

Assessment of volcanic hazards from explosive eruptions on islands: the case of São Miguel (Azores)

Tese de Doutoramento

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Doutoramento em
Geologia



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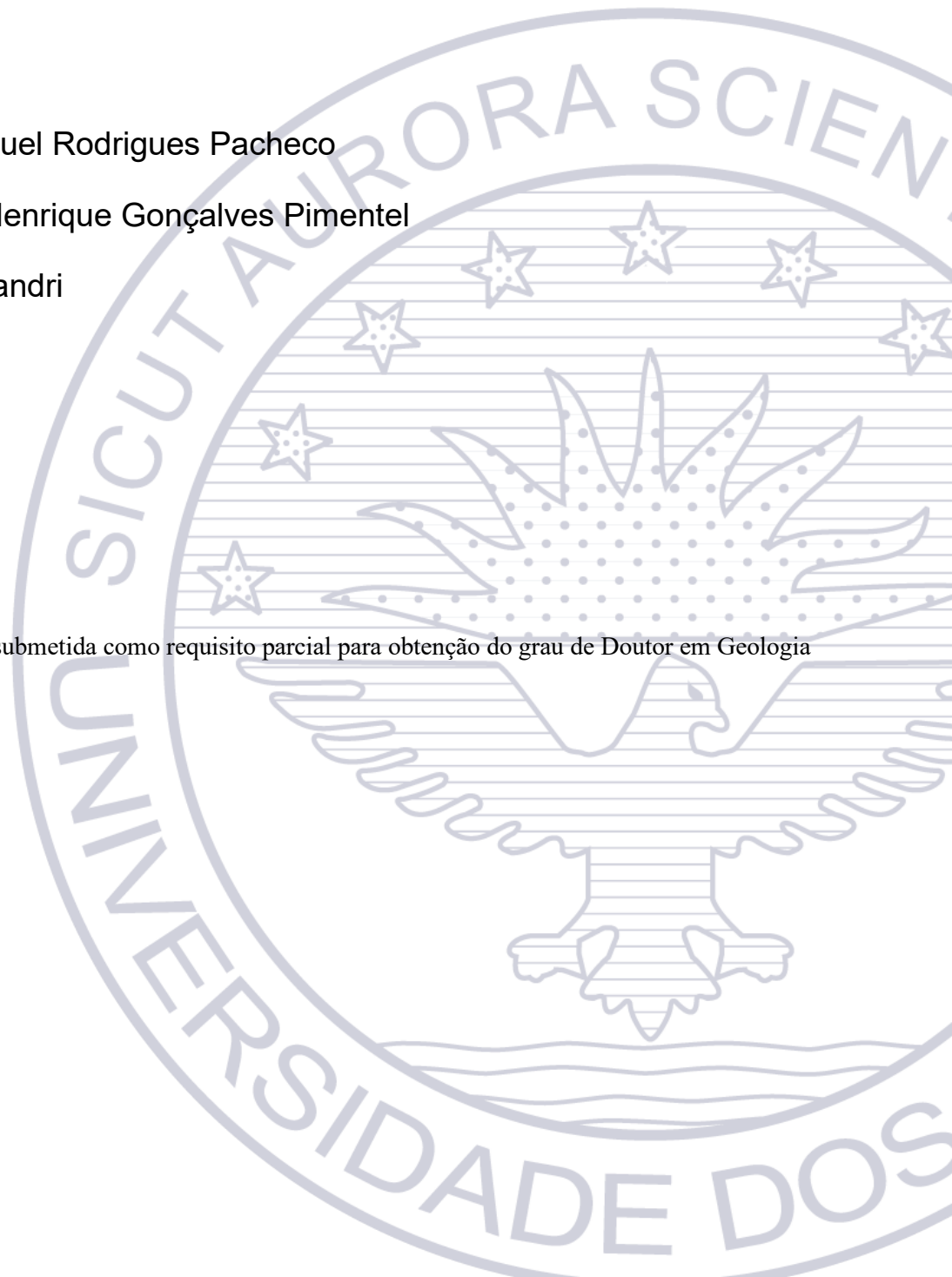
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REPÚBLICA
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EDUCAÇÃO, CIÊNCIA
E INOVAÇÃO

To my parents, with all my love and gratitude.

*In memory of Luís Jaime Linhares, who remains a part of my life despite his absence and whose
memory gave me the strength to carry out this work.*

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Abstract

Volcanic islands face unique challenges when impacted by explosive eruptions due to their geographic isolation, small land area, typical rough topography, and proximity of populated areas and infrastructure to volcanic centres. The stratigraphic record of island volcanoes is often incomplete or poorly preserved, generating large uncertainties regarding their past eruptive behaviour, limiting eruption forecasting.

São Miguel Island in the Azores Archipelago is one such case, hosting three active central volcanoes (Sete Cidades, Fogo, and Furnas) that have produced a wide variety of eruptions in the last millennia, ranging from highly explosive trachytic events to basaltic flank eruptions.

This work presents, for the first time in the Azores, a long-term Probabilistic Volcanic Hazard Assessment (PVHA) using São Miguel Island as a case study. The development of this type of analysis requires the integration of different sources of information, including the probability of future eruptions, the probability of opening new vents, and probabilistic numerical simulations of tephra fallout for different eruption scenarios, which are combined into Bayesian Event Trees to generate probability maps, hazard maps, and hazard curves.

Temporal analysis was performed first to estimate inter-event times (IET), i.e., the time intervals between successive eruptive events, using different statistical distributions, and to compute the probabilities of an eruption in the next 50 years for each central volcano. This was achieved by implementing an innovative methodology that focuses on the generation of synthetic catalogues by randomly assigning stratigraphic-consistent ages and accounting for age uncertainties of past

events. Catalogues of basaltic (*s.l.*) and trachytic (*s.l.*) events (BT catalogues), and catalogues of trachytic (*s.l.*) events (T catalogues) were generated for each of the three central volcanoes.

The results revealed that Sete Cidades data are non-stationary, suggesting an incomplete eruptive record or changes in eruption frequency over time. The mean IET were shorter for Sete Cidades Volcano (154 yr and 205 yr for BT and T catalogues, respectively) than for Fogo (546 yr for BT catalogues and 909 yr for T catalogues) and Furnas volcanoes (318 yr for T catalogues). The mean probabilities of an eruption within the next 50 years are higher for Sete Cidades (21% for BT and 17% for T catalogues), followed by Furnas (13% for T catalogues), and Fogo (8% for BT and 5% for T catalogues).

Spatial analysis was performed separately for each central volcano to identify areas with a higher probability of hosting future eruptive centres. This was accomplished by implementing the kernel method and using the location of past vents, either central vents or eruptive fissures. Different datasets were considered for this analysis: basaltic (*s.l.*) and trachytic (*s.l.*) centres together, including fissures and central vents (BT datasets), trachytic (*s.l.*) vents of explosive and effusive events (T datasets), and only explosive trachytic (*s.l.*) vents (ET datasets).

Different kernel functions (Gaussian, Cauchy, Exponential, and Uniform) were explored and the best degree of clustering of eruptive centres (given by a smoothing parameter h) was determined for each dataset of each volcano. Vent opening probability maps (susceptibility maps) were computed by combining the pair (kernel function and smoothing parameter) that best described the empirical cumulative distribution function of the distance between eruptive centres.

The results show that for the Sete Cidades BT dataset, the most likely locations to host future vents are located on the southeast flank (30%), the caldera (17%), and on the southwest flank (8.7%). However, when considering future trachytic (*s.l.*) vents, higher probabilities were obtained for the caldera (51%) and the southwest sector (28%). Explosive trachytic (*s.l.*) eruptions are more likely to occur only inside the caldera (83%). On what concerns Fogo Volcano, the most likely locations to host future eruptive centres (BT dataset) include the west-northwest flank

(29%), the caldera (9.6%), and the southwest flank (6%). Regarding future trachytic (*s.l.*) events, the most probable locations to host new vents are the west-northwest flank (25%), the caldera (17%), and the north-northeast flank (15%). Explosive trachytic (*s.l.*) eruptions are more likely to occur inside the caldera (29%) and on the north flank (9.3%). For Furnas Volcano, the most probable locations to host future eruptive centres (BT dataset) are inside the caldera complex (34%), on the northern flank (31%), and on the eastern flank (15%). Regarding the opening of future trachytic (*s.l.*) vents, the most likely locations are the interior of the caldera complex (63%) and on the north flank (21%). In the case of explosive trachytic (*s.l.*) eruptions, future vents are highly probable inside the caldera complex (91%).

A long-term PVHA framework, rooted on Bayesian inference, was applied to each central volcano, focusing on explosive trachytic (*s.l.*) eruptions to evaluate the impact of tephra load on São Miguel Island over the next 50 years (absolute probabilities) and conditional to the occurrence of a future VEI 4 eruption (conditional probabilities).

The computed absolute probability maps indicate a higher probability of exceeding lower tephra load thresholds (e.g. 1 and 10 kg/m²) in the next 50 years compared to higher accumulations of tephra (e.g. 400 kg/m²), with Sete Cidades and Furnas volcanoes being the main contributors to exceeding these tephra loads.

The obtained hazard maps indicate that tephra loads between 200 kg/m² and 300 kg/m² and between 50 kg/m² and 200 kg/m² (thicknesses of 20 to 30 cm and 5 to 20 cm) are expected at locations close to Sete Cidades and Furnas, respectively, suggesting that these volcanoes represent a greater threat to local populations over the next 50 years.

The hazard curves computed for critical infrastructures such as the Ponta Delgada airport, Divino Espírito Santo hospital, and Pico Vermelho geothermal powerplant reveal that Sete Cidades Volcano represents the greatest threat to the airport and the hospital, while Fogo Volcano has the greatest impact on the geothermal powerplant within the next 50 years.

Combining the results of the PVHA for each volcano revealed that the area between Relva and Caloura parishes, in the southern part of São Miguel, and the area of Nordeste parish, are less vulnerable to tephra fallout in the next 50 years

Resumo

As ilhas vulcânicas enfrentam desafios únicos quando afetadas por erupções explosivas devido ao seu isolamento geográfico, área terrestre limitada, topografia acidentada e proximidade de áreas povoadas e infraestruturas a sistemas vulcânicos.

O registo estratigráfico de vulcões insulares encontra-se frequentemente incompleto ou mal preservado, gerando incertezas relativamente ao seu comportamento eruptivo passado, limitando a previsão vulcânica.

A ilha de São Miguel no arquipélago dos Açores é um destes casos, alojando três vulcões centrais ativos (Sete Cidades, Fogo e Furnas) que produziram uma grande variedade de erupções vulcânicas nos últimos milénios, desde eventos traquíticos altamente explosivos até erupções basálticas nos seus flancos.

Este estudo apresenta, pela primeira vez nos Açores, uma Avaliação Probabilística de Perigosidade Vulcânica a longo prazo usando a ilha de São Miguel como caso de estudo. Este tipo de análise requer a integração de diferentes tipos de informação, incluindo da probabilidade de futuras erupções, da probabilidade espacial de abertura de novos centros eruptivos, e dos resultados de simulações numéricas probabilísticas de queda de tefra para diferentes cenários eruptivos que são incorporados em árvores de eventos Bayesianas para gerar mapas de probabilidade, mapas de perigosidade e curvas de perigosidade.

A análise temporal foi realizada em primeiro lugar para estimar o tempo entre os eventos (TEE), i.e., o tempo entre eventos eruptivos sucessivos, utilizando diferentes distribuições estatísticas, e

para estimar a probabilidade de uma erupção em cada vulcão central nos próximos 50 anos. Para tal, foi implementada uma metodologia inovadora que assenta na geração de catálogos sintéticos, atribuindo aleatoriamente uma idade estratigraficamente consistente e incluindo a incerteza nas idades de eventos passados. Foram gerados catálogos de eventos basálticos (*s.l.*) e traquíticos (*s.l.*) (catálogos BT) e catálogos de eventos traquíticos (*s.l.*) (catálogos T) para cada um dos três vulcões centrais.

Os resultados obtidos indicaram que os dados do Vulcão das Sete Cidades não são estacionários, sugerindo um registo eruptivo incompleto ou mudanças na frequência eruptiva ao longo do tempo. Os tempos médios entre eventos são mais curtos para o Vulcão das Sete Cidades (154 anos e 205 anos para eventos dos catálogos BT e T, respetivamente) do que para os vulcões do Fogo (546 anos para eventos BT e 909 anos para eventos T) e Furnas (318 anos para eventos T). A probabilidade média de uma erupção nos próximos 50 anos é mais elevada para o Vulcão das Sete Cidades (21% para eventos BT e 17% para eventos T), seguido pelos vulcões das Furnas (13% para eventos T) e Fogo (8% para eventos BT e 5% para eventos T).

A análise espacial foi realizada separadamente para cada vulcão central para identificar áreas com maior probabilidade de alojar futuros centros eruptivos. Isto foi conseguido através da implementação do método *kernel* e da utilização das localizações de centros eruptivos passados, quer pontos eruptivos quer fissuras eruptivas. Para esta análise foram considerados diferentes conjuntos de dados: centros eruptivos basálticos (*s.l.*) e traquíticos (*s.l.*) juntos, incluindo pontos e fissuras (conjunto de dados BT), centros eruptivos traquíticos (*s.l.*) de eventos explosivos e efusivos (conjunto de dados T), e centros eruptivos traquíticos (*s.l.*) explosivos (conjunto de dados ET).

Diferentes funções *kernel* (Gaussiana, Cauchy, Exponencial e Uniforme) foram exploradas e foi calculado o melhor grau de *clustering* dos centros eruptivos (dado pelo parâmetro de suavização *h*) para cada conjunto de dados de cada vulcão. Foram gerados mapas de probabilidade para abertura de novos centros eruptivos (mapas de suscetibilidade) combinando o par (função *kernel*

e parâmetro de suavização h) que melhor descreve a função de distribuição empírica cumulativa da distância entre os centros eruptivos.

Os resultados indicam que, quando considerando o conjunto de dados BT das Sete Cidades, as áreas mais prováveis para alojarem novos centros eruptivos estão concentradas no setor sudeste (30%), na caldeira (17%), e no setor sudoeste (8.7%); no entanto, quando considerando futuros centros eruptivos traquíticos (*s.l.*), valores mais elevados de probabilidade foram obtidos para a área da caldeira (51%), bem como, para o setor sudoeste (28%). Futuros centros eruptivos explosivos traquíticos (*s.l.*) são mais prováveis de ocorrer apenas dentro da caldeira (83%).

As áreas prováveis para alojarem novos centros eruptivos BT no Fogo correspondem ao setor oeste-noroeste (29%), ao interior da caldeira (9.6%), e ao setor sudoeste (6%). Futuros centros eruptivos traquíticos (*s.l.*) são mais prováveis de ocorrer no flanco oeste-noroeste (25%), dentro da caldeira (17%), e no setor norte-nordeste (15%), enquanto futuros centros explosivos traquíticos (*s.l.*) são mais prováveis de se formarem dentro da caldeira (29%) e no setor norte (9.3%).

As áreas mais prováveis de alojarem novos centros eruptivos BT nas Furnas estão localizadas no interior do complexo de caldeiras (63%), bem como, nos setores norte (31%) e este (15%). Futuros centros eruptivos T são mais prováveis de ocorrer dentro do complexo de caldeiras (63%) e no setor norte (21%), enquanto futuros centros ET têm maior probabilidade de se formarem dentro do complexo de caldeiras (91%).

Por fim, uma estrutura para a Avaliação Probabilística de Perigosidade Vulcânica a longo prazo, que tem por base a inferência Bayesiana, foi aplicada individualmente a cada sistema vulcânico, considerando apenas eventos ET, para avaliar o impacto de cargas específicas de cinza na ilha de São Miguel nos próximos 50 anos (probabilidade absoluta), bem como, condicionando a análise à ocorrência de uma erupção VEI 4 (probabilidade condicionada).

Os mapas de probabilidade absoluta obtidos indicam que a probabilidade de exceder cargas menores (1 kg/m^2 e 10 kg/m^2) é maior quando comparada com a probabilidade de exceder cargas maiores (400 kg/m^2), sendo os vulcões das Sete Cidades e Furnas os maiores contribuidores para que estas cargas sejam excedidas.

Os mapas de perigosidade obtidos indicam que podem ocorrer cargas entre os 200 kg/m^2 e 300 kg/m^2 e entre 50 kg/m^2 e 200 kg/m^2 (espessuras de 20 a 30 cm e de 5 a 20 cm) em locais próximos das Sete cidades e Furnas, respetivamente, sugerindo que estes vulcões representam uma ameaça maior para as populações nos próximos 50 anos.

As curvas de perigosidade obtidas para os próximos 50 anos para infraestruturas críticas, como o aeroporto de Ponta Delgada, o hospital do Divino Espírito Santo e a central geotérmica do Pico Vermelho, revelam que o Vulcão das Sete Cidades representa uma ameaça maior para o aeroporto e o hospital, enquanto o Fogo poderá ter maior impacto na central geotérmica.

A junção das análises PVHA desenvolvidas para cada vulcão indica que a área da Relva à Caloura, bem como, a freguesia do Nordeste, são consideradas as áreas menos vulneráveis à queda de cinza nos próximos 50 anos.

Chapter 1

Introduction

Chapter 1. Introduction

1.1. Preliminary note

Volcanic eruptions have marked populations around the world, either because of their fascinating character or because of their destructive power. Volcanoes are not randomly distributed across the Earth. Instead, they are predominantly located along lithospheric plate boundaries, where interactions between the crust and mantle occur (Tilling, 1989). Intraplate volcanism can also occur, often associated with magmatic plumes.

Depending on magma properties, such as volatile content, chemical and physical composition, volcanic eruptions can range from effusive to explosive events. Among explosive eruptions, Plinian and Sub-Plinian events, are considered the most dangerous due to their capacity to cause significant destruction, socioeconomic impacts, and even to affect global climate (Cas and Wright, 1988; Cioni et al., 2000). These types of eruptions are characterized by the ejection of tephra into the atmosphere, forming high convective columns that are dispersed by the wind. These eruptive columns can become unstable and collapse, generating pyroclastic density currents (PDCs), that can flow for tens of kilometres along the ground and cause extensive damage in their path (Cas and Wright, 1988; Cioni et al., 2000).

The original classification of explosive eruptions is mostly based on the characteristics of the resulting deposits, where the degree of fragmentation and the dispersion of the ejected material play key roles (Cas and Wright, 1988; Walker, 1973). However, it is only through the quantification of eruption source parameters such as volume, column height, magnitude, and

intensity combined with external factors, such as water interaction, or lack thereof, and wind influence that eruptions dimensions and impact can be fully understood.

On small territories, such as volcanic islands, determining these parameters is a challenge. In fact, deposits from island volcanoes are often poorly preserved, leading to uncertainties in the reconstruction of past events and, thus, constraining volcanic hazard assessment.

Tephra fallout and pyroclastic density currents (PDCs) are the most common volcanic hazards resulting from explosive eruptions. Tephra and PDCs are considered the most hazardous as they can have devastating impacts on both local and global scales.

There is an extensive record of the destructive consequences of these volcanic products worldwide, particularly given that many communities are near active volcanoes. An extreme example of these impacts is the destruction caused by the 1815 eruption of Mount Tambora, Indonesia. This eruption has been recognized as the largest explosive event in the last 10,000 years. The eruption, which began on 5th April and lasted until 11th April, was a VEI 7 event marked by multiple Plinian phases and pyroclastic flows. This event is estimated to have produced between 30 km³ and >300 km³ of tephra volume and killed more than 90,000 people, both from direct destruction and from secondary effects such as tsunamis, starvation and disease (Self et al., 1984). The ash ejected into the atmosphere spread globally, significantly affecting the climate in the following years (Stothers, 1984) and impacting the year of 1816, known as “the year without a summer”.

Similarly, the 1991 eruption of Mount Pinatubo in the Philippines was one of the largest eruptions of the 20th century. Between 12th June and 16th June, Pinatubo erupted at least 16 times, severely affecting a densely populated region. The most catastrophic phase occurred on 15th June, when a massive eruption sent ash clouds up to 35 kilometres high into the atmosphere and generated pyroclastic density currents (PDCs), filling valleys with deposits up to 200 metres thick. This event released over 5 km³ ash into the atmosphere (Koyaguchi and Tokuno, 1993; Casadeval et al., 1996; Newhall et al., 1997), causing the collapse of thousands of roofs and about 800 fatalities.

The Azores archipelago is particularly prone to volcanic eruptions due to its complex geological setting. Small volcanic islands like those in the Azores are especially vulnerable to volcanic hazards, as people live side by side with active volcanoes in a small territory. In such regions, the impact of explosive eruptions is even larger due to their typically limited land area, remote location and rugged topography. These geographic constraints make crisis management and evacuations very challenging on volcanic islands.

The presented study focuses on applying a long-term Probabilistic Volcanic Hazard Assessment (PVHA) approach to evaluate hazards associated with tephra fallout produced during explosive eruptions at the three active central volcanoes of São Miguel Island, Sete Cidades, Fogo, and Furnas volcanoes. By applying probabilistic models, this work aims to improve the understanding of the potential hazards posed by future eruptions in the Azores, contributing to a more effective disaster preparedness and risk mitigation strategies in this vulnerable region.

1.2. Thesis objectives and organization

The present work aims to contribute to enhance scientific knowledge and help mitigate the impact of explosive eruptions at volcanic islands, particularly regarding tephra fallout impacts, by focussing on exploring methods to assess volcanic hazard on small islands, such the Azores, which are prone to explosive eruptions and therefore vulnerable to their products. This study is designed to address several key scientific questions:

- o Given the constraints of small volcanic islands (e.g. incomplete eruption records), is it possible to accurately reconstruct the past eruptive record and estimate inter-event times?
- o What is the probability of a future eruption in the active central volcanoes of São Miguel?
- o Which areas are most likely to host future vents in each of the active central volcanoes of São Miguel?

- o Which areas of São Miguel Island are most likely of being affected by tephra fallout if a future explosive eruption is produced by any of the three active central volcanoes of São Miguel?
- o What is the expected tephra load at critical infrastructures (e.g., Airport, Hospital, and the Pico Vermelho geothermal powerplant) if an eruption occurs at any of the active central volcanoes of São Miguel?
- o What are the exceedance probabilities of a specific critical infrastructure being affected by significant tephra load thresholds?
- o What are the best practices to assess the volcanic hazards related to explosive eruptions on volcanic islands?

The thesis is organized into five chapters:

The first chapter provides a general introduction to the thesis. It includes a preliminary note on explosive eruptions, an overview of thesis organisation and objectives, a review of the geological setting of the Azores, a description of the study area and the central volcanoes explored during this work, and a current state-on-the-art on probabilistic volcanic hazard assessment.

Chapter two focusses on the temporal analysis performed using synthetic eruptive catalogues from each volcano to estimate inter-event times and the probability of a future eruption in a specific timeframe. The chapter opens with a preliminary note about the temporal analysis approach, followed by a detailed description of the implemented methodology. The results concerning data stationarity, inter-even times estimation, best renewal models, hazard rate, and the probability of a future eruption are then presented and discussed. Main conclusions of this analysis are also presented.

Chapter three addresses the spatial analysis performed to each volcano, using the distribution of past eruptive events to identify most likely locations to host future eruptive centres. The chapter

opens with a preliminary note on the spatial analysis approach, followed by the description of the applied methodology, which is based on the location of past eruptive centres and in the application of different kernel functions. The resulting spatial probability maps obtained for each volcano are then presented and discussed. The chapter closes with the main conclusions of this analysis, offering key insights into the spatial distribution of future activity.

Chapter four is dedicated to the application of a complete long-term Probabilistic Volcanic Hazard Assessment (PVHA) approach to each volcano. It includes a preliminary note on PVHA, as well as the methodologies used to perform simulations using the HAZMAP software, to construct Bayesian Event Trees, and to produce final probability maps, hazard maps, and hazard curves for tephra fallout. The results are presented and discussed, and main conclusions are laid out in the end of the chapter.

Chapter five, presents the final remarks of this work, summarising the main conclusions of each analysis performed. It also introduces a flowchart outlining best practises to assess volcanic hazards on small territories, using São Miguel Island as study case.

1.3. Geological setting of the Azores

The Azores archipelago, located in the North Atlantic Ocean, consists of nine volcanic islands distributed along a WNW-ESE direction, forming three geographic groups: the Oriental group (São Miguel and Santa Maria islands), the Central group (Terceira, Graciosa, São Jorge, Pico, and Faial islands), and the Occidental group (Flores and Corvo islands). The geodynamic setting of the Azores is particularly complex as the archipelago lies at a triple junction (Lourenço et al., 1998; Vogt and Jung, 2004) between North American (NA), Eurasian (EU) and Nubian (NU) lithospheric plates (Searl, 1980). The boundaries between these plates are defined by major tectonic structures, including the Mid-Atlantic Ridge (MAR), the Terceira Rift (TR), the East

Azores Fracture Zone (EAFZ) (Heezen et al., 1959), and the GLORIA Fault (Laughton et al., 1972; Laughton and Whitmarsh, 1974; Searl, 1980) (Fig. 1.1).

The Mid-Atlantic Ridge separates the Eurasian and Nubian tectonic plates from the North American plate, while the boundary between Eurasian and Nubian plates is more complex. This boundary is defined by the Terceira Rift to the west and GLORIA Fault at east, forming the westernmost and central segments of Açores-Gibraltar Fracture Zone, respectively.

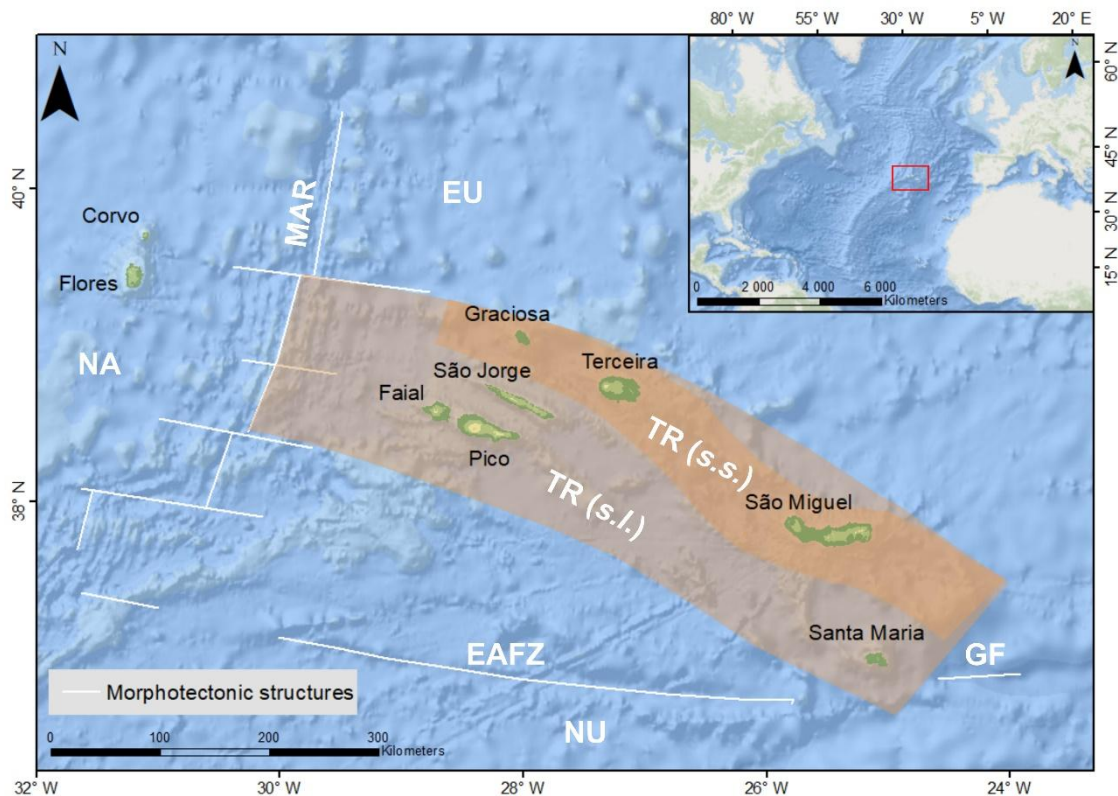


Figure 1. 1. Location of the Azores Archipelago and São Miguel Island at the triple junction of the North American (NA), Eurasian (EU), and Nubian (NU) lithospheric plates and the main morphotectonic structures of the region: MAR - Mid-Atlantic Ridge, EAFZ - East Azores Fracture Zone, GF - Gloria Fault, the lighter orange shaded area marks the Terceira Rift sensu lato and the darker orange shaded area marks the Terceira Rift sensu stricto (after Carmo et al. 2015). The upper-right inset shows the location of the Azores Archipelago (red box) in the North Atlantic Ocean.

The Terceira Rift (*s.s*) (Machado, 1959a) is a WNW-ESE trending zone characterized by an alternating alignment of volcanic edifices (islands and seamounts) and basins. It displays a right-transensional behaviour, suggesting a hyper-slow spreading rate of this structure. It also functions

as shear zone between Eurasian and Nubian lithospheric plates, accommodating a differential movement between them (Krause and Watkins, 1970; Laughton and Whitmarsh, 1974; Searle, 1980; Madeira and Ribeiro, 1990; Madeira and Brum da Silveira, 2003; Vogt and Jung, 2004; Fernandes et al., 2006; Dias et al., 2007; Verzhbitsky et al., 2011; Madeira et al., 2015).

The GLORIA Fault marks the boundary between the Eurasian and Nubian plates to the east and is characterized as a right-lateral transform fault (Laughton et al., 1972; Argus et al., 1989; Verzhbitsky et al., 2011).

The East Azores Fracture Zone, at west from GLORIA Fault and south from Terceira Rift (*s.s.*), is considered an inactive tectonic structure due to the low seismicity in this area. This structure is interpreted as a remnant of the old plate boundary between the Eurasian and Nubian plates (Searle, 1980; Luis et al., 1994; Dias et al., 2007).

Despite its geodynamic setting, the magmatic complexity of the Azores is linked to the interaction between the Mid-Atlantic Ridge along with a possible hotspot (e.g., Schilling, 1975; White et al., 1976; Cannat et al., 1999; Gente et al., 2003; Montelli et al., 2004; Silveira et al., 2006; Yang et al., 2006; Beier et al., 2008). In fact, geochemical (e.g., Schilling, 1975; White et al., 1976, and many others) and geophysical (e.g., Luis et al., 1994; Detrick et al., 1995, and others) evidence revealed a low-seismic-velocity anomaly in the mantle underlying the Azores Plateau, suggesting mantle-melting processes. However, its location and origin remain uncertain.

The complex geological framework of the Azores makes the region prone to seismic and volcanic activity, predominantly concentrated along Terceira Rift (*s.l.*) and Mid-Atlantic Ridge (Gaspar et al., 2015a; Madeira et al., 2015). In fact, since the islands were first settled in the 15th century, several destructive seismic and volcanic events have impacted local populations.

Seismicity

The Azores region has frequently experienced earthquakes and seismic crises over the centuries, some of which have had severe impacts on local communities, causing human casualties and considerable damages. Since the 15th century, approximately, 30 destructive earthquakes have been recorded in the islands of the oriental and central geographic groups (Fig. 1.2) (Gaspar et al., 2015b; Silva et al., 2020).

Seismicity in the Azores typically follows two main patterns: mainshock-aftershock events and seismic swarms. Mainshock-aftershock events are predominantly distributed along major regional tectonic structures, such as the Mid-Atlantic-Ridge and Terceira Rift (*s.l.*) (e.g. Silva et al., 2012).

Among the many recorded destructive earthquakes in the Azores, few events stand up, such as follows:

One of the earliest and most devastating earthquakes in the Azores occurred on 22nd October 1522 on São Miguel Island, with its epicentre north of Vila Franca do Campo (Fructuoso, 1583?). This event reached an intensity of X on the EMS-98 scale (Silveira et al., 2003) and triggered several landslides across the island. Vila Franca do Campo was the most affected parish, where a major debris flow buried the town resulting in the deaths of about 5000 people. (Fructuoso, 1583?).

The most powerful earthquake documented in the Azores took place on 9th July 1757, near the north coast of São Jorge Island. This event had an estimated magnitude of 7.4 and an intensity of X (EMS-98) (Silva, 2005). The earthquake caused a massive destruction on São Jorge Island, and damaged buildings in Pico, Terceira, and Faial islands. Approximately 1000 deaths were reported in São Jorge, as well as 11 in Pico and 1 in Terceira Island. More recently (1st January 1980), Terceira was affected by a 7.2 magnitude earthquake (Hirn et al., 1980), which caused several damages on the islands of Terceira, São Jorge, Graciosa, Pico and Faial (Hirn et al., 1980). The event resulted in 59 deaths, 400 injuries, and the displacement of thousands of people.

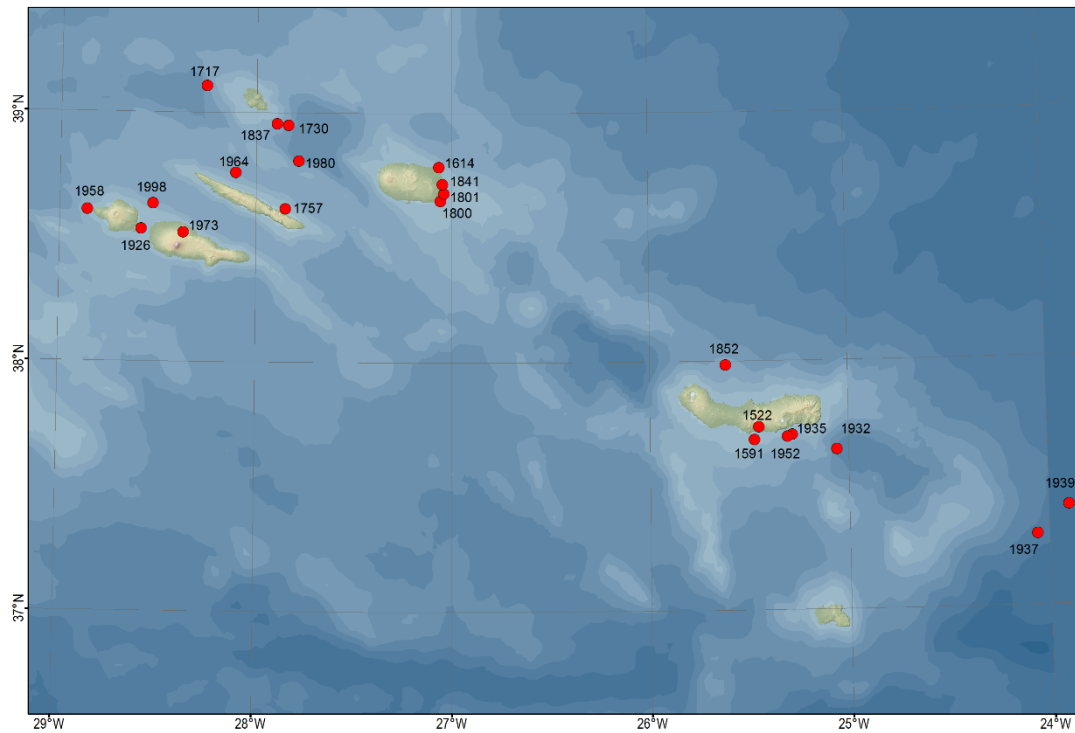


Figure 1. 2. Epicentral locations of destructive earthquakes in the Azores archipelago during historical times (Gaspar et al. 2015b).

Seismic swarms are also common in the Azores, often associated with active volcanic and geothermal regions. For instance, the seismic crisis before and during 1957/58 Capelinhos eruption on Faial Island (Machado, 1960). More than 200 earthquakes have been, firstly, recorded on the easternmost part of Faial Island, between 16th to 27th September 1957, and later, the activity migrated westward. Since the beginning of the eruption (27th September), seismic activity has decreased until May 1958, being its most intense phase between the 12th and 13th May (Machado 1959b; Lobão, 1999), with approximately 450 recorded earthquakes. During this period, violent events were recorded, reaching an intensity of X. The Capelinhos eruption along with its seismic crisis had several impacts in the island, contributing to the emigration of its population.

One of the most prominent seismic crises in São Miguel Island began on 10th May 2005 in Fogo-Congro seismogenic region (Wallenstein et al., 2009), where more than 46,000 earthquakes were recorded by the Azores Seismological Surveillance System (SIVISA) (now known as Centre for

Information and Seismovolcanic Surveillance of the Azores (CIVISA)) between May and December.

Lately, from 19th March 2022 to June 2022, a seismic crisis affected São Jorge Island. During this period more than 40,000 seismic events were recorded by CIVISA, most of them of low magnitude. The strongest event was recorder on 29 March, and it was a 3.8 magnitude event. This seismic crisis was interpreted as a dyke intrusion beneath the central part of São Jorge Island, with the eastern segment located at depts between 2 to 7 km and the western segment located between 7 and 13 km deep (D'Araújo, 2022; D'Araújo et al., 2023). Later that year, another seismic crisis began in Santa Bárbara Volcano (Terceira Island). So far, more than 34,000 events were recorded, and the most energetic earthquake occurred on 14th January 2024, with a magnitude (ML) of 4.5 (CIVISA unpublished data).

Figure 1.3 illustrates the distribution of the seismicity in the Azores Region.

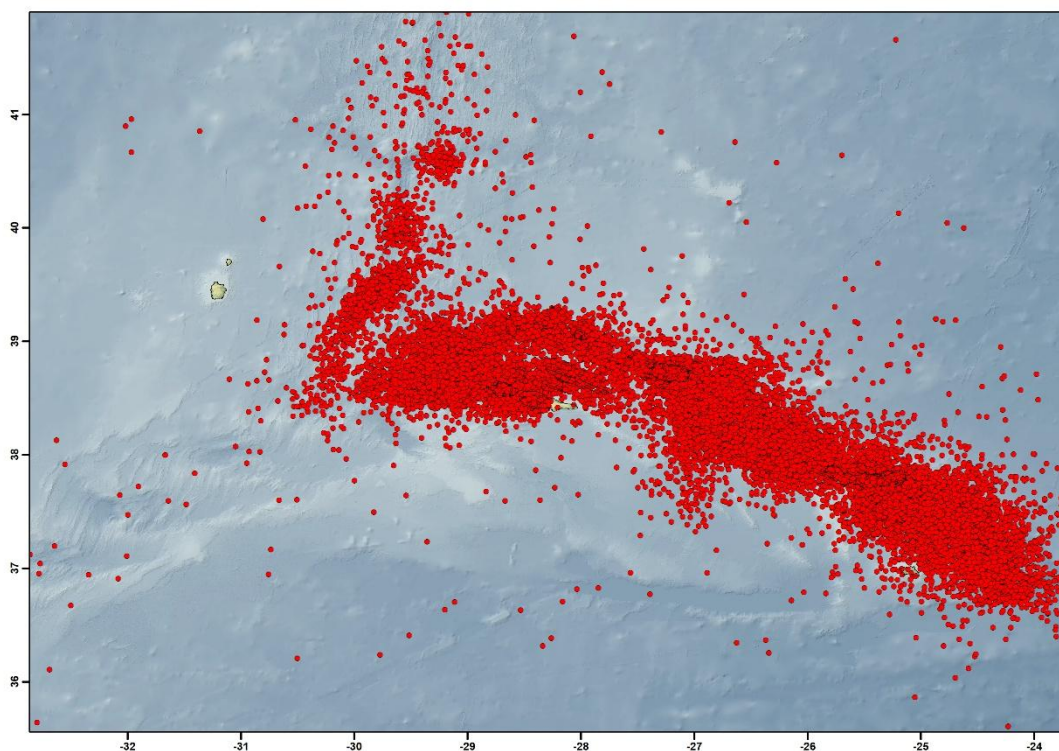


Figure 1. 3. Azores epicentres chart from 1980 to 2023 (data from CIVISA 2023).

Volcanic activity

The Azores archipelago exhibits eruptions with a wide range of eruptive styles, varying from effusive basaltic (*s.l.*) eruptions to explosive trachytic (*s.l.*) events, reflecting its complex geodynamic setting.

Since the settlement of the islands (15th century), at least 28 volcanic eruptions have been documented in the Azores region (Fig. 1.4). Among them, 15 events occurred on land, on the islands of São Miguel, Terceira, São Jorge, Pico, and Faial (Gaspar et al., 2015b). The eruptions exhibited eruptive styles that ranged from Hawaiian to sub-Plinian eruptions, often accompanied by hydromagmatic phases.

Basaltic eruptions are mostly linked to important active fissure systems. The 1563 AD basaltic (*s.l.*) eruption illustrates one of these type of events. It was a Hawaiian eruption at Pico do Sapateiro, that produced two lava flows that reached the parishes of Ribeira Seca and Rabo de Peixe (Wallenstein, 1998, 1999; Ferreira, 2000). This event partially destroyed Ribeira Seca parish, and some fields became unusable for cultivation. In 1808, a Hawaiian/Strombolian style eruption, with phreatomagmatic phases, took place in Manadas Fissural Volcanic System in São Jorge Island. Lava flows and “nuées ardentes” destroyed the Urzelina church, 67 houses, several fields, vineyards, and more than 30 people were killed (Weston, 1964; Silveira, 1808, 1982; Madeira, 1998).

Explosive trachytic (*s.l.*) eruptions were also common in the Azores, typically linked to the stratovolcanoes of the islands. In historical times, explosive eruptions have occurred more frequently in São Miguel Island. Examples of these type of events occurred in historical times, including the AD 1563 eruption at Fogo caldera and the eruptions of AD 1439/43 and AD 1630 at Furnas Volcano. The AD 1563 explosive eruption at Fogo was of sub-Plinian style and produced tephra fall and small surges. During this event, the eastern part of São Miguel Island was covered by ash, many roofs collapsed, several houses were destroyed due to seismic activity, and two people died due to gas inhalation (Fructuoso, 1583?; Walker and Croasdale, 1971;

Wallenstein, 1999; Aguiar, 2018). The AD 1439/43 sub-Plinian eruption in Furnas was the first documented volcanic eruption on the island. The event was associated to important hydromagmatic phases and produced tephra fall and a trachytic (*s.l.*) dome at its final stage (Queiroz et al., 1995; Madeira, 1998; Guest et al., 1999). The AD 1630 event was the last sub-Plinian eruption recorded in São Miguel Island. It produced tephra fall, pyroclastic density currents, and a lava dome at its final stage. At least 195 people died as result of PDCs, and several buildings were destroyed by ash accumulation and seismic activity (Cole et al., 1995, 1999; Guest et al., 1999).

Emergent submarine volcanic activity has also been reported in the Azores. These events exhibited a basaltic nature, forming occasionally small islets, such as the Surtseyan eruptions of 1638, 1720, and 1811. The 1957-58 eruption of Capelinhos, located northwest of Faial Island, was the major submarine eruption in this region. It started as a Surtseyan eruption and transitioned to Hawaiian/Strombolian styles (Machado 1959a; Cole et al., 2001). This eruption led to the collapse of several houses, destruction of fields, and triggered emigration (Machado, 1959a; Cole et al., 2001; Coutinho et al., 2010).

The most recent submarine eruption reported in Azores occurred at Serreta Submarine Ridge, offshore Terceira Island, and lasted from 1998 to 2001 (Gaspar et al., 2003; Kueppers et al., 2012; Casas et al., 2018). This eruption was characterized by the emission of basaltic bodies that emerged through the water and floated on the sea surface, known as “lava balloons” (Gaspar et al., 2003). These structures consist of low-density juvenile basaltic structures characterized by a basaltic thin shell sealing a hollow filled with gas (Gaspar et al., 2003).

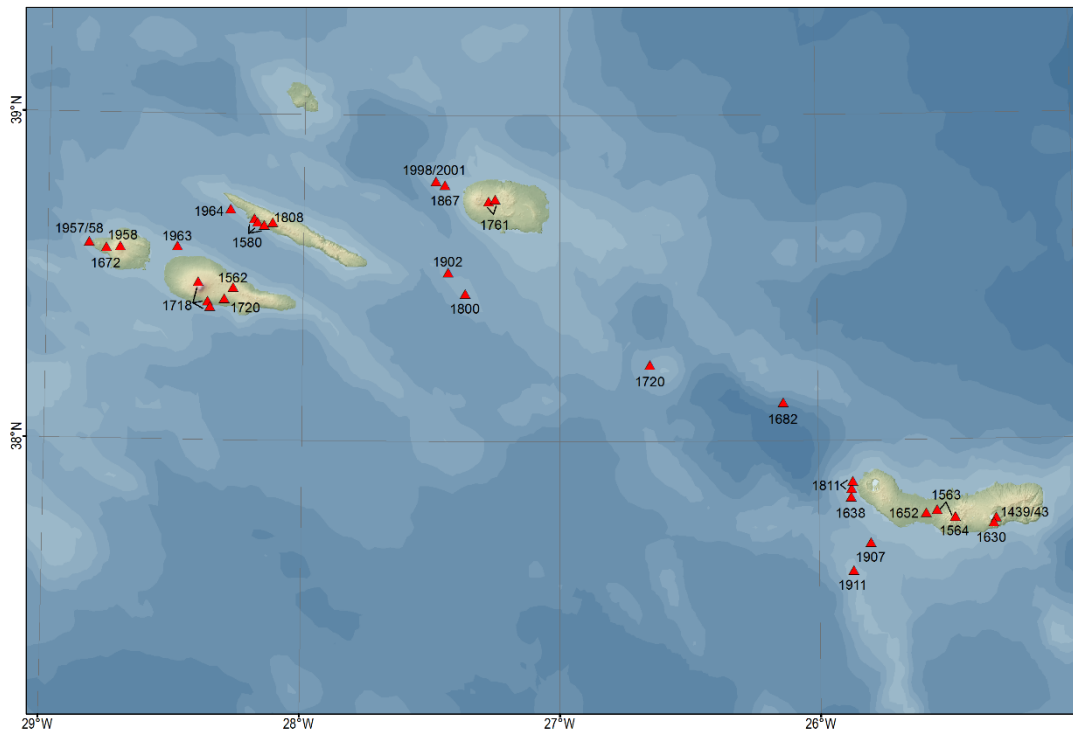


Figure 1. 4. Location of historical eruptions in the Azores archipelago (adapted from Weston, 1964; Queiroz et al., 1995; Queiroz, 1997; Gaspar et al., 2003).

1.4. Study Area

The present study focuses on São Miguel Island, which is the largest (744,7 km²) and most populated (133,000 inhabitants) of the archipelago. This island comprises five active volcanic systems, including three central volcanoes, Sete Cidades, Fogo, and Furnas, and two fissure zones associated to basaltic activity: Picos Fissure Volcanic System and the Congro Fissure Volcanic System. The easternmost part of the island is marked by two older volcanic systems, Povoação Volcano and Nordeste Volcanic System, that are considered extinct (Duncan et al., 2015) (Fig. 1.5).

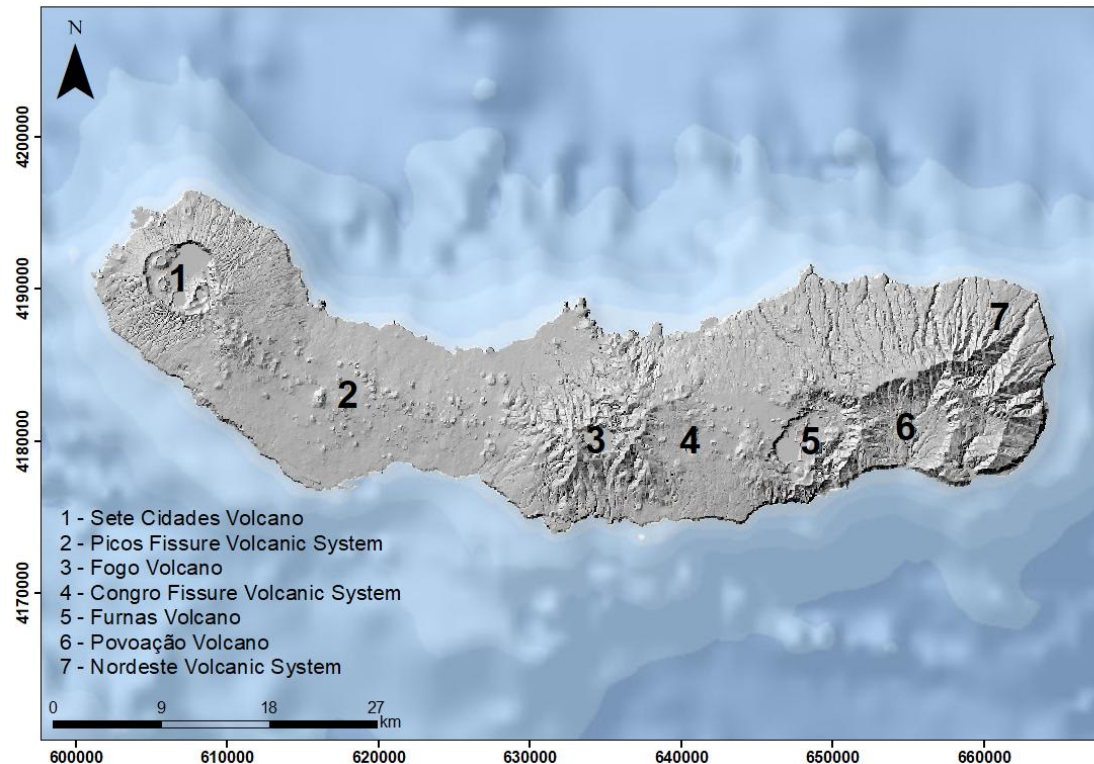


Figure 1. 5. Digital elevation model of São Miguel (UTM projection, zone 26N) with identification of the volcanic systems forms the island (1 - Sete Cidades Volcano, 2 - Picos Fissure Volcanic System, 3 - Fogo Volcano, 4 - Congro Fissure Volcanic System, 5 - Furnas Volcano, 6 - Povoação Volcano, 7 - Nordeste Volcanic System, following Gaspar et al., 2015a). UTM projection, Zone 26N, Datum WGS1984.

The three active central volcanoes of São Miguel will be main subject of the work due to their complex eruptive behaviour and high potential to generate hazardous phenomena, capable of causing devastating consequences on both local and global scales. Therefore, they will be described in more detail from a volcanological perspective.

Sete Cidades Volcano

Sete Cidades Volcano is the westernmost central volcano of São Miguel (Fig. 1.5). It is a low-relief edifice (845 m a.s.l.) characterised by a broadly circular caldera with a diameter of approximately 5 km. Secondary volcanic forms are present within the caldera, including pumice cones, *maars*, and trachytic lava domes, as well as four lakes. Scoria cones are the most frequent

type of volcanic edifices at Sete Cidades, dominating its west and southeast flanks (Queiroz 1997; Queiroz et al., 2015).

The oldest K/Ar dated rock ($210,000 \pm 8000$ yr; Moore, 1983) is a trachytic lava found at the base of the northern caldera wall, suggesting that subaerial activity at Sete Cidades probably dates back more than 250,000 yr ago (Queiroz, 1997; Queiroz et al., 2015).

The stratigraphy of Sete Cidades is divided into two main groups (Queiroz, 1997). The Inferior Group includes all products older than 36,000 yr and is mainly composed of basaltic to trachytic lavas and a few weathered pyroclastic deposits (i.e., pyroclastic density current and pumice fall deposits), which record the early history of the volcano, from the shield-building stage to the subaerial construction of the central edifice. The Superior Group comprises all products younger than 36,000 yr and is subdivided into six formations. The major formations of Risco ($35,740 \pm 810$ ^{14}C yr BP; Queiroz, 1997), Bretanha ($28,750 \pm 240$ ^{14}C yr BP; Queiroz, 1997), and Santa Bárbara ($15,740 \pm 200$ ^{14}C yr BP; Queiroz, 1997), composed of complex successions of trachytic pumice fall beds, surge deposits, ignimbrites, and breccias, record three paroxysmal eruptions related to different phases of formation of Sete Cidades caldera. These major pyroclastic formations are intercalated by the subordinate Ajuda and Lombas formations, which comprise various pyroclastic deposits and basaltic lavas (Queiroz, 1997; Queiroz et al., 2015).

The Lagoas Formation is the youngest of the Superior Group and is composed of the Cascalho Negro and Pepom members, which together represent the post-caldera volcanism. The Cascalho Negro Member is stratigraphically constrained between the Santa Bárbara Formation (representing the last caldera-forming event; Porreca et al., 2018) and the Fogo A deposit (4520 ± 90 ^{14}C yr BP; Wallenstein, 1999), the main stratigraphic marker horizon of São Miguel. Cascalho Negro is formed by a sequence of deposits (CN1 to CN11) that includes trachytic pumice fall deposits, lava domes and associated block and ash flow deposits, basaltic lavas, scoria and tuff deposits, which record at least 11 small-magnitude trachytic and basaltic eruptions. The Pepom Member is predominantly composed of a series of trachytic pyroclastic deposits (P1 to

P17) overlying the Fogo A deposit, which includes pumice lapilli and ash fall, and minor pyroclastic density current deposits. These result from 17 intra-caldera explosive eruptions, frequently hydromagmatic and of Sub-Plinian scale that occurred in the last ~5000 yr. Pepom also comprises basaltic lavas and scoria deposits erupted from vents on the flanks of the volcano (Queiroz et al., 2008, 2015).

Fogo Volcano

Fogo Volcano (also known as Água de Pau Volcano), in the centre of the island (Fig. 1.5), is the highest (947 m a.s.l.) of the active central volcanoes of São Miguel and its summit hosts a 3 km wide caldera. Fogo caldera is occupied by one major lake, three smaller lagoons, a pumice cone, tuff rings and cones. Pumice cones and tuff rings/cones also occur on its flanks, along with several scoria cones and trachytic lava domes (Wallenstein, 1999; Wallenstein et al., 2015).

The oldest K/Ar age obtained for Fogo is $280,000 \pm 140,000$ yr (Muecke et al., 1974), determined for a submarine basaltic lava collected from a drill core, which represents, although with large uncertainty, the period before the subaerial emergence of the volcanic edifice (Wallenstein, 1999; Wallenstein et al., 2015).

The stratigraphy of Fogo is split into two major groups (Wallenstein, 1999). The Lower Group is formed by all products older than 40,000 yr and includes submarine (pillow) lavas, subaerial sequences of basaltic products interbedded with trachytic pyroclastic deposits (pumice fall beds and ignimbrites), trachytic lavas, and undifferentiated volcanoclastic deposits. This sequence records the early history of the volcano, up to the formation of the outer caldera (Wallenstein, 1999; Wallenstein et al., 2015). The Upper Group comprises the products emitted in the last 40,000 yr. Due to the difficulty of correlating eruptive sequences in different locations, the pre-5000 yr stratigraphic sequences of the Upper Group are described separately for the northern and southern flanks (Wallenstein, 1999; Wallenstein et al., 2015). The northern sequence includes the

Porto Formoso eruptive sequence (a deposit near the top is dated at $21,340 \pm 130$ ^{14}C yr BP; Wallenstein, 1999), Chã das Gatas eruptive sequence, Coroa da Mata Formation ($18,600 \pm 300$ ^{14}C yr BP; Moore and Rubin, 1991), Barrosa eruptive sequence, and Fenaís da Luz eruptive sequence. While the southern sequence comprises the Roída da Praia and Ribeira Chã formations. The Roída da Praia Formation is composed of a large number of pumice fall deposits and ignimbrites interbedded with lahars and basaltic pyroclasts, representing approximately 65 eruptive events, some of which of high magnitude. Roída da Praia is subdivided into three members: the Lower (a deposit in the middle part is dated at $>34,200$ ^{14}C yr BP; Shotton and Williams, 1973), Intermediate (base dated at $14,620 \pm 60$ ^{14}C yr BP; Wallenstein, 1999), and Upper members. The Ribeira Chã Formation comprises a pumice fall deposit and an ignimbrite (Lower and Upper members, respectively) that record a single paroxysmal event (Wallenstein, 1999; Wallenstein et al., 2015).

The activity of the last ~5000 yr is primarily represented by the Pisão, Fogo A, and Lombadas formations and the products of the AD 1563 historical eruptions. The Pisão Formation (4760 ± 60 ^{14}C yr BP; Wallenstein, 1999) corresponds to a trachytic pyroclastic fall deposit resulting from a single eruption. Fogo A Formation (4520 ± 90 ^{14}C yr BP; Wallenstein, 1999), the best stratigraphic marker horizon for the island, includes a Lower Member composed of pumice lapilli fall layers interbedded with hydromagmatic ash and surges, and an Upper Member formed by pumice lapilli fall layers and a voluminous ignimbrite. It corresponds to the largest event (Plinian) of the last 5000 yr at São Miguel (e.g., Walker and Croasdale, 1971; Booth et al., 1978; Bursik et al., 1992; Wallenstein, 1999; Pensa et al., 2015a, b; Wallenstein et al., 2015). Lombadas Formation encompasses three trachytic pyroclastic fall deposits produced during the last 3000 yr: Fogo B (3240 ± 90 ^{14}C yr BP, Shotton et al., 1970), Fogo C, and Fogo D (Booth et al., 1978; Wallenstein, 1999). The post-5000 yr activity also comprises three scoria cones and associated lavas related to basaltic flank eruptions. Two historical eruptions took place at Fogo Volcano in AD 1563, just four days apart. The first was a Sub-Plinian eruption located inside Fogo caldera that produced a trachytic pumice lapilli and ash fall deposit (Walker and Croasdale, 1971;

Wallenstein, 1999; Aguiar, 2018). The second was a Hawaiian-style eruption on the northern flank (Pico do Sapateiro), which produced two small-volume basaltic lava flows. In AD 1564 a probable phreatic explosion took place at the same location of the AD 1563 trachytic eruption (Wallenstein, 1999, Wallenstein et al., 2005, 2007, 2015).

Furnas Volcano

Furnas Volcano is the easternmost of the three active central volcanoes of São Miguel (Fig. 1.5). Unlike Sete Cidades and Fogo volcanoes, it lacks a well-developed edifice and instead corresponds to a nested caldera complex (805 m a.s.l.), with the outer caldera measuring approximately 5×8 km and the inner caldera measuring approximately (6×3.5) km. Pumice rings, pumice cones and trachytic lava domes are present within the inner caldera. However, a sequence of trachytic lava domes dominates the western flank of Furnas. Scoria cones occur outside of the caldera, mainly to the north and east.

The oldest rock, K/Ar dated at $93,000 \pm 9000$ yr (Moore, 1991a), is a mafic lava that overlies the Povoação/Nordeste lava pile, implying that volcanic activity at Furnas had started at that time (Guest et al., 1999, 2015).

The stratigraphy of Furnas is divided into three main groups (Guest et al., 1999). The Lower Furnas Group includes all products older than 30,000 yr that overlie the Basal Lavas. It comprises trachytic pyroclastic deposits (ignimbrites, pumice fall, and ash fall deposits), debris flow deposits, block and ash flow deposits, and trachytic lavas (Guest et al., 1999, 2015). The Lower Furnas Group is organised into several units: the Amoras Formation, Garajau Trachytic Lava, Albufeira Formation, Quente Block and Ash flow unit, Cavaleiro Formation, and Povoação Ignimbrite Formation (underlying paleosols dated between 30,000 and 35,000 yr BP; Guest et al., 1999). This sequence represents the early, predominantly explosive activity of the volcano up to the first caldera-forming eruption associated with the genesis of the main/outer caldera (recorded

by the Povoação Ignimbrite Formation) (Guest et al., 1999; Duncan et al., 1999). The Middle Furnas Group comprises deposits constrained between ~30,000 and ~5000 yr BP, and it is composed of numerous pumice lapilli and ash fall deposits, ignimbrites, and lavas with associated debris flow. It includes the Tufo Formation (dated around 27,000 yr BP; Guest et al., 1999), Mouco Formation, Salto dos Ingleses Formation (loosely dated between 27,000 and 23,000 yr BP based on lake sediments; Moore and Rubin, 1991), Ponta Garça Ignimbrite Formation ($17,240 \pm 70$ ^{14}C yr BP; Guest et al., 1999), Cancelinha Formation, Gado Formation, and Pico do Ferro Unit (an underlying paleosol is dated at $11,230 \pm 100$ yr BP; Moore, 1991a, b). The Ponta Garça Ignimbrite Formation corresponds to a sequence of pyroclastic flow and surge deposits, which records a major eruption at Furnas Volcano. The Cancelinha Formation is composed of, at least, nine trachytic pyroclastic fall deposits stratigraphically constrained between the Ponta Garça Ignimbrite and the Fogo A deposit. The Middle Furnas Group also comprises the Pico do Canário Formation, which corresponds to a trachytic centre (polygenetic cone) outside the caldera.

The Upper Furnas Group represents the last 5000 yr of activity at Furnas Volcano. It comprises a sequence of trachytic pyroclastic deposits (Furnas A to Furnas AD 1630), overlying the Fogo A deposit, which are mostly composed of pumice lapilli layers interbedded with fine ash layers. These result from 10 intra-caldera Sub-Plinian eruptions with alternating magmatic and hydromagmatic phases (Pacheco, 1995; Guest et al., 1999; Cole et al., 1995, 1999; Guest et al., 2015). Furnas C (1870 ± 120 ^{14}C yr BP; Guest et al., 1999), which represents the largest event in the last 5000 yr, is divided into two main units: Unit 1 is composed of fine ash, rarely interbedded with lapilli layers and surge deposits, and Unit 2 includes coarse pumice lapilli layers interbedded with ash (Pacheco, 1995; Guest et al., 2015). Two historical eruptions were recorded at Furnas Volcano, in AD 1439-43 and AD 1630. The Furnas AD 1439-43 eruption (also known as Furnas I) was located at Pico do Gaspar and produced pumice lapilli and ash fall, and a trachytic dome in the final stage (Cole et al., 1999, Guest et al., 1999, 2015). The Furnas AD 1630 eruption (or Furnas J) was located near the southern rim of the caldera. It produced pumice lapilli and ash fall,

pyroclastic density currents, and a trachytic dome in the final stage (Cole et al., 1995; Guest et al., 1999, 2015).

1.5. Current State of the art on Probabilistic Volcanic Hazard Assessment

Assessing volcanic hazards to manage and mitigate the associated risks has become a top priority on the volcanology domain (Blong, 1984; Tilling, 1989; Barberi et al., 1990; Orsi et al., 2004), especially for volcanoes that are located near urbanized areas. However, it has been a challenge for the scientific community due to nature, available data and complexity of any volcanic system and its processes (De la Cruz-Reyna, 1996; Becerril et al., 2014), generating uncertainties and making volcanic hazard assessment a difficult task.

Volcanic hazard assessment has evolved significantly over the past several decades, transitioning from simpler deterministic approaches to more sophisticated quantitative and probabilistic methodologies (e.g., Scandone et al., 1993; Newhall and Hoblitt, 2002; Aspinall et al., 2003; Martin et al., 2004; Marzocchi et al., 2004; Connor et al., 2006; Jaquet et al., 2006; Marzocchi and Zuccarelli, 2006; Marzocchi et al., 2006; Jaquet et al., 2008; Marti et al., 2008a; Marzocchi et al., 2008; Neri et al., 2008; Sandri et al., 2012; Bebbington, 2013; Bebbington, 2014a; Sandri et al., 2014; Selva et al., 2014; Bebbington, 2015; Bevilacqua et al., 2016; Bevilacqua et al., 2017; Tierz et al., 2017; Sandri et al., 2018; Tierz et al., 2020, and others). Pioneer studies had their focus on the mapping of products from past eruptions assuming that future activity will follow previous patterns, such as, size, style and location (e.g. Rossi et al., 1984; Baker, 1985; Houghton et al., 1987; Stieltjes and Mirgon, 1998). However, the unpredictable nature of volcanic systems, along with their inherent variability, limits the effectiveness of purely deterministic predictions (e.g. Marzocchi, 1996; Marzocchi, 1977; Sparks, 2003). Moreover, volcanic systems are stochastic, exhibiting a high degree of freedom, and consequently generating uncertainties on evolution of volcanic processes and possible outcomes, requiring a probabilistic approach to quantify volcanic hazards (Marzocchi and Bebbington, 2012).

The term *probabilistic volcanic hazard assessment* (PVHA; Marzocchi et al., 2007) was introduced to differentiate qualitative approaches from more quantitative methods. In PVHA, the impact of a hazardous phenomenon, generated by a volcanic event, in a specific location is quantified by the exceedance probability of a selected set of thresholds in a given time window (e.g., Martinez-Montezinhos et al., 2022). Probabilistic approaches do not diminish the relevance nor discredit deterministic studies. Nevertheless, PVHA analysis is preferred in modern volcanology as it accounts for the uncertainties arising from limited knowledge of physical processes, or epistemic uncertainty, and from the natural variability of the processes, also known as aleatory uncertainty (e.g., Budnitz et al., 1997; Bonadonna et al., 2005; Macedonio et al., 2008; Marti et al., 2008b; Neri et al., 2008; Folch et al., 2009; Marzocchi et al., 2010; Bias et al., 2014; Marzocchi and Jordan, 2014; Barsotti et al., 2018; Selva et al., 2018; Marzocchi et al., 2021). For this reason, PVHA has become a main tool for hazard analysis and risk mitigation, supporting decision-making, crisis management, and land-use planning in volcanic regions (e.g., Selva et al., 2014; Constantinescu et al., 2022; Sandri et al., 2023a; among others).

Early probabilistic techniques are focused on the definition of one reference eruptive scenario (e.g., Orsi et al., 2004), typically the most probable one or the maximum expected event (Barberi et al., 1990). Over time, studies have incorporated sets of likely eruptive scenarios, including either their relative probability or occurrence in time (e.g., Thouret et al., 1999; Mariño et al., 2007). More recent studies rely on the use of semi-empirical and statistical models, numerical models, or combine both techniques with field observations (e.g., Iverson et al., 1998; Cioni et al., 2003; Bonadonna, 2006; Vicari et al., 2007; Cioni et al., 2008; Esposti Ongaro et al., 2008; Favalli et al., 2009; Kelfoun et al., 2009; Lirer et al., 2010; Suzuki and Koyaguchi, 2013; Gueugneau et al., 2020;). Modern hazard studies are mostly probabilistic, where the use of Bayesian Event Trees (BETs) is increasing. In BETs probabilities are, frequently, achieved through the elicitation of expert judgement procedure (e.g., Aspinall, 2006; Neri et al., 2008) and/or using robust statistical methods and models (e.g., Selva et al., 2010; Marti et al., 2008a; Bias et al., 2013a, b).

Bayesian inference has emerged as a powerful tool in probabilistic volcanic hazard assessment (e.g., to estimate temporal and spatial patterns in volcanism through the use of probability density functions) enabling to quantify uncertainties and update probabilities as new data becomes available (Aspinall et al., 2003; Marzocchi et al., 2008; Christophersen et al., 2018).

Bayesian inference relies on Bayes' theorem (Eq.1), where initial beliefs or knowledge about a hypothesis, known as prior probability, can be described as a probability distribution or, for continuous variables, as a probability density function (PDF) (e.g., Tarantola, 1990; Debski, 2004). Once new data is collected, prior PDFs can be updated and recast into new PDF (likelihood function), giving information about how likely the observed data is. This new information is then used to modify prior PDFs into posterior PDFs. In addition, the prior distribution represents the uncertainty regarding a specific hypothesis before observing any data, while the posterior distribution reflects the updated beliefs after incorporating the observed data.

$$2. \quad P(A|B) = \frac{P(A \cap B)}{P(B)} = \frac{P(B|A) \cdot P(A)}{P(B)} \quad (\text{Eq. 1})$$

In Eq. 1, $P(A)$ is the prior probability of observing A, $P(B|A)$ is the likelihood function, $P(B)$ prior probability of observing B, and $P(A|B)$ is the posterior probability.

Volcanic hazard assessments require two different time scales. In this context, eruption forecasting can be carried out on short-term and/or long-term. Short-term (hours/days) hazard assessment is based on instrumental monitoring of the precursor phenomena, such as seismicity, hydrothermal phenomena, ground deformation and others. It allows to forecast the location of a probable vent and the time of onset of a future eruption (e.g., Newhall and Hoblitt, 2002; Marzocchi et al., 2008, Bonflis et al., 2012, and others). Long-term (years/tens-of-years) hazard assessment, on the other hand, is related to the past behaviour of a volcano. In this type of approach, datasets of past events are, normally, analysed through statistical methods, allowing a better understanding of future eruptions and the estimation of their probable type and size (e.g., Klein, 1982; Bebbington and Lai, 1996a; Sandri et al., 2021).

Current long-term probabilistic volcanic hazard assessment studies are based on four key steps: (1) analysing the distribution of events in time to estimate the probability of an eruption in a specific time window, (2) identifying potential locations for new vents, (3) computing eruption scenarios, and (4) evaluating the impact of volcanic events in different locations.

Temporal distribution of events for probability estimation

Volcanic eruptions are inherently complex and unpredictable. However, the analysis of previous patterns provides valuable insights into the timing of future activity. In fact, one of the most effective ways to assess the long-term probability of a future eruption is to understand how past events are distributed over time.

Key parameters in forecasting eruptions include the estimation of recurrence rates (i.e., the frequency of volcanic events in time; Connor et al., 2015), response periods (i.e., the time between a triggering event and a volcanic response; Jenkins et al., 2012), and/or inter-event times (i.e., the time elapsed between successive events) (e.g., Wickman, 1966a; Klein, 1982; Mulargia et al., 1985; Molloy et al., 2009; Jenkins et al., 2012; Sandri et al., 2021; Fenner et al., 2023). In addition, the time elapsed since the last eruption when compared to the estimated recurrence interval, further refines these predictions.

Statistical models can be used to analyse these temporal metrics, helping in the recognition of patterns in volcanic activity and, thus, providing highlights about when the next eruption might occur (Connor et al., 2015; Poland and Anderson, 2020). Ideally these models require event onset times and complete catalogues, however, in earth systems, this kind of information is often hard to estimate.

In classical temporal analysis, eruptive events are modelled as a stochastic point process, where each individual occurrence is considered an independent random event in time (e.g., Sandri et al., 2021). This means that the onset times of eruptive events are considered the most important piece

of information (Garcia-Aristizabal et al., 2012), therefore, describing waiting times of the physical process that lead to renewed volcanic activity. In this case, to effectively evaluate time series of events, some statistical models depend on steady-state data (i.e., if data is stationary) and this can be evaluated by the application of simple tests as Kolmogorov-Smirnov test and change point detection techniques (Mulargia et al., 1987; Burt et al., 1994; Burgos et al., 2022).

Steady-state models, such as the exponential model from Poisson process (e.g., De la Cruz-Reyna, 1991; Wickman, 1966a; Marzocchi and Zaccarelli, 2006), failure models on Weibull distribution (e.g., Voight, 1989; Bebbington and Lai, 1996b), Power-law models (Pyle, 1998), BPT (Garcia-Aristizabal et al., 2012, 2013), LogLogistic (Connor et al., 2003), Lognormal (Bebbington and Lai, 1996b), Gamma, Sel-exciting models (Bebbington and Cronin, 2011; Bevilacqua et al., 2016), renewal models (e.g. Sandri et al., 2021), and mixtures of some distributions (Mendoza-Rosas and la Cruz-Reyna, 2008; Turner et al., 2008), are frequently used and they assume that the parameters that generated data remain constant over time.

Usually, this type of approach can be applied when there are no evident patterns in volcanic activity or, for instance, when information about onset times of eruptive events is uncertain.

However, volcanic activity often exhibits episodic behaviour across different timescales, where temporal clusters of events are commonly observed (e.g., Wickman, 1966a; Conway et al., 1998; Jones et al., 1999; Cronin et al., 2001; Bebbington, 2010; Bevilacqua et al., 2016, Sandri et al., 2021; Selva et al., 2022). For this reason, the non-stationary behaviour of some volcanic systems requires non-steady state models to analyse time series of eruptions. In this context, non-steady state models have been applied in several studies, starting from the simpler nonhomogeneous Poisson model (e.g., Ho, 1991), to Hidden Markov models to identify and model eruptive regimes (e.g., Wickman, 1966b; Bebbington, 2007).

Other studies focus on the assumption that response times are directly linked to the size of subsequent eruptions or the sizes of eruptions and their subsequent response times, known as Size-Predictable models and Time-Predictable models, respectively (De la Cruz Reyna, 1991;

Burt et al., 1994; Sandri et al., 2005; Marzocchi and Zaccarelli, 2006; Bebbington, 2008; Passarelli et al., 2010; Garcia-Aristizabal et al., 2012; Sandri et al., 2017). Frequency-Size models are also important to estimate return periods of hazardous events. To this end, several models have emerged in the literature such as the ones based on exponential magnitude distribution, as used in seismology (i.e., Gutenberg-Richter model, Gutenberg and Richter, 1944) (e.g., De la Cruz Reyna, 1991; Mendoza-Rosas and De la Cruz-Reyna, 2008; Sandri et al., 2021), or the extreme value theory (e.g., Mason et al., 2004; Coles and Sparks, 2006; Mendoza-Rosas and la Cruz-Reyna, 2008; Deligne et al., 2010; Furlan, 2010; Sobradelo et al., 2011).

In time series analysis, selecting an appropriate model is critical to make accurate predictions. The Akaike Information Criteria (AIC) is the most widely used tool for model selection (Connor et al., 2015). It helps in identifying the model that best balances goodness-of-fit of the data with model complexity, thus, providing a reliable metric for comparing different models. The model with the lowest AIC is considered the best balance between model complexity and data fitting. In addition, AIC tends to favour simpler models, i.e. models described by only one parameter are often preferred over those described by two or more parameters.

Identifying potential locations for new vents

Spatial distribution analysis of volcanic vents provides valuable information about magma emplacement patterns and the underlying structure of volcanic systems. Vent distributions are often controlled by the geometry of magma sources at depth, stress field, and pre-existing structures (e.g., Cañon-Tapia, 2021). Moreover, the prediction of future volcanic vents is critical for anticipating the type, size, and extent of volcanic hazards, thereby, minimizing the impact of volcanic activity. For this reason, spatial probability maps (susceptibility maps) of a vent opening are a key factor in probabilistic volcanic hazard assessment.

The base line to identify potential sites for future volcanic activity lies on the mapping of past eruptive centres, assuming that future activity will follow previous patterns (e.g., Rosi, 1996; Molist, 2017). However, more accurate predictions require the combination of the location and age of past vents along with structural geology, such as faults and dikes, to inform about structural weaknesses and possible paths for magma ascent. Additionally, geophysical and geochemical data offer real-time insights into the ongoing behaviour of magmatic systems (e.g., Alberico et al., 2007; Capello et al., 2012; Giudicepietro et al., 2015). This information is, frequently, combined with various probabilistic statistical models to unravel patterns in past activity and identify likelihood areas to host new vents.

Several probabilistic techniques and models have been used to estimate likely locations for new eruptive centres, some of which rely on Bayesian inference (e.g., Martin et al., 2004).

Some studies suggests that the spatial distribution of new eruptive centres may be random (e.g., De Bremond S'Ars et al., 1995). In such cases, the Homogeneous Poisson process is used, and the spatial distribution of volcanism is modelled under a uniform spatial point process (stochastic modelling) (Connor and Hill, 1995; Martin et al., 2004). However, in many cases, the distribution eruptive centres is not random, as vents often form clusters (e.g., Tadini et al., 2014, Mazzarini and Isola, 2024) Usually, spatial patterns can be statistically demonstrated by applying Clark-Evans test (Clark and Evans, 1954; Philo and Philo, 2021), also known as nearest-neighbour analysis, which compares the observed average distance between neighbouring points to the expected nearest neighbour distances for a random point distribution. In such cases, a non-homogeneous Poisson process provides a straightforward alternative to model clustered random data, as well as Cox processes.

Cox processes is a Poisson point process, whose intensity function is itself a random process that can vary across the domain (Jaquel et al., 2008; Adams et al., 2009; Choi and Baccelli, 2018). This method is typically used when there is uncertainty or variability in the factors that influences vent formation. In fact, non-homogeneous Poisson processes have been the most common

approach used among studies to identify likely locations to host new eruptive centres (e.g., Connor and Hill, 1995; Condit and Connor, 1996; Conway et al., 1998; Martin et al., 2003).

Models based on non-homogeneous Poisson process can be, broadly, divided into spatiotemporal nearest-neighbour models and a kernel technique. In the first case, spatiotemporal recurrence rate is a function of distance to and ages of events. On the other hand, the kernel technique is used to estimate the local intensity of eruptive centres (Connor and Hill, 1995; Felpeto et al., 2007; Jaquet et al., 2008; Martí and Felpeto, 2010; Connor et al., 2012; Cappello et al., 2012; Favalli et al., 2012, Cappello et al., 2013). Kernel density estimation (Lutz and Gutman, 1995) allows for the estimation of the spatial density of eruptive centres using the locations of past vents and/or structural features as a basis (e.g., Martin et al., 2004; Connor and Connor, 2009; Bebbington and Cronin, 2011; Connor et al., 2012; Bevilacqua et al., 2015a), therefore, assuming that new vents will not form far from the existing ones. In this method, the spatial variation is represented as a function of the distance from nearby eruptive centres, along with a smoothing parameter h , also known as bandwidth. This way, kernel estimations require the combination of a kernel function, and a smoothing parameter h . Gaussian kernel and Cauchy kernel functions have been widely used in the literature for spatial density estimation (e.g., Martin et al., 2004). However, the Exponential and Uniform kernel functions have also recently been introduced for modelling the spatial intensity of eruptive vents, thereby informing on the spatial probability of new vent formation (e.g., Sandri et al., 2023b, 2024).

The smoothing parameter plays a crucial role in shaping the probability distribution based on the distances from volcanic features or vents. Indeed, narrow bandwidths emphasizes densities around past vents, while the use of broad bandwidths can result in an overly smooth density estimate. Determining the optimal smoothing parameter remains a challenge and several techniques have been applied to estimate the smoothing parameter h , for instance, the least square cross-validation - LSCV (Cappello et al., 2012), the h_{opt} score (Silverman, 1986), and the sum of asymptotic mean squared error selector (SAMSE) (Connor et al., 2012). More recently, QVAST tool (Bartolini et al., 2013) has emerged in the literature for volcanic susceptibility, allowing for

the selection of a suitable smoothing parameter h for input data and the generation of the PDFs through the use of a Gaussian kernel function.

Computing eruptive scenarios

Computing eruptive scenarios has become an indispensable component in volcanic hazard assessment. In fact, volcanic hazard assessment relies on simulation models to generate eruptive scenarios and predict their potential impacts.

Volcanoes can produce a range of hazards, such as lava flows, ashfall, pyroclastic density currents (PDCs), and *lahars*. The extension and impact of these hazards varies in function of eruption style, size, and location, threatening communities in several ways. For this reason, understanding and mapping these hazards is crucial for effective risk management, emergency planning and to improve preparedness strategies (e.g., Martí et al., 2011; Bartolini et al., 2017; Jiménez et al., 2020; Vázquez et al., 2021).

Deterministic and probabilistic approaches can be used to model eruptive scenarios. Deterministic approaches usually provide the maximum area affected by a volcanic product based on past events. In contrast, probabilistic approaches show the probability that a specific location will be affected by a phenomenon (Bartolini et al., 2017).

Eruptive scenarios have been developed in a wide range of formats over the last decades. First studies were based on event narratives (e.g., Johnston et al., 1997; Galderisi et al., 2011), describing future volcanic eruptions in a story-like format. Over the past decades, volcanic hazard assessment studies primarily relied on the concept of “eruptive scenario”, where eruption conditions were subjectively defined. Some of these studies were based on the most representative eruptive scenario, either in the most probable or in the largest-scale case scenario, assuming that a future eruption will not differ from the selected scenario (e.g., Macedonio et al., 2008; Barsotti et al., 2018).

Other methods focused on the use of eruption range scenarios. These methods seek to address the influence of natural variability by averaging the outcomes of hundreds of simulations, in which eruption parameters are sampled from a wide range of eruptive conditions (e.g., Bonadonna et al., 2005; Folch and Sulpizio, 2010; Prata et al., 2019).

More recent approaches rely on the concept of continuum of possible combinations of eruptive parameters, where many simulations are performed (e.g., Sulpizio et al., 2012; Sandri et al., 2016; Titos et al., 2022). In this case, key eruption source parameters are defined and randomly selected from probability distributions, and statistical combinations of these parameters are weighted according to their probability of occurrence, i.e., giving higher weight to most probable combinations (e.g. Sandri et al., 2016; Titos et al., 2022).

In tephra modelling, for instance, some studies focus on a single scenario, or several eruptive scenarios combined with a single wind profile or a set of wind profiles (e.g., Folch and Sulpizio 2010; Bonasia et al., 2012). However, to incorporate variability either in eruption source parameters or weather conditions, multiple eruptive scenarios alongside a broad set of wind profiles are used in numerical simulations (e.g., Cioni et al., 2003; Bonadonna et al., 2005; Macedonio et al., 2008; Costa et al., 2009; Bonasia et al., 2012; Bonasia et al., 2014; Becerril et al., 2014; Macedonio et al., 2016; Biass et al., 2017; Martinez-Montesinos et al., 2022).

Several studies concentrate in modelling only a single type of hazard (e.g., Tephra fall, PDC's, lava flows, and others). However, volcanic eruptions often trigger different types of hazards in the same event. Therefore, modern probabilistic approaches have shifted towards a multi-hazard framework (e.g. Becerril et al., 2014; 2017; Martí et al., 2022), offering a holistic risk assessment.

The following table (Table 1) summarizes examples of tools used to simulate different types of volcanic products.

Table 1. 1. Non-exhaustive list of tools for simulating different types of volcanic products.

Simulation Models	Product (s) Modelled	References
VORIS	Tephra (deposition), PDCs, Lava flows	Felpeto, 2002, 2007
HAZMAP	Tephra (deposition)	Macedonio et al., 2005
FALL3D	Tephra (dispersion and deposition)	Folch et al. 2009; 2020
HYSPLIT	Tephra (dispersion and deposition)	Draxler and Hess, 1997, 1998
TEPHRA2	Tephra (dispersion and deposition)	Bonadonna et al., 2005
TEPHRAPROB	Tephra (dispersion and deposition)	Bias et al., 2016
Ash3D	Tephra (dispersion and deposition)	Schwaiger et al., 2012; Mastin et al., 2013
PUFF	Tephra (dispersion)	Searcy et al., 1998
VOL-CALPUFF	Tephra (dispersion and deposition)	Barsotti et al., 2008
Lpac	PDCs	De Michieli et al., 2010
Pybox	PDCs	Ongaro et al., 2016
Pyflow_2.0	PDCs	Dioguardi and Mele, 2018
Titan2D	PDCs, Lahar	Patra et al., 2005
VolcFlow	PDCs, Lahar, Lava flows	Kelfoun and Druitt, 2005; Kelfoun and Vargas, 2015
LAHARZ	PDCs, Lahar	Schilling, 1998
Q-LavHA	Lava flows	Mossoux et al., 2016
FLOWGO	Lava flows	Chevrel et al., 2018
MAGFLOW	Lava flows	Cappello et al, 2016
Swelava	Lava flows	Costa and Macedonio, 2005

Probabilistic Volcanic Hazard Assessment (PVHA)

Forecasting volcanic eruptions and their possible outcomes requires a structured and logical interpretation of different sources of evidence, as the unpredictable nature of volcanic behaviour often leads to high levels of uncertainty. In PVHA, common approaches include the use of tools based on Bayesian Belief Networks (BBN) or Event Trees (ET).

Bayesian Belief Networks (BBNs) (Aspinall et al., 2003) are graphical models where individual nodes represent distinct uncertain variables, and arcs indicates casual of influence connections between them (Jensen, 1996). Each node is linked to conditional probabilities that define its relationships with connected nodes in the network. Usually, these relationships are modelled through statistical probability distributions when enough data is available, or as discrete conditional states when reliable information is available, or as expert judgements or subjective probabilities when data is limited and uncertain (e.g., Aspinall et al., 2002; Aspinall, 2006).

Event Trees (ET) are graphical representations of events in a format of nodes and branches, in which each branch is a possible step from a general prior event through subsequent intermediate events to a final outcome (Connor et al., 2001; Newhall and Hoblitt, 2002). Different pathways can be selected over the ET, where probabilities of each node are combined to obtain the overall probability of the occurrence of a specific event.

Classical Event Trees were primarily used as conceptual frameworks to discuss probabilities of possible volcanic outcomes, providing a structured way to map out scenarios, from unrest to specific hazards (e.g., tephra fall, PDCs, lava flows). However, these early techniques often relied on purely empirical probability estimates (Newhall and Hoblitt, 2002), assuming a certain level of certainty in the probabilities.

Modern Event Trees, known as Bayesian Event Trees, have their roots in a Bayesian framework. The use of Bayesian inference allows for the evaluation of the probability distribution at each node, rather than a single probability, and enables the integration of both statistical and modelled data to build these distributions (Marzocchi et al., 2004, 2008; Marzocchi and Bebbington, 2012). Moreover, BET enables the dynamic updating of probabilities as new data becomes available or monitoring data is updated.

Assessing probability distributions at each node is crucial to capture uncertainties, (aleatory and epistemic) (Marzocchi et al., 2004, 2008, 2010) that are, frequently, expressed by average values and percentiles (10th, 50th, and 90th, Newhall and Hoblitt, 2002; Woo, 2009; Marzocchi et al., 2012). Therefore, the mean value of the probability distribution is assumed to be the best guess about the unknown frequency of an event at each node, representing a degree of aleatory uncertainty. Meanwhile, the spread of the distribution reflects the uncertainty around this unknown frequency, addressing the epistemic uncertainty.

Both BBN and BET methods incorporate multiple parameters and handle uncertainty. However, a crucial difference lies on the capacity of Bayesian approach in BET to explicitly and

systematically integrate both aleatory and epistemic uncertainty into the analysis (Marzocchi et al., 2008).

Several e-tools have been developed to facilitate the implementation of BET in PVHA for both short-term and long-term, allowing for the incorporation of different sources of information (e.g., past data, models, monitoring, and others). These tools are designed to assess and visualize the probability that a region or location will be affected by a volcanic event and the related uncertainties (e.g., Marzocchi et al., 2010; Sobradelo et al., 2013; Tonini et al., 2015a; Bartolini et al., 2017; Bertin et al., 2019). Bayesian Event Tree for Eruption Forecast tool (BET_EF; Marzocchi et al., 2008) is, frequently, implemented on short-term PVHAs (e.g., for emergency management), while the most common tools in long-term PVHAs (e.g., land-use planning) are Hazard Assessment Event tree (HASSET; Sobradelo et al., 2013), Bayesian Event Tree for Volcanic Hazard (BET_VH; Marzocchi et al., 2010), and PyBET_VH which is an updated version of BET_VH (e.g., Tonini et al., 2015a; Strehlow et al., 2017; Wild et al., 2019; Constantinescu et al., 2022).

In long-term probabilistic volcanic hazard assessment approaches, results are typically expressed in a form of hazard curves, probability maps, and hazard maps, each reflecting either the absolute or conditional probabilities.

Hazard curves illustrate the exceedance probability of different intensity thresholds for several target points of interest (e.g., airports, main roads, and others) (e.g., Hill et al., 1998; Connor et al., 2001; Bonadonna et al., 2005; Bonadonna, 2006; Magill et al., 2006). Hazard curves are the most complete output from hazard analysis as they incorporate all the information on aleatory and epistemic uncertainties. From hazard curves, probability maps and hazard maps can be generated.

Probability maps represent the exceedance probability of a specific intensity threshold at specific locations. Absolute and conditional probability maps differ in the way that probabilities are displayed. Therefore, absolute probability maps incorporate the probability of an eruption occurring in a specific timeframe, considering hazards from all possible vent locations and

eruption sizes, each weighted by its own probability of occurrence (e.g., Sandri et al., 2014; Tonini et al., 2015b). Conversely, conditional probability maps display probabilities given an eruption or a specific scenario (e.g., Connor et al., 2001; Bonadona et al., 2005; Magill et al., 2006).

Hazard maps indicate the intensity of a given hazardous phenomena impacting specific locations with a given exceedance probability in a given time window. Similarly to probability maps, hazard maps can include absolute or conditional probabilities.

1.6. Previous studies of hazard assessment in the Azores

Despite significant efforts to enhance the understanding of volcanic hazards and risks in the Azores, the region still lacks a complete Probabilistic Volcanic Hazard Assessment. Instead, several studies have explored individual components of volcanic hazard over the past decades.

One of the earliest studies was conducted by Jones et al. (1999), where authors statistically analysed the frequency of eruptions at Furnas Volcano based on the last 5000 years of activity, and estimated the probability of an eruption within the next 5, 10, 25, 50 and 75 years. Later, Gomes (2003) presented a master thesis in which different input parameters were tested to model lava flows on São Miguel Island using VORIS software. An Event Tree was developed for the first time for the Azores by Queiroz et al. (2008). In this work the authors addressed probabilities for possible scenarios at Sete Cidades Volcano through the expert elicitation method. That same year, Cole et al. (2008) performed simulations for tephra fallout from Sub-Plinian eruptions at Sete Cidades Volcano using HAZMAP to evaluate the impact of tephra in Ponta Delgada. They also modelled PDCs at Sete Cidades Volcano to assess their spatial distribution.

Furthering these efforts, Gaspar et al. (2015a) estimated recurrence intervals for different styles of activity, based on the last 5000 years of activity, and simulated different volcanic products to identify susceptible areas. Cappello et al. (2015) developed a study where the authors assessed lava-flow hazards on Pico Island. For that, the authors estimated the probability of future vent

opening and the probability of each expected type of eruption of and performed simulations of lava-flows using MAGFLOW model.

Pedrazzi et al. (2015) developed a study to evaluate the impact of effusive eruptions from Eguas-Carvão fissure system on São Miguel Island. The authors performed lava flow simulations using MAGFLOW model and combined these simulations with the spatial probability of a vent opening and the event probabilities of each expected type of eruption.

Simulations of Sub-Plinian eruptions were also performed at Fogo Volcano. For instance, Aguiar (2018) performed simulations for tephra fall using the estimated eruption source parameters for the total deposit of AD 1563 eruption and for its most significant layer. Additionally, Medeiros et al. (2021) evaluated the impact of Sub-Plinian eruptions (tephra fall and PDCs) at Fogo Volcano in Vila Franca parish. Both studies used VORIS software to model volcanic products.

The absence of a comprehensive Probabilistic Volcanic Hazard Assessment (PVHA) in the Azores has significant implications for risk management and mitigation strategies in the region. In fact, the lack of an integrated probabilistic framework that incorporates the probabilities of different volcanic hazards poses challenges for effective land-use planning and to develop robust emergency response plans. Implementing a full PVHA would not only enhance the scientific understanding of volcanic processes in the Azores, where most of the volcanos are dormant, but also provide useful information for decision makers, improving preparedness and contributing for the safety and resilience of insular populations living near active volcanoes.

Chapter 2

**Inter-event time analysis to estimate the probability
of an eruption at the active central volcanoes of São
Miguel (Azores)**

Chapter 2. Inter-event time analysis to estimate the probability of an eruption at the active central volcanoes of São Miguel (Azores)

2.1. Preliminary Note

Central volcanoes (or polygenetic volcanoes) exhibit a wide range of volcanic activity, producing eruptions with diverse magma compositions, eruptive styles, and sizes (Walker, 2000; Giordano and Caricchi, 2022), and, consequently, generating numerous hazardous phenomena with severe impacts on local communities and far-reaching effects on global economy and climate (Cas and Wright, 1988; Hansen et al., 1992; Mazzocchi et al., 2010; Wilson et al., 2012; Brown et al., 2017).

The eruptive behaviour varies widely among volcanoes, ranging from those with high eruption frequency to those with long repose periods. Understanding the temporal patterns of volcanic eruptions may provide important clues regarding periodicities, trends and even triggers for eruptions, contributing to a more effective eruption forecast and management of their impacts. However, these complex and somewhat unpredictable temporal behaviours make long-term hazard assessment a very challenging task.

The potential to forecast eruptions by analysing volcanic repose intervals (also known as Inter-event times) have been a focus of modern research in volcanic hazard assessment (Wickman, 1996a,b; Klein, 1982; Mulargia et al., 1985). Inter-event time analysis using renewal models has emerged as a pivotal methodology in estimating the probability of a future volcanic eruption. This models (e.g., Exponential, BPT, Weibull, LogLogistic, Lognormal, and Gamma) are rooted in

stochastic processes, where the inherent randomness and variability in eruption timing are considered (e.g., Bebbington, 2007, 2014b; Cronin et al., 2001; De la Cruz Reyna, 1993; Ho, 1991; Marzocchi and Zaccarelli et al., 2006; Mulargia, 1987; Sandri et al., 2021; Wolpert et al., 2018). However, this type of approaches requires data completeness, and it is well known that unrecorded eruptions are common as the temporal frame increases (Rougier et al., 2018), underestimating recurrence periods and probability estimation of future eruptions (Jenkins et al. 2012; Mead and Magill, 2014).

Applying this methodology on small territories, such as islands, presents additional constraints. In fact, the knowledge of the eruptive record of island volcanoes, such as in the Azores, is often limited due to the incomplete preservation of the stratigraphic record, as pyroclastic deposits are easily eroded, and a significant portion of the ejected material may fall offshore (e.g., Trofimovs et al., 2006; Kueppers et al., 2019; Pimentel et al., 2015). This strongly difficult the reconstruction of past events, thereby limiting Inter-event times (IET) estimation and, consequently, the prediction of future volcanic activity and their possible outcomes.

To overcome the issues related to past activity of island volcanoes, long-term approaches to forecast volcanic activity have incorporated the age-related uncertainty of past events. This is achieved by the use of an innovative methodology based on the generation of synthetic catalogues, which are a sequence of eruptive events within a specific time frame, where synthetic but stratigraphy-consistent ages are randomly assigned to unknown-age-range events (i.e., events without an estimated age – e.g., without radiocarbon age) (e.g., Selva et al., 2022) and to known-age-range events (i.e., events with an estimated radiocarbon age and the associated error), to evaluate the temporal distribution of eruptive events over time and estimate the probability of future volcanic activity.

In this chapter a robust temporal analysis is carried out on the three active central volcanoes of São Miguel, which have a long eruptive record over the last millennia yet most of their events remain undated or poorly reconstructed. To perform the analysis, synthetic catalogues were

generated for Sete Cidades, Fogo, and Furnas volcanoes, and inter-event times (IETs) (i.e., the time intervals between successive eruptive events) were calculated through different statistical distributions to compute the probability of an eruption on a specific time window.

This is a valuable methodology for volcanic regions where eruptive record is frequently incomplete (e.g., islands, remote environments), enabling a more accurate volcanic hazard assessment. Moreover, it also offers decision-makers a crucial tool to improve long-term volcanic hazard assessments and to define effective strategies for risk reduction.

2.2. Methodology

2.2.1. Field studies

Field surveys were conducted in 2021/2022 to identify and characterize the recent stratigraphic sequences of the three active central volcanoes: Sete Cidades, Fogo, and Furnas. The limits of individual deposits were set across geological discontinuities such as paleosols and erosion surfaces. The deposits were described in terms of spatial distribution, thickness, grain size, components, internal structures, lithological characteristics (e.g., pyroclastic deposits or lava flows; mafic or felsic rocks, which were translated as basaltic *sensu lato* or trachytic *sensu lato*, knowing that volcanism at São Miguel is typically bimodal; see Gaspar et al., 2015c), eruptive style, and size (based on the available Volcanic Explosivity Index [VEI, Newhall and Self, 1982] in literature or estimated through comparison of field observations). Additionally, available radiocarbon ages or historical dates of the events were also compiled.

Poor preservation and difficulties in recognition of older sequences constraint the establishment of stratigraphic correlations across locations, thereby limiting this study to younger sequences. For this reason, the temporal analysis was performed considering the last 16,000 years of Sete Cidades eruptive record, using Santa Bárbara Formation as stratigraphic horizon; the stratigraphic sequence from Fogo was limited to the southern flank, using Roída da Praia Intermediate Member

as stratigraphic marker, which provides the most detailed and comprehensive stratigraphic succession of the last 15,000 years. For Furnas Vulcano, Ponta Garça Ignimbrite Formation was used as stratigraphic marker, limiting the analysis to the last 17,000 years.

Therefore, two types of catalogues were defined to perform the study: (1) catalogues with the whole dataset of eruptive events, including both basaltic (*s.l.*) and trachytic (*s.l.*) eruptions (Referred as BT catalogues), and (2) catalogues of explosive trachytic (*s.l.*) eruptions (Referred as T catalogues).

2.2.2. Temporal analysis

The analysis in the time domain was performed independently for each volcanic system. The following method is described for a given volcanic system and repeated to them all.

In this study, the eruptive events were considered randomly independent in time, at times $t_1 < t_2 < \dots < t_i$. To perform this analysis, synthetic catalogues were built by assigning eruption dates to all eruptive events of the considered eruptive sequences (see Selva et al., 2022). Therefore, ages were randomly assigned to known-age-range events incorporating their uncertainty age-range. For unknown-age-range events, eruption dates were randomly assigned while maintaining the stratigraphic sequence (i.e., placing these events within the time interval between the eruption dates of the previous and following known-age-range events). As result, 1000 synthetic catalogues were generated considering the whole dataset of events (BT catalogues) of each volcanic system, and subsets of trachytic (*s.l.*) events (T catalogues) were obtained by excluding basaltic (*s.l.*) events from the whole dataset.

The stationarity of the IET-generating process data, which reflects that data is generated by a stationary process whose parameters do not change over time, was evaluated by applying the Kolmogorov-Smirnov one-sample (KS1) test to each synthetic catalogue's complete part, following the approach proposed by Bebbington (2012). Thus, each catalogue was tested against

a Uniform distribution of eruptive events through time to reject significant deviations from stationarity in the IET's generating process.

For all nonstationary catalogues, the completeness of the data was assessed by plotting the cumulative number of eruptions in time and then applying the change point detection algorithm for linear regimes (*ishcange* function implemented in MATLAB) to identify break-in-slopes (e.g., Burgos et al., 2022). This function allows for the detection of the point where a statistical property of a signal changes significantly (Killick et al., 2012). Thus, when applying that function, the threshold was set = 1 to find the most abrupt change point in the data. For all nonstationary catalogues, only the most recent stationary portion of catalogues was used (i.e., defined by the most abrupt break-in-slope (or change point), assuming the time after which the eruption catalogue is complete), and KS1 test was repeated.

Inter-event times (IETs), defined as the time intervals between successive events $\tau_i = t_{i+1} - t_i$ ($i = 1, 2, \dots$), were computed for each synthetic catalogue complete part, where τ is the sequence of random independent variables and t_i is the original series of events.

Six renewal models (Table 2.1) were fitted to the stationary and complete portion of each synthetic catalogue, as in Sandri et al. (2021), such as: Brownian Passage Time (BPT) (Garcia-Aristizabal et al., 2012, 2013), the Exponential model describing IETs from a Poisson process (e.g., De la Cruz-Reyna, 1991; Marzocchi and Zaccarelli, 2006), Gamma, LogLogistic (Connor et al., 2003), Lognormal (Bebbington and Lai, 1996b) and Weibull (e.g., Voight, 1989; Bebbington and Lai, 1996b) models, taking into account the time elapsed since the last eruption in each synthetic catalogue, also known as censoring time (x).

Table 2. 1. Renewal models used to perform the analysis.

Model	Formula
Exponential	$\lambda e^{-\lambda X}$
BPT	$\sqrt{\frac{\lambda}{2\pi X^3}} e^{-\frac{\lambda(X-\mu)^2}{2\mu^2 X}}$
Weibull	$\frac{\beta}{\alpha} \left(\frac{X}{\alpha}\right)^{\beta-1} e^{-(X/\alpha)^\beta}$
LogLogistic	$\frac{kX^{k-1}\mu^{-k}}{[1 + (X/\mu)^k]^2}$
Lognormal	$\frac{1}{X\sigma\sqrt{2\pi}} e^{-\frac{(\ln(X)-\mu)^2}{2\sigma^2}}$
Gamma	$\frac{1}{b^a\Gamma(a)} X^{a-1} e^{(-x/b)}$

Each renewal model was tested through the KS1 test to evaluate if the hypothesis of a given synthetic catalogue being explained by a given renewal model can be rejected. In the cases where this is not verified, the Akaike Information Criteria (AIC) was calculated. The AIC balances model simplicity and goodness-of-fit of the data. Therefore, the renewal model with the lowest AIC among those that cannot be rejected by the KS1 test was selected as the one that best describes the occurrence of eruptive events in time for a given catalogue.

The hazard rate (i.e., failure rate) was calculated and plotted for each catalogue to evaluate the behaviour of the considered models. For a history-dependent point process, the hazard rate is assumed to be the ratio of the probability density function $f(x)$ to the survival function $S(x)$ (Brain et al., 1978) and it is described as:

$$H(x) = \frac{f(x)}{S(x)} = \frac{f(x)}{1-F(x)}$$

where $H(x)$ is the instantaneous event rate at time t conditional on survival until the time t , assuming $x = (t - t_L)$, being t_L the time of the occurrence of the last event before time t , and $1 - F(x) = S(x)$, for $x \geq 0$, is the survival function.

The probability of having an eruptive event in the next 50 years, which is a common timeline for long-term volcanic hazard assessment, (Garcia-Aristizabal et al., 2012; Sandri et al., 2021) was computed for each synthetic catalogue, according to the best model selected by the AIC and given the current censoring time (i.e., given that no event has occurred since the last one), following the equation:

$$\Pr_{(x, x+\Delta t)} = \frac{\int_x^{x+\Delta t} f(s) ds}{1 - F(x)}$$

where x is the time elapsed since the last eruption, $\Pr_{(x, x+\Delta t)}$ is the conditional probability of an eruption will occur in a time interval $(x, x+\Delta t)$, given an interval of $x = (t - t_L)$ years since the occurrence of the last eruption.

To account for uncertainty on the best model's parameters, 10 values of each model parameter were sampled for each synthetic catalogue. For models described by more than one parameter, a multivariate normal distribution for the model parameters was assumed, and the values were sampled while considering the covariance between model parameters. Then, for every synthetic catalogue, 10 different values of the probability of an eruption in 50 years were computed. The distribution of such probability, given no event occurred since the last in the catalogue, was obtained by merging the 10 values of the probability of an eruption in 50 years from the 1000 synthetic catalogues, obtaining 10,000 values that represent the distribution of this probability. The final result of the probability of an eruption in 50 years is provided based on the computation of the 90% confidence range of this probability, which includes the uncertainty on the unknown-age-range or poorly-dated events, on the renewal process generating the IETs, and on its parameters.

2.3. Temporal analysis results

2.3.1. Eruptive record

Field surveys enabled to identify and determine the number of eruptions for each volcano in the considered timeframe (as shown in Table 2.2), as well as to characterize the type of eruptions based on magma composition (classified as basaltic (*s.l.*) or trachytic (*s.l.*), eruptive style, size, given by the Volcanic Explosivity Index (VEI), and eruption age whenever available (Appendix A1).

In the case of Sete Cidades Volcano, 24 trachytic (*s.l.*) eruptions and 12 basaltic (*s.l.*) flank events were identified over the last 16,000 years, indicating that at least 36 eruptions since Santa Bárbara eruption occurred ($15,740 \pm 200$ ^{14}C years BP, Queiroz, 1997).

Considering the time threshold set for the Fogo Volcano (15,000 years), at least 21 eruptions occurred since Roída da Praia Intermediate Member formation ($14,620 \pm 60$ ^{14}C yr BP, Wallenstein, 1999), of which 16 were trachytic (*s.l.*) eruptions and 5 were basaltic (*s.l.*) flank events.

For Furnas Volcano, 26 trachytic (*s.l.*) eruptions were identified in the last 17,000 years (i.e., since the eruption of Ponta Garça Ignimbrite dated at $17,240 \pm 70$ ^{14}C years BP; Guest et al., 1999).

Figure 2.1 illustrates the recent stratigraphic sequences of the three active central volcanoes (Sete Cidades, Fogo, and Furnas), as well as their formations and the ages of the eruptive events (whenever available).

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Table 2. 2. Number of recognized eruptive events of the three active central volcanoes of São Miguel in the considered timeframes.

	Sete Cidades Volcano	Fogo Volcano	Furnas Volcano
Stratigraphic threshold (^{14}C yr BP)	15,740 $\pm$ 200	14,620 $\pm$ 60	17,240 $\pm$ 70
No. of trachytic <i>s.l.</i> events (T)	24	16	26
No. of basaltic <i>s.l.</i> events (B)	12	5	0
Total No. of events (BT)	36	21	26

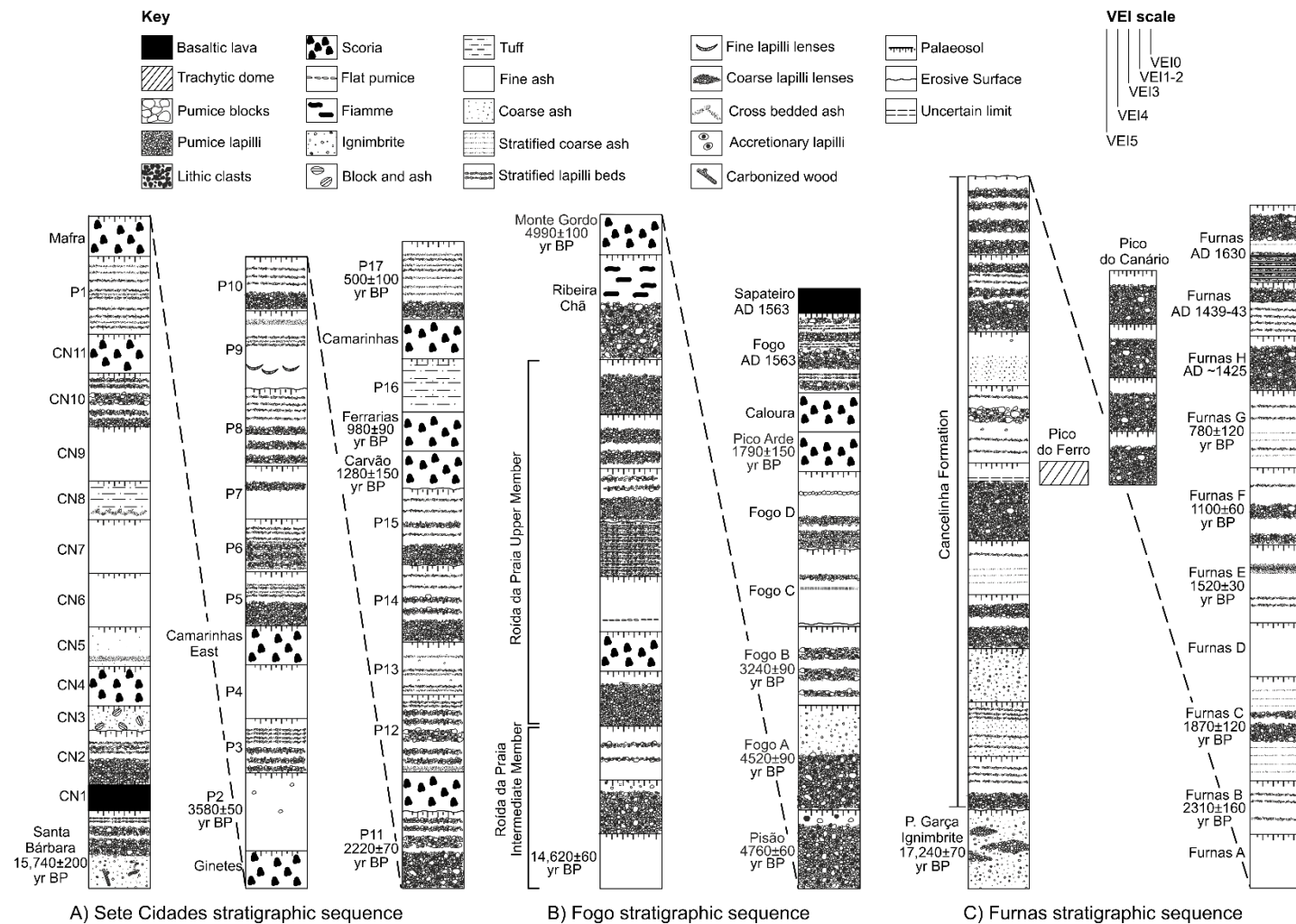


Figure 2. 1. Generalised vertical stratigraphic sequences of a) Sete Cidades, b) Fogo, and c) Furnas volcanoes. Due to the piecemeal nature of deposition and preservation the logs illustrated here are scaled such that the thickness of the unit is proportional to the estimated Volcanic Explosivity Index (VEI). Ages are in ¹⁴C years BP and historical eruptions in AD years.

2.3.2. Stationarity and completeness of the data

The Kolmogorov-Smirnov test on events of the considered catalogues allows for the identification of the portion of events that are rejected or not at 1% and 5% significance levels. Figure 2.2 shows the cumulative distribution function of onset times and relationship for a perfect stationary process, indicating the proportion of events that fit within the 95% and 99% confidence intervals, which are illustrated by dashed and solid lines, respectively.

The application of the KSI to the Sete Cidades BT and T catalogues resulted in the rejection of stationarity in all synthetic catalogues at 5% and 1% significance levels. (Fig.2.2A, B). To further explore this issue, the cumulative number of eruptive events was plotted through time for the two cases (i.e., for BT and T catalogues) (Fig.2.3A and 2.3B, respectively).

The results are given by graphic representation consisting of step functions of different colours, where each step corresponds to an eruptive event. The synthetic ages assigned to events with an unknown-age-range encompass a large range of values on the x-axis, while for radiocarbon-dated events the range of the synthetic ages is concentrated within the measurement error margin.

The change point detection algorithm tuned for a linear regime, which finds the most abrupt change in the rate of events, identified an objective break-in-slope in the cumulative number of eruptions in time (Fig. 2.3A, B). With this method, the most abrupt change in slope was detected in about 95% of the synthetic catalogues in both BT and T cases, before or around 3570 years BP (Fig. 2.3A, B). By considering the mean ages of events, the most abrupt change in rates was detected at 3578 years BP among BT and T catalogues, supporting the partitioning of the data around that age.

The KS1 test was re-run to verify the stationarity of BT <3578 yr and T <3578 yr catalogues from Sete Cidades Volcano (Fig. 2.2C, D). The test never rejects stationarity when analysing BT <3578 yr catalogues (with a portion of 0 for 5% and 1% significance levels), while for T <3578 yr

catalogues stationarity is rejected at 5% significance level, with a portion of rejected catalogues of 0.01%.

Stationarity KS1 test results for Fogo BT catalogues show that the portion of synthetic catalogues for which stationarity is rejected is 0.02 and 1.0×10^{-3} at the 5% and 1 % significance levels, respectively (Fig. 2.2E). For the trachytic catalogues (T), the corresponding portions are 1.0×10^{-3} and 0 at 5% and 1% significance levels, respectively (Fig. 2.2F).

For Furnas volcano only trachytic (*s.l.*) events were recognized. The KS1 test results show that the corresponding portions of catalogues where stationarity is rejected are 0.28 and 0.07 at the 5% and 1% significance levels, respectively (Fig. 2.2G).

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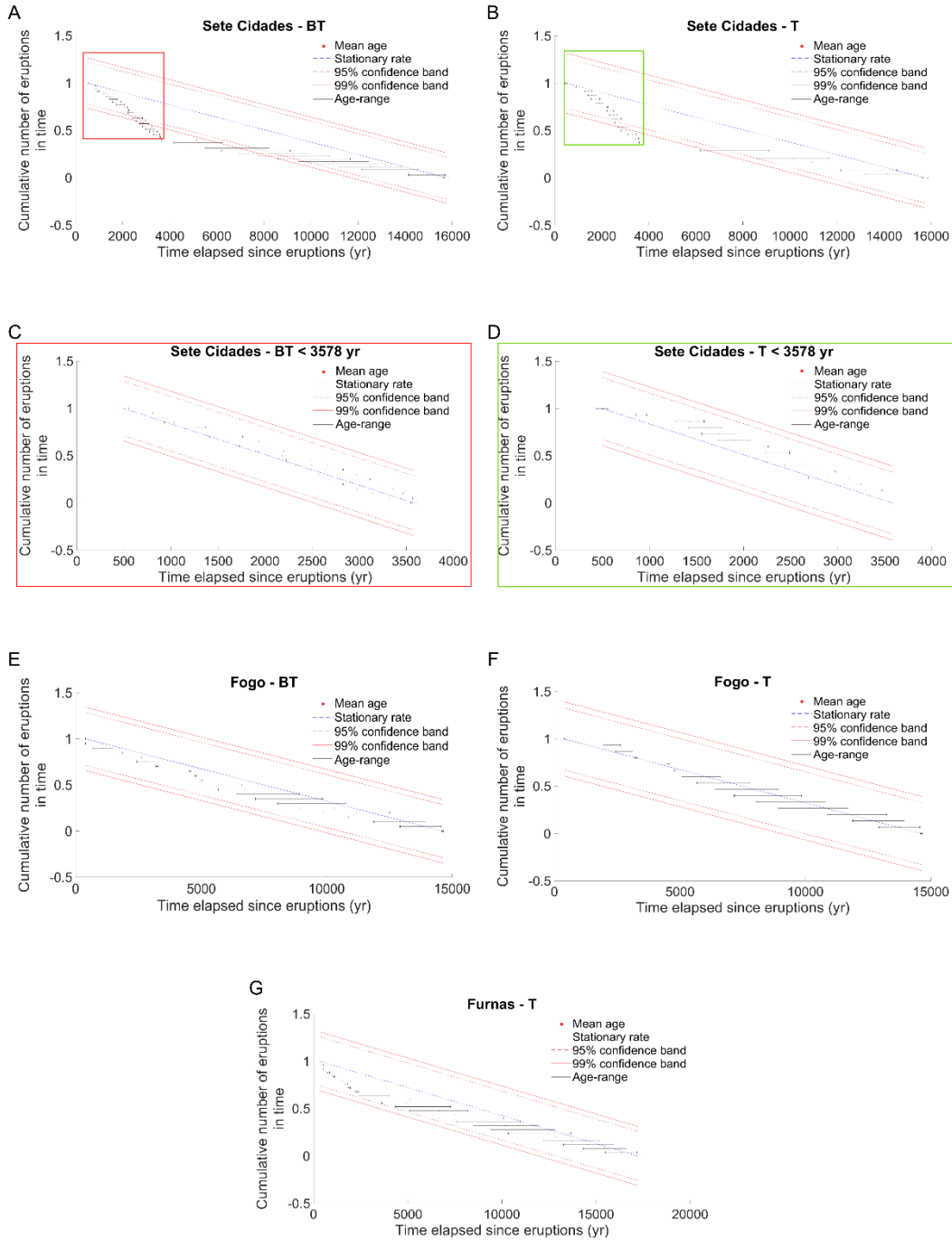


Figure 2. 2. Cumulative distribution function of onset times and relationship for a perfect stationarity process. (A) considering basaltic and trachytic events erupted over the last $15,740 \pm 200$ yr BP at Sete Cidades; (B) considering trachytic events erupted over the last $15,740 \pm 200$ yr BP at Sete Cidades; (C) considering basaltic and trachytic events erupted over the last 3578 yr at Sete Cidades; (D) considering trachytic events erupted over the last 3578 yr at Sete Cidades; (E) considering basaltic and trachytic events erupted over the last $14,620 \pm 60$ yr BP at Fogo; (F) considering trachytic events erupted over the last $14,620 \pm 60$ yr BP at Fogo; (G) considering trachytic events erupted over the last $17,240 \pm 70$ yr BP at Furnas. In each panel, the legend shows the age data (mean: red dot; age-range in synthetic catalogues: black solid line), the perfectly stationary rate (dashed blue line), and the 95% and 99% confidence interval (respectively dashed and solid red lines).

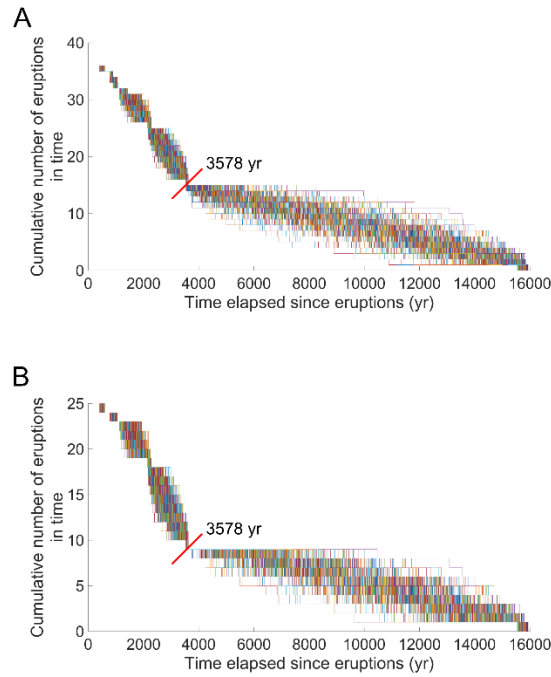


Figure 2. 3. Plot of the cumulative number of eruptions in time, considering: (A) the basaltic and trachytic events from Sete Cidades and (B) only trachytic events from Sete Cidades

2.3.3. Renewal models

At the following table (Table 2.3) are presented the number of times that each distribution fits the considered synthetic catalogues, including the associated AIC, and the cases where all the renewal models were rejected by the KSI test. An example of the best fitting model of each renewal model type to the empirical cumulative distribution function (ECDF) to the IETs in a given synthetic catalogue taken randomly out of the 1000 synthetic catalogue is shown, for each volcano, in figure 2.4.

Analysing the complete portion of Sete Cidades BT data (i.e., BT <3578 yr BP catalogues), 998 catalogues were modelled by at least one renewal model. Among them, the Exponential distribution was most frequently the best model, fitting 743 catalogues. Similarly, for the stationary portion of Sete Cidades T data (i.e., T <3578 yr BP catalogues), the Exponential distribution was also the best model, fitting 780 out of a total of 999 catalogues that could be

modelled through one of the renewal models. Nevertheless, in both BT and T catalogues, it is notable that the BPT outperforms the other distributions in a non-negligible percentage of cases (>10% among all the synthetic catalogues).

The analysis of Fogo BT catalogues show that every catalogue has been modelled by at least one distribution. Despite the Exponential distribution is the model that best describes how events are dispersed through time, fitting 509 catalogues, Gamma distribution is also a suitable model, fitting a similar number of cases of BT catalogues (491). All Fogo T catalogues were described by, at least, one renewal model. Among them, the Exponential distribution is the one that describes more frequently the occurrence of the events in time, fitting 649 catalogues. However, Weibull and BPT revealed to be the most effective models for a significant portion of the Fogo T catalogues (approximately 18% and 16%, respectively).

A total of 960 catalogues were modelled when analysing T catalogues from Furnas Volcano. Among the catalogues, 846 were fitted by the Exponential distribution, which is the best model in this case. However, the Weibull model also emerged as a good fitting model in a non-negligible number of the cases (8.5%).

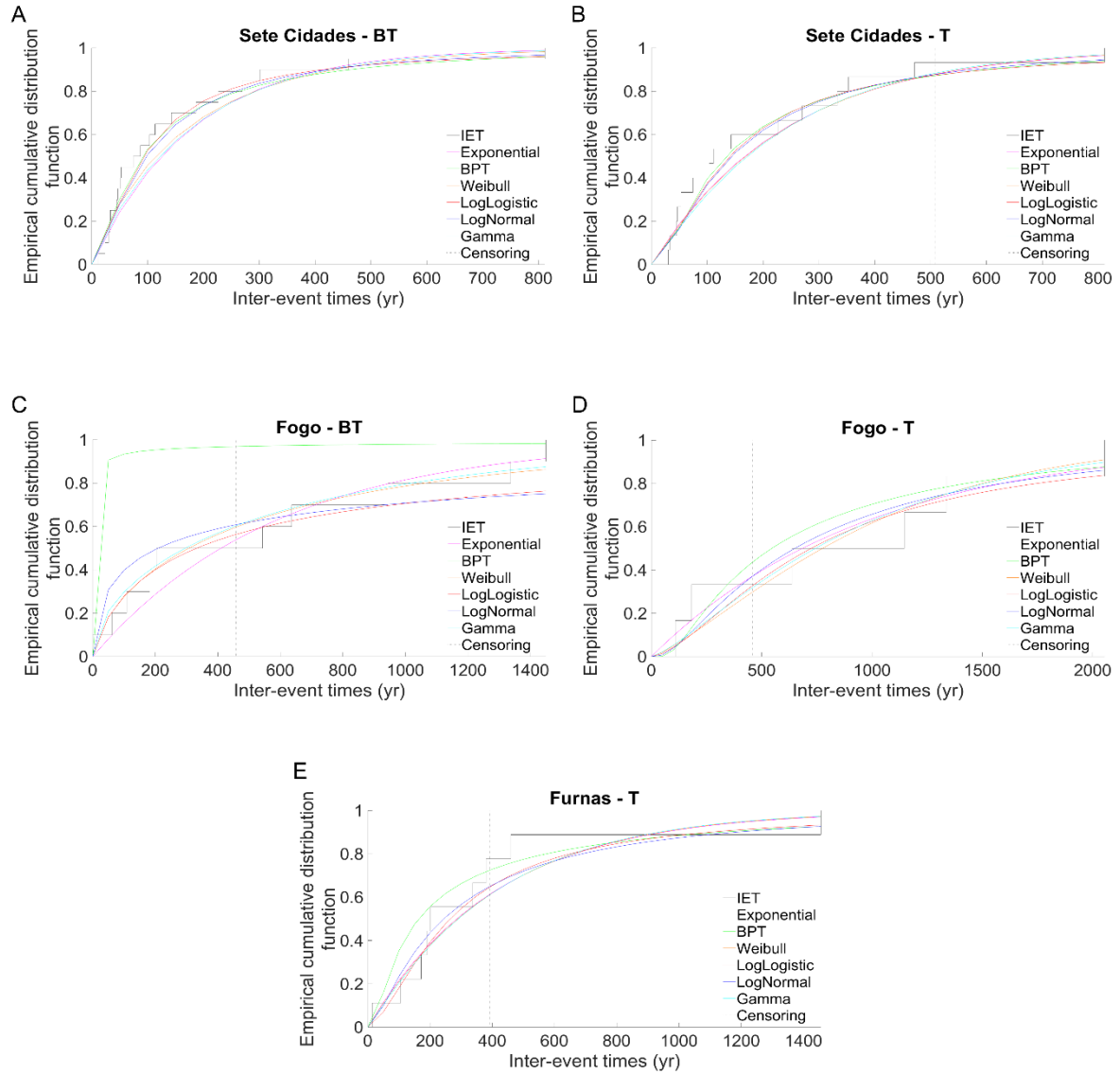


Figure 2. 4. Example of model fit to the ECDF of the Inter-event times for one of the synthetic catalogues chosen random out of the set of 1000 (black solid line). In each panel, the solid lines represent the best-fitting model for each of the six renewal models, for the specific volcano and synthetic catalogue. The colours of the models are coherent with Figure 2.10. A) Sete Cidades BT complete dataset (with BT events younger than 3578 yr); B) Sete Cidades T complete dataset (with T events younger than 3578 yr); C) Fogo BT complete dataset; D) Fogo T complete dataset; E) Furnas T complete dataset.

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Table 2. 3. Number of times that each renewal model fits the considered data.

Models	Catalogues				
	Sete Cidades		Fogo		Furnas
	BT <3578 yr	T <3578 yr	BT	T	T
	No. fit	No. fit	No. fit	No. fit	No. fit
Exponential	743 (AIC 250.6)	780 (AIC 197.1)	509 (AIC 150.3)	649 (AIC 97.1)	846 (AIC 125.7)
WBL	9 (AIC 252.5)	8 (AIC 198.8)	0 (AIC 152.3)	179 (AIC 97.9)	85 (AIC 126.8)
Log-logistic	27 (AIC 254.7)	9 (AIC 201.2)	0 (AIC 156.8)	0 (AIC 99.1)	23 (AIC 128.9)
BPT	116 (AIC 259.5)	139 (AIC 206.7)	0 (AIC 186.4)	163 (AIC 99.1)	0 (AIC 133.6)
Log-normal	47 (AIC 254.5)	16 (AIC 201.2)	0 (AIC 160.2)	0 (AIC 98.8)	0 (AIC 129.9)
Gamma	56 (AIC 252.5)	47 (AIC 198.7)	491 (AIC 151.7)	9 (AIC 98.1)	6 (AIC 127.2)
Total	998	999	1000	1000	960
Not fitted	2	1	0	0	40

2.3.4. Hazard rate

The hazard rate was calculated and plotted for each synthetic catalogue to better understand the behaviour of the candidate models (Fig. 2.5, 2.6, 2.7, 2.8, 2.9).

The Exponential distribution is frequently the best model among catalogues, suggesting that the hazard rate, for these cases, remains constant over time.

The WBL model describes some of the Sete Cidades BT <3578 yr BP, Sete Cidades T <3578 yr BP, Fogo T, and Furnas T catalogues. On the light of this model, the hazard rate exhibits fluctuations, increasing and decreasing abruptly after an event with the tendency to remain constant over time, or it increases after an event showing a tendency to be constant over time.

Yet, there are some cases (e.g., Sete Cidades T <3578 yr BP, Fogo T, and Furnas T catalogues) in which the hazard rate notably increases over time.

Log-Logistic model fits Sete Cidades BT <3578 yr, Sete Cidades T <3578 yr, and Furnas T catalogues. According to this model, the hazard rate exhibits a smooth increase after an event and decreases slowly over time.

The BPT can describe a significant number of catalogues (e.g., Sete Cidades BT <3578 yr BP, Sete Cidades T <3578 yr BP, and Fogo T catalogues). According to this model, the hazard rate initially increases and decreases sharply after an event, remaining constant over time, or it gradually increases after an event, followed by a smooth decrease or a tendency to be constant over time.

The Log-Normal model only fits catalogues from Sete Cidades. In these cases, it is observed that the hazard rate exhibits a sharp increase and subsequent decrease after an event, showing a smooth decrease over time, or it increases after an event and slowly decreases over time. In some other cases, it is observed an increase of the hazard rate after an event, followed by a slowly decreasing over time.

The Gamma model is frequently a good fitting model, describing almost half of Fogo BT catalogues. This model suggests that the hazard rate either increases or decrease quickly after an event, remaining constant after it hits a plateau. In some other cases, the hazard rate gradually increases after an event and remain constant over time.

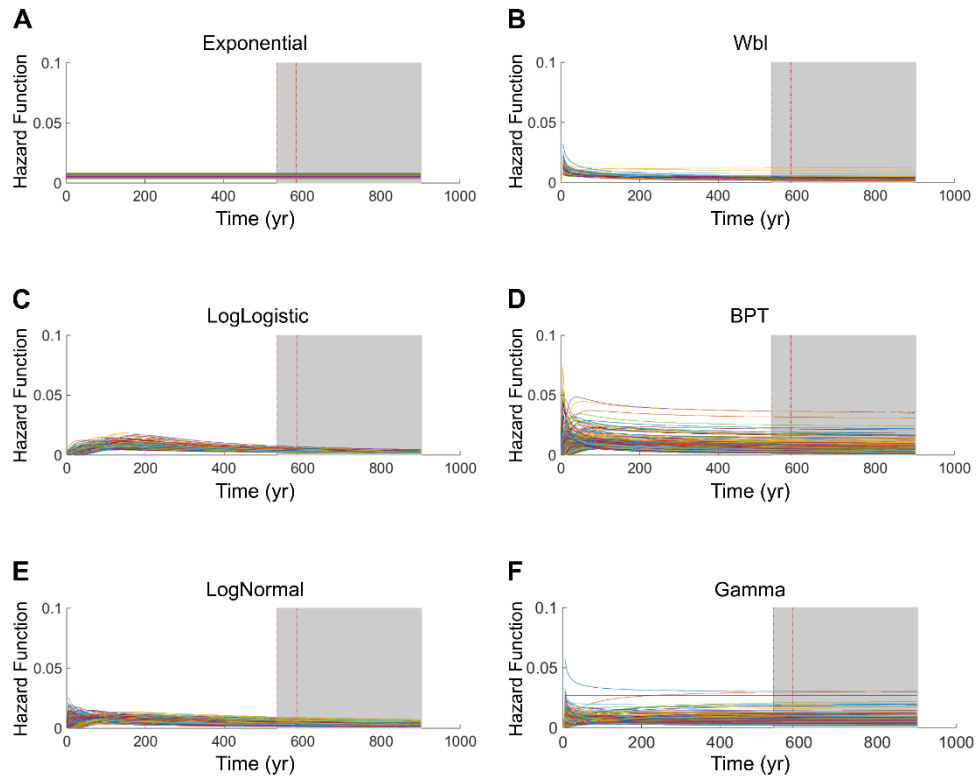


Figure 2. 5. Plot of the Hazard rate for Sete Cidades BT catalogues using different models: A) Exponential model; B) Weibull model; C) Loglogistic model; D) BPT model; E) Lognormal model; F) Gamma model.

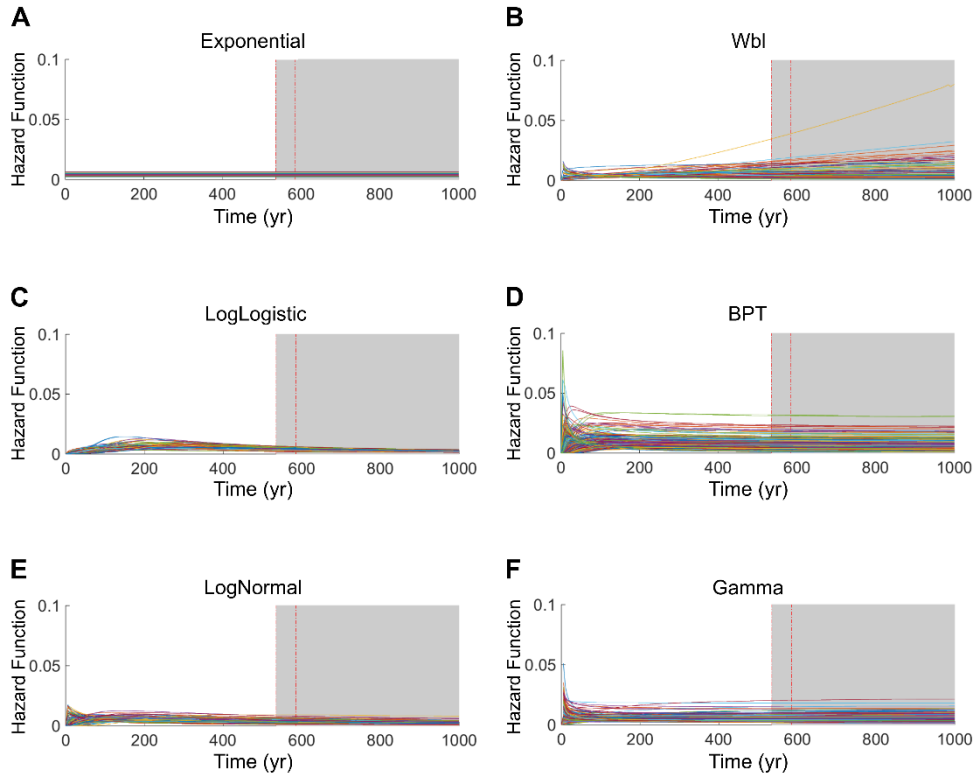


Figure 2. 6. Plot of the Hazard rate for Sete Cidades T catalogues using different models: A) Exponential model; B) Weibull model; C) Loglogistic model; D) BPT model; E) Lognormal model; F) Gamma model.

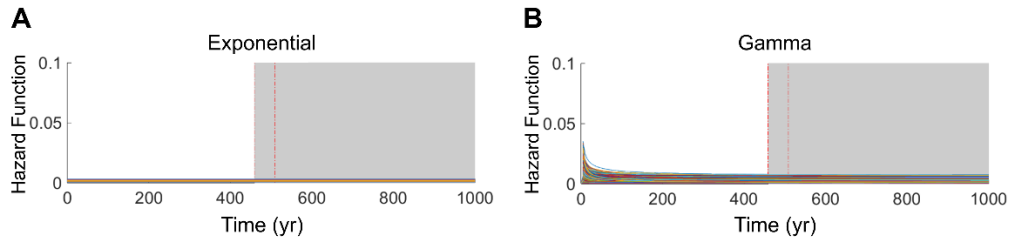


Figure 2. 7. Plot of the Hazard rate for Fogo BT catalogues using the A) Exponential model and B) Gamma model.

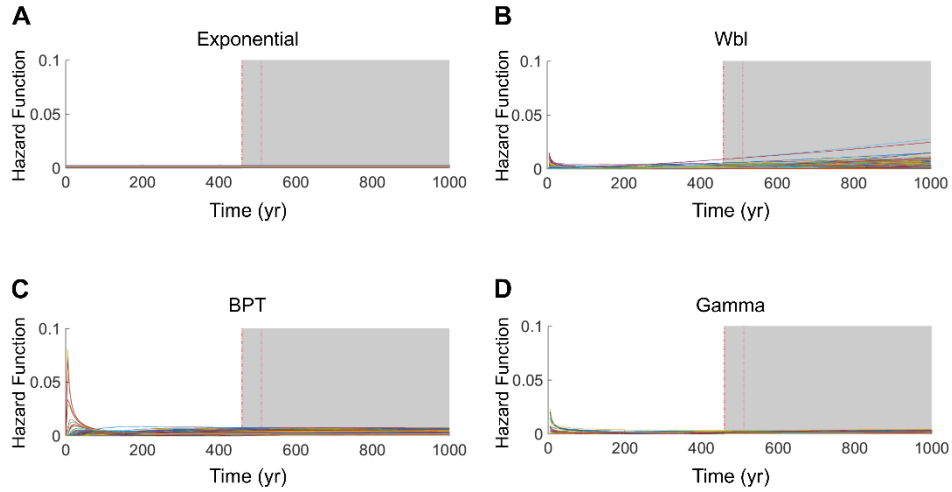


Figure 2. 8. Plot of the Hazard rate for Fogo T catalogues using different models: A) Exponential model; B) Weibull model; C) BPT model; D) Gamma model.

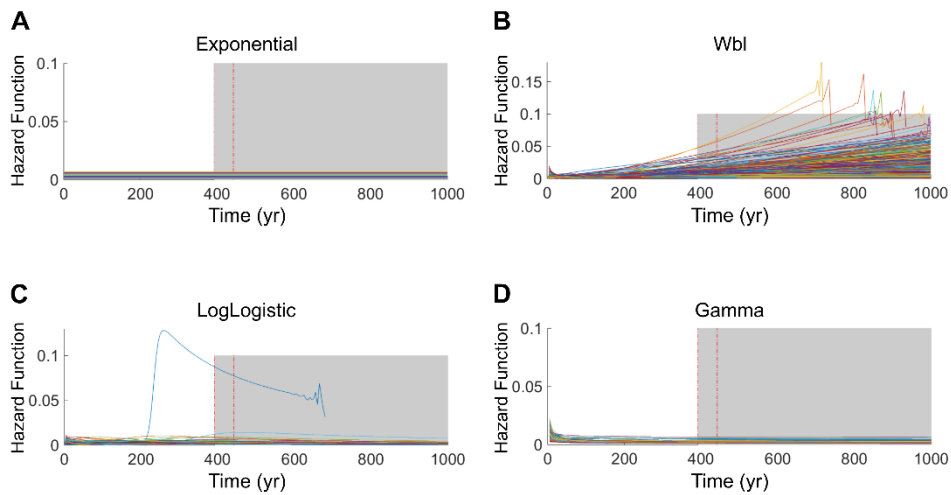


Figure 2. 9. Plot of the Hazard rate for Furnas T catalogues using different models: A) Exponential model; B) Weibull model; C) Loglogistic model; D) Gamma model.

2.3.5 Inter-Event Times and Probability estimation

In this section, it is presented the statistics of the obtained IETs according to the best fitting renewal models and the uncertainty on their parameters, as well as the statistics on the estimated probability of an eruption in the next 50 years, for each volcano and type of eruption (Table 2.4).

As an example, Figure 2.10 illustrates the fit of the preferred model to the ECDF of the IETs in a synthetic catalogue taken at random out of the 1000 catalogues (the same catalogue of Figure 2.4). The fit to the ECDF of the set of 10 models of the same type of the preferred model, but in which the model parameters are sampled from a multivariate normal distribution considering covariance (in case the parameters are more than one), is also presented for each volcano.

The current censoring time, i.e., the time elapsed since the last eruption, was taken into account to perform all the calculations. Thus, the minimum, maximum, and mean IET values were obtained, and the mean probability of an eruption in 50 years, as well as the respective 90% confidence range interval, were computed, considering, and not considering the uncertainty on the parameters of the best model.

Through the analysis of Sete Cidades BT <3578 yr BP catalogues, it was obtained a wide range between the minimum and maximum modelled IETs (from 0.005 to 852 years). The mean IETs was estimated to be 154 years. The obtained mean value provides information on the order of magnitude of the expected time between eruptions at Sete Cidades. Similarly, the analysis of Sete Cidades T <3578 yr BP catalogues revealed that IETs range from a minimum of 0.005 years (about 18 days) to a maximum of 1.15×10^3 years (maximum IET), with a mean IET of 205 years.

Analysing Fogo BT catalogues, IETs ranging from a minimum of 7.18×10^{-4} years to a maximum of 4.83×10^3 years were estimated. Mean IET of 546 was obtained. From Fogo T catalogues, it was obtained a range in the modelled IETs from a minimum of 0.23 years (approximately 3 months) to a maximum of 5.06×10^3 years, with a mean IET of 909 years.

The analysis of Furnas T catalogues provides a range in the modelled IETs from 0.19 years (about 2.5 months) to 5.65×10^3 years. Mean IET of 318 years was also estimated.

For a given volcano and type of eruption, the probability distribution of an eruption occurring in the next 50 years (Fig. 2.10) conditional to the current censoring time was estimated, among the synthetic catalogues, by fitting the IET data to the best model for every catalogue. Therefore, a

single probability value was obtained for each synthetic catalogue, resulting in a sample of 1000 values that approximate the distribution.

The uncertainty on the best model parameters was incorporated by sampling (with covariance) 10 different values of the model parameters and computing the corresponding probability in 50 years, obtaining a sample of 10×1000 values of such probability. To synthesize the results of this analysis, for each volcano and type of eruption, the 90% confidence interval of the probability distribution of an eruption in 50 years was provided (Table 2.4), either considering or not the uncertainty on the model parameters.

Based on the 90% confidence interval, the probability of a basaltic (*s.l.*) or trachytic (*s.l.*) eruption in the next 50 years at Sete Cidades Volcano ranges from 12% to 32% (mean 21%) when considering the uncertainty on the best model parameters, and from 13% to 24% (mean 22%), when the uncertainty is not accounted. The probability of a future trachytic (*s.l.*) eruption at the same volcano was range from 11% to 26% (mean 17%), when accounting for the uncertainty on the best model parameters, and between 12% to 19% (mean 18%), when the uncertainty on the model parameters is neglected.

The 90% confidence interval of the probability of an eruption of basaltic (*s.l.*) or trachytic (*s.l.*) nature in the next 50 years at Fogo Volcano is 4% to 14% (mean 8%) when the uncertainty on the best model parameters are accounted, and is 6% to 9% (mean 7%) if the uncertainty on the parameters is not included; while regarding the occurrence of an trachytic (*s.l.*) eruption in the next 50 years, the 90% confidence interval is 2% to 10% (mean 5%) and 4% to 8% (mean 5%), when considering and excluding the uncertainty on the model parameters, respectively.

According to the 90% confidence interval, the probability of a trachytic (*s.l.*) eruption in the next 50 years at Furnas Volcano ranges from 6% to 26% (mean 13%) when accounting for uncertainty on the best model parameters, and from 9% to 27% (mean 15%), when this uncertainty is not considered.

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The histograms of the obtained samples are illustrated at Figure 2.11, with and without considering the uncertainty on the best model's parameters, giving an idea on the dispersal and skewness of the estimated distribution.

Table 2. 4. Inter-event times and estimated probabilities of an eruption in the next 50 years, considering each central volcano.

	Catalogues				
	Sete Cidades		Fogo		Furnas
	BT <3578yr	T <3578yr	BT	T	T
Censoring time (y)	472-672	472-672	459	459	392
Minimum IET (y)	0.005	0.005	7.18×10^{-4}	0.23	0.19
Maximum IET (y)	852	1.15×10^3	4.83×10^3	5.06×10^3	5.65×10^3
Mean IET (y)	154	205	546	909	318
P Mean 50 years (%)	21	17	8	5	13
Conf. range 90% (%)	12-32	11-26	4-14	2-10	6-26
σ^a	-	6	-	5	8
Λ^b	-	37	-	17	16
P Mean 50 years (%)	22	18	7	5	15
Conf. range 90% (%)	13-24	12-19	6-9	4-8	9-27

^aStandard deviation of the probabilities in 50 years.

^bCorresponding Lambda estimated by applying equation 23 in Chapter 4.

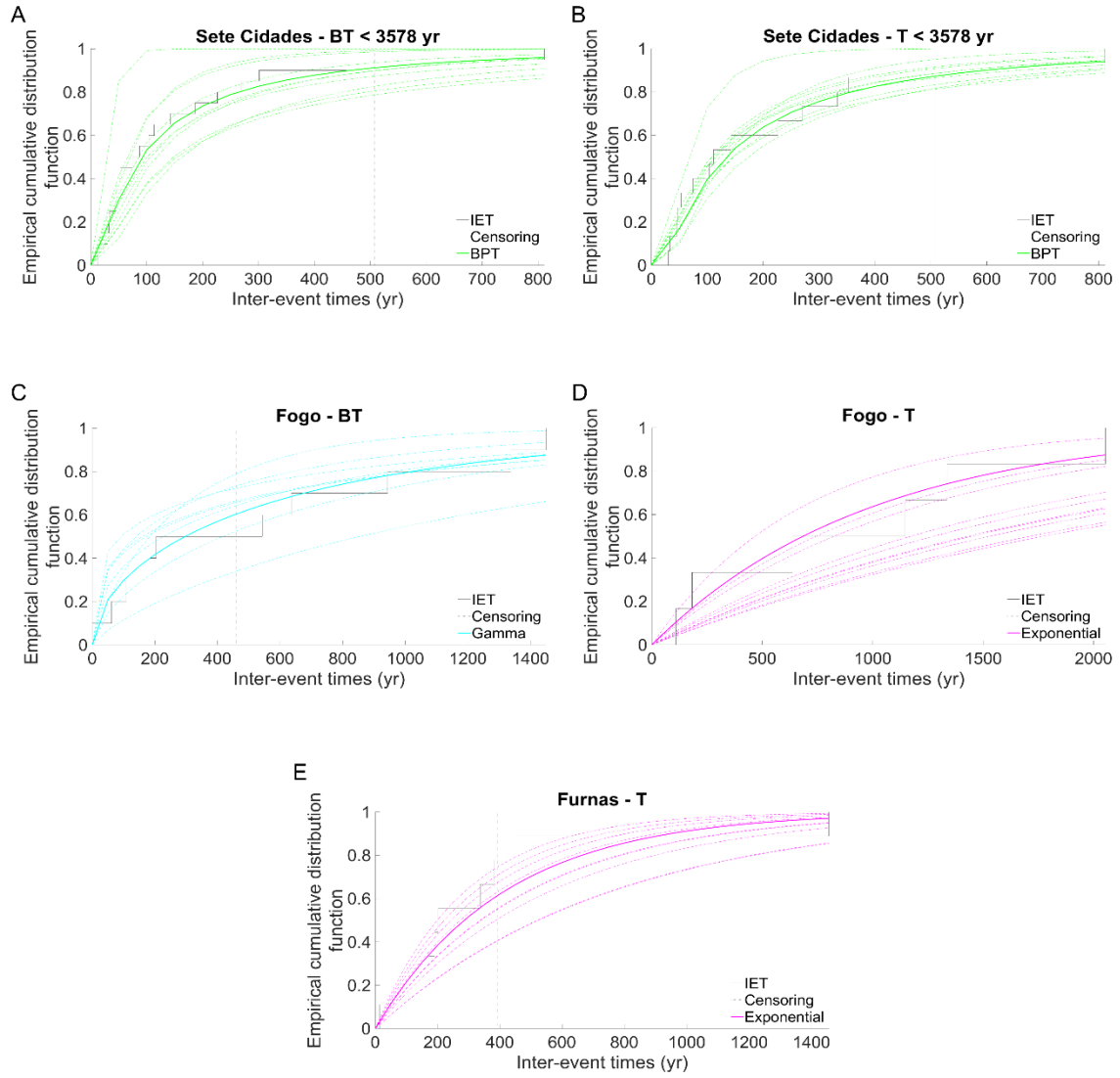


Figure 2. 10. Example of model fit to the empirical cumulative distribution function (ECDF) of the inter-event times (IETs) for a synthetic catalogue chosen randomly out of the set of 1000 catalogues (black solid line). In each panel, the solid line represents the preferred model with the best-estimate parameters for the specific volcano and synthetic catalogue, while the set of dashed lines shows 10 models describing the uncertainty on the best-estimate parameters of the preferred model. The 10 models come from the 10 samples of the preferred model's parameters, considering their covariance when they are more than one. The colour of the model is coherent with the example of model fit on the same catalogue, as shown in Figure 2.4 of Online Resource 2. A) Sete Cidades BT complete dataset (with BT events younger than 3578 yr BP); B) Sete Cidades T complete dataset (with T events younger than 3578 yr BP); C) Fogo BT complete dataset; D) Fogo T complete dataset; and E) Furnas T complete dataset.

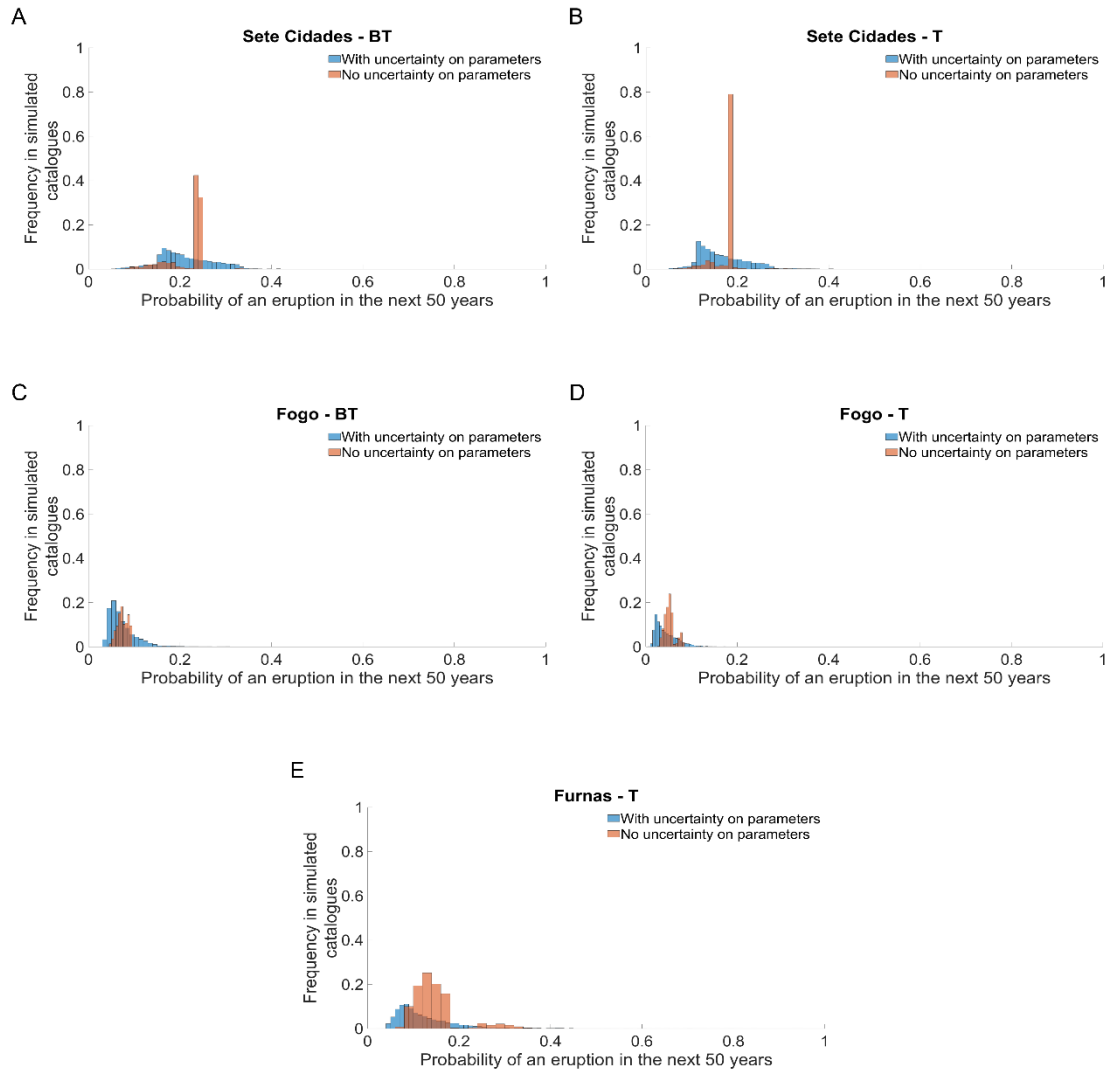


Figure 2. 11. Normalized Probability histograms obtained considering the complete portion of the catalogues: A) Sete Cidades BT <3578 yr BP catalogues; B) Sete Cidades T <3578 yr BP catalogues; C) Fogo BT catalogues; D) Fogo T catalogues; E) Furnas T catalogues.

2.4. Discussion

All the three active central volcanoes of São Miguel can generate destructive eruptive events as a consequence of their geological setting. The impact of an explosive eruption is even largest in small territories, such the Azores archipelago, where populations live side by side to the major volcanic edifices of the island.

The stratigraphy and eruptive history of the three active central volcanoes of São Miguel (Sete Cidades, Fogo, and Furnas) have been studied by numerous authors over the last decades (see Geological background section). Despite the knowledge acquired, many eruptions are still undated or poorly reconstructed, as the eruptive record is often incompletely preserved, generating large uncertainties about how eruptions were distributed through time and, therefore, making the estimation of recurrence intervals and probabilities of future eruptions very challenging tasks.

In this study, a stochastic modelling to unravel the eruptive behaviour of Sete Cidades, Fogo, and Furnas volcanoes was used. Given the poor preservation and knowledge of older stratigraphic sequences, this study was limited to the younger sequences of each central volcano.

Temporal boundaries were defined for each volcanic system due to limitations on the recognition of older sequences. Thus, to perform the analysis, the temporal boundary of $15,740 \pm 200$ 14C yr BP, given by Santa Bárbara Formation, was used for Sete Cidades, the temporal boundary of $14,620 \pm 60$ 14C yr BP, given by Roída da Praia Intermediate Member, was used for Fogo, and $17,240 \pm 70$ 14C yr BP, given by Ponta Garça Ignimbrite, was used for Furnas.

During the considered time periods, Sete Cidades produced a higher number of eruptions (36 eruptions) when compared to Fogo and Furnas (at least 21 and 26 eruptions, respectively). Of the three volcanoes, Furnas is clearly distinct, as it only produced trachytic (*s.l.*) events, whereas eruptions at Sete Cidades and Fogo were of basaltic (*s.l.*) and trachytic (*s.l.*) nature.

Only a limited number of events within the identified sequences have been dated through radiocarbon methods. Furnas has the largest number of dated events (accounting for 9), followed by Fogo (5 trachytic (*s.l.*) and 3 basaltic (*s.l.*)) and Sete Cidades (4 trachytic (*s.l.*) and 3 basaltic (*s.l.*)).

To overcome the lack of knowledge regarding temporal distribution of the eruptive events, a methodology based on synthetic catalogues was implemented (e.g., Bevilacqua et al., 2016; Selva

et al., 2022) to randomly assign stratigraphy-consistent synthetic ages to the unknown events, respecting the stratigraphic order, and quantify the uncertainty associated with their ages.

The analysis was conducted for two groups of datasets: (1) catalogues composed of both of basaltic (*s.l.*) and trachytic (*s.l.*) events (BT catalogues), and 2) catalogues composed only of trachytic (*s.l.*) events (T catalogues), as these are the most common type of eruption at São Miguel's active central volcanoes and are also the most hazardous. This aimed to estimate the total probability of a future basaltic (*s.l.*) or trachytic (*s.l.*) eruption at Sete Cidades and Fogo volcanoes, as well as to estimate the probability of a future explosive trachytic eruption in each volcano.

Several probability distributions have been commonly employed to analyse recurrence intervals, which can be used to forecast eruptions (e.g., Wickman, 1966a,b; Klein, 1982; Mulargia et al., 1985). However, this type of studies requires a complete dataset of the eruptive catalogues.

The stationarity/completeness evaluation of the considered BT and T catalogues revealed that Sete Cidades has the highest percentage of catalogues that are non-stationary (at 5% and 1% significance levels), whereas the catalogues of Furnas and Fogo are mostly all stationary. This suggests that data from Sete Cidades may be incomplete. This led to a search for break-in-slope in the cumulative number of eruptions in time of the BT and T catalogues, allowing for the detection of a change point.

Regarding stationarity concept, the existence of a change point may be resulted from under-recording of small-magnitude events over the older part of the stratigraphic sequences. On the other hand, and leaving behind the stationarity hypothesis, it may suggest an increase in the eruptive frequency over time and/or changes in the eruptive style. Therefore, the results derived from the break-in-slope analysis justified the partition of Sete Cidades BT and T data at the common and abrupt change point detected among the catalogues (~3578 years BP) to obtain the complete part of the eruptive record. The detection of a break-in slope around ~3578 yr BP in the

Sete Cidades BT and T catalogues may indicate a possible increase in eruption frequency over time, which is consistent with the current knowledge of the eruptive record. Therefore, for Sete Cidades, it can be assumed that the eruptive record is only complete for the last 3578 yr of activity.

Upon analysing the datasets with different renewal models, it was found that the Exponential distribution, which characterizes the IETs in synthetic catalogues as a Poisson process, consistently provides the best fit in most of the cases. With this model, the hazard rate is assumed to be constant over time. This result was expected, as for the unknown-age-range events, only their stratigraphic order was respected during the age-generating process, which is equivalent to generate occurrences in time whose IETs are exponentially distributed. Nevertheless, as catalogues incorporate both known age and known age-range events, overall IETs distribution may not be Exponential, which justifies the need to test other renewal models. In fact, for all datasets (Sete Cidades BT, Sete Cidades T, Fogo BT, Fogo T and Furnas T) it is observed that the Exponential distribution is not the best model according to AIC for more than 10% of the synthetic catalogues. For instance, the BPT model fits a considerable number of synthetic catalogues from Sete Cidades BT and T datasets, indicating that the hazard rate increases or decreases after an eruption and tends to remain constant over time.

In the case of Fogo BT analysis, the Gamma distribution emerges as the best model almost as frequently as the Exponential distribution, indicating a decrease in the hazard rate trough time; BPT and Weibull models frequently describe the occurrence of the trachytic events from Fogo over time. In this case, BPT indicates an initial increase or decrease in the hazard rate after an event, which tends to be constant over time. On the other hand, the Weibull model shows a decrease in the hazard rate after an eruption and trends to increase or to be constant over time; The Weibull distribution has also a good fit regarding Furnas T dataset, showing a decrease of the hazard rate after an event and a subsequent increase over time.

Frequently, the minimum IET generated from the best model indicates that eruptions may occur within a few days, which is compatible with the eruptive record (e.g., the two Fogo AD 1563 eruptions in just four days).

Considering BT catalogues (Sete Cidades BT <3578 yr and Fogo BT datasets), shorter expected IET was obtained for Sete Cidades, suggesting that this volcano produced eruptions more frequently than Fogo Volcano. Regarding the times between trachytic (*s.l.*) eruptions (Sete Cidades T <3578 yr, Fogo T and Furnas T datasets), largest expected IET's were estimated for Fogo, followed by Furnas and Sete Cidades.

Previous studies attempted to estimate the recurrence intervals for explosive events in São Miguel. For instance, Gaspar et al. (2015a) calculated eruption frequencies and recurrence intervals for different eruptive styles at the same volcanoes. However, this was a simplified approach in which the period of time considered (last 5000 yr of activity) was divided by the number of events in that time. The authors reported recurrence intervals for trachytic (*s.l.*) eruptions of 294, 833, and 500 years for Sete Cidades, Fogo, and Furnas, respectively. Comparing the mean IETs obtained in this study for T catalogues (which are mostly composed of trachytic (*s.l.*) explosive eruptions), the results for Sete Cidades and Fogo volcanoes (205 and 909 yr, respectively) are close to those obtained by Gaspar et al. (2015a). However, in the case of Furnas volcano, mean IETs of 318 yr were estimated in this work, showing a higher discrepancy in relation to the recurrence interval estimated by Gaspar et al. (2015a).

Despite experienced a lower eruptive frequency over the last 5000 years of activity when compared to the other two central volcanoes of the island (Sete Cidades and Furnas), Fogo Volcano is considered one of the most hazardous volcanoes in the Azores. This is due not only to the fact that it was the only one that produced the largest Plinian eruption during this period (Fogo A) (Walker and Croasdale, 1971; Booth et al., 1978; Wallenstein et al., 2015), but also due to its location in the central part of São Miguel, suggesting that a future eruption in Fogo could have a significant impact on the entire island (Medeiros et al., 2021).

Regarding the probability of a future eruption of basaltic (*s.l.*) or trachytic (*s.l.*) nature, the probability density function model shows that Sete Cidades is more likely to produce this type of events over the next 50 years (12% to 32% accounting for the uncertainty on the parameters; 13% to 24% without uncertainty on the parameters) than Fogo (4% to 14% and 6% to 9%, respectively).

The highest probability to produce a trachytic (*s.l.*) explosive eruption on the next 50 years was achieved for Sete Cidades (11% to 26% accounting for the uncertainty on the parameters; 12% to 19% without uncertainty on the parameters); followed by Furnas (6% to 26% accounting for the uncertainty on the parameters; 9% to 27% without uncertainty on the parameters), and Fogo (2% to 10% accounting for the uncertainty on the parameters; 4% to 8% without uncertainty on the parameters).

Only a few studies have focussed on calculating the probability of future eruptions in the Azores, partly because this is a challenging process, especially for dormant or low activity volcanoes. For instance, Queiroz et al. (2008) designed an event tree for Sete Cidades based on the eruptive record of the volcano. The probabilities for each node of the event tree were obtained by expert elicitation. The authors conclude that (1) given unrest, the probability to have an eruption at Sete Cidades is, approximately, 1/3rd of the probability of no eruption occur, (2) it is 2 times more likely to have basaltic strombolian and submarine eruptions than a trachytic eruption and (3) it is more likely to have an intracaldera trachytic event than a trachytic eruption at volcano flanks. Such results are quite comparable to the ones obtained during the present work, especially in what concerns to point 1; while for point 2 the current study seems to provide a relatively similar probability for a future eruption at Sete Cidades, regardless of whether BT or T catalogues were considered.

Other example is the work published by Jones et al. (1999), where the authors used statistical modelling to analyse the rate of eruptions through a Poisson probability model based on data from the last 5000 yr of activity. They also estimated the probability of no eruption in the next 5, 10,

25, 50, 75, and 100 yr from the publication date. For the time window of 50 years, the authors estimated the probability of an eruption at Furnas of about $\sim 3\%$, which is lower than the estimated value during the present work.

This type of approach allows to manage volcanic systems characterized by incomplete eruptive records, accounting for the related uncertainties on datasets, and provides important highlights to predict the eruptive behaviour.

2.5. Conclusions

The analysis of inter-event times (IETs) provides important clues regarding the stochastic behaviour of a volcano and is a crucial step in improving eruption forecasts.

São Miguel Island (Azores Archipelago) hosts three active central volcanoes (Sete Cidades, Fogo, and Furnas) that have the potential to generate hazardous eruptions that may affect local communities and even have far-reaching impacts on the North Atlantic airspace.

Although the stratigraphy and eruptive sequences of the three active central volcanoes of São Miguel (Sete Cidades, Fogo, and Furnas) have been studied by several authors, many eruptive events remain undated and/or poorly reconstructed. Incomplete eruptive records are common on small islands, such as on São Miguel Island, leading to uncertainties regarding past eruptive activity, with consequences on the estimation of eruption source parameters, IETs, and probabilities of future eruptions.

To overcome the constraints associated with the uncertainties in eruptive records, a methodology focused on the generation of synthetic catalogues was implemented. This process allowed the generation of random ages for unknown age or unknown age-range events, following their stratigraphic order and considering age-related uncertainties.

The under-recording of small-magnitude events, particularly from the oldest part of the eruptive sequences, may be one of the factors contributing to the detection of breaks-in-slope during this analysis (e.g., such in Sete Cidades datasets). Despite this, the possibility of potential changes in eruptive regimes over time should not be underestimated. Nonetheless, stationarity evaluation suggests that data from Sete Cidades Volcano were either generated from a non-stationary process or may be incomplete. However, this was not the case for Fogo and Furnas volcanoes, which revealed to be stationary. To ensure that the data from Sete Cidades Volcano was stationary, the portion of the datasets containing events older than 3578 years BP was discarded.

The Exponential distribution is typically the model that best fits most of the catalogues from the different datasets. This happens for two reasons: the Exponential distribution is the simplest model (characterised by only one parameter), therefore, it is preferred by the Akaike Information Criteria AIC; and the generation of synthetic eruption ages for unknown age-range events is equivalent to the generation of Poissonian events, whose IET distribution is described by the Exponential model. However, across all analysed volcanic systems and types of eruptions, alternative renewal models (Gamma, BPT, Weibull) frequently emerge as the most suitable models in a substantial proportion (>10%) of cases.

The inter-event times estimated using BT datasets from Sete Cidades and Fogo volcanoes revealed that Sete Cidades has a shorter IET than Fogo. Consistent with this results, Sete Cidades is more likely to produce a basaltic (*s.l.*) or trachytic (*s.l.*) eruption within the next 50 years (mean of about 21%) than Fogo (mean of about 8%). IET estimation through T catalogues revealed that Fogo has the longest expected IET, followed by Furnas and Sete Cidades. In this case, it is once again Sete Cidades Volcano the more likely to produce a trachytic (*s.l.*) eruption over the next 50 years (mean of about 17%), followed by Furnas (mean of about 13%) and Fogo (mean of about 5%).

It is noted that this approach fails in considering the current monitoring data. In fact, although Fogo has a lowest eruptive frequency, and consequently it is less likely to produce an eruption in

the future, it is recognized as one of the most dangerous volcanoes in the Azores region. Therefore, Fogo has displayed several indicators of unrest over the past 20 years (Silva et al., 2012) and its potential hazard should not be neglected.

This study reflects an effort to improve one of the cornerstones of volcanic hazard assessment (the estimation of the probability of an eruption in a given time window) through a stochastic analysis that incorporates the uncertainties associated with incomplete eruptive records. The present approach can be applied to regions prone to volcanic eruptions and thus vulnerable to their hazards, such as islands, tropical environments, or remote areas, providing authorities with suitable and sound information to mitigate volcanic risk.

Chapter 3

Spatial probability estimation of vent opening at the three active central volcanoes of São Miguel Island (Azores)

Chapter 3. Spatial probability estimation of vent opening at the three active central volcanoes of São Miguel Island (Azores)

3.1. Preliminary note

Forecasting the location of future volcanic activity is a crucial, but challenging, task for effective volcanic hazard assessment. Determining the likelihood of locations to host new emission centres provides important clues regarding the variety of outcomes that can be generated in function of different scenarios that significantly depends on the location of the eruptive centre and the geological context.

Long-term approaches to estimate the location of vent opening requires analysing the spatial distribution of previous eruptive centres and structural data of the volcanic region (Connor and Hill, 1995; Favalli et al., 2012). For this purpose, it is assumed that the stress field has remained constant over time, and future forecasts are guided by the patterns in past vent locations (Martí and Felpeto, 2010). In this context, several studies have been developed to assess the susceptibility to future eruptive centres based on the location of past events or structural data (e.g., Felpeto et al., 2007; Jaquet et al., 2008; Martí and Felpeto, 2010; Favalli et al., 2012, Connor et al., 2012; Cappello et al., 2012, 2013), by applying kernel density functions (e.g. Gaussian and Cauchy). Kernel functions allow for the estimation of the spatial density of eruptive centres, assuming that new vents are likely to form near existing ones (Martin et al., 2004; Jaquet et al., 2008). According to these functions, the spatial probability of a new vent opening is represented by the distance from near volcanic structures or eruptive centres and a smoothing parameter h (also known as bandwidth) (Martin et al., 2004) that controls how probabilities are spread over the area (i.e., smaller h values concentrate the probabilities around preexisting structures, while larger h values

spread probabilities over a broad area. As the smoothing parameter h strongly influences how probabilities are distributed (Martin et al., 2004; Jaquet et al., 2008), there have been an effort to develop methods to estimate optimal bandwidths. Although this is still a challenge, in recent literature, Bartolini et al. (2013) introduced QVAST (QGIS for Volcanic Susceptibility) tool that integrates different techniques to asses optimal bandwidth values, such as the last square cross-validation method (LSCV) (Cappello et al., 2012), $\hat{h}$ score (Silverman, 1986), and the sum of asymptotic mean squares error selector H (SAMSE) (Connor et al., 2012), thereby facilitating the estimation of probability density functions and the development of spatial susceptibility maps (see Bartolini et al., 2013 for more details).

This chapter is dedicated to the spatial probability of vent opening at the three active central volcanoes of São Miguel Island (Azores), namely Sete Cidades, Fogo, and Furnas, each with a large record of trachytic (*s.l.*) explosive and effusive activity, as well as basaltic (*s.l.*) flank eruptions, over the last millennia. To perform this analysis, the location of past eruptive centres, either in a form of single eruptive centres (central vents) or in a form of eruptive fissures (i.e., when multiple single central vents occur within the same volcanic edifice), was used and four kernel functions were explored to model the probability distribution of a new vent at each volcanic system.

For dormant or low activity volcanoes, such in the Azores, long-term hazard assessment approaches, based on the eruptive behaviour are of outmost importance to develop robust land-use policies and risk mitigation strategies.

3.2. Methodology

3.2.1. Eruptive centres

The mapping of basaltic (*s.l.*) and trachytic (*s.l.*) eruptive centres was based on geomorphological expressions. The identification and georeferentiation of these centres were carried out through an extensive analysis of existing catalogues, as well as using the orthophoto map of São Miguel Island and aerial photography.

For the spatial analysis, three categories of eruptive centres were considered, as in Becerril et al. (2013): (1) isolated craters from single cones or from geomorphological expressions as central vents (e.g., for basaltic (*s.l.*) and trachytic (*s.l.*) central vents), (2) craters without an observed cone (e.g., maars), and (3) craters within the same volcanic edifice (e.g., as observed at some cinder cones), which were considered to be eruptive fissures.

The emission centres that have been identified do not encompass every eruption that occurred in each volcanic system used in this study, as the precise location of most of these events is difficult to estimate. Moreover, some evidence of these events may have been obliterated by recent volcanic eruptions.

Tectonic structures identified at São Miguel Island were not considered for this analysis due to the lack of robust information, i.e., many of these structures were characterized as lineaments or as probable faults, which does not confirm their existence. In contrast, volcanic cones provide a direct evidence of magma ascent, while many tectonic structures are purely tectonic without any associated magmatic activity. Cones tend to align with possible tectonic features and considering both types of geological features (i.e., past vents and faults) could lead to redundant information as data would be accounted twice.

Studies (e.g., Rivalta et al., 2019) have also shown that dike propagation is linked to the stress field. This suggests that although tectonic structures may be present, they do not necessary coincide with magma pathways. Moreover, incorporating the tectonic structures would require assigning weights for the different types of datasets (i.e., volcanic edifices vs tectonic structures),

introducing subjectivity. However, the inclusion of this type of dataset could be explored on further research.

3.2.2. Spatial probability estimation

To estimate the spatial probability of a vent opening it was, firstly, defined a target domain for each central volcano, considering the physical limits of each volcanic system. A cell size grid 50×50 m was defined for each case, balancing the spatial resolution and computational efficiency. Thus, a total of 47049 grid cells (N_c) were used for Sete Cidades Volcano, 53250 cells for Fogo Volcano, and 37706 cells for Furnas Volcano.

The spatial analysis was carried out by implementing the spatial kernel method proposed by Lutz and Gutman (1995), using the locations of past basaltic (*s.l.*) and trachytic (*s.l.*) eruptive centres. By implementing this method, it is assumed that the rate of openings in a given point (x_P, y_P) of the target domain is influenced by the known past eruptive centres (N_{ec}) and eruptive fissures (N_{ef}), given by:

$$\lambda_{x_P, y_P} = \frac{\sum_{i=1}^{N_{ec}} f(d_i; 0, h)}{N_{ec}} + \frac{\sum_{j=1}^{N_{ef}} f(d_j; 0, h)}{N_{ef}}$$

where λ_{x_P, y_P} is the rate of openings in a specific point (x_P, y_P) , d_i and d_j are the minimum Euclidean distances between the point (x_P, y_P) and the i^{th} central vent and j^{th} eruptive fissure, and $f(d_i; 0, h)$ and $f(d_j; 0, h)$ are the probability density functions of the kernel function used, with 0 mean and h smoothing parameter, which is related to the dispersion around the mean (i.e., the degree of clustering).

The spatial probability of future eruptive centres opening at each point (x_P, y_P) were obtained by renormalizing the computed rate λ_{x_P, y_P} over all N_c grid cells at each considered domain, according to (Sandri et al., 2024):

$$Pr_{x_P, y_P} = \frac{\lambda_{x_P, y_P}}{\sum_{k=1}^{N_c} \lambda_{x_k, y_k}}$$

where Pr_{x_P, y_P} is the probability in a given point, λ_{x_P, y_P} is the computed rate of openings in a given point, N_c is the number of grid cells.

To perform the analysis, four kernel functions including Gaussian, Cauchy (as in Martin et al., 2004), Exponential, and Uniform functions (as in Sandri et al., 2024) were tested along with different smoothing parameter (h) values.

The empirical cumulative distribution function (ECDF) of the distance to the nearest neighbour (central vents and eruptive fissures) was plotted and subsequently compared to the cumulative distribution generated through different kernel functions to identify and select the pair (kernel function + smoothing parameter h) that best describes the ECDF of the distance between eruptive centres. This method selects the best pair as the one that best describes the ECDF of the distance between an eruptive centre (i.e., central vents and fissures) to the closest one.

The mean-squared error function, which measures the mean-squared difference between expected values and actual values (i.e., it measures the difference between the estimated probability density function and the data distribution) was also used to improve the evaluation of the best pair. In this case, the one with the smallest associated error was considered the best pair.

Finally, spatial probability maps were generated using the best kernel function chosen and the estimated optimal bandwidth.

The procedure was conducted for the three central volcanoes, considering (1) basaltic (*s.l.*) and trachytic (*s.l.*) (BT) eruptive centres together (fissures and/or central vents), (2) only trachytic (*s.l.*) (T) eruptive centres (central vents), and (3) explosive trachytic (*s.l.*) (ET) eruptive centres (central vents).

3.3. Spatial analysis results

3.3.1. Eruptive centres dataset

A total of 66 basaltic (*s.l.*) central vents, 8 basaltic (*s.l.*) eruptive fissures, and 26 trachytic (*s.l.*) central vents (where 13 of which are explosive trachytic (*s.l.*) central vents were identified in Sete Cidades Volcano (Table 3.1). The basaltic (*s.l.*) eruptive centres are mostly concentrated on the eastern and southwestern flanks of the volcano, while the trachytic (*s.l.*) eruptive centres occurred mostly inside of Sete Cidades caldera and on the southwest flank, and the explosive trachytic (*s.l.*) central vents are only observed inside of the caldera (Fig. 3.1) (Appendix A.2).

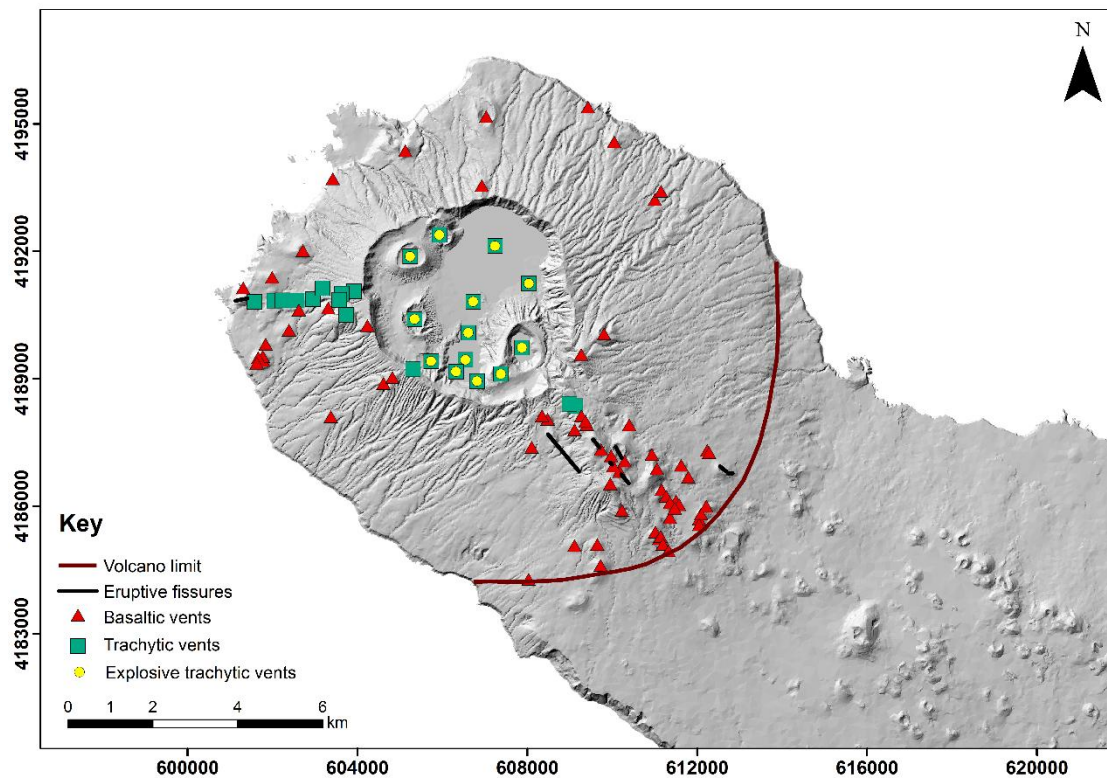


Figure 3. 1. Location of the basaltic and trachytic emission centres and eruptive fissures identified at Sete Cidades Volcano. UTM projection, Zone 26N, Datum WGS1984.

The identified eruptive centres in Fogo Volcano comprised 44 basaltic (*s.l.*) central vents, one basaltic (*s.l.*) eruptive fissure, and 44 trachytic (*s.l.*) central vents (where 12 of which are explosive trachytic (*s.l.*) eruptive centres) (Table 3.1). The basaltic (*s.l.*) eruptive centres are concentrated

on the northern, western, and southwestern flanks, whereas the trachytic (*s.l.*) eruptive centres are often observed within Fogo caldera and on its northern and northwestern flanks. The explosive trachytic (*s.l.*) central vents are located inside of the caldera, however, some of them occur at the northern flank, including locations near the coastline. (Fig. 3.2) (Appendix A.2).

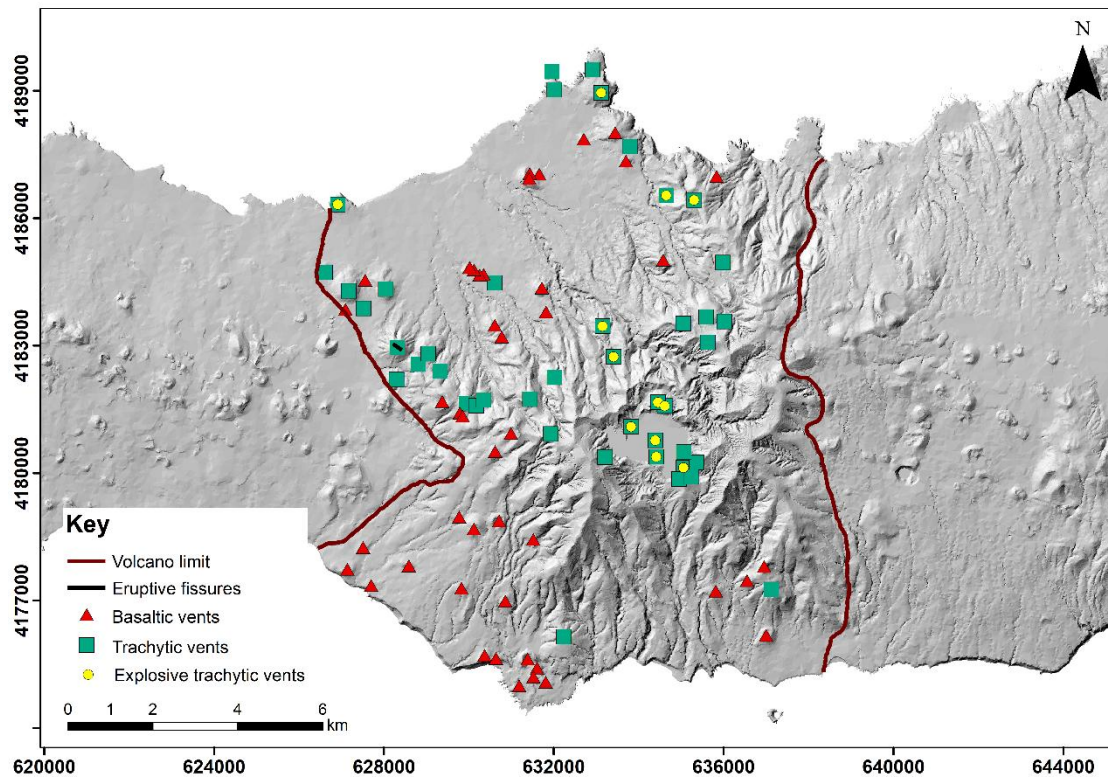


Figure 3. 2. Location of the basaltic and trachytic emission centres and eruptive fissures identified at Fogo Volcano. UTM projection, Zone 26N, Datum WGS1984.

At Furnas Volcano, 30 basaltic (*s.l.*) central vents and 21 trachytic (*s.l.*) central vents were mapped (being 12 of which explosive trachytic (*s.l.*) central vents). Basaltic (*s.l.*) central vents are typically found to the east and north of Furnas caldera complex. Trachytic (*s.l.*) central vents are prevalent within the caldera complex and on the north flank, and explosive trachytic (*s.l.*) central vents only occur inside of the youngest caldera (Table 3.1) (Fig. 3.3) (Appendix A.2).

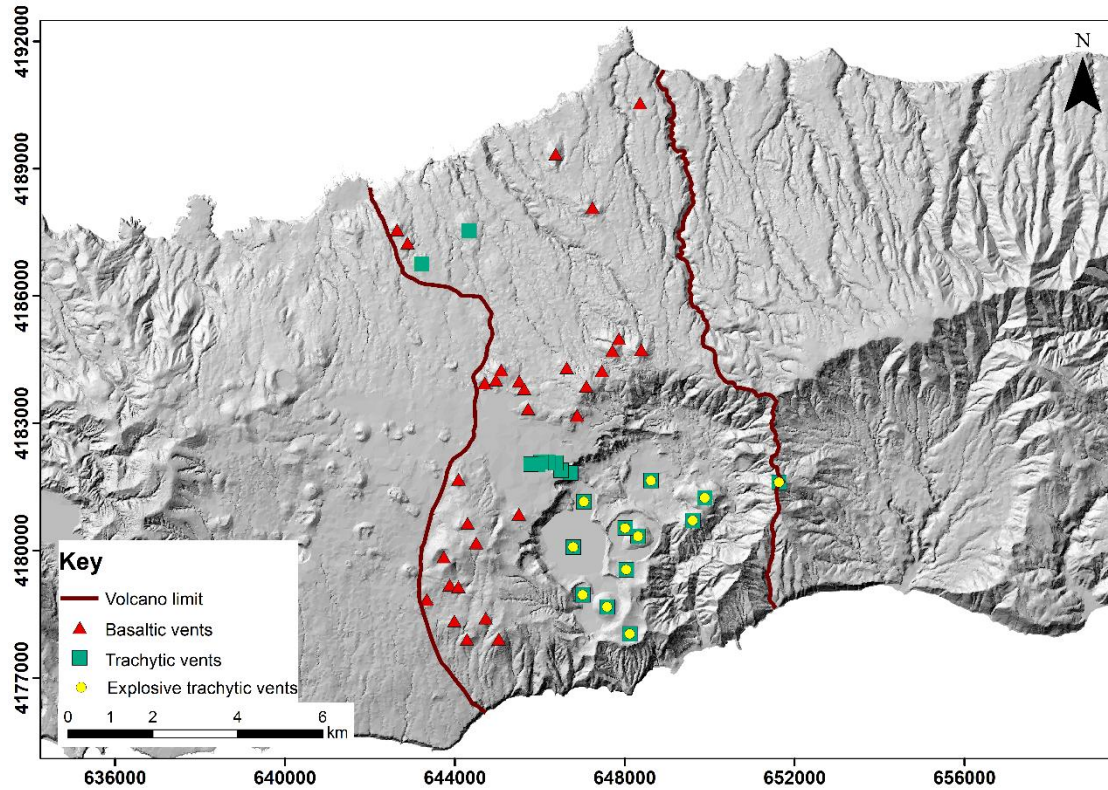


Figure 3. 3. Location of the basaltic and trachytic emission centres identified at Furnas Volcano. UTM projection, Zone 26N, Datum WGS1984.

Table 3. 1. Number of eruptive centers (vents and fissures) of basaltic and trachytic nature identified for the central volcanoes of São Miguel Island (Sete Cidades, Fogo and Furnas).

	Sete Cidades	Fogo	Furnas
Basaltic <i>s.l.</i> central vents (B)	66	44	30
Basaltic <i>s.l.</i> fissures	8	1	0
Trachytic <i>s.l.</i> central vents (T)	26	44	21
Explosive trachytic <i>s.l.</i> central vents (ET)	13	12	12
Total eruptive centres (BT)	100	89	51

3.3.2. Kernel function and optimal bandwidth (h) estimation

The Gaussian, Cauchy, Exponential, and Uniform kernel functions along with a range of optimal bandwidth (h) values (given by the degree of clustering) from 100 to 1600 meters, selected based on observed distances between eruptive centres, were tested. This allowed for the selection of the

pair (kernel function and optimal bandwidth) that best describes the considered datasets (Fig. 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, and 3.12).

The mean-squared error was applied to provide a best evaluation of the best kernel function and degree of clustering of the data. Results are presented at Table 3.2.

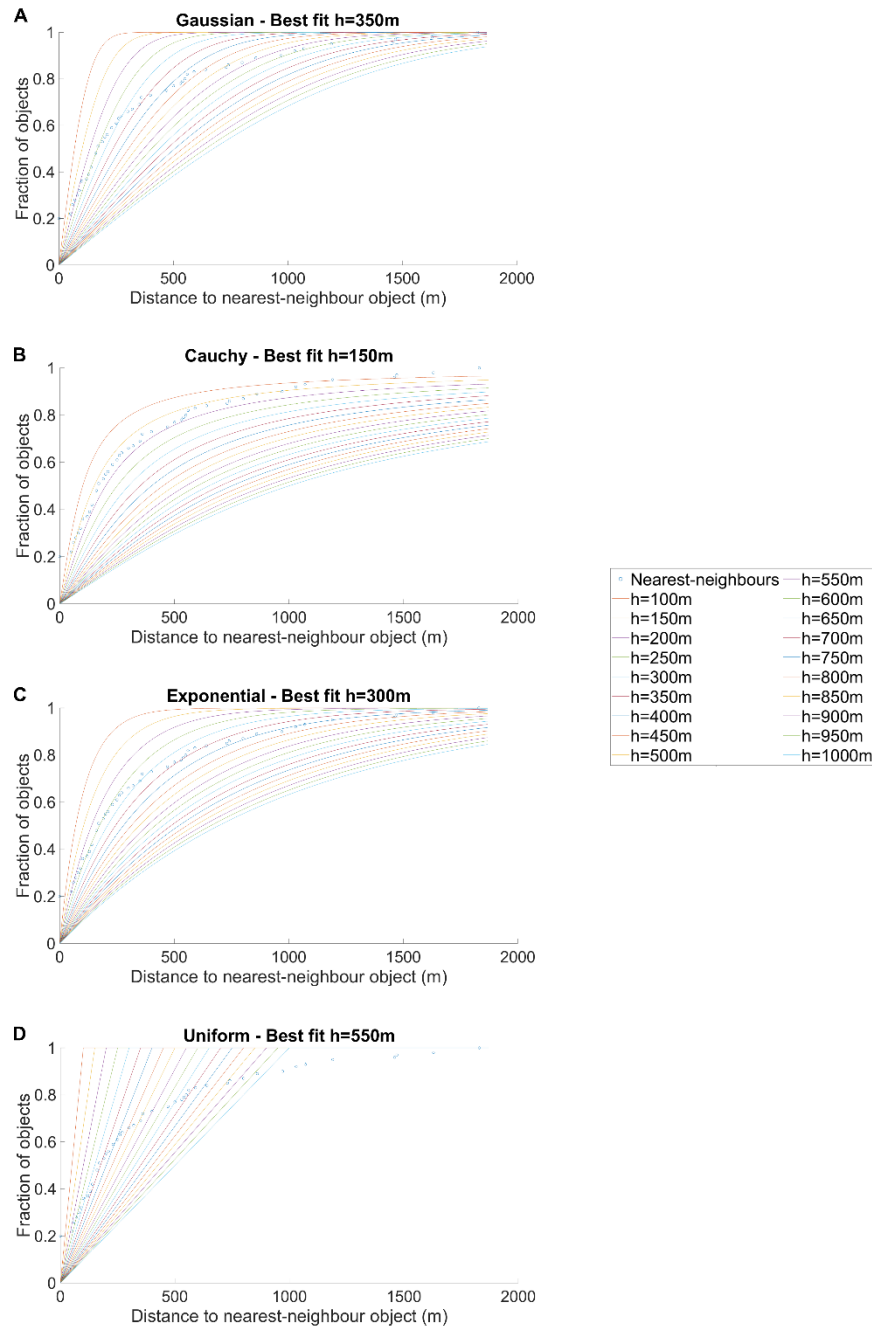


Figure 3. 4. Nearest neighbour test for probability density function using Sete Cidades BT dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

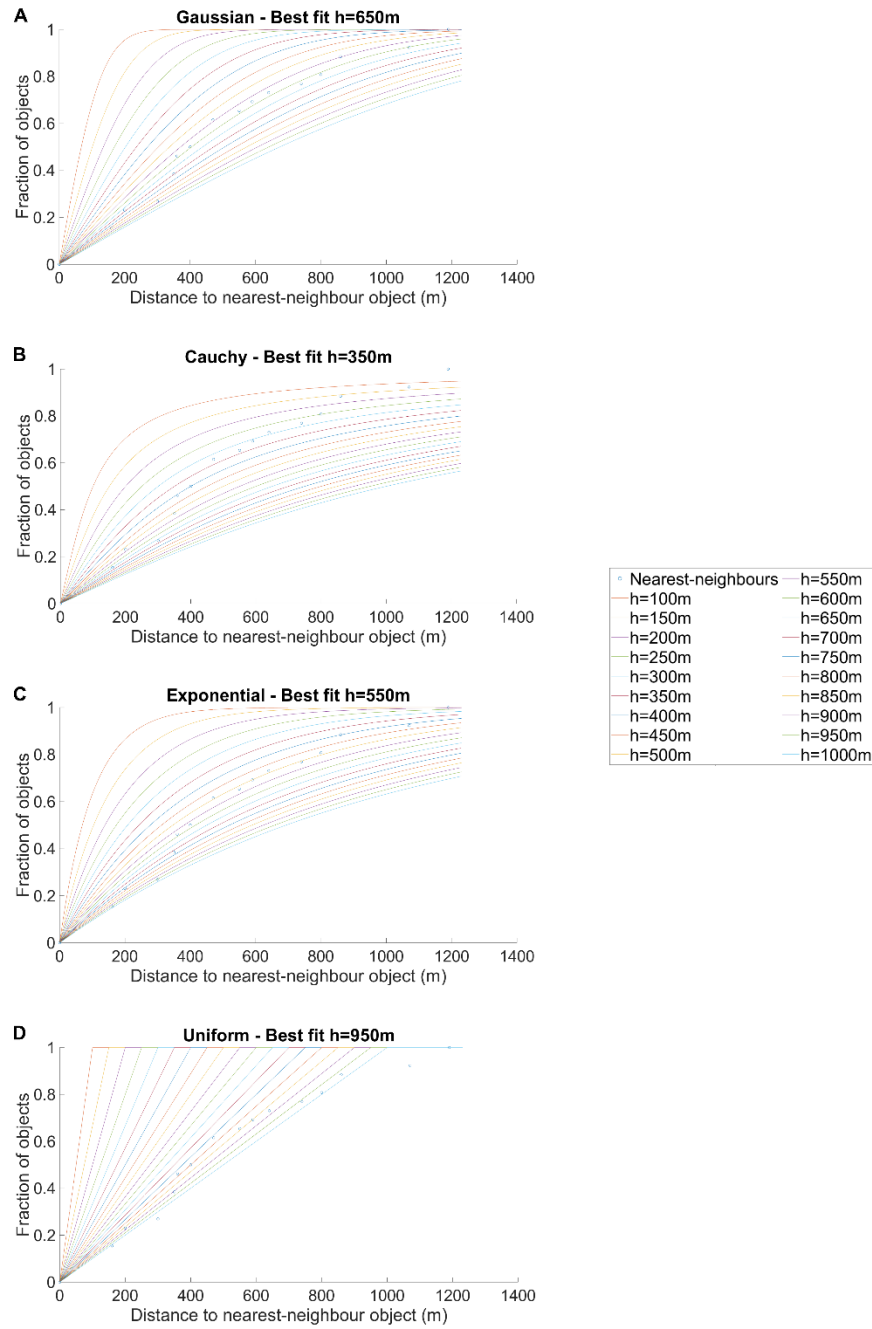


Figure 3. 5. Nearest neighbour test for probability density function using Sete Cidades T dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

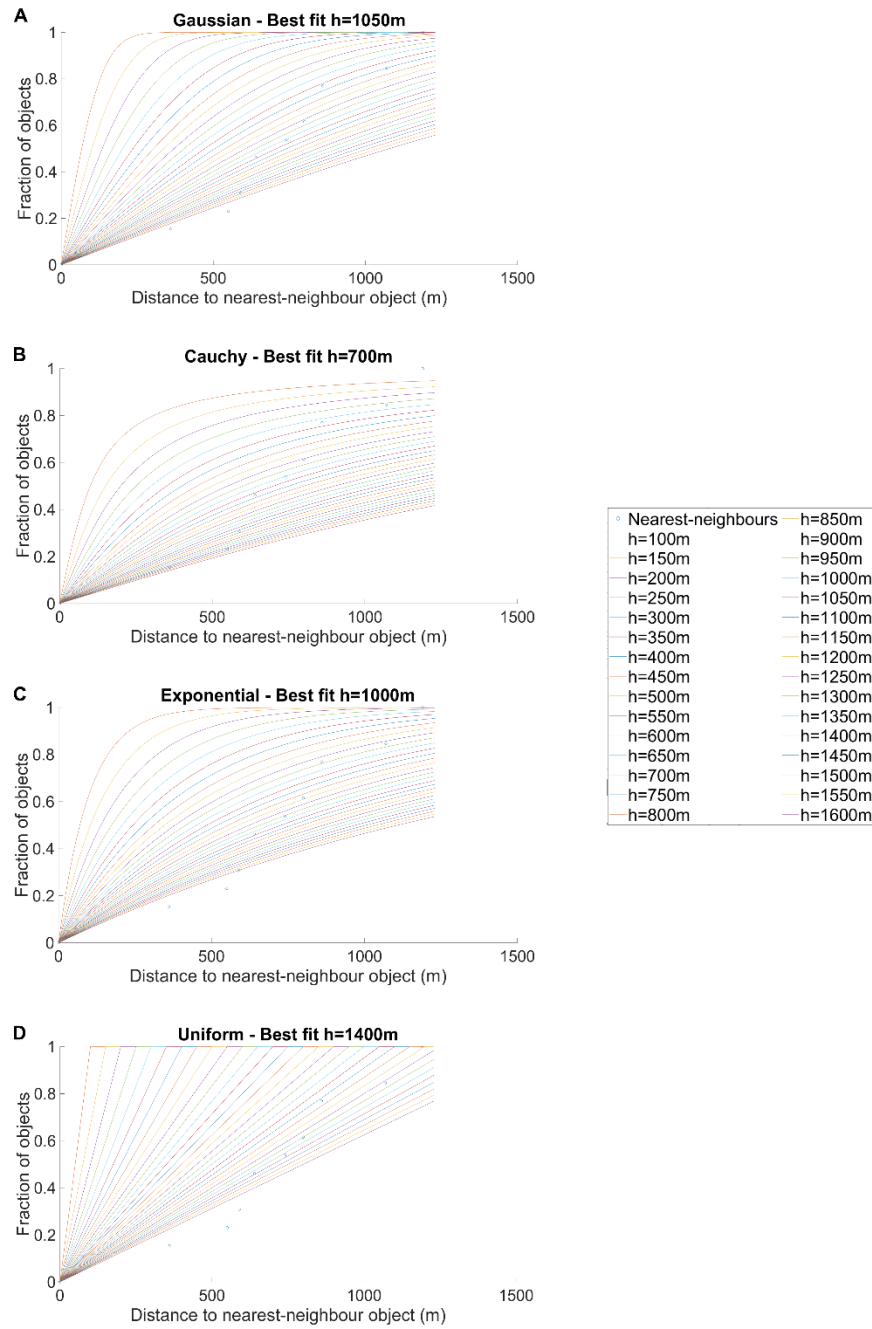


Figure 3. 6. Nearest neighbour test for probability density function using Sete Cidades ET dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

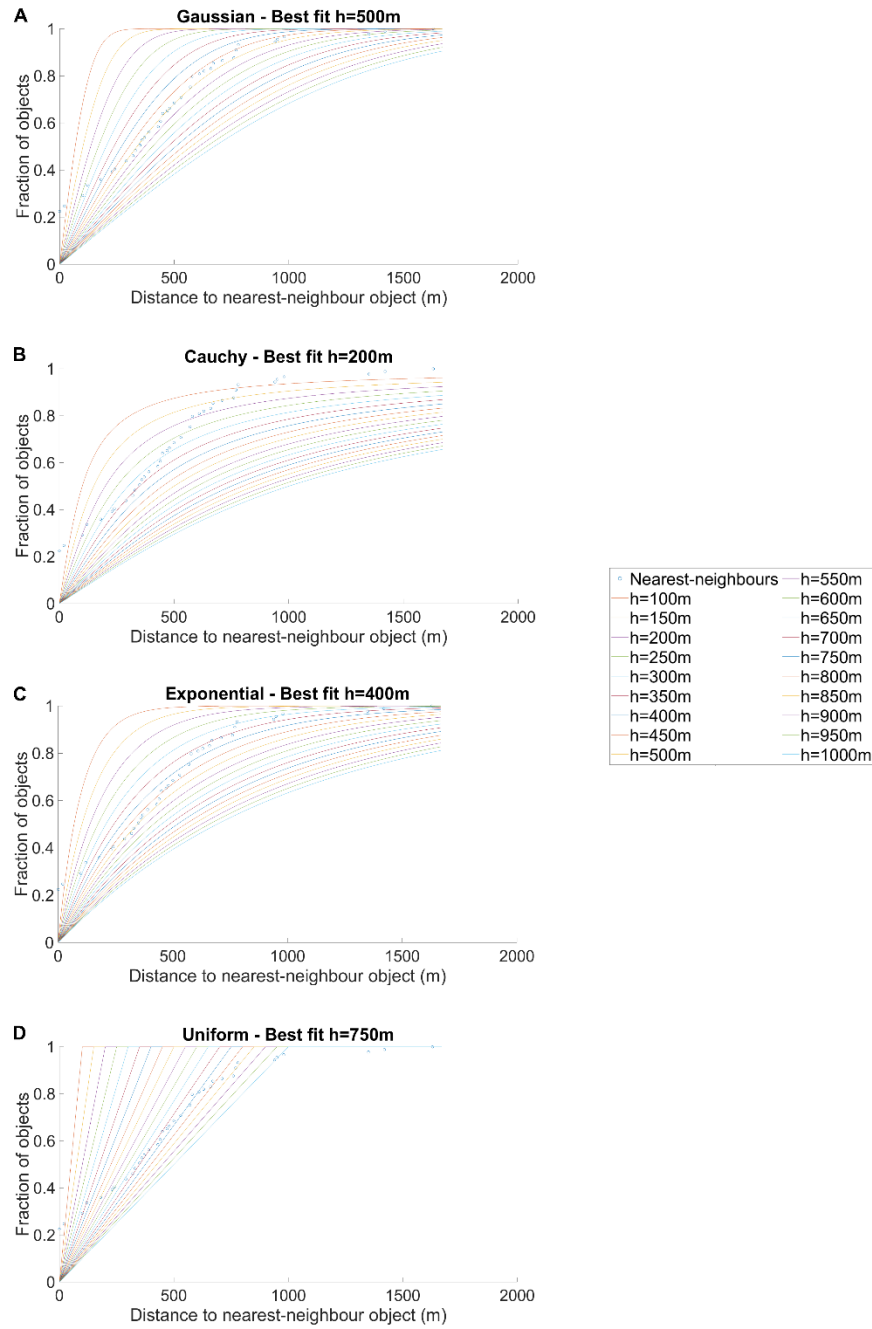


Figure 3. 7. Nearest neighbour test for probability density function using Fogo BT dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

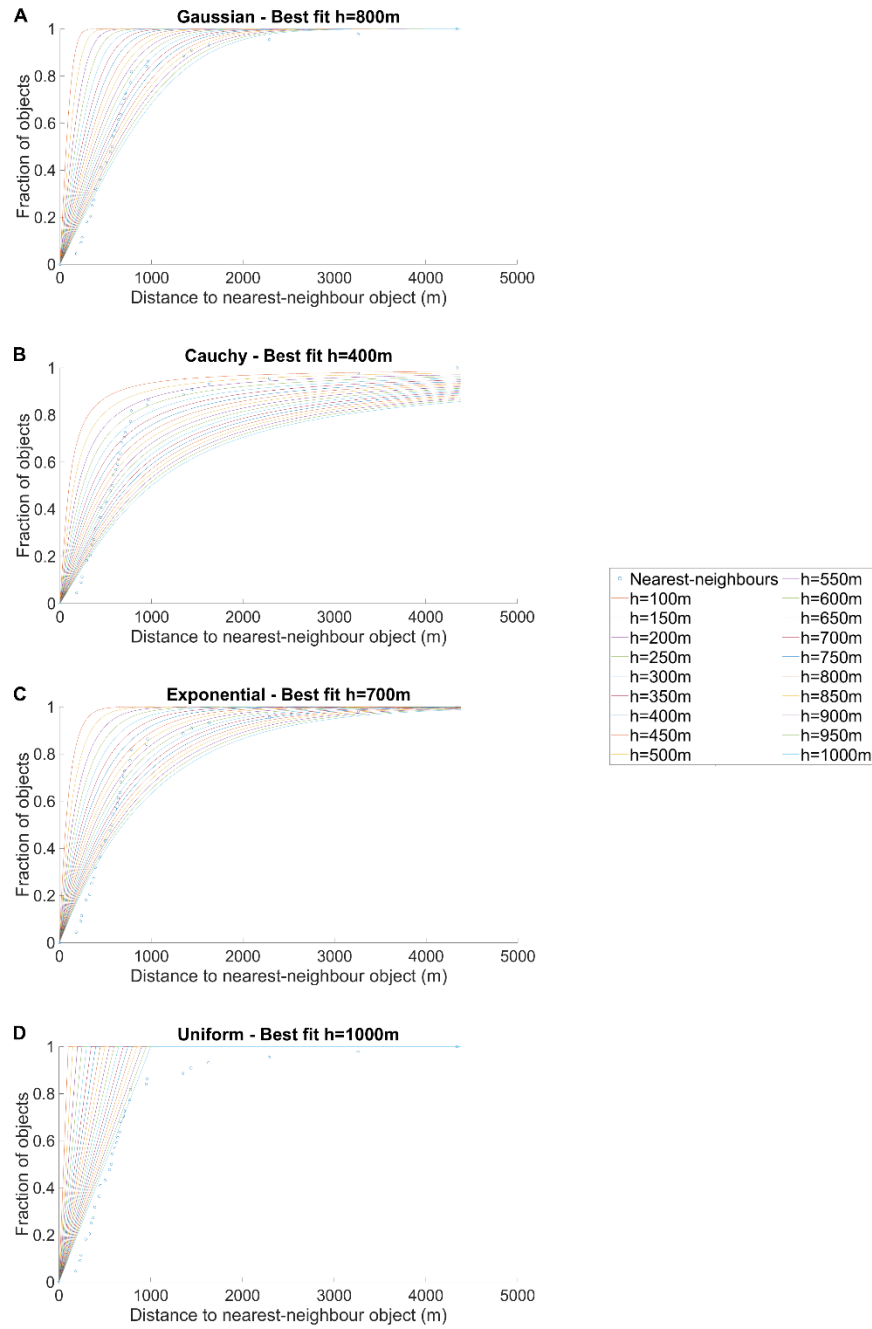


Figure 3. 8. Nearest neighbour test for probability density function using Fogo T dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

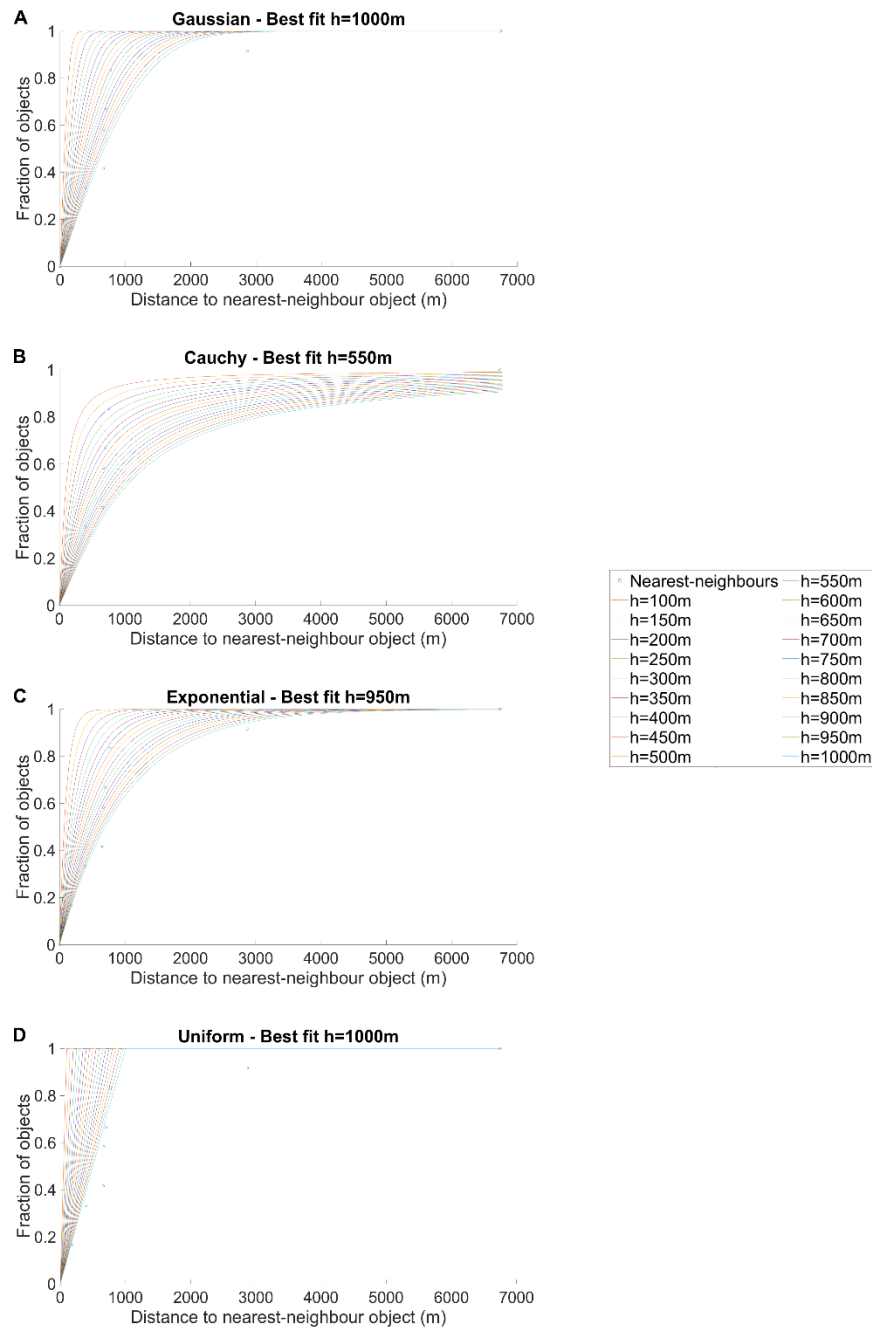


Figure 3. 9. Nearest neighbour test for probability density function using Fogo ET dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

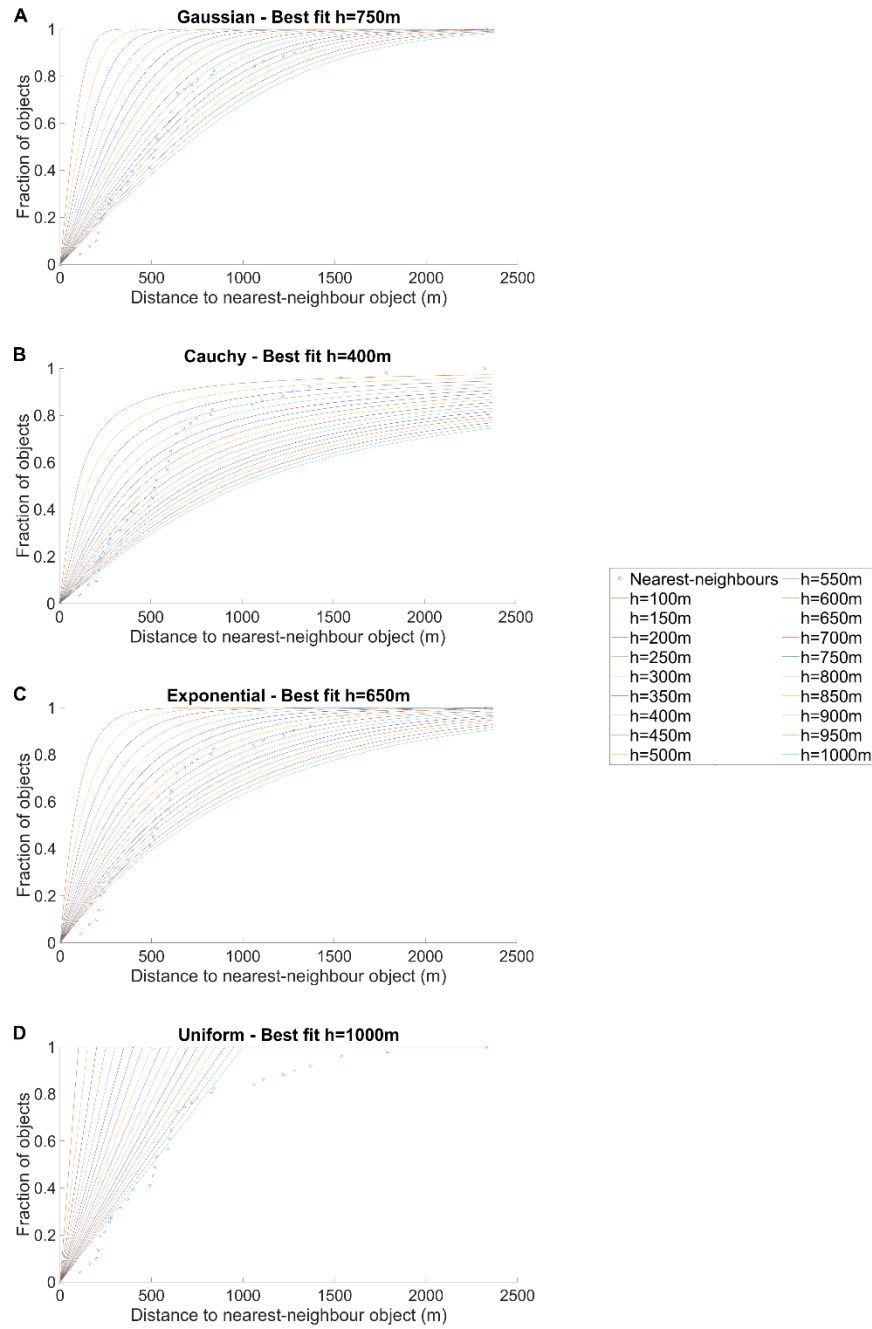


Figure 3. 10. Nearest neighbour test for probability density function using Furnas BT dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

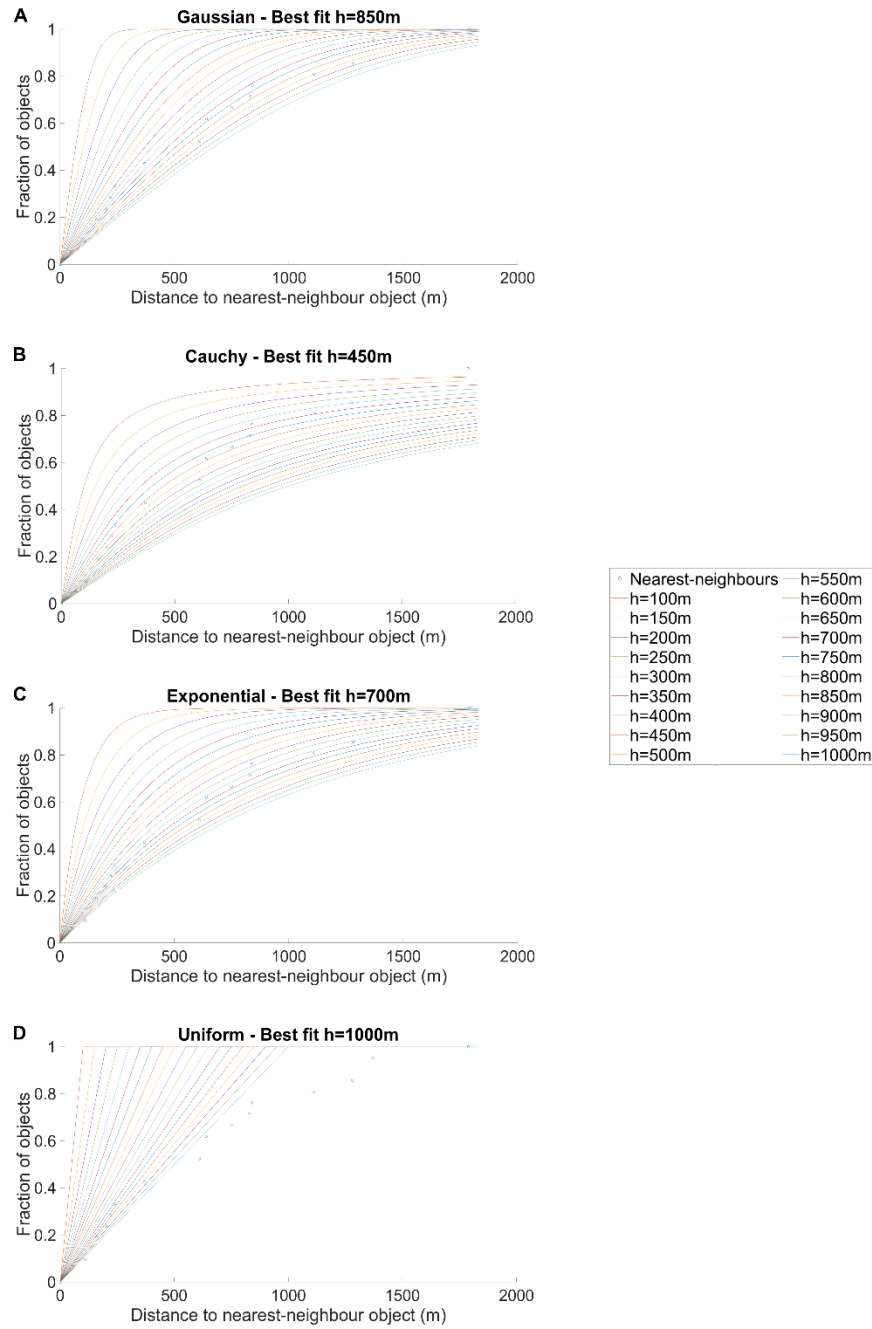


Figure 3. 11. Nearest neighbour test for probability density function using Furnas T dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

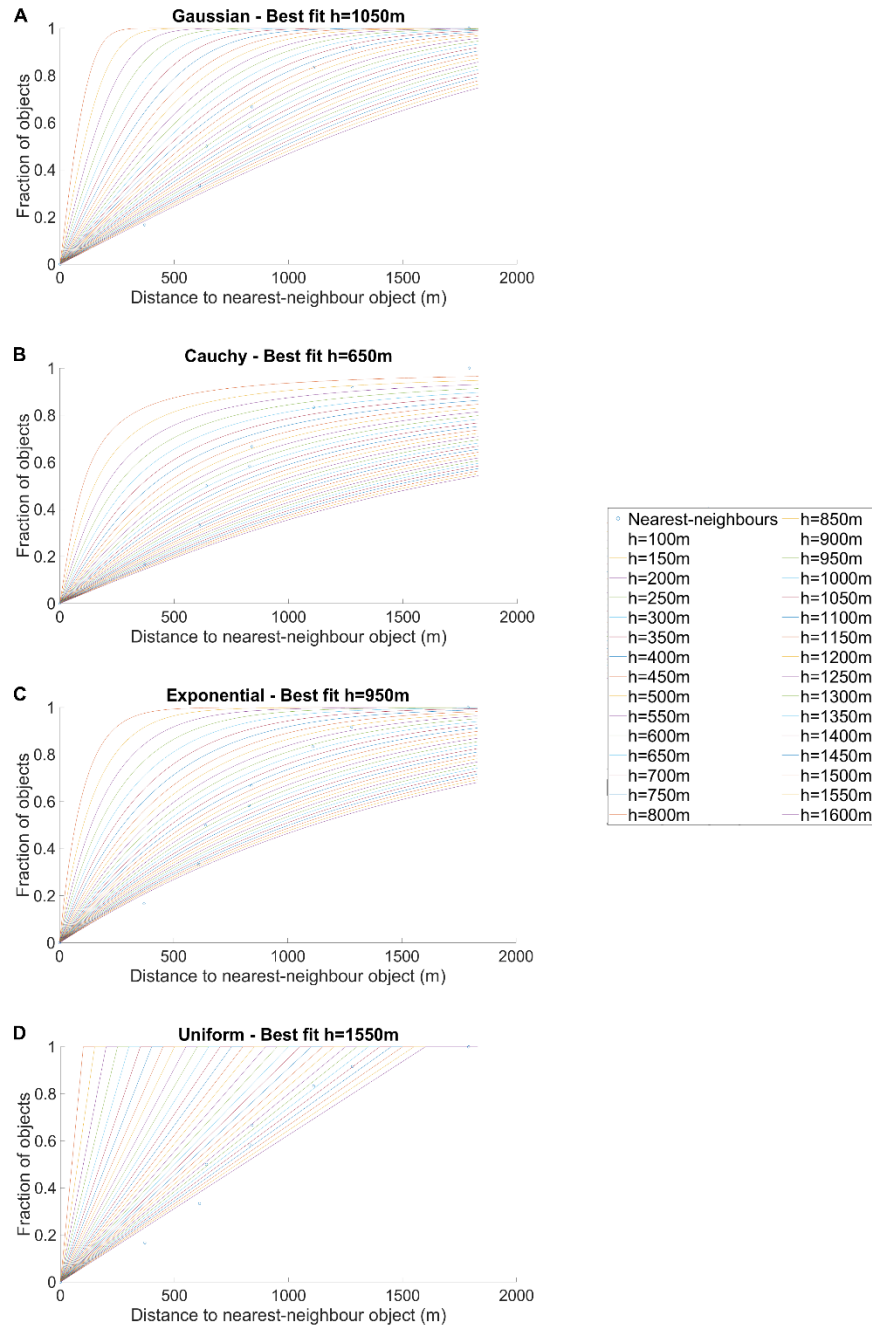


Figure 3. 12. Nearest neighbour test for probability density function using Furnas ET dataset, exploring different Kernel functions: A) Gaussian; B) Cauchy; C) Exponential; D) Uniform.

Chapter 3. Spatial probability estimation of vent opening at the three active central volcanoes of São Miguel Island (Azores)

Table 3. 2. Mean-squared error obtained for different kernel functions and optimal bandwidth estimations for different datasets from Sete Cidades, Fogo, and Furnas volcanoes.

	Gaussian	Cauchy	Exponential	Uniform	h (m)
Sete Cidades BT	0.078	0.039	0.049	0.111	150
Sete Cidades T	0.058	0.114	0.087	0.071	650
Sete Cidades ET	0.145	0.178	0.170	0.122	1400
Fogo BT	0.053	0.095	0.055	0.071	500
Fogo T	0.056	0.088	0.064	0.073	800
Fogo ET	0.101	0.067	0.089	0.120	550
Furnas BT	0.046	0.105	0.065	0.073	750
Furnas T	0.042	0.087	0.054	0.115	850
Furnas ET	0.115	0.168	0.147	0.097	1550

The results of the analysis of Sete Cidades BT dataset (Fig. 3.4) reveal that the Cauchy distribution with an optimal bandwidth of 150 meters had the lowest mean-squared error of 0.039 (Table 3.2), indicating that this is the best that best describes the data. When considering the T dataset from the same volcano, results show that the smallest mean-squared error of 0.058 (Table 3.2) was obtained for the Gaussian distribution with an optimal bandwidth of 650 meters (Fig. 3.5). From Sete Cidades ET dataset analysis the smallest mean-squared error of 0.122 was achieved for the Uniform distribution with an optimal bandwidth of 1400 meters (Fig. 3.6).

Fogo BT dataset results (Fig. 3.7) show the lowest mean-squared error of 0.053 (Table 3.2) was obtained for the Gaussian distribution with an estimated optimal bandwidth of 500 meters. For Fogo T dataset (Fig. 3.8) the best pair was the Gaussian distribution with an optimal bandwidth of 800 meters, with the associated mean-squared error of 0.056 (Table 3.2). The same analysis performed to Fogo ET dataset show that the smallest mean-squared error of about 0.067 was obtained for the Cauchy distribution with an optimal bandwidth of 550 meters (Table 3.2) (Fig. 3.9).

The Gaussian distribution with an optimal bandwidth of 750 meters yielded the smallest mean-squared error of 0.046 (Table 3.2) when using Furnas BT dataset (Fig. 3.10). From Furnas T

dataset analysis, was observed that the Gaussian distribution with an optimal bandwidth of 850 meters yielded the lowest mean-squared error of 0.042 (Fig. 3.11) (Table 3.2). Conversely, the results of the analysis of Furnas ET dataset, revealed that lowest mean-squared error of 0.097 was obtained for the Uniform distribution, with an estimated optimal bandwidth of 1550 meters (Table 3.2) (Fig. 3.12).

3.3.3. Spatial probability estimation of a vent opening

Spatial probability of a vent opening at the three active central volcanoes of São Miguel Island was achieved by combining the pair that best describes the empirical cumulative distribution function of the distance to the nearest neighbour. The presented maps show the estimated probabilities for different locations, which were posteriorly summed to provide a final result of such probabilities.

Considering the opening of a BT eruptive centre at Sete Cidades Volcano, the most probable locations are at the southeast and southwest flanks, and inside of the caldera, with estimated probabilities of 3.0×10^{-1} (30%), 8.7×10^{-2} (8.7%) and 1.7×10^{-1} (17%), respectively (Fig. 3.13). However, considering only trachytic (*s.l.*) eruptive centres it is more likely to open a new eruptive centre at the caldera itself and at the southwest flank, with estimated probabilities of 5.1×10^{-1} (51%) and 2.8×10^{-1} (28%), respectively (Fig. 3.14), while considering the opening of an explosive trachytic (*s.l.*) eruptive centre, the probabilities are concentrated inside of the caldera, with an estimated probability of 8.3×10^{-1} (83%) (Fig. 3.15).

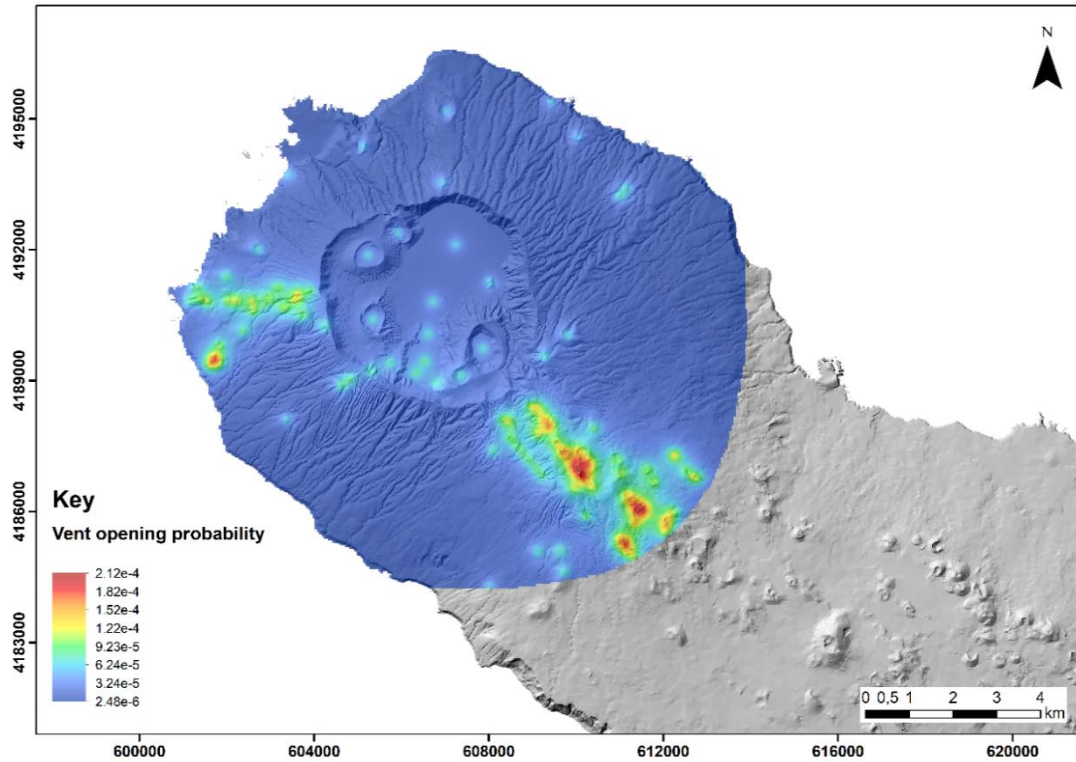


Figure 3. 13. Spatial vent opening probability map considering Sete Cidades BT dataset and using the Cauchy distribution with an optimal bandwidth of 150 m. UTM projection, Zone 26N, Datum WGS1984.

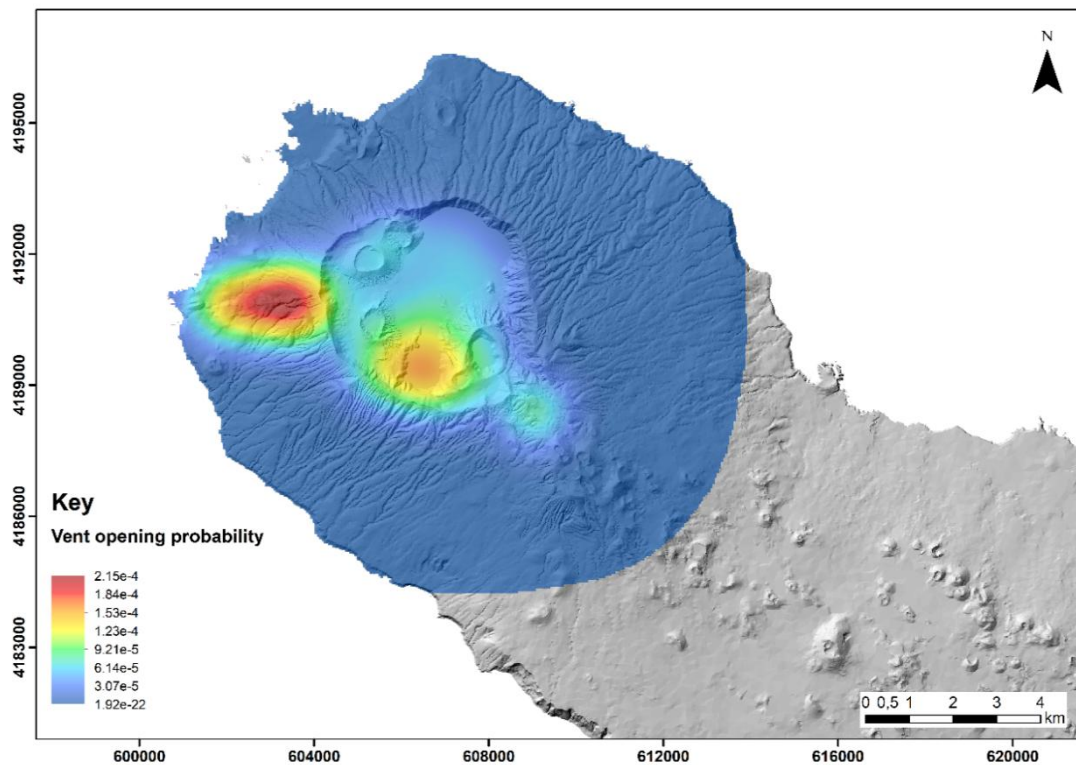


Figure 3. 14. Spatial vent opening probability map considering Sete Cidades T dataset and using the Gaussian distribution with an optimal bandwidth of 650 m. UTM projection, Zone 26N, Datum WGS1984.

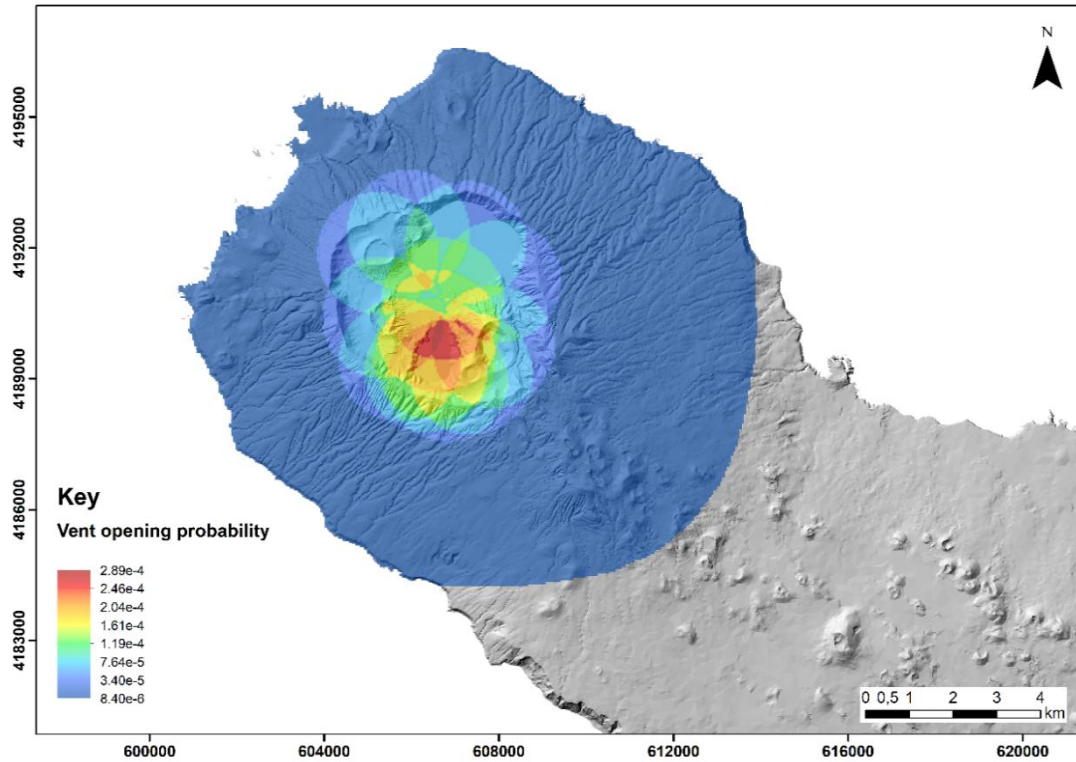


Figure 3. 15. Spatial vent opening probability map considering Sete Cidades ET dataset and using the Uniform distribution with an optimal bandwidth of 1400 m. UTM projection, Zone 26N, Datum WGS1984.

The spatial probability maps regarding a future basaltic (*s.l.*) or trachytic (*s.l.*) eruptive centre at Fogo Volcano suggests that the most probable locations for new openings are at the west-northwest sector (2.9×10^{-1} ; 29%), inside the caldera (9.6×10^{-2} ; 9.6%), and at the southwest sector (6.0×10^{-2} ; 6%) (Fig. 3.16).

The most probable areas to host future trachytic (*s.l.*) eruptive n centres at Fogo Volcano are concentrated at the west-northwest sector, inside of the caldera, and at the north-northeast sector, with estimated probabilities of 2.5×10^{-1} (25%), 1.7×10^{-1} (17%), and 1.5×10^{-1} (15%), respectively (Fig. 3.17).

The most probable sites for future explosive trachytic (*s.l.*) eruptive centres at Fogo are mostly located inside of Fogo Caldera, with an estimated probability of 2.9×10^{-1} (29%). However, although less likely, towards northwest near the caldera there are also potential locations to host a new explosive eruptive centre, with estimated probabilities of about 9.3×10^{-2} (9.3%) (Fig.

3.18).

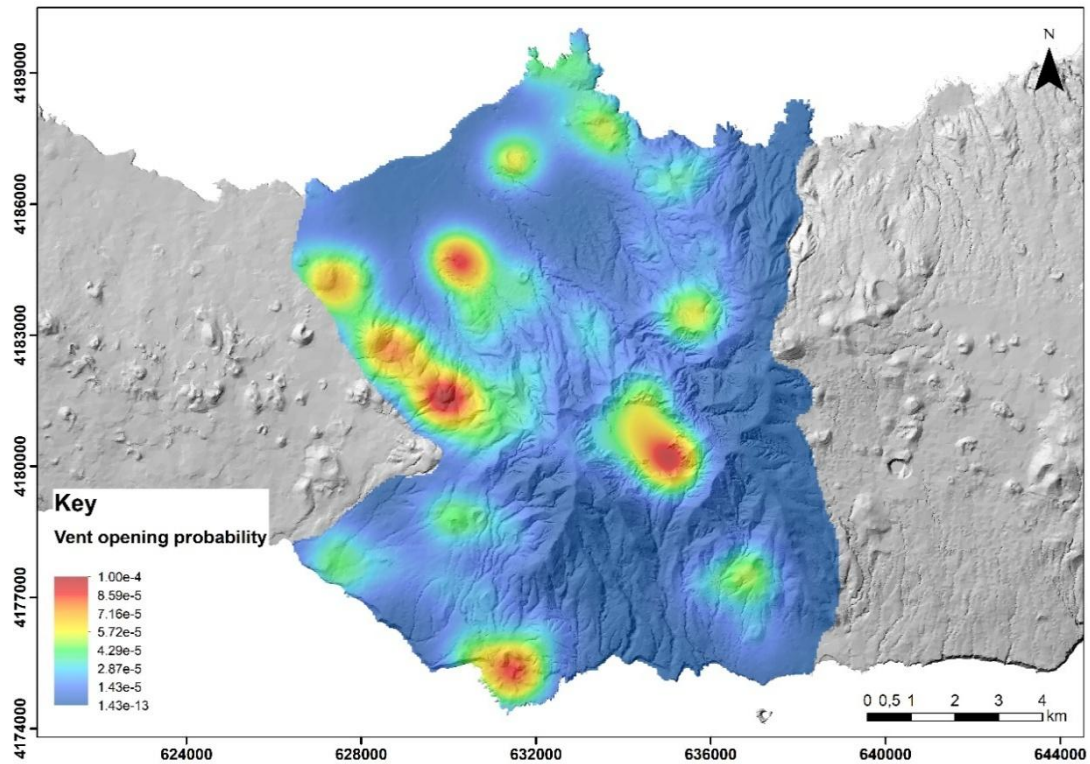


Figure 3. 16. Spatial vent opening probability map considering Fogo BT dataset and using the Gaussian distribution with an optimal bandwidth of 500 m. UTM projection, Zone 26N, Datum WGS1984.

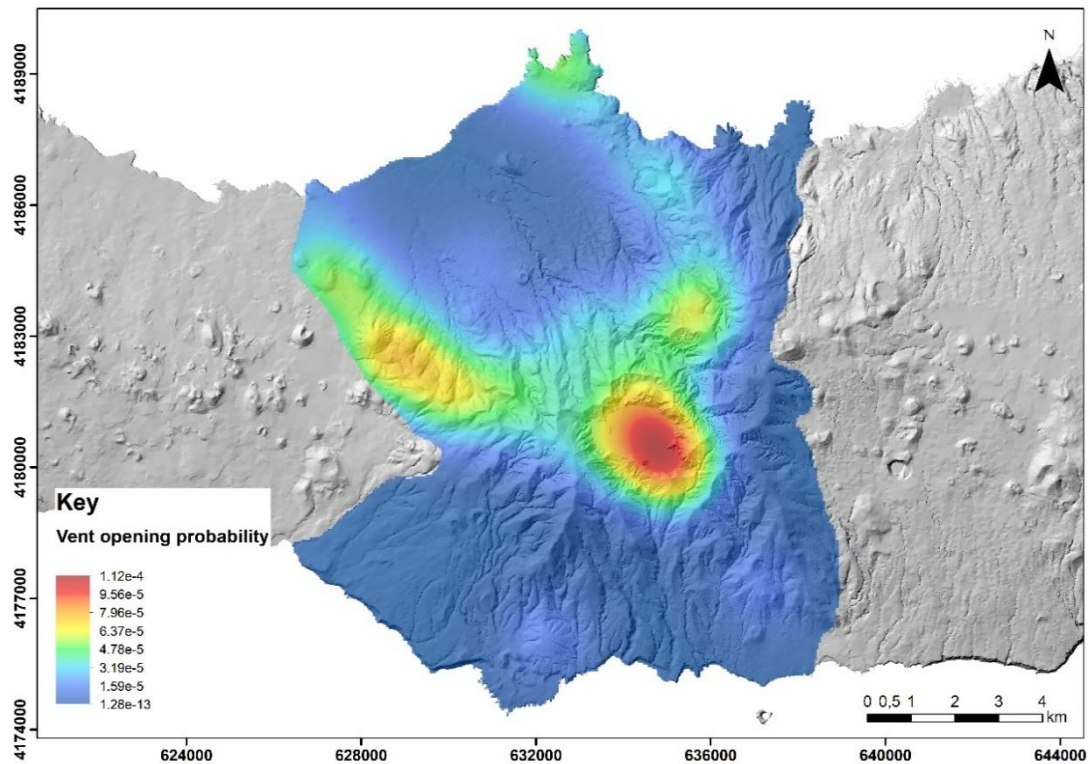


Figure 3. 17. Spatial vent opening probability map considering Fogo T dataset and using the Gaussian distribution with an optimal bandwidth of 800 m. UTM projection, Zone 26N, Datum WGS1984.

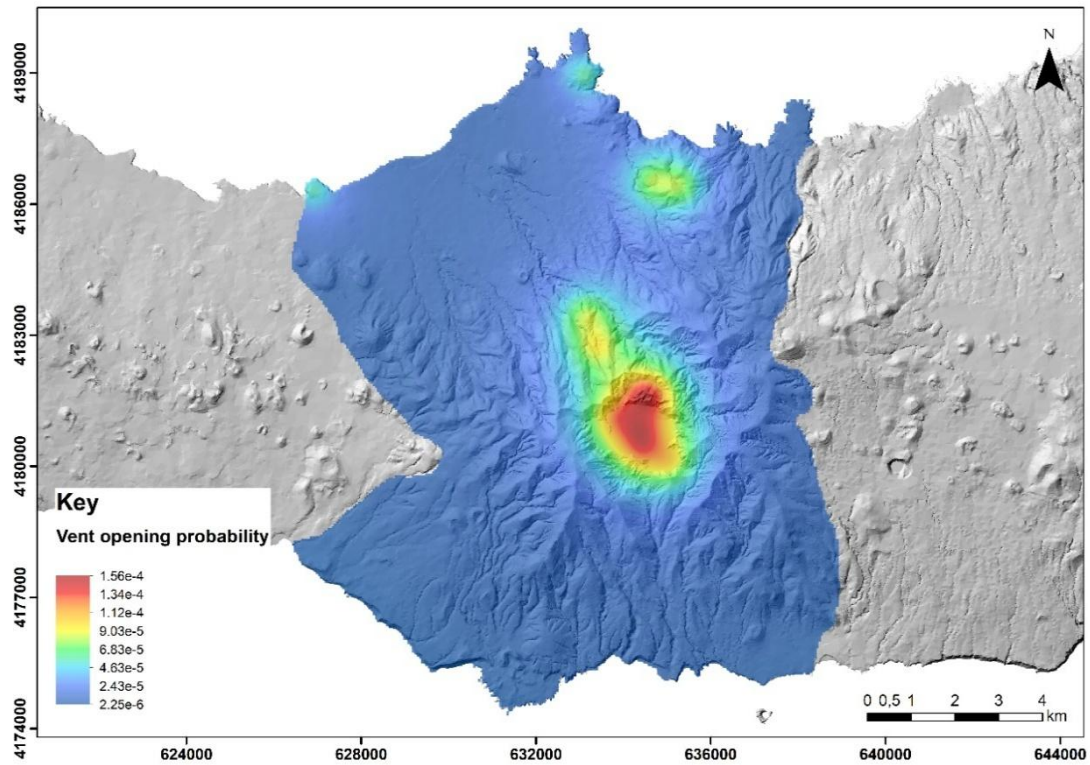


Figure 3. 18. Spatial vent opening probability map considering Fogo ET dataset and using the Cauchy distribution with an optimal bandwidth of 550 m. UTM projection, Zone 26N, Datum WGS1984.

Future openings of a basaltic (*s.l.*) or trachytic (*s.l.*) eruptive centre at Furnas Volcano are most likely to occur inside of the caldera complex (3.4×10^{-1} ; 34%), at the northeastern sector, mostly at Pico do Ferro domes area (3.1×10^{-1} , 31%), and at the east sector (1.5×10^{-1} , 15%) (Fig.3.19).

Considering only the trachytic (*s.l.*) eruptive centres from Furnas Volcano, higher probabilities for future openings were estimated for the area inside of the caldera complex (6.3×10^{-1} , 63%), as well as for the northeastern sector (2.1×10^{-1} , 21%) (Fig. 3.20).

Future explosive trachytic (*s.l.*) eruptive centres at Furnas are most probable to occur inside of the caldera, with an estimated probability of 9.1×10^{-1} (91%) (Fig. 3.21).

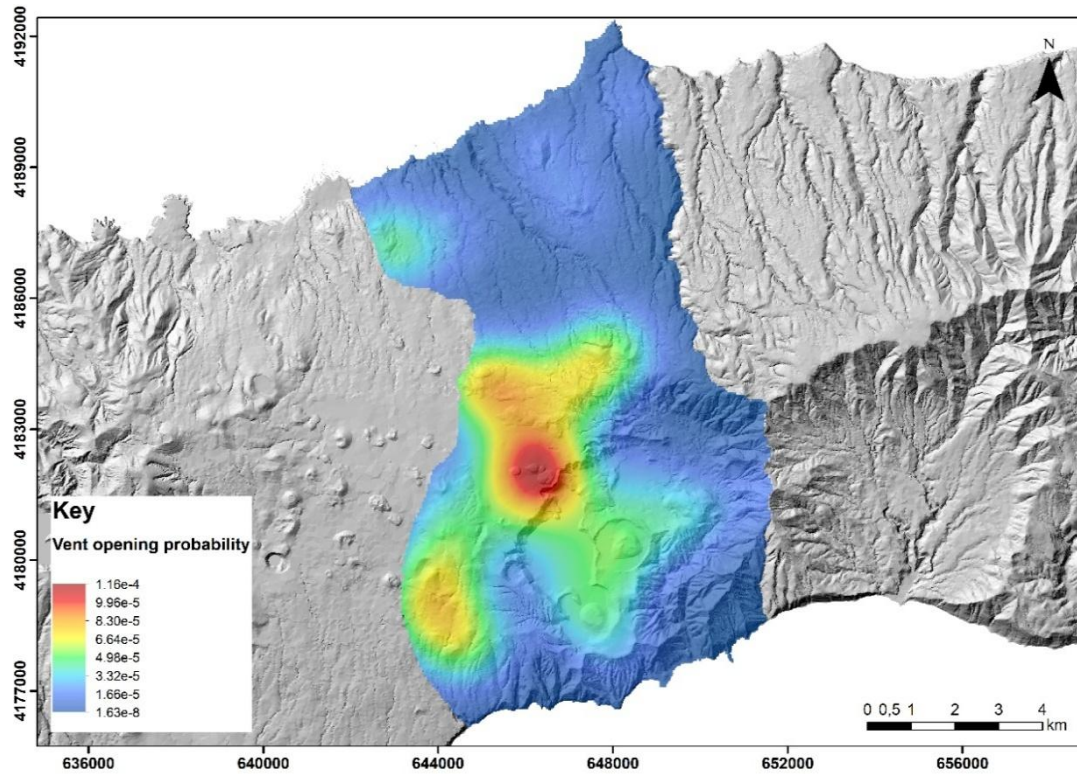


Figure 3. 19. Spatial vent opening probability map considering Furnas BT dataset and using the Gaussian distribution with an optimal bandwidth of 750 m. UTM projection, Zone 26N, Datum WGS1984.

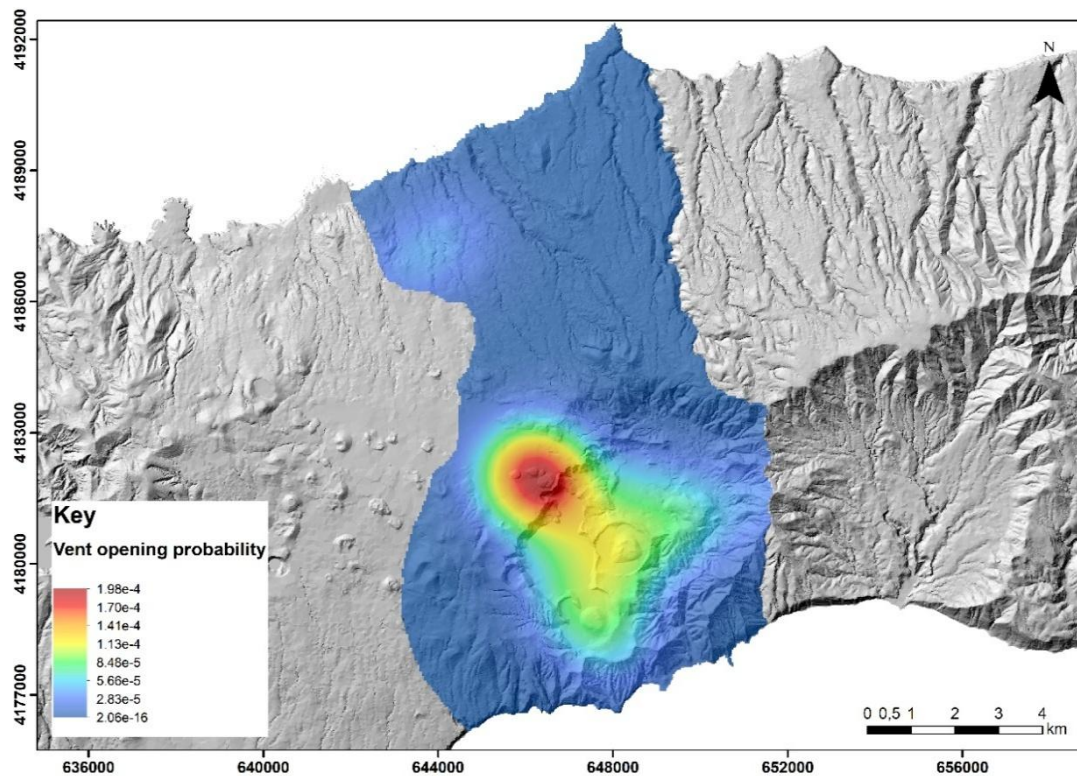


Figure 3. 20. Spatial vent opening probability map considering Furnas T dataset and using the Gaussian distribution with an optimal bandwidth of 850 m. UTM projection, Zone 26N, Datum WGS1984.

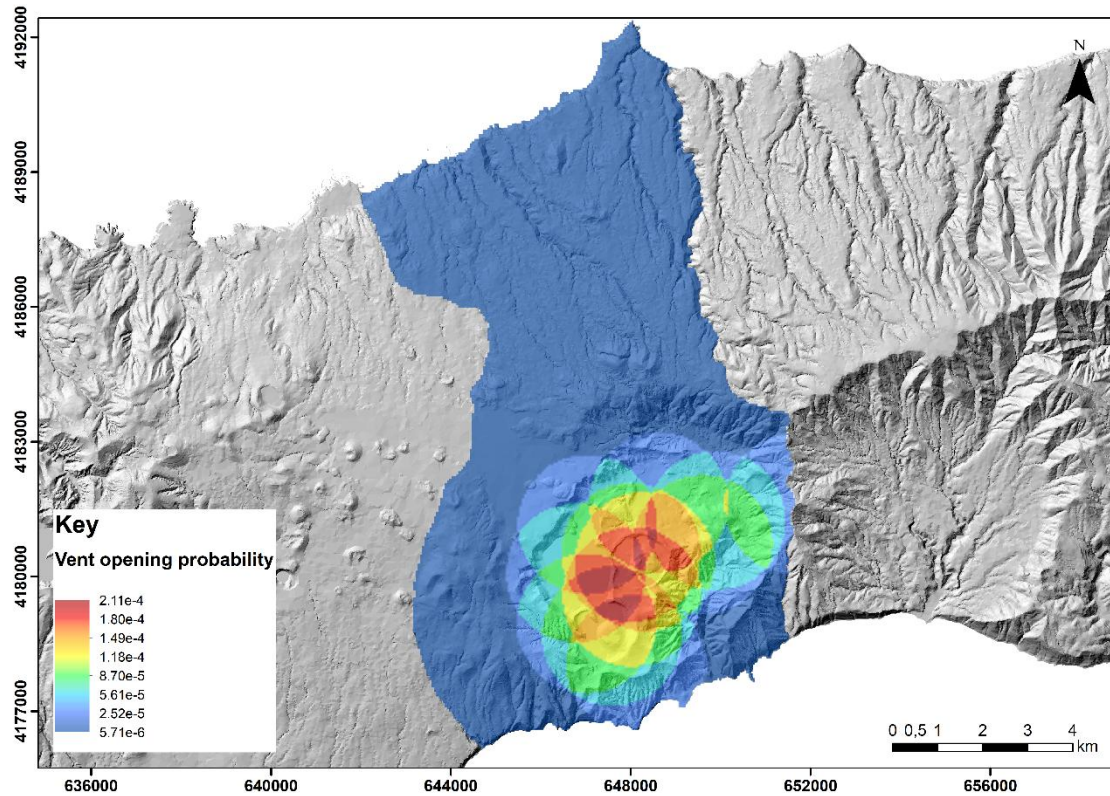


Figure 3. 21. Spatial vent opening probability map considering Furnas ET dataset and using the Uniform distribution with an optimal bandwidth of 1550 m. UTM projection, Zone 26N, Datum WGS1984.

3.4. Discussion

The spatial probability of a vent opening is one of the most important and complex tasks in volcanic hazard assessment, providing valuable insights into potential eruption sites. The location of past eruptive centres from the three active central volcanoes of São Miguel Island, either in a form of central vents or eruptive fissures, was used to compute the probability of a vent opening in each of these volcanic systems, and thus to identify probable locations of hosting future eruptions.

Eruptive centres were mapped using the ortophotomap and aerial photography. The criteria to classify the eruptive centres followed Becerril et al. (2013). Thus, it was considered as eruptive centres: (1) isolated craters from single cones or geomorphological expressions as central vents (e.g., for basaltic (*s.l.*) and trachytic (*s.l.*) vents), (2) craters without an observed cone as vents (e.g., maars), and (3) craters of coalescent cinder cones, which were considered as eruptive

fissures. Nevertheless, this process faced limitations in identifying eruptive centres, such as destruction of past locations by subsequent events or burial under volcanic deposits or vegetation.

The kernel density method was implemented to estimate the spatial density of future eruptive centres considering the location of past events (e.g., Bebbington and Cronin, 2011; Connor et al., 2012; Mazzarini et al., 2013; Bevilacqua et al., 2015b). Literature show that previous studies have commonly concentrated on the application of the Gaussian and Cauchy kernel functions to estimate the probability of a future vent in a specific location (e.g., Bartolini et al., 2013). Here, four different kernel functions were explored to perform this analysis, as in Sandri et al. (2024), namely, the Gaussian, Cauchy, Exponential, and Uniform distributions. Despite the frequent use of these models in the literature on probabilistic volcanic hazard assessment (e.g., Conway et al., 1998; Connor et al., 2000; Martí et al., 2022; Martin et al., 2004), the decision to incorporate them in the present study was supported by the fact that all models assume their maximum at the past eruptive centres, with their probabilities decreasing asymptotically or abruptly with increasing distance from the source. For instance, although the Gaussian, Cauchy, and Exponential distributions decrease at different rates, they all exhibit a similar behaviour in this regard.

Among all the considered models, the Uniform distribution is seldom used, and it considers a uniform degree of uncertainty about the location of past volcanic events. In the light of this model, the potential location of past activity could also be a possible future eruptive centre.

In general, all these functions give a clue to predict the location of future volcanic activity, having in common the fact that probabilities are assumed to be higher at regions with a dense concentration of eruptive centres, and they decline to zero, either gradually or abruptly, as the distance from these centres increases.

The smoothing parameter h is fundamental for kernel density estimation, influencing the width of the kernel and thus controlling the degree of smoothing. Therefore, smaller h leads to a kernel density estimation that follows the data points, while larger h leads to smoother kernel density estimations (Becerril et al., 2013; Bevilacqua et al., 2015b). While several methods exist for

selecting the optimal h , such as least square cross-validation (LSCV) (Cappello et al., 2012), Ho_{pt} score (Silverman, 1986), asymptotic mean square error sum selector (Connor et al., 2012), and others, the method proposed by Martin et al. (2004) was applied in this study. This method allows for the selection of the best kernel function and optimal bandwidth by comparing the empirical cumulative distribution function (ECDF) of the distance to the nearest neighbour with the cumulative distribution generated using different kernel functions and smoothing parameter values. The mean squared error method was applied to select the pair that best represents the ECDF distance to the nearest neighbour. In fact, this method calculates the average squared difference between the estimated and actual values, offering a more reliable result compared to visual inspection.

Several datasets of eruptive centres from each volcano were used to perform this analysis, such as (1) BT datasets to obtain the spatial probability of a new vent independently of its nature, (2) T datasets to obtain the spatial probability of a new trachytic (*s.l.*) vent, and (3) ET datasets to obtain the spatial probability of future explosive trachytic (*s.l.*) eruptions as they are, frequently, hazardous phenomena.

The results of this analysis reveal that the Gaussian distribution emerges frequently as the best model (e.g., for Sete T, Fogo BT, Fogo T, Furnas BT, and Furnas T datasets). This distribution allocates higher probabilities to regions that are near to its average, with significant decreasing probabilities towards areas that are located further from the distribution's average. Therefore, it is inferred that new eruptive centres are more likely to occur close to previous ones. The Gaussian distribution seems to represent well clusters of events, suggesting that at the fitted datasets clustering of eruptive centres occurs.

The Cauchy distribution also showed up when BT data from Sete Cidades and ET data from Fogo were analysed. According to this model, the spatial probability to host a new vent is more dispersed around the average of the distribution, which is in regions with a higher density of emission centres, suggesting that the likelihood of a new vent spreads to areas further away from the areas with higher density of eruptive centres. For eruptive centres that are located far from the

highest concentration of points, the Cauchy distribution appears to be a good fitting model as it has ticker tails when compared to the Gaussian model. This is translated by the location of eruptive centres both in Sete Cidades BT and Fogo ET datasets where it is possible to observed groups (small clustering's) of eruptive centres along with more dispersed centres from that clusters.

The Uniform distribution represents the datasets from Sete Cidades ET and Furnas ET. This model posits that there is no preferred location to host a new vent and, consequently, the spatial probability is uniform across all locations. The fitting of the Uniform model to these datasets can be justified by the fact that all ET eruptive centres from Sete Cidades and Furnas are located only inside of the calderas, and it is assumed that all points within the caldera have the same probability of hosting a new vent. However, volcanism often exhibits spatial patterns (Martin et al., 2004), and the Uniform distribution might not consider them.

The Exponential model fails to fit the datasets. According to this model, higher probabilities of hosting a new vent are expected near existing volcanic centres or in high-density regions, with this probability dropping exponentially with distance to these areas. Furthermore, the Exponential model requires independence between events, a condition that is not consistently observed in geological contexts.

Regarding smoothing parameter h , which is directly related to the density of eruptive centres and the size of the volcanic field, the results revealed optimal bandwidths ranging from 150 m to 1550 m. Narrow bandwidths (e.g., 150 m, 500 m, and others) were observed when using datasets with high number of eruptive centres located near to each other's (e.g., Sete Cidades BT, Fogo BT, and others). In these cases, it is observed a height density near past eruptive centres, as result of narrower bandwidths (e.g. Becerril et al., 2013). Broad bandwidths were also estimated in this study (e.g., 1400 m and 1550 m for Sete Cidades ET and Furnas ET datasets, respectively). This can be explained by the small number of eruptive centres in the datasets along with largest distances between them. In these cases, it is observed that probabilities are uniformly dispersed, providing a generalized view of vent opening in the same region.

The results of the sum of the probabilities at each point reveals that when considering BT dataset from Sete Cidades Volcano, the most probable locations to host new vents are concentrated at the southeast flank (30%), at the caldera (17%), and at the southwest flank (8.7%). Though the analysis of Sete Cidades T dataset, higher probabilities to host new vents were estimated for locations inside of the caldera (51%) and for the southwest flank (28%); while analysing the ET dataset, most probable locations are located only inside the caldera, with an estimated probability of 83%.

At Fogo Volcano, likely locations to host future BT vents occur at the west-northwest flank (29%), inside of the caldera (9.6%), and at the southwest flank (6%). Regarding a future trachytic (*s.l.*) eruption at Fogo, the most probable locations to host new vents corresponds to the west-northwest flank (25%), as well as to the caldera (17%) and to the north-northeast flank (15%). Explosive trachytic (*s.l.*) eruptions at Fogo are more likely to occur inside of the caldera (29%) and at the north flank (9.3%).

In the case of Furnas Volcano, the most probable locations to host future BT vents are located inside of the caldera complex (34%), at the northern flank (31%), and at the east flank (15%). The most probable locations for future trachytic (*s.l.*) vent openings are located inside of the caldera complex (63%) and at the north flank (21%); while considering future ET openings, likely locations are concentrated only inside of the caldera complex (91%).

Overall, the estimated probabilities in this study are mostly concentrated in areas exhibiting a higher density of central vents or eruptive fissures. This is particularly evident in the susceptibility maps obtained using BT datasets, where highest probabilities to host a new vent are frequently attributed to areas with predominance of basaltic (*s.l.*) eruptive centres, which is align with the fact that basaltic (*s.l.*) eruptions occurred more frequently. Moreover, the distribution of the probabilities is strongly conditioned by narrow bandwidths combined with dense basaltic (*s.l.*) fields in the flanks of the volcanoes (e.g., Sete Cidades BT); while trachytic (*s.l.*) eruptive centres have a lower weight in the probability estimation. In addition, locations where eruptive fissures occur (e.g., the southeast flank of Sete Cidades in the BT dataset), exhibit higher probabilities as

the method allocates highest probability values to lines (e.g., eruptive fissure) than to points (e.g., central eruptive centres).

The results obtained from the analysis of T datasets show that the probability distribution of a future trachytic (*s.l.*) eruptive centre is biased by the presence of trachytic (*s.l.*) domes. For instance, in the case of Sete Cidades and Furnas, the likely sites to host a future trachytic (*s.l.*) eruptive centre are located on the flanks of these volcanoes where several domes occur, concentrating the probability of a new trachytic (*s.l.*) eruptive centre outside the caldera.

The spatial probability maps regarding a future explosive trachytic (*s.l.*) eruption indicates that likely locations to host a new emission centre of this nature are concentrated within the caldera of the three central volcanoes. Although this is expected, as most of the previous explosive trachytic (*s.l.*) activity took place inside of the calderas, the potential of a new explosive emission centre on the flanks of these volcanoes cannot be ignored (e.g. Fogo B eruption; Wallenstein, 1999; Wallenstein et al., 2015).

3.5. Conclusions

More accurate long-term hazard assessment requires estimating the spatial probability of a vent opening. This type of approach, mostly based on the location of past emission centres, is a key to identify spatial patterns in volcanic activity and to predict potential eruption sites. However, this can be a challenging task, especially in volcanic regions where the knowledge on past activity is limited.

Here, the kernel approach was implemented to estimate the spatial probability of a vent opening at the three active central volcanoes of São Miguel Island (Sete Cidades, Fogo, and Furnas). The present study expanded upon the standard use of the Gaussian and Cauchy kernel functions, which are most utilized in the literature, by incorporating the Exponential and Uniform functions.

Through the combination of the best pair, which is the kernel function and the optimal bandwidth, spatial probability maps were produced considering different datasets. The results revealed that the Gaussian is frequently the most suitable model for the considered data (e.g. Sete Cidades T, Fogo BT, Fogo T, Furnas BT, and Furnas T). Other functions were the most suitable for specific datasets, such as the Cauchy, which had the best fit for Sete Cidades BT and Fogo ET datasets, and the Uniform fitting best Sete Cidades ET and Furnas ET datasets.

During this analysis, optimal narrow bandwidths were obtained (e.g., 150 m, 500 m, 550 m, among others). In these cases, lower h values had a significant impact on probability distribution, resulting in an increase in intensity around regions densely occupied by emission centres.

The main results of this analysis suggests that potential eruptive centres at Sete Cidades Volcano, either of basaltic (*s.l.*) or trachytic (*s.l.*) nature, are more likely to form at the southeast flank (30%), inside of the caldera (17%), and at the southwest flank (8.7%). Trachytic (*s.l.*) eruptive centres are more likely to occur within the caldera (51%) and at the southwest flank of the volcano (28%). Explosive trachytic (*s.l.*) eruptive centres are expected to occur within the caldera (83%).

Likely locations to host a new basaltic (*s.l.*) or trachytic (*s.l.*) eruptive centres at Fogo Volcano are concentrated at the north-northwest flank (29%), followed by the caldera (9.6%), and the southwest sector (6%). Future trachytic (*s.l.*) eruptive centres at Fogo are more likely to occur at the west-northwest sector (25%), within the caldera (17%), and at the north-northeast sector (15%). Considering future explosive trachytic (*s.l.*) eruptive centres at Fogo, higher probability values were estimated for locations within the caldera (29%) and for the north sector (9.3%).

A new eruptive centre at Furnas Volcano, regardless of magma type (i.e., basaltic (*s.l.*) or trachytic (*s.l.*)) is more likely to form within the caldera complex (34%), at the north sector (31%), namely at Pico do Ferro domes area, as well as at the east sector (15%). Likely locations to host a new trachytic (*s.l.*) eruptive centre at Furnas occur within the caldera complex (63%), as well as the north sector (21%). Similar to the others central volcanoes of São Miguel, the opening of a future explosive trachytic (*s.l.*) eruptive centre is expected within Furnas caldera complex (91%).

Despite the present study excluding the incorporation of tectonic structures, these features can be added to give a more detailed evaluation of spatial probability of future vent openings. Along with the incorporation of the regional stress field (e.g., Rivalta et al., 2019) for a more comprehensive understanding of possible magma pathways.

Through this effort, potential sites for future volcanic activity were identified at the three active central volcanoes of São Miguel. Recognizing likely locations to host new emission centres allows for the identification of possible scenarios and outcomes, thereby enhancing preparedness and response measures.

Chapter 4

Long-term Probabilistic Volcanic Hazard

Assessment (PVHA)

Chapter 4. Long-term Probabilistic Volcanic Hazard Assessment (PVHA)

4.1. Preliminary note

Long-term probabilistic volcanic hazard assessment (PVHA) has become an essential methodology for understanding and mitigating risks associated with volcanic activity. This type of approach is particularly important for regions characterised by low activity and/or incomplete and poorly preserved events, such as islands, where rarity of eruptions can lead to underestimation of risk. Moreover, a long-term (PVHA) approach constitutes a framework to evaluate the likelihood of volcanic events over extended timescales (years, decades), enabling the identification and assessment of potential hazards and their probability of occurrence, that is usually neglected using only deterministic approaches.

The development of a complete long-term PVHA requires the integration of different sources of data and techniques to improve the evaluation. For instance, it requires the incorporation the temporal probability of events in a time window (i.e., the probability of future eruptions), the spatial probability of future activity, and results from numerical models used to simulate the impact of the hazardous event considered (e.g., tephra dispersal and accumulation), that are posteriorly integrated into a Bayesian framework.

One of the most important tools in PVHA are Bayesian Event Trees (BETs), which allow for the integration of different sources of data to estimate absolute and conditional probabilities of specific phenomena.

A key strength of PVHA is the ability to incorporate both aleatoric and epistemic uncertainty that arises from the inherent natural variability of volcanic processes and from the lack of knowledge about them, respectively.

Although long-term PVHA have been proposed in the literature, the development of a full approach like this remains rare. This is mostly related to the difficulty in assessing volcanic hazards (e.g., Selva et al., 2019, Griffiths et al., 2024; López-Savaedra et al., 2023a; López-Savaedra et al., 2023b; Maurizio et al., 2024), especially in regions where dormant volcanoes are present, such in the Azores archipelago, and eruptive records and geological data are limited.

In this chapter, a full PVHA was conducted for each active central volcano (Sete Cidades, Fogo, and Furnas) to estimate the long-term probability of exceeding specific tephra load thresholds associated to explosive trachytic eruptions at São Miguel Island. This analysis incorporated the results from Chapters 2 and 3, regarding probability estimates of future eruptions in the next 50 years and the spatial probability distribution of future vent opening, respectively.

Numerical simulations were performed for each volcano to evaluate the impact of tephra fallout, considering different eruption sizes and vent positions, as well as wind data over the last 31 years to consider the long-term wind statistics. All results were integrated into a Bayesian Event Tree, providing as outcomes: probability maps, hazard maps, and hazard curves, with epistemic uncertainty associated.

Results of this work provide significant insights into potential hazards, offering support to scientists, civil protection agencies, and other decision-makers. Moreover, the outputs of the present analysis are essential tools to guide land-use planning, to develop emergency response plans, enhancing local communities' resilience. In addition, the methodologies developed in the present work for the first time on São Miguel Island, serve as basis procedures that can be applied in locations worldwide, where data is scarce, and the uncertainties are large.

4.2. Methodology

4.2.1. Definition of eruptive scenarios and volcanological inputs

In the present study, only trachytic explosive eruptions were considered to define eruptive scenarios, as these are the most frequent type of hazardous eruptive phenomenon recorded in the geological record. Simulations were conducted for two Plinian-style VEI 5 scenarios (Fogo and Furnas), three Plinian-style VEI 4 scenarios (Sete Cidades, Fogo, and Furnas), and one Sub-Plinian style VEI 3 scenario that was replicated for all three volcanoes.

The eruption source parameters for each eruptive scenario were estimated considering only volumes related to tephra fall (i.e., excluding the volumes associated to PDCs). Therefore, volumes were estimated from Sulpizio et al. (2005). A particle density of 800 kg/m^3 was considered to estimate the respective tephra fallout mass. Eruption magnitudes were obtained from Pyle (2000). Column heights for each scenario were set using data in the literature. Mass eruption rate values were obtained through Mastin (2014).

The simulations of a Plinian-style VEI 5 scenario at Fogo Volcano were based on the eruption that produced the Fogo A deposit ($4520 \pm 90 \text{ yr BP}$; Wallenstein, 1999). This eruption is regarded as the largest event in the last 5000 years of activity of Fogo Volcano and overall São Miguel Island. For the scenario, a column height of 27 km (Gaspar et al., 2015a) was considered. The total tephra fall volume was estimated at 2.28 km^3 , corresponding to a tephra mass of $1.8 \times 10^{12} \text{ kg}$ and a magnitude of 5.3 (Table 4.1).

The VEI 5 Plinian scenario for Furnas Volcano was based on Furnas C deposit, dated to $1,870 \pm 120 \text{ yr BP}$ (Guest et al., 1999). To perform this simulation, a column height of 17 km (Pacheco, 1995) was assumed. The tephra fall volume was estimated at 1.07 km^3 , with a total tephra mass of $1.8 \times 10^{12} \text{ kg}$ and a magnitude of 4.9 (Table 4.1).

Sub-Plinian VEI 4 scenarios were simulated for all three volcanoes. At Sete Cidades, the scenario was based on the eruption that formed Sete-P11 deposit, dated to $2220 \pm 70 \text{ yr BP}$ (Queiroz,

1997). To model this scenario, a column height of 18 km (Cole et al., 2008) was used. A tephra fall volume of 0.53 km^3 was estimated for this event, a total tephra mass of 4.2×10^{11} , and a magnitude of 4.6 (Table 4.1).

The VEI 4 scenario for Fogo Volcano is similar to the explosive eruption of AD 1563, which achieved a column height of 19 km (Aguilar, 2018). The estimated tephra fall volume for this eruption was 0.53 km^3 , corresponding to a total tephra mass of 4.2×10^{11} , and a magnitude of 4.6 (Table 4.1).

The VEI 4 scenario at Furnas comes from the explosive phase of the AD 1630 historical eruption. For this scenario, a column height of 13 km (Cole et al., 1995) was considered. The estimated tephra fall volume, total tephra mass, and magnitude were 0.22 km^3 , $1.8 \times 10^{11} \text{ kg}$, and 4.2, respectively (Table 4.1).

To simulate a Sub-Plinian VEI 3 event, a synthetic scenario was created, and numerical simulations were conducted for all the three volcanoes using the same eruption source parameters. For this scenario, a column height of 8 km was adopted, as it frequently represents the lower range of column heights associated to layers from VEI 4 eruptions. The total tephra fall volume was estimated based on the L1 layer from Sete P-8 deposit (Cole et al., 2008), yielding a value of 0.02 km^3 . This corresponds to a total tephra mass of $1.9 \times 10^{10} \text{ kg}$ and a magnitude of 3.3 (Table 4.1).

Table 4. 1. Summary of volcanological inputs used to perform numerical simulations.

Eruption source parameters							
Scenario	Volcano	VEI	Column height (km)	Volume (km ³) ^f	Mass (kg)	Magnitude ^g	MER (kg/m ³) ^h
Plinian	Fogo	5	27 ^a	2.28	1.8x10 ¹²	5.3	1.22x10 ⁸
Plinian	Furnas	5	17 ^b	1.07	8.6x10 ¹¹	4.9	1.79x10 ⁷
Sub-plinian	Sete Cidades	4	18 ^c	0.52	4.2x10 ¹¹	4.6	2.27x10 ⁷
Sub-plinian	Fogo	4	19 ^d	0.53	4.2x10 ¹¹	4.6	2.84x10 ⁷
Sub-plinian	Furnas	4	13 ^e	0.22	1.8x10 ¹¹	4.2	5.87x10 ⁶
Sub-plinian	All the three	3	8 ^e	0.02	1.9x10 ¹⁰	3.3	7.83 x10 ⁵

^aEstimated by Bursik et al. (1992); Gaspar et al. (2015a).

^bEstimated by Pacheco (1995).

^cEstimated by Cole et al. (2008).

^dEstimated by Aguiar (2018).

^eEstimated by Cole et al. (1999).

^fVolumes estimated from Sulpizio et al. (2005).

^gEstimated from Pyle (2000).

^hEstimated from Mastin (2014).

4.2.2. Wind data

Wind data was sourced from ERA 5 reanalysis by the European Centre for Medium-Range Weather Forecasts. To perform the analysis, wind data were extracted specifically for São Miguel area, bounded between 37.96°N to 37.66°N and 25.91°W to 25.08°W. To capture variations in wind patterns, monthly wind data was collected from January 1, 1992, to December 31, 2022 (31 years). The extraction of wind data accounted for leap years (1992, 1996, 2000, 2004, 2008, 2012, 2016, and 2020). Each file provides hourly wind data from 00:00h to 23:00h with a horizontal resolution of 0.25° × 0.25° and include 37 vertical pressure levels, ranging from 1000 hPa to 1 hPa. The data was converted into daily means and merged, resulting in a dataset of 11,323 vertical wind profiles. The wind files were organized into a format requested for numerical simulations, incorporating 60 Z-levels, starting at an altitude of 500 m and increasing every 500 m up to 30,000 m high.

4.2.3. HAZMAP model and input parameters

The simulation of each eruptive scenario was performed using HAZMAP, a simulation code written in FORTRAN90 that simulates the dispersion from a Plinian column and the sedimentation of volcanic particles from discrete point sources (see Macedonio et al., 2005 for details). HAZMAP allows for two different modes of running, including the “deposit mode”, for ground deposit analysis, and “probability mode”, to estimate the exceedance probability of a given threshold.

The physical model used by HAZMAP describes the diffusion, transport, and sedimentation of particles, in a two-dimensional domain from one or more point sources. In the atmosphere, particle dispersion is, typically, controlled by turbulent diffusion and wind transport. In contrast, fallout is governed by particles settling velocity which depends on gravitational forces and air drag (Armienti et al., 1988; Macedonio et al., 1988).

The HAZMAP ash transport model is based on several assumptions as follows. For instance, the model assumes that at distances beyond the eruption column, the concentration of particles C_i with a specific settling velocity $v_{s,i}$ is represented through a mass conservation equation (Eq.1) as bellow:

$$\frac{\partial C_j}{\partial t} + w_x \frac{\partial C_j}{\partial x} + w_y \frac{\partial C_j}{\partial y} + w_z \frac{\partial C_j}{\partial z} - \frac{\partial v_{s,j} C_j}{\partial z} = K_x \frac{\partial^2 C_j}{\partial x^2} + K_y \frac{\partial^2 C_j}{\partial y^2} + K_z \frac{\partial^2 C_j}{\partial z^2} + S$$

Eq. 1

where the spatial coordinates are given by (x, y, z) , wind velocity components are given by (w_x, w_y, w_z) , t is the time, the diffusion coefficients are assumed to be constant and are given by $(K_x, K_y, \text{ and } K_z)$, and S is the source functions.

Horizontal components of wind and turbulence usually exceed the vertical components. For this reason, vertical wind component (w_z) and vertical diffusion coefficient (K_z) are neglected to simplify the model (Pasquill, 1974; Armienti et al., 1988). Therefore, atmospheric diffusion is

confined to the plane x, y (horizontal), assuming isotropic horizontal diffusion, given by $K_x = K_y = K$.

The column shape is modelled according to the following equation (Eq.2) and assuming that all particles are released simultaneously, at $t = t_0$, from vertical point sources above the crater. Thus, the column shape is given by:

$$S(x, y, z, t) = \delta(t - t_0) \sum_k^{N_k} M_k \delta(x - x_v) \delta(y - y_v) \delta(z - z_k) \quad \text{Eq. 2}$$

where δ is the Dirac distribution, N_k gives the total number of point sources, M_k denotes the mass of particles emitted from the k -th point source located at coordinates (x_v, y_v, z_k) , being x_v and y_v the vent position.

The dispersion of particles emitted from a point source (x_0, y_0, z_0) within an infinite domain, assuming uniform wind conditions and a constant settling velocity, is thus based on the three-dimensional advection-diffusion-sedimentation equation:

$$\frac{\partial C_j}{\partial t} + w_x \frac{\partial C_j}{\partial x} + w_y \frac{\partial C_j}{\partial y} - v_{s,j} \frac{\partial C_j}{\partial z} = K_x \frac{\partial^2 C_j}{\partial x^2} + K_y \frac{\partial^2 C_j}{\partial y^2} + K_z \frac{\partial^2 C_j}{\partial z^2} \quad \text{Eq. 3}$$

An analytical solution for equation 3, is given by:

$$C(x, y, z, t) = \frac{1}{4\pi K t} \exp \left[\frac{-(x-x_0-w_x t)^2 + (y-y_0-w_y t)^2}{4K t} \right] \times \frac{1}{\sqrt{4\pi K_z t}} \exp \left[\frac{-(z-z_0+v_{s,j} t)^2}{4K_z t} \right] \quad \text{Eq. 4}$$

Equation 4 can be simplified as the limit of $K_z \rightarrow 0$, describing particle dispersion in a horizontal layer with a settling velocity v_s :

$$C(x, y, z, t) = \frac{1}{4\pi K t} \exp \left[\frac{-(x-x_0-w_x t)^2 + (y-y_0-w_y t)^2}{4K t} \right] \delta(z - z_0 + v_{s,j} t) \quad \text{Eq. 5}$$

In HAZMAP, the three-dimensional computational space is divided into discrete horizontal layers, each governed by equation 5, simplifying the 3D domain into a 2D framework. This allows for the representation of a real wind profile and vertical variations in settling velocity as a layered wind and settling velocity profile. Similarly, to estimate volcanic ash transport, the vertical

domain is typically divided into N_{layers} , each containing a set of N_{sources} point sources (e.g., Suzuki, 1983; Glaze and Self, 1991).

Furthermore, accounting for the influence of the wind, atmospheric turbulence, and gravity, it is assumed that particles, following a Gaussian distribution, disperse laterally due to turbulence, settle into the underlying layer as a result of gravity, and shift horizontally as their centre moves with the wind. Thus, the final position of the mass distribution centre at the ground $\vec{x}_{Gi} = (x_{Gi}, y_{Gi})$ is given by:

$$\vec{x}_{Gi} = \vec{x}_{0i} + \sum_k \vec{w}_k \Delta t_k \quad \text{Eq. 6}$$

where the point source layer is denoted by i , $\vec{x}_{0i}$ represents the horizontal coordinates of the point source i , $\sum_k$ is the sum on the generic layer between the point source and the ground, $\vec{w}_k$ indicates the horizontal wind velocity in the layer k , and Δt_k is the residence time of particles in the layer k (see Macedonio et al., 2005 for more details).

The final variance of the mass distribution at the ground σ_{Gi}^2 , as the mass spreads horizontally until reach the ground, is:

$$\sigma_{Gi}^2 = 2K \sum_k \Delta t_k \quad \text{Eq. 7}$$

The vertical domain is, typically, divided into N_{layers} as wind profiles and settling velocities can vary with altitude. In this way, the total mass deposited on the ground M_G can be calculated as the sum of contributions from all point sources and settling velocities as bellow:

$$M_G(x, y) = \sum_{j=1}^{N_{vs}} \sum_{i=1}^{N_{sources}} \frac{M_i f_i}{2\pi\sigma^2} \exp \left[\frac{-(x - x_G)^2 + (y - y_{Gi})^2}{2\sigma^2_{Gi}} \right] \quad \text{Eq. 8}$$

Where the total number of mass classes is denoted by N_{vs} , the total mass emitted from a point source in the layer i is represented by M_i , and the fraction of mass of a settling velocity class j is given by f_j .

In HAZMAP, the mass distribution within the eruptive column is addressed through a modification of the original Suzuki formula (Eq.9) (Suzuki, 1983):

$$S(x, y, z, t) = S_0 \left\{ \left(1 - \frac{z}{H} \right) \exp \left[A \left(\frac{z}{H} - 1 \right) \right] \right\}^\lambda \delta(t - t_0) \delta(x - x_v) \delta(y - y_v) \quad \text{Eq. 9}$$

where S_0 indicates the normalisation constant, H represents the column height, A and λ are the Suzuki coefficients, and x_v, y_v are the vent coordinates.

Such modification enables the representation of a mushroom-shaped column, and introduces an improved discretization of the vertical column, allowing for a more accurate evaluation of the vertical mass distribution, once the direct use of equation 9 results in a zero mass at $z = H$. In this way, the column is divided into several layers, and the mass distribution is calculated by integrating equation 9 within each layer. Thus, for a column discretized into N_s sources at equally spaced elevations $z_i = i\Delta z$ (where $i = 1, \dots, N_s$ and $\Delta z = H/N_s$), the mass in each source point is given by:

$$S_i = \int_{z_i - \Delta z/2}^{z_i + \Delta z/2} S(x_v, y_v, z, t) dz \quad \text{Eq. 10}$$

This integral is evaluated using:

$$\int S(x_v, y_v, z, t) dz = S_0 \frac{H}{(A\lambda)^{\lambda+1}} \Gamma_L \left(\lambda + 1, A\lambda \left(1 - \frac{z}{H} \right) \right) \delta(t - t_0) \delta(x - x_v) \delta(y - y_v) \quad \text{Eq. 11}$$

where Γ_L is the lower incomplete Gamma function (see Macedonio et al., 2005 for more details).

To perform the simulations, the *geninp.inp* (Appendix A.3) file was filled in and used to automatically generate the *hazmap.inp* file to be read by HAZMAP. Each simulation was performed from a central point on São Miguel Island, located at coordinates 632369 Easting and 4185351 Northing (UTM, Zone 26N). To account for the spatial probability of future vent opening, the deposit simulated from the centre of São Miguel was then displaced over all the possible vent location considered at each volcanic system.

The HAZMAP simulation mode was set to mode 1, which corresponds to the “*probability mode*”.

The computational domain was represented by a uniform grid, including 300×300 cells (NX, NY), and a grid spacing of $500 \text{ m} \times 500 \text{ m}$ (DX, DY), being its centre located at the same coordinates from where simulations were performed.

The settling velocity model was defined as model 2, corresponding to Ganser (1993) model, to account for particles sphericity of about 0.8 – 0.9, with the settling velocity considered as a function of the altitude.

The total eruption mass was set according to table 4.1 for each scenario, and the mass distribution followed the Suzuki model.

The column height was defined following the cases in table 4.1 and subdivided in steps of 500 m to account for the variability of the wind and settling velocities in altitude. In buoyant plumes it was frequently observed that the ratio between the height of buoyancy (H_B) and the maximum height (H_T) is $3/4$ (Morton et al., 1956; Sparks, 1986). To account for this, the Suzuki coefficient A was set as 4. The Suzuki coefficient λ was set as 1 to account for a more homogenous particle distribution over the plume (figure 4.1). A diffusion coefficient of $5000 \text{ m}^2/\text{s}$ was used to represent horizontal particle dispersion (e.g. Macedonio et al., 2016).

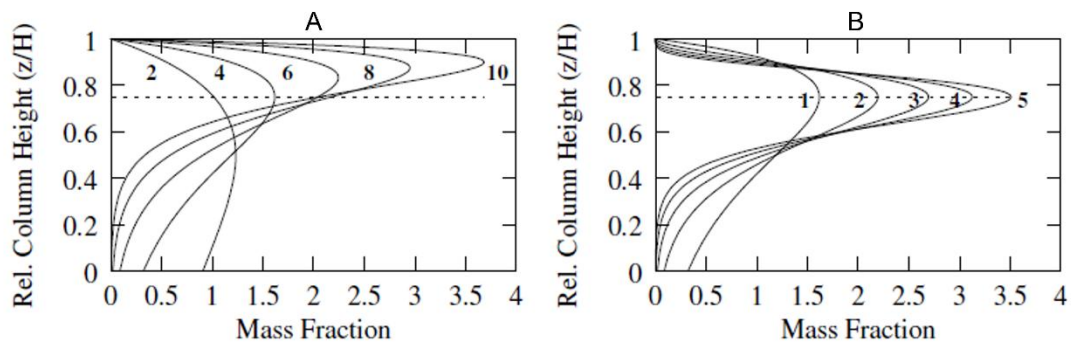


Figure 4. 1. Column shape and mass distribution inside the eruption column. A) Mass distribution for different values of Suzuki coefficient A and assuming $\lambda = 1$. B) Mass distribution for different values of Suzuki coefficient λ and assuming $A = 4$. The dashed line illustrates the $3/4$ of the column height (Macedonio et al., 2005).

Furthermore, 9 intensity thresholds for tephra load were specified for hazard assessment, that are 1, 10, 50, 100, 200, 300, 400, 500, and 1000 kg/m², corresponding approximately to 1 mm, 1 cm, 5 cm, 10 cm, 20 cm, 30 cm, 40 cm, 50 cm and 1 m in thickness, respectively.

The limited characterization of particles (e.g., density, diameter, and shape) produced by the studied volcanoes led to the use of PyVolcans (Tierz et al., 2019) to identify analogous volcanoes. Thus, the total grain size distribution (TGSD) estimated by Poret et al. (2020) for the AD 79 eruption and the Pollena eruption of Mount Vesuvius volcano were used to represent particle classes and reconstruct the particle size distribution for the considered scenarios. In this case, the TGSD of AD 79 eruption was used as reference for the largest scale scenario, a VEI 5 event, while the TGSD of the Pollena eruption was used to represent the particle distribution during a VEI 4 and a VEI 3 event. In total, 16 particle classes were considered.

4.2.4. Bayesian Event Trees

Bayesian Event Trees (BETs) were developed individually for each of the three volcanoes. This was achieved by designing multiple MATLAB scripts following the same approach as the BET_VH scheme (Marzocchi et al., 2010) that focuses on a long-term Probabilistic Volcanic Hazard Assessment (PVHA).

Therefore, the BETs incorporate eight theoretical stages (nodes), enabling a more comprehensive analysis and facilitating an evaluation of the potential impacts on the territory. At each node of the BETs, different sources of data, such as geological information (representing past data) and modelling or theoretical insights (representing prior data), can be incorporated and combined into a posterior probability distribution through Bayesian inference, that accounts for both types of data and includes an assessment of the associated uncertainty.

The general BET model allows for the incorporation of both monitoring and non-monitoring data to estimate the pdf of the j -th event at k -th node, using (See Marzocchi et al., 2008, including its supplementary material, for more details:

$$[\theta_k^{(j)}] = yk [\theta_k^{(j)\{M\}}] + (1 - yk) [\theta_k^{(j)\{\overline{M}\}}] \quad \text{Eq. 12}$$

where $\theta_k^{(j)}$ is the linear combination of probabilities based on two types of information, yk is a variable in the interval $[0,1]$ that sets the degree at which monitoring data control the posterior probabilities with respect to the non-monitoring part, $\theta_k^{(j)\{M\}}$ is the monitoring part of the equation, and $\theta_k^{(j)\{\overline{M}\}}$ corresponds to the non-monitoring part in the equation. Each function $[\theta_k^{(j)\{. \}}]$ of equation 12 is estimated using Bayes theorem. As the present work uses a similar approach as in BET_VH, the non-monitoring part of the equation was not considered. In this case, only information from theoretical, models, and past data was accounted. Thus, $[\theta_k^{(j)\{\overline{M}\}}]$ was estimated as follows (Marzocchi et al., 2008):

$$[\theta_k^{(j)\{\overline{M}\}}] = [\theta_k^{(j)\{\overline{M}\}} \vee y] = \frac{[\theta_k^{(j)\{\overline{M}\}}]_{prior} [y \vee \theta_k^{(j)\{\overline{M}\}}]}{[y]} \quad \text{Eq. 13}$$

where the posterior distribution, given a set of data y , is $[\theta_k^{(j)\{\overline{M}\}} \vee y]$, $[\theta_k^{(j)\{\overline{M}\}}]_{prior}$ is the prior distribution where the knowledge coming from theoretical models or beliefs is accounted, the sampling distribution, also known as *likelihood* function, is $[y \vee \theta_k^{(j)\{\overline{M}\}}]$, and $[y]$ is a normalizing factor where the total probability of observing data y is accounted (See Marzocchi et al., 2008 for more details). In addition, if data $[y]$ is not available, prior estimations relies only on theoretical models and/or beliefs. In this case, the prior distribution is given by (Marzocchi et al., 2008):

$$[\theta_k^{(j)}] = [\theta_k^{(j)\{\overline{M}\}}] \quad \text{Eq. 14}$$

Prior distribution estimates

The prior distribution for a j -th event at k -th node is modelled through a Dirichlet distribution (Gelman et al., 1995; Marzocchi et al., 2004; Marzocchi et al., 2008), that describes the probability for a generic multivariate random variable (i.e., with more than two possible outcomes are possible) (e.g., different vent locations, or eruptive sizes). The Dirichlet distribution describing the random variable $\xi = (\xi^{(1)}, \dots, \xi^{(J)})$ is expressed as:

$$[\xi] = Di_J(\alpha_1, \dots, \alpha_J) = \frac{\Gamma(\alpha_1 + \dots + \alpha_J)}{\Gamma(\alpha_1) \dots \Gamma(\alpha_J)} [\xi^{(1)}]^{\alpha_1-1} \dots [\xi^{(J)}]^{\alpha_J-1} \quad \text{Eq. 15}$$

where the Gamma function is given by $\Gamma(\cdot)$, J denotes the number of mutually exclusive and exhaustive possible events, $\alpha_j > 0$, $\xi^{(1)}, \dots, \xi^{(J)} > 0$, $\sum_{j=1}^J \xi^{(j)} = 1$.

Specifically in BET_VH, for some cases, the prior distribution is given by:

$$[\theta_k^{\{M\}}]_{prior} \equiv Di_{J_k}(\alpha_k^{(1)}, \dots, \alpha_k^{(J_k)}) \quad \text{Eq. 16}$$

where the number of possible mutually exclusive and exhaustive events at the node k -th is given by J_k , and $\alpha_k^{(1)}, \dots, \alpha_k^{(J_k)}$ are the parameters of the distribution that are dependent on the node in consideration (see Marzocchi et al., 2008 for more details).

The Dirichlet distribution is unimodal with its domain between $[0,1]$. For this specific case (e.g., multivariate random variables), the mean, which is the “best guess” for the aleatory uncertainty, and variance, representing the epistemic uncertainty, are given by the following equations, respectively (Marzocchi et al., 2008):

$$E[\theta_k^{(j)[M]}]_{prior} \equiv \theta_k^{(j)[M]} = \frac{\alpha_k^{(j)}}{\alpha_k^{(0)}} \quad \text{Eq. 17}$$

$$V = [\theta_k^{(j)[M]}]_{prior} = \frac{\alpha_k^{(j)} (\alpha_k^{(0)} - \alpha_k^{(j)})}{(\alpha_k^{(0)})^2 (\alpha_k^{(0)} + 1)} \quad \text{Eq. 18}$$

where $E[\cdot]$ and $V[\cdot]$ are the expected value and variance of the pdf, respectively, and $\alpha_k^{(0)} \equiv \sum_{j=1}^{J_k} \alpha_k^{(j)}$.

When there are only two mutually exclusive events ($J = 2$; i.e., “yes” or “no”), the Dirichlet distribution simplifies to the Beta distribution as:

$$[\xi] = \text{Beta}(\alpha, \beta) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} \xi^{\alpha-1} (1 - \xi)^{\beta-1} \quad \text{Eq. 19}$$

where $\alpha, \beta > 0$, and $\alpha, \beta \geq 1$ is a condition for the pdf to be finite (e.g., Gelman et al., 1995; see Marzocchi et al., 2008 for details). In such case, equations 17 and 18 can be modified to obtain the mean and variance for the Beta distribution.

When is not possible to estimate a feasible prior model due to lack of data, for instance, a state of maximum ignorance is set using the uniform distribution. In this limit case of the Dirichlet (Beta) distribution, it is assumed that $\alpha_k^{(1)} = \dots = \alpha_k^{(J)} = 1$ ($\alpha_k = \beta_k = 1$), where the mean and variance at k -th node are expressed, respectively:

$$E \left[\theta_k^{(j)[\overline{M}]} \right]_{prior} \equiv \theta_k^{(j)\{\overline{M}\}} = \frac{1}{J_k} \quad \text{Eq. 20}$$

$$V = \left[\theta_k^{(j)[\overline{M}]} \right]_{prior} = \frac{J_k - 1}{J_k^2 (J_k + 1)} \quad \text{Eq. 21}$$

where $\theta_k^{(j)\{\overline{M}\}}$ is the average of the distributions.

On the contrary, when a high degree of certainty about event probabilities is verified, i.e. $\alpha_k^{(j)} \rightarrow \infty$, $V \left[\theta_k^{(j)[\overline{M}]} \right] \rightarrow 0$, the Dirichlet distribution approaches a Dirac's δ distribution, indicating that the distribution is centred around the average. For these cases, the variance is parameterized through the “equivalent number of data” $\Lambda_k^{\{\overline{M}\}}$, which expresses the degree of confidence on prior information (See Marzochhi et al., 2008 for details). In other words, the equivalent number of data (which is at minimum equal to 1) parametrises a sort of confidence on the best guess, and its meaning can be summarized broadly as “the number of data one needs to collect to significantly

change the mind on the best-guess". Thus, the equivalent number of data and variance are expressed as:

$$\Lambda_k^{\{\overline{M}\}} = \alpha_k^{(0)} - J_k + 1 \quad \text{Eq. 22}$$

$$V = \left[\theta_k^{(j)\{\overline{M}\}} \right]_{prior} = \frac{\theta_k^{(j)\{\overline{M}\}} (1 - \theta_k^{(j)\{\overline{M}\}})}{\Lambda_k^{\{\overline{M}\}} + J_k} \quad \text{Eq. 23}$$

Likelihood function

In BET model, the past data at node k -th is used to refine probability estimates into posterior probabilities through the so-called likelihood function denoted as $\left[y_k \vee \theta_k^{\{\overline{M}\}} \right]_{prior}$, as prescribed by the Bayes theorem. For multivariate random variables $\xi = (\xi^{(1)}, \dots, \xi^{(J)})$, the multinomial likelihood is the conjugate of the Dirichlet, a feature that simplifies greatly the computation of the posterior. The multinomial likelihood is expressed as (Marzocchi et al., 2008):

$$[y \vee \xi] = Mu_j(y^1, \dots, y^J; \xi) = \binom{\sum_{j=1}^J y^{(j)}}{y^{(1)} \dots y^{(J)}} (\xi^{(1)})^{y^{(1)}} \dots (\xi^{(J)})^{y^{(J)}} \quad \text{Eq. 24}$$

where the number of successes related to the event j with probability $\xi^{(j)}$ is expressed by $y^{(j)}$, the data vector is defined by $y = (y^{(1)}, \dots, y^{(J)})$, and the total number of data n is expressed by $\sum_{j=1}^J y^{(j)}$.

In BET_VH, the likelihood function is given by (see Marzocchi et al., 2008 for details):

$$\left[y_k \vee \theta_k^{\{\overline{M}\}} \right] \equiv Mu_{J_k}(y_k^{(1)}, \dots, y_k^{(J_k)}; \theta_k^{\{\overline{M}\}}) \quad \text{Eq. 25}$$

where the number of possible mutually exclusive and exhaustive events at k -th node is again J_k .

Similarly to the previous section (e.g., equation 19), when $J = 2$, a multinomial distribution simplifies to a binomial distribution. For those particular cases, equation 24 is adapted, considering: y_k as the number of occurrences of an event in a dataset of n_k data, $J = 2$, $\xi^{(1)} = \theta_k$, $\xi^{(2)} = 1 - \theta_k$, $y^{(1)} = y_k$, and $y^{(2)} = n_k - y_k$ (See Marzocchi et al., 2008 for details). Thus, the likelihood function is described as:

$$\left[y_k \vee \theta_k^{[\overline{M}]} \right] \equiv \text{Bin}(y_k, n_k, \theta_k) = \binom{n_k}{y_k} \theta_k^{y_k} (1 - \theta_k)^{n_k - y_k} \quad \text{Eq. 26}$$

Posterior distribution estimates

For multivariate cases, using the Bayes theorem and taking advantage of the conjugacy property between Dirichlet and multinomial, the posterior distribution for $\theta_k^{\{\overline{M}\}}$ is estimated through (Marzocchi et al., 2008):

$$\left[\theta_k^{\{\overline{M}\}} \right] \equiv \left[\theta_k^{\{\overline{M}\}} \vee y_k \right] = \text{Di}_{J_k} \left(\alpha_k^{(j)} + y_k^{(j)}; j = 1, \dots, J_k \right) \quad \text{Eq. 27}$$

where $y_k^{(j)}$ denotes the same as in equation 25, and $\alpha_k^{(j)}$ represents the same as in equation 16.

For univariate cases, the posterior distribution simplifies further to (Marzocchi et al., 2008):

$$\left[\theta_k^{\{\overline{M}\}} \right] \equiv \left[\theta_k^{\{\overline{M}\}} \vee y_k \right] = \text{Beta}(\alpha_k + y_k, \beta_k + n_k - y_k) \quad \text{Eq. 28}$$

Probabilities at each node and input parameters

Node 1-2-3: probability of eruption

The three first nodes of the BETs are related to the occurrence of the eruption, which condenses the probabilities of having the unrest (node 1), the presence of magma given unrest (node 2), and the occurrence of an eruption given a magmatic unrest (node 3). Node 1-2-3 provide information

if an eruption occurs, or not, in the time interval $(t_0, t_0 + \tau)$, where the present time is denoted by t_0 and τ is the forecasting time window (see Marzocchi et al., 2008; Marzocchi et al., 2010). In this case, there are only two possible outcomes: *eruption* or *no eruption*. For this node, prior probabilities are achieved using:

$$[\theta_{1-2-3}]_{prior} = Beta(\alpha_1, \beta_1) \quad \text{Eq. 29}$$

being α_1 and β_1 deduced from the average θ_1 and from the equivalent number of data Λ_1 , as above (Marzocchi et al., 2008; Marzocchi et al., 2010):

$$\theta_1 = \frac{\alpha_1}{\alpha_1 + \beta_1} \quad \text{Eq. 30}$$

$$\Lambda_1 = \alpha_1 + \beta_1 - 1 \quad \text{Eq. 31}$$

In this way, the posterior distribution, given that past data is available, is estimated using:

$$[\theta_{1-2-3}] = [\theta_{1-2-3} \vee y_{1-2-3}] = Beta(\alpha_1 + y_{1-2-3}, \beta_1 + n_{1-2-3} - y_{1-2-3}) \quad \text{Eq. 32}$$

where the number of past eruptions occurred is denoted by y_{1-2-3} , and n_{1-2-3} is the total number of not overlaps time windows of length τ .

For the present work, a time window τ of 50 years was considered. As input values to set eruption probability, results estimated in the Chapter 2 regarding the mean probability of an explosive trachytic eruption at each volcano were used. Thus, the mean probability of an explosive eruption in the next 50 years at Sete Cidades is 17%, at Fogo is 5%, and at Furnas is 13%.

The equivalent number of data Λ was computed by means of equation 23, in which V (variance) is the square of the standard deviation among the probabilities of eruption in 50 years computed for the 1000 synthetic catalogues (see Table 2.4 in Chapter 2). The result is $\Lambda_1 = 37$, 17, and 16, for Sete Cidades (T case), Fogo (T case) and Furnas (T case), respectively.

Node 4: vent location

This node gives information about the spatial probability of vent opening, i.e, if an eruptive vent will open in a specific location (I_4), assuming that an eruption will occur. In this node there are several possible vent locations, meaning that there are I_4 possible and mutually exclusive outcomes. In node 4, the model for prior probabilities for I_4 vent locations is set by a Dirichlet distribution (see Marzocchi et al., 2008; Marzocchi et al., 2010):

$$[\theta_4]_{prior} = Di_{I_4}(\alpha_4^{(1)}, \dots, \alpha_4^{(I_4)}) \quad \text{Eq. 33}$$

where $\alpha_4^{(i)}$ are obtained by inverting the following equations, starting from the average probabilities $\Theta_4^{(i)}$ ($i=1, \dots, I_4$) and equivalent number of data Λ_4 :

$$\begin{aligned} \theta_4^i &= \frac{\alpha_4^i}{\sum_{i=1}^{I_4} \alpha_4^i} \\ \Lambda_4 &= \sum_{i=1}^{I_4} \alpha_4^i - I_4 + 1 \end{aligned} \quad \text{Eq. 34}$$

The prior distribution is updated using the past data through:

$$[\theta_4] = [\theta_4 \vee y_4] = Di_{I_4}(\alpha_4^{(1)} + y_4^{(1)}, \dots, \alpha_4^{(I_4)} + y_4^{(I_4)}) \quad \text{Eq. 35}$$

where the number of past eruptions in vent location i is expressed by $y_4^{(i)}$.

The prior spatial probability of vent opening θ_4^i in each vent location i ($i=1, \dots, I_4$), was estimated in Chapter 3. However, for computational reasons, the initial grid 50×50 m used to estimate the spatial density was downgraded to a grid of 500×500 m cell size; in each new larger grid cell, the prior probability was set as the sum of the probabilities of the 50-m grid's cells belonging to it. (Appendix A.4). A total of 783 grid cells (of 500 m step) were considered for Sete Cidades Volcano, 952 for Fogo Volcano, and 770 for Furnas Volcano. The equivalent number of data was set to $\Lambda_4 = 1$ as maximum ignorance. To avoid data repetition, the number of eruptions in each vent location was not accounted at this node.

Node 5: Eruption size/style

This node is related to the probability of an eruption size or type (J_5), conditional on the occurrence of an eruption at a specific location. The prior distribution for size class at the i -th vent is given by:

$$[\theta_{5;i}]_{prior} = Di_{J_5}(\alpha_{5;i}^{(1)}, \dots, \alpha_{5;i}^{(J_5)}) \quad \text{Eq. 36}$$

Where each $\alpha_{5;i}^{(j)}$ is estimated through the mean θ_5 and equivalent number of data Λ_5 formulas, as observed for node 4.

The prior distribution is updated into the posterior distribution using the past data and the following equation (Marzocchi et al., 2010):

$$[\theta_{5;i}] = [\theta_{5;i} \vee y_{5;i}] = Di_{J_5}(\alpha_{5;i}^{(1)} + y_{5;i}^{(1)}, \dots, \alpha_{5;i}^{(J_5)} + y_{5;i}^{(J_5)}) \quad \text{Eq. 37}$$

here, $y_{5;i}^{(j)}$ denotes the number of past eruptions of a specific size class (j) located in vent (i).

The following table (Table 4.2) summarizes the input parameters used to complete node 5 in each analysis. For all three volcanoes, the probability distribution of the sizes is not spatially dependent (i.e., it is equal for all possible vent positions).

For Sete Cidades, two eruption sizes were considered, a VEI 3 and VEI 4 events, while for Fogo and Furnas, three sizes were considered, a VEI 3, a VEI 4, and a VEI 5 event. The probabilities of each size were achieved in a form of relative frequencies of occurrence (between 0 and 1). For this node, the equivalent number of data was set $\Lambda_5 = 1$.

Table 4. 2. Relative frequencies of the occurrence of eruptions of a given size.

	Probability VEI 3	VEI 3 past data	Probability VEI 4	VEI 4 past data	Probability VEI 5	VEI 5 past data
Sete Cidades	0.5	8	0.5	8	-	-
Fogo	0.56	9	0.31	5	0.13	2
Furnas	0.6	15	0.36	9	0.04	1

Node 6: generated hazards

At node 6, the probability that a specific hazardous phenomena will be generated conditional to the occurrence of an eruption of a specific size/type is set. This node only has two possible outcomes “*generation*” or “*no generation*” The prior distribution and their parameters are estimated as for node 1-2-3, following:

$$\left[\theta_{6;j}^{(p)}\right]_{prior} = Beta\left(\alpha_{6;j}^{(p)}, \beta_{6;j}^{(p)}\right) \quad \text{Eq. 38}$$

Similar to the previous nodes, $\alpha_{6;j}^{(p)}$ and $\beta_{6;j}^{(p)}$ are estimated from the mean $\theta_{6;j}$ and equivalent number of data $\Lambda_{6;j}$.

In this node, past data refines prior probabilities into a posterior using the following formula:

$$\left[\theta_{6;j}^{(p)}\right] = \left[\theta_{6;j}^{(p)} \vee y_{6;j}^{(p)}\right] = Beta\left(\alpha_{6;j}^{(p)} + y_{6;j}^{(p)}, \beta_{6;j}^{(p)} + n_{6;j} - y_{6;j}^{(p)}\right) \quad \text{Eq. 39}$$

Where $y_{6;j}$ is the number of times that the phenomenon was generated out of $n_{6;j}$ eruptions of size j .

As hazardous phenomena, only tephra fall was considered to perform this analysis. At node 6, the equivalent number of data was set $\Lambda_6 = 1$.

Node 7: hazard reaching areas

At this node, the probability of a specific area (k) being reached given the occurrence of a hazardous phenomena (p) during an eruption of a specific size class (j) in a specific vent location (i) is assessed. Here, there are only two possible outcomes: *the area k is reached or is not reached* by a hazardous phenomenon. Prior and posterior probabilities are estimated through, respectively (Marzocchi et al., 2008; Marzocchi et al., 2010):

$$\left[\theta_{7;i,j,p}^{(k)}\right]_{prior} = Beta\left(\alpha_{7;i,j,p}^{(k)}, \beta_{7;i,j,p}^{(k)}\right) \quad \text{Eq. 40}$$

$$\left[\theta_{7;i,j,p}^{(k)}\right] = \left[\theta_{7;i,j,p}^{(k)} \vee y_{7;i,j,p}^{(k)}\right] = Beta\left(\alpha_{7;i,j,p}^{(k)} + y_{7;i,j,p}^{(k)}, \beta_{7;i,j,p}^{(k)} + n_{7;i,j,p} - y_{7;i,j,p}^{(k)}\right) \quad \text{Eq. 41}$$

where $n_{7;i,j,p}$ denotes the number of past eruptions of size i and from vent i that generated the phenomenon p , and $y_{7;i,j,p}$ is the number of such eruptions that reached the area k .

To implement node 7, a cell size grid of 500×500 m was created covering São Miguel Island (Appendix A.5). In total, 2984 possible areas were obtained. For this node, an equivalent number of data was set $\Lambda_7 = 10$.

Node 8: hazard reaching threshold

This node gives the exceedance probability of a specific intensity threshold (s) given that a selected area is reached by a hazardous phenomenon produced by an eruption of a size class in a specific location. In this case, only two outcomes are possible: *the selected threshold is overcome or not*. The prior and posterior probabilities in Node 8 are achieved using the same equations as in node 7 (See Marzocchi et al., 2008; Marzocchi et al., 2010). Thus, the probabilities are obtained using, respectively:

$$\left[\theta_{8;i,j,p,k}^{(s)}\right]_{prior} = Beta\left(\alpha_{8;i,j,p,k}^{(s)}, \beta_{8;i,j,p,k}^{(s)}\right) \quad \text{Eq. 42}$$

$$\left[\theta_{8;i,j,p,k}^{(s)}\right] = \left[\theta_{8;i,j,p,k}^{(s)} \vee y_{8;i,j,p,k}^{(s)}\right] = Beta\left(\alpha_{8;i,j,p,k}^{(s)} + y_{8;i,j,p,k}^{(s)}, \beta_{8;i,j,p,k}^{(s)} + n_{8;i,j,p,k} - y_{8;i,j,p,k}^{(s)}\right) \quad \text{Eq. 43}$$

For this analysis, 9 intensity thresholds for tephra load were considered, such as 1, 10, 50, 100, 200, 300, 400, 500, and 1000 kg/m², and the equivalent number of data was set $\Lambda_8 = 10$.

Figures 4.2, 4.3, and 4.4 illustrates the general configuration of the BETs produced for each volcano.

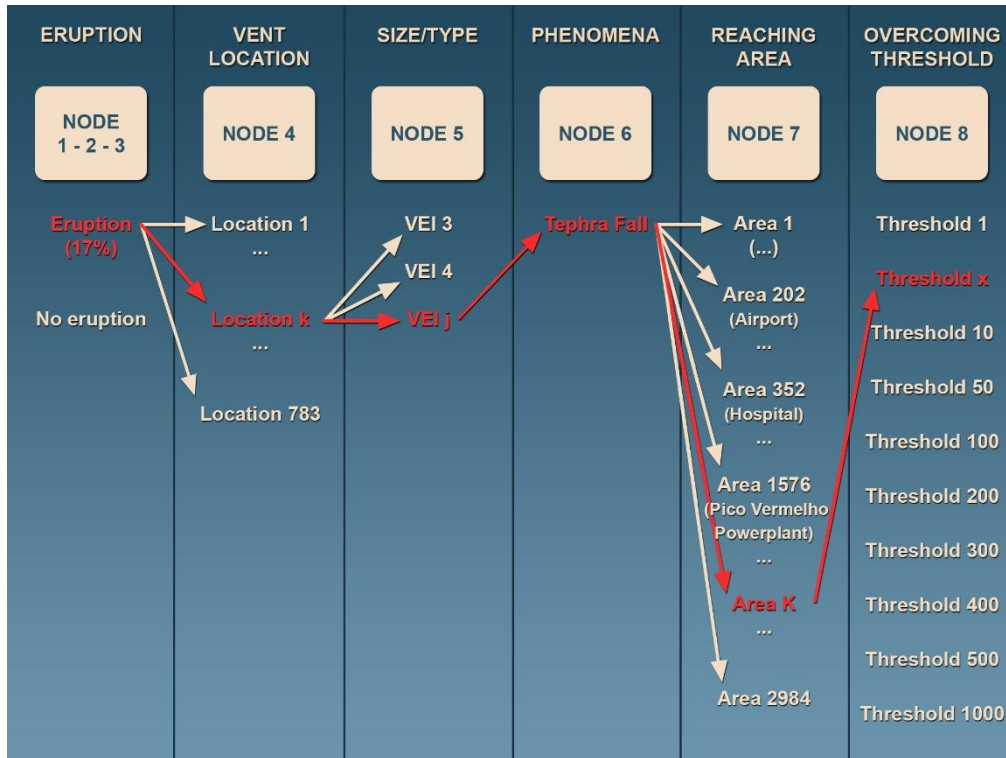


Figure 4. 2. Bayesian Event Tree produced for Sete Cidades Volcano.

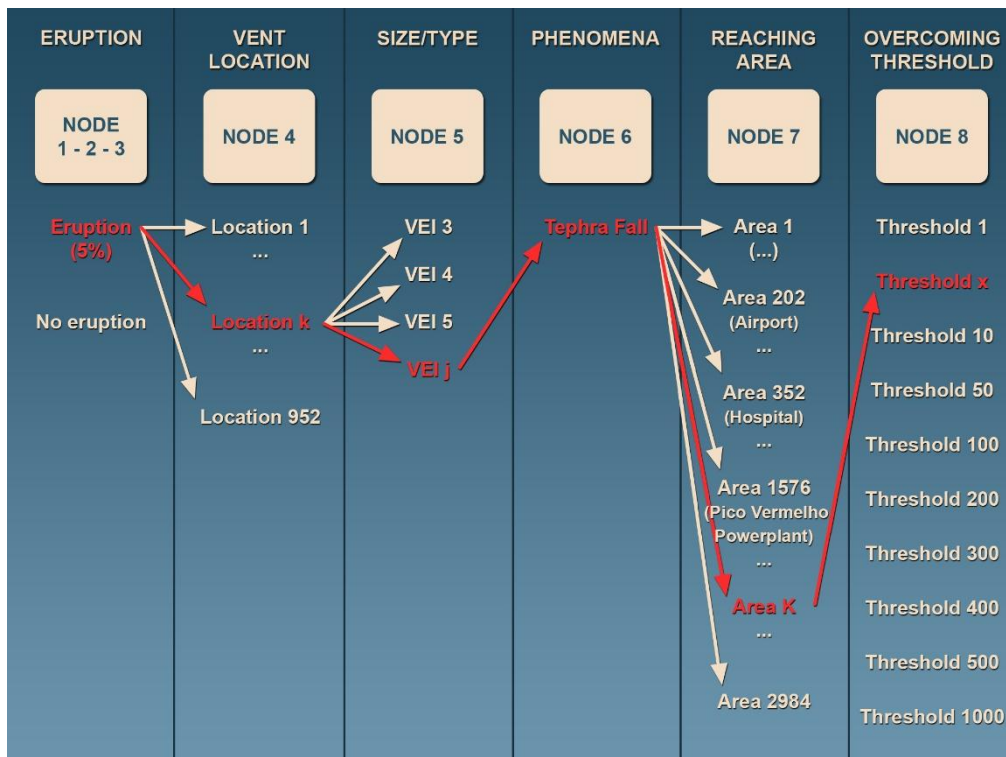


Figure 4. 3. Bayesian Event Tree produced for Fogo Volcano.

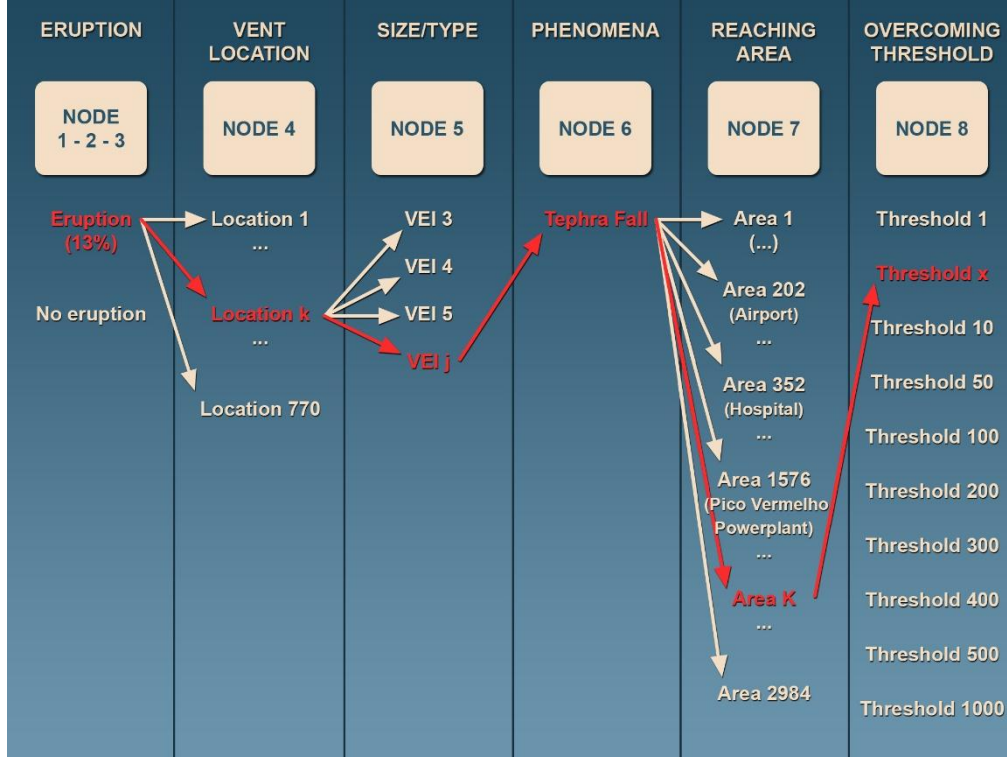


Figure 4. 4. Bayesian Event Tree produced for Furnas Volcano.

4.2.5. Long-term Probabilistic Volcanic Hazard Assessment analysis

Integration of simulation outputs

To perform a complete long-term PVHA, the analysis requires the integration of simulation outputs from tephra fall models into the BETs. HAZMAP outputs were incorporated into the analysis by converting them into parameters, i.e., average (θ_m) and equivalent number of data (Λ_m), for prior probability distributions at nodes 7 and 8. Thus, the average and the equivalent number of data at nodes 7 and 8 were achieved using, respectively (Selva et al., 2010):

$$\theta_{7,i,j}^{(k)} = \frac{\bar{\alpha}_{7,i,j}^{(k)}}{\bar{\alpha}_{7,i,j}^{(k)} + \bar{\beta}_{7,i,j}^{(k)}} \left\{ \frac{\bar{\alpha}_{7,i,j}^{(k)} + \bar{\beta}_{7,i,j}^{(k)}}{\bar{\alpha}_{7,i,j}^{(k)} + \bar{\beta}_{7,i,j}^{(k)} + \Lambda_m} \right\} + \frac{v_{7,i,j}^{(k)}}{N_r} \left\{ \frac{\Lambda_m}{\bar{\alpha}_{7,i,j}^{(k)} + \bar{\beta}_{7,i,j}^{(k)} + \Lambda_m} \right\} \quad \text{Eq. 44}$$

$$\Lambda_{7,i,j}^{(k)} = \bar{\alpha}_{7,i,j}^{(k)} + \bar{\beta}_{7,i,j}^{(k)} - 1 + \Lambda_m \quad \text{Eq. 45}$$

and for Node 8 are (Selva et al., 2010):

$$\theta_{8;i,j,k}^{(s)} = \frac{\bar{\alpha}_{8;i,j,k}^{(s)}}{\bar{\alpha}_{8;i,j,k}^{(s)} + \bar{\beta}_{8;i,j,k}^{(s)}} \left\{ \frac{\bar{\alpha}_{8;i,j,k}^{(s)} + \bar{\beta}_{8;i,j,k}^{(s)}}{\bar{\alpha}_{8;i,j,k}^{(s)} + \bar{\beta}_{8;i,j,k}^{(s)} + \Lambda_m} \right\} + \frac{v_{8;i,j,k}^{(s)}}{v_{7;i,j}^{(k)}} \left\{ \frac{\Lambda_m}{\bar{\alpha}_{8;i,j,k}^{(s)} + \bar{\beta}_{8;i,j,k}^{(s)} + \Lambda_m} \right\} \quad \text{Eq. 46}$$

$$\Lambda_{8;i,j,k}^{(s)} = \bar{\alpha}_{8;i,j,k}^{(s)} + \bar{\beta}_{8;i,j,k}^{(s)} - 1 + \Lambda_m \quad \text{Eq. 47}$$

where $\bar{\alpha}_{7;i,j}^{(k)}$, $\bar{\beta}_{7;i,j}^{(k)}$, $\bar{\alpha}_{8;i,j,k}^{(s)}$, $\bar{\beta}_{8;i,j,k}^{(s)}$ are the hyper-prior parameters related to the Beta distribution at Nodes 7 and 8, N_r is the number of model runs, $v_{7;i,j}^{(k)}$ is the number of reaching episodes out of the N_r , $v_{8;i,j,k}^{(s)}$ is the number of overcoming episodes out of the N_r , and Λ_m is the equivalent number of data related to the model (See Selva et al., 2010 for details).

For this analysis, hyper-prior parameters were used to avoid strictly-zero probabilities for areas not reached by simulations, replacing zero probabilities with very low probabilities. To do so, hyper-prior parameters were set =1 for both nodes 7 and 8, representing a uniform distribution as the least informative starting hypothesis, that was then updated according to the results of HAZMAP simulations. The number of HAZMAP runs for different eruption settings (scenarios) was set into 1000, i.e, $N_r = 1000$, and the equivalent number of data was set $\Lambda_m=10$ for nodes 7 and 8.

Combining probabilities to complete the PVHA

The probabilities at each node of the BET are conditional on the selection of a specific path, and they can be obtained for a single eruptive setting or for a combination of them. To types of probabilities were computed, absolute and conditional.

Absolute probabilities were obtained by multiplying the probabilities along the selected path. Therefore, the long-term absolute probability $[\Phi_a]$ on an area (k) being reached by a hazardous

phenomenon (p) exceeding a selected threshold (s), resulting from the combination of different eruptive settings, in the next 50 years, is given by (Marzocchi et al., 2010):

$$[\Phi_a] = [\theta_{1-2-3}] \sum_{i \in \tilde{I}} \left([\theta_4^{(i)}] \sum_{j \in I} [\theta_{5,i}^{(j)}] [\theta_{6,j}^{(p)}] [\theta_{7,i,j,p}^{(k)}] [\theta_{8,i,j,p,k}^{(s)}] \right) \quad \text{Eq. 48}$$

Conditional probabilities were obtained from conditional probability distributions at each node. Thus, for node 5, the conditional probability of an eruption of size j occurs in a location belonging to the set $\tilde{I}$, given an eruption $[\Phi_b]$, is defined by:

$$[\Phi_b] = \frac{\sum_{i \in \tilde{I}} ([\theta_4^{(i)}] [\theta_{5,i}^{(j)}])}{\sum_{i \in \tilde{I}} [\theta_4^{(i)}]} \quad \text{Eq. 49}$$

In this way, as for nodes 6, 7, and 8 are conditioned to the eruptive setting, the eruptive setting probability $[\Phi_{ES}]$, assuming an eruption occurs, is expressed as (See Marzocchi et al., 2010 for details):

$$[\Phi_{ES}] \equiv [\theta_{\{i \in \tilde{I}, j \in I\}}] = \sum_{i \in \tilde{I}} \left([\theta_4^{(i)}] \sum_{j \in I} [\theta_{5,i}^{(j)}] \right) \quad \text{Eq. 50}$$

With this assumption, the conditional probabilities at nodes 6 $[\Phi_c]$, 7 $[\Phi_d]$, and 8 $[\Phi_e]$, are then defined, respectively, as:

$$[\Phi_c] = \frac{\sum_{i \in \tilde{I}} ([\theta_4^{(i)}] \sum_{j \in I} [\theta_{5,i}^{(j)}] [\theta_{6,j}^{(p)}])}{\Phi_{ES}} \quad \text{Eq. 51}$$

$$[\Phi_d] = \frac{\sum_{i \in \tilde{I}} ([\theta_4^{(i)}] \sum_{j \in I} [\theta_{5,i}^{(j)}] [\theta_{6,j}^{(p)}] [\theta_{7,i,j,p}^{(k)}])}{\Phi_{ES}} \quad \text{Eq. 52}$$

$$[\Phi_e] = \frac{\sum_{i \in \tilde{I}} ([\theta_4^{(i)}] \sum_{j \in I} [\theta_{5,i}^{(j)}] [\theta_{6,j}^{(p)}] [\theta_{7,i,j,p}^{(k)}] [\theta_{8,i,j,p,k}^{(s)}])}{\Phi_{ES}} \quad \text{Eq. 53}$$

The conditional probabilities for each possible eruption scenario (each vent location with size class j) were then summed, weighting them to their respective probabilities. Therefore, the averaged conditional probability reflects the exceeding probability of a specific threshold in area

k, given an eruption of a specific size class from any potential vent location. For the present case conditional probabilities were obtained for a VEI 4 event and considering all possible vent locations at each volcanic system, assuming that an eruption occurs.

Hazard Curves, Probability maps and Hazard maps

Hazard curves, probability maps and hazard maps are the main outcomes of a PVHA analysis. Hazard curves (θ) are the representation of the probability that an intensity measure (X) exceeds a specific threshold (x) in a target area ($\vec{a}$), at least once in the time window ΔT (e.g. Marzocchi et al., 2008; Marzocchi et al., 2010; Selva et al., 2014; Thompson et al., 2015; Martinez-Montesinhos et al., 2022). They are, in fact, a survivor function that describe the aleatory uncertainty. In this context, hazard curves are expressed as:

$$\theta^{(h,\vec{a},\Delta T)}(x) = P^{(h,\vec{a},\Delta T)}(X \geq x) \quad \text{Eq. 54}$$

The contributions of different eruptive scenarios are accounted to generate hazard curves using:

$$\theta^{(h,\vec{a},\Delta T)}(x) = P(\Delta T, E) \int_{\Omega} P(vs \vee E) P^{(h,\vec{a},\Delta T)}(X \geq x \vee vs) dvs \quad \text{Eq. 55}$$

$$\approx P(\Delta T, E) \sum_i^N [P(VS_i \vee E) P^{(h,\vec{a},\Delta T)}(X \geq x \vee VS_i)] \quad \text{Eq. 56}$$

where intensity measures are expressed as X , h denotes the hazardous phenomena, intensity values or thresholds are expressed as x , the target area is $\vec{a}$, ΔT is the time window, E is the event eruption, vs represents the possible volcanic scenarios, and Ω represents the infinite set of possible sources.

Absolute hazard curves, and hazard curves conditional to a VEI 4 eruption, the most probable scenario and common among the three volcanoes, were generated for each volcano for three target

areas (locations), such as the Ponta Delgada airport, the Divino Espirito Santo hospital, and Pico Vermelho geothermal powerplant as they constitute main infrastructures in the island. In this context, the exceedance probability for specific thresholds was analysed for each infrastructure, such as the exceedance probability of 1 kg/m^2 at the airport, 400 kg/m^2 at the hospital area, and 10 kg/m^2 at Pico Vermelho geothermal powerplant (See Wilson et al., 2012 and Wilson et al., 2014 for details).

From hazard curves, absolute (50-year forecast) and conditional (to a VEI 4 event) probability maps were generated for São Miguel Island considering the occurrence of eruptions at each volcanic system and the three intensity thresholds mentioned above (1 , 10 and 400 kg/m^2) (e.g. Wilson et al., 2012; Wilson et al., 2014). For each threshold, exceedance probability maps were computed considering, for each case, the 5th, 50th, and 95th percentiles.

For the whole island, absolute hazard maps and hazard maps conditional to a VEI 4 eruption were also constructed, assuming eruptions in each volcano separately, at 5% exceedance probability. Each hazard curve, probability and hazard maps were generated for all three volcanoes separately.

Absolute probability maps for São Miguel were also computed by combining the PVHA results from all three volcanoes. In this case, eruptions from all three volcanoes were used and all intensity thresholds were considered, such as 1 , 10 , 50 , 100 , 200 , 300 , 400 , 500 , and 1000 kg/m^2 .

4.3. Long-term Probabilistic Volcanic Hazard Assessment results

4.3.1. Tephra fall numerical simulations

Numerical simulations were conducted for each volcano considering different eruption sizes. Each scenario incorporated its own eruption source parameters. For Sete Cidades, simulations were performed for a VEI 3 and VEI 4 scenarios, while for Fogo and Furnas VEI 3, VEI 4, and a VEI 5 scenarios were considered. The simulations with HAZMAP were post-processed to achieve exceedance probabilities for each threshold (1 , 10 , 50 , 100 , 200 , 300 , 400 , 500 , and 1000 kg/m^2),

conditional to specific eruption sizes, and considering all possible vent locations at each volcanic system.

To illustrate the results of simulations, here are present, as examples, the maps showing the exceedance probability for 1, 10, and 400 kg/m² of tephra ground load on São Miguel Island, for each eruptive size and considering only one vent location at each volcano. Figures 4.5, 4.6, and 4.7 illustrate the results for VEI 3 (left maps) and VEI 4 (right maps) scenarios at Sete Cidades, Fogo, and Furnas, respectively. Figure 4.8 represents the VEI 5 scenario at Fogo (left maps) and Furnas (right maps). Load thresholds are organized in an ascending order, from the top (A and D) to the bottom (C and D), from 1 to 400 kg/m².

The main differences in exceedance probability maps are strongly guided by the different volcanological inputs used to perform the simulations. For instance, lower eruptive columns (e.g., VEI 3 scenario) limit tephra fallout to areas around the volcanoes, while higher eruptive columns (e.g., VEI 4 and VEI 5 scenarios) determine a wider tephra dispersion and deposition area to distant locations. Moreover, the elliptical pattern in exceedance probability is consistent with the prevailing wind directions in the Azores over the year.

Comparing the exceedance probabilities of each threshold, the maps show that lower load thresholds exhibit a wider spatial distribution with higher exceedance probabilities over a larger area, while higher load thresholds (e.g., 400 kg/m²) are limited essentially near the volcano and, in some cases, there is no location where the load threshold is exceeded with significant probability (e.g. Fig.4.5 C).

By comparing the three volcanoes, the result for each scenario suggests that future eruptions at Fogo Volcano have a largest potential to impact São Miguel overall, due to its location in the central part of the island and its capability to generate VEI 5 eruptions. This is followed by eruptions at Sete Cidades Volcano, which is the westernmost of the three central volcanoes and, thus, tephra is dispersed all through the island due to the prevailing wind directions in the Azores.

Conversely, as Furnas Volcano is the easternmost of the three active central volcanoes, even if this volcano is capable of VEI 5 eruptions, its eruptions seem to have the lower impact in the island, as the dispersion and deposition of tephra are expected to occur, predominantly, toward the eastern end of São Miguel.

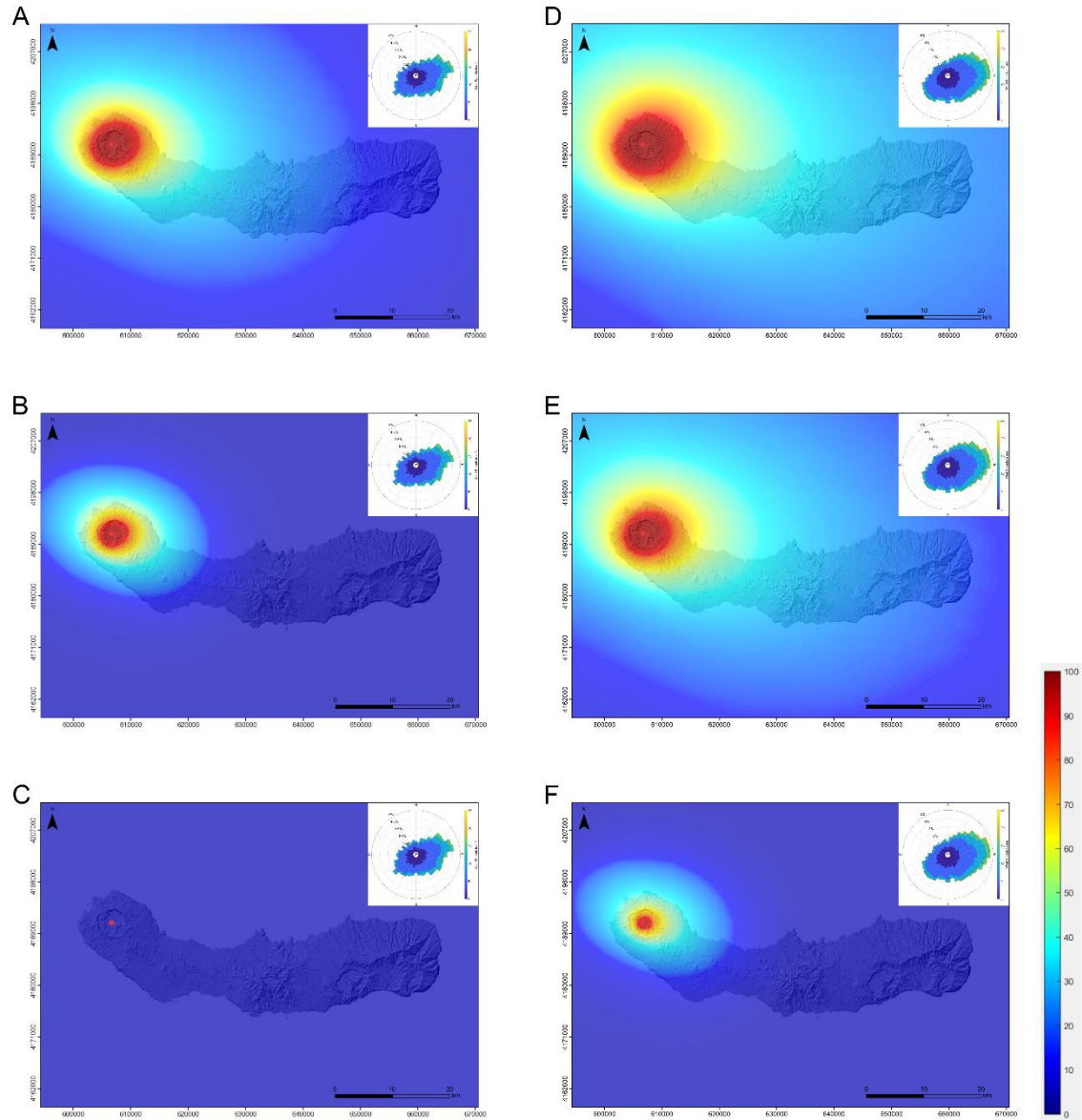


Figure 4. 5. Example of simulation results considering a VEI 3 scenario at a specific vent at Sete Cidades Volcano (left column) showing the exceedance probabilities of different intensity thresholds: A) 1 kg/m², B) 10 kg/m², and C) 400 kg/m². Example of simulation results considering a VEI 4 scenario at a specific vent at Sete Cidades Volcano (right column) showing the exceedance probabilities of different intensity thresholds: A) 1 kg/m², B) 10 kg/m², and C) 400 kg/m².

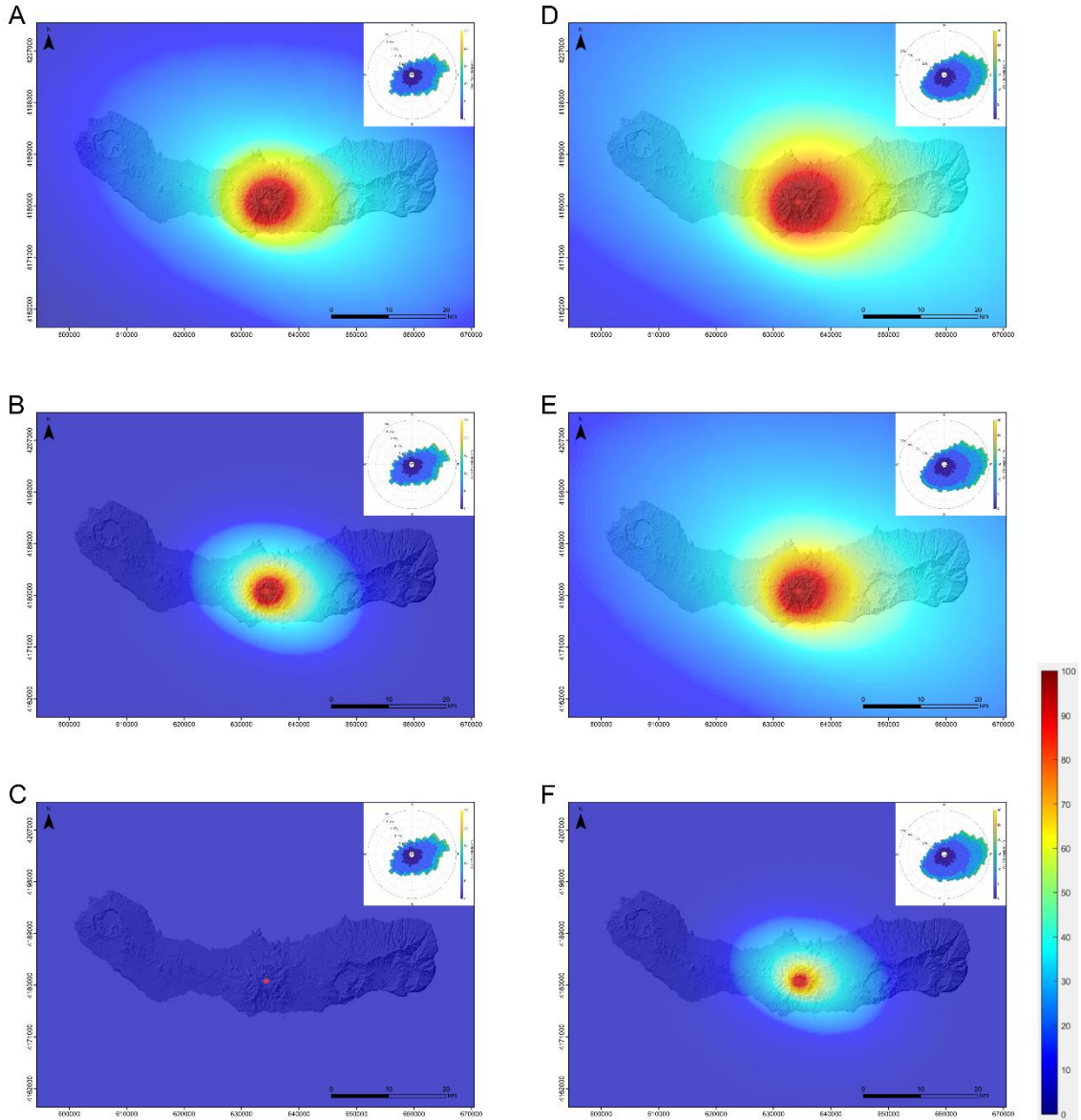


Figure 4. 6. Example of simulation results considering a VEI 3 scenario at a specific vent at Fogo Volcano (left column) showing the exceedance probabilities of different intensity thresholds: A) 1 kg/m², B) 10 kg/m², and C) 400 kg/m². Example of simulation results considering a VEI 4 scenario at a specific vent at Fogo Volcano (right column) showing the exceedance probabilities of different intensity thresholds: A) 1 kg/m², B) 10 kg/m², and C) 400 kg/m².

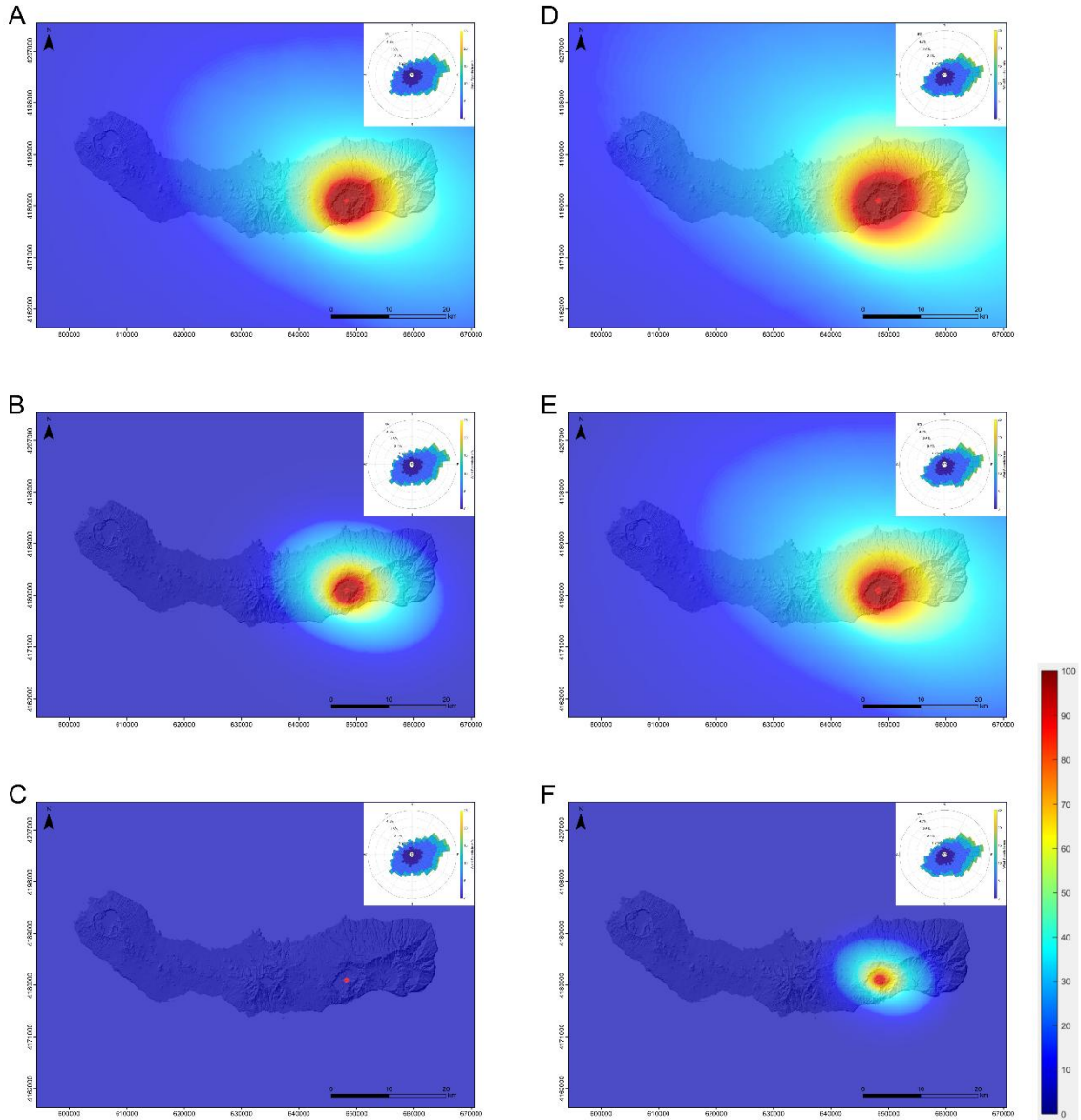


Figure 4. 7. Example of simulation results considering a VEI 3 scenario at a specific vent at Furnas Volcano (left column) showing the exceedance probabilities of different intensity thresholds: A) 1 kg/m², B) 10 kg/m², and C) 400 kg/m². Example of simulation results considering a VEI 4 scenario at a specific vent at Furnas Volcano (right column) showing the exceedance probabilities of different intensity thresholds: A) 1 kg/m², B) 10 kg/m², and C) 400 kg/m².

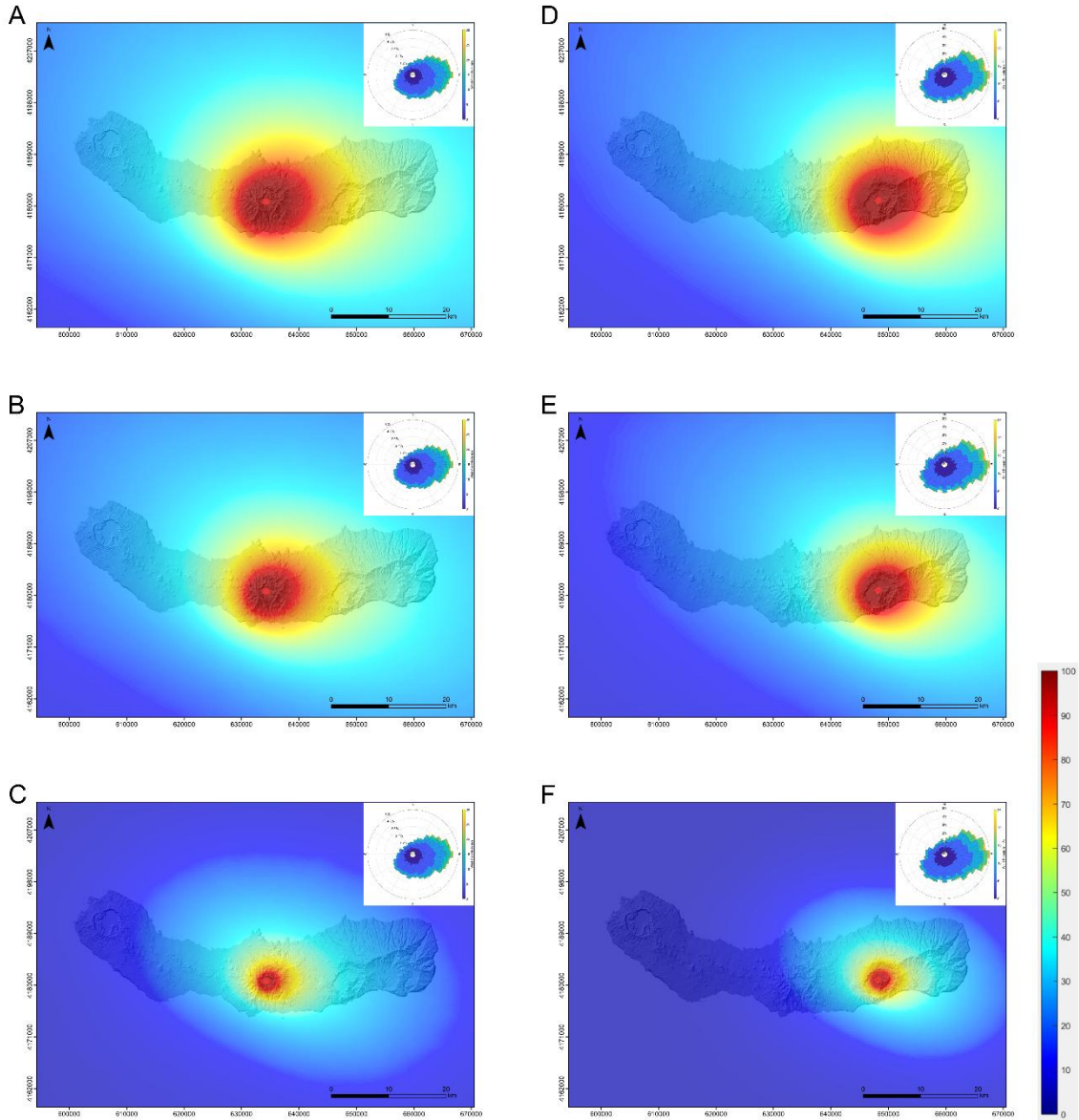


Figure 4. 8. Example of simulation results considering a VEI 5 scenario at a specific vent at Fogo Volcano (left column) showing the exceedance probabilities of different intensity thresholds: A) 1 kg/m², B) 10 kg/m², and C) 400 kg/m². Example of simulation results considering a VEI 5 scenario at a specific vent at Furnas Volcano (right column) showing the exceedance probabilities of different intensity thresholds: A) 1kg/m², B) 10kg/m², and C) 400kg/m².

4.3.2. Probability Maps

The presented probability maps consider the spatial uncertainty on future vent's position by combining the simulations at each vent along with the results of the spatial analysis performed in Chapter 3.

Each panel (from Fig. 4.9 to 4.17) comprises a set of maps illustrating the exceedance probability of specific thresholds (e.g. 1, 10, and 400 kg/m²) (see Appendix A6 for details) .

The maps on the left side depict absolute probabilities, showing the exceedance probability of specific thresholds in the next 50 years, while the maps on the right side show conditional probabilities on the occurrence of a VEI 4 eruption. Each column in the panels contains three maps corresponding to different probability percentiles, i.e., the 5th, 50th, and 95th percentiles. Probability results are shown in a logarithmic scale providing a better detail on the visualization of the variability of probability values, especially for the lower ones.

The 50-year forecast absolute probability that tephra load will exceed 1 kg/m² if an eruption occurs at Sete Cidades Volcano is presented at Figure 4.9A to C. Map A (Fig. 4.9A), representing the 5th percentile, exhibits a distinct west-to-east gradient, ranging from $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$) on the western sector of the island, to $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$) in the east sector. Based on the 50th percentile of exceedance probability map (Fig. 4.9B), there are higher probabilities of exceed 1 kg/m² in the next 50 years in the west sector of São Miguel, with estimated probabilities of $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$), decreasing to the east sector to $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$). The 95th percentile absolute probability map (Fig. 4.9C) obviously displays higher probabilities across the entire island. Higher probabilities of overcoming 1 kg/m² are expected in the west sector of São Miguel ($\log_{10}(P) = -0.8$; $P \cong 16\%$), while lower values are expected in the east half of the island ($\log_{10}(P) = -1$; $P \cong 10\%$).

The conditional probability maps for a VEI 4 eruption at Sete Cidades Volcano (Fig. 4.9E, F, G) demonstrate a more or less uniform pattern across all percentiles, with higher values concentrated in the west half of the island $\log_{10}(P) = 0$ (i.e., $P \cong 100\%$), decreasing to $\log_{10}(P) = -0.5$ (i.e., $P \cong 30\%$) at the east sector of the island.

The maps of absolute probability of exceeding 10 kg/m² if an eruption occurs at Sete Cidades Volcano are shown in Figure 4.10A to C. Analysing the map of the 5th percentile (Fig. 4.10A),

probability values range from $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$), in the western sector near Sete Cidades volcano, to $\log_{10}(P) = -2.5$ (i.e., $P \cong 0.3\%$) from more or less Ribeira Grande municipality to the eastern part of the island. At the 50th percentile absolute probability map (Fig. 4.10B), higher probabilities were obtained as well as for the western sector, with estimated values of $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$), and lower values were achieved to the centre and east sector, with estimated values of about $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$). Map C (Fig. 4.10C) indicates the absolute exceedance probability based on the 95th percentile. Similarly to the previous maps, higher and lower probabilities were obtained for the same sectors mentioned above, respectively. Thus, the higher values (west portion of the island) obtained were $\log_{10}(P) = -0.5$ (i.e., $P \cong 32\%$), and the lower ones (centre and east) were $\log_{10}(P) = -1.8$ (i.e., $P \cong 2\%$).

Regarding conditional probabilities to the occurrence of a VEI 4 eruption (Fig 4.10D to F), maps D, E, and F show homogeneous results between them, all maintaining higher probabilities across most of their extent, however, higher values were estimated for the western sector of São Miguel, with estimated probabilities of $\log_{10}(P) = 0$ (i.e., $P \cong 100\%$), and lower exceedance probabilities were obtained for the eastern edges of the island of about $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$).

Absolute and conditional probability maps of exceeding 400 kg/m^2 (Fig. 4.11.A to F) reveal largest variations in the probability over the island, with a clear west-to-east gradient. Considering the 5th percentile (Fig. 4.11A), the highest exceedance probability is expected mostly in the Sete Cidades caldera, with estimated values of about $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$), while low probabilities are reached only until the central part of the island of $\log_{10}(P) = -6.8$ (i.e., $P \cong 0.00002\%$). At the 50th percentile map (Fig. 4.11B), the highest exceedance probability values are in the western region, of about $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$), and lower values were computed only until Furnas parish, (see Appendix A.7 for parishes location) with expected probabilities of exceeding 400 kg/m^2 of about $\log_{10}(P) = -6.5$ (i.e., $P \cong 0.00003\%$). Based on the 95th percentile of this probability (Fig. 4.11C), highest probabilities are reached in the western region, with

estimated values of $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$), while low values were obtained only at the distance of Furnas parish of about $\log_{10}(P) = -6$ (i.e., $P \cong 0.0001\%$).

Conditional probability maps are similar between them showing, from one to another, a smaller and progressive expansion the red area (Fig. 4.11D, E, F) In this cases, higher probabilities occur, as well, at the west half of the island, reaching $\log_{10}(P) = -0.4$ (i.e., $P \cong 40\%$), and lower values were estimated until Furnas parish of $\log_{10}(P) = 6$ (i.e., $P \cong 0.0001\%$).

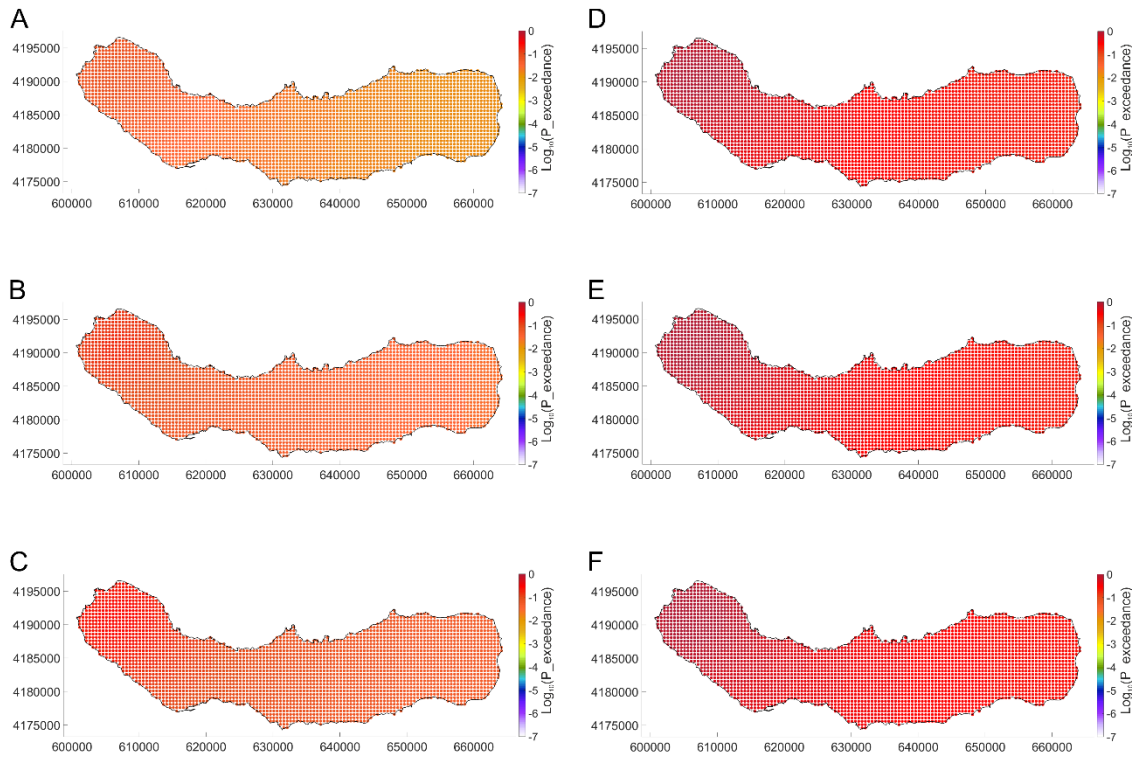


Figure 4. 9. Probability maps obtained considering eruptions of any size at Sete Cidades Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 1 kg/m² in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 1 kg/m², considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

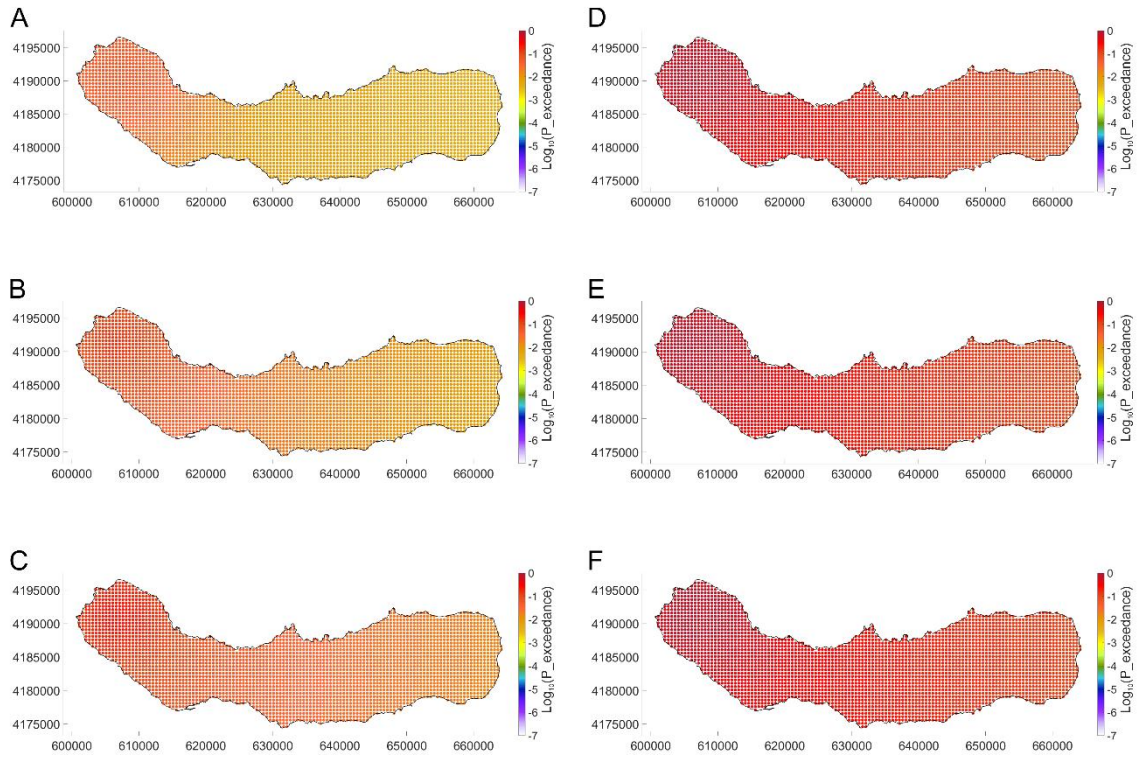


Figure 4. 10. Probability maps obtained considering eruptions of any size at Sete Cidades Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 10 kg/m^2 in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 10 kg/m^2 , considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

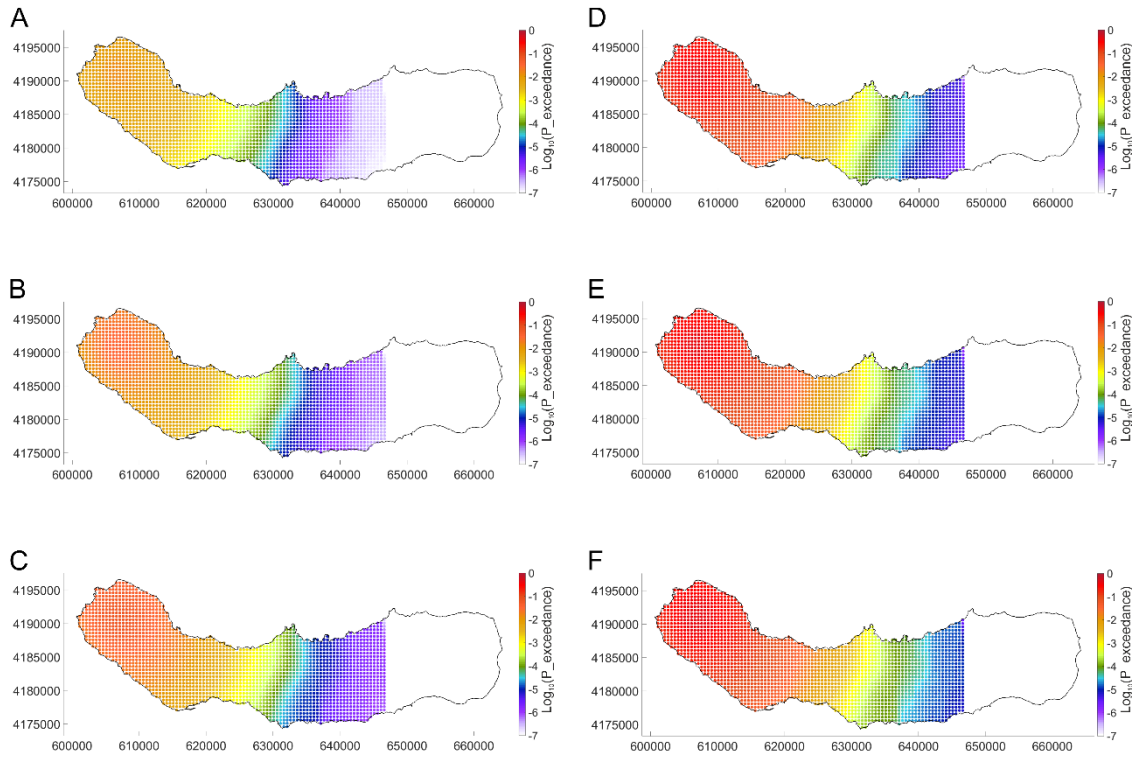


Figure 4. 11. Probability maps obtained considering eruptions of any size at Sete Cidades Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 400 kg/m² in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 400 kg/m², considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

Figures 4.12, 4.13, and 4.14 illustrate the absolute and conditional probabilities of exceeding thresholds of 1, 10, and 400 kg/m² if an eruption occurs at Fogo Volcano.

Based on the 5th percentile map (Fig. 4.12A), the absolute probabilities of exceeding 1 kg/m² range from $\log_{10}(P) = -2.5$ (i.e., $P \cong 0.3\%$), at the central part of the island where Fogo Volcano is located, to $\log_{10}(P) = -3.5$ (i.e., $P \cong 0.03\%$) at the west and east edges of the island. Considering the 50th percentile of this probability (Fig. 4.12B), higher values were estimated in the centre of São Miguel of $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$), and lower values were estimated for the western and eastern ends of the island, with estimated probabilities of $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$). Map C (Fig. 4.12C) illustrates the 95th percentile of this probability. In this case, higher probabilities

are concentrated in the central part of the island, reaching a value of $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$), and lower values are evenly distributed to west and east, where probabilities reach $\log_{10}(P) = -1.2$ (i.e., $P \cong 6\%$).

The estimated probabilities conditional to a VEI 4 eruption based on the three percentiles (Fig. 4.12D, E, F) are similar. Facing this type of eruption scenario, there is a high probability of 1 kg/m² be exceeded over all island, with estimated probabilities ranging from $\log_{10}(P) = 0$ (i.e., $P \cong 100\%$) in the central part of the island to $\log_{10}(P) = -0.4$ (i.e., $P \cong 40\%$) at the extremes west and east.

The 5th percentile map of the absolute exceedance probability of 10 kg/m² (Fig. 4.13A), show that probabilities range from $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$) at the central part of the island to $\log_{10}(P) = -3.7$ (i.e., $P \cong 0.02\%$) at the west and east sector of the island. Figure 4.13B illustrates the 50th percentile of the absolute probability of exceeding 10 kg/m², where higher probabilities are concentrated in the centre of the island, reaching a probability of $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$) to $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$) at the western and east sectors of São Miguel. The 95th percentile map (Fig. 4.13C) show, once again, higher probabilities in the central part of São Miguel, reaching $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$), and lower probabilities distributed towards west and east, with values around $\log_{10}(P) = -1.8$ (i.e., $P \cong 2\%$).

Conditional probability maps of exceedance probability of 10 kg/m² regarding a VEI 4 eruption at Fogo Volcano (Fig. 4.13D, E, F) show similarities. Under this eruption scenario, it is expected that this threshold will be overcome in the entire island. In this case, there is a $\log_{10}(P) = 0$ (i.e., $P \cong 100\%$) probability of exceed the intensity threshold in the central part of the island, an exceedance probability of $\log_{10}(P) = -0.8$ (i.e., $P \cong 16\%$) at the west sector, and an exceedance probability of $\log_{10}(P) = -0.3$ (i.e., $P \cong 50\%$) at the east end.

Analysing the 5th percentile map of the absolute exceedance probability for the threshold 400 kg/m² (Fig. 4.14A), estimated exceedance probabilities ranged from $\log_{10}(P) = -3.5$ (i.e., $P \cong$

0.03%), at the centre of the island to $\log_{10}(P) = -5$ (i.e., $P \cong 0.001\%$) at the east and west ends. Map B (Fig. 4.14B) show the 50th percentile of this probability, revealing higher probabilities of exceeding 400 kg/m² in the central part of the island, such as $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$), especially in Fogo Volcano area, and lower probabilities, such as $\log_{10}(P) = -4$ (i.e., $P \cong 0.01\%$), distributed to the west (largest area of low probabilities) and to the east. In the 95th percentile map (Fig. 4.14C), the central part of São Miguel continues to exhibit the highest probabilities ($\log_{10}(P) = -1.5$; $P \cong 3\%$), decreasing towards west and east to $\log_{10}(P) = -3$ (i.e., $P \cong 0.1\%$).

Obtained conditional probability maps (Fig. 4.14D, E, F) show a similar pattern between them. Based on these maps, 400 kg/m² has higher probabilities ($\log_{10}(P) = -0.8$; $P \cong 16\%$) to be overcome in a large area of the central part of São Miguel, Ponta Delgada to Furnas parishes, decreasing to $\log_{10}(P) = -4$ (i.e., $P \cong 0.01\%$) towards the edges of São Miguel.

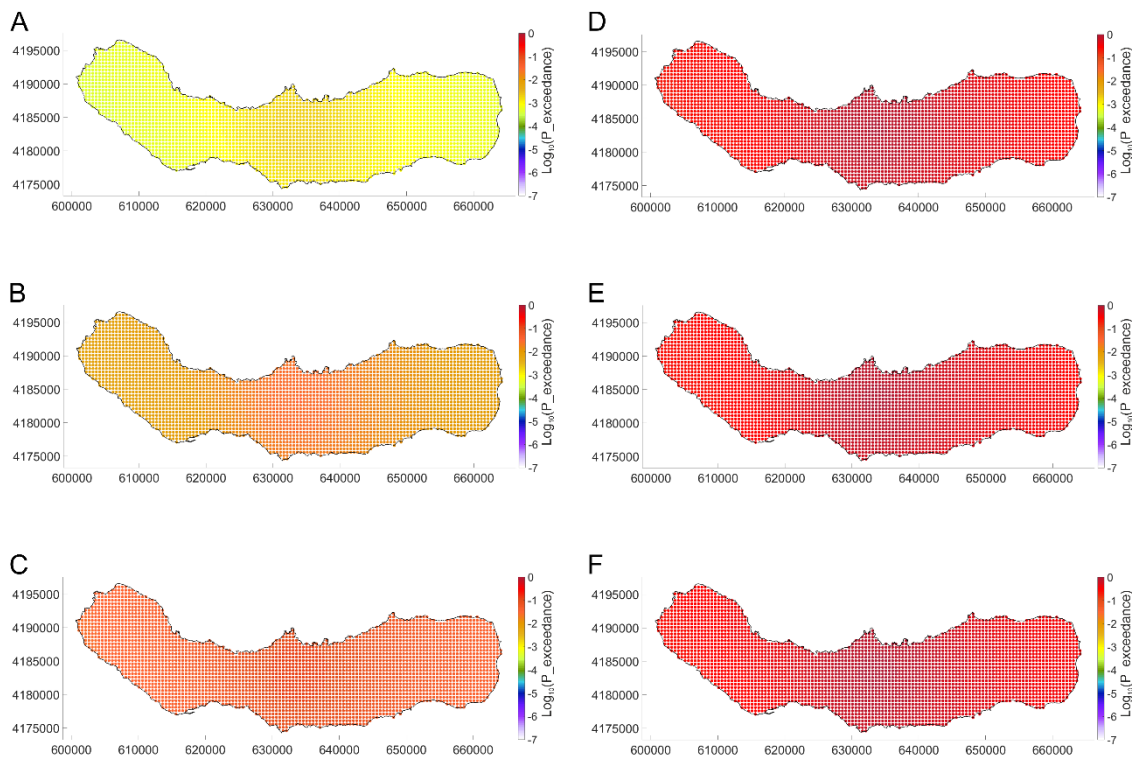


Figure 4. 12. Probability maps obtained considering eruptions of any size at Fogo Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 1 kg/m² in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps

showing exceedance probabilities of overcoming 1 kg/m^2 , considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

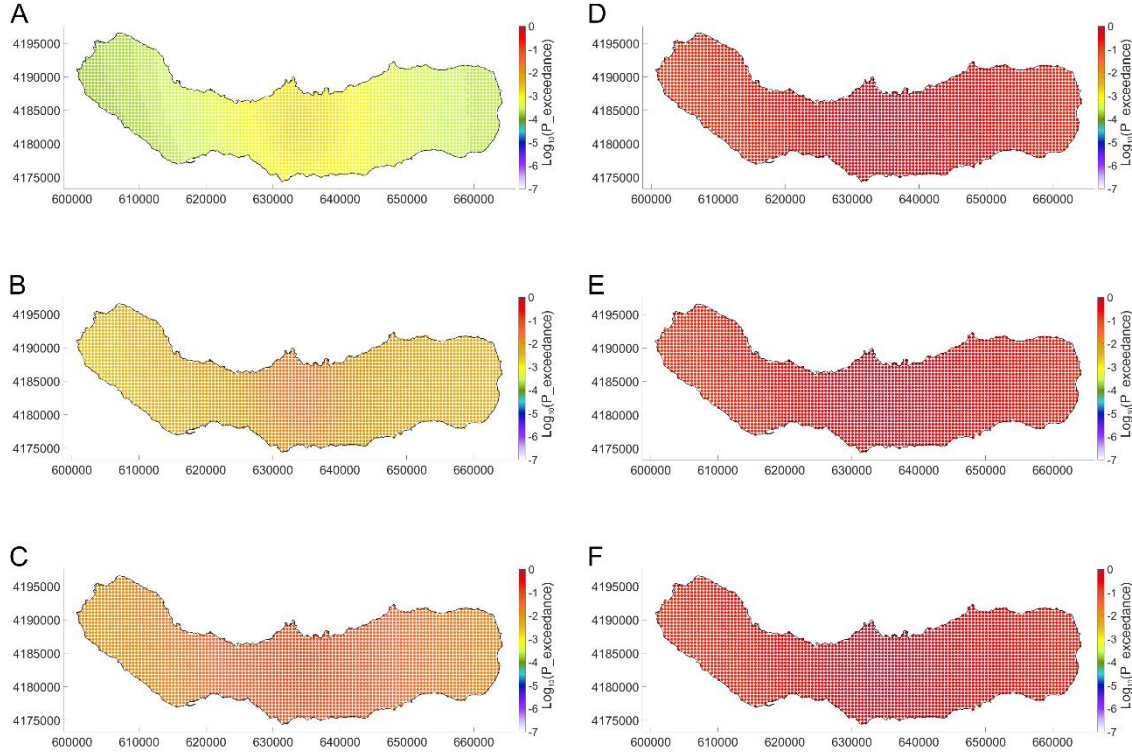


Figure 4. 13. Probability maps obtained considering eruptions of any size at Fogo Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 10 kg/m^2 in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 10 kg/m^2 , considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

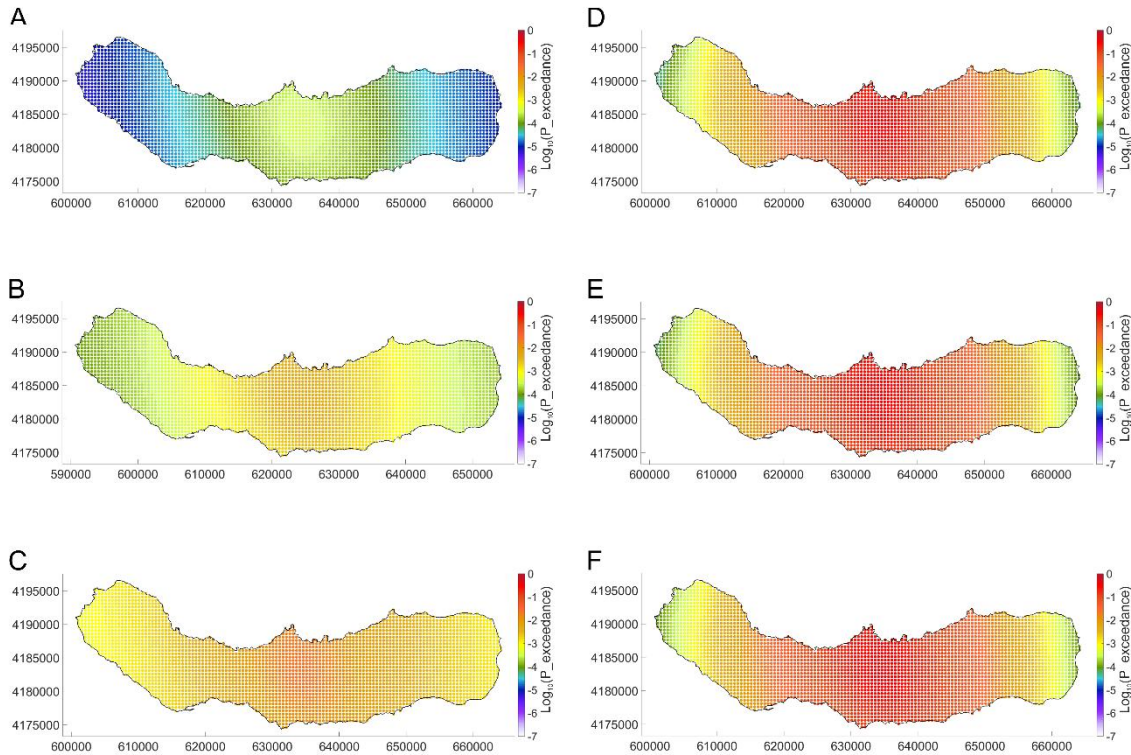


Figure 4. 14. Probability maps obtained considering eruptions of any size at Fogo Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 400 kg/m² in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 400 kg/m², considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

The following probability maps in Figures 4.15, 4.16, and 4.17 illustrate the estimated absolute (50-year forecast) and conditional probabilities conditional to a VEI 4 eruption of exceeding 1, 10, and 400 kg/m² of tephra load, respectively, if an eruption took place at Furnas Volcano.

Analysing the results for the first threshold (1 kg/m²), at the 5th percentile absolute probability map (Fig. 4.15A), estimated probabilities range from $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$) (approximately at Furnas caldera) to $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$), with lower values to the west. Map B corresponds to the 50th percentile of the absolute probability (Fig. 4.15B) and shows an increase at the estimated probabilities. In this case, probabilities vary from $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$), at caldera area, to $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$) at the western (lower probabilities) and

east edges. Higher probabilities are represented at the 95th percentile map (Fig. 4.15C). Based on this map, 1 kg/m² will be exceeded in almost all over the island, reaching a maximum exceedance probability of $\log_{10}(P) = -0.5$ (i.e., $P \cong 32\%$) in Furnas location and neighbouring areas and a minimum exceedance probability of $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$) in the west half of São Miguel.

Conditional probability maps to a VEI 4 eruption at Furnas suggests that 1 kg/m² has a very high probability to be overcome if this scenario occurs, with a maximum exceedance probability of $\log_{10}(P) = 0$ (i.e., $P \cong 100\%$) at Furnas location and neighbouring areas, decreasing towards west to $\log_{10}(P) = -0.8$ (i.e., $P \cong 16\%$) (Fig. 4.15D, E, F).

For the 10 kg/m² threshold, the 5th percentile absolute probability map (Fig. 4.16A) indicates, as for previous threshold, low exceedance probabilities, especially at the western region of the island. In this case, estimated probabilities ranges from $\log_{10}(P) = -1.5$ (i.e., $P \cong 10\%$) to $\log_{10}(P) = -3$ (i.e., $P \cong 0.1\%$), indicating a very low possibility of this threshold be overcome in the next 50 years. Based on the 50th percentile map of the same probability (Fig. 4.16B), there is an increase in the estimated exceedance probability, varying from $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$) in Furnas region to $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$) at island's edges, where lowest probabilities are expected at the west sector. The 95th percentile of the exceedance probability (Fig. 4.16C) suggests a $\log_{10}(P) = -0.5$ (i.e., $P \cong 32\%$) probability of this threshold be overcome in the next 50 years in Furnas region, while lower exceedance values are expected at the western side of the island, with estimated probabilities of $\log_{10}(P) = -1.8$ (i.e., $P \cong 2\%$).

Conditional probability maps for a VEI 4 eruption (Fig. 4.16D, E, F) suggests a similar pattern in the distribution of the estimated exceedance probabilities at each percentile. Based on this scenario and percentiles, 10 kg/m² has $\log_{10}(P) = 0$ (i.e., $P \cong 100\%$) probability of being overcome in Furnas location, decreasing westward to $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$).

The 5th percentile map (Fig. 4.17A) of the exceedance probability of 400 kg/m² of tephra load in the next 50 years (absolute probability) exhibit higher probabilities at the eastern end of de island

($\log_{10}(P) = -2$ (i.e., $P \cong 1\%$), decreasing towards west ($\log_{10}(P) = -6.5$; $P \cong 0.0003\%$) and east ($\log_{10}(P) = -4.5$; $P \cong 0.003\%$). The 50th percentile map indicates higher exceedance probabilities also in Furnas region and neighbouring areas of $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$), while these probabilities reached a value of $\log_{10}(P) = -3.5$ (i.e., $P \cong 0.03\%$) at the east end and $\log_{10}(P) = -6.5$ (i.e., $P \cong 0.00003$) towards west (Fig. 4.17B). Based on the last percentile of the absolute exceedance probability (95th, Fig. 4.17C), 400 kg/m² of tephra has $\log_{10}(P) = -0.7$ (i.e., $P \cong 20\%$) probability of being overcome in Furnas region, decreasing significantly to the west part of the island to $\log_{10}(P) = -6$ (i.e., $P \cong 0.0001\%$), and to the east to $\log_{10}(P) = -2.5$ (i.e., $P \cong 0.3\%$).

Conditional probability maps evaluating the probability of exceedance of 400 kg/m² of tephra as result of a VEI 4 eruption at Furnas Volcano (Fig. 4.17D, E, F) show a similar pattern of probability distribution across the island between the different probability percentiles. In these cases, higher exceedance probabilities were estimated for the east half of São Miguel, with maximum probability values of $\log_{10}(P) = -0.5$ (i.e., $P \cong 32\%$) in Furnas caldera, decreasing to $\log_{10}(P) = -3.5$ (i.e., $P \cong 0.03\%$) and to $\log_{10}(P) = -6$ (i.e., $P \cong 0.0001\%$) towards east and west, respectively.

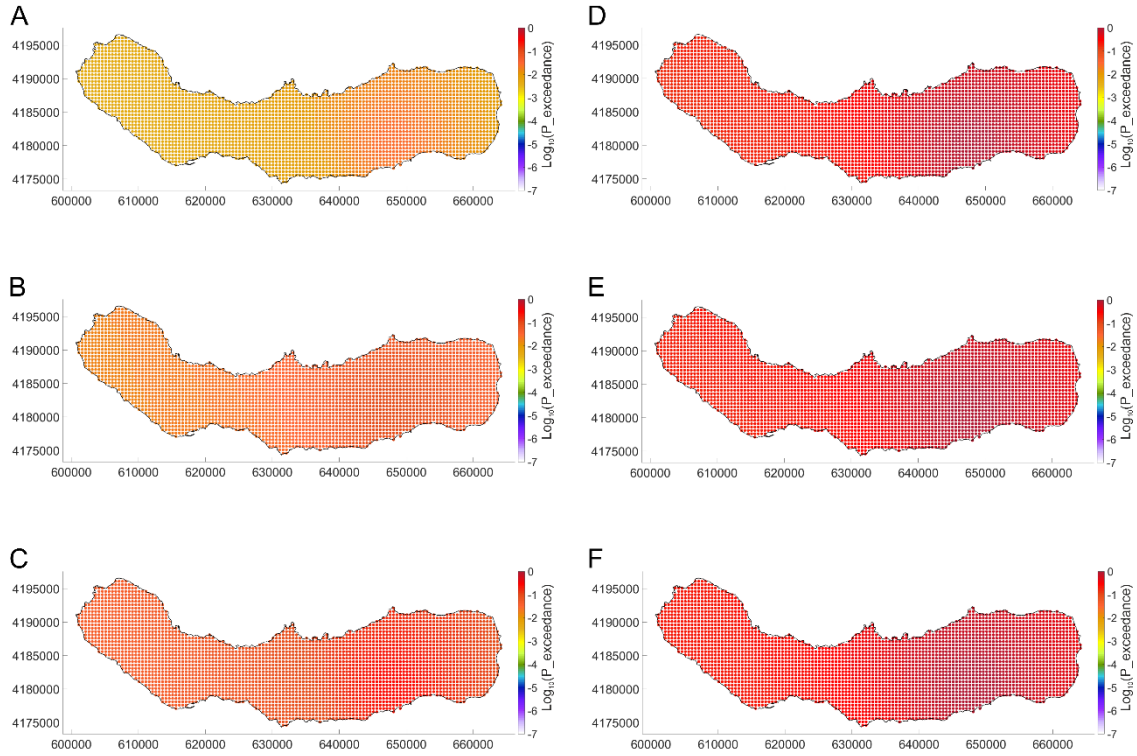


Figure 4. 15. Probability maps obtained considering eruptions of any size at Furnas Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 1 kg/m^2 in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 1 kg/m^2 , considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

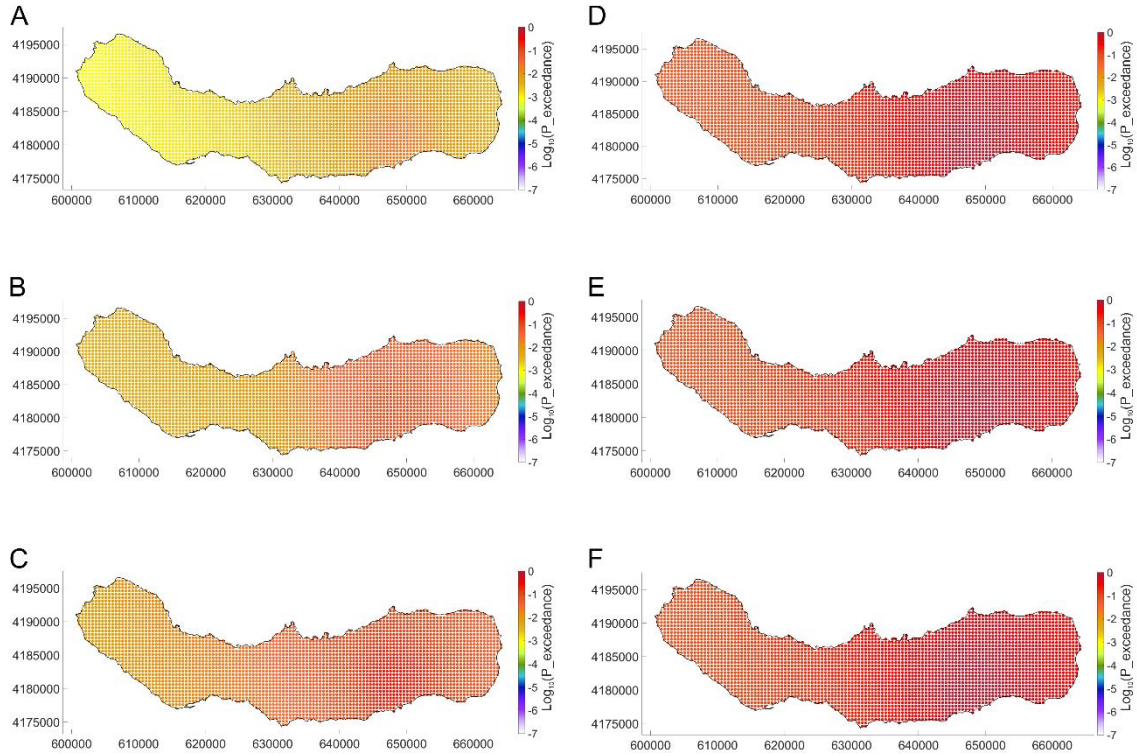


Figure 4. 16. Probability maps obtained considering eruptions of any size at Furnas Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 10 kg/m^2 in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 10 kg/m^2 , considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

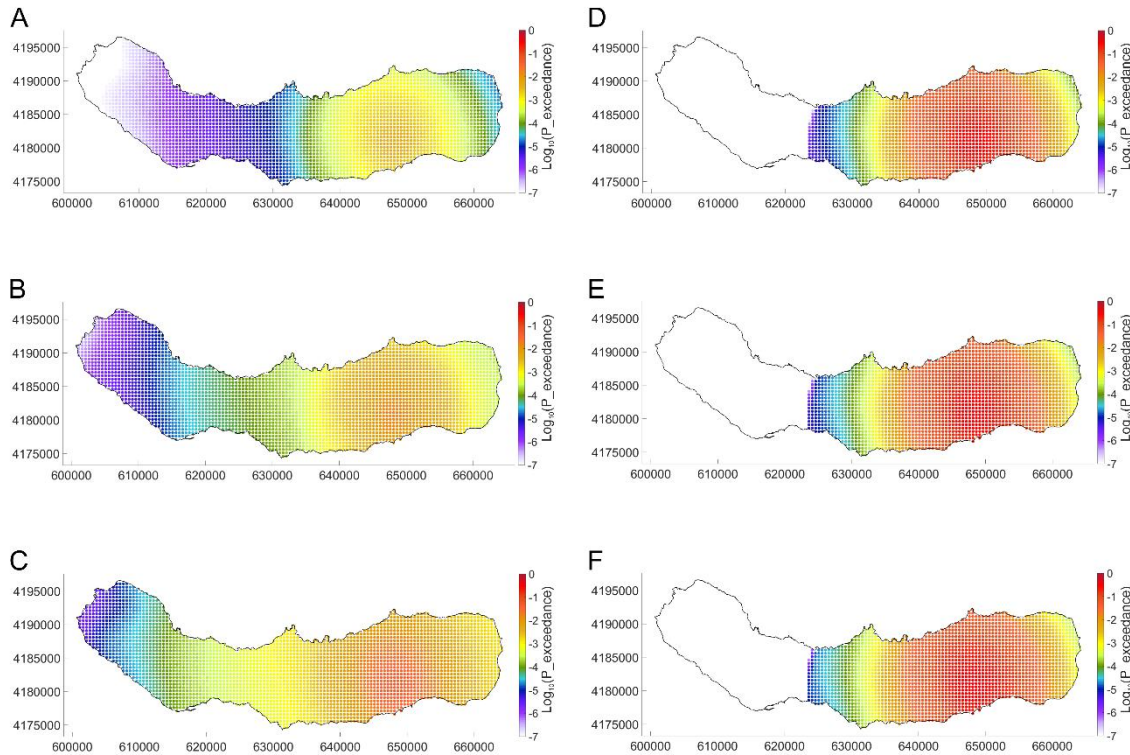


Figure 4. 17. Probability maps obtained considering eruptions of any size at Furnas Volcano (left side maps) and considering a VEI 4 eruption at the same volcano (right side maps). Left side maps: absolute probability maps showing exceedance probabilities of overcoming 400 kg/m² in the next 50 years, considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile. Right side maps: conditional probability maps showing exceedance probabilities of overcoming 400 kg/m², considering: A) the 5th probability percentile, B) the 50th probability percentile, and C) the 95th probability percentile.

4.3.3. Hazard Maps

Hazard maps were also generated considering uncertainty in vent's position. The following figures (Fig. 4.18, 4.19, 4.20; See Appendix 8 for details) represent the hazard maps generated for each volcano, considering both the absolute (for 50-year forecast) and the conditional probability to the occurrence of a VEI 4 eruption. Each map illustrates the intensity thresholds for tephra load with a 5% exceedance probability.

The absolute hazard maps for Sete Cidades Volcano (Fig. 4.18A) indicates that tephra loads from 200 to 300 kg/m² have 5% probability to be overcome in the next 50 years at, almost, all of the western part of the island. The conditional hazard map for Sete Cidades (Fig. 4.18B) reveals a

broader distribution with significant loads extending into central and eastern area of the island. Therefore, the map B (Fig. 4.18B) indicates that a threshold of 1000 kg/m² has 5% probability to be overcome from the western end of São Miguel to Relva parish, between 700 to 400 kg/m² will be overcome in the airport and hospital area (see Fig. 4.21 from the next section), and at most of the on-land area there are a 5% probability of tephra varying from 300 to 50 kg/m².

Regarding Fogo Volcano, the obtained absolute hazard map (Fig. 4.19A) shows that only very low values of tephra loads (no colour in the map) have 5% probability of being exceeded in the next 50 years. To capture finer-scale variations, map A' (Fig. 4.19A') incorporates an expanded scale (0 - 2 kg/m²), suggesting that 1 kg/m² has 5% to be exceeded in the next 50 years in the entire island.

The map B (Fig. 4.19B) illustrates the conditional hazard map to the occurrence of an VEI 4 eruption at Fogo Volcano. Based on the occurrence of this scenario, the thresholds that has 5% probability of being exceeded are 1000 kg/m² in the entire central part of São Miguel, from Lagoa to Furnas parishes, 700 to 400 kg/m² near adjacent locations (e.g., São Roque and Furnas), decreasing towards west and east to loads of 300 to 50 kg/m².

Absolute hazard maps obtained for Furnas Volcano show that tephra loads of 200 to 50 kg/m² have 5% of being exceeded in the next 50 years, mostly in Furnas caldera location (Fig. 4.20A). In contrast, the conditional hazard map (Fig. 4.20B) shows higher loads with the same exceedance probability if an VEI 4 eruption occurs at Furnas. Therefore, the thresholds that have 5% probability of being exceeded are 1000 kg/m², mostly at Furnas and near areas towards north and east, from Ponta Garça to Povoação, 700 to 400 kg/m² in near areas, showing the same dispersion pattern of the previous threshold, and 200 to 50 kg/m² (or low), specially towards west.

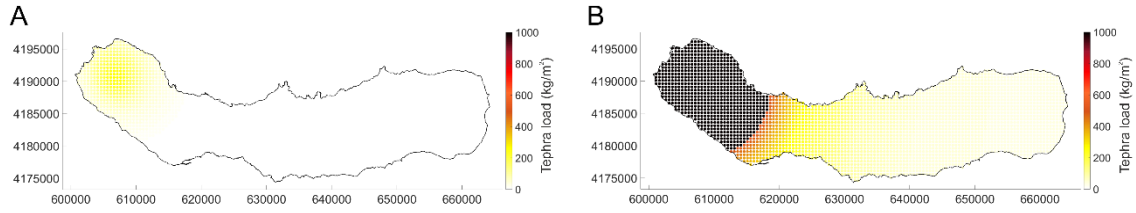


Figure 4. 18. Sete Cidades Hazard Maps showing the thresholds with 5% probability of being exceeded. A) considering the absolute probabilities for a 50-year forecast; B) considering conditional probabilities conditional to the occurrence of a VEI 4 eruption.

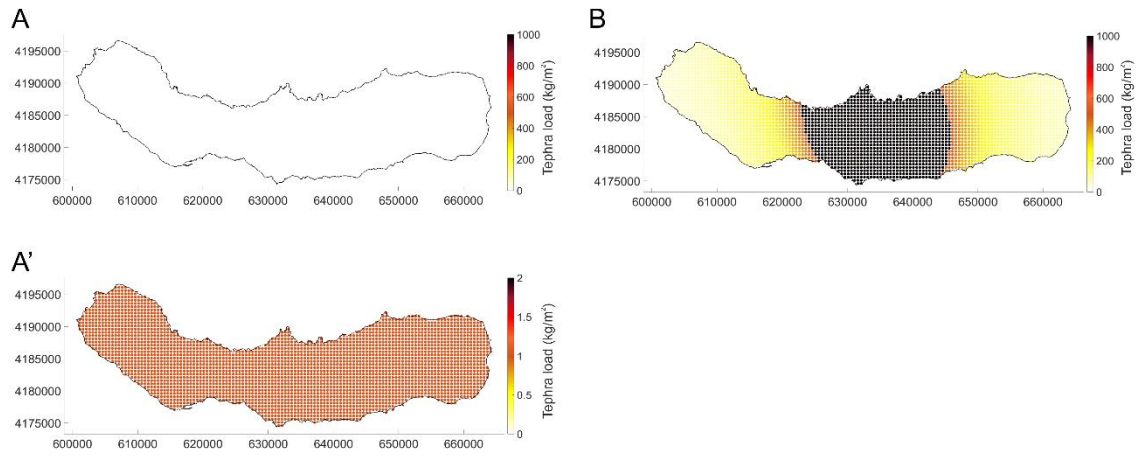


Figure 4. 19. Fogo Hazard Maps showing the thresholds with 5% probability of being exceeded. A and A') considering the absolute probabilities for a 50-year forecast; B) considering conditional probabilities conditional to the occurrence of a VEI 4 eruption.

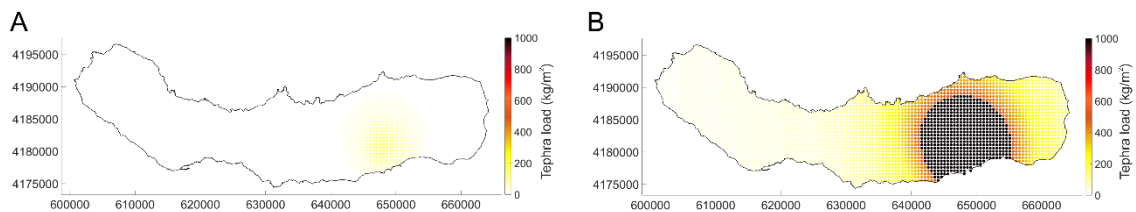


Figure 4. 20. Furnas Hazard Maps showing the thresholds with 5% probability of being exceeded. A and A') considering the absolute probabilities for a 50-year forecast; B) considering conditional probabilities conditional to the occurrence of a VEI 4 eruption.

4.3.4. Hazard Curves

Hazard curves can be computed for any point of the target grid considered in this work (2984 locations). However, for this analysis, three specific locations representing critical infrastructures were selected, such as Ponta Delgada airport, Divino Espírito Santo hospital, and Pico Vermelho geothermal powerplant (Fig. 4.21).

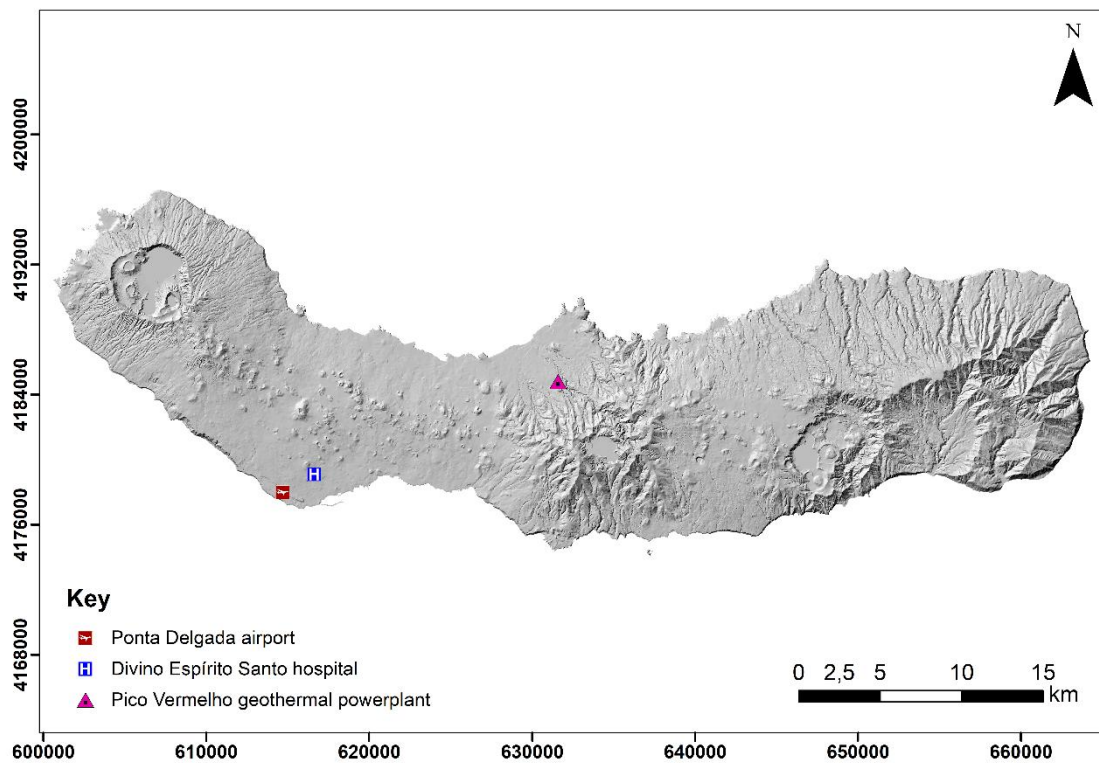


Figure 4. 21. Location of the critical infrastructure used to compute hazard curves.

At these locations, the 50-year forecast absolute (left column in the next figures) and conditional to a VEI 4 eruption (right column in the next figures) exceedance probability of any threshold, corresponding to tephra load, up to 1000 kg/m^2 can be analysed. Absolute hazard curves were computed considering all eruption sizes considered in this analysis, while conditional hazard curves were computed considering a VEI 4 eruption.

Nonetheless, this analysis focuses on the minimum tephra load values likely to cause damage on the respective infrastructures: 1 kg/m^2 at the airport, 400 kg/m^2 at the hospital, and 10 kg/m^2 at

the geothermal powerplant, as previously mentioned. In the following figures (Fig. 4.22, 4.23, and 4.24), the red dashed line represents the average exceedance probability (50th percentile) for each threshold, while the black dashed lines illustrate the same probability given by the 10th and 90th percentiles, representing the uncertainty.

Figure 4.22 show the exceedance probability of specific thresholds at chosen locations considering eruptions at Sete Cidades Volcano. Absolute hazard curves obtained for the airport (Fig. 4.22A) location indicates that the exceedance probability of 1 kg/m² in the next 50 years range from $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$) to $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$), with a mean exceedance probability of $\log_{10}(P) = -1.2$ (i.e., $P \cong 6\%$). Conditional hazard curves (Fig. 4.22D) suggests a higher probability of exceed 1 kg/m² at the airport if a VEI 4 eruption occurs at Sete Cidades Volcano, with an estimated value for the three percentiles of $\log_{10}(P) = -0.3$ (i.e., $P \cong 50\%$).

The absolute hazard curves computed for the hospital (Fig. 4.22B) reveals that the probability of exceed 400 kg/m² in the next 50 years, vary from $\log_{10}(P) = -2.7$ (i.e., $P \cong 2\%$) to $\log_{10}(P) = -2.2$ (i.e., $P \cong 0.6\%$), and the average is $\log_{10}(P) = -2.4$ (i.e., $P \cong 0.4\%$). The figure 4.22E show the conditional hazard curves obtained for the same location. In this case, the exceedance probability of overcoming 400 kg/m² vary from $\log_{10}(P) = -1.4$ (i.e., $P \cong 3.9\%$) to $\log_{10}(P) = -1.3$ (i.e., $P \cong 5\%$), and its average is $\log_{10}(P) = -1.3$ (i.e., $P \cong 5\%$).

Absolute hazard curves obtained for geothermal powerplant location (Fig. 4.22C) indicates probabilities of overcoming 10 kg/m² in the next 50 years that range from $\log_{10}(P) = -1.9$ (i.e., $P \cong 1.3\%$) to $\log_{10}(P) = -1.4$ (i.e., $P \cong 4\%$), with a mean probability of $\log_{10}(P) = -1.7$ (i.e., $P \cong 2\%$). Based on a VEI 4 scenario at Sete Cidades Volcano, the conditional hazard curves (Fig. 4.22F) suggests that the exceedance probability of 10 kg/m² at this location range from $\log_{10}(P) = -0.7$ (i.e., $P \cong 20\%$) to $\log_{10}(P) = -0.6$ (i.e., $P \cong 25\%$), and the average exceedance probability is $\log_{10}(P) = -0.6$ (i.e., $P \cong 25\%$).

The exceedance probabilities for specific tephra load thresholds in the selected locations, based on eruptions from Fogo Volcano, are shown in figure 4.23. The Absolute probabilities of exceeding 1 kg/m^2 at the airport within the next 50 years range from $\log_{10}(P) = -2.9$ (i.e., $P \cong 0.1\%$) to $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$), with an average probability of $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$) (Fig. 4.23A). Under a VEI 4 eruption at Fogo, this probability increases to values between $\log_{10}(P) = -0.56$ (i.e., $P \cong 27.5\%$) and $\log_{10}(P) = -0.52$ (i.e., $P \cong 30\%$), with an estimated average exceedance probability of is $\log_{10}(P) = -0.54$ (i.e., $P \cong 28.4\%$) (Fig. 4.23D).

Absolute hazard curves computed for the hospital location (Fig. 4.23B) the probability of exceeding 400 kg/m^2 of tephra over the next 50 years range from $\log_{10}(P) = -4.2$ (i.e., $P \cong 0.006\%$) to $\log_{10}(P) = -2.8$ (i.e., $P \cong 0.16\%$), and the average probability to overcome this threshold in load is $\log_{10}(P) = -3.3$ (i.e., $P \cong 0.05\%$). Conditional hazard curves to a VEI 4 eruption (Fig. 4.23E), the exceedance probability of this threshold rises to probabilities that vary between $\log_{10}(P) = -1.9$ (i.e., $P \cong 1.3\%$) to $\log_{10}(P) = -1.8$ (i.e., $P \cong 2\%$), with estimated average probability of is $\log_{10}(P) = -1.86$ (i.e., $P \cong 1.25\%$).

Absolute hazard curves computed for the geothermal powerplant location, (Fig. 4.23C) reveals that the probability of exceeding 10 kg/m^2 of tephra in the next 50 years in this location range from $\log_{10}(P) = -2.5$ (i.e., $P \cong 0.3\%$) to $\log_{10}(P) = -1.1$ (i.e., $P \cong 8\%$), with an average exceedance probability of is $\log_{10}(P) = -1.6$ (i.e., $P \cong 2.5\%$). The conditional hazard curves showing the probability of exceeding 10 kg/m^2 at the geothermal powerplant location if an VEI 4 eruption occurs at Fogo Volcano are illustrated by Figure 4.23F. In this case, exceedance probabilities range between $\log_{10}(P) = -0.16$ (i.e., $P \cong 69\%$) and $\log_{10}(P) = -0.14$ (i.e., $P \cong 72\%$), with an estimated mean value of is $\log_{10}(P) = -0.15$ (i.e., $P \cong 71\%$).

Figure 4.24 represents the exceedance probabilities for specific tephra load thresholds at selected locations, considering eruptive scenarios at Furnas Volcano.

For the airport, the analysis of absolute hazard curves (Fig. 4.24A) show that the minimum, maximum, and mean probability of exceeding 1 kg/m² in the next 50 years is $\log_{10}(P) = -2.1$ (i.e., $P \cong 0.8\%$), $\log_{10}(P) = -1.4$ (i.e., $P \cong 4\%$), and $\log_{10}(P) = -1.7$ (i.e., $P \cong 2\%$), respectively. Conditional hazard curves to a VEI 4 eruption (Fig. 4.24D) suggests higher probability estimates for the same threshold and location, being the minimum, the maximum and mean probabilities $\log_{10}(P) = -0.7$ (i.e., $P \cong 19.95\%$), $\log_{10}(P) = -0.68$ (i.e., $P \cong 20.89\%$), and $\log_{10}(P) = -0.69$ (i.e., $P \cong 20.42\%$), respectively.

Absolute hazard curves computed for the hospital location (Fig. 4.24B) show that the probabilities of exceed 400 kg/m² in this location in the next 50 years range from $\log_{10}(P) = -5.4$ (i.e., $P \cong 0.0004\%$) to $\log_{10}(P) = -3.9$ (i.e., $P \cong 0.01\%$), and its average is $\log_{10}(P) = -4.6$ (i.e., $P \cong 0.003\%$). Under a VEI 4 scenario at Furnas, the conditional hazard curve indicates that tephra load will never reach 400 kg/m² at the hospital location (Fig. 4.24E).

At the geothermal powerplant location, the absolute hazard curve shows that the probability of overcoming a tephra load of 10 kg/m² can vary between $\log_{10}(P) = -2.3$ (i.e., $P \cong 0.5\%$) and $\log_{10}(P) = -1.5$ (i.e., $P \cong 3\%$), in the next 50 years, with an estimated mean value of $\log_{10}(P) = -1.8$ (i.e., $P \cong 1.6\%$) (Fig. 4.24C). Considering a VEI 4 eruption at Furnas, these probabilities are higher. In this case, the probability of exceed 10 kg/m² at the geothermal powerplant location ranges from $\log_{10}(P) = -0.7$ (i.e., $P \cong 19.95\%$) to $\log_{10}(P) = -0.66$ (i.e., $P \cong 22\%$), with an average probability of $\log_{10}(P) = -0.68$ (i.e., $P \cong 20.89\%$) (Fig. 4.24F).

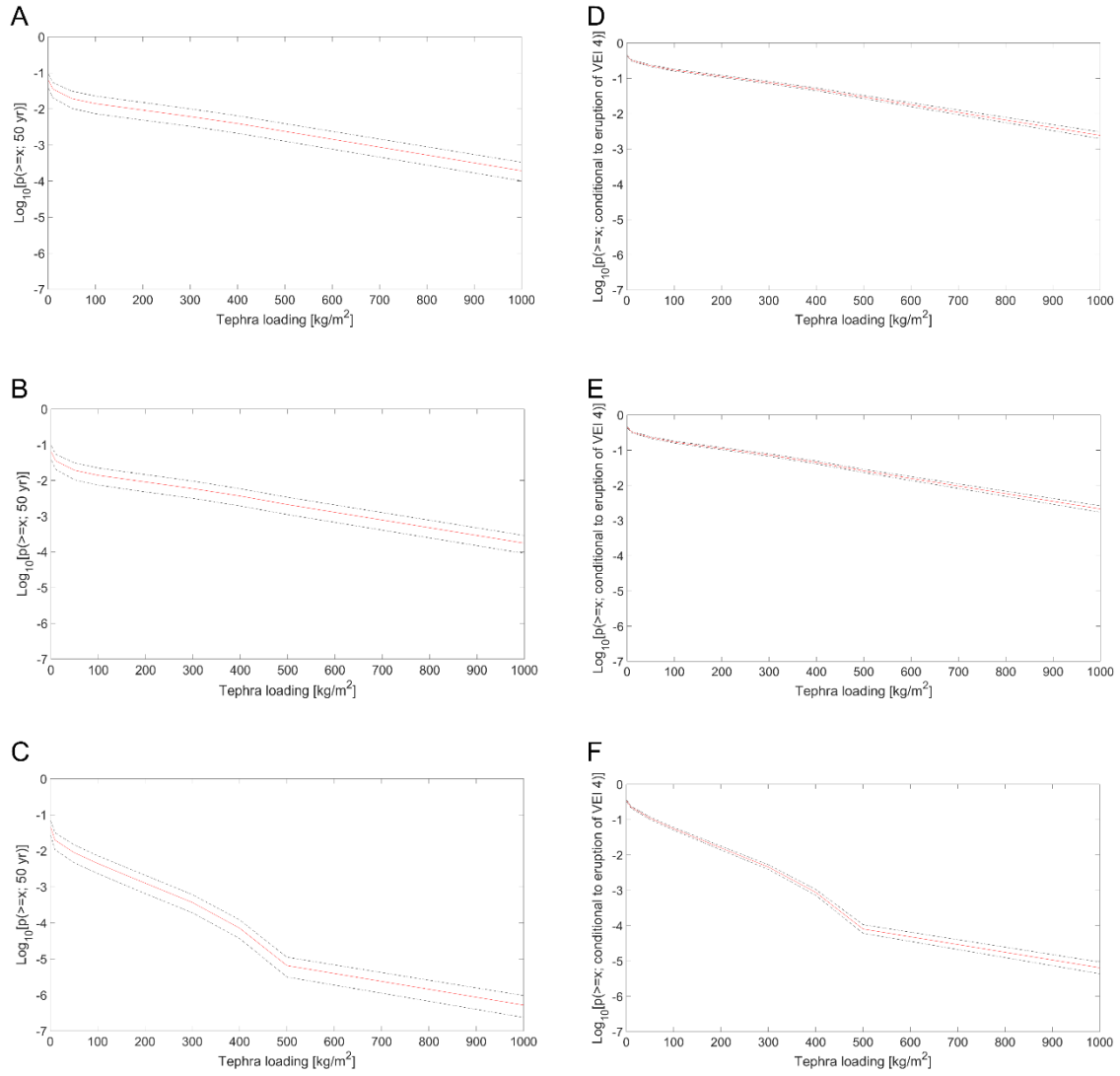


Figure 4. 22. Hazard curves obtained for the selected locations considering eruptions from Sete Cidades Volcano. Left column: Absolute hazard curves showing exceedance probabilities over the next 50 years for several tephra load thresholds at: A) Airport location; B) Divino Espirito Santo Hospital location, and C) Pico Vermelho Geothermal powerplant location. Right Column: Conditional hazard curves showing conditional exceedance probabilities to the occurrence of a VEI 4 eruption for several tephra load thresholds at. D) Airport location; E) Divino Espirito Santo Hospital location, and F) Pico Vermelho Geothermal powerplant location.

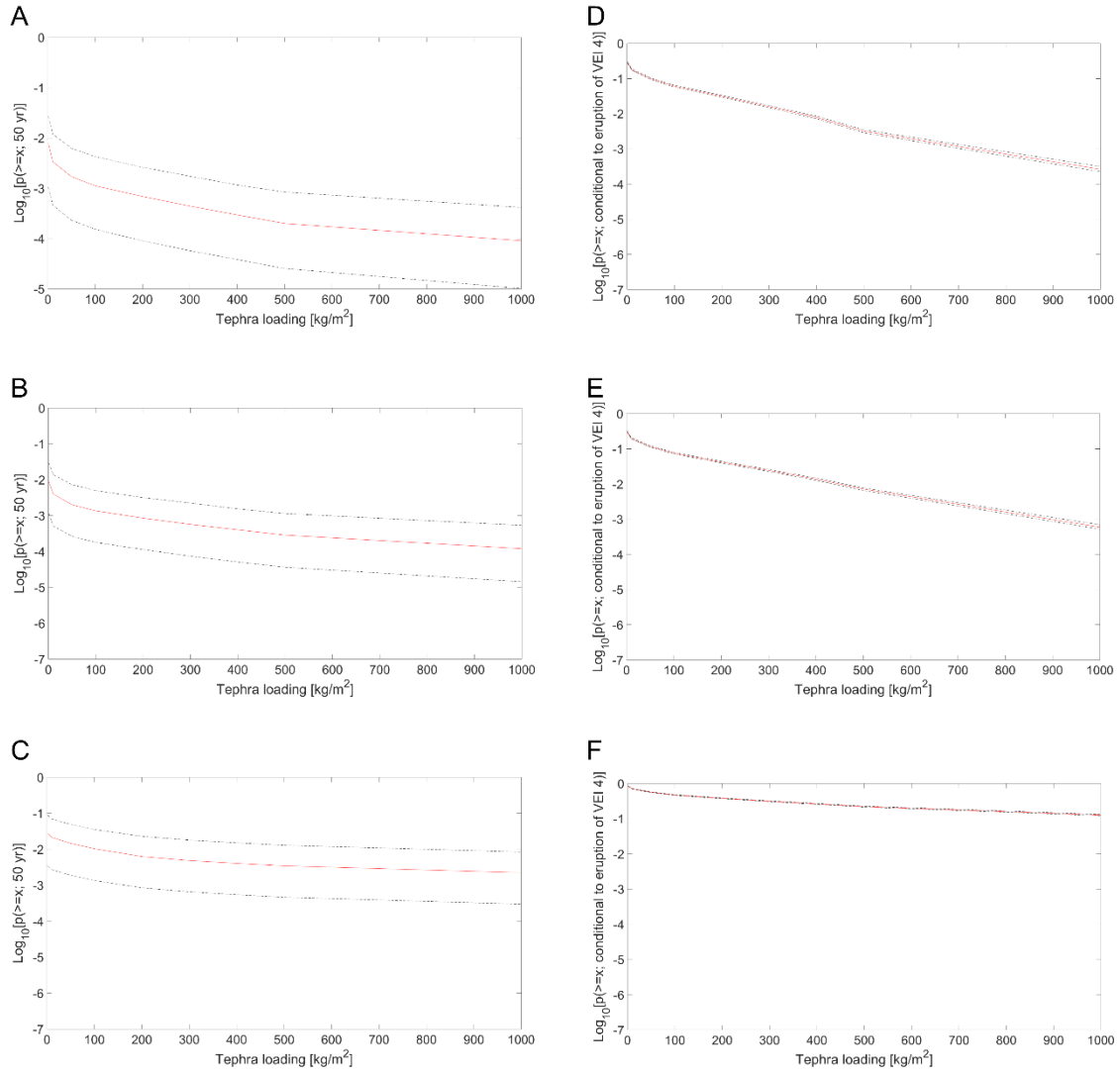


Figure 4. 23. Hazard curves obtained for the selected locations considering eruptions from Fogo Volcano. Left column: Absolute hazard curves showing exceedance probabilities over the next 50 years for several tephra load thresholds at: A) Airport location; B) Divino Espirito Santo Hospital location, and C) Pico Vermelho Geothermal powerplant location. Right Column: Conditional hazard curves showing conditional exceedance probabilities to the occurrence of a VEI 4 eruption for several tephra load thresholds at: D) Airport location; E) Divino Espirito Santo Hospital location, and F) Pico Vermelho Geothermal powerplant location.

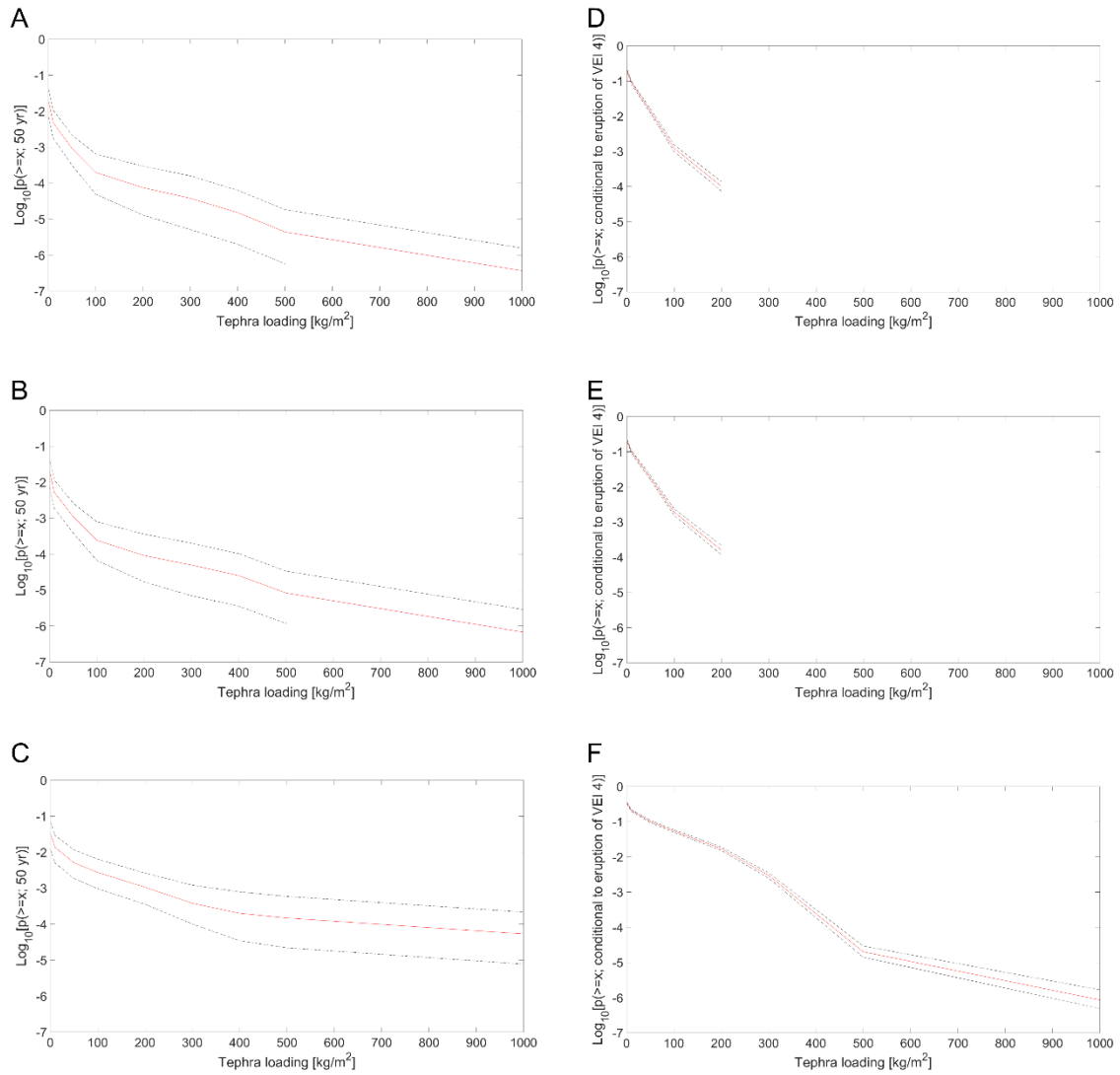


Figure 4. 24. Hazard curves obtained for the selected locations considering eruptions from Furnas Volcano. Left column: Absolute hazard curves showing exceedance probabilities over the next 50 years for several tephra load thresholds at: A) Airport location; B) Divino Espirito Santo Hospital location, and C) Pico Vermelho Geothermal powerplant location. Right Column: Conditional hazard curves showing conditional exceedance probabilities to the occurrence of a VEI 4 eruption for several tephra load thresholds at: D) Airport location; E) Divino Espirito Santo Hospital location, and F) Pico Vermelho Geothermal powerplant location.

4.3.5. Absolute probability maps for São Miguel Island: combined probabilities from the three volcanoes

The provided set of maps (Fig. 4.25) illustrates the spatial distribution of the exceedance probability of each tephra load threshold over a 50-year period, i.e. the absolute probability, on

São Miguel Island. Each map reflects the exceedance probability by combining the probabilistic outputs from the three central volcanoes considered: Sete Cidades, Fogo, and Furnas, considering the uncertainty on the spatial position of future vents, the uncertainty on the eruption size and the temporal probability of eruptions at the three volcanoes.

Considering the lowest threshold of 1 kg/m^2 , the map shows high exceedance probabilities spatially distributed across the entire island, indicating a high probability of exceed this threshold in the next 50 years, especially at the near areas around the central volcanos ($\log_{10}(P) = -0.5$; $P \cong 30\%$). Despite the dispersion of probabilities seems to be uniform, it is possible to distinguish a lighter red colour, from the north to the south, in the area from the Sete Cidades limit to the beginning of Fogo Volcano, and from the east limit of Povoação to the eastern edge of the island. In these locations, the estimated exceedance probabilities were $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$).

The map containing the exceedance probabilities of 10 kg/m^2 of tephra indicates that there is still a high chance of overcome this threshold in the next 50 years, particularly in proximity to the central volcanoes, with estimated exceedance probability of $\log_{10}(P) = -0.5$ (i.e., $P \cong 30\%$). Lower values of this probability were estimated for the central part of the island and eastern end of about $\log_{10}(P) = -1.3$ (i.e., $P \cong 5\%$).

The spatial dispersion of the exceedance probability of overcoming 50 kg/m^2 of tephra is similar to the previous cases. However, probabilities seem to decrease overall. Higher exceedance probability values were obtained in near locations around the main volcanoes, such as $\log_{10}(P) = -0.5$ (i.e., $P \cong 30\%$) at Sete Cidades and Furnas locations, $\log_{10}(P) = -0.8$ (i.e., $P \cong 16\%$) at Fogo location, decreasing to $\log_{10}(P) = -1.5$ (i.e., $P \cong 3.2\%$) between Sete Cidades and Fogo volcanoes, and to $\log_{10}(P) = -1.75$ (i.e., $P \cong 1.8\%$), at the eastern edge of São Miguel.

Regarding the exceedance probability of 100 kg/m^2 in the next 50 years in São Miguel, higher values ($\log_{10}(P) = -0.5$ (i.e., $P \cong 30\%$) are concentrated essentially around Sete Cidades Volcano and a and Furnas caldera's location, while at Fogo location this probability is about , $\log_{10}(P)$

= -0.8 (i.e., $P \cong 16\%$), with a smaller red area compared to the previous case. At the central part of the island and at the eastern end, exceedance probabilities of $\log_{10}(P) = -1.75$ (i.e., $P \cong 1.8\%$) and $\log_{10}(P) = -2.25$ (i.e., $P \cong 0.6\%$) were estimated, respectively.

The maximum exceedance probabilities of overcoming 200 kg/m^2 in the next 50 years were obtained for the surrounding areas of the central volcanoes, with estimated probabilities of $\log_{10}(P) = -0.5$ (i.e., $P \cong 30\%$) near Sete Cidades and Furnas volcanoes, followed by Fogo Volcano location with estimated probabilities of $\log_{10}(P) = -1.75$ (i.e., $P \cong 1.8\%$), the area from north to south between Ponta Delgada and Caloura with estimated probabilities of about $\log_{10}(P) = -2.25$ (i.e., $P \cong 0.6\%$), and the east of the island with estimated probabilities of $\log_{10}(P) = -2.50$ (i.e., $P \cong 0.32\%$).

The map of the exceedance probability of 300 kg/m^2 in the next 50 years indicates, as well, higher probabilities for the western part of São Miguel, where is located Sete Cidades Volcano, and for Furnas area, with estimated probabilities of $\log_{10}(P) = -0.7$ (i.e., $P \cong 19.95\%$). At the surrounding areas of Sete Cidades and Furnas, and for Fogo Volcano location, exceedance probabilities were estimated of $\log_{10}(P) = -1.75$ (i.e., $P \cong 1.8\%$) and $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$), respectively. Lower probabilities cover the area between the centre of Ponta Delgada to Caloura ($\log_{10}(P) = -2.25$; $P \cong 0.6\%$) and Nordeste parish ($\log_{10}(P) = -2.75$; $P \cong 0.18\%$).

The 50 year-forecast of the exceedance probability of 400 kg/m^2 and 500 kg/m^2 at São Miguel reveals that, in both cases, higher probabilities are concentrated in Sete Cidades and Furnas locations, with maximum estimated probabilities of $\log_{10}(P) = -0.9$ (i.e., $P \cong 12.59\%$) at Sete Cidades, and about $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$) at Furnas, for booth thresholds. At the surrounding areas of these volcanoes, the exceedance probability was estimated to be $\log_{10}(P) = -1.75$ (i.e., $P \cong 1.8\%$). Based on these maps, 400 and 500 kg/m^2 has an estimated exceedance probability of about $\log_{10}(P) = -2$ (i.e., $P \cong 1\%$) and $\log_{10}(P) = -2.25$ (i.e., $P \cong 0.6\%$) at Fogo Volcano area. Lower values of this probability are present between the airport location and

Caloura parish ($\log_{10}(P) = -2.75$; $P \cong 0.18\%$ for both thresholds), and at Nordeste parish ($\log_{10}(P) = -3.25$; $P \cong 0.06\%$ and $\log_{10}(P) = -3.5$; $P \cong 0.03\%$ for 400 and 500 kg/m², respectively).

The map illustrating the exceedance probabilities for threshold 1000 kg/m² suggests that there is a very low to negligence probability to have tephra accumulations of this magnitude in the next 50 years in São Miguel. In this case, the area of Sete Cidades Volcano area is more likely to exceed 1000 kg/m², with an estimated probability of about $\log_{10}(P) = -1$ (i.e., $P \cong 10\%$), followed by Furnas caldera area, with estimated exceedance probabilities of about $\log_{10}(P) = -1.75$ (i.e., $P \cong 1.8\%$). Fogo volcano area has a very low expression, as shown in the previous maps. At this location, the maximum value of the probability to exceed 1000 kg/m² is about $\log_{10}(P) = -2.5$ (i.e., $P \cong 0.32\%$). These probabilities decrease in areas around the three central volcanos to $\log_{10}(P) = -3.25$ (i.e., $P \cong 0.06\%$). Almost negligible exceedance probabilities for this threshold were estimated for the area between the airport and Lagoa, as well as for Nordeste parish ($\log_{10}(P) = -4.5$; $P \cong 0.003\%$ or lower).

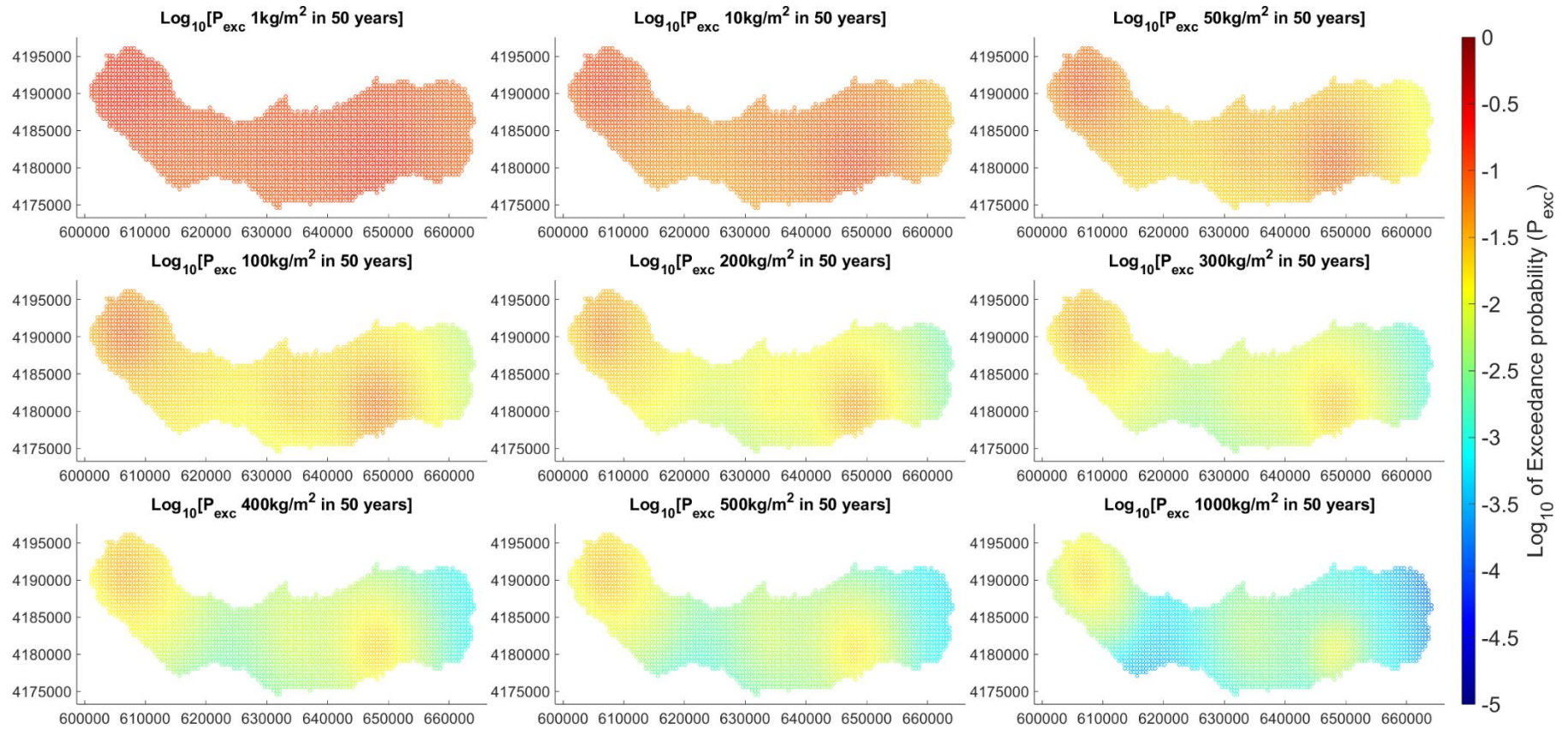


Figure 4. 25. São Miguel Island absolute probability maps resulting from the combination of the long-term probabilistic volcanic hazard assessment (PVHA) of the three central volcanoes, showing the exceeding probabilities of several tephra load thresholds in the next 50 years.

4.4. Discussion

The present study focuses on the development of a full long-term PVHA, for the first time, for São Miguel Island, aiming to estimate exceedance probabilities for specific tephra load thresholds, produced during explosive trachytic eruptions, over the next 50 years, as well as exceedance probabilities conditioned to a VEI 4 eruption. The analysis was conducted, independently, for each active central volcanoes of the island.

To develop a full PVHA, the results of the temporal and the spatial analysis of vent opening obtained in Chapters 2 and 3, respectively, were incorporated. Numerical simulations of different eruption scenarios were performed for each volcano, accounting for wind variability by including wind data from the last 31 years. The simulations were performed using HAZMAP model in the “*probability mode*” to obtain the exceedance probabilities of specific tephra loads (1, 10, 50, 100, 200, 300, 400, 500, and 1000 kg/m²). Each scenario was characterised by specific eruption source parameters, varying mostly the column heights and eruption tephra mass.

Bayesian Event Trees were constructed for each volcano by integrating these different sources of information. Key outputs of this analysis, for each volcano, include probability maps, to evaluate the exceedance probability of specific thresholds, hazard maps, to evaluate which thresholds have 5% probability of being exceeded and where, and hazard curves, to analyse what is the probability of the considered thresholds being exceeded in a specific location. These results were produced based on absolute probabilities (for a 50-year forecast), and on conditional probabilities (conditional to an eruption of a VEI 4). The PVHA results of each volcano were posteriorly combined to obtain absolute probability maps for São Miguel Island.

While the use of deterministic approaches typically focuses on one single eruptive scenario, such as the most probable or worst-case scenarios, PVHA integrates a wide range of possible outcomes and accounts for uncertainties that arises from natural variability of volcanic processes (aleatory uncertainty) and from the limited knowledge of volcanic systems (epistemic uncertainty). Moreover, PVHA approaches are integrated into a Bayesian framework, enabling to work with

probability density functions instead of single probability values, as well as to update these probabilities as new data becomes available. Furthermore, by implementing a PVHA, hazard is quantified in a probabilistic way, offering valuable insights into potential outcomes and their probability of occurrence, which is crucial to develop and improve effective response strategies and mitigation measures.

The results of this analysis will be discussed in the following sections.

4.4.1. Tephra fallout numerical simulations

Numerical simulations of different eruptive scenarios were performed for the three volcanoes by running the HAZMAP using the “*probability mode*”. For Fogo and Furnas volcanoes, VEI 3, VEI 4, and VEI 5 scenarios were considered, while for Sete Cidades only a VEI3 and a VEI 4 scenarios were modelled, as VEI 5 eruptions are absent in the catalogue of events of the last 16,000 years.

Analysing and comparing the results obtained for different eruption sizes, it is evident that the eruption source parameters, as eruptive column height, and tephra mass, clearly influences the dispersion and deposition of tephra and, thus, the spatial distribution of the exceedance probabilities. For instance, VEI 4 and VEI 5 scenarios results show a wider spatial distribution of exceedance probabilities, which translates the dispersion and deposition of tephra. In fact, larger eruptions, typically, emit larger volumes of tephra and higher eruptive columns that can reach the stratosphere (12-50 km), allowing for a long-range tephra transport and dispersion (e.g., Folch, 2012; McLean et al., 2024; Watt et al., 2009). Moreover, the dispersion and deposition of different grain size classes depends, for example, on the settling velocity, which is directly linked to particles size, particles density, and atmospheric conditions (e.g., Armienti et al., 1988). Coarse-grained clasts deposit closer to the vent, while fine-grained size clasts, such ash, can travel in the atmosphere for thousands of kilometres (e.g., Armienti et al., 1988). This can explain the occurrence of higher exceedance probabilities for different thresholds in the surrounding areas of

the volcano when compared to distant locations, as well as the higher exceedance probabilities observed for smaller thresholds (e.g., 1 and 10 kg/m²) comparing to the ones obtained for the larger thresholds (e.g., 400 kg/m²).

The tephra dispersion and deposition patterns observed in the figures 4.5 to 4.8 follow an elliptical shape and show main dispersion axis to the east. This pattern is consistent with the statistical analysis developed during the present work for wind data collected for São Miguel over the last 31 years, which show preferential winds blowing to the east. Moreover, Pimentel et al. (2006) conducted a statistical analysis of wind profiles from the Azores region based on radiosonde data from Terceira Island, indicating prevailing wind patterns with the same directions, which is well known as the westerlies (Saez et al., 2025).

Several works have focused on numerical simulations of tephra deposition in the Azores region (e.g., Aguiar, 2018; Medeiros et al., 2021; and many others), however, probabilistic simulations, are still scarce in the literature. Cole et al. (2008) performed tephra load and probabilistic simulations for Sete Cidades Volcano using as reference the input parameters of the P17 (VEI 3) and P11 (VEI 4) deposits. The authors performed these simulations considering wind data from summer and winter seasons over 25 years. In terms of dispersion patterns, the present work exhibits similar dispersion axis to the ones in Cole et al. (2008). The authors also present the 5% probability of thresholds being exceeded; this will be discussed in the section dedicated to the hazard maps.

Comparing all three volcanoes, future eruptions at Fogo Volcano are expected to have the largest impact, especially as result of its location in the central part of the island. Sete Cidades is located at the westernmost part of São Miguel, i.e., upwind, which favours the dispersion of tephra over the island when dispersed by the wind. Based on this, is expected that a large area of São Miguel will be covered by tephra during future eruptions in Sete Cidades. In the other hand, Furnas Volcano is located at the eastern part of the island, i.e., downwind. According to the prevailing winds, tephra from Furnas will impact, mostly, the eastern part of São Miguel.

4.4.2. Bayesian Event Trees

Bayesian Event Trees (BETs) have been recognised as a valuable tool PVHA (for short-term and long-term), providing insights about the progression of volcanic events and their associated probabilities. Traditionally, event trees for volcanic hazard assessment incorporate nodes that start from the restless condition to possible outcomes or scenarios, where probabilities are assessed based on the expert elicitation method or probability quantification is absent.

Event trees have been constructed in the past for two of the three central volcanoes from São Miguel: Sete Cidades and Fogo Volcano. The event tree for Sete Cidades was firstly constructed by Queiroz et al. (2008). The authors used expert judgement to define event probabilities and outcomes. Despite considered a pivotal advancement regarding the use of probabilistic approach in the Azores and the associated uncertainties, which provided the first clues about probable outcomes, the use of expert opinions may introduce subjectivity. Under EUROVOLC project a deterministic event tree was constructed for Fogo Volcano (Pimentel, 2021), which provides possible pathways to different scenarios. However, the absence of probability estimates in each node limits its utility for different stakeholders.

During this work, three BETs were constructed, one for each volcano, incorporated into a long-term PVHA analysis. These event trees were inserted into a Bayesian framework where uncertainties were accounted to estimate final probabilities at the nodes. Each event tree contains 8 nodes, from restless to exceedance probabilities of overcoming specific tephra loads. To estimate the probabilities in each node, the same approach as in BET_VH was followed (see section 4.2.4).

The extended structure of the event trees, with 8 nodes, allows for the detailed representation of volcanic processes, offering a robust hazard probability quantification of a specific phenomenon. This is a key advantage for complex volcanic systems, such the Azores, where geological data is frequently incomplete or poorly preserved, leading to uncertainties and gaps on the knowledge.

The possibility to model specific intensity thresholds with this tree structure, improves its utility for practical hazard and risk assessment. Therefore, different intensity thresholds can be modelled allowing stakeholders (e.g., Government decision makers, civil protection, scientists, and others) to focus on specific scenarios that align with their priorities to define effective response and mitigation measures. For instance, even small amounts of volcanic ash may affect flight routes, disrupt airport operations, damage airplane engines, and reduce visibility during take-off and landing, putting at risk aviation safety (Folch and Sulpizio, 2010). By assessing the exceedance probabilities of critical tephra load thresholds, airport managers can determine when airport closures and/or if it is needed to divert flights.

Although the present work focuses on a single hazard (tephra load), the flexibility of BETs allows to manage a variety of volcanic scenarios and model different outcomes simultaneously (e.g., tephra load, PDCs, lava flows). This feature is crucial for the Azores, where volcanoes can exhibit a wide range of volcanic eruptive styles and outcomes, with different impacts on communities and infrastructures.

This multi-hazard capability provides a holistic comprehension of volcanic hazard and their risks, supporting decision makers and long-term planning. (Baxter et al., 2008; Hayes et al., 2019).

4.4.3. Probability maps

Absolute probability maps were constructed to provide a visualization of exceedance probabilities of specific tephra load thresholds over the next 50 years, considering eruptions from Sete Cidades, Fogo, and Furnas, individually. Probability maps conditional to a VEI 4 eruption were also computed to evaluate the exceedance probability of the same thresholds under the occurrence of the most probable scenario at São Miguel Island (Medeiros et al., 2021).

To account for variability and uncertainty of the model, probability maps were computed based on three probability percentiles: the 5th percentile, representing the best-case scenario, the 50th

percentile, corresponding to the mean probabilities and the “best-guess” scenario or the most probable, and the 95th percentile which indicates the worst-case scenario. Moreover, the computation of probabilities at different percentiles have been used in volcanic hazard assessment helping to quantify and represent epistemic uncertainty (Selva et al., 2018; Tonini et al., 2015a). This is useful as it offers to stakeholders a range of possibilities that may require different management strategies.

In this work, three tephra load thresholds are represented (1, 10, and 400 kg/m²), providing an example of the application of this methodology on São Miguel. Therefore, the choice of the present intensity thresholds relies on the impacts that they have on critical infrastructure. Although this analysis focuses only on the impacts in specific infrastructures (e.g. Ponta Delgada airport, Divino Espírito Santo hospital, and Pico Vermelho geothermal powerplant), exceeding the proposed thresholds may have severe consequences, for example, on electrical and water supply, roads, critical components, and buildings (Wilson et al., 2012; Wilson et al., 2014).

The spatial distribution of exceedance probabilities follows the wind directions compiled for a 31-year period, as expected, aligning with the prevailing wind patterns in the Azores region, which blows to the east (Pimentel et al., 2006), also known as westerly winds (Saez et al., 2025).

The absolute probability maps of exceeding 1 kg/m² in the next 50 years, produced by eruptions at the three volcanoes, individually, and based on the three probability percentiles, indicates that there is the possibility of the entire island be covered by 1 kg/m² of tephra. This exceedance probabilities varies from volcano to volcano and between percentiles, impacting the island in different ways. Thus, estimated probabilities using eruptions from Sete Cidades Volcano range from 1% (west sector and around the volcano) to 3% (towards east) using the 5th percentile, between 10% (at west) to 3% (at east portion of the island) based on the 50th percentile, and between 16% (west sector) to 10% (east sector).

Considering the same percentiles, the obtained exceedance probabilities for a 50-year forecast using eruptions from Fogo Volcano range from 0.3% (at the centre of the island) to 0.03% (at the western and east ends) based on the 5th percentile, ranged between 3% (at the centre of the island) to 1% (at the western and east ends) using the 50th percentile, and ranged between 10% (centre of the island) to 6% (towards west and east) based on the 95th percentile.

For Furnas Volcano, and considering the same percentiles, the results varied from 10% (at Furnas parish location and east edge) to 1% (towards west), 10% (at Furnas caldera location) to 3% (to the west), and between 32% (at Furnas parish and at the east edge of São Miguel) to 10% (at the west portion of the island).

The results are clearly influenced by the input probabilities of future trachytic explosive eruption over the next 50 years at each volcano used in this framework (17% for Sete Cidades, 5% for Fogo, and 13% for Furnas, see Chapter 2), explaining, for example, the very low to negligible exceedance probabilities obtained for Fogo Volcano. Although Sete Cidades has a higher estimate for a future eruption, Furnas Volcano reveals to be the one with the higher exceedance probabilities to overcome 1 kg/m² in the next 50 years, that results from the existence of a VEI 5 scenario in Furnas PVHA workflow which is absent in the Sete Cidades PVHA. Despite, Furnas Volcano exhibits higher probabilities to overcome the selected threshold, the 50th and 95th percentiles maps from Sete Cidades and Fogo volcanoes show reasonable exceedance probabilities which should not be underestimated. Moreover, the obtained maps suggest higher impacts on the west sector of São Miguel if an eruption occurs at Sete Cidades Volcano, while the most affected portion of the island will be its central part and the east sector in an eruption occur at Fogo and Furnas volcanoes, respectively.

A similar pattern to the one observed in the spatial distribution of the absolute exceedance probabilities for tephra load threshold of 1 kg/m² is detected regarding 10 kg/m². However, in this case, exceedance probabilities are lower when compared to the previous threshold. Thus, the absolute exceedance probabilities to overcome 10 kg/m² of tephra load in the next 50 years

considering eruptions from Sete Cidades Volcano varied between 3% (west sector) and 0.3% (from the centre towards east) based on the 5th percentile, 3% (west) to 1% (from the centre towards east edge) based on the 50th percentile, and between 32% (at the west) and 2% (from the centre to the east portion of the island) according to the 95th percentile.

For Fogo Volcano, the estimated values based on 5th percentile vary from 1% (centre of the island) to 0.02 (towards east and west). As for the 50th and 95th percentile, the obtained probabilities ranged from 3% (centre of the island) to 1% (at west and east, being lower at the west), and from 10% (at the centre of the island) to 2% (at both west and east sectors), respectively.

Higher probabilities were estimated for Furnas Volcano, as previously shown. Based on the 5th percentile, probabilities ranged from 10% (Furnas parish and east) to 0.1% (towards west), while for the 50th and 95th percentiles, probabilities ranged from 10% (at Furnas parish) to 1% (for both west and east sectors), and from 32% (at Furnas parish and east sector) to 2% (at the westernmost edge of São Miguel), respectively. Based on these results, and similar to the previous case, Furnas seems to have the higher probability of exceeding 10 kg/m² over the next 50 years.

The obtained absolute exceedance probabilities for the next 50 years are even smaller regarding the tephra load threshold of 400 kg/m². Typically, exceedance probabilities decrease as tephra load threshold values increases, especially at distal locations, and this have been demonstrated in the literature (e.g., Massaro et al., 2023). In fact, to exceed high tephra loads requires specific meteorological conditions and more powerful volcanic eruptions.

Based on Sete Cidades results, considering the 5th percentile of the absolute exceedance probabilities, higher probability values (1%) are concentrated around the volcano centre and neighbouring areas, decreasing significantly to 0.00002% to the centre of the island. Based on the 50th percentile, exceedance probabilities range from 3% (at the westernmost sector) to 0.00003% (covering an area until reach Furnas parish), while using the 95th percentile probabilities range from 10% (at the west sector of the island) to 0.0001% (close to Furnas parish). At these maps, it

is observed that there are no values covering some portions of the island. The absent of these values was intentional as these locations exhibit so low exceedance probabilities that the code automatically attributed values very close to zero. For this reason, it is decided to show probability values higher than $\log_{10}(P)-7$. These very low probabilities in distal regions can be justified by the inverse relation between exceedance probabilities and intensity thresholds values, as well as result from the volcanological inputs, once only a VEI 3 and VEI 4 events were considered in the Sete Cidades PVHA framework.

Due to very low probability of having an eruption at Fogo Volcano within the next 50 years, exceedance probabilities are, once again, very low, especially using the 5th percentile where exceedance probabilities of 400 kg/m² over the next 50 years are concentrated only at the central part of São Miguel Island, with very low values (varying from 0.03% at the centre of the island to 0.001% at the west and east ends). As for the 50th percentile, exceedance probabilities vary from 1% (at the centre of the island) to 0.01% (towards west and east). Considering the 95th percentile, probabilities range from 3% (at the central part of the island) to 0.1% (towards west and east). Some of the probability maps for Fogo show lower probabilities at the westernmost part of the island when compared to the east sector, clearly showing the influence of the prevailing winds in the region.

Considering eruptions from Furnas, absolute probability map obtained using the 5th percentile suggests higher exceedance probabilities for the selected threshold (400 kg/m²) higher at Furnas parish location (1%), decreasing to 0.003% (east) and to 0.0003% (west). Exceedance probabilities from the 50th percentile vary from 1% (at Furnas parish) to 0.03% (towards east) and 0.0003% (towards west), while probabilities from the 95th percentile range from 20% (at Furnas parish) to 0.3% (towards east) and to 0.0001% (towards west). As observed before, for the lowest percentiles, some locations exhibit very low to negligible probabilities, and it was chosen not to represent them. Comparing all three volcanoes, higher exceedance probabilities were estimated for Sete Cidades and Furnas volcanoes.

The exceedance probability maps conditional to a VEI 4 eruption show much higher probabilities when compared to the absolute probability maps, which is consistent with initial expectations, as conditional probability maps of a specific size assume that the scenario has already taken place, while the absolute probability maps incorporate the probability of occurrence of each size in a given time frame, which is usually low.

In analogy to what is observed for the absolute probability maps, the conditional exceedance probabilities are higher as the probability percentiles increase and decrease when large tephra load values are considered. Therefore, regarding the threshold of 1 kg/m^2 , conditional probability maps obtained for different percentiles exhibit a similar spatial probability distribution.

Under a VEI 4 scenario at Sete Cidades Volcano, there is 100% probability of exceed 1 kg/m^2 at the entire western sector of São Miguel, decreasing to 30% towards east. The occurrence of a VEI 4 eruption at Fogo Volcano show also very high exceedance probabilities covering the central part of the island (100%), which decreases towards west and east to 40%.

The same tephra load threshold has very high probabilities of being exceed over the entire east end of the island (100% probability) decreasing to 16% towards west, if a VEI 4 event occur at Furnas Volcano.

All three volcanoes exhibit very high exceedance probabilities to overcome 1 kg/m^2 . Higher probabilities are mostly concentrated in the areas around the emission centres; however, considerable probabilities are also expected at the distal locations, which was not observed from the absolute probability maps.

Conditional probability maps of exceeding 10 kg/m^2 are similar between percentiles. Under a VEI 4 scenario at Sete Cidades, exceeding probabilities range from 100% (at the western sector) to 10% (towards east). Based on Fogo VEI 4 scenario, there is 100% probability of exceed 10 kg/m^2 in the entire part of the island, decreasing towards east to 50% and to 16% to the west. In such

case, higher probabilities at the east side compared to the west are favoured by the prevailing winds in the input meteorological data.

Considering an VEI 4 eruption at Furnas Volcano, higher exceedance probabilities for the selected threshold (100%) are concentrated at Furnas parish location and at the east side of the island, reaching 10% exceedance probability towards west.

Conditional probability maps regarding the overcoming probability of 400 kg/m² under a VEI 4 scenario show, once again, similarities between percentiles.

Based on Sete Cidades VEI 4 scenario, higher probabilities are concentrated in the caldera area, with probability to exceed the selected threshold of 40%, decreasing until reach Furnas parish to 0.0001%. As mentioned before, the absence of exceedance probability values from Furnas towards east resulted from very low computed probability values in these locations that the code almost considered zero probability. For this reason, it is opted not to show them. One plausible explanation to these very low probabilities is the absence of a VEI 5 scenario at Sete Cidades Volcano. However, it is also consistent with the dispersion patterns from past events, where deposits from most of eruption did not reach distant locations.

Conditional probability maps for the same scenario (VEI 4) and tephra load (400 kg/m²) at Fogo Volcano suggests that there is a considerable exceedance probability of 16% in the central part of the island, being largest in Fogo edifice location, decreasing towards west and east to 0.01%.

Despite very low probabilities on the edges of São Miguel, which are extremely conditioned by prevailing winds, past records of VEI 4 eruptions, have shown that under specific wind conditions deposits may reach distant locations with considerable tephra thickness. This is the case the 1563 AD eruption, where deposits reached the eastern tip of the island with an estimated thickness between 20 to 50 cm.

Exceedance probabilities for the selected threshold (400 kg/m²), and considering a VEI 4 eruption at Furnas Volcano, indicate higher values for Furnas parish area (32%), decreasing towards east

to 0.03% and to 0.0001% at the west. This very low probabilities, and the absence of probability values towards west are directly linked to the location of Furnas Volcano in the east side of the island, whose tephra is expected to be dispersed and deposited towards east.

Comparing all three volcanoes, higher conditional probabilities of overcoming 1 and 10 kg/m² were obtained for Fogo Volcano. However, when analysing the exceedance probabilities for the higher threshold (400 kg/m²), Sete Cidades presents greater values.

The presented maps offer valuable insights to decision makers, allowing to inform which areas are more likely to be affected by tephra load, serving as guide for infrastructure enhancements, resource allocation, and definition of evacuation strategies. Moreover, they are a crucial tool to enhance emergency preparedness and the resilience of local communities.

4.4.4. Hazard maps

Hazard maps were constructed, individually, based on eruptions of each volcano, where thresholds with 5% probability to be overcome in each location are shown. Therefore, absolute hazard maps for a 50-year forecast and conditional hazard maps to an eruption of VEI 4 are presented.

Absolute hazard maps obtained for Sete Cidades eruptions indicate a 5% probability that 200 to 300 kg/m² (thickness of 20 to 30 cm) of tephra load will be overcome, only, at the western part of São Miguel Island in the next 50 years. Fogo absolute hazard maps indicate a 5% exceedance probability of very low threshold, 1 kg/m² (thickness of 1 mm), covering the entire island. Furnas absolute hazard maps show that 50 to 200 kg/m² (thickness of 5 a 20 cm) of tephra have 5% probability of being exceeded, mostly inside of Furnas caldera in the next 50 years.

Under these scenarios, there is a chance to experience in the next 50 years, for instance, severe roof damage on buildings in the surrounding areas of Sete Cidades, as well as structural damage

and disruption of electrical material, severe contamination of water supply (Blong, 1984; Zuccaro et al., 2008; Wilson et al., 2012; Wilson et al., 2014; Craig et al., 2016; Blong et al., 2017; Valente et al., 2022), possible road closure, structural damage to communications components or even permanent disruption (Wilson et al., 2012; Wilson et al., 2014).

At Furnas, for instance, buildings will suffer light to severe roof damage (Wilson et al., 2012; Wilson et al., 2014), damage to exposed material disruption to electrical supply, as well as, possible clogging filters of water supply (Craig et al., 2016; Wilson et al., 2012), damage on pumping equipment and contamination of water, communications may be blocked or suffer structural damage (Wilson et al., 2012; Wilson et al., 2014; Craig et al., 2016).

Fogo hazard maps suggest that there is, for instance, the possibility of filters clogging in the water supply, as well as reduced visibility over the entire island.

The presented results are, once again, constrained to the input probability of an eruption over the next 50 years. For this reason, and because this is a 50-year forecast, low to medium intensity thresholds are highlight on the present maps.

Conditional hazard maps to a VEI 4 eruption show larger intensity thresholds with a 5% probability of being exceeded, which also follows the prevailing winds in the Azores. In the case of a VEI 4 eruption at Sete Cidades, conditional hazard maps indicate that the entire western sector of the island to Relva parish has 5% probability of being covered for 1000 kg/m² (thickness of 1 m) of tephra. With significant tephra loads like this, it is expected complete roof collapse and severe damage on buildings, as well as complete burial of roads.

Tephra loads from 400 to 700 kg/m² (thickness of 40 to 70 cm) are expected at the hospital and airport location, decreasing towards west from 300 to 50 kg/m² (thickness of 30 a 5 cm). The obtained results show discrepancies when compared to those obtained by Cole et al. (2008), who modelled a similar VEI 4 scenario based on Sete Cidades P11 eruption. For the same locations (hospital and airport), the authors obtained 5% exceedance probabilities of overcoming tephra

load thresholds of 2 m, 1 m and between 75 to 35 cm, respectively. The observed differences may result from the use of different tephra mass values during simulations (4.2×10^{11} in the present work vs 6.06×10^{11} in Cole et al., 2008), as well as differences in meteorological data, and because here the analysis do not extend beyond 1 m.

Fogo conditional hazard maps show that there is 5% exceedance probability of exceed 1000 kg/m^2 (thickness of 1 m) of tephra. in the central area of São Miguel, from Lagoa to Furnas parish. At the adjacent areas, tephra loads of 700 to 400 kg/m^2 (thickness of 70 to 40 cm) are expected, decreasing towards west and east to 300 to 50 kg/m^2 (thickness of 30 to 5 cm).

Furnas conditional hazard maps indicates that 1000 kg/m^2 of tephra has 5% probability of being exceed mostly at Furnas parish and at the neighbouring areas extending from Ponta Garça to Povoação. Tephra loads of 700 to 400 kg/m^2 have 5% probability of being exceed at nearby locations, decreasing to 200 to 50 kg/m^2 towards east and west.

Tephra loads of this magnitude will have several impacts on critical infrastructure of São Miguel, including, for instance, disruption of transportation networks, damage of electrical supply, failure in power and communications, water contamination, severe damage in local buildings, as well as closure of airports and ports. Pomonis et al. (1999) classified roof types from residential buildings in Furnas and Ribeira Quente (São Miguel Island) to assess the impact of tephra. The authors identify four categories of roofs (see Pomonis et al., 1999 for details). Their findings are summarised at the following table (Pomonis et al., 1999):

Table 4. 3. Summary of critical tephra load thresholds for roof collapse in São Miguel Island (adapted from Pomonis et al., 1999).

Roof type	Wet ash (cm) 50% probability of collapse	Wet ash (cm) 90% probability of collapse	Dry ash (cm) 50% probability of collapse	Dry ash (cm) 90% probability of collapse
A (50% of buildings)	20	28	40	56
B and C (25% and 15% of buildings, respectively)	25	21	30	42
D (10% of buildings)	11	15.5	22	31

Several years has passed since this study, making this work somewhat outdated, however it can still be used as reference to assess tephra impact on local buildings. Although field campaigns were conducted only for Furnas and Ribeira Quente, these locations can be assumed as analogues to other towns and parishes on the island, showing similarities in the type of construction.

Comparing data in table 4.3 with the results illustrated in the presented hazard maps, it is possible to assume that, for a 50-year forecast, and considering wet ash, buildings of type A, B, and C have 50% to 90% probability of collapse, while the ones of type D have $\geq 90\%$ probability of collapse. For dry ash, only buildings of type D may collapse, with a probability between 50% and 90%.

Under a VEI 4 scenario, for tephra loads of 1000 kg/m^2 (thickness of 1 m) it is expected that almost 100% of buildings would collapse. For tephra loads of 700 kg/m^2 (thickness of 70 cm), all buildings of the four categories have a probability of collapse $\geq 90\%$. For tephra loads of 400 kg/m^2 (thickness of 40 cm) it is expected that edifices from type A have 50 to 90 % probability of collapse if the ash is dry and $\geq 90\%$ probability of collapse if the ash is wet. Buildings of type B, C, and D, have $\geq 90\%$ probability of collapse independently if ash is dry or wet.

Under 300 kg/m^2 (thickness of 30 cm), type A buildings have 50 % probability of collapse only if the ash is wet, and no collapse may occur if ash is dry. Buildings of type B and C have 50% probability of collapse under dry ash and $\geq 90\%$ probability of collapse considering wet ash. Buildings of type C are more vulnerable, showing almost 90 % probability of collapse, independently of having dry or wet ash.

Considering tephra loads of 200 kg/m^2 (thickness of 20 cm), only edifices of type D may collapse under the presence of dry ash. Buildings of types A, B, and C have 50% to 90% of collapse under the presence of wet ash, while for buildings of type D, this probability is higher than 90%.

Lower tephra load thresholds as 50 and 1 kg/m^2 (thickness of 5 cm and 1 mm, respectively) will not have impact on roofs. Instead, they may affect several components and the airport of the island. This will be explored in further sections.

Although the maximum tephra load threshold under analysis in the present work is 1000 kg/m^2 (thickness of 1 m), it is well known that large explosive eruptions (e.g., VEI 4) worldwide, including in the Azores, have produced large tephra loads, particularly, near the vent. For instance, Sete P 11 deposit show maximum tephra thickness of about 30 m near Sete Cidades caldera; Fogo AD 1563 eruption produced tephra thickness of about 20 m near Fogo Lake, and Furnas produced several eruptions where tephra thickness reached 30 m near the vent.

4.4.5. Hazard curves

Hazard curves were computed for three locations, as examples, corresponding to main infrastructures in São Miguel, such as the Ponta Delgada airport, Divino Espírito Santo hospital, and Pico Vermelho geothermal powerplant.

Assessing the impact of tephra at the airport is of outmost importance to consider it will be used as one of the possible gateways for evacuation during a catastrophe, as well as to support the arrival of emergency aid. Moreover, the airport is the main infrastructure for incoming tourism, and its disruption may have severe consequences on local economy.

The Divino Espírito Santo hospital was the only hospital in São Miguel until 2021, the date when a private hospital was built in Lagoa town. However, it is still considered one of the main infrastructures as it provides universal and free healthcare services for all the population. Hospitals and health facilities must remain operational to provide medical care during and after a catastrophic event, such a volcanic eruption, justifying the need to assess ash impacts in such infrastructures.

Geothermal energy is responsible of about 70% of electricity in São Miguel Island, being the Pico Vermelho geothermal powerplant the one with the highest energy production. Tephra impacts on such infrastructure may lead to a reduction on energy supply, and overload on other electrical

supply infrastructures, such as fossil fuel infrastructures, which may not have the capacity for current energy demand.

In this context, for each selected point, only the minimum thresholds that have capacity to impact such infrastructures will be analysed.

Comparing the absolute hazard curves obtained for the airport location, 1 kg/m^2 has between 3% to 10% of being exceeded if an eruption occurs at Sete Cidades within the next 50 years, while this threshold has an exceedance probability between 0.1% and 3% if an eruption occurs at Fogo. Regarding an eruption at Furnas Volcano, the exceedance probability varies from 0.8% to 4%. From the three volcanoes, Sete Cidades may have the largest impact on the airport, exhibiting the highest range of exceedance probability.

Conditional hazard curves for the same location and threshold also show higher exceedance probabilities of 1 kg/m^2 when using data from Sete Cidades (50%), followed by Fogo (27.5% to 30%), and Furnas (19.95% to 20.89%).

Although some of the presented probabilities are low, especially absolute probabilities, they should not be overlooked. Moreover, despite prevailing winds suggest ash dispersion and deposition to the east, conditional probabilities suggest a very high probability of overcoming this threshold at the airport if a VEI 4 eruption occurs at any of the three volcanos. The exceedance of this tephra load threshold (1 kg/m^2) should have severe consequences for civil aviation, affecting airport operations and aviation safety. In fact, even small amounts of volcanic ash (thickness of 1 mm – 2 mm) can be enough to cause airport closure. Visibility can be compromised during take-off and landing, and to cause flights to reroute due ash concentrations even at small levels of the atmosphere as ash damage aircraft turbines and ventilation systems (Blong, 1984; Guffanti et al., 2008; Folch and Sulpizio, 2010, Wilson et al., 2014). Grounded aircrafts, as well landing strips and other equipment can be damaged, requiring frequent cleaning operations (Casadevall, 1994;

Miller and Casadeval, 2000; Guffanti and Miller, 2002; Guffanti et al., 2005; Guffanti et al., 2008, Wilson et al., 2014).

This scenario (VEI 4) may lead to economic losses, affecting significantly local economy and the Atlantic airspace. As an example, there is the Eyjafjallajökull eruption in Iceland in 2010, emitting about 750 tons of volcanic ash into the atmosphere (Budd et al., 2011). This eruption caused the major impact in the airspace worldwide, leading to airport closures and flights cancellation over Europe (Jónsdóttir, 2011), with severe consequences in economy tourism of Iceland, Ireland, Finland, and United Kingdom (Medeiros et al., 2021). This is an analogue scenario that may occur in the Azores region, posing several consequences on local communities.

Absolute hazard curves computed for the hospital location intend to evaluate exceedance probabilities of tephra load of 400 kg/m^2 (thickness of 40 cm) over the next 50 years. Analysing the obtained results for all three volcanoes, estimated exceedance probabilities were: between 0.6% and 2% using eruptions from Sete Cidades, between 0.006% and 0.16% using eruptions from Fogo, and between 0.0004% and 0.01% using eruptions from Furnas.

Conditional hazard curves for the same location and considering the same tephra load threshold (400 kg/m^2) indicates, again, that if a VEI 4 eruption occurs at each volcano, this threshold has higher probability to be overcome if the event occurs at Sete Cidades Volcano (3.9% to 5%), followed by the occurrence of an eruption at Fogo (1.3% to 2%).

Under a similar scenario at Furnas (VEI 4), results show that 400 kg/m^2 are never exceeded at the hospital location. This is the opposite of what happens when comparing to absolute hazard curves, where there is a low exceedance probability, which can be related to the presence of a VEI 5 scenario when estimating absolute exceedance probabilities.

Therefore, the impact of tephra at the hospital is linked to the building and/or roof damage or collapse (e.g., Blong, 1984; Spence et al., 1996; Spence et al., 2005; Wilson et al., 2014). It is estimated that tephra thicknesses between 1 to 10 cm are enough to cause light roof damage,

gutter damage and window abrasion; thicknesses between 10-50 cm can cause severe roof damage and possible partial collapse, while thicknesses ≥ 50 cm can lead to complete roof collapse and severe damage on buildings structure (Blong, 1984, Wilson et al., 2014).

The type of damage also depends on type of construction, type of roof, and ash density (e.g., Spence et al., 1996; Blong, 1984; Spence et al., 2005, Pomonis et al., 1999; Zuccaro et al., 2008; Wilson, 2014; Blong et al., 2017). In that case, the hospital edifice is made of concrete walls, with a flat roof. Although exceedance probabilities of 400 kg/m^2 of tephra load are relatively low, they still represent a threat. With tephra loads of this magnitude, it is expected to observe severe roof damage and even partial collapse, requiring reparation measures.

Analysing the absolute hazard curves for the Pico Vermelho geothermal powerplant to evaluate the exceedance probabilities of 10 kg/m^2 in the next 50 years, suggests higher probabilities if an eruption occurs at Fogo Volcano (2.5% - 8%), while if an eruption occur at Sete Cidades and Furnas over the same period, exceedance probabilities range from 1.3% to 4% and from 0.5% to 3%, respectively.

Under a VEI 4 scenario, higher exceedance probabilities for the same threshold (10 kg/m^2) were also observed if the scenario took place at Fogo Volcano, with exceedance probabilities ranging from 69% to 72%, followed by Sete Cidades (20% to 25%) and Furnas (19.95% to 22%). These results were expected due to the proximity of the geothermal powerplant to Fogo Volcano.

Despite Sete Cidades is located at a slightly greater distance from the Pico Vermelho powerplant than Furnas, they exhibit similar exceedance probabilities, as Sete Cidades's location favours the dispersion of tephra to the east.

Tephra impacts on electrical supply may constrain energy production and distribution leading to electrical outages (Craig et al., 2016). Possible abrasion to some moving parts as well infiltration of tephra into substation gravel may occur under tephra thicknesses between 3 - 10 mm. Between 1 to 10 cm of tephra are enough to damage exposed equipment with moving parts (e.g., turbines)

and break electrical lines, while thicknesses of 10 cm may lead to structural damage to some equipment that generates and distributes energy, as well cause irreparable damage to moving parts as hydropower turbines) (e.g., Blong, 1984; Wilson et al., 2014, Craig et al., 2016, Suto, 2022). Electrical outages can also occur as result of flashovers due to electrical discharges resulting from tephra layering on surfaces (e.g., Blong, 1984; Bebbington et al., 2008; Wilson et al., 2014).

As a significant amount of electrical energy at São Miguel depends on Pico Vermelho geothermal powerplant, exceeding 10 kg/m² can make the difference between applying cleaning measures and repairing equipment. Reparations may occur for several days, which may have expensive costs and constrain electrical supply over the island.

The computed hazard curves constitute examples of locations where it is possible to evaluate the variation of tephra accumulation under different eruptive scenarios. Different evaluations for other locations can be selected according to the user's needs, such as evaluate the impact of tephra accumulation at ports, main roads, communication towers, water springs, agricultural fields, other energy supply spots and components, and others.

4.4.6. Absolute probability maps for São Miguel: combined probabilities from the three volcanoes

The PVHAs performed for each volcanic system were combined to obtain a 50-year forecast of exceeding the considered tephra load thresholds on São Miguel Island.

The results obtained from the combination of probabilities indicate that lower tephra loads, as 1 kg/m² and 10 kg/m² have a high possibility of being exceeded in the next 50 years across the entire island.

For the first threshold (1 kg/m^2), exceedance probability distribution is more homogeneous, reaching about 30% probability of being exceed, especially near the central volcanoes, while at the eastern end of the island this probability seems to decrease to 10%.

For the second threshold (10 kg/m^2), higher exceedance probabilities were obtained around central volcanoes (30%), and lower values were obtained to the central part of São Miguel, between Relva parish and the western flank of Fogo Volcano, as well as to the eastern end of São Miguel, with estimated exceedance probabilities of 5% for both areas.

In both cases, this highlights the dispersal potential of fine-grained tephra (volcanic ash), exhibiting a long-range transportation. Volcanic ash may reach even greater distances, depending on meteorological conditions (wind velocity) and eruption source parameters (column height), remaining into the atmosphere for long periods of time (Brown et al., 2011; Howell, 2007) impacting the North Atlantic airspace.

For tephra loads of 50 kg/m^2 , 100 kg/m^2 , and 200 kg/m^2 , the same exceedance probability value of 30% was obtained for Sete Cidades and Furnas. For Fogo, exceedance probabilities of 16% were obtained for thresholds 50 and 100 kg/m^2 , and an exceedance probability value of 1.8% was obtained regarding the tephra load of 200 kg/m^2 . Although these probabilities are similar, it is noted that the area corresponding to these highest values is decreasing as tephra accumulation increases.

For the area between Sete Cidades and Fogo volcanoes, exceedance probabilities of 3.2%, 1.8%, and 0.6% were obtained for the same thresholds (50 , 100 , and 200 kg/m^2 , respectively), while for the east sector of the island the estimated probabilities were 1.8%, 0.6%, and 0.32%, respectively.

Exceedance probabilities of overcoming 300 kg/m^2 over the next 50 years are still higher for Sete Cidades and Furnas (19.95%), while for Fogo exceedance probability of 1% were estimated. The neighbouring areas of Sete Cidades and Furnas present very low exceedance probabilities (1.8%).

The probability of exceed such tephra load is even smaller away from the vent, such as at the on-land extension from Ponta Delgada to Caloura locations (0.6%), and Nordeste parish (0.18%).

Exceedance probabilities distribution, for the next 50 years, regarding tephra load thresholds of 400 kg/m^2 and 500 kg/m^2 exhibits a similar pattern. However, in these cases, probability estimates indicate a general decrease. Thus, higher exceedance probability values were obtained for Sete Cidades area (12.59% for both thresholds), followed by Furnas Volcano area (10%). For Fogo Volcano area, exceedance probabilities range from 0.6% to 1%, which is a very low probability. From the airport location to Caloura an exceedance probability of 0.18% was estimated for both thresholds, while for Nordeste parish exceedance probabilities ranged from 0.03% to 0.06%.

Considering the possibility of exceeding 1000 kg/m^2 in São Miguel over the next 50 years, Sete Cidades location is the one that exhibit the highest exceedance probability (10%), while at Furnas and Fogo areas there is a lower probability of exceeding the same threshold over the same period, 1.8% and 0.32%, respectively. At the rest of the island, probabilities are even lower and almost negligible.

Analysing the absolute probability maps combined for the three volcanoes, highest probabilities were obtained for lower tephra loads, as expected, showing that there is a reasonable probability of 1 kg/m^2 (thickness of 1 mm) and 10 kg/m^2 (thickness of 1 cm) being exceed over the next 50 years across the entire island, ranging from 5% to 30%. The exceedance of these thresholds may affect most of the island's populations. Particularly, it may have significant impact on the local airport, and affect electrical and water supply, wastewater network, and roads and vehicles, across the entire island.

For larger thresholds (e.g., 50 kg/m^2 - 500 kg/m^2) higher exceedance probabilities are concentrated around the central volcanoes or at neighbouring areas, particularly near Sete Cidades and Furnas volcanoes. This may suggest that communities that live near these locations are more vulnerable to tephra impacts. Tephra loads of this magnitude pose several threats to local buildings, and may

disrupt transportation, as well as constraint the access to water and electricity (Spence et al., 2005; Wilson et al., 2014).

The exceedance probability of exceed 1000 kg/m² of tephra load is very low, suggesting that it is less likely to occur within the next 50 years, however even this scenario is not negligible, particularly near Sete Cidades Volcano.

Overall, obtained exceedance probabilities suggests that Sete Cidades Volcano region, as well as most of the western sector, are more vulnerable to tephra fallout, with exceedance probabilities for the considered tephra loads, ranging from 30% to 10%, followed by Furnas and Fogo areas. The elevated threat observed at these locations directly depends on proximity to possible emission centres, where larger tephra is more likely to settle, as well as on the prevailing winds in the Azores region.

Comparing the three volcanoes, Sete Cidades seems to be more hazardous, contributing more to elevated exceedance probabilities regarding tephra fallout, while Fogo seems to have a smaller impact on probability calculations. This is due to the Sete Cidades Volcano location (the westernmost volcano of the island), favouring the dispersion of tephra downwind, as well as due to the previous estimated probability of an eruption in the next 50 years, which is very low at Fogo (mean 5%) and higher for Sete Cidades (mean 17%).

The entire island presents a significant degree of hazard considering low tephra load thresholds, however, for higher loads, the area from Relva parish to Caloura (from north to south coast), as well as Nordeste parish seems to be the less vulnerable places in São Miguel to high tephra loads in the next 50 years.

Overall, the approach used in this work to conduct a full long-term PVHA for tephra fallout on São Miguel show similarities with most of the probabilistic frameworks applied worldwide, which incorporate, for instance, eruption recurrence estimates, spatial probabilities of vent

openings, wind data analysis, numerical simulations for tephra and other hazards, and/or Bayesian event trees, with associated hazard curves and probability and hazard maps. For instance, studies conducted for the Canary Islands, where a long-term volcanic hazard assessment was performed for El Hierro Island (e.g., Becerril, 2014) or for Italian volcanoes to evaluate the impact of tephra (e.g., Sandri et al., 2012; Selva et al., 2017; Martínéz-Montesinhos et al., 2022; Massaro et al., 2023), among many others (e.g., Marzocchi et al., 2010; Tonini et al., 2015a; Bias et al., 2017; Alatorre-Ibargüengoita et al., 2021; Marzocchi et al., 2021; Bertin et al., 2022; Osman et al., 2024; and others).

Until now, hazard assessment studies on São Miguel, as well as on other islands in the Azores, relied only on deterministic models, sometimes incorporated in outdated probabilistic frameworks. However, recent advancements on hazard assessment have allow to apply a complete PVHA that accounts for different sources of uncertainty, providing a more “accurate” hazard assessment.

The application of a full PVHA on island volcanoes is of outmost importance as communities and infrastructure are concentrated near active volcanic systems. Thus, the development of a full PVHA for island volcanoes, such as the ones at São Miguel Island, can provide important insights into hazard awareness and preparedness, infrastructure protection, and for long-term land-planning, enhancing local communities’ resilience. Moreover, the application of a PVHA for tephra fallout at São Miguel, one of the most frequent types of hazards worldwide, offers an important contribution to regional and global volcanology.

Locally, it can be used as the basis for the Azores resilience and sustainable development (e.g. sustainable tourism development). In fact, main outcomes of this work allow for the identification of tephra dispersion and deposition patterns, informing about vulnerable communities and critical infrastructures (e.g., ports, airports, energy supplies, and others), supporting emergency planning, mitigation and evacuation strategies, and long-term planning strategies. Moreover, it enhances preparedness in a region prone to volcanism and to associated hazards. Globally, it contributes,

for instance, for international datasets and aviation safety. Furthermore, the application of this type of approach on a remote island, can be seen as a case study, where the same methodologies can be used in similar regions, such as the Canary Islands, Hawaii, and others, where hazard studies are typically challenged by incomplete records and large uncertainties.

4.5. Conclusions

Small active volcanic islands, such as São Miguel in the Azores, are prone to volcanic eruptions and, thus, vulnerable to the impacts of the associated hazards due to limited on-land area, rough topography, and high population densities and infrastructures located in the proximity of volcanic systems. Such susceptibility enhances the importance of hazard quantification to effectively identify and define mitigation strategies. However, volcanic hazard assessment on islands often faces challenges as geological records of island volcanoes are frequently incomplete, generating uncertainties regarding eruptive behaviour.

This study represents a step forward in volcanic hazard assessment in Azores region, providing, for the first time, a robust long-term probabilistic volcanic hazard assessment (PVHA) for tephra fallout on São Miguel Island. Moreover, it represents an important transition from the use of only deterministic approaches to the implementation of hazard quantification methods.

The aim of this chapter was to develop a full long-term PVHA for tephra fallout from the three active central volcanoes of São Miguel, to evaluate the impact of trachytic explosive eruptions.

The implementation of this approach required the combination of several sources of information and methods, where uncertainties arising from natural variability of volcanic processes (aleatoric uncertainty) and from the limited knowledge of volcanic systems (epistemic uncertainty) were accounted for. Therefore, the applied methodology combined information from temporal and spatial analysis developed previously in this work, as well as numerical simulations of tephra fallout for different eruptive scenarios, to develop Bayesian Event Trees and ultimately a robust

evaluation of the impact tephra load (from 1 to 1000 kg/m²) exceedance probabilities on São Miguel. These probabilities were assessed considering both absolute probabilities for a 50-year forecast and as conditional probabilities conditional to the occurrence of a VEI 4 scenario at each central volcano.

Key findings show that lower tephra load thresholds (1 and 10 kg/m²) exhibit higher exceedance probabilities, covering the entire island, when compared to the exceedance probabilities obtained for largest tephra load values (400 kg/m² in this case).

Absolute exceedance probabilities show very low values when compared to the conditional probabilities. However, results show significant absolute exceedance probabilities of exceed 1 and 10 kg/m² of tephra over the next 50 years, considering Sete Cidades and Furnas eruptions. This highlights the influence of the use of eruption probability estimates as input to perform a complete PVHA, being very low in Fogo Volcano and, consequently, diminishing exceedance probabilities considering Fogo eruptions.

Higher values of exceedance probabilities are, typically, greater in the surrounding areas of the three volcanoes, and its dispersion is strongly conditioned by the location of the emission centres (upwind vs downwind) and by the prevailing westerly winds in the Azores region.

Absolute hazard maps illustrating the 5% exceedance probabilities of tephra load thresholds indicate, once again, lower values compared to the conditional exceedance probabilities. However, significant tephra accumulation may occur over the next 50 years (e.g., 200 kg/m² - 300kg/m² - thickness of 20 - 30 cm - near Sete Cidades; 50 kg/m² - 200 kg/m² - thickness of 5 - 20 cm - at Furnas village). This suggests that there is a low, but non negligible, change of buildings and other supply systems to suffer tephra impacts over the next 50 years.

The computation of hazard curves for Ponta Delgada airport, Divino Espírito Santo hospital and Pico Vermelho geothermal powerplant illustrated the utility of PVHA to identify vulnerabilities

in different locations and guide mitigation strategies. Main results suggest that a future eruption at each central volcano may threaten these infrastructures in different ways.

Absolute hazard curves suggests that Sete Cidades represents the main threat to the airport and hospital infrastructures in the next 50 years, with higher estimated exceedance probabilities, while Fogo can cause more damage to the Pico Vermelho geothermal powerplant over the same period. Exceedance probabilities are higher under a VEI 4 scenario, indicating that Sete Cidades may have a greater impact on the airport, followed by Fogo, and Furnas.

Considering the hospital and the specific threshold in load into analysis (400 kg/m^2), only products from Sete Cidades and Fogo volcanoes may affect this infrastructure. Pico Vermelho powerplant may be affected by all three volcanoes, where is Fogo the major threat, followed by Sete Cidades and Furnas.

Merging all three PVHA from the three central volcanoes, it is notable that the whole island is vulnerable to tephra fallout in the next 50 years, being particularly susceptible to lower tephra loads (e.g., 1 and 10 kg/m^2).

Regarding medium to high tephra loads, communities and infrastructures near the active volcanoes are more vulnerable. This may suggest the necessity to define mitigation strategies, especially for this location and considering different types of infrastructures. Therefore, it is observed that the area from Relva to Caloura, as well as Nordeste parish are the less vulnerable locations to tephra fallout in the next 50 years. However, this will always depend on eruption source parameters and from meteorological conditions at the moment of the eruption.

This study represents an example of the flexibility of a PVHA, demonstrating the value of applying an approach like this, especially on volcanic islands, where assessing volcanic hazards is a challenge. The development of a full long-term PVHA not only provides a better understanding of potential hazards of island volcanoes, as well it is a crucial tool for decision

makers and emergency and land-use planning, strengthening the preparedness and resilience of local communities.

Chapter 5

Final Remarks

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5.1. Final Remarks

Volcanic eruptions have been threatening societies since the early history of humanity. The unpredictable nature of volcanic processes makes the assessment of volcanic hazards a complex and challenging task. Eruptions can generate a wide range of volcanic products, including tephra fall, PDCs, lava flows, gases, lahars and others, which poses different threats to human life, critical infrastructure, economic sector, and the environment.

Small volcanic islands, such as those of the Azores, are particularly vulnerable to volcanic hazards due to their limited area and irregular topography, where populations and critical infrastructure are often concentrated near active volcanoes. Understanding eruptive patterns on islands with dormant active volcanoes or low eruptive frequency volcanic systems, such as São Miguel, presents unique challenges, as the reconstruction of past activity is greatly conditioned by incomplete geological records. Moreover, islands are typically isolated, limiting access to resources and restricting emergency responses. For this reason, the development of robust methodologies that allow for hazard quantification is crucial for island volcanoes to support decision-makers, response operations, and enhance populations resilience.

To date, volcanic hazard assessment studies in the Azores region relied almost exclusively on deterministic approaches, focusing on specific past events to model the most probable or worst-case scenarios. Although this method provides insights into deposition and dispersion patterns of volcanic products, it is often limited in addressing a full range of possible scenarios and their probability of occurrence, as well as in incorporating uncertainties that arise from the inherent

variability of volcanic processes (aleatory uncertainty) and from the limited knowledge of volcanic systems (epistemic uncertainty).

To overcome the limitations of deterministic approaches and enhance the effectiveness of hazard assessment in the Azores, a complete long-term probabilistic volcanic hazard assessment (PVHA) framework was applied on São Miguel Island.

Probabilistic methods are typically well-suited for volcanic environments characterised by large uncertainties, as they allow for the incorporation of the variability related to volcanological and meteorological data. For this reason, probabilistic approaches that account for data uncertainties are of paramount importance as they improve the ability to predict and plan response strategies for a wide range of eruptive scenarios.

The present study focused on assessing the impacts of tephra fallout on the island of São Miguel, which is one of the most frequent and widespread volcanic hazards, related to explosive eruptions at the three active central volcanoes (Sete Cidades, Fogo, and Furnas).

The long-term PVHA frameworks applied in this study were rooted in Bayesian inference. In Bayesian inference, prior beliefs, such as geological records, meteorological inputs, model outputs, and others, are incorporated and refined as new datasets may become available. New data are then used to modify prior probabilities into posterior probabilities, which are parameterised by the confidence degree of the data. For this reason, Bayesian inference is crucial to address and manage uncertainties. This is useful for regions like São Miguel, where volcanic processes are complex and eruptive records are often incomplete, limiting the use of traditional hazard assessment methods.

A long-term PVHA approach was developed for each of the three active central volcanoes of São Miguel, which incorporated four key tasks: (1) the development of a temporal analysis where inter-event times (IETs) were estimated to calculate the probability of an eruption for the next 50 years; (2) the development of a spatial analysis to estimate the probability of opening new vents;

(3) the use of probabilistic numerical models to simulate tephra fallout for different eruptive scenarios, and (4) the development of Bayesian Event Trees to evaluate exceedance probabilities of specific tephra load thresholds, within the next 50 years, and conditional to a VEI 4 scenario.

The temporal analysis was performed using two types of event catalogues: basaltic (*s.l.*) and trachytic (*s.l.*) events together (BT catalogues) and only trachytic (*s.l.*) events (T catalogues). In the case of Furnas Volcano, as the eruptive record of the last 17,000 yr B.P. does not include basaltic eruptions, only trachytic explosive events were considered.

The analysis indicates that the Sete Cidades dataset was generated by a non-stationary process or reveals data incompleteness, contrasting to what was observed for Fogo and Furnas volcanoes. For this reason, in the case of Sete Cidades Volcano, the portion of the catalogues older than 3578 yr B.P. was excluded from the analysis.

The exponential distribution was the best fitting renewal model for most of the considered catalogues. However, there was also a significant number of catalogues that were best fitted by other distributions (e.g. Gamma, BPT, and Weibull).

IETs estimations using BT catalogues indicate that Sete Cidades Volcano has shorter IETs when compared to Fogo, and therefore, it is more likely to produce a basaltic or trachytic eruption over the next 50 years. IETs results using T catalogues indicate that shorter IETs were estimated for Sete Cidades, followed by Furnas and Fogo volcanoes, suggesting that Sete Cidades is more likely to produce a trachytic eruption over the next 50 years, when compared to the other two central volcanoes.

The spatial analysis was performed for each central volcano considering different types of vents: (1) basaltic (*s.l.*) and trachytic (*s.l.*) vents together (BT); (2) trachytic (*s.l.*) vents (T), irrespectively of being effusive or explosive, and (3) explosive trachytic (*s.l.*) vents only (ET). For this analysis different smoothing parameters (h) and kernel functions (i.e., Gamma, Cauchy, Exponential, and Uniform) were tested, extending the study beyond the usual use of Gaussian and Cauchy

functions. Therefore, spatial probability maps of vent opening were obtained through the best pair (h + kernel function).

Results indicate that the Gaussian distribution was frequently the best fit to the data (e.g. Sete Cidades T, Sete Cidades ET, Fogo BT, Fogo T, Furnas BT, Furnas T, and Furnas ET). The Cauchy distribution also fits data from Sete Cidades (BT) and Fogo (ET) volcanoes.

The results obtained for Sete Cidades Volcano suggest that the southwest and west flanks are more likely to host a new basaltic (*s.l.*) or trachytic (*s.l.*) eruptive centre. Trachytic (*s.l.*) eruptive centres are more likely to open in the south sector of Sete Cidades caldera and along the west flank, while explosive trachytic (*s.l.*) eruptive centres are more likely to open on the southern sector within the caldera.

For Fogo Volcano, basaltic (*s.l.*) or trachytic (*s.l.*) eruptive centres are more likely to open on the southeast sector within the caldera, as well on the southwest, west, and northwest flanks. New eruptive centres are also more likely to occur at the southeast sector within caldera, as well as at the west and northeast flanks. Explosive trachytic (*s.l.*) eruptions are more likely in the eastern half of Fogo caldera.

For Furnas Volcano, basaltic (*s.l.*) or trachytic (*s.l.*) eruptive centres are more likely to form at the Pico do Ferro domes area. Whereas trachytic (*s.l.*) eruptions are more likely to occur at Pico do Ferro area and at Furnas caldera, while explosive trachytic(*s.l.*) eruptive centres are expected to occur exclusively within the caldera.

The PVHA framework for the three active central volcanoes was developed considering only explosive trachytic eruptions, as they are the most common and hazardous event.

The goal of the PVHA was to evaluate the impact of specific tephra load thresholds in the next 50 years, and conditional to a VEI 4 eruption on the island of São Miguel.

The results from the previous analyses (temporal and spatial) were incorporated and numerical simulations were performed to construct Bayesian Event Trees and to produce hazard curves, probability maps, and hazard maps.

Probability maps show that lower tephra load thresholds (e.g., 1 and 10 kg/m²) exhibit higher exceedance probabilities over the next 50 years, over most of the island, when compared to higher load thresholds (e.g., 400 kg/m²), which are frequently more localized in certain areas. Moreover, these results suggest that Sete Cidades and Furnas volcanoes may be the main contributors to these tephra accumulations.

Under a VEI 4 scenario, all three volcanoes can generate large amounts of tephra, impacting differently São Miguel Island.

Hazard maps representing the 5% exceedance probability thresholds, considering absolute probabilities, suggest that Sete Cidades and Furnas volcanoes may represent a higher threat to local communities in the next 50 years, with tephra accumulations reaching tephra loads of 200 kg/m² to 300 kg/m², and 50 kg/m² to 200 kg/m², respectively (thickness of 20 to 30 cm and 5 to 20 cm, respectively) on neighbouring areas of these volcanoes. Higher tephra loads are expected under a VEI 4 scenario at each of the volcanoes.

Consecutively, it is observed that absolute probability values (i.e., for the 50-year forecast), both for probability and hazard maps, are lower than conditional probability values (i.e., when assuming a VEI 4 scenario). This shows the influence of the input parameters on the analysis, especially regarding the estimated probabilities of occurrence of an explosive trachytic eruption in the next 50 years, which are used to compute absolute probabilities. For this reason, the probabilities are frequently lower for Fogo Volcano when compared to the other two volcanoes, as it exhibits the lowest probability of an eruption in the next 50 years. Nevertheless, Fogo is considered one of the most hazardous volcanoes in the Azores, as it produced the largest eruption in the last 5000 years.

Hazard curves were computed for Ponta Delgada airport, the Divino Espirito Santo hospital, and the Pico Vermelho geothermal powerplant to evaluate the impact of specific intensity thresholds of tephra load over the next 50 years.

The results indicate that Sete Cidades Volcano represents the greatest threat to the airport and hospital, while Fogo Volcano may have the greatest impact on the geothermal powerplant.

Under a VEI 4 scenario, it is expected that Sete Cidades will have the greatest impact on the airport, followed by Fogo and Furnas volcanoes.

Regarding the hospital, results suggest that eruptions from Sete Cidades and Fogo may impact this infrastructure. Pico Vermelho geothermal powerplant is vulnerable to tephra loads from the three volcanos, Fogo being the greatest threat.

By combining the PVHA from each volcano into a single 50 year-forecast analysis, it is possible to conclude that there is a significant chance that the entire island will be covered by tephra fall, especially with lower tephra loads, while higher loads are expected at the areas around the central volcanoes. For the same period, the southern coastal area from the airport to the south flank of Fogo, as well as the northeast end of the island are considered the less vulnerable locations to tephra fallout in the next 50 years.

Overall, the three active central volcanoes on São Miguel have the potential to generate hazardous phenomena, which may cause complete disruption on a local scale, as well as significant impacts across the North Atlantic airspace.

According to their location on the island, which may be more or less favourable to the dispersion of tephra by the prevailing westerly winds, the different volcanoes will have distinct impacts on localities across the island.

For instance, Sete Cidades Volcano is located on the western sector of São Miguel, suggesting higher impacts on this part of the island. However, tephra from Sete Cidades is expected to

disperse to the east due to the prevailing winds, reaching, in some cases, the eastern end of the island. Regarding Fogo Volcano, which occupies the central part of São Miguel, tephra fall could have a major impact across the entire length of the island. On the other hand, Furnas Volcano is in the eastern half of the island and therefore tephra fall is expected to have a larger impact on the eastern part of São Miguel.

Developing a full PVHA to assess volcanic hazards on São Miguel Island was challenging, especially in what concerns the compilation of the required input data. For instance, establishing stratigraphic correlations of pyroclastic sequences from the north to south flanks of the volcanoes is often difficult. This led to the selection of specific portions of the eruptive sequences, which were considered the most representative, to use in the temporal analysis. Furthermore, the identification and characterization of the older eruptive events is challenging, which limited the study to the younger sequence (i.e., for Sete Cidades Volcano the last 16,000 yr B.P, for Fogo Volcano the last 15,000 yr B.P, and for Furnas Volcano the last 17,000 yr B.P).

Radiocarbon ages are scarce across the eruptive sequences, generating uncertainties about the distribution of events through time, and consequently, the past eruptive behaviour of these volcanoes.

Past eruptive vents were also difficult to recognize, as some were densely vegetated, eroded or covered by the products of subsequent eruptions. Moreover, among the several tectonic features identified in previous works, only a few are confirmed tectonic structures, while a large number are inferred based on the alignment of volcanic vents. This supported the choice of not including tectonic structures in the spatial analysis to avoid significant bias. However, it is also known that faults are often considered in similar studies as one of the main types of data used to estimate vent opening probabilities.

To address some of the challenges mentioned so far, a flowchart is presented here containing the methodological framework proposed in this study, which could be considered as best practise to assess volcanic hazards on islands (Fig. 5.1).

The flowchart outlines the methodology developed during this work, containing the main steps to perform a complete PVHA, where four major steps are recognized: temporal analysis, spatial analysis, numerical simulations, and Bayesian Event Trees.

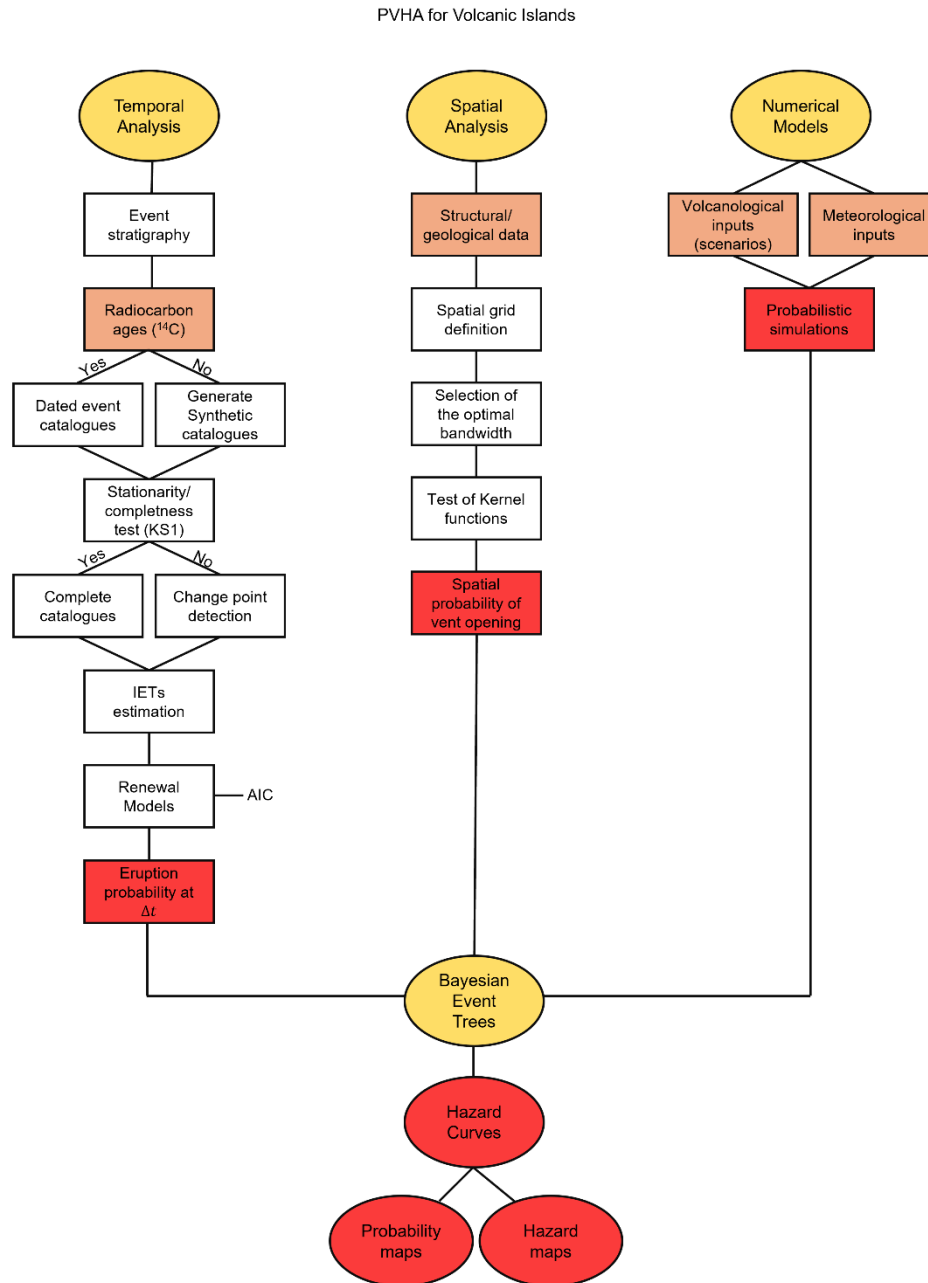


Figure 5. 1. Flowchart containing the proposed best practice to assess volcanic hazards on islands. The yellow colour indicates the main tasks of the framework; White colour indicates the steps of the analysis; Orange colour indicates the input data; Red colour indicates the outputs of the analysis.

Temporal analysis is often applied to better understand the eruptive behaviour of volcanoes over time, providing the basis to forecast future eruptions in a specific timeframe. In this case, the temporal analysis relied on the generation of synthetic catalogues, where synthetic but stratigraphy-consistent ages were assigned to the eruptive events. This approach allowed to overcome the limitations related to the undated and poorly preserved eruptive records on the island (see Chapter 2 for details).

Understanding where the next eruption may occur provides important clues regarding potential outcomes and associated hazards. Spatial probability maps of the opening of new vents were obtained based on the location of past emission centres, including single vents and eruptive fissures. Four kernel functions and several smoothing parameters were explored to model the probability distribution of a new vent opening at each volcanic system (see Chapter 3 for details).

Probabilistic numerical modelling is a key component of PVHA, allowing the simulation of a wide range of potential eruptive scenarios, where wind variability is typically included. This is crucial to better understand and capture the variety of possible outcomes and their impacts. In this study, different sizes of eruptions were modelled to evaluate the impact of tephra fall (see Chapter 4 for details). However, other hazards can be modelled and incorporated into this framework, providing a more robust hazard assessment analysis. The outcomes of the previous steps were incorporated into Bayesian event trees to produce hazard curves, probability maps, and hazard maps.

The proposed flowchart summarizes, not only, the methodology applied but also represents a useful tool to guide volcanic hazard assessments in other regions, where these practices can be adapted to specific volcanic island contexts.

The present study offers a more comprehensive methodology to the assessment of volcanic hazards on islands, such as the Azores, where geological records are frequently incomplete and events are poorly reconstructed, generating uncertainties regarding the past behaviour. The

implementation of such an approach, for the first time on São Miguel Island, represents a step forward in hazard assessment, shifting from deterministic to probabilistic approaches.

This robust methodology improves the understanding of volcanic processes and associated hazards, as well as offers a versatile tool to guide decision making. A key strength of this framework lies in its flexibility and adaptability. While specific load thresholds were used in this work to analyse the impacts of tephra fall in specific infrastructures (e.g., Ponta Delgada airport, Divino Espírito Santo hospital, and Pico Vermelho geothermal powerplant), different intensity thresholds can be selected to tailor assessments according to the stakeholders' needs. For instance, the impact of tephra loads on buildings, ports, main roads, communications, and many other cases, can be assessed.

Outcomes of this research offer valuable insights into volcanic hazards and their impact on small territories, such as São Miguel Island. Moreover, they provide a scientific foundation to evaluate vulnerable locations, contributing to an optimized long-term land-use planning.

The probabilistic framework presented in this study enables the anticipation of potential scenarios and their impacts on population centres and critical infrastructures, allowing decision makers to draw effective mitigation and response strategies, as well as plan resource allocation and community training programs. Additionally, it enables scientists and government bodies to communicate the risk efficiently. For these reasons, hazard curves, probability maps, and hazard maps are important tools in assisting scientists, civil protection, policymakers, and other decision-makers, guiding the development of effective emergency response plans, prioritizing mitigation strategies, and enhancing the resilience of local communities.

Furthermore, the applicability of this approach can be extended beyond São Miguel and the Azores region and applied to volcanic regions worldwide, encouraging the use of PVHA approaches on volcanic islands, with limited geological data and high associated uncertainty.

Further Research

As highlighted during this work, all three active central volcanoes of São Miguel have the potential to generate hazardous phenomena. Although tephra fall is the most common volcanic product in the eruptive sequences used to perform this analysis, pyroclastic density currents (PDCs) were also produced during past explosive trachytic eruptions (e.g., Santa Bárbara, Fogo A, Furnas AD 1630, and others). For this reason, it is important to develop a full multi-hazard approach that includes PDCs and other types of volcanic hazards. This would provide an even more robust volcanic hazard assessment study for São Miguel Island, contributing to the development of more effective mitigation strategies.

Probabilistic numerical models are essential to perform a complete and robust PVHA. In this work, numerical simulations were performed using the HAZMAP model and its probability mode. While this represents an advance regarding previous models, it still fails in accounting for variability of volcanological inputs within the same scenario, i.e., the use of a range of column heights instead of a single value for each eruptive scenario. Future research should focus on the use of more robust numerical models that account for both volcanological and meteorological data variability (e.g., Fall3D).

Furthermore, probabilistic models for other types of volcanic hazards should also be used and their results incorporated into a full PVHA, allowing to capture the full range of possible outcomes.

Although this study focuses on São Miguel Island, this methodological approach can be applied to other islands of the Azores, particularly to the islands prone to trachytic explosive eruptions, like Terceira, Faial and Graciosa. This would allow for a broader understanding of volcanic hazards across the Azores, enhancing emergency preparedness in the region

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APPENDICES

Appendix A.1

Eruptive records

Sete Cidades Volcano whole dataset					
Formation	Age	Deposit	Nature	Style	VEI
Santa Bárbara	15740±200 yr BP [1]	Santa Bárbara	Trachytic	Sub-Plinian	≥4*
Lagoas-Cascalho Negro	Unknown	CN1	Basaltic	Hawaiian	0*
	Unknown	CN2	Trachytic	Sub-Plinian	≥3*
	Unknown	CN3	Trachytic	Dome forming	0
	Unknown	CN4	Basaltic	Strombolian	1-2*
	Unknown	CN5	Trachytic	Dome forming	1-2*
	Unknown	CN6	Trachytic	Sub-Plinian	≥3*
	Unknown	CN7	Trachytic	Sub-Plinian	≥3*
	Unknown	CN8	Basaltic	Strombolian	1-2*
	Unknown	CN9	Trachytic	Sub-Plinian	≥3*
	Unknown	CN10	Trachytic	Sub-Plinian	≥3*
	Unknown	CN11	Basaltic	Strombolian	1-2*
Lagoas - Pepom	Unknown	Sete P-1	Trachytic	Sub-Plinian	4 [4]
	Unknown	Pico de Mafra	Basaltic	Strombolian	1-2*
	Unknown	Pico dos Ginetes	Basaltic	Strombolian	1-2*
	3580±50 yr BP [1]	Sete P-2	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-3	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-4	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Cone E Camarinhas	Basaltic	Strombolian	1-2*
	Unknown	Sete P-5	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-6	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-7	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-8	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-9	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-10	Trachytic	Sub-Plinian	<3 [4]
	2220±70 yr BP [1]	Sete P-11	Trachytic	Sub-Plinian	4 [4]
	Unknown	Basaltic Pyroclasts	Basaltic	Strombolian	1-2*
	Unknown	Sete P-12	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-13	Trachytic	Sub-Plinian	3 [4]

	Unknown	Sete P-14	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-15	Trachytic	Sub-Plinian	4 [4]
	1280±150 yr BP [2]	Pico do Carvão	Basaltic	Strombolian	1-2*
	980±90 yr BP [2]	Pico as Ferrarias	Basaltic	Strombolian	1-2*
	Unknown	Sete P-16	Trachytic	Sub-Plinian	<3 [4]
	840±60 yr BP [2]	Pico das Camarinhas	Basaltic	Strombolian	2*
	500±100 yr BP [2]/ 663±105 yr BP [3]	Sete P-17	Trachytic	Sub-Plinian	4 [4]

[1] Queiroz, G. (1997). Vulcão das Sete Cidades (S. Miguel, Açores): história eruptiva e avaliação do hazard. PhD thesis, Universidade dos Açores (In Portuguese).

[2] Moore, R. B.; Rubin, M. (1991). Radiocarbon dates for lava flows and pyroclastic deposits on São Miguel, Azores. Radiocarbon, 33(01), 151-164.

[3] Shotton, FW and Williams, REG 1971 Birmingham University radiocarbon dates V. Radiocarbon 13(2): 141-156.

[4] Queiroz, G., Pacheco, J. M., Gaspar, J. L., Aspinall, W., Guest, J. E. and Ferreira, T. (2008). The last 5000 years of activity at Sete Cidades volcano (S. Miguel Island, Azores): implications for hazard assessment. Journal of Volcanology and Geothermal Research, 178, 562–573.

*Value estimated by comparison of field observations with other deposits

Sete Cidades Volcano complete dataset					
Formation	Age	Deposit	Nature	Style	VEI
Lagoas - Pepom	3580±50 yr BP [1]	Sete P-2	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-3	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-4	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Cone E Camarinhas	Basaltic	Strombolian	1-2*
	Unknown	Sete P-5	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-6	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-7	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-8	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-9	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-10	Trachytic	Sub-Plinian	<3 [4]
	2220±70 yr BP [1]	Sete P-11	Trachytic	Sub-Plinian	4 [4]
	Unknown	Basaltic Pyroclasts	Basaltic	Strombolian	1-2*
	Unknown	Sete P-12	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-13	Trachytic	Sub-Plinian	3 [4]
	Unknown	Sete P-14	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-15	Trachytic	Sub-Plinian	4 [4]
	1280±150 yr BP [2]	Pico do Carvão	Basaltic	Strombolian	1-2*
	980±90 yr BP [2]	Pico as Ferrarias	Basaltic	Strombolian	1-2*
	Unknown	Sete P-16	Trachytic	Sub-Plinian	<3 [4]
	840±60 yr BP [2]	Pico das Camarinhas	Basaltic	Strombolian	2*
	500±100 yr BP [2]/ 663±105 yr BP [3]	Sete P-17	Trachytic	Sub-Plinian	4 [4]

[1] Queiroz, G. (1997). Vulcão das Sete Cidades (S. Miguel, Açores): história eruptiva e avaliação do hazard. PhD thesis, Universidade dos Açores (In Portuguese).

[2] Moore, R. B.; Rubin, M. (1991). Radiocarbon dates for lava flows and pyroclastic deposits on São Miguel, Azores. Radiocarbon, 33(01), 151-164.

[3] Shotton, FW and Williams, REG 1971 Birmingham University radiocarbon dates V. Radiocarbon 13(2): 141-156.

[4] Queiroz, G., Pacheco, J. M., Gaspar, J. L., Aspinall, W., Guest, J. E. and Ferreira, T. (2008). The last 5000 years of activity at Sete Cidades volcano (S. Miguel Island, Azores): implications for hazard assessment. Journal of Volcanology and Geothermal Research, 178, 562–573.

*Value estimated by comparison of field observations with other deposits

Fogo Volcano dataset					
Formation	Age	Deposit	Nature	Style	VEI
Roída da Praia - Intermediate	14620±60 yr BP [1]	RPM1	Trachytic	Sub-Plinian	3*
	Unknown	RPM2	Trachytic	Sub-Plinian	≥3*
	Unknown	RPM3	Trachytic	Sub-Plinian	3*
Roída da Praia - Upper	Unknown	RPU1	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU2	Basaltic	Strombolian	1-2*
	Unknown	RPU3	Trachytic	Sub-Plinian ?	3*
	Unknown	RPU4	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU5	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU6	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU7	Trachytic	Sub-Plinian	≥3*
Ribeira Chã	8-12 kyr (Unknown)	Ribeira Chã	Trachytic	Plinian	≥4/5*
Pre-FogoA	4990±100 yr BP [2]	Monte Gordo	Basaltic	Strombolian	1-2*
Pisão	4760±60 yr BP [1]	Pisão	Trachytic	Sub-Plinian	4*
Fogo A	4520±90 yr BP [1]	Fogo A	Trachytic	Plinian	5 [4]
Lombadas	3240±90 yr BP [3]	Fogo B	Trachytic	Sub-Plinian	4 [5]
	Unknown	Fogo C	Trachytic	Sub-Plinian	4 [5]
	Unknown	Fogo D	Trachytic	Sub-Plinian	4 [5]
Post-FogoA	1790±150 yr BP [2]	Pico Arde	Basaltic	Strombolian	1-2*
Post-FogoA	Unknown	Caloura	Basaltic	Strombolian	1-2*
Fogo 1563	1563 AD	Fogo 1563T	Trachytic	Sub-Plinian	4 [6]
Post-FogoA	1563 AD	Sapateiro 1563	Basaltic	Hawaiian	0*

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*Value estimated by comparison of field observations with other deposits

Furnas Volcano dataset					
Formation	Age	Deposit	Nature	Style	VEI
Ponta Garça Ignimbrite	17240±70 yr BP [1]	Ponta Garça Ignimbrite	Trachytic	Plinian?	≥4*
Cancelinha	Unknown	C1	Trachytic	Sub-Plinian	≥3*
	Unknown	C2	Trachytic	Sub-Plinian	≥3*
	Unknown	C3	Trachytic	Sub-Plinian	≥3*
	Unknown	C4	Trachytic	Sub-Plinian	≥3*
	Unknown	C5	Trachytic	Sub-Plinian?	≥3*
	Unknown	C6	Trachytic	Sub-Plinian	≥4*
	Unknown	C7	Trachytic	Sub-Plinian	≥3*
	Unknown	C8	Trachytic	Sub-Plinian?	≥3*
	Unknown	C9	Trachytic	Sub-Plinian	≥4*
	Unknown	C10	Trachytic	Sub-Plinian	≥4*
Pico do Ferro Domes	< 12 kyr BP (Unknown)	Pico do Ferro Domes	Trachytic	Dome forming	0
Pico do Canário	Unknown	PC1	Trachytic	Sub-Plinian	3*
Pico do Canário	Unknown	PC2	Trachytic	Sub-Plinian	3*
Pico do Canário	Unknown	PC3	Trachytic	Sub-Plinian	3*
Pico do Canário	Unknown	PC4	Trachytic	Sub-Plinian	3*
Upper Furnas Gru	Unknown	Furnas A	Trachytic	Sub-Plinian	3 [5]
	2310±160 yr BP [1]	Furnas B	Trachytic	Sub-Plinian	3 [5]
	1870±120 yr BP [1]	Furnas C	Trachytic	Sub-Plinian	5
	Unknown	Furnas D	Trachytic	Sub-Plinian	3 [5]
	1520±30 yr BP [2]	Furnas E	Trachytic	Sub-Plinian/Dome forming	4 [2]
	800±60 AD[1]/1100±60 yr BP [3]	Furnas F	Trachytic	Sub-Plinian	4 [5]
	1170±120 AD [1]/780±120 yr BP [3]	Furnas G	Trachytic	Sub-Plinian	4 [5]
	~1425 AD [1]/490±50 yr BP and 560±50 yr BP [4]	Furnas H	Trachytic	Sub-Plinian	3 [5]
	1439-43 AD	Furnas 1439-43	Trachytic	Sub-Plinian/Dome Forming	3 [5]
	1630 AD	Furnas 1630	Trachytic	Sub-Plinian/Dome forming	4

[1] Guest, J. E.; Gaspar, J. L.; Cole, P. D.; Queiroz, G.; Duncan, A. M.; Wallenstein, N.; Ferreira, T.; Pacheco, J. M. (1999). Volcanic Geology Of Furnas Volcano, São Miguel, Azores. Journal Of Volcanology And Geothermal Research, 92, 1-2.

- [2] Aguiar, S. (2018). Contribuição para o estudo da estratigrafia dos vulcões Fogo e Furnas (S. Miguel, Açores): implicações para a sua história eruptiva recente, MSc thesis, Universidade dos Açores, Portugal, 158 pp., (in Portuguese).
- [3] Moore, R. B.; Rubin, M. (1991). Radiocarbon dates for lava flows and pyroclastic deposits on São Miguel, Azores. *Radiocarbon*, 33(01), 151-164.
- [4] Guest, J.E., A.M. Duncan, P.D. Cole, J.L. Gaspar, G. Queiroz, N. Wallenstein & T. Ferreira. (1994). Preliminary Report On The Volcanic Geology Of Furnas Volcano, Sao Miguel, Azores, 24 Pp. Furnas Elv Open File Report N°1, Ec Environment Programme - Furnas European Laboratory Volcano, Project 06 - Eruptive History And Hazard. In : Queiroz, G., Gaspar, J.L., Cole, P.D., Guest, J.E., Wallenstein, N., Duncan, A.M. and Pacheco, J. (1995). Erupções Vulcânicas no Vale das Furnas (Ilha de São Miguel, Açores) Na primeira metade do século XV. *Açoreana*, 8(1): 159-165 (In Portuguese).
- [5] Loughlin, S.C., Vye-Brown, Sparks, R.S.J., Brown, S.K., Barclay, J., Calder, E., Jolly, G., Komorowski, J.-C., Mandeville, C., Newhall, C., Palma, J., Potter, S. e Valentine, G. (2015). An introduction to global volcanic hazard and risk. In: Loughlin, S.C., Sparks, S., Brown, S.K., Jenkins, S.F., Vye-Brown, C. (Eds.), *Global volcanic hazards and risk*: 410p.

*Value estimated by comparison of field observations with other deposits

Appendix A.1

Eruptive records

Sete Cidades Volcano whole dataset					
Formation	Age	Deposit	Nature	Style	VEI
Santa Bárbara	15740±200 yr BP [1]	Santa Bárbara	Trachytic	Sub-Plinian	≥4*
Lagoas-Cascalho Negro	Unknown	CN1	Basaltic	Hawaiian	0*
	Unknown	CN2	Trachytic	Sub-Plinian	≥3*
	Unknown	CN3	Trachytic	Dome forming	0
	Unknown	CN4	Basaltic	Strombolian	1-2*
	Unknown	CN5	Trachytic	Dome forming	1-2*
	Unknown	CN6	Trachytic	Sub-Plinian	≥3*
	Unknown	CN7	Trachytic	Sub-Plinian	≥3*
	Unknown	CN8	Basaltic	Strombolian	1-2*
	Unknown	CN9	Trachytic	Sub-Plinian	≥3*
	Unknown	CN10	Trachytic	Sub-Plinian	≥3*
	Unknown	CN11	Basaltic	Strombolian	1-2*
Lagoas - Pepom	Unknown	Sete P-1	Trachytic	Sub-Plinian	4 [4]
	Unknown	Pico de Mafra	Basaltic	Strombolian	1-2*
	Unknown	Pico dos Ginetes	Basaltic	Strombolian	1-2*
	3580±50 yr BP [1]	Sete P-2	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-3	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-4	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Cone E Camarinhas	Basaltic	Strombolian	1-2*
	Unknown	Sete P-5	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-6	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-7	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-8	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-9	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-10	Trachytic	Sub-Plinian	<3 [4]
	2220±70 yr BP [1]	Sete P-11	Trachytic	Sub-Plinian	4 [4]
	Unknown	Basaltic Pyroclasts	Basaltic	Strombolian	1-2*
	Unknown	Sete P-12	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-13	Trachytic	Sub-Plinian	3 [4]

	Unknown	Sete P-14	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-15	Trachytic	Sub-Plinian	4 [4]
	1280±150 yr BP [2]	Pico do Carvão	Basaltic	Strombolian	1-2*
	980±90 yr BP [2]	Pico as Ferrarias	Basaltic	Strombolian	1-2*
	Unknown	Sete P-16	Trachytic	Sub-Plinian	<3 [4]
	840±60 yr BP [2]	Pico das Camarinhas	Basaltic	Strombolian	2*
	500±100 yr BP [2]/ 663±105 yr BP [3]	Sete P-17	Trachytic	Sub-Plinian	4 [4]

[1] Queiroz, G. (1997). Vulcão das Sete Cidades (S. Miguel, Açores): história eruptiva e avaliação do hazard. PhD thesis, Universidade dos Açores (In Portuguese).

[2] Moore, R. B.; Rubin, M. (1991). Radiocarbon dates for lava flows and pyroclastic deposits on São Miguel, Azores. Radiocarbon, 33(01), 151-164.

[3] Shotton, FW and Williams, REG 1971 Birmingham University radiocarbon dates V. Radiocarbon 13(2): 141-156.

[4] Queiroz, G., Pacheco, J. M., Gaspar, J. L., Aspinall, W., Guest, J. E. and Ferreira, T. (2008). The last 5000 years of activity at Sete Cidades volcano (S. Miguel Island, Azores): implications for hazard assessment. Journal of Volcanology and Geothermal Research, 178, 562–573.

*Value estimated by comparison of field observations with other deposits

Sete Cidades Volcano complete dataset					
Formation	Age	Deposit	Nature	Style	VEI
Lagoas - Pepom	3580±50 yr BP [1]	Sete P-2	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-3	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-4	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Cone E Camarinhas	Basaltic	Strombolian	1-2*
	Unknown	Sete P-5	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-6	Trachytic	Sub-Plinian	<4 [4]
	Unknown	Sete P-7	Trachytic	Sub-Plinian	<3 [4]
	Unknown	Sete P-8	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-9	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-10	Trachytic	Sub-Plinian	<3 [4]
	2220±70 yr BP [1]	Sete P-11	Trachytic	Sub-Plinian	4 [4]
	Unknown	Basaltic Pyroclasts	Basaltic	Strombolian	1-2*
	Unknown	Sete P-12	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-13	Trachytic	Sub-Plinian	3 [4]
	Unknown	Sete P-14	Trachytic	Sub-Plinian	4 [4]
	Unknown	Sete P-15	Trachytic	Sub-Plinian	4 [4]
	1280±150 yr BP [2]	Pico do Carvão	Basaltic	Strombolian	1-2*
	980±90 yr BP [2]	Pico as Ferrarias	Basaltic	Strombolian	1-2*
	Unknown	Sete P-16	Trachytic	Sub-Plinian	<3 [4]
	840±60 yr BP [2]	Pico das Camarinhas	Basaltic	Strombolian	2*
	500±100 yr BP [2]/ 663±105 yr BP [3]	Sete P-17	Trachytic	Sub-Plinian	4 [4]

[1] Queiroz, G. (1997). Vulcão das Sete Cidades (S. Miguel, Açores): história eruptiva e avaliação do hazard. PhD thesis, Universidade dos Açores (In Portuguese).

[2] Moore, R. B.; Rubin, M. (1991). Radiocarbon dates for lava flows and pyroclastic deposits on São Miguel, Azores. Radiocarbon, 33(01), 151-164.

[3] Shotton, FW and Williams, REG 1971 Birmingham University radiocarbon dates V. Radiocarbon 13(2): 141-156.

[4] Queiroz, G., Pacheco, J. M., Gaspar, J. L., Aspinall, W., Guest, J. E. and Ferreira, T. (2008). The last 5000 years of activity at Sete Cidades volcano (S. Miguel Island, Azores): implications for hazard assessment. Journal of Volcanology and Geothermal Research, 178, 562–573.

*Value estimated by comparison of field observations with other deposits

Fogo Volcano dataset					
Formation	Age	Deposit	Nature	Style	VEI
Roída da Praia - Intermediate	14620±60 yr BP [1]	RPM1	Trachytic	Sub-Plinian	3*
	Unknown	RPM2	Trachytic	Sub-Plinian	≥3*
	Unknown	RPM3	Trachytic	Sub-Plinian	3*
Roída da Praia - Upper	Unknown	RPU1	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU2	Basaltic	Strombolian	1-2*
	Unknown	RPU3	Trachytic	Sub-Plinian ?	3*
	Unknown	RPU4	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU5	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU6	Trachytic	Sub-Plinian	≥3*
	Unknown	RPU7	Trachytic	Sub-Plinian	≥3*
Ribeira Chã	8-12 kyr (Unknown)	Ribeira Chã	Trachytic	Plinian	≥4/5*
Pre-FogoA	4990±100 yr BP [2]	Monte Gordo	Basaltic	Strombolian	1-2*
Pisão	4760±60 yr BP [1]	Pisão	Trachytic	Sub-Plinian	4*
Fogo A	4520±90 yr BP [1]	Fogo A	Trachytic	Plinian	5 [4]
Lombadas	3240±90 yr BP [3]	Fogo B	Trachytic	Sub-Plinian	4 [5]
	Unknown	Fogo C	Trachytic	Sub-Plinian	4 [5]
	Unknown	Fogo D	Trachytic	Sub-Plinian	4 [5]
Post-FogoA	1790±150 yr BP [2]	Pico Arde	Basaltic	Strombolian	1-2*
Post-FogoA	Unknown	Caloura	Basaltic	Strombolian	1-2*
Fogo 1563	1563 AD	Fogo 1563T	Trachytic	Sub-Plinian	4 [6]
Post-FogoA	1563 AD	Sapateiro 1563	Basaltic	Hawaiian	0*

[1] Wallenstein, N. (1999). Estudo da história recente e do comportamento eruptivo do vulcão do Fogo S.Miguel, Açores). Avaliação preliminar do “hazard”. Tese de Doutoramento no ramo Geologia, especialidade de Vulcanologia, Departamento de Geociências, Universidade dos Açores, 266 p. (in Portuguese).

[2] Moore, R. B.; Rubin, M. (1991). Radiocarbon dates for lava flows and pyroclastic deposits on São Miguel, Azores. Radiocarbon, 33(01), 151-164.

[3] Shotton, F.W., Blundell, D.J. and Williams, R.E.G. (1970). Birmingham University radiocarbon dates, IV. Radiocarbon 2, 385-399, 392.

[4] Walker, G. P. L.; Croasdale, R. (1971). Two plinian-type eruptions in the Azores. Journal of the Geological Society, 127(1), 17-55.

[5] Loughlin, S.C., Vye-Brown, Sparks, R.S.J., Brown, S.K., Barclay, J., Calder, E., Jolly, G., Komorowski, J.-C., Mandeville, C., Newhall, C., Palma, J., Potter, S. e Valentine, G. (2015). An introduction to global volcanic hazard and risk. In: Loughlin, S.C., Sparks, S., Brown, S.K., Jenkins, S.F., Vye-Brown, C. (Eds.), Global volcanic hazards and risk: 410p.

[6] Aguiar, S. (2018). Contribuição para o estudo da estratigrafia dos vulcões Fogo e Furnas (S. Miguel, Açores): implicações para a sua história eruptiva recente, MSc thesis, Universidade dos Açores, Portugal, 158 pp., (in Portuguese).

*Value estimated by comparison of field observations with other deposits

Furnas Volcano dataset					
Formation	Age	Deposit	Nature	Style	VEI
Ponta Garça Ignimbrite	17240±70 yr BP [1]	Ponta Garça Ignimbrite	Trachytic	Plinian?	≥4*
Cancelinha	Unknown	C1	Trachytic	Sub-Plinian	≥3*
	Unknown	C2	Trachytic	Sub-Plinian	≥3*
	Unknown	C3	Trachytic	Sub-Plinian	≥3*
	Unknown	C4	Trachytic	Sub-Plinian	≥3*
	Unknown	C5	Trachytic	Sub-Plinian?	≥3*
	Unknown	C6	Trachytic	Sub-Plinian	≥4*
	Unknown	C7	Trachytic	Sub-Plinian	≥3*
	Unknown	C8	Trachytic	Sub-Plinian?	≥3*
	Unknown	C9	Trachytic	Sub-Plinian	≥4*
	Unknown	C10	Trachytic	Sub-Plinian	≥4*
Pico do Ferro Domes	< 12 kyr BP (Unknown)	Pico do Ferro Domes	Trachytic	Dome forming	0
Pico do Canário	Unknown	PC1	Trachytic	Sub-Plinian	3*
Pico do Canário	Unknown	PC2	Trachytic	Sub-Plinian	3*
Pico do Canário	Unknown	PC3	Trachytic	Sub-Plinian	3*
Pico do Canário	Unknown	PC4	Trachytic	Sub-Plinian	3*
Upper Furnas Gru	Unknown	Furnas A	Trachytic	Sub-Plinian	3 [5]
	2310±160 yr BP [1]	Furnas B	Trachytic	Sub-Plinian	3 [5]
	1870±120 yr BP [1]	Furnas C	Trachytic	Sub-Plinian	5
	Unknown	Furnas D	Trachytic	Sub-Plinian	3 [5]
	1520±30 yr BP [2]	Furnas E	Trachytic	Sub-Plinian/Dome forming	4 [2]
	800±60 AD[1]/1100±60 yr BP [3]	Furnas F	Trachytic	Sub-Plinian	4 [5]
	1170±120 AD [1]/780±120 yr BP [3]	Furnas G	Trachytic	Sub-Plinian	4 [5]
	~1425 AD [1]/490±50 yr BP and 560±50 yr BP [4]	Furnas H	Trachytic	Sub-Plinian	3 [5]
	1439-43 AD	Furnas 1439-43	Trachytic	Sub-Plinian/Dome Forming	3 [5]
	1630 AD	Furnas 1630	Trachytic	Sub-Plinian/Dome forming	4

[1] Guest, J. E.; Gaspar, J. L.; Cole, P. D.; Queiroz, G.; Duncan, A. M.; Wallenstein, N.; Ferreira, T.; Pacheco, J. M. (1999). Volcanic Geology Of Furnas Volcano, São Miguel, Azores. Journal Of Volcanology And Geothermal Research, 92, 1-2.

- [2] Aguiar, S. (2018). Contribuição para o estudo da estratigrafia dos vulcões Fogo e Furnas (S. Miguel, Açores): implicações para a sua história eruptiva recente, MSc thesis, Universidade dos Açores, Portugal, 158 pp., (in Portuguese).
- [3] Moore, R. B.; Rubin, M. (1991). Radiocarbon dates for lava flows and pyroclastic deposits on São Miguel, Azores. *Radiocarbon*, 33(01), 151-164.
- [4] Guest, J.E., A.M. Duncan, P.D. Cole, J.L. Gaspar, G. Queiroz, N. Wallenstein & T. Ferreira. (1994). Preliminary Report On The Volcanic Geology Of Furnas Volcano, Sao Miguel, Azores, 24 Pp. Furnas Elv Open File Report N°1, Ec Environment Programme - Furnas European Laboratory Volcano, Project 06 - Eruptive History And Hazard. In : Queiroz, G., Gaspar, J.L., Cole, P.D., Guest, J.E., Wallenstein, N., Duncan, A.M. and Pacheco, J. (1995). Erupções Vulcânicas no Vale das Furnas (Ilha de São Miguel, Açores) Na primeira metade do século XV. *Açoreana*, 8(1): 159-165 (In Portuguese).
- [5] Loughlin, S.C., Vye-Brown, Sparks, R.S.J., Brown, S.K., Barclay, J., Calder, E., Jolly, G., Komorowski, J.-C., Mandeville, C., Newhall, C., Palma, J., Potter, S. e Valentine, G. (2015). An introduction to global volcanic hazard and risk. In: Loughlin, S.C., Sparks, S., Brown, S.K., Jenkins, S.F., Vye-Brown, C. (Eds.), *Global volcanic hazards and risk*: 410p.

*Value estimated by comparison of field observations with other deposits

Appendix A.2

Location of past eruptive centres in each volcano

Sete Cidades basaltic central eruptive centres		
ID	Longitude	Latitude
1	609267	4189574
2	608100	4187390
3	609110	4187800
4	609270	4188129
5	609953	4186532
6	610931	4187219
7	611049	4186883
8	610399	4187919
9	610228	4185905
10	611162	4186390
11	611269	4186240
12	611498	4186129
13	611573	4186040
14	611360	4186086
15	611623	4186966
16	611789	4186687
17	612237	4187314
18	612280	4187263
19	611359	4185734
20	608028	4184284
21	609113	4185076
22	609647	4185102
23	609723	4184609
24	611011	4185397
25	611105	4185244
26	611138	4185292
27	611190	4185108
28	612046	4185700
29	612090	4185820
30	612213	4186004
31	609805	4190058
32	610045	4194579
33	607029	4195172
34	605126	4194367
35	602713	4192021
36	601990	4191388
37	601838	4189815
38	602387	4190147
39	602618	4190621
40	603371	4188109
41	606927	4193548
42	611001	4193217
43	611147	4193415
44	603312	4190670

45	604613	4188894
46	604822	4189032
47	609427	4195396
48	611467	4185955
49	601772	4189437
50	601768	4189528
51	601661	4189498
52	601627	4189368
53	612046	4185566
54	611325	4184955
55	601309	4191142
56	603419	4193708
57	604233	4190254
58	609402	4187925
59	609370	4188002
60	608476	4188049
61	608344	4188133
62	610169	4186819
63	609737	4187337
64	610025	4186950
65	610288	4187067
66	609973	4187190

Sete Cidades trachytic central eruptive centres		
ID	Longitude	Latitude
1	601576	4190812
2	602038	4190840
3	602232	4190846
4	602573	4190845
5	602950	4190873
6	603179	4191132
7	603916	4191056
8	603628	4191003
9	603569	4190858
10	603736	4190503
11	605347	4190404
12	605307	4189224
13	606541	4189451
14	607377	4189112
15	607873	4189734
16	606727	4190816
17	608037	4191243
18	607240	4192126
19	605928	4192388
20	605238	4191879
21	606818	4188947

22	606321	4189170
23	606612	4190085
24	605733	4189413
25	609131	4188359
26	608987	4188412

Sete Cidades explosive trachytic central eruptive centres		
ID	Longitude	Latitude
1	605928	4192388
2	605238	4191879
3	607240	4192126
4	608037	4191243
5	606727	4190816
6	606612	4190085
7	606541	4189451
8	606321	4189170
9	605733	4189413
10	605347	4190404
11	606818	4188947
12	607377	4189112
13	607873	4189734

Sete Cidades basaltic eruptive fissures extreams					
ID	Longitude	Latitude	Longitude	Latitude	Length (m)
1	601128	4190835	601407	4190894	285
2	609548	4185572	609704	4187379	248
3	610084	4187394	610225	4187137	294
4	609945	4187028	609995	4186983	68
5	610211	4186752	610385	4186539	275
6	608488	4187691	609213	4186826	1130
7	612536	4186938	612687	4186816	194
8	612731	4186772	612834	4186772	103

Fogo basaltic central eruptive centres		
ID	Longitude	Latitude
1	627140	4177739
2	627510	4178250
3	628586	4177820
4	627699	4177359
5	629825	4177294
6	630859	4176992
7	630370	4175715
8	630639	4175642
9	631385	4175630
10	631605	4175418
11	631519	4175204
12	631812	4175081
13	631184	4174998
14	631519	4178441
15	630713	4178881
16	630120	4178688
17	629774	4178972
18	637000	4176186
19	635814	4177225
20	636552	4177473
21	636953	4177805
22	630617	4180511
23	630989	4180938
24	629371	4181688
25	627093	4183856
26	627559	4184542
27	630773	4183209
28	630610	4183481
29	631719	4184357
30	632707	4187861
31	633445	4188012
32	633699	4187345
33	634575	4185017
34	631660	4187036
35	631432	4187051
36	631420	4186940
37	635834	4186984
38	630347	4184679
39	630252	4184664
40	630119	4184787
41	630019	4184843
42	629788	4181416
43	629856	4181343
44	631819	4183795

Fogo trachytic central eruptive centres		
ID	Longitude	Latitude
1	632916	4189499
2	633115	4188955
3	633790	4187689
4	626914	4186324
5	634647	4186539
6	635305	4186428
7	635984	4184959
8	636017	4183570
9	635589	4183678
10	635048	4183519
11	635624	4183078
12	633151	4183459
13	626614	4184729
14	627168	4184291
15	628044	4184332
16	627521	4183879
17	628314	4182957
18	628296	4182202
19	628808	4182563
20	629045	4182817
21	629322	4182402
22	629940	4181641
23	630171	4181588
24	630346	4181726
25	631437	4181741
26	632015	4182255
27	631927	4180927
28	634613	4181584
29	634455	4181667
30	633822	4181094
31	633203	4180379
32	634415	4180387
33	635058	4180129
34	632238	4176153
35	637122	4177264
36	634392	4180772
37	635360	4180253
38	635059	4180495
39	634951	4179860
40	635233	4179910
41	631955	4189453
42	630607	4184480
43	633410	4182740

Fogo explosive trachytic central eruptive centres		
ID	Longitude	Latitude
1	634415	4180387
2	634392	4180772
3	633822	4181094
4	634455	4181667
5	634613	4181584
6	635058	4180129
7	634647	4186539
8	635305	4186428
9	626914	4186324
10	633115	4188955
11	633151	4183459
12	633410	4182740

Fogo basaltic eruptive fissures extreams					
ID	Longitude	Latitude	Longitude	Latitude	Length (m)
1	628208	4183044	628422	4182895	261

Furnas basaltic central eruptive centres		
ID	Longitude	Latitude
1	645034	4177916
2	644284	4177908
3	644727	4178411
4	643987	4178345
5	643338	4178850
6	643877	4179191
7	644081	4179149
8	643740	4179851
9	644503	4180180
10	644300	4180645
11	645509	4180857
12	644087	4181680
13	644705	4183949
14	644966	4184019
15	645091	4184255
16	645517	4183995
17	645633	4183812
18	645723	4183340
19	646878	4183191

20	647095	4183874
21	646636	4184308
22	647460	4184234
23	647710	4184711
24	647863	4184996
25	648391	4184732
26	642886	4187247
27	642640	4187560
28	646373	4189344
29	647240	4188082
30	648360	4190547

Furnas trachytic central eruptive centres		
ID	Longitude	Latitude
1	643216	4186751
2	644335	4187536
3	648119	4178039
4	647586	4178674
5	648037	4179550
6	648316	4180337
7	646786	4180083
8	647040	4181156
9	648621	4181652
10	649887	4181243
11	649602	4180711
12	646724	4181832
13	646502	4181893
14	646381	4182065
15	646185	4182089
16	646034	4182086
17	645952	4182028
18	645793	4182040
19	648011	4180531
20	647012	4178956
21	651636	4181608

Furnas explosive trachytic central eruptive centres		
ID	Longitude	Latitude
1	647040	4181156
2	646786	4180083
3	647012	4178956
4	647586	4178674
5	648119	4178039
6	648037	4179550
7	648316	4180337
8	648011	4180531
9	648621	4181652
10	651636	4181608
11	649887	4181243
12	649602	4180711

Appendix A.3

HAZMAP input parameters for each scenario

VEI 3 scenario for all volcanoes

```

1          # Mode (0=deposit; 1=hazmap)
0          # Grid type (0=uniform, 1=from file)
2          # Settling velocity model
1          # Settling velocity is a function of Z
1          # Write list of cell coordinates (file grid.out)
0          # Write particles spectra
0          # Write settling velocities (file vset.out)
2          # Format of the output file
300 300    # Number of grid cells (NX,NY), used if gridtype=0
500. 500.  # Grid spacing (DX,DY), used if gridtype=0
632369. 4185351. # Coordinates of the center of the grid
1.9E10     # Total Mass
1          # Mass distribution model (0=from file, 1=Suzuki)
632369. 4185351. 0.0 # Coordinates of the vent (X,Y,Z)
8000.      # Column height (a.s.l.)
16         # Number of vertical source points
4. 1.      # Suzuki coefficients
5000.      # Diffusion coefficient
9          # Number of loading thresholds
1. 10. 50. 100. 200. 300. 400. 500. 1000. # Thresholds
16         # Number of particles types
0.064000000000000000 800 0.8500000000000000 1.9400000000000000
0.032000000000000000 800 0.8500000000000000 3.6300000000000000
0.016000000000000000 800 0.8500000000000000 5.6700000000000000
0.008000000000000000 800 0.8500000000000000 7.8400000000000000
0.004000000000000000 800 0.8500000000000000 9.4400000000000000
0.002000000000000000 800 0.8500000000000000 9.6300000000000000
0.001000000000000000 800 0.8500000000000000 8.6800000000000000
0.000500000000000000 1200 0.8500000000000000 6.7300000000000000
0.000250000000000000 1200 0.8500000000000000 4.9200000000000000
0.000125000000000000 1200 0.8500000000000000 7.1600000000000000
6.2500000000000000e-05 2300 0.8500000000000000 14.8900000000000000
3.1250000000000000e-05 2300 0.8500000000000000 14.0600000000000000
1.5625000000000000e-05 2300 0.8500000000000000 4.7900000000000000
7.8125000000000000e-06 2300 0.8500000000000000 0.5800000000000000
3.9062500000000000e-06 2300 0.8500000000000000 0.0500000000000000
1.9531250000000000e-06 2300 0.8500000000000000 0

```

VEI 4 scenario for Sete Cidades Volcano

```

1          # Mode (0=deposit; 1=hazmap)
0          # Grid type (0=uniform, 1=from file)
2          # Settling velocity model
1          # Settling velocity is a function of Z
1          # Write list of cell coordinates (file grid.out)
0          # Write particles spectra
0          # Write settling velocities (file vset.out)
2          # Format of the output file
300 300    # Number of grid cells (NX,NY), used if gridtype=0
500. 500.  # Grid spacing (DX,DY), used if gridtype=0
632369. 4185351. # Coordinates of the center of the grid
4.2E11     # Total Mass
1          # Mass distribution model (0=from file, 1=Suzuki)
632369. 4185351. 0.0 # Coordinates of the vent (X,Y,Z)
18000.     # Column height (a.s.l.)
36         # Number of vertical source points
4. 1.      # Suzuki coefficients
5000.      # Diffusion coefficient
9          # Number of loading thresholds
1. 10. 50. 100. 200. 300. 400. 500. 1000. # Thresholds
16         # Number of particles types
0.064000000000000000 800 0.8500000000000000 1.9400000000000000
0.032000000000000000 800 0.8500000000000000 3.6300000000000000
0.016000000000000000 800 0.8500000000000000 5.6700000000000000
0.008000000000000000 800 0.8500000000000000 7.8400000000000000
0.004000000000000000 800 0.8500000000000000 9.4400000000000000
0.002000000000000000 800 0.8500000000000000 9.6300000000000000
0.001000000000000000 800 0.8500000000000000 8.6800000000000000
0.000500000000000000 1200 0.8500000000000000 6.7300000000000000
0.000250000000000000 1200 0.8500000000000000 4.9200000000000000
0.000125000000000000 1200 0.8500000000000000 7.1600000000000000
6.250000000000000e-05 2300 0.8500000000000000 14.8900000000000000
3.125000000000000e-05 2300 0.8500000000000000 14.0600000000000000
1.562500000000000e-05 2300 0.8500000000000000 4.7900000000000000
7.812500000000000e-06 2300 0.8500000000000000 0.5800000000000000
3.906250000000000e-06 2300 0.8500000000000000 0.0500000000000000
1.953125000000000e-06 2300 0.8500000000000000 0

```

VEI 4 scenario for Fogo Volcano

```

1          # Mode (0=deposit; 1=hazmap)
0          # Grid type (0=uniform, 1=from file)
2          # Settling velocity model
1          # Settling velocity is a function of Z
1          # Write list of cell coordinates (file grid.out)
0          # Write particles spectra
0          # Write settling velocities (file vset.out)
2          # Format of the output file
300 300    # Number of grid cells (NX,NY), used if gridtype=0
500. 500.  # Grid spacing (DX,DY), used if gridtype=0
632369. 4185351. # Coordinates of the center of the grid
4.2E11     # Total Mass
1          # Mass distribution model (0=from file, 1=Suzuki)
632369. 4185351. 0.0 # Coordinates of the vent (X,Y,Z)
19000.     # Column height (a.s.l.)
38         # Number of vertical source points
4. 1.      # Suzuki coefficients
5000.      # Diffusion coefficient
9          # Number of loading thresholds
1. 10. 50. 100. 200. 300. 400. 500. 1000. # Thresholds
16         # Number of particles types
0.064000000000000000 800 0.8500000000000000 1.9400000000000000
0.032000000000000000 800 0.8500000000000000 3.6300000000000000
0.016000000000000000 800 0.8500000000000000 5.6700000000000000
0.008000000000000000 800 0.8500000000000000 7.8400000000000000
0.004000000000000000 800 0.8500000000000000 9.4400000000000000
0.002000000000000000 800 0.8500000000000000 9.6300000000000000
0.001000000000000000 800 0.8500000000000000 8.6800000000000000
0.000500000000000000 1200 0.8500000000000000 6.7300000000000000
0.000250000000000000 1200 0.8500000000000000 4.9200000000000000
0.000125000000000000 1200 0.8500000000000000 7.1600000000000000
6.2500000000000000e-05 2300 0.8500000000000000 14.8900000000000000
3.1250000000000000e-05 2300 0.8500000000000000 14.0600000000000000
1.5625000000000000e-05 2300 0.8500000000000000 4.7900000000000000
7.8125000000000000e-06 2300 0.8500000000000000 0.5800000000000000
3.9062500000000000e-06 2300 0.8500000000000000 0.0500000000000000
1.9531250000000000e-06 2300 0.8500000000000000 0

```

VEI 4 scenario for Furnas Volcano

```

1          # Mode (0=deposit; 1=hazmap)
0          # Grid type (0=uniform, 1=from file)
2          # Settling velocity model
1          # Settling velocity is a function of Z
1          # Write list of cell coordinates (file grid.out)
0          # Write particles spectra
0          # Write settling velocities (file vset.out)
2          # Format of the output file
300 300    # Number of grid cells (NX,NY), used if gridtype=0
500. 500.  # Grid spacing (DX,DY), used if gridtype=0
632369. 4185351. # Coordinates of the center of the grid
1.8E11     # Total Mass
1          # Mass distribution model (0=from file, 1=Suzuki)
632369. 4185351. 0.0 # Coordinates of the vent (X,Y,Z)
13000.     # Column height (a.s.l.)
26         # Number of vertical source points
4. 1.      # Suzuki coefficients
5000.      # Diffusion coefficient
9          # Number of loading thresholds
1. 10. 50. 100. 200. 300. 400. 500. 1000. # Thresholds
16         # Number of particles types
0.064000000000000000 800 0.8500000000000000 1.9400000000000000
0.032000000000000000 800 0.8500000000000000 3.6300000000000000
0.016000000000000000 800 0.8500000000000000 5.6700000000000000
0.008000000000000000 800 0.8500000000000000 7.8400000000000000
0.004000000000000000 800 0.8500000000000000 9.4400000000000000
0.002000000000000000 800 0.8500000000000000 9.6300000000000000
0.001000000000000000 800 0.8500000000000000 8.6800000000000000
0.000500000000000000 1200 0.8500000000000000 6.7300000000000000
0.000250000000000000 1200 0.8500000000000000 4.9200000000000000
0.000125000000000000 1200 0.8500000000000000 7.1600000000000000
6.2500000000000000e-05 2300 0.8500000000000000 14.8900000000000000
3.1250000000000000e-05 2300 0.8500000000000000 14.0600000000000000
1.5625000000000000e-05 2300 0.8500000000000000 4.7900000000000000
7.8125000000000000e-06 2300 0.8500000000000000 0.5800000000000000
3.9062500000000000e-06 2300 0.8500000000000000 0.0500000000000000
1.9531250000000000e-06 2300 0.8500000000000000 0

```


VEI 5 scenario for Fogo Volcano

```

1          # Mode (0=deposit; 1=hazmap)
0          # Grid type (0=uniform, 1=from file)
2          # Settling velocity model
1          # Settling velocity is a function of Z
1          # Write list of cell coordinates (file grid.out)
0          # Write particles spectra
0          # Write settling velocities (file vset.out)
2          # Format of the output file
300 300    # Number of grid cells (NX,NY), used if gridtype=0
500. 500.  # Grid spacing (DX,DY), used if gridtype=0
632369. 4185351.  # Coordinates of the center of the grid
1.8E12     # Total Mass
1          # Mass distribution model (0=from file, 1=Suzuki)
632369. 4185351. 0.0 # Coordinates of the vent (X,Y,Z)
2700.      # Column height (a.s.l.)
54         # Number of vertical source points
4. 1.      # Suzuki coefficients
5000.      # Diffusion coefficient
9          # Number of loading thresholds
1. 10. 50. 100. 200. 300. 400. 500. 1000. # Thresholds
16         # Number of particles types
0.064000000000000000 800 0.8500000000000000 0.9700000000000000
0.032000000000000000 800 0.8500000000000000 2.3000000000000000
0.016000000000000000 800 0.8500000000000000 4.3800000000000000
0.008000000000000000 800 0.8500000000000000 7.1000000000000000
0.004000000000000000 800 0.8500000000000000 10.0300000000000000
0.002000000000000000 800 0.8500000000000000 12.1900000000000000
0.001000000000000000 800 0.8500000000000000 12.5100000000000000
0.000500000000000000 1200 0.8500000000000000 10.7700000000000000
0.000250000000000000 1200 0.8500000000000000 8.4400000000000000
0.000125000000000000 1200 0.8500000000000000 6.7800000000000000
6.2500000000000000e-05 2300 0.8500000000000000 8.9300000000000000
3.1250000000000000e-05 2300 0.8500000000000000 9.1700000000000000
1.5625000000000000e-05 2300 0.8500000000000000 5.0500000000000000
7.8125000000000000e-06 2300 0.8500000000000000 1.2200000000000000
3.9062500000000000e-06 2300 0.8500000000000000 0.1600000000000000
1.9531250000000000e-06 2300 0.8500000000000000 0.0200000000000000

```

VEI 5 scenario for Furnas Volcano

```

1          # Mode (0=deposit; 1=hazmap)
0          # Grid type (0=uniform, 1=from file)
2          # Settling velocity model
1          # Settling velocity is a function of Z
1          # Write list of cell coordinates (file grid.out)
0          # Write particles spectra
0          # Write settling velocities (file vset.out)
2          # Format of the output file
300 300    # Number of grid cells (NX,NY), used if gridtype=0
500. 500.  # Grid spacing (DX,DY), used if gridtype=0
632369. 4185351. # Coordinates of the center of the grid
8.6E11     # Total Mass
1          # Mass distribution model (0=from file, 1=Suzuki)
632369. 4185351. 0.0 # Coordinates of the vent (X,Y,Z)
17000.     # Column height (a.s.l.)
34          # Number of vertical source points
4. 1.      # Suzuki coefficients
5000.      # Diffusion coefficient
9          # Number of loading thresholds
1. 10. 50. 100. 200. 300. 400. 500. 1000. # Thresholds
16         # Number of particles types
0.06400000000000000 800 0.8500000000000000 0.9700000000000000
0.03200000000000000 800 0.8500000000000000 2.3000000000000000
0.01600000000000000 800 0.8500000000000000 4.3800000000000000
0.00800000000000000 800 0.8500000000000000 7.1000000000000000
0.00400000000000000 800 0.8500000000000000 10.0300000000000000
0.00200000000000000 800 0.8500000000000000 12.1900000000000000
0.00100000000000000 800 0.8500000000000000 12.5100000000000000
0.00050000000000000 1200 0.8500000000000000 10.7700000000000000
0.00025000000000000 1200 0.8500000000000000 8.4400000000000000
0.00012500000000000 1200 0.8500000000000000 6.7800000000000000
6.250000000000000e-05 2300 0.8500000000000000 8.9300000000000000
3.125000000000000e-05 2300 0.8500000000000000 9.1700000000000000
1.562500000000000e-05 2300 0.8500000000000000 5.0500000000000000
7.812500000000000e-06 2300 0.8500000000000000 1.2200000000000000
3.906250000000000e-06 2300 0.8500000000000000 0.1600000000000000
1.953125000000000e-06 2300 0.8500000000000000 0.0200000000000000

```

Appendix A.4

Vent opening probabilities

Sete Cidades BT vent opening			
ID	Longitude	Latitude	Probability
1	600199	4183757	0,00E+00
2	600699	4183757	0,00E+00
3	601199	4183757	0,00E+00
4	601699	4183757	0,00E+00
5	602199	4183757	0,00E+00
6	602699	4183757	0,00E+00
7	603199	4183757	0,00E+00
8	603699	4183757	0,00E+00
9	604199	4183757	0,00E+00
10	604699	4183757	0,00E+00
11	605199	4183757	0,00E+00
12	605699	4183757	0,00E+00
13	606199	4183757	0,00E+00
14	606699	4183757	0,00E+00
15	607199	4183757	0,00E+00
16	607699	4183757	0,00E+00
17	608199	4183757	0,00E+00
18	608699	4183757	0,00E+00
19	609199	4183757	0,00E+00
20	609699	4183757	0,00E+00
21	610199	4183757	0,00E+00
22	610699	4183757	0,00E+00
23	611199	4183757	0,00E+00
24	611699	4183757	0,00E+00
25	612199	4183757	0,00E+00
26	612699	4183757	0,00E+00
27	613199	4183757	0,00E+00
28	613699	4183757	0,00E+00
29	614199	4183757	0,00E+00
30	600199	4184257	0,00E+00
31	600699	4184257	0,00E+00
32	601199	4184257	0,00E+00
33	601699	4184257	0,00E+00
34	602199	4184257	0,00E+00
35	602699	4184257	0,00E+00
36	603199	4184257	0,00E+00
37	603699	4184257	0,00E+00
38	604199	4184257	0,00E+00
39	604699	4184257	0,00E+00

40	605199	4184257	0,00E+00
41	605699	4184257	1,19E-05
42	606199	4184257	8,20E-05
43	606699	4184257	2,24E-04
44	607199	4184257	3,36E-04
45	607699	4184257	8,14E-04
46	608199	4184257	1,56E-03
47	608699	4184257	5,95E-04
48	609199	4184257	5,41E-04
49	609699	4184257	5,07E-04
50	610199	4184257	5,21E-05
51	610699	4184257	0,00E+00
52	611199	4184257	0,00E+00
53	611699	4184257	0,00E+00
54	612199	4184257	0,00E+00
55	612699	4184257	0,00E+00
56	613199	4184257	0,00E+00
57	613699	4184257	0,00E+00
58	614199	4184257	0,00E+00
59	600199	4184757	0,00E+00
60	600699	4184757	0,00E+00
61	601199	4184757	0,00E+00
62	601699	4184757	0,00E+00
63	602199	4184757	0,00E+00
64	602699	4184757	0,00E+00
65	603199	4184757	0,00E+00
66	603699	4184757	0,00E+00
67	604199	4184757	0,00E+00
68	604699	4184757	0,00E+00
69	605199	4184757	1,19E-04
70	605699	4184757	3,36E-04
71	606199	4184757	4,58E-04
72	606699	4184757	5,39E-04
73	607199	4184757	6,88E-04
74	607699	4184757	1,06E-03
75	608199	4184757	1,44E-03
76	608699	4184757	1,60E-03
77	609199	4184757	2,72E-03
78	609699	4184757	4,45E-03
79	610199	4184757	2,51E-03
80	610699	4184757	2,25E-03

81	611199	4184757	2,29E-03
82	611699	4184757	7,61E-05
83	612199	4184757	0,00E+00
84	612699	4184757	0,00E+00
85	613199	4184757	0,00E+00
86	613699	4184757	0,00E+00
87	614199	4184757	0,00E+00
88	600199	4185257	0,00E+00
89	600699	4185257	0,00E+00
90	601199	4185257	0,00E+00
91	601699	4185257	0,00E+00
92	602199	4185257	0,00E+00
93	602699	4185257	0,00E+00
94	603199	4185257	0,00E+00
95	603699	4185257	0,00E+00
96	604199	4185257	4,09E-05
97	604699	4185257	2,05E-04
98	605199	4185257	4,00E-04
99	605699	4185257	4,49E-04
100	606199	4185257	5,06E-04
101	606699	4185257	5,87E-04
102	607199	4185257	7,08E-04
103	607699	4185257	8,90E-04
104	608199	4185257	1,15E-03
105	608699	4185257	1,83E-03
106	609199	4185257	3,91E-03
107	609699	4185257	4,40E-03
108	610199	4185257	3,08E-03
109	610699	4185257	5,07E-03
110	611199	4185257	1,22E-02
111	611699	4185257	4,73E-03
112	612199	4185257	7,18E-04
113	612699	4185257	0,00E+00
114	613199	4185257	0,00E+00
115	613699	4185257	0,00E+00
116	614199	4185257	0,00E+00
117	600199	4185757	0,00E+00
118	600699	4185757	0,00E+00
119	601199	4185757	0,00E+00
120	601699	4185757	0,00E+00
121	602199	4185757	0,00E+00
122	602699	4185757	0,00E+00
123	603199	4185757	0,00E+00
124	603699	4185757	0,00E+00
125	604199	4185757	3,24E-04
126	604699	4185757	4,24E-04

127	605199	4185757	4,58E-04
128	605699	4185757	5,03E-04
129	606199	4185757	5,63E-04
130	606699	4185757	6,47E-04
131	607199	4185757	7,66E-04
132	607699	4185757	9,36E-04
133	608199	4185757	1,19E-03
134	608699	4185757	1,60E-03
135	609199	4185757	2,21E-03
136	609699	4185757	2,97E-03
137	610199	4185757	4,95E-03
138	610699	4185757	5,21E-03
139	611199	4185757	9,97E-03
140	611699	4185757	1,02E-02
141	612199	4185757	9,55E-03
142	612699	4185757	5,00E-04
143	613199	4185757	0,00E+00
144	613699	4185757	0,00E+00
145	614199	4185757	0,00E+00
146	600199	4186257	0,00E+00
147	600699	4186257	0,00E+00
148	601199	4186257	0,00E+00
149	601699	4186257	0,00E+00
150	602199	4186257	0,00E+00
151	602699	4186257	0,00E+00
152	603199	4186257	9,07E-06
153	603699	4186257	2,47E-04
154	604199	4186257	4,58E-04
155	604699	4186257	4,86E-04
156	605199	4186257	5,21E-04
157	605699	4186257	5,68E-04
158	606199	4186257	6,33E-04
159	606699	4186257	7,27E-04
160	607199	4186257	8,66E-04
161	607699	4186257	1,07E-03
162	608199	4186257	1,36E-03
163	608699	4186257	1,83E-03
164	609199	4186257	2,64E-03
165	609699	4186257	4,18E-03
166	610199	4186257	6,44E-03
167	610699	4186257	5,96E-03
168	611199	4186257	1,21E-02
169	611699	4186257	1,11E-02
170	612199	4186257	6,49E-03
171	612699	4186257	2,82E-03
172	613199	4186257	3,09E-05

173	613699	4186257	0,00E+00
174	614199	4186257	0,00E+00
175	600199	4186757	0,00E+00
176	600699	4186757	0,00E+00
177	601199	4186757	0,00E+00
178	601699	4186757	0,00E+00
179	602199	4186757	0,00E+00
180	602699	4186757	8,10E-05
181	603199	4186757	4,31E-04
182	603699	4186757	5,27E-04
183	604199	4186757	5,46E-04
184	604699	4186757	5,70E-04
185	605199	4186757	6,04E-04
186	605699	4186757	6,52E-04
187	606199	4186757	7,22E-04
188	606699	4186757	8,32E-04
189	607199	4186757	1,02E-03
190	607699	4186757	1,35E-03
191	608199	4186757	1,83E-03
192	608699	4186757	2,66E-03
193	609199	4186757	5,49E-03
194	609699	4186757	7,48E-03
195	610199	4186757	1,41E-02
196	610699	4186757	7,37E-03
197	611199	4186757	8,00E-03
198	611699	4186757	8,13E-03
199	612199	4186757	5,43E-03
200	612699	4186757	7,35E-03
201	613199	4186757	1,64E-03
202	613699	4186757	0,00E+00
203	614199	4186757	0,00E+00
204	600199	4187257	0,00E+00
205	600699	4187257	0,00E+00
206	601199	4187257	0,00E+00
207	601699	4187257	0,00E+00
208	602199	4187257	2,31E-04
209	602699	4187257	5,62E-04
210	603199	4187257	6,74E-04
211	603699	4187257	6,98E-04
212	604199	4187257	6,84E-04
213	604699	4187257	6,93E-04
214	605199	4187257	7,22E-04
215	605699	4187257	7,67E-04
216	606199	4187257	8,41E-04
217	606699	4187257	9,66E-04
218	607199	4187257	1,22E-03

219	607699	4187257	2,03E-03
220	608199	4187257	4,14E-03
221	608699	4187257	5,69E-03
222	609199	4187257	6,46E-03
223	609699	4187257	1,15E-02
224	610199	4187257	1,43E-02
225	610699	4187257	7,03E-03
226	611199	4187257	5,95E-03
227	611699	4187257	5,10E-03
228	612199	4187257	7,34E-03
229	612699	4187257	4,50E-03
230	613199	4187257	1,69E-03
231	613699	4187257	1,12E-05
232	614199	4187257	0,00E+00
233	600199	4187757	0,00E+00
234	600699	4187757	0,00E+00
235	601199	4187757	0,00E+00
236	601699	4187757	5,46E-05
237	602199	4187757	6,72E-04
238	602699	4187757	8,16E-04
239	603199	4187757	1,35E-03
240	603699	4187757	1,24E-03
241	604199	4187757	9,12E-04
242	604699	4187757	8,95E-04
243	605199	4187757	9,13E-04
244	605699	4187757	9,47E-04
245	606199	4187757	1,02E-03
246	606699	4187757	1,15E-03
247	607199	4187757	1,40E-03
248	607699	4187757	2,21E-03
249	608199	4187757	5,10E-03
250	608699	4187757	7,35E-03
251	609199	4187757	9,43E-03
252	609699	4187757	8,81E-03
253	610199	4187757	6,51E-03
254	610699	4187757	4,50E-03
255	611199	4187757	2,95E-03
256	611699	4187757	2,55E-03
257	612199	4187757	2,90E-03
258	612699	4187757	2,03E-03
259	613199	4187757	1,23E-03
260	613699	4187757	1,86E-04
261	614199	4187757	0,00E+00
262	600199	4188257	0,00E+00
263	600699	4188257	0,00E+00
264	601199	4188257	0,00E+00

265	601699	4188257	1,93E-04
266	602199	4188257	9,29E-04
267	602699	4188257	1,06E-03
268	603199	4188257	2,47E-03
269	603699	4188257	1,98E-03
270	604199	4188257	1,25E-03
271	604699	4188257	1,37E-03
272	605199	4188257	1,31E-03
273	605699	4188257	1,27E-03
274	606199	4188257	1,36E-03
275	606699	4188257	1,53E-03
276	607199	4188257	1,69E-03
277	607699	4188257	2,14E-03
278	608199	4188257	5,11E-03
279	608699	4188257	6,85E-03
280	609199	4188257	1,07E-02
281	609699	4188257	5,59E-03
282	610199	4188257	3,63E-03
283	610699	4188257	2,83E-03
284	611199	4188257	1,91E-03
285	611699	4188257	1,61E-03
286	612199	4188257	1,42E-03
287	612699	4188257	1,17E-03
288	613199	4188257	8,94E-04
289	613699	4188257	3,39E-04
290	614199	4188257	0,00E+00
291	600199	4188757	0,00E+00
292	600699	4188757	0,00E+00
293	601199	4188757	0,00E+00
294	601699	4188757	1,12E-03
295	602199	4188757	1,49E-03
296	602699	4188757	1,28E-03
297	603199	4188757	1,34E-03
298	603699	4188757	1,39E-03
299	604199	4188757	1,88E-03
300	604699	4188757	4,16E-03
301	605199	4188757	2,56E-03
302	605699	4188757	2,03E-03
303	606199	4188757	2,35E-03
304	606699	4188757	3,46E-03
305	607199	4188757	2,91E-03
306	607699	4188757	2,37E-03
307	608199	4188757	2,47E-03
308	608699	4188757	3,40E-03
309	609199	4188757	4,31E-03
310	609699	4188757	2,80E-03

311	610199	4188757	2,07E-03
312	610699	4188757	1,66E-03
313	611199	4188757	1,36E-03
314	611699	4188757	1,15E-03
315	612199	4188757	9,96E-04
316	612699	4188757	8,43E-04
317	613199	4188757	6,95E-04
318	613699	4188757	3,80E-04
319	614199	4188757	0,00E+00
320	600199	4189257	0,00E+00
321	600699	4189257	0,00E+00
322	601199	4189257	7,01E-04
323	601699	4189257	7,44E-03
324	602199	4189257	3,20E-03
325	602699	4189257	1,74E-03
326	603199	4189257	1,48E-03
327	603699	4189257	1,50E-03
328	604199	4189257	1,96E-03
329	604699	4189257	4,06E-03
330	605199	4189257	4,62E-03
331	605699	4189257	4,43E-03
332	606199	4189257	4,79E-03
333	606699	4189257	5,15E-03
334	607199	4189257	4,00E-03
335	607699	4189257	3,07E-03
336	608199	4189257	2,11E-03
337	608699	4189257	2,11E-03
338	609199	4189257	2,80E-03
339	609699	4189257	2,15E-03
340	610199	4189257	1,57E-03
341	610699	4189257	1,26E-03
342	611199	4189257	1,05E-03
343	611699	4189257	8,98E-04
344	612199	4189257	7,77E-04
345	612699	4189257	6,69E-04
346	613199	4189257	5,70E-04
347	613699	4189257	4,00E-04
348	614199	4189257	0,00E+00
349	600199	4189757	0,00E+00
350	600699	4189757	0,00E+00
351	601199	4189757	2,11E-03
352	601699	4189757	8,48E-03
353	602199	4189757	4,69E-03
354	602699	4189757	2,62E-03
355	603199	4189757	2,03E-03
356	603699	4189757	1,99E-03

357	604199	4189757	2,16E-03
358	604699	4189757	2,15E-03
359	605199	4189757	2,46E-03
360	605699	4189757	3,12E-03
361	606199	4189757	3,12E-03
362	606699	4189757	3,91E-03
363	607199	4189757	2,36E-03
364	607699	4189757	3,39E-03
365	608199	4189757	2,61E-03
366	608699	4189757	1,78E-03
367	609199	4189757	3,33E-03
368	609699	4189757	2,73E-03
369	610199	4189757	1,65E-03
370	610699	4189757	1,06E-03
371	611199	4189757	8,59E-04
372	611699	4189757	7,36E-04
373	612199	4189757	6,40E-04
374	612699	4189757	5,58E-04
375	613199	4189757	4,85E-04
376	613699	4189757	3,84E-04
377	614199	4189757	0,00E+00
378	600199	4190257	0,00E+00
379	600699	4190257	1,59E-05
380	601199	4190257	2,27E-03
381	601699	4190257	3,70E-03
382	602199	4190257	5,22E-03
383	602699	4190257	4,78E-03
384	603199	4190257	3,58E-03
385	603699	4190257	4,20E-03
386	604199	4190257	4,52E-03
387	604699	4190257	2,42E-03
388	605199	4190257	3,19E-03
389	605699	4190257	2,54E-03
390	606199	4190257	2,33E-03
391	606699	4190257	3,77E-03
392	607199	4190257	1,98E-03
393	607699	4190257	1,78E-03
394	608199	4190257	1,59E-03
395	608699	4190257	1,36E-03
396	609199	4190257	1,52E-03
397	609699	4190257	2,80E-03
398	610199	4190257	1,63E-03
399	610699	4190257	9,06E-04
400	611199	4190257	7,26E-04
401	611699	4190257	6,25E-04
402	612199	4190257	5,47E-04

403	612699	4190257	4,82E-04
404	613199	4190257	4,23E-04
405	613699	4190257	3,72E-04
406	614199	4190257	0,00E+00
407	600199	4190757	0,00E+00
408	600699	4190757	3,31E-04
409	601199	4190757	5,34E-03
410	601699	4190757	6,67E-03
411	602199	4190757	7,99E-03
412	602699	4190757	8,69E-03
413	603199	4190757	7,96E-03
414	603699	4190757	8,52E-03
415	604199	4190757	3,83E-03
416	604699	4190757	2,10E-03
417	605199	4190757	2,32E-03
418	605699	4190757	1,96E-03
419	606199	4190757	1,84E-03
420	606699	4190757	3,60E-03
421	607199	4190757	1,91E-03
422	607699	4190757	1,52E-03
423	608199	4190757	1,49E-03
424	608699	4190757	1,16E-03
425	609199	4190757	1,05E-03
426	609699	4190757	1,07E-03
427	610199	4190757	9,21E-04
428	610699	4190757	7,36E-04
429	611199	4190757	6,24E-04
430	611699	4190757	5,45E-04
431	612199	4190757	4,82E-04
432	612699	4190757	4,27E-04
433	613199	4190757	3,78E-04
434	613699	4190757	3,13E-04
435	614199	4190757	0,00E+00
436	600199	4191257	0,00E+00
437	600699	4191257	3,26E-04
438	601199	4191257	3,04E-03
439	601699	4191257	5,06E-03
440	602199	4191257	5,64E-03
441	602699	4191257	4,66E-03
442	603199	4191257	6,15E-03
443	603699	4191257	6,05E-03
444	604199	4191257	3,37E-03
445	604699	4191257	1,76E-03
446	605199	4191257	1,62E-03
447	605699	4191257	1,47E-03
448	606199	4191257	1,46E-03

449	606699	4191257	1,84E-03
450	607199	4191257	1,53E-03
451	607699	4191257	1,94E-03
452	608199	4191257	2,94E-03
453	608699	4191257	1,10E-03
454	609199	4191257	8,47E-04
455	609699	4191257	7,67E-04
456	610199	4191257	6,97E-04
457	610699	4191257	6,22E-04
458	611199	4191257	5,54E-04
459	611699	4191257	4,93E-04
460	612199	4191257	4,37E-04
461	612699	4191257	3,88E-04
462	613199	4191257	3,44E-04
463	613699	4191257	2,77E-04
464	614199	4191257	0,00E+00
465	600199	4191757	0,00E+00
466	600699	4191757	0,00E+00
467	601199	4191757	0,00E+00
468	601699	4191757	2,09E-03
469	602199	4191757	2,83E-03
470	602699	4191757	3,29E-03
471	603199	4191757	2,53E-03
472	603699	4191757	2,09E-03
473	604199	4191757	1,69E-03
474	604699	4191757	1,59E-03
475	605199	4191757	3,09E-03
476	605699	4191757	1,78E-03
477	606199	4191757	1,36E-03
478	606699	4191757	1,35E-03
479	607199	4191757	1,77E-03
480	607699	4191757	1,47E-03
481	608199	4191757	1,29E-03
482	608699	4191757	8,84E-04
483	609199	4191757	7,20E-04
484	609699	4191757	6,51E-04
485	610199	4191757	6,09E-04
486	610699	4191757	5,73E-04
487	611199	4191757	5,28E-04
488	611699	4191757	4,72E-04
489	612199	4191757	4,14E-04
490	612699	4191757	3,62E-04
491	613199	4191757	3,19E-04
492	613699	4191757	2,48E-04
493	614199	4191757	0,00E+00
494	600199	4192257	0,00E+00

495	600699	4192257	0,00E+00
496	601199	4192257	0,00E+00
497	601699	4192257	5,59E-04
498	602199	4192257	1,49E-03
499	602699	4192257	2,91E-03
500	603199	4192257	1,70E-03
501	603699	4192257	1,30E-03
502	604199	4192257	1,18E-03
503	604699	4192257	1,26E-03
504	605199	4192257	1,95E-03
505	605699	4192257	2,49E-03
506	606199	4192257	2,29E-03
507	606699	4192257	1,38E-03
508	607199	4192257	2,94E-03
509	607699	4192257	1,40E-03
510	608199	4192257	8,66E-04
511	608699	4192257	7,12E-04
512	609199	4192257	6,31E-04
513	609699	4192257	5,94E-04
514	610199	4192257	5,93E-04
515	610699	4192257	6,13E-04
516	611199	4192257	5,94E-04
517	611699	4192257	5,05E-04
518	612199	4192257	4,15E-04
519	612699	4192257	3,49E-04
520	613199	4192257	3,01E-04
521	613699	4192257	1,55E-04
522	614199	4192257	0,00E+00
523	600199	4192757	0,00E+00
524	600699	4192757	0,00E+00
525	601199	4192757	0,00E+00
526	601699	4192757	0,00E+00
527	602199	4192757	7,70E-04
528	602699	4192757	9,98E-04
529	603199	4192757	1,08E-03
530	603699	4192757	1,00E-03
531	604199	4192757	9,32E-04
532	604699	4192757	9,40E-04
533	605199	4192757	1,06E-03
534	605699	4192757	1,55E-03
535	606199	4192757	1,56E-03
536	606699	4192757	1,13E-03
537	607199	4192757	1,15E-03
538	607699	4192757	9,17E-04
539	608199	4192757	7,13E-04
540	608699	4192757	6,18E-04

541	609199	4192757	5,75E-04
542	609699	4192757	5,74E-04
543	610199	4192757	6,48E-04
544	610699	4192757	9,43E-04
545	611199	4192757	1,10E-03
546	611699	4192757	6,65E-04
547	612199	4192757	4,42E-04
548	612699	4192757	3,43E-04
549	613199	4192757	2,86E-04
550	613699	4192757	1,04E-04
551	614199	4192757	0,00E+00
552	600199	4193257	0,00E+00
553	600699	4193257	0,00E+00
554	601199	4193257	0,00E+00
555	601699	4193257	0,00E+00
556	602199	4193257	0,00E+00
557	602699	4193257	4,55E-05
558	603199	4193257	9,45E-04
559	603699	4193257	1,11E-03
560	604199	4193257	8,40E-04
561	604699	4193257	7,97E-04
562	605199	4193257	8,29E-04
563	605699	4193257	8,86E-04
564	606199	4193257	9,63E-04
565	606699	4193257	1,50E-03
566	607199	4193257	1,47E-03
567	607699	4193257	7,92E-04
568	608199	4193257	6,27E-04
569	608699	4193257	5,62E-04
570	609199	4193257	5,46E-04
571	609699	4193257	5,76E-04
572	610199	4193257	7,26E-04
573	610699	4193257	1,94E-03
574	611199	4193257	4,11E-03
575	611699	4193257	9,76E-04
576	612199	4193257	4,66E-04
577	612699	4193257	3,34E-04
578	613199	4193257	1,89E-04
579	613699	4193257	1,51E-05
580	614199	4193257	0,00E+00
581	600199	4193757	0,00E+00
582	600699	4193757	0,00E+00
583	601199	4193757	0,00E+00
584	601699	4193757	0,00E+00
585	602199	4193757	0,00E+00
586	602699	4193757	0,00E+00

587	603199	4193757	7,56E-04
588	603699	4193757	2,01E-03
589	604199	4193757	8,12E-04
590	604699	4193757	8,00E-04
591	605199	4193757	8,94E-04
592	605699	4193757	8,01E-04
593	606199	4193757	8,37E-04
594	606699	4193757	1,82E-03
595	607199	4193757	1,81E-03
596	607699	4193757	7,31E-04
597	608199	4193757	5,73E-04
598	608699	4193757	5,32E-04
599	609199	4193757	5,48E-04
600	609699	4193757	6,23E-04
601	610199	4193757	7,46E-04
602	610699	4193757	1,15E-03
603	611199	4193757	1,88E-03
604	611699	4193757	7,91E-04
605	612199	4193757	4,28E-04
606	612699	4193757	2,55E-04
607	613199	4193757	1,13E-05
608	613699	4193757	0,00E+00
609	614199	4193757	0,00E+00
610	600199	4194257	0,00E+00
611	600699	4194257	0,00E+00
612	601199	4194257	0,00E+00
613	601699	4194257	0,00E+00
614	602199	4194257	0,00E+00
615	602699	4194257	0,00E+00
616	603199	4194257	2,28E-04
617	603699	4194257	7,87E-04
618	604199	4194257	6,90E-04
619	604699	4194257	1,06E-03
620	605199	4194257	2,53E-03
621	605699	4194257	9,13E-04
622	606199	4194257	7,10E-04
623	606699	4194257	8,05E-04
624	607199	4194257	7,93E-04
625	607699	4194257	6,25E-04
626	608199	4194257	5,34E-04
627	608699	4194257	5,24E-04
628	609199	4194257	5,99E-04
629	609699	4194257	9,65E-04
630	610199	4194257	1,37E-03
631	610699	4194257	7,73E-04
632	611199	4194257	6,25E-04

633	611699	4194257	3,89E-04
634	612199	4194257	1,48E-04
635	612699	4194257	2,17E-05
636	613199	4194257	0,00E+00
637	613699	4194257	0,00E+00
638	614199	4194257	0,00E+00
639	600199	4194757	0,00E+00
640	600699	4194757	0,00E+00
641	601199	4194757	0,00E+00
642	601699	4194757	0,00E+00
643	602199	4194757	0,00E+00
644	602699	4194757	0,00E+00
645	603199	4194757	5,71E-06
646	603699	4194757	3,87E-04
647	604199	4194757	5,38E-04
648	604699	4194757	7,87E-04
649	605199	4194757	1,30E-03
650	605699	4194757	7,37E-04
651	606199	4194757	6,34E-04
652	606699	4194757	8,71E-04
653	607199	4194757	1,04E-03
654	607699	4194757	6,33E-04
655	608199	4194757	5,13E-04
656	608699	4194757	5,42E-04
657	609199	4194757	7,33E-04
658	609699	4194757	1,35E-03
659	610199	4194757	2,27E-03
660	610699	4194757	5,62E-04
661	611199	4194757	1,24E-04
662	611699	4194757	0,00E+00
663	612199	4194757	0,00E+00
664	612699	4194757	0,00E+00
665	613199	4194757	0,00E+00
666	613699	4194757	0,00E+00
667	614199	4194757	0,00E+00
668	600199	4195257	0,00E+00
669	600699	4195257	0,00E+00
670	601199	4195257	0,00E+00
671	601699	4195257	0,00E+00
672	602199	4195257	0,00E+00
673	602699	4195257	0,00E+00
674	603199	4195257	2,98E-05
675	603699	4195257	3,11E-04
676	604199	4195257	2,45E-04
677	604699	4195257	1,96E-04
678	605199	4195257	1,40E-04

679	605699	4195257	4,63E-04
680	606199	4195257	5,60E-04
681	606699	4195257	1,29E-03
682	607199	4195257	2,36E-03
683	607699	4195257	6,60E-04
684	608199	4195257	4,85E-04
685	608699	4195257	5,77E-04
686	609199	4195257	1,67E-03
687	609699	4195257	1,74E-03
688	610199	4195257	2,47E-04
689	610699	4195257	7,14E-06
690	611199	4195257	0,00E+00
691	611699	4195257	0,00E+00
692	612199	4195257	0,00E+00
693	612699	4195257	0,00E+00
694	613199	4195257	0,00E+00
695	613699	4195257	0,00E+00
696	614199	4195257	0,00E+00
697	600199	4195757	0,00E+00
698	600699	4195757	0,00E+00
699	601199	4195757	0,00E+00
700	601699	4195757	0,00E+00
701	602199	4195757	0,00E+00
702	602699	4195757	0,00E+00
703	603199	4195757	0,00E+00
704	603699	4195757	3,41E-06
705	604199	4195757	0,00E+00
706	604699	4195757	0,00E+00
707	605199	4195757	0,00E+00
708	605699	4195757	1,31E-05
709	606199	4195757	2,52E-04
710	606699	4195757	5,95E-04
711	607199	4195757	6,80E-04
712	607699	4195757	4,82E-04
713	608199	4195757	4,17E-04
714	608699	4195757	4,86E-04
715	609199	4195757	5,77E-04
716	609699	4195757	3,80E-05
717	610199	4195757	0,00E+00
718	610699	4195757	0,00E+00
719	611199	4195757	0,00E+00
720	611699	4195757	0,00E+00
721	612199	4195757	0,00E+00
722	612699	4195757	0,00E+00
723	613199	4195757	0,00E+00
724	613699	4195757	0,00E+00

725	614199	4195757	0,00E+00
726	600199	4196257	0,00E+00
727	600699	4196257	0,00E+00
728	601199	4196257	0,00E+00
729	601699	4196257	0,00E+00
730	602199	4196257	0,00E+00
731	602699	4196257	0,00E+00
732	603199	4196257	0,00E+00
733	603699	4196257	0,00E+00
734	604199	4196257	0,00E+00
735	604699	4196257	0,00E+00
736	605199	4196257	0,00E+00
737	605699	4196257	0,00E+00
738	606199	4196257	0,00E+00
739	606699	4196257	2,71E-04
740	607199	4196257	3,67E-04
741	607699	4196257	3,31E-04
742	608199	4196257	1,70E-04
743	608699	4196257	5,82E-05
744	609199	4196257	0,00E+00
745	609699	4196257	0,00E+00
746	610199	4196257	0,00E+00
747	610699	4196257	0,00E+00
748	611199	4196257	0,00E+00
749	611699	4196257	0,00E+00
750	612199	4196257	0,00E+00
751	612699	4196257	0,00E+00
752	613199	4196257	0,00E+00
753	613699	4196257	0,00E+00
754	614199	4196257	0,00E+00

755	600199	4196757	0,00E+00
756	600699	4196757	0,00E+00
757	601199	4196757	0,00E+00
758	601699	4196757	0,00E+00
759	602199	4196757	0,00E+00
760	602699	4196757	0,00E+00
761	603199	4196757	0,00E+00
762	603699	4196757	0,00E+00
763	604199	4196757	0,00E+00
764	604699	4196757	0,00E+00
765	605199	4196757	0,00E+00
766	605699	4196757	0,00E+00
767	606199	4196757	0,00E+00
768	606699	4196757	1,21E-05
769	607199	4196757	5,12E-05
770	607699	4196757	3,02E-06
771	608199	4196757	0,00E+00
772	608699	4196757	0,00E+00
773	609199	4196757	0,00E+00
774	609699	4196757	0,00E+00
775	610199	4196757	0,00E+00
776	610699	4196757	0,00E+00
777	611199	4196757	0,00E+00
778	611699	4196757	0,00E+00
779	612199	4196757	0,00E+00
780	612699	4196757	0,00E+00
781	613199	4196757	0,00E+00
782	613699	4196757	0,00E+00
783	614199	4196757	0,00E+00

Sete Cidades T vent opening			
ID	Longitude	Latitude	Probability
1	600199	4183757	0,00E+00
2	600699	4183757	0,00E+00
3	601199	4183757	0,00E+00
4	601699	4183757	0,00E+00
5	602199	4183757	0,00E+00
6	602699	4183757	0,00E+00
7	603199	4183757	0,00E+00
8	603699	4183757	0,00E+00
9	604199	4183757	0,00E+00
10	604699	4183757	0,00E+00
11	605199	4183757	0,00E+00
12	605699	4183757	0,00E+00
13	606199	4183757	0,00E+00
14	606699	4183757	0,00E+00
15	607199	4183757	0,00E+00
16	607699	4183757	0,00E+00
17	608199	4183757	0,00E+00
18	608699	4183757	0,00E+00
19	609199	4183757	0,00E+00
20	609699	4183757	0,00E+00
21	610199	4183757	0,00E+00
22	610699	4183757	0,00E+00
23	611199	4183757	0,00E+00
24	611699	4183757	0,00E+00
25	612199	4183757	0,00E+00
26	612699	4183757	0,00E+00
27	613199	4183757	0,00E+00
28	613699	4183757	0,00E+00
29	614199	4183757	0,00E+00
30	600199	4184257	0,00E+00
31	600699	4184257	0,00E+00
32	601199	4184257	0,00E+00
33	601699	4184257	0,00E+00
34	602199	4184257	0,00E+00
35	602699	4184257	0,00E+00
36	603199	4184257	0,00E+00
37	603699	4184257	0,00E+00
38	604199	4184257	0,00E+00
39	604699	4184257	0,00E+00
40	605199	4184257	0,00E+00
41	605699	4184257	0,00E+00
42	606199	4184257	0,00E+00
43	606699	4184257	0,00E+00
44	607199	4184257	0,00E+00
45	607699	4184257	0,00E+00

46	608199	4184257	0,00E+00
47	608699	4184257	0,00E+00
48	609199	4184257	0,00E+00
49	609699	4184257	0,00E+00
50	610199	4184257	0,00E+00
51	610699	4184257	0,00E+00
52	611199	4184257	0,00E+00
53	611699	4184257	0,00E+00
54	612199	4184257	0,00E+00
55	612699	4184257	0,00E+00
56	613199	4184257	0,00E+00
57	613699	4184257	0,00E+00
58	614199	4184257	0,00E+00
59	600199	4184757	0,00E+00
60	600699	4184757	0,00E+00
61	601199	4184757	0,00E+00
62	601699	4184757	0,00E+00
63	602199	4184757	0,00E+00
64	602699	4184757	0,00E+00
65	603199	4184757	0,00E+00
66	603699	4184757	0,00E+00
67	604199	4184757	0,00E+00
68	604699	4184757	0,00E+00
69	605199	4184757	0,00E+00
70	605699	4184757	0,00E+00
71	606199	4184757	0,00E+00
72	606699	4184757	0,00E+00
73	607199	4184757	0,00E+00
74	607699	4184757	0,00E+00
75	608199	4184757	0,00E+00
76	608699	4184757	0,00E+00
77	609199	4184757	0,00E+00
78	609699	4184757	0,00E+00
79	610199	4184757	0,00E+00
80	610699	4184757	0,00E+00
81	611199	4184757	0,00E+00
82	611699	4184757	0,00E+00
83	612199	4184757	0,00E+00
84	612699	4184757	0,00E+00
85	613199	4184757	0,00E+00
86	613699	4184757	0,00E+00
87	614199	4184757	0,00E+00
88	600199	4185257	0,00E+00
89	600699	4185257	0,00E+00
90	601199	4185257	0,00E+00
91	601699	4185257	0,00E+00

92	602199	4185257	0,00E+00
93	602699	4185257	0,00E+00
94	603199	4185257	0,00E+00
95	603699	4185257	0,00E+00
96	604199	4185257	0,00E+00
97	604699	4185257	0,00E+00
98	605199	4185257	0,00E+00
99	605699	4185257	0,00E+00
100	606199	4185257	0,00E+00
101	606699	4185257	0,00E+00
102	607199	4185257	0,00E+00
103	607699	4185257	1,07E-08
104	608199	4185257	3,73E-08
105	608699	4185257	7,67E-08
106	609199	4185257	9,05E-08
107	609699	4185257	6,12E-08
108	610199	4185257	2,37E-08
109	610699	4185257	0,00E+00
110	611199	4185257	0,00E+00
111	611699	4185257	0,00E+00
112	612199	4185257	0,00E+00
113	612699	4185257	0,00E+00
114	613199	4185257	0,00E+00
115	613699	4185257	0,00E+00
116	614199	4185257	0,00E+00
117	600199	4185757	0,00E+00
118	600699	4185757	0,00E+00
119	601199	4185757	0,00E+00
120	601699	4185757	0,00E+00
121	602199	4185757	0,00E+00
122	602699	4185757	0,00E+00
123	603199	4185757	0,00E+00
124	603699	4185757	0,00E+00
125	604199	4185757	0,00E+00
126	604699	4185757	0,00E+00
127	605199	4185757	0,00E+00
128	605699	4185757	1,43E-08
129	606199	4185757	2,78E-08
130	606699	4185757	4,31E-08
131	607199	4185757	8,05E-08
132	607699	4185757	3,01E-07
133	608199	4185757	1,01E-06
134	608699	4185757	2,07E-06
135	609199	4185757	2,43E-06
136	609699	4185757	1,64E-06
137	610199	4185757	6,33E-07

138	610699	4185757	1,40E-07
139	611199	4185757	1,75E-08
140	611699	4185757	0,00E+00
141	612199	4185757	0,00E+00
142	612699	4185757	0,00E+00
143	613199	4185757	0,00E+00
144	613699	4185757	0,00E+00
145	614199	4185757	0,00E+00
146	600199	4186257	0,00E+00
147	600699	4186257	0,00E+00
148	601199	4186257	0,00E+00
149	601699	4186257	0,00E+00
150	602199	4186257	0,00E+00
151	602699	4186257	0,00E+00
152	603199	4186257	0,00E+00
153	603699	4186257	0,00E+00
154	604199	4186257	3,67E-08
155	604699	4186257	1,14E-07
156	605199	4186257	2,53E-07
157	605699	4186257	4,98E-07
158	606199	4186257	8,98E-07
159	606699	4186257	1,29E-06
160	607199	4186257	1,80E-06
161	607699	4186257	4,94E-06
162	608199	4186257	1,56E-05
163	608699	4186257	3,14E-05
164	609199	4186257	3,68E-05
165	609699	4186257	2,48E-05
166	610199	4186257	9,54E-06
167	610699	4186257	2,10E-06
168	611199	4186257	2,64E-07
169	611699	4186257	1,88E-08
170	612199	4186257	0,00E+00
171	612699	4186257	0,00E+00
172	613199	4186257	0,00E+00
173	613699	4186257	0,00E+00
174	614199	4186257	0,00E+00
175	600199	4186757	0,00E+00
176	600699	4186757	0,00E+00
177	601199	4186757	0,00E+00
178	601699	4186757	0,00E+00
179	602199	4186757	0,00E+00
180	602699	4186757	0,00E+00
181	603199	4186757	1,91E-08
182	603699	4186757	1,66E-07
183	604199	4186757	8,34E-07

184	604699	4186757	2,58E-06
185	605199	4186757	5,54E-06
186	605699	4186757	1,01E-05
187	606199	4186757	1,68E-05
188	606699	4186757	2,26E-05
189	607199	4186757	2,60E-05
190	607699	4186757	4,90E-05
191	608199	4186757	1,37E-04
192	608699	4186757	2,71E-04
193	609199	4186757	3,16E-04
194	609699	4186757	2,12E-04
195	610199	4186757	8,15E-05
196	610699	4186757	1,79E-05
197	611199	4186757	2,24E-06
198	611699	4186757	1,59E-07
199	612199	4186757	0,00E+00
200	612699	4186757	0,00E+00
201	613199	4186757	0,00E+00
202	613699	4186757	0,00E+00
203	614199	4186757	0,00E+00
204	600199	4187257	0,00E+00
205	600699	4187257	0,00E+00
206	601199	4187257	0,00E+00
207	601699	4187257	0,00E+00
208	602199	4187257	0,00E+00
209	602699	4187257	2,67E-08
210	603199	4187257	2,61E-07
211	603699	4187257	2,14E-06
212	604199	4187257	1,08E-05
213	604699	4187257	3,33E-05
214	605199	4187257	6,98E-05
215	605699	4187257	1,19E-04
216	606199	4187257	1,84E-04
217	606699	4187257	2,32E-04
218	607199	4187257	2,36E-04
219	607699	4187257	3,08E-04
220	608199	4187257	6,96E-04
221	608699	4187257	1,33E-03
222	609199	4187257	1,54E-03
223	609699	4187257	1,03E-03
224	610199	4187257	3,94E-04
225	610699	4187257	8,64E-05
226	611199	4187257	1,08E-05
227	611699	4187257	7,67E-07
228	612199	4187257	3,09E-08
229	612699	4187257	0,00E+00

230	613199	4187257	0,00E+00
231	613699	4187257	0,00E+00
232	614199	4187257	0,00E+00
233	600199	4187757	0,00E+00
234	600699	4187757	0,00E+00
235	601199	4187757	0,00E+00
236	601699	4187757	3,55E-08
237	602199	4187757	3,00E-07
238	602699	4187757	5,32E-07
239	603199	4187757	2,39E-06
240	603699	4187757	1,62E-05
241	604199	4187757	7,93E-05
242	604699	4187757	2,45E-04
243	605199	4187757	5,08E-04
244	605699	4187757	8,25E-04
245	606199	4187757	1,18E-03
246	606699	4187757	1,41E-03
247	607199	4187757	1,32E-03
248	607699	4187757	1,28E-03
249	608199	4187757	2,12E-03
250	608699	4187757	3,74E-03
251	609199	4187757	4,26E-03
252	609699	4187757	2,84E-03
253	610199	4187757	1,09E-03
254	610699	4187757	2,37E-04
255	611199	4187757	2,96E-05
256	611699	4187757	2,10E-06
257	612199	4187757	8,43E-08
258	612699	4187757	0,00E+00
259	613199	4187757	0,00E+00
260	613699	4187757	0,00E+00
261	614199	4187757	0,00E+00
262	600199	4188257	0,00E+00
263	600699	4188257	0,00E+00
264	601199	4188257	0,00E+00
265	601699	4188257	1,78E-06
266	602199	4188257	7,33E-06
267	602699	4188257	9,93E-06
268	603199	4188257	2,01E-05
269	603699	4188257	7,86E-05
270	604199	4188257	3,42E-04
271	604699	4188257	1,04E-03
272	605199	4188257	2,14E-03
273	605699	4188257	3,36E-03
274	606199	4188257	4,51E-03
275	606699	4188257	5,09E-03

276	607199	4188257	4,53E-03
277	607699	4188257	3,60E-03
278	608199	4188257	4,11E-03
279	608699	4188257	6,15E-03
280	609199	4188257	6,77E-03
281	609699	4188257	4,46E-03
282	610199	4188257	1,70E-03
283	610699	4188257	3,71E-04
284	611199	4188257	4,61E-05
285	611699	4188257	3,26E-06
286	612199	4188257	1,31E-07
287	612699	4188257	0,00E+00
288	613199	4188257	0,00E+00
289	613699	4188257	0,00E+00
290	614199	4188257	0,00E+00
291	600199	4188757	0,00E+00
292	600699	4188757	0,00E+00
293	601199	4188757	0,00E+00
294	601699	4188757	5,63E-05
295	602199	4188757	1,04E-04
296	602699	4188757	1,27E-04
297	603199	4188757	1,73E-04
298	603699	4188757	3,21E-04
299	604199	4188757	9,31E-04
300	604699	4188757	2,62E-03
301	605199	4188757	5,33E-03
302	605699	4188757	8,15E-03
303	606199	4188757	1,04E-02
304	606699	4188757	1,11E-02
305	607199	4188757	9,57E-03
306	607699	4188757	6,94E-03
307	608199	4188757	5,63E-03
308	608699	4188757	6,25E-03
309	609199	4188757	6,25E-03
310	609699	4188757	4,02E-03
311	610199	4188757	1,52E-03
312	610699	4188757	3,30E-04
313	611199	4188757	4,10E-05
314	611699	4188757	2,89E-06
315	612199	4188757	1,16E-07
316	612699	4188757	0,00E+00
317	613199	4188757	0,00E+00
318	613699	4188757	0,00E+00
319	614199	4188757	0,00E+00
320	600199	4189257	0,00E+00
321	600699	4189257	0,00E+00

322	601199	4189257	1,01E-04
323	601699	4189257	6,15E-04
324	602199	4189257	8,38E-04
325	602699	4189257	9,89E-04
326	603199	4189257	1,16E-03
327	603699	4189257	1,37E-03
328	604199	4189257	2,02E-03
329	604699	4189257	4,24E-03
330	605199	4189257	8,14E-03
331	605699	4189257	1,22E-02
332	606199	4189257	1,50E-02
333	606699	4189257	1,54E-02
334	607199	4189257	1,30E-02
335	607699	4189257	9,23E-03
336	608199	4189257	6,17E-03
337	608699	4189257	4,57E-03
338	609199	4189257	3,56E-03
339	609699	4189257	2,11E-03
340	610199	4189257	7,78E-04
341	610699	4189257	1,68E-04
342	611199	4189257	2,07E-05
343	611699	4189257	1,46E-06
344	612199	4189257	5,84E-08
345	612699	4189257	0,00E+00
346	613199	4189257	0,00E+00
347	613699	4189257	0,00E+00
348	614199	4189257	0,00E+00
349	600199	4189757	0,00E+00
350	600699	4189757	0,00E+00
351	601199	4189757	1,28E-03
352	601699	4189757	2,84E-03
353	602199	4189757	3,88E-03
354	602699	4189757	4,51E-03
355	603199	4189757	5,00E-03
356	603699	4189757	4,97E-03
357	604199	4189757	4,49E-03
358	604699	4189757	5,43E-03
359	605199	4189757	8,57E-03
360	605699	4189757	1,21E-02
361	606199	4189757	1,46E-02
362	606699	4189757	1,47E-02
363	607199	4189757	1,22E-02
364	607699	4189757	8,83E-03
365	608199	4189757	5,64E-03
366	608699	4189757	3,08E-03
367	609199	4189757	1,54E-03

368	609699	4189757	6,98E-04
369	610199	4189757	2,34E-04
370	610699	4189757	4,89E-05
371	611199	4189757	5,98E-06
372	611699	4189757	4,20E-07
373	612199	4189757	1,67E-08
374	612699	4189757	0,00E+00
375	613199	4189757	0,00E+00
376	613699	4189757	0,00E+00
377	614199	4189757	0,00E+00
378	600199	4190257	0,00E+00
379	600699	4190257	1,93E-05
380	601199	4190257	3,90E-03
381	601699	4190257	7,45E-03
382	602199	4190257	1,03E-02
383	602699	4190257	1,20E-02
384	603199	4190257	1,30E-02
385	603699	4190257	1,22E-02
386	604199	4190257	9,07E-03
387	604699	4190257	6,83E-03
388	605199	4190257	7,51E-03
389	605699	4190257	9,37E-03
390	606199	4190257	1,10E-02
391	606699	4190257	1,13E-02
392	607199	4190257	9,47E-03
393	607699	4190257	6,97E-03
394	608199	4190257	4,60E-03
395	608699	4190257	2,33E-03
396	609199	4190257	8,27E-04
397	609699	4190257	2,21E-04
398	610199	4190257	4,98E-05
399	610699	4190257	8,71E-06
400	611199	4190257	1,00E-06
401	611699	4190257	6,89E-08
402	612199	4190257	0,00E+00
403	612699	4190257	0,00E+00
404	613199	4190257	0,00E+00
405	613699	4190257	0,00E+00
406	614199	4190257	0,00E+00
407	600199	4190757	0,00E+00
408	600699	4190757	3,83E-04
409	601199	4190757	5,66E-03
410	601699	4190757	1,12E-02
411	602199	4190757	1,57E-02
412	602699	4190757	1,86E-02
413	603199	4190757	2,02E-02

414	603699	4190757	1,85E-02
415	604199	4190757	1,30E-02
416	604699	4190757	7,89E-03
417	605199	4190757	6,35E-03
418	605699	4190757	6,71E-03
419	606199	4190757	7,63E-03
420	606699	4190757	8,20E-03
421	607199	4190757	7,35E-03
422	607699	4190757	5,92E-03
423	608199	4190757	4,34E-03
424	608699	4190757	2,36E-03
425	609199	4190757	8,07E-04
426	609699	4190757	1,66E-04
427	610199	4190757	2,14E-05
428	610699	4190757	1,90E-06
429	611199	4190757	1,33E-07
430	611699	4190757	0,00E+00
431	612199	4190757	0,00E+00
432	612699	4190757	0,00E+00
433	613199	4190757	0,00E+00
434	613699	4190757	0,00E+00
435	614199	4190757	0,00E+00
436	600199	4191257	0,00E+00
437	600699	4191257	4,06E-04
438	601199	4191257	2,96E-03
439	601699	4191257	9,53E-03
440	602199	4191257	1,37E-02
441	602699	4191257	1,68E-02
442	603199	4191257	1,86E-02
443	603699	4191257	1,71E-02
444	604199	4191257	1,19E-02
445	604699	4191257	7,33E-03
446	605199	4191257	5,74E-03
447	605699	4191257	5,50E-03
448	606199	4191257	5,67E-03
449	606699	4191257	6,17E-03
450	607199	4191257	6,27E-03
451	607699	4191257	5,79E-03
452	608199	4191257	4,56E-03
453	608699	4191257	2,54E-03
454	609199	4191257	8,83E-04
455	609699	4191257	1,80E-04
456	610199	4191257	2,11E-05
457	610699	4191257	1,43E-06
458	611199	4191257	5,69E-08
459	611699	4191257	0,00E+00

460	612199	4191257	0,00E+00
461	612699	4191257	0,00E+00
462	613199	4191257	0,00E+00
463	613699	4191257	0,00E+00
464	614199	4191257	0,00E+00
465	600199	4191757	0,00E+00
466	600699	4191757	0,00E+00
467	601199	4191757	0,00E+00
468	601699	4191757	4,35E-03
469	602199	4191757	6,92E-03
470	602699	4191757	8,83E-03
471	603199	4191757	1,01E-02
472	603699	4191757	9,43E-03
473	604199	4191757	7,09E-03
474	604699	4191757	5,58E-03
475	605199	4191757	5,80E-03
476	605699	4191757	5,95E-03
477	606199	4191757	5,51E-03
478	606699	4191757	5,48E-03
479	607199	4191757	5,75E-03
480	607699	4191757	5,34E-03
481	608199	4191757	3,90E-03
482	608699	4191757	2,02E-03
483	609199	4191757	6,74E-04
484	609699	4191757	1,35E-04
485	610199	4191757	1,57E-05
486	610699	4191757	1,04E-06
487	611199	4191757	3,92E-08
488	611699	4191757	0,00E+00
489	612199	4191757	0,00E+00
490	612699	4191757	0,00E+00
491	613199	4191757	0,00E+00
492	613699	4191757	0,00E+00
493	614199	4191757	0,00E+00
494	600199	4192257	0,00E+00
495	600699	4192257	0,00E+00
496	601199	4192257	0,00E+00
497	601699	4192257	7,49E-04
498	602199	4192257	1,96E-03
499	602699	4192257	2,69E-03
500	603199	4192257	3,20E-03
501	603699	4192257	3,15E-03
502	604199	4192257	2,89E-03
503	604699	4192257	3,57E-03
504	605199	4192257	5,17E-03
505	605699	4192257	6,07E-03

506	606199	4192257	5,62E-03
507	606699	4192257	5,07E-03
508	607199	4192257	4,89E-03
509	607699	4192257	4,06E-03
510	608199	4192257	2,48E-03
511	608699	4192257	1,08E-03
512	609199	4192257	3,22E-04
513	609699	4192257	6,09E-05
514	610199	4192257	6,91E-06
515	610699	4192257	4,54E-07
516	611199	4192257	1,70E-08
517	611699	4192257	0,00E+00
518	612199	4192257	0,00E+00
519	612699	4192257	0,00E+00
520	613199	4192257	0,00E+00
521	613699	4192257	0,00E+00
522	614199	4192257	0,00E+00
523	600199	4192757	0,00E+00
524	600699	4192757	0,00E+00
525	601199	4192757	0,00E+00
526	601699	4192757	0,00E+00
527	602199	4192757	2,91E-04
528	602699	4192757	4,61E-04
529	603199	4192757	5,97E-04
530	603699	4192757	6,57E-04
531	604199	4192757	8,86E-04
532	604699	4192757	1,76E-03
533	605199	4192757	3,22E-03
534	605699	4192757	4,27E-03
535	606199	4192757	4,13E-03
536	606699	4192757	3,50E-03
537	607199	4192757	3,03E-03
538	607699	4192757	2,24E-03
539	608199	4192757	1,16E-03
540	608699	4192757	4,11E-04
541	609199	4192757	1,01E-04
542	609699	4192757	1,68E-05
543	610199	4192757	1,79E-06
544	610699	4192757	1,14E-07
545	611199	4192757	0,00E+00
546	611699	4192757	0,00E+00
547	612199	4192757	0,00E+00
548	612699	4192757	0,00E+00
549	613199	4192757	0,00E+00
550	613699	4192757	0,00E+00
551	614199	4192757	0,00E+00

552	600199	4193257	0,00E+00
553	600699	4193257	0,00E+00
554	601199	4193257	0,00E+00
555	601699	4193257	0,00E+00
556	602199	4193257	0,00E+00
557	602699	4193257	5,72E-06
558	603199	4193257	6,26E-05
559	603699	4193257	9,24E-05
560	604199	4193257	2,12E-04
561	604699	4193257	5,94E-04
562	605199	4193257	1,28E-03
563	605699	4193257	1,88E-03
564	606199	4193257	1,88E-03
565	606699	4193257	1,51E-03
566	607199	4193257	1,18E-03
567	607699	4193257	8,01E-04
568	608199	4193257	3,75E-04
569	608699	4193257	1,13E-04
570	609199	4193257	2,23E-05
571	609699	4193257	3,05E-06
572	610199	4193257	2,84E-07
573	610699	4193257	1,69E-08
574	611199	4193257	0,00E+00
575	611699	4193257	0,00E+00
576	612199	4193257	0,00E+00
577	612699	4193257	0,00E+00
578	613199	4193257	0,00E+00
579	613699	4193257	0,00E+00
580	614199	4193257	0,00E+00
581	600199	4193757	0,00E+00
582	600699	4193757	0,00E+00
583	601199	4193757	0,00E+00
584	601699	4193757	0,00E+00
585	602199	4193757	0,00E+00
586	602699	4193757	0,00E+00
587	603199	4193757	1,83E-06
588	603699	4193757	9,74E-06
589	604199	4193757	3,69E-05
590	604699	4193757	1,29E-04
591	605199	4193757	3,15E-04
592	605699	4193757	4,96E-04
593	606199	4193757	5,07E-04
594	606699	4193757	3,85E-04
595	607199	4193757	2,72E-04
596	607699	4193757	1,72E-04
597	608199	4193757	7,61E-05

598	608699	4193757	2,09E-05
599	609199	4193757	3,54E-06
600	609699	4193757	3,91E-07
601	610199	4193757	2,96E-08
602	610699	4193757	0,00E+00
603	611199	4193757	0,00E+00
604	611699	4193757	0,00E+00
605	612199	4193757	0,00E+00
606	612699	4193757	0,00E+00
607	613199	4193757	0,00E+00
608	613699	4193757	0,00E+00
609	614199	4193757	0,00E+00
610	600199	4194257	0,00E+00
611	600699	4194257	0,00E+00
612	601199	4194257	0,00E+00
613	601699	4194257	0,00E+00
614	602199	4194257	0,00E+00
615	602699	4194257	0,00E+00
616	603199	4194257	4,93E-08
617	603699	4194257	7,92E-07
618	604199	4194257	4,30E-06
619	604699	4194257	1,76E-05
620	605199	4194257	4,66E-05
621	605699	4194257	7,71E-05
622	606199	4194257	7,95E-05
623	606699	4194257	5,73E-05
624	607199	4194257	3,66E-05
625	607699	4194257	2,15E-05
626	608199	4194257	9,15E-06
627	608699	4194257	2,41E-06
628	609199	4194257	3,77E-07
629	609699	4194257	3,59E-08
630	610199	4194257	0,00E+00
631	610699	4194257	0,00E+00
632	611199	4194257	0,00E+00
633	611699	4194257	0,00E+00
634	612199	4194257	0,00E+00
635	612699	4194257	0,00E+00
636	613199	4194257	0,00E+00
637	613699	4194257	0,00E+00
638	614199	4194257	0,00E+00
639	600199	4194757	0,00E+00
640	600699	4194757	0,00E+00
641	601199	4194757	0,00E+00
642	601699	4194757	0,00E+00
643	602199	4194757	0,00E+00

644	602699	4194757	0,00E+00
645	603199	4194757	0,00E+00
646	603699	4194757	3,97E-08
647	604199	4194757	3,19E-07
648	604699	4194757	1,44E-06
649	605199	4194757	4,08E-06
650	605699	4194757	6,95E-06
651	606199	4194757	7,17E-06
652	606699	4194757	4,93E-06
653	607199	4194757	2,85E-06
654	607699	4194757	1,54E-06
655	608199	4194757	6,34E-07
656	608699	4194757	1,63E-07
657	609199	4194757	2,47E-08
658	609699	4194757	0,00E+00
659	610199	4194757	0,00E+00
660	610699	4194757	0,00E+00
661	611199	4194757	0,00E+00
662	611699	4194757	0,00E+00
663	612199	4194757	0,00E+00
664	612699	4194757	0,00E+00
665	613199	4194757	0,00E+00
666	613699	4194757	0,00E+00
667	614199	4194757	0,00E+00
668	600199	4195257	0,00E+00
669	600699	4195257	0,00E+00
670	601199	4195257	0,00E+00
671	601699	4195257	0,00E+00
672	602199	4195257	0,00E+00
673	602699	4195257	0,00E+00
674	603199	4195257	0,00E+00
675	603699	4195257	0,00E+00
676	604199	4195257	1,26E-08
677	604699	4195257	4,86E-08
678	605199	4195257	1,13E-07
679	605699	4195257	3,53E-07
680	606199	4195257	3,69E-07
681	606699	4195257	2,44E-07
682	607199	4195257	1,28E-07
683	607699	4195257	6,33E-08
684	608199	4195257	2,50E-08
685	608699	4195257	0,00E+00
686	609199	4195257	0,00E+00
687	609699	4195257	0,00E+00
688	610199	4195257	0,00E+00
689	610699	4195257	0,00E+00

690	611199	4195257	0,00E+00
691	611699	4195257	0,00E+00
692	612199	4195257	0,00E+00
693	612699	4195257	0,00E+00
694	613199	4195257	0,00E+00
695	613699	4195257	0,00E+00
696	614199	4195257	0,00E+00
697	600199	4195757	0,00E+00
698	600699	4195757	0,00E+00
699	601199	4195757	0,00E+00
700	601699	4195757	0,00E+00
701	602199	4195757	0,00E+00
702	602699	4195757	0,00E+00
703	603199	4195757	0,00E+00
704	603699	4195757	0,00E+00
705	604199	4195757	0,00E+00
706	604699	4195757	0,00E+00
707	605199	4195757	0,00E+00
708	605699	4195757	0,00E+00
709	606199	4195757	0,00E+00
710	606699	4195757	0,00E+00
711	607199	4195757	0,00E+00
712	607699	4195757	0,00E+00
713	608199	4195757	0,00E+00
714	608699	4195757	0,00E+00
715	609199	4195757	0,00E+00
716	609699	4195757	0,00E+00
717	610199	4195757	0,00E+00
718	610699	4195757	0,00E+00
719	611199	4195757	0,00E+00
720	611699	4195757	0,00E+00
721	612199	4195757	0,00E+00
722	612699	4195757	0,00E+00
723	613199	4195757	0,00E+00
724	613699	4195757	0,00E+00
725	614199	4195757	0,00E+00
726	600199	4196257	0,00E+00
727	600699	4196257	0,00E+00
728	601199	4196257	0,00E+00
729	601699	4196257	0,00E+00
730	602199	4196257	0,00E+00
731	602699	4196257	0,00E+00
732	603199	4196257	0,00E+00
733	603699	4196257	0,00E+00
734	604199	4196257	0,00E+00
735	604699	4196257	0,00E+00

736	605199	4196257	0,00E+00
737	605699	4196257	0,00E+00
738	606199	4196257	0,00E+00
739	606699	4196257	0,00E+00
740	607199	4196257	0,00E+00
741	607699	4196257	0,00E+00
742	608199	4196257	0,00E+00
743	608699	4196257	0,00E+00
744	609199	4196257	0,00E+00
745	609699	4196257	0,00E+00
746	610199	4196257	0,00E+00
747	610699	4196257	0,00E+00
748	611199	4196257	0,00E+00
749	611699	4196257	0,00E+00
750	612199	4196257	0,00E+00
751	612699	4196257	0,00E+00
752	613199	4196257	0,00E+00
753	613699	4196257	0,00E+00
754	614199	4196257	0,00E+00
755	600199	4196757	0,00E+00
756	600699	4196757	0,00E+00
757	601199	4196757	0,00E+00
758	601699	4196757	0,00E+00
759	602199	4196757	0,00E+00

760	602699	4196757	0,00E+00
761	603199	4196757	0,00E+00
762	603699	4196757	0,00E+00
763	604199	4196757	0,00E+00
764	604699	4196757	0,00E+00
765	605199	4196757	0,00E+00
766	605699	4196757	0,00E+00
767	606199	4196757	0,00E+00
768	606699	4196757	0,00E+00
769	607199	4196757	0,00E+00
770	607699	4196757	0,00E+00
771	608199	4196757	0,00E+00
772	608699	4196757	0,00E+00
773	609199	4196757	0,00E+00
774	609699	4196757	0,00E+00
775	610199	4196757	0,00E+00
776	610699	4196757	0,00E+00
777	611199	4196757	0,00E+00
778	611699	4196757	0,00E+00
779	612199	4196757	0,00E+00
780	612699	4196757	0,00E+00
781	613199	4196757	0,00E+00
782	613699	4196757	0,00E+00
783	614199	4196757	0,00E+00

Sete Cidades ET vent opening			
ID	Longitude	Latitude	Probability
1	600199	4183757	0,00E+00
2	600699	4183757	0,00E+00
3	601199	4183757	0,00E+00
4	601699	4183757	0,00E+00
5	602199	4183757	0,00E+00
6	602699	4183757	0,00E+00
7	603199	4183757	0,00E+00
8	603699	4183757	0,00E+00
9	604199	4183757	0,00E+00
10	604699	4183757	0,00E+00
11	605199	4183757	0,00E+00
12	605699	4183757	0,00E+00
13	606199	4183757	0,00E+00
14	606699	4183757	0,00E+00
15	607199	4183757	0,00E+00
16	607699	4183757	0,00E+00
17	608199	4183757	0,00E+00
18	608699	4183757	0,00E+00
19	609199	4183757	0,00E+00
20	609699	4183757	0,00E+00
21	610199	4183757	0,00E+00
22	610699	4183757	0,00E+00
23	611199	4183757	0,00E+00
24	611699	4183757	0,00E+00
25	612199	4183757	0,00E+00
26	612699	4183757	0,00E+00
27	613199	4183757	0,00E+00
28	613699	4183757	0,00E+00
29	614199	4183757	0,00E+00
30	600199	4184257	0,00E+00
31	600699	4184257	0,00E+00
32	601199	4184257	0,00E+00
33	601699	4184257	0,00E+00
34	602199	4184257	0,00E+00
35	602699	4184257	0,00E+00
36	603199	4184257	0,00E+00
37	603699	4184257	0,00E+00
38	604199	4184257	0,00E+00
39	604699	4184257	0,00E+00
40	605199	4184257	0,00E+00
41	605699	4184257	0,00E+00
42	606199	4184257	0,00E+00
43	606699	4184257	0,00E+00
44	607199	4184257	0,00E+00
45	607699	4184257	0,00E+00

46	608199	4184257	0,00E+00
47	608699	4184257	0,00E+00
48	609199	4184257	0,00E+00
49	609699	4184257	0,00E+00
50	610199	4184257	0,00E+00
51	610699	4184257	0,00E+00
52	611199	4184257	0,00E+00
53	611699	4184257	0,00E+00
54	612199	4184257	0,00E+00
55	612699	4184257	0,00E+00
56	613199	4184257	0,00E+00
57	613699	4184257	0,00E+00
58	614199	4184257	0,00E+00
59	600199	4184757	0,00E+00
60	600699	4184757	0,00E+00
61	601199	4184757	0,00E+00
62	601699	4184757	0,00E+00
63	602199	4184757	0,00E+00
64	602699	4184757	0,00E+00
65	603199	4184757	0,00E+00
66	603699	4184757	0,00E+00
67	604199	4184757	0,00E+00
68	604699	4184757	0,00E+00
69	605199	4184757	0,00E+00
70	605699	4184757	0,00E+00
71	606199	4184757	0,00E+00
72	606699	4184757	0,00E+00
73	607199	4184757	0,00E+00
74	607699	4184757	0,00E+00
75	608199	4184757	0,00E+00
76	608699	4184757	0,00E+00
77	609199	4184757	0,00E+00
78	609699	4184757	0,00E+00
79	610199	4184757	0,00E+00
80	610699	4184757	0,00E+00
81	611199	4184757	0,00E+00
82	611699	4184757	0,00E+00
83	612199	4184757	0,00E+00
84	612699	4184757	0,00E+00
85	613199	4184757	0,00E+00
86	613699	4184757	0,00E+00
87	614199	4184757	0,00E+00
88	600199	4185257	0,00E+00
89	600699	4185257	0,00E+00
90	601199	4185257	0,00E+00
91	601699	4185257	0,00E+00

92	602199	4185257	0,00E+00
93	602699	4185257	0,00E+00
94	603199	4185257	0,00E+00
95	603699	4185257	0,00E+00
96	604199	4185257	0,00E+00
97	604699	4185257	0,00E+00
98	605199	4185257	0,00E+00
99	605699	4185257	0,00E+00
100	606199	4185257	0,00E+00
101	606699	4185257	0,00E+00
102	607199	4185257	0,00E+00
103	607699	4185257	0,00E+00
104	608199	4185257	0,00E+00
105	608699	4185257	0,00E+00
106	609199	4185257	0,00E+00
107	609699	4185257	0,00E+00
108	610199	4185257	0,00E+00
109	610699	4185257	0,00E+00
110	611199	4185257	0,00E+00
111	611699	4185257	0,00E+00
112	612199	4185257	0,00E+00
113	612699	4185257	0,00E+00
114	613199	4185257	0,00E+00
115	613699	4185257	0,00E+00
116	614199	4185257	0,00E+00
117	600199	4185757	0,00E+00
118	600699	4185757	0,00E+00
119	601199	4185757	0,00E+00
120	601699	4185757	0,00E+00
121	602199	4185757	0,00E+00
122	602699	4185757	0,00E+00
123	603199	4185757	0,00E+00
124	603699	4185757	0,00E+00
125	604199	4185757	0,00E+00
126	604699	4185757	0,00E+00
127	605199	4185757	0,00E+00
128	605699	4185757	0,00E+00
129	606199	4185757	0,00E+00
130	606699	4185757	0,00E+00
131	607199	4185757	0,00E+00
132	607699	4185757	0,00E+00
133	608199	4185757	0,00E+00
134	608699	4185757	0,00E+00
135	609199	4185757	0,00E+00
136	609699	4185757	0,00E+00
137	610199	4185757	0,00E+00

138	610699	4185757	0,00E+00
139	611199	4185757	0,00E+00
140	611699	4185757	0,00E+00
141	612199	4185757	0,00E+00
142	612699	4185757	0,00E+00
143	613199	4185757	0,00E+00
144	613699	4185757	0,00E+00
145	614199	4185757	0,00E+00
146	600199	4186257	0,00E+00
147	600699	4186257	0,00E+00
148	601199	4186257	0,00E+00
149	601699	4186257	0,00E+00
150	602199	4186257	0,00E+00
151	602699	4186257	0,00E+00
152	603199	4186257	0,00E+00
153	603699	4186257	0,00E+00
154	604199	4186257	0,00E+00
155	604699	4186257	0,00E+00
156	605199	4186257	0,00E+00
157	605699	4186257	0,00E+00
158	606199	4186257	0,00E+00
159	606699	4186257	0,00E+00
160	607199	4186257	0,00E+00
161	607699	4186257	0,00E+00
162	608199	4186257	0,00E+00
163	608699	4186257	0,00E+00
164	609199	4186257	0,00E+00
165	609699	4186257	0,00E+00
166	610199	4186257	0,00E+00
167	610699	4186257	0,00E+00
168	611199	4186257	0,00E+00
169	611699	4186257	0,00E+00
170	612199	4186257	0,00E+00
171	612699	4186257	0,00E+00
172	613199	4186257	0,00E+00
173	613699	4186257	0,00E+00
174	614199	4186257	0,00E+00
175	600199	4186757	0,00E+00
176	600699	4186757	0,00E+00
177	601199	4186757	0,00E+00
178	601699	4186757	0,00E+00
179	602199	4186757	0,00E+00
180	602699	4186757	0,00E+00
181	603199	4186757	0,00E+00
182	603699	4186757	0,00E+00
183	604199	4186757	0,00E+00

184	604699	4186757	0,00E+00
185	605199	4186757	0,00E+00
186	605699	4186757	0,00E+00
187	606199	4186757	0,00E+00
188	606699	4186757	0,00E+00
189	607199	4186757	0,00E+00
190	607699	4186757	0,00E+00
191	608199	4186757	0,00E+00
192	608699	4186757	0,00E+00
193	609199	4186757	0,00E+00
194	609699	4186757	0,00E+00
195	610199	4186757	0,00E+00
196	610699	4186757	0,00E+00
197	611199	4186757	0,00E+00
198	611699	4186757	0,00E+00
199	612199	4186757	0,00E+00
200	612699	4186757	0,00E+00
201	613199	4186757	0,00E+00
202	613699	4186757	0,00E+00
203	614199	4186757	0,00E+00
204	600199	4187257	0,00E+00
205	600699	4187257	0,00E+00
206	601199	4187257	0,00E+00
207	601699	4187257	0,00E+00
208	602199	4187257	0,00E+00
209	602699	4187257	0,00E+00
210	603199	4187257	0,00E+00
211	603699	4187257	0,00E+00
212	604199	4187257	0,00E+00
213	604699	4187257	0,00E+00
214	605199	4187257	0,00E+00
215	605699	4187257	0,00E+00
216	606199	4187257	0,00E+00
217	606699	4187257	0,00E+00
218	607199	4187257	0,00E+00
219	607699	4187257	0,00E+00
220	608199	4187257	0,00E+00
221	608699	4187257	0,00E+00
222	609199	4187257	0,00E+00
223	609699	4187257	0,00E+00
224	610199	4187257	0,00E+00
225	610699	4187257	0,00E+00
226	611199	4187257	0,00E+00
227	611699	4187257	0,00E+00
228	612199	4187257	0,00E+00
229	612699	4187257	0,00E+00

230	613199	4187257	0,00E+00
231	613699	4187257	0,00E+00
232	614199	4187257	0,00E+00
233	600199	4187757	0,00E+00
234	600699	4187757	0,00E+00
235	601199	4187757	0,00E+00
236	601699	4187757	0,00E+00
237	602199	4187757	0,00E+00
238	602699	4187757	0,00E+00
239	603199	4187757	0,00E+00
240	603699	4187757	0,00E+00
241	604199	4187757	0,00E+00
242	604699	4187757	0,00E+00
243	605199	4187757	0,00E+00
244	605699	4187757	4,68E-04
245	606199	4187757	2,84E-03
246	606699	4187757	4,15E-03
247	607199	4187757	3,93E-03
248	607699	4187757	2,28E-03
249	608199	4187757	2,81E-04
250	608699	4187757	0,00E+00
251	609199	4187757	0,00E+00
252	609699	4187757	0,00E+00
253	610199	4187757	0,00E+00
254	610699	4187757	0,00E+00
255	611199	4187757	0,00E+00
256	611699	4187757	0,00E+00
257	612199	4187757	0,00E+00
258	612699	4187757	0,00E+00
259	613199	4187757	0,00E+00
260	613699	4187757	0,00E+00
261	614199	4187757	0,00E+00
262	600199	4188257	0,00E+00
263	600699	4188257	0,00E+00
264	601199	4188257	0,00E+00
265	601699	4188257	0,00E+00
266	602199	4188257	0,00E+00
267	602699	4188257	0,00E+00
268	603199	4188257	0,00E+00
269	603699	4188257	0,00E+00
270	604199	4188257	0,00E+00
271	604699	4188257	3,12E-04
272	605199	4188257	3,00E-03
273	605699	4188257	8,49E-03
274	606199	4188257	1,18E-02
275	606699	4188257	1,26E-02

276	607199	4188257	1,04E-02
277	607699	4188257	7,21E-03
278	608199	4188257	4,15E-03
279	608699	4188257	4,06E-04
280	609199	4188257	0,00E+00
281	609699	4188257	0,00E+00
282	610199	4188257	0,00E+00
283	610699	4188257	0,00E+00
284	611199	4188257	0,00E+00
285	611699	4188257	0,00E+00
286	612199	4188257	0,00E+00
287	612699	4188257	0,00E+00
288	613199	4188257	0,00E+00
289	613699	4188257	0,00E+00
290	614199	4188257	0,00E+00
291	600199	4188757	0,00E+00
292	600699	4188757	0,00E+00
293	601199	4188757	0,00E+00
294	601699	4188757	0,00E+00
295	602199	4188757	0,00E+00
296	602699	4188757	0,00E+00
297	603199	4188757	0,00E+00
298	603699	4188757	0,00E+00
299	604199	4188757	0,00E+00
300	604699	4188757	2,53E-03
301	605199	4188757	6,30E-03
302	605699	4188757	1,24E-02
303	606199	4188757	1,63E-02
304	606699	4188757	1,77E-02
305	607199	4188757	1,66E-02
306	607699	4188757	1,27E-02
307	608199	4188757	7,93E-03
308	608699	4188757	4,21E-03
309	609199	4188757	1,56E-04
310	609699	4188757	0,00E+00
311	610199	4188757	0,00E+00
312	610699	4188757	0,00E+00
313	611199	4188757	0,00E+00
314	611699	4188757	0,00E+00
315	612199	4188757	0,00E+00
316	612699	4188757	0,00E+00
317	613199	4188757	0,00E+00
318	613699	4188757	0,00E+00
319	614199	4188757	0,00E+00
320	600199	4189257	0,00E+00
321	600699	4189257	0,00E+00

322	601199	4189257	0,00E+00
323	601699	4189257	0,00E+00
324	602199	4189257	0,00E+00
325	602699	4189257	0,00E+00
326	603199	4189257	0,00E+00
327	603699	4189257	0,00E+00
328	604199	4189257	5,93E-04
329	604699	4189257	4,96E-03
330	605199	4189257	1,08E-02
331	605699	4189257	1,74E-02
332	606199	4189257	1,96E-02
333	606699	4189257	2,12E-02
334	607199	4189257	2,00E-02
335	607699	4189257	1,60E-02
336	608199	4189257	7,87E-03
337	608699	4189257	5,24E-03
338	609199	4189257	1,50E-03
339	609699	4189257	0,00E+00
340	610199	4189257	0,00E+00
341	610699	4189257	0,00E+00
342	611199	4189257	0,00E+00
343	611699	4189257	0,00E+00
344	612199	4189257	0,00E+00
345	612699	4189257	0,00E+00
346	613199	4189257	0,00E+00
347	613699	4189257	0,00E+00
348	614199	4189257	0,00E+00
349	600199	4189757	0,00E+00
350	600699	4189757	0,00E+00
351	601199	4189757	0,00E+00
352	601699	4189757	0,00E+00
353	602199	4189757	0,00E+00
354	602699	4189757	0,00E+00
355	603199	4189757	0,00E+00
356	603699	4189757	0,00E+00
357	604199	4189757	2,15E-03
358	604699	4189757	6,24E-03
359	605199	4189757	1,11E-02
360	605699	4189757	1,79E-02
361	606199	4189757	2,33E-02
362	606699	4189757	2,55E-02
363	607199	4189757	2,27E-02
364	607699	4189757	1,79E-02
365	608199	4189757	7,74E-03
366	608699	4189757	4,46E-03
367	609199	4189757	2,18E-03

368	609699	4189757	0,00E+00
369	610199	4189757	0,00E+00
370	610699	4189757	0,00E+00
371	611199	4189757	0,00E+00
372	611699	4189757	0,00E+00
373	612199	4189757	0,00E+00
374	612699	4189757	0,00E+00
375	613199	4189757	0,00E+00
376	613699	4189757	0,00E+00
377	614199	4189757	0,00E+00
378	600199	4190257	0,00E+00
379	600699	4190257	0,00E+00
380	601199	4190257	0,00E+00
381	601699	4190257	0,00E+00
382	602199	4190257	0,00E+00
383	602699	4190257	0,00E+00
384	603199	4190257	0,00E+00
385	603699	4190257	0,00E+00
386	604199	4190257	2,87E-03
387	604699	4190257	5,06E-03
388	605199	4190257	8,33E-03
389	605699	4190257	1,77E-02
390	606199	4190257	2,01E-02
391	606699	4190257	2,34E-02
392	607199	4190257	2,15E-02
393	607699	4190257	1,77E-02
394	608199	4190257	8,93E-03
395	608699	4190257	5,99E-03
396	609199	4190257	2,18E-03
397	609699	4190257	0,00E+00
398	610199	4190257	0,00E+00
399	610699	4190257	0,00E+00
400	611199	4190257	0,00E+00
401	611699	4190257	0,00E+00
402	612199	4190257	0,00E+00
403	612699	4190257	0,00E+00
404	613199	4190257	0,00E+00
405	613699	4190257	0,00E+00
406	614199	4190257	0,00E+00
407	600199	4190757	0,00E+00
408	600699	4190757	0,00E+00
409	601199	4190757	0,00E+00
410	601699	4190757	0,00E+00
411	602199	4190757	0,00E+00
412	602699	4190757	0,00E+00
413	603199	4190757	0,00E+00

414	603699	4190757	0,00E+00
415	604199	4190757	3,09E-03
416	604699	4190757	5,46E-03
417	605199	4190757	8,46E-03
418	605699	4190757	1,45E-02
419	606199	4190757	1,42E-02
420	606699	4190757	1,30E-02
421	607199	4190757	1,51E-02
422	607699	4190757	1,31E-02
423	608199	4190757	7,52E-03
424	608699	4190757	5,52E-03
425	609199	4190757	2,72E-03
426	609699	4190757	0,00E+00
427	610199	4190757	0,00E+00
428	610699	4190757	0,00E+00
429	611199	4190757	0,00E+00
430	611699	4190757	0,00E+00
431	612199	4190757	0,00E+00
432	612699	4190757	0,00E+00
433	613199	4190757	0,00E+00
434	613699	4190757	0,00E+00
435	614199	4190757	0,00E+00
436	600199	4191257	0,00E+00
437	600699	4191257	0,00E+00
438	601199	4191257	0,00E+00
439	601699	4191257	0,00E+00
440	602199	4191257	0,00E+00
441	602699	4191257	0,00E+00
442	603199	4191257	0,00E+00
443	603699	4191257	0,00E+00
444	604199	4191257	3,78E-03
445	604699	4191257	6,27E-03
446	605199	4191257	8,12E-03
447	605699	4191257	1,31E-02
448	606199	4191257	1,62E-02
449	606699	4191257	1,36E-02
450	607199	4191257	1,18E-02
451	607699	4191257	1,06E-02
452	608199	4191257	6,93E-03
453	608699	4191257	3,18E-03
454	609199	4191257	3,12E-03
455	609699	4191257	0,00E+00
456	610199	4191257	0,00E+00
457	610699	4191257	0,00E+00
458	611199	4191257	0,00E+00
459	611699	4191257	0,00E+00

460	612199	4191257	0,00E+00
461	612699	4191257	0,00E+00
462	613199	4191257	0,00E+00
463	613699	4191257	0,00E+00
464	614199	4191257	0,00E+00
465	600199	4191757	0,00E+00
466	600699	4191757	0,00E+00
467	601199	4191757	0,00E+00
468	601699	4191757	0,00E+00
469	602199	4191757	0,00E+00
470	602699	4191757	0,00E+00
471	603199	4191757	0,00E+00
472	603699	4191757	4,99E-04
473	604199	4191757	3,12E-03
474	604699	4191757	5,37E-03
475	605199	4191757	8,08E-03
476	605699	4191757	9,61E-03
477	606199	4191757	1,29E-02
478	606699	4191757	1,17E-02
479	607199	4191757	1,08E-02
480	607699	4191757	8,40E-03
481	608199	4191757	6,24E-03
482	608699	4191757	4,06E-03
483	609199	4191757	2,59E-03
484	609699	4191757	0,00E+00
485	610199	4191757	0,00E+00
486	610699	4191757	0,00E+00
487	611199	4191757	0,00E+00
488	611699	4191757	0,00E+00
489	612199	4191757	0,00E+00
490	612699	4191757	0,00E+00
491	613199	4191757	0,00E+00
492	613699	4191757	0,00E+00
493	614199	4191757	0,00E+00
494	600199	4192257	0,00E+00
495	600699	4192257	0,00E+00
496	601199	4192257	0,00E+00
497	601699	4192257	0,00E+00
498	602199	4192257	0,00E+00
499	602699	4192257	0,00E+00
500	603199	4192257	0,00E+00
501	603699	4192257	2,18E-04
502	604199	4192257	3,09E-03
503	604699	4192257	5,52E-03
504	605199	4192257	6,24E-03
505	605699	4192257	6,74E-03

506	606199	4192257	1,01E-02
507	606699	4192257	8,77E-03
508	607199	4192257	8,68E-03
509	607699	4192257	6,27E-03
510	608199	4192257	6,24E-03
511	608699	4192257	4,15E-03
512	609199	4192257	7,18E-04
513	609699	4192257	0,00E+00
514	610199	4192257	0,00E+00
515	610699	4192257	0,00E+00
516	611199	4192257	0,00E+00
517	611699	4192257	0,00E+00
518	612199	4192257	0,00E+00
519	612699	4192257	0,00E+00
520	613199	4192257	0,00E+00
521	613699	4192257	0,00E+00
522	614199	4192257	0,00E+00
523	600199	4192757	0,00E+00
524	600699	4192757	0,00E+00
525	601199	4192757	0,00E+00
526	601699	4192757	0,00E+00
527	602199	4192757	0,00E+00
528	602699	4192757	0,00E+00
529	603199	4192757	0,00E+00
530	603699	4192757	0,00E+00
531	604199	4192757	1,81E-03
532	604699	4192757	5,31E-03
533	605199	4192757	6,24E-03
534	605699	4192757	6,27E-03
535	606199	4192757	8,30E-03
536	606699	4192757	6,30E-03
537	607199	4192757	5,34E-03
538	607699	4192757	3,78E-03
539	608199	4192757	4,00E-03
540	608699	4192757	6,55E-04
541	609199	4192757	0,00E+00
542	609699	4192757	0,00E+00
543	610199	4192757	0,00E+00
544	610699	4192757	0,00E+00
545	611199	4192757	0,00E+00
546	611699	4192757	0,00E+00
547	612199	4192757	0,00E+00
548	612699	4192757	0,00E+00
549	613199	4192757	0,00E+00
550	613699	4192757	0,00E+00
551	614199	4192757	0,00E+00

552	600199	4193257	0,00E+00
553	600699	4193257	0,00E+00
554	601199	4193257	0,00E+00
555	601699	4193257	0,00E+00
556	602199	4193257	0,00E+00
557	602699	4193257	0,00E+00
558	603199	4193257	0,00E+00
559	603699	4193257	0,00E+00
560	604199	4193257	0,00E+00
561	604699	4193257	1,78E-03
562	605199	4193257	4,87E-03
563	605699	4193257	4,49E-03
564	606199	4193257	3,81E-03
565	606699	4193257	5,62E-03
566	607199	4193257	3,84E-03
567	607699	4193257	2,90E-03
568	608199	4193257	1,06E-03
569	608699	4193257	0,00E+00
570	609199	4193257	0,00E+00
571	609699	4193257	0,00E+00
572	610199	4193257	0,00E+00
573	610699	4193257	0,00E+00
574	611199	4193257	0,00E+00
575	611699	4193257	0,00E+00
576	612199	4193257	0,00E+00
577	612699	4193257	0,00E+00
578	613199	4193257	0,00E+00
579	613699	4193257	0,00E+00
580	614199	4193257	0,00E+00
581	600199	4193757	0,00E+00
582	600699	4193757	0,00E+00
583	601199	4193757	0,00E+00
584	601699	4193757	0,00E+00
585	602199	4193757	0,00E+00
586	602699	4193757	0,00E+00
587	603199	4193757	0,00E+00
588	603699	4193757	0,00E+00
589	604199	4193757	0,00E+00
590	604699	4193757	0,00E+00
591	605199	4193757	5,62E-04
592	605699	4193757	1,72E-03
593	606199	4193757	1,72E-03
594	606699	4193757	5,62E-04
595	607199	4193757	2,50E-04
596	607699	4193757	3,12E-05
597	608199	4193757	0,00E+00

598	608699	4193757	0,00E+00
599	609199	4193757	0,00E+00
600	609699	4193757	0,00E+00
601	610199	4193757	0,00E+00
602	610699	4193757	0,00E+00
603	611199	4193757	0,00E+00
604	611699	4193757	0,00E+00
605	612199	4193757	0,00E+00
606	612699	4193757	0,00E+00
607	613199	4193757	0,00E+00
608	613699	4193757	0,00E+00
609	614199	4193757	0,00E+00
610	600199	4194257	0,00E+00
611	600699	4194257	0,00E+00
612	601199	4194257	0,00E+00
613	601699	4194257	0,00E+00
614	602199	4194257	0,00E+00
615	602699	4194257	0,00E+00
616	603199	4194257	0,00E+00
617	603699	4194257	0,00E+00
618	604199	4194257	0,00E+00
619	604699	4194257	0,00E+00
620	605199	4194257	0,00E+00
621	605699	4194257	0,00E+00
622	606199	4194257	0,00E+00
623	606699	4194257	0,00E+00
624	607199	4194257	0,00E+00
625	607699	4194257	0,00E+00
626	608199	4194257	0,00E+00
627	608699	4194257	0,00E+00
628	609199	4194257	0,00E+00
629	609699	4194257	0,00E+00
630	610199	4194257	0,00E+00
631	610699	4194257	0,00E+00
632	611199	4194257	0,00E+00
633	611699	4194257	0,00E+00
634	612199	4194257	0,00E+00
635	612699	4194257	0,00E+00
636	613199	4194257	0,00E+00
637	613699	4194257	0,00E+00
638	614199	4194257	0,00E+00
639	600199	4194757	0,00E+00
640	600699	4194757	0,00E+00
641	601199	4194757	0,00E+00
642	601699	4194757	0,00E+00
643	602199	4194757	0,00E+00

644	602699	4194757	0,00E+00
645	603199	4194757	0,00E+00
646	603699	4194757	0,00E+00
647	604199	4194757	0,00E+00
648	604699	4194757	0,00E+00
649	605199	4194757	0,00E+00
650	605699	4194757	0,00E+00
651	606199	4194757	0,00E+00
652	606699	4194757	0,00E+00
653	607199	4194757	0,00E+00
654	607699	4194757	0,00E+00
655	608199	4194757	0,00E+00
656	608699	4194757	0,00E+00
657	609199	4194757	0,00E+00
658	609699	4194757	0,00E+00
659	610199	4194757	0,00E+00
660	610699	4194757	0,00E+00
661	611199	4194757	0,00E+00
662	611699	4194757	0,00E+00
663	612199	4194757	0,00E+00
664	612699	4194757	0,00E+00
665	613199	4194757	0,00E+00
666	613699	4194757	0,00E+00
667	614199	4194757	0,00E+00
668	600199	4195257	0,00E+00
669	600699	4195257	0,00E+00
670	601199	4195257	0,00E+00
671	601699	4195257	0,00E+00
672	602199	4195257	0,00E+00
673	602699	4195257	0,00E+00
674	603199	4195257	0,00E+00
675	603699	4195257	0,00E+00
676	604199	4195257	0,00E+00
677	604699	4195257	0,00E+00
678	605199	4195257	0,00E+00
679	605699	4195257	0,00E+00
680	606199	4195257	0,00E+00
681	606699	4195257	0,00E+00
682	607199	4195257	0,00E+00
683	607699	4195257	0,00E+00
684	608199	4195257	0,00E+00
685	608699	4195257	0,00E+00
686	609199	4195257	0,00E+00
687	609699	4195257	0,00E+00
688	610199	4195257	0,00E+00
689	610699	4195257	0,00E+00

690	611199	4195257	0,00E+00
691	611699	4195257	0,00E+00
692	612199	4195257	0,00E+00
693	612699	4195257	0,00E+00
694	613199	4195257	0,00E+00
695	613699	4195257	0,00E+00
696	614199	4195257	0,00E+00
697	600199	4195757	0,00E+00
698	600699	4195757	0,00E+00
699	601199	4195757	0,00E+00
700	601699	4195757	0,00E+00
701	602199	4195757	0,00E+00
702	602699	4195757	0,00E+00
703	603199	4195757	0,00E+00
704	603699	4195757	0,00E+00
705	604199	4195757	0,00E+00
706	604699	4195757	0,00E+00
707	605199	4195757	0,00E+00
708	605699	4195757	0,00E+00
709	606199	4195757	0,00E+00
710	606699	4195757	0,00E+00
711	607199	4195757	0,00E+00
712	607699	4195757	0,00E+00
713	608199	4195757	0,00E+00
714	608699	4195757	0,00E+00
715	609199	4195757	0,00E+00
716	609699	4195757	0,00E+00
717	610199	4195757	0,00E+00
718	610699	4195757	0,00E+00
719	611199	4195757	0,00E+00
720	611699	4195757	0,00E+00
721	612199	4195757	0,00E+00
722	612699	4195757	0,00E+00
723	613199	4195757	0,00E+00
724	613699	4195757	0,00E+00
725	614199	4195757	0,00E+00
726	600199	4196257	0,00E+00
727	600699	4196257	0,00E+00
728	601199	4196257	0,00E+00
729	601699	4196257	0,00E+00
730	602199	4196257	0,00E+00
731	602699	4196257	0,00E+00
732	603199	4196257	0,00E+00
733	603699	4196257	0,00E+00
734	604199	4196257	0,00E+00
735	604699	4196257	0,00E+00

736	605199	4196257	0,00E+00
737	605699	4196257	0,00E+00
738	606199	4196257	0,00E+00
739	606699	4196257	0,00E+00
740	607199	4196257	0,00E+00
741	607699	4196257	0,00E+00
742	608199	4196257	0,00E+00
743	608699	4196257	0,00E+00
744	609199	4196257	0,00E+00
745	609699	4196257	0,00E+00
746	610199	4196257	0,00E+00
747	610699	4196257	0,00E+00
748	611199	4196257	0,00E+00
749	611699	4196257	0,00E+00
750	612199	4196257	0,00E+00
751	612699	4196257	0,00E+00
752	613199	4196257	0,00E+00
753	613699	4196257	0,00E+00
754	614199	4196257	0,00E+00
755	600199	4196757	0,00E+00
756	600699	4196757	0,00E+00
757	601199	4196757	0,00E+00
758	601699	4196757	0,00E+00
759	602199	4196757	0,00E+00

760	602699	4196757	0,00E+00
761	603199	4196757	0,00E+00
762	603699	4196757	0,00E+00
763	604199	4196757	0,00E+00
764	604699	4196757	0,00E+00
765	605199	4196757	0,00E+00
766	605699	4196757	0,00E+00
767	606199	4196757	0,00E+00
768	606699	4196757	0,00E+00
769	607199	4196757	0,00E+00
770	607699	4196757	0,00E+00
771	608199	4196757	0,00E+00
772	608699	4196757	0,00E+00
773	609199	4196757	0,00E+00
774	609699	4196757	0,00E+00
775	610199	4196757	0,00E+00
776	610699	4196757	0,00E+00
777	611199	4196757	0,00E+00
778	611699	4196757	0,00E+00
779	612199	4196757	0,00E+00
780	612699	4196757	0,00E+00
781	613199	4196757	0,00E+00
782	613699	4196757	0,00E+00
783	614199	4196757	0,00E+00

Fogo BT vent opening			
ID	Longitude	Latitude	Probability
1	625949	4173807	0,00E+00
2	626449	4173807	0,00E+00
3	626949	4173807	0,00E+00
4	627449	4173807	0,00E+00
5	627949	4173807	0,00E+00
6	628449	4173807	0,00E+00
7	628949	4173807	0,00E+00
8	629449	4173807	0,00E+00
9	629949	4173807	0,00E+00
10	630449	4173807	0,00E+00
11	630949	4173807	0,00E+00
12	631449	4173807	0,00E+00
13	631949	4173807	0,00E+00
14	632449	4173807	0,00E+00
15	632949	4173807	0,00E+00
16	633449	4173807	0,00E+00
17	633949	4173807	0,00E+00
18	634449	4173807	0,00E+00
19	634949	4173807	0,00E+00
20	635449	4173807	0,00E+00
21	635949	4173807	0,00E+00
22	636449	4173807	0,00E+00
23	636949	4173807	0,00E+00
24	637449	4173807	0,00E+00
25	637949	4173807	0,00E+00
26	638449	4173807	0,00E+00
27	638949	4173807	0,00E+00
28	639449	4173807	0,00E+00
29	625949	4174307	0,00E+00
30	626449	4174307	0,00E+00
31	626949	4174307	0,00E+00
32	627449	4174307	0,00E+00
33	627949	4174307	0,00E+00
34	628449	4174307	0,00E+00
35	628949	4174307	0,00E+00
36	629449	4174307	0,00E+00
37	629949	4174307	0,00E+00
38	630449	4174307	0,00E+00
39	630949	4174307	0,00E+00
40	631449	4174307	3,70E-04
41	631949	4174307	0,00E+00
42	632449	4174307	0,00E+00
43	632949	4174307	0,00E+00
44	633449	4174307	0,00E+00
45	633949	4174307	0,00E+00

46	634449	4174307	0,00E+00
47	634949	4174307	0,00E+00
48	635449	4174307	0,00E+00
49	635949	4174307	0,00E+00
50	636449	4174307	0,00E+00
51	636949	4174307	0,00E+00
52	637449	4174307	0,00E+00
53	637949	4174307	0,00E+00
54	638449	4174307	0,00E+00
55	638949	4174307	0,00E+00
56	639449	4174307	0,00E+00
57	625949	4174807	0,00E+00
58	626449	4174807	0,00E+00
59	626949	4174807	0,00E+00
60	627449	4174807	0,00E+00
61	627949	4174807	0,00E+00
62	628449	4174807	0,00E+00
63	628949	4174807	0,00E+00
64	629449	4174807	0,00E+00
65	629949	4174807	0,00E+00
66	630449	4174807	0,00E+00
67	630949	4174807	1,41E-03
68	631449	4174807	4,71E-03
69	631949	4174807	3,51E-03
70	632449	4174807	9,04E-04
71	632949	4174807	0,00E+00
72	633449	4174807	0,00E+00
73	633949	4174807	0,00E+00
74	634449	4174807	0,00E+00
75	634949	4174807	0,00E+00
76	635449	4174807	0,00E+00
77	635949	4174807	0,00E+00
78	636449	4174807	0,00E+00
79	636949	4174807	1,84E-06
80	637449	4174807	3,58E-06
81	637949	4174807	0,00E+00
82	638449	4174807	0,00E+00
83	638949	4174807	0,00E+00
84	639449	4174807	0,00E+00
85	625949	4175307	0,00E+00
86	626449	4175307	0,00E+00
87	626949	4175307	0,00E+00
88	627449	4175307	0,00E+00
89	627949	4175307	0,00E+00
90	628449	4175307	0,00E+00
91	628949	4175307	0,00E+00

92	629449	4175307	1,34E-04	138	638449	4175807	8,04E-05
93	629949	4175307	5,52E-04	139	638949	4175807	0,00E+00
94	630449	4175307	7,00E-04	140	639449	4175807	0,00E+00
95	630949	4175307	4,78E-03	141	625949	4176307	0,00E+00
96	631449	4175307	7,84E-03	142	626449	4176307	0,00E+00
97	631949	4175307	5,64E-03	143	626949	4176307	0,00E+00
98	632449	4175307	2,05E-03	144	627449	4176307	0,00E+00
99	632949	4175307	5,63E-04	145	627949	4176307	0,00E+00
100	633449	4175307	7,47E-05	146	628449	4176307	7,90E-05
101	633949	4175307	1,84E-06	147	628949	4176307	3,25E-04
102	634449	4175307	3,04E-06	148	629449	4176307	7,28E-04
103	634949	4175307	3,12E-05	149	629949	4176307	1,48E-03
104	635449	4175307	4,36E-05	150	630449	4176307	2,45E-03
105	635949	4175307	4,59E-05	151	630949	4176307	2,77E-03
106	636449	4175307	1,52E-04	152	631449	4176307	2,68E-03
107	636949	4175307	3,49E-04	153	631949	4176307	2,75E-03
108	637449	4175307	2,80E-04	154	632449	4176307	2,32E-03
109	637949	4175307	1,11E-04	155	632949	4176307	8,19E-04
110	638449	4175307	2,04E-05	156	633449	4176307	2,62E-04
111	638949	4175307	0,00E+00	157	633949	4176307	1,00E-04
112	639449	4175307	0,00E+00	158	634449	4176307	9,08E-05
113	625949	4175807	0,00E+00	159	634949	4176307	1,89E-04
114	626449	4175807	0,00E+00	160	635449	4176307	4,14E-04
115	626949	4175807	0,00E+00	161	635949	4176307	7,36E-04
116	627449	4175807	0,00E+00	162	636449	4176307	1,32E-03
117	627949	4175807	0,00E+00	163	636949	4176307	2,44E-03
118	628449	4175807	0,00E+00	164	637449	4176307	1,47E-03
119	628949	4175807	1,94E-05	165	637949	4176307	5,36E-04
120	629449	4175807	6,27E-04	166	638449	4176307	1,71E-04
121	629949	4175807	1,98E-03	167	638949	4176307	1,50E-05
122	630449	4175807	4,58E-03	168	639449	4176307	0,00E+00
123	630949	4175807	4,88E-03	169	625949	4176807	0,00E+00
124	631449	4175807	5,67E-03	170	626449	4176807	0,00E+00
125	631949	4175807	4,24E-03	171	626949	4176807	0,00E+00
126	632449	4175807	2,39E-03	172	627449	4176807	0,00E+00
127	632949	4175807	8,87E-04	173	627949	4176807	2,84E-04
128	633449	4175807	2,79E-04	174	628449	4176807	7,30E-04
129	633949	4175807	8,17E-05	175	628949	4176807	7,26E-04
130	634449	4175807	5,77E-05	176	629449	4176807	1,10E-03
131	634949	4175807	8,79E-05	177	629949	4176807	1,66E-03
132	635449	4175807	1,75E-04	178	630449	4176807	2,10E-03
133	635949	4175807	3,48E-04	179	630949	4176807	2,66E-03
134	636449	4175807	7,39E-04	180	631449	4176807	1,69E-03
135	636949	4175807	1,29E-03	181	631949	4176807	1,28E-03
136	637449	4175807	8,75E-04	182	632449	4176807	9,66E-04
137	637949	4175807	3,41E-04	183	632949	4176807	4,66E-04

184	633449	4176807	1,81E-04	230	628449	4177807	2,73E-03
185	633949	4176807	9,23E-05	231	628949	4177807	2,01E-03
186	634449	4176807	1,31E-04	232	629449	4177807	1,61E-03
187	634949	4176807	3,58E-04	233	629949	4177807	1,88E-03
188	635449	4176807	9,78E-04	234	630449	4177807	1,65E-03
189	635949	4176807	1,69E-03	235	630949	4177807	1,46E-03
190	636449	4176807	2,02E-03	236	631449	4177807	1,25E-03
191	636949	4176807	2,44E-03	237	631949	4177807	7,89E-04
192	637449	4176807	1,73E-03	238	632449	4177807	3,68E-04
193	637949	4176807	7,03E-04	239	632949	4177807	1,66E-04
194	638449	4176807	2,35E-04	240	633449	4177807	9,18E-05
195	638949	4176807	4,37E-05	241	633949	4177807	9,07E-05
196	639449	4176807	0,00E+00	242	634449	4177807	1,64E-04
197	625949	4177307	0,00E+00	243	634949	4177807	3,88E-04
198	626449	4177307	0,00E+00	244	635449	4177807	9,41E-04
199	626949	4177307	1,64E-04	245	635949	4177807	1,77E-03
200	627449	4177307	1,70E-03	246	636449	4177807	3,01E-03
201	627949	4177307	2,59E-03	247	636949	4177807	3,92E-03
202	628449	4177307	1,67E-03	248	637449	4177807	2,10E-03
203	628949	4177307	1,35E-03	249	637949	4177807	7,30E-04
204	629449	4177307	1,76E-03	250	638449	4177807	2,30E-04
205	629949	4177307	2,63E-03	251	638949	4177807	4,53E-05
206	630449	4177307	2,04E-03	252	639449	4177807	0,00E+00
207	630949	4177307	2,16E-03	253	625949	4178307	0,00E+00
208	631449	4177307	1,26E-03	254	626449	4178307	2,09E-04
209	631949	4177307	7,30E-04	255	626949	4178307	1,31E-03
210	632449	4177307	4,40E-04	256	627449	4178307	3,06E-03
211	632949	4177307	2,31E-04	257	627949	4178307	2,19E-03
212	633449	4177307	1,12E-04	258	628449	4178307	1,71E-03
213	633949	4177307	8,35E-05	259	628949	4178307	1,48E-03
214	634449	4177307	1,56E-04	260	629449	4178307	1,64E-03
215	634949	4177307	4,64E-04	261	629949	4178307	2,38E-03
216	635449	4177307	1,49E-03	262	630449	4178307	2,38E-03
217	635949	4177307	2,92E-03	263	630949	4178307	2,06E-03
218	636449	4177307	3,54E-03	264	631449	4178307	2,39E-03
219	636949	4177307	4,07E-03	265	631949	4178307	1,32E-03
220	637449	4177307	2,54E-03	266	632449	4178307	4,55E-04
221	637949	4177307	8,51E-04	267	632949	4178307	1,84E-04
222	638449	4177307	2,64E-04	268	633449	4178307	1,24E-04
223	638949	4177307	5,42E-05	269	633949	4178307	1,51E-04
224	639449	4177307	0,00E+00	270	634449	4178307	2,38E-04
225	625949	4177807	0,00E+00	271	634949	4178307	3,77E-04
226	626449	4177807	1,39E-04	272	635449	4178307	5,75E-04
227	626949	4177807	2,28E-03	273	635949	4178307	8,73E-04
228	627449	4177807	3,50E-03	274	636449	4178307	1,34E-03
229	627949	4177807	2,74E-03	275	636949	4178307	1,66E-03

276	637449	4178307	1,05E-03	322	632449	4179307	4,52E-04
277	637949	4178307	4,31E-04	323	632949	4179307	4,34E-04
278	638449	4178307	1,52E-04	324	633449	4179307	5,56E-04
279	638949	4178307	3,00E-05	325	633949	4179307	8,67E-04
280	639449	4178307	0,00E+00	326	634449	4179307	1,56E-03
281	625949	4178807	0,00E+00	327	634949	4179307	2,37E-03
282	626449	4178807	0,00E+00	328	635449	4179307	2,06E-03
283	626949	4178807	0,00E+00	329	635949	4179307	1,09E-03
284	627449	4178807	5,87E-04	330	636449	4179307	5,13E-04
285	627949	4178807	1,04E-03	331	636949	4179307	2,74E-04
286	628449	4178807	8,30E-04	332	637449	4179307	1,57E-04
287	628949	4178807	1,02E-03	333	637949	4179307	8,11E-05
288	629449	4178807	2,15E-03	334	638449	4179307	3,23E-05
289	629949	4178807	4,00E-03	335	638949	4179307	0,00E+00
290	630449	4178807	3,75E-03	336	639449	4179307	0,00E+00
291	630949	4178807	2,97E-03	337	625949	4179807	0,00E+00
292	631449	4178807	2,10E-03	338	626449	4179807	0,00E+00
293	631949	4178807	1,16E-03	339	626949	4179807	0,00E+00
294	632449	4178807	4,57E-04	340	627449	4179807	0,00E+00
295	632949	4178807	2,47E-04	341	627949	4179807	0,00E+00
296	633449	4178807	2,41E-04	342	628449	4179807	4,06E-05
297	633949	4178807	3,53E-04	343	628949	4179807	2,35E-04
298	634449	4178807	5,72E-04	344	629449	4179807	5,55E-04
299	634949	4178807	7,81E-04	345	629949	4179807	1,37E-03
300	635449	4178807	7,84E-04	346	630449	4179807	1,66E-03
301	635949	4178807	6,59E-04	347	630949	4179807	1,48E-03
302	636449	4178807	6,04E-04	348	631449	4179807	1,02E-03
303	636949	4178807	5,62E-04	349	631949	4179807	7,29E-04
304	637449	4178807	3,90E-04	350	632449	4179807	6,92E-04
305	637949	4178807	1,94E-04	351	632949	4179807	1,00E-03
306	638449	4178807	7,87E-05	352	633449	4179807	1,35E-03
307	638949	4178807	7,03E-06	353	633949	4179807	1,91E-03
308	639449	4178807	0,00E+00	354	634449	4179807	3,56E-03
309	625949	4179307	0,00E+00	355	634949	4179807	6,43E-03
310	626449	4179307	0,00E+00	356	635449	4179807	5,23E-03
311	626949	4179307	0,00E+00	357	635949	4179807	2,01E-03
312	627449	4179307	0,00E+00	358	636449	4179807	6,71E-04
313	627949	4179307	1,19E-04	359	636949	4179807	2,34E-04
314	628449	4179307	4,07E-04	360	637449	4179807	9,22E-05
315	628949	4179307	7,16E-04	361	637949	4179807	3,98E-05
316	629449	4179307	1,66E-03	362	638449	4179807	1,09E-05
317	629949	4179307	2,62E-03	363	638949	4179807	0,00E+00
318	630449	4179307	2,47E-03	364	639449	4179807	0,00E+00
319	630949	4179307	1,99E-03	365	625949	4180307	0,00E+00
320	631449	4179307	1,20E-03	366	626449	4180307	0,00E+00
321	631949	4179307	7,06E-04	367	626949	4180307	0,00E+00

368	627449	4180307	0,00E+00	414	636449	4180807	5,68E-04
369	627949	4180307	0,00E+00	415	636949	4180807	1,86E-04
370	628449	4180307	0,00E+00	416	637449	4180807	6,05E-05
371	628949	4180307	0,00E+00	417	637949	4180807	1,81E-05
372	629449	4180307	0,00E+00	418	638449	4180807	1,19E-07
373	629949	4180307	1,37E-03	419	638949	4180807	0,00E+00
374	630449	4180307	2,82E-03	420	639449	4180807	0,00E+00
375	630949	4180307	2,63E-03	421	625949	4181307	0,00E+00
376	631449	4180307	1,72E-03	422	626449	4181307	0,00E+00
377	631949	4180307	1,35E-03	423	626949	4181307	0,00E+00
378	632449	4180307	1,23E-03	424	627449	4181307	0,00E+00
379	632949	4180307	2,11E-03	425	627949	4181307	0,00E+00
380	633449	4180307	2,83E-03	426	628449	4181307	4,33E-05
381	633949	4180307	3,40E-03	427	628949	4181307	2,04E-03
382	634449	4180307	5,95E-03	428	629449	4181307	5,39E-03
383	634949	4180307	8,10E-03	429	629949	4181307	8,21E-03
384	635449	4180307	6,56E-03	430	630449	4181307	6,01E-03
385	635949	4180307	2,38E-03	431	630949	4181307	4,34E-03
386	636449	4180307	7,31E-04	432	631449	4181307	3,49E-03
387	636949	4180307	2,26E-04	433	631949	4181307	2,82E-03
388	637449	4180307	7,35E-05	434	632449	4181307	1,71E-03
389	637949	4180307	2,60E-05	435	632949	4181307	1,44E-03
390	638449	4180307	3,93E-06	436	633449	4181307	2,41E-03
391	638949	4180307	0,00E+00	437	633949	4181307	4,21E-03
392	639449	4180307	0,00E+00	438	634449	4181307	5,11E-03
393	625949	4180807	0,00E+00	439	634949	4181307	3,83E-03
394	626449	4180807	0,00E+00	440	635449	4181307	2,00E-03
395	626949	4180807	0,00E+00	441	635949	4181307	9,23E-04
396	627449	4180807	0,00E+00	442	636449	4181307	3,76E-04
397	627949	4180807	0,00E+00	443	636949	4181307	1,41E-04
398	628449	4180807	0,00E+00	444	637449	4181307	5,08E-05
399	628949	4180807	1,09E-04	445	637949	4181307	1,64E-05
400	629449	4180807	2,04E-03	446	638449	4181307	1,23E-06
401	629949	4180807	3,62E-03	447	638949	4181307	0,00E+00
402	630449	4180807	4,26E-03	448	639449	4181307	0,00E+00
403	630949	4180807	4,39E-03	449	625949	4181807	0,00E+00
404	631449	4180807	3,02E-03	450	626449	4181807	0,00E+00
405	631949	4180807	2,87E-03	451	626949	4181807	0,00E+00
406	632449	4180807	1,77E-03	452	627449	4181807	0,00E+00
407	632949	4180807	1,93E-03	453	627949	4181807	3,28E-05
408	633449	4180807	2,94E-03	454	628449	4181807	2,14E-03
409	633949	4180807	4,47E-03	455	628949	4181807	4,08E-03
410	634449	4180807	6,15E-03	456	629449	4181807	6,69E-03
411	634949	4180807	5,57E-03	457	629949	4181807	8,39E-03
412	635449	4180807	3,77E-03	458	630449	4181807	6,62E-03
413	635949	4180807	1,63E-03	459	630949	4181807	3,82E-03

460	631449	4181807	3,86E-03	506	626449	4182807	0,00E+00
461	631949	4181807	2,80E-03	507	626949	4182807	0,00E+00
462	632449	4181807	1,71E-03	508	627449	4182807	3,46E-04
463	632949	4181807	1,27E-03	509	627949	4182807	3,88E-03
464	633449	4181807	1,66E-03	510	628449	4182807	6,89E-03
465	633949	4181807	2,71E-03	511	628949	4182807	6,83E-03
466	634449	4181807	4,55E-03	512	629449	4182807	4,66E-03
467	634949	4181807	3,09E-03	513	629949	4182807	2,97E-03
468	635449	4181807	1,39E-03	514	630449	4182807	2,87E-03
469	635949	4181807	6,74E-04	515	630949	4182807	2,72E-03
470	636449	4181807	3,20E-04	516	631449	4182807	2,07E-03
471	636949	4181807	1,38E-04	517	631949	4182807	1,93E-03
472	637449	4181807	5,44E-05	518	632449	4182807	1,66E-03
473	637949	4181807	1,99E-05	519	632949	4182807	2,01E-03
474	638449	4181807	2,32E-06	520	633449	4182807	2,89E-03
475	638949	4181807	0,00E+00	521	633949	4182807	1,72E-03
476	639449	4181807	0,00E+00	522	634449	4182807	1,39E-03
477	625949	4182307	0,00E+00	523	634949	4182807	1,80E-03
478	626449	4182307	0,00E+00	524	635449	4182807	2,56E-03
479	626949	4182307	0,00E+00	525	635949	4182807	2,15E-03
480	627449	4182307	0,00E+00	526	636449	4182807	1,02E-03
481	627949	4182307	1,62E-03	527	636949	4182807	3,87E-04
482	628449	4182307	5,33E-03	528	637449	4182807	7,70E-05
483	628949	4182307	5,98E-03	529	637949	4182807	0,00E+00
484	629449	4182307	5,89E-03	530	638449	4182807	0,00E+00
485	629949	4182307	4,54E-03	531	638949	4182807	0,00E+00
486	630449	4182307	3,59E-03	532	639449	4182807	0,00E+00
487	630949	4182307	2,68E-03	533	625949	4183307	0,00E+00
488	631449	4182307	2,61E-03	534	626449	4183307	0,00E+00
489	631949	4182307	3,12E-03	535	626949	4183307	0,00E+00
490	632449	4182307	2,00E-03	536	627449	4183307	1,72E-03
491	632949	4182307	1,53E-03	537	627949	4183307	4,08E-03
492	633449	4182307	1,87E-03	538	628449	4183307	4,80E-03
493	633949	4182307	1,85E-03	539	628949	4183307	3,75E-03
494	634449	4182307	2,02E-03	540	629449	4183307	2,72E-03
495	634949	4182307	1,76E-03	541	629949	4183307	2,48E-03
496	635449	4182307	1,33E-03	542	630449	4183307	3,98E-03
497	635949	4182307	9,27E-04	543	630949	4183307	4,16E-03
498	636449	4182307	4,93E-04	544	631449	4183307	2,48E-03
499	636949	4182307	2,13E-04	545	631949	4183307	2,03E-03
500	637449	4182307	7,04E-05	546	632449	4183307	1,68E-03
501	637949	4182307	9,80E-06	547	632949	4183307	2,45E-03
502	638449	4182307	0,00E+00	548	633449	4183307	2,48E-03
503	638949	4182307	0,00E+00	549	633949	4183307	1,42E-03
504	639449	4182307	0,00E+00	550	634449	4183307	1,48E-03
505	625949	4182807	0,00E+00	551	634949	4183307	2,99E-03

552	635449	4183307	4,38E-03	598	630449	4184307	5,98E-03
553	635949	4183307	3,98E-03	599	630949	4184307	4,14E-03
554	636449	4183307	1,81E-03	600	631449	4184307	3,40E-03
555	636949	4183307	5,90E-04	601	631949	4184307	3,12E-03
556	637449	4183307	1,36E-04	602	632449	4184307	1,43E-03
557	637949	4183307	0,00E+00	603	632949	4184307	8,85E-04
558	638449	4183307	0,00E+00	604	633449	4184307	7,47E-04
559	638949	4183307	0,00E+00	605	633949	4184307	7,88E-04
560	639449	4183307	0,00E+00	606	634449	4184307	1,18E-03
561	625949	4183807	0,00E+00	607	634949	4184307	1,68E-03
562	626449	4183807	0,00E+00	608	635449	4184307	2,13E-03
563	626949	4183807	1,26E-03	609	635949	4184307	2,11E-03
564	627449	4183807	5,36E-03	610	636449	4184307	1,28E-03
565	627949	4183807	4,13E-03	611	636949	4184307	5,23E-04
566	628449	4183807	2,83E-03	612	637449	4184307	1,79E-04
567	628949	4183807	1,98E-03	613	637949	4184307	1,72E-05
568	629449	4183807	1,88E-03	614	638449	4184307	0,00E+00
569	629949	4183807	2,63E-03	615	638949	4184307	0,00E+00
570	630449	4183807	3,96E-03	616	639449	4184307	0,00E+00
571	630949	4183807	3,72E-03	617	625949	4184807	0,00E+00
572	631449	4183807	3,21E-03	618	626449	4184807	1,59E-03
573	631949	4183807	3,30E-03	619	626949	4184807	3,56E-03
574	632449	4183807	1,81E-03	620	627449	4184807	3,95E-03
575	632949	4183807	1,82E-03	621	627949	4184807	3,10E-03
576	633449	4183807	1,62E-03	622	628449	4184807	1,74E-03
577	633949	4183807	1,05E-03	623	628949	4184807	1,27E-03
578	634449	4183807	1,36E-03	624	629449	4184807	2,46E-03
579	634949	4183807	2,83E-03	625	629949	4184807	6,72E-03
580	635449	4183807	4,16E-03	626	630449	4184807	7,75E-03
581	635949	4183807	3,94E-03	627	630949	4184807	3,83E-03
582	636449	4183807	1,88E-03	628	631449	4184807	2,27E-03
583	636949	4183807	6,27E-04	629	631949	4184807	1,68E-03
584	637449	4183807	1,96E-04	630	632449	4184807	8,48E-04
585	637949	4183807	1,19E-05	631	632949	4184807	4,80E-04
586	638449	4183807	0,00E+00	632	633449	4184807	4,67E-04
587	638949	4183807	0,00E+00	633	633949	4184807	8,48E-04
588	639449	4183807	0,00E+00	634	634449	4184807	1,90E-03
589	625949	4184307	0,00E+00	635	634949	4184807	1,80E-03
590	626449	4184307	5,53E-04	636	635449	4184807	1,67E-03
591	626949	4184307	4,60E-03	637	635949	4184807	2,37E-03
592	627449	4184307	6,14E-03	638	636449	4184807	1,33E-03
593	627949	4184307	4,95E-03	639	636949	4184807	4,71E-04
594	628449	4184307	2,65E-03	640	637449	4184807	1,56E-04
595	628949	4184307	1,55E-03	641	637949	4184807	1,70E-05
596	629449	4184307	2,15E-03	642	638449	4184807	0,00E+00
597	629949	4184307	4,39E-03	643	638949	4184807	0,00E+00

644	639449	4184807	0,00E+00	690	634449	4185807	1,30E-03
645	625949	4185307	0,00E+00	691	634949	4185807	1,59E-03
646	626449	4185307	4,75E-04	692	635449	4185807	1,49E-03
647	626949	4185307	1,69E-03	693	635949	4185807	1,11E-03
648	627449	4185307	1,61E-03	694	636449	4185807	6,41E-04
649	627949	4185307	1,25E-03	695	636949	4185807	2,77E-04
650	628449	4185307	8,31E-04	696	637449	4185807	1,02E-04
651	628949	4185307	8,04E-04	697	637949	4185807	3,09E-05
652	629449	4185307	1,60E-03	698	638449	4185807	0,00E+00
653	629949	4185307	3,30E-03	699	638949	4185807	0,00E+00
654	630449	4185307	3,43E-03	700	639449	4185807	0,00E+00
655	630949	4185307	2,05E-03	701	625949	4186307	0,00E+00
656	631449	4185307	1,18E-03	702	626449	4186307	0,00E+00
657	631949	4185307	7,68E-04	703	626949	4186307	1,84E-03
658	632449	4185307	4,61E-04	704	627449	4186307	6,85E-04
659	632949	4185307	3,13E-04	705	627949	4186307	3,73E-04
660	633449	4185307	3,83E-04	706	628449	4186307	2,01E-04
661	633949	4185307	8,20E-04	707	628949	4186307	1,84E-04
662	634449	4185307	1,83E-03	708	629449	4186307	2,77E-04
663	634949	4185307	1,71E-03	709	629949	4186307	4,51E-04
664	635449	4185307	1,45E-03	710	630449	4186307	7,20E-04
665	635949	4185307	1,79E-03	711	630949	4186307	1,23E-03
666	636449	4185307	1,05E-03	712	631449	4186307	1,73E-03
667	636949	4185307	3,84E-04	713	631949	4186307	1,36E-03
668	637449	4185307	1,29E-04	714	632449	4186307	7,64E-04
669	637949	4185307	1,89E-05	715	632949	4186307	5,65E-04
670	638449	4185307	0,00E+00	716	633449	4186307	6,91E-04
671	638949	4185307	0,00E+00	717	633949	4186307	1,10E-03
672	639449	4185307	0,00E+00	718	634449	4186307	2,14E-03
673	625949	4185807	0,00E+00	719	634949	4186307	2,81E-03
674	626449	4185807	6,48E-05	720	635449	4186307	2,80E-03
675	626949	4185807	1,25E-03	721	635949	4186307	1,50E-03
676	627449	4185807	9,71E-04	722	636449	4186307	6,85E-04
677	627949	4185807	5,83E-04	723	636949	4186307	2,64E-04
678	628449	4185807	3,86E-04	724	637449	4186307	9,20E-05
679	628949	4185807	4,03E-04	725	637949	4186307	2,38E-05
680	629449	4185807	6,87E-04	726	638449	4186307	0,00E+00
681	629949	4185807	1,11E-03	727	638949	4186307	0,00E+00
682	630449	4185807	1,24E-03	728	639449	4186307	0,00E+00
683	630949	4185807	1,08E-03	729	625949	4186807	0,00E+00
684	631449	4185807	8,92E-04	730	626449	4186807	0,00E+00
685	631949	4185807	6,61E-04	731	626949	4186807	5,37E-05
686	632449	4185807	4,28E-04	732	627449	4186807	0,00E+00
687	632949	4185807	3,27E-04	733	627949	4186807	1,33E-05
688	633449	4185807	4,14E-04	734	628449	4186807	6,91E-05
689	633949	4185807	7,52E-04	735	628949	4186807	8,74E-05

736	629449	4186807	1,36E-04	782	638449	4187307	1,23E-06
737	629949	4186807	2,89E-04	783	638949	4187307	0,00E+00
738	630449	4186807	7,49E-04	784	639449	4187307	0,00E+00
739	630949	4186807	2,19E-03	785	625949	4187807	0,00E+00
740	631449	4186807	4,76E-03	786	626449	4187807	0,00E+00
741	631949	4186807	3,13E-03	787	626949	4187807	0,00E+00
742	632449	4186807	1,42E-03	788	627449	4187807	0,00E+00
743	632949	4186807	1,14E-03	789	627949	4187807	0,00E+00
744	633449	4186807	1,53E-03	790	628449	4187807	0,00E+00
745	633949	4186807	1,88E-03	791	628949	4187807	0,00E+00
746	634449	4186807	2,43E-03	792	629449	4187807	0,00E+00
747	634949	4186807	2,71E-03	793	629949	4187807	2,22E-05
748	635449	4186807	2,77E-03	794	630449	4187807	3,92E-04
749	635949	4186807	2,40E-03	795	630949	4187807	1,01E-03
750	636449	4186807	9,28E-04	796	631449	4187807	1,72E-03
751	636949	4186807	2,92E-04	797	631949	4187807	1,94E-03
752	637449	4186807	9,05E-05	798	632449	4187807	2,72E-03
753	637949	4186807	2,13E-05	799	632949	4187807	3,62E-03
754	638449	4186807	0,00E+00	800	633449	4187807	4,58E-03
755	638949	4186807	0,00E+00	801	633949	4187807	4,00E-03
756	639449	4186807	0,00E+00	802	634449	4187807	7,57E-04
757	625949	4187307	0,00E+00	803	634949	4187807	1,00E-04
758	626449	4187307	0,00E+00	804	635449	4187807	6,52E-05
759	626949	4187307	0,00E+00	805	635949	4187807	4,38E-05
760	627449	4187307	0,00E+00	806	636449	4187807	1,93E-04
761	627949	4187307	0,00E+00	807	636949	4187807	8,08E-06
762	628449	4187307	0,00E+00	808	637449	4187807	1,15E-05
763	628949	4187307	2,58E-06	809	637949	4187807	1,50E-05
764	629449	4187307	1,63E-05	810	638449	4187807	1,81E-06
765	629949	4187307	1,68E-04	811	638949	4187807	0,00E+00
766	630449	4187307	6,74E-04	812	639449	4187807	0,00E+00
767	630949	4187307	2,06E-03	813	625949	4188307	0,00E+00
768	631449	4187307	4,44E-03	814	626449	4188307	0,00E+00
769	631949	4187307	3,27E-03	815	626949	4188307	0,00E+00
770	632449	4187307	2,04E-03	816	627449	4188307	0,00E+00
771	632949	4187307	2,19E-03	817	627949	4188307	0,00E+00
772	633449	4187307	3,41E-03	818	628449	4188307	0,00E+00
773	633949	4187307	3,57E-03	819	628949	4188307	0,00E+00
774	634449	4187307	1,92E-03	820	629449	4188307	0,00E+00
775	634949	4187307	1,44E-03	821	629949	4188307	0,00E+00
776	635449	4187307	1,53E-03	822	630449	4188307	3,02E-05
777	635949	4187307	1,23E-03	823	630949	4188307	3,04E-04
778	636449	4187307	7,59E-04	824	631449	4188307	9,97E-04
779	636949	4187307	1,83E-04	825	631949	4188307	1,65E-03
780	637449	4187307	6,24E-05	826	632449	4188307	2,41E-03
781	637949	4187307	2,26E-05	827	632949	4188307	3,15E-03

828	633449	4188307	3,48E-03	874	628449	4189307	0,00E+00
829	633949	4188307	1,29E-03	875	628949	4189307	0,00E+00
830	634449	4188307	0,00E+00	876	629449	4189307	0,00E+00
831	634949	4188307	0,00E+00	877	629949	4189307	0,00E+00
832	635449	4188307	0,00E+00	878	630449	4189307	0,00E+00
833	635949	4188307	0,00E+00	879	630949	4189307	0,00E+00
834	636449	4188307	0,00E+00	880	631449	4189307	0,00E+00
835	636949	4188307	0,00E+00	881	631949	4189307	2,27E-03
836	637449	4188307	0,00E+00	882	632449	4189307	1,23E-03
837	637949	4188307	5,60E-06	883	632949	4189307	3,46E-03
838	638449	4188307	7,28E-07	884	633449	4189307	8,81E-04
839	638949	4188307	0,00E+00	885	633949	4189307	0,00E+00
840	639449	4188307	0,00E+00	886	634449	4189307	0,00E+00
841	625949	4188807	0,00E+00	887	634949	4189307	0,00E+00
842	626449	4188807	0,00E+00	888	635449	4189307	0,00E+00
843	626949	4188807	0,00E+00	889	635949	4189307	0,00E+00
844	627449	4188807	0,00E+00	890	636449	4189307	0,00E+00
845	627949	4188807	0,00E+00	891	636949	4189307	0,00E+00
846	628449	4188807	0,00E+00	892	637449	4189307	0,00E+00
847	628949	4188807	0,00E+00	893	637949	4189307	0,00E+00
848	629449	4188807	0,00E+00	894	638449	4189307	0,00E+00
849	629949	4188807	0,00E+00	895	638949	4189307	0,00E+00
850	630449	4188807	0,00E+00	896	639449	4189307	0,00E+00
851	630949	4188807	0,00E+00	897	625949	4189807	0,00E+00
852	631449	4188807	3,16E-04	898	626449	4189807	0,00E+00
853	631949	4188807	2,69E-03	899	626949	4189807	0,00E+00
854	632449	4188807	2,85E-03	900	627449	4189807	0,00E+00
855	632949	4188807	3,39E-03	901	627949	4189807	0,00E+00
856	633449	4188807	1,49E-03	902	628449	4189807	0,00E+00
857	633949	4188807	0,00E+00	903	628949	4189807	0,00E+00
858	634449	4188807	0,00E+00	904	629449	4189807	0,00E+00
859	634949	4188807	0,00E+00	905	629949	4189807	0,00E+00
860	635449	4188807	0,00E+00	906	630449	4189807	0,00E+00
861	635949	4188807	0,00E+00	907	630949	4189807	0,00E+00
862	636449	4188807	0,00E+00	908	631449	4189807	0,00E+00
863	636949	4188807	0,00E+00	909	631949	4189807	1,07E-04
864	637449	4188807	0,00E+00	910	632449	4189807	0,00E+00
865	637949	4188807	0,00E+00	911	632949	4189807	1,66E-03
866	638449	4188807	0,00E+00	912	633449	4189807	8,92E-05
867	638949	4188807	0,00E+00	913	633949	4189807	0,00E+00
868	639449	4188807	0,00E+00	914	634449	4189807	0,00E+00
869	625949	4189307	0,00E+00	915	634949	4189807	0,00E+00
870	626449	4189307	0,00E+00	916	635449	4189807	0,00E+00
871	626949	4189307	0,00E+00	917	635949	4189807	0,00E+00
872	627449	4189307	0,00E+00	918	636449	4189807	0,00E+00
873	627949	4189307	0,00E+00	919	636949	4189807	0,00E+00

920	637449	4189807	0,00E+00
921	637949	4189807	0,00E+00
922	638449	4189807	0,00E+00
923	638949	4189807	0,00E+00
924	639449	4189807	0,00E+00
925	625949	4190307	0,00E+00
926	626449	4190307	0,00E+00
927	626949	4190307	0,00E+00
928	627449	4190307	0,00E+00
929	627949	4190307	0,00E+00
930	628449	4190307	0,00E+00
931	628949	4190307	0,00E+00
932	629449	4190307	0,00E+00
933	629949	4190307	0,00E+00
934	630449	4190307	0,00E+00
935	630949	4190307	0,00E+00
936	631449	4190307	0,00E+00

937	631949	4190307	0,00E+00
938	632449	4190307	0,00E+00
939	632949	4190307	0,00E+00
940	633449	4190307	0,00E+00
941	633949	4190307	0,00E+00
942	634449	4190307	0,00E+00
943	634949	4190307	0,00E+00
944	635449	4190307	0,00E+00
945	635949	4190307	0,00E+00
946	636449	4190307	0,00E+00
947	636949	4190307	0,00E+00
948	637449	4190307	0,00E+00
949	637949	4190307	0,00E+00
950	638449	4190307	0,00E+00
951	638949	4190307	0,00E+00
952	639449	4190307	0,00E+00

Fogo T vent opening			
ID	Longitude	Latitude	Probability
1	625949	4173807	0,00E+00
2	626449	4173807	0,00E+00
3	626949	4173807	0,00E+00
4	627449	4173807	0,00E+00
5	627949	4173807	0,00E+00
6	628449	4173807	0,00E+00
7	628949	4173807	0,00E+00
8	629449	4173807	0,00E+00
9	629949	4173807	0,00E+00
10	630449	4173807	0,00E+00
11	630949	4173807	0,00E+00
12	631449	4173807	0,00E+00
13	631949	4173807	0,00E+00
14	632449	4173807	0,00E+00
15	632949	4173807	0,00E+00
16	633449	4173807	0,00E+00
17	633949	4173807	0,00E+00
18	634449	4173807	0,00E+00
19	634949	4173807	0,00E+00
20	635449	4173807	0,00E+00
21	635949	4173807	0,00E+00
22	636449	4173807	0,00E+00
23	636949	4173807	0,00E+00
24	637449	4173807	0,00E+00
25	637949	4173807	0,00E+00
26	638449	4173807	0,00E+00
27	638949	4173807	0,00E+00
28	639449	4173807	0,00E+00
29	625949	4174307	0,00E+00
30	626449	4174307	0,00E+00
31	626949	4174307	0,00E+00
32	627449	4174307	0,00E+00
33	627949	4174307	0,00E+00
34	628449	4174307	0,00E+00
35	628949	4174307	0,00E+00
36	629449	4174307	0,00E+00
37	629949	4174307	0,00E+00
38	630449	4174307	0,00E+00
39	630949	4174307	0,00E+00
40	631449	4174307	1,63E-05
41	631949	4174307	0,00E+00
42	632449	4174307	0,00E+00
43	632949	4174307	0,00E+00
44	633449	4174307	0,00E+00

45	633949	4174307	0,00E+00
46	634449	4174307	0,00E+00
47	634949	4174307	0,00E+00
48	635449	4174307	0,00E+00
49	635949	4174307	0,00E+00
50	636449	4174307	0,00E+00
51	636949	4174307	0,00E+00
52	637449	4174307	0,00E+00
53	637949	4174307	0,00E+00
54	638449	4174307	0,00E+00
55	638949	4174307	0,00E+00
56	639449	4174307	0,00E+00
57	625949	4174807	0,00E+00
58	626449	4174807	0,00E+00
59	626949	4174807	0,00E+00
60	627449	4174807	0,00E+00
61	627949	4174807	0,00E+00
62	628449	4174807	0,00E+00
63	628949	4174807	0,00E+00
64	629449	4174807	0,00E+00
65	629949	4174807	0,00E+00
66	630449	4174807	0,00E+00
67	630949	4174807	4,72E-05
68	631449	4174807	2,30E-04
69	631949	4174807	3,45E-04
70	632449	4174807	2,05E-04
71	632949	4174807	0,00E+00
72	633449	4174807	0,00E+00
73	633949	4174807	0,00E+00
74	634449	4174807	0,00E+00
75	634949	4174807	0,00E+00
76	635449	4174807	0,00E+00
77	635949	4174807	0,00E+00
78	636449	4174807	0,00E+00
79	636949	4174807	3,04E-07
80	637449	4174807	6,03E-07
81	637949	4174807	0,00E+00
82	638449	4174807	0,00E+00
83	638949	4174807	0,00E+00
84	639449	4174807	0,00E+00
85	625949	4175307	0,00E+00
86	626449	4175307	0,00E+00
87	626949	4175307	0,00E+00
88	627449	4175307	0,00E+00
89	627949	4175307	0,00E+00
90	628449	4175307	0,00E+00

91	628949	4175307	0,00E+00	137	637949	4175807	1,84E-04
92	629449	4175307	7,40E-07	138	638449	4175807	5,65E-05
93	629949	4175307	5,57E-06	139	638949	4175807	0,00E+00
94	630449	4175307	1,53E-05	140	639449	4175807	0,00E+00
95	630949	4175307	2,26E-04	141	625949	4176307	0,00E+00
96	631449	4175307	5,38E-04	142	626449	4176307	0,00E+00
97	631949	4175307	8,25E-04	143	626949	4176307	0,00E+00
98	632449	4175307	8,22E-04	144	627449	4176307	0,00E+00
99	632949	4175307	4,80E-04	145	627949	4176307	0,00E+00
100	633449	4175307	1,04E-04	146	628449	4176307	0,00E+00
101	633949	4175307	2,37E-06	147	628949	4176307	3,37E-07
102	634449	4175307	1,58E-06	148	629449	4176307	3,87E-06
103	634949	4175307	4,22E-06	149	629949	4176307	2,70E-05
104	635449	4175307	6,10E-06	150	630449	4176307	1,29E-04
105	635949	4175307	9,26E-06	151	630949	4176307	4,22E-04
106	636449	4175307	3,29E-05	152	631449	4176307	9,43E-04
107	636949	4175307	7,17E-05	153	631949	4176307	1,45E-03
108	637449	4175307	6,90E-05	154	632449	4176307	1,52E-03
109	637949	4175307	3,83E-05	155	632949	4176307	1,09E-03
110	638449	4175307	8,25E-06	156	633449	4176307	5,37E-04
111	638949	4175307	0,00E+00	157	633949	4176307	1,82E-04
112	639449	4175307	0,00E+00	158	634449	4176307	4,50E-05
113	625949	4175807	0,00E+00	159	634949	4176307	2,64E-05
114	626449	4175807	0,00E+00	160	635449	4176307	8,67E-05
115	626949	4175807	0,00E+00	161	635949	4176307	2,57E-04
116	627449	4175807	0,00E+00	162	636449	4176307	5,26E-04
117	627949	4175807	0,00E+00	163	636949	4176307	7,38E-04
118	628449	4175807	0,00E+00	164	637449	4176307	7,10E-04
119	628949	4175807	4,18E-08	165	637949	4176307	4,67E-04
120	629449	4175807	3,41E-06	166	638449	4176307	2,02E-04
121	629949	4175807	2,47E-05	167	638949	4176307	1,96E-05
122	630449	4175807	1,18E-04	168	639449	4176307	0,00E+00
123	630949	4175807	3,85E-04	169	625949	4176807	0,00E+00
124	631449	4175807	8,61E-04	170	626449	4176807	0,00E+00
125	631949	4175807	1,32E-03	171	626949	4176807	0,00E+00
126	632449	4175807	1,38E-03	172	627449	4176807	0,00E+00
127	632949	4175807	9,95E-04	173	627949	4176807	0,00E+00
128	633449	4175807	4,85E-04	174	628449	4176807	1,86E-08
129	633949	4175807	1,41E-04	175	628949	4176807	2,85E-07
130	634449	4175807	3,89E-05	176	629449	4176807	2,91E-06
131	634949	4175807	1,38E-05	177	629949	4176807	2,03E-05
132	635449	4175807	3,44E-05	178	630449	4176807	9,69E-05
133	635949	4175807	1,01E-04	179	630949	4176807	3,17E-04
134	636449	4175807	2,07E-04	180	631449	4176807	7,08E-04
135	636949	4175807	2,91E-04	181	631949	4176807	1,09E-03
136	637449	4175807	2,79E-04	182	632449	4176807	1,14E-03

183	632949	4176807	8,19E-04	229	627949	4177807	0,00E+00
184	633449	4176807	4,04E-04	230	628449	4177807	1,11E-08
185	633949	4176807	1,38E-04	231	628949	4177807	7,31E-08
186	634449	4176807	3,88E-05	232	629449	4177807	5,75E-07
187	634949	4176807	4,18E-05	233	629949	4177807	3,78E-06
188	635449	4176807	1,52E-04	234	630449	4177807	1,78E-05
189	635949	4176807	4,48E-04	235	630949	4177807	5,80E-05
190	636449	4176807	9,16E-04	236	631449	4177807	1,30E-04
191	636949	4176807	1,28E-03	237	631949	4177807	2,00E-04
192	637449	4176807	1,23E-03	238	632449	4177807	2,14E-04
193	637949	4176807	8,13E-04	239	632949	4177807	1,65E-04
194	638449	4176807	3,67E-04	240	633449	4177807	1,08E-04
195	638949	4176807	7,05E-05	241	633949	4177807	9,71E-05
196	639449	4176807	0,00E+00	242	634449	4177807	1,36E-04
197	625949	4177307	0,00E+00	243	634949	4177807	1,95E-04
198	626449	4177307	0,00E+00	244	635449	4177807	2,94E-04
199	626949	4177307	0,00E+00	245	635949	4177807	5,31E-04
200	627449	4177307	0,00E+00	246	636449	4177807	9,34E-04
201	627949	4177307	0,00E+00	247	636949	4177807	1,26E-03
202	628449	4177307	1,01E-08	248	637449	4177807	1,20E-03
203	628949	4177307	1,47E-07	249	637949	4177807	7,92E-04
204	629449	4177307	1,50E-06	250	638449	4177807	3,57E-04
205	629949	4177307	1,04E-05	251	638949	4177807	7,36E-05
206	630449	4177307	4,99E-05	252	639449	4177807	0,00E+00
207	630949	4177307	1,63E-04	253	625949	4178307	0,00E+00
208	631449	4177307	3,64E-04	254	626449	4178307	0,00E+00
209	631949	4177307	5,58E-04	255	626949	4178307	0,00E+00
210	632449	4177307	5,87E-04	256	627449	4178307	1,26E-08
211	632949	4177307	4,23E-04	257	627949	4178307	3,96E-08
212	633449	4177307	2,12E-04	258	628449	4178307	1,25E-07
213	633949	4177307	8,13E-05	259	628949	4178307	3,44E-07
214	634449	4177307	4,16E-05	260	629449	4178307	8,31E-07
215	634949	4177307	6,82E-05	261	629949	4178307	2,18E-06
216	635449	4177307	2,01E-04	262	630449	4178307	6,74E-06
217	635949	4177307	5,47E-04	263	630949	4178307	1,93E-05
218	636449	4177307	1,10E-03	264	631449	4178307	4,32E-05
219	636949	4177307	1,53E-03	265	631949	4178307	7,32E-05
220	637449	4177307	1,47E-03	266	632449	4178307	9,99E-05
221	637949	4177307	9,69E-04	267	632949	4178307	1,29E-04
222	638449	4177307	4,37E-04	268	633449	4178307	1,95E-04
223	638949	4177307	9,50E-05	269	633949	4178307	3,51E-04
224	639449	4177307	0,00E+00	270	634449	4178307	5,79E-04
225	625949	4177807	0,00E+00	271	634949	4178307	7,49E-04
226	626449	4177807	0,00E+00	272	635449	4178307	7,50E-04
227	626949	4177807	0,00E+00	273	635949	4178307	6,76E-04
228	627449	4177807	0,00E+00	274	636449	4178307	6,94E-04

275	636949	4178307	7,61E-04	321	631949	4179307	4,30E-04
276	637449	4178307	6,86E-04	322	632449	4179307	6,82E-04
277	637949	4178307	4,45E-04	323	632949	4179307	1,08E-03
278	638449	4178307	2,00E-04	324	633449	4179307	1,77E-03
279	638949	4178307	3,93E-05	325	633949	4179307	2,95E-03
280	639449	4178307	0,00E+00	326	634449	4179307	4,44E-03
281	625949	4178807	0,00E+00	327	634949	4179307	5,32E-03
282	626449	4178807	0,00E+00	328	635449	4179307	4,73E-03
283	626949	4178807	0,00E+00	329	635949	4179307	3,04E-03
284	627449	4178807	4,38E-08	330	636449	4179307	1,41E-03
285	627949	4178807	4,90E-07	331	636949	4179307	5,02E-04
286	628449	4178807	1,41E-06	332	637449	4179307	1,63E-04
287	628949	4178807	3,56E-06	333	637949	4179307	5,91E-05
288	629449	4178807	7,21E-06	334	638449	4179307	1,96E-05
289	629949	4178807	1,21E-05	335	638949	4179307	0,00E+00
290	630449	4178807	1,99E-05	336	639449	4179307	0,00E+00
291	630949	4178807	3,72E-05	337	625949	4179807	0,00E+00
292	631449	4178807	7,18E-05	338	626449	4179807	0,00E+00
293	631949	4178807	1,31E-04	339	626949	4179807	0,00E+00
294	632449	4178807	2,26E-04	340	627449	4179807	0,00E+00
295	632949	4178807	3,80E-04	341	627949	4179807	0,00E+00
296	633449	4178807	6,62E-04	342	628449	4179807	5,18E-06
297	633949	4178807	1,18E-03	343	628949	4179807	3,89E-05
298	634449	4178807	1,88E-03	344	629449	4179807	9,96E-05
299	634949	4178807	2,34E-03	345	629949	4179807	3,61E-04
300	635449	4178807	2,14E-03	346	630449	4179807	4,70E-04
301	635949	4178807	1,45E-03	347	630949	4179807	5,89E-04
302	636449	4178807	8,08E-04	348	631449	4179807	8,00E-04
303	636949	4178807	4,63E-04	349	631949	4179807	1,11E-03
304	637449	4178807	3,00E-04	350	632449	4179807	1,55E-03
305	637949	4178807	1,76E-04	351	632949	4179807	2,27E-03
306	638449	4178807	7,69E-05	352	633449	4179807	3,50E-03
307	638949	4178807	6,96E-06	353	633949	4179807	5,45E-03
308	639449	4178807	0,00E+00	354	634449	4179807	7,67E-03
309	625949	4179307	0,00E+00	355	634949	4179807	8,76E-03
310	626449	4179307	0,00E+00	356	635449	4179807	7,56E-03
311	626949	4179307	0,00E+00	357	635949	4179807	4,75E-03
312	627449	4179307	0,00E+00	358	636449	4179807	2,13E-03
313	627949	4179307	6,73E-07	359	636949	4179807	6,84E-04
314	628449	4179307	1,06E-05	360	637449	4179807	1,60E-04
315	628949	4179307	2,68E-05	361	637949	4179807	3,08E-05
316	629449	4179307	5,15E-05	362	638449	4179807	4,31E-06
317	629949	4179307	7,94E-05	363	638949	4179807	0,00E+00
318	630449	4179307	1,11E-04	364	639449	4179807	0,00E+00
319	630949	4179307	1,65E-04	365	625949	4180307	0,00E+00
320	631449	4179307	2,67E-04	366	626449	4180307	0,00E+00

367	626949	4180307	0,00E+00	413	635949	4180807	4,56E-03
368	627449	4180307	0,00E+00	414	636449	4180807	1,94E-03
369	627949	4180307	0,00E+00	415	636949	4180807	5,97E-04
370	628449	4180307	0,00E+00	416	637449	4180807	1,31E-04
371	628949	4180307	0,00E+00	417	637949	4180807	1,90E-05
372	629449	4180307	0,00E+00	418	638449	4180807	5,99E-08
373	629949	4180307	9,61E-04	419	638949	4180807	0,00E+00
374	630449	4180307	1,47E-03	420	639449	4180807	0,00E+00
375	630949	4180307	1,60E-03	421	625949	4181307	0,00E+00
376	631449	4180307	1,83E-03	422	626449	4181307	0,00E+00
377	631949	4180307	2,16E-03	423	626949	4181307	0,00E+00
378	632449	4180307	2,63E-03	424	627449	4181307	0,00E+00
379	632949	4180307	3,52E-03	425	627949	4181307	0,00E+00
380	633449	4180307	5,18E-03	426	628449	4181307	7,57E-05
381	633949	4180307	7,61E-03	427	628949	4181307	2,66E-03
382	634449	4180307	9,99E-03	428	629449	4181307	4,51E-03
383	634949	4180307	1,07E-02	429	629949	4181307	5,28E-03
384	635449	4180307	8,83E-03	430	630449	4181307	5,35E-03
385	635949	4180307	5,38E-03	431	630949	4181307	4,94E-03
386	636449	4180307	2,37E-03	432	631449	4181307	4,55E-03
387	636949	4180307	7,43E-04	433	631949	4181307	4,21E-03
388	637449	4180307	1,65E-04	434	632449	4181307	3,90E-03
389	637949	4180307	2,61E-05	435	632949	4181307	4,20E-03
390	638449	4180307	1,66E-06	436	633449	4181307	5,57E-03
391	638949	4180307	0,00E+00	437	633949	4181307	7,53E-03
392	639449	4180307	0,00E+00	438	634449	4181307	8,73E-03
393	625949	4180807	0,00E+00	439	634949	4181307	8,09E-03
394	626449	4180807	0,00E+00	440	635449	4181307	5,81E-03
395	626949	4180807	0,00E+00	441	635949	4181307	3,18E-03
396	627449	4180807	0,00E+00	442	636449	4181307	1,32E-03
397	627949	4180807	0,00E+00	443	636949	4181307	4,06E-04
398	628449	4180807	0,00E+00	444	637449	4181307	9,25E-05
399	628949	4180807	1,26E-04	445	637949	4181307	1,47E-05
400	629449	4180807	1,95E-03	446	638449	4181307	5,29E-07
401	629949	4180807	3,06E-03	447	638949	4181307	0,00E+00
402	630449	4180807	3,30E-03	448	639449	4181307	0,00E+00
403	630949	4180807	3,25E-03	449	625949	4181807	0,00E+00
404	631449	4180807	3,27E-03	450	626449	4181807	0,00E+00
405	631949	4180807	3,34E-03	451	626949	4181807	0,00E+00
406	632449	4180807	3,50E-03	452	627449	4181807	0,00E+00
407	632949	4180807	4,22E-03	453	627949	4181807	4,59E-05
408	633449	4180807	5,94E-03	454	628449	4181807	3,34E-03
409	633949	4180807	8,34E-03	455	628949	4181807	5,73E-03
410	634449	4180807	1,02E-02	456	629449	4181807	6,49E-03
411	634949	4180807	1,02E-02	457	629949	4181807	6,71E-03
412	635449	4180807	7,87E-03	458	630449	4181807	6,26E-03

459	630949	4181807	5,51E-03	505	625949	4182807	0,00E+00
460	631449	4181807	4,93E-03	506	626449	4182807	0,00E+00
461	631949	4181807	4,44E-03	507	626949	4182807	0,00E+00
462	632449	4181807	3,94E-03	508	627449	4182807	5,92E-04
463	632949	4181807	3,92E-03	509	627949	4182807	5,11E-03
464	633449	4181807	4,75E-03	510	628449	4182807	6,91E-03
465	633949	4181807	6,00E-03	511	628949	4182807	7,31E-03
466	634449	4181807	6,63E-03	512	629449	4182807	6,43E-03
467	634949	4181807	5,94E-03	513	629949	4182807	4,95E-03
468	635449	4181807	4,23E-03	514	630449	4182807	3,63E-03
469	635949	4181807	2,40E-03	515	630949	4182807	2,89E-03
470	636449	4181807	1,09E-03	516	631449	4182807	2,72E-03
471	636949	4181807	3,96E-04	517	631949	4182807	2,89E-03
472	637449	4181807	1,11E-04	518	632449	4182807	3,22E-03
473	637949	4181807	2,34E-05	519	632949	4182807	3,62E-03
474	638449	4181807	1,47E-06	520	633449	4182807	3,87E-03
475	638949	4181807	0,00E+00	521	633949	4182807	3,97E-03
476	639449	4181807	0,00E+00	522	634449	4182807	4,21E-03
477	625949	4182307	0,00E+00	523	634949	4182807	4,69E-03
478	626449	4182307	0,00E+00	524	635449	4182807	4,85E-03
479	626949	4182307	0,00E+00	525	635949	4182807	4,12E-03
480	627449	4182307	0,00E+00	526	636449	4182807	2,67E-03
481	627949	4182307	2,22E-03	527	636949	4182807	1,28E-03
482	628449	4182307	6,38E-03	528	637449	4182807	2,66E-04
483	628949	4182307	7,37E-03	529	637949	4182807	0,00E+00
484	629449	4182307	7,28E-03	530	638449	4182807	0,00E+00
485	629949	4182307	6,47E-03	531	638949	4182807	0,00E+00
486	630449	4182307	5,40E-03	532	639449	4182807	0,00E+00
487	630949	4182307	4,54E-03	533	625949	4183307	0,00E+00
488	631449	4182307	4,12E-03	534	626449	4183307	0,00E+00
489	631949	4182307	3,91E-03	535	626949	4183307	0,00E+00
490	632449	4182307	3,72E-03	536	627449	4183307	2,50E-03
491	632949	4182307	3,76E-03	537	627949	4183307	5,52E-03
492	633449	4182307	4,17E-03	538	628449	4183307	6,12E-03
493	633949	4182307	4,70E-03	539	628949	4183307	5,74E-03
494	634449	4182307	4,98E-03	540	629449	4183307	4,57E-03
495	634949	4182307	4,74E-03	541	629949	4183307	3,23E-03
496	635449	4182307	3,95E-03	542	630449	4183307	2,25E-03
497	635949	4182307	2,79E-03	543	630949	4183307	1,74E-03
498	636449	4182307	1,60E-03	544	631449	4183307	1,63E-03
499	636949	4182307	7,07E-04	545	631949	4183307	1,90E-03
500	637449	4182307	2,02E-04	546	632449	4183307	2,50E-03
501	637949	4182307	1,72E-05	547	632949	4183307	3,14E-03
502	638449	4182307	0,00E+00	548	633449	4183307	3,40E-03
503	638949	4182307	0,00E+00	549	633949	4183307	3,41E-03
504	639449	4182307	0,00E+00	550	634449	4183307	3,88E-03

551	634949	4183307	4,99E-03	597	629949	4184307	1,62E-03
552	635449	4183307	5,82E-03	598	630449	4184307	1,72E-03
553	635949	4183307	5,33E-03	599	630949	4184307	1,55E-03
554	636449	4183307	3,63E-03	600	631449	4184307	1,12E-03
555	636949	4183307	1,79E-03	601	631949	4184307	8,49E-04
556	637449	4183307	4,79E-04	602	632449	4184307	9,61E-04
557	637949	4183307	0,00E+00	603	632949	4184307	1,24E-03
558	638449	4183307	0,00E+00	604	633449	4184307	1,40E-03
559	638949	4183307	0,00E+00	605	633949	4184307	1,55E-03
560	639449	4183307	0,00E+00	606	634449	4184307	2,17E-03
561	625949	4183807	0,00E+00	607	634949	4184307	3,36E-03
562	626449	4183807	0,00E+00	608	635449	4184307	4,41E-03
563	626949	4183807	1,03E-03	609	635949	4184307	4,39E-03
564	627449	4183807	5,04E-03	610	636449	4184307	3,21E-03
565	627949	4183807	5,42E-03	611	636949	4184307	1,68E-03
566	628449	4183807	4,89E-03	612	637449	4184307	6,27E-04
567	628949	4183807	3,87E-03	613	637949	4184307	5,50E-05
568	629449	4183807	2,83E-03	614	638449	4184307	0,00E+00
569	629949	4183807	2,13E-03	615	638949	4184307	0,00E+00
570	630449	4183807	1,75E-03	616	639449	4184307	0,00E+00
571	630949	4183807	1,45E-03	617	625949	4184807	0,00E+00
572	631449	4183807	1,20E-03	618	626449	4184807	1,68E-03
573	631949	4183807	1,24E-03	619	626949	4184807	4,19E-03
574	632449	4183807	1,69E-03	620	627449	4184807	4,38E-03
575	632949	4183807	2,24E-03	621	627949	4184807	3,68E-03
576	633449	4183807	2,47E-03	622	628449	4184807	2,53E-03
577	633949	4183807	2,57E-03	623	628949	4184807	1,53E-03
578	634449	4183807	3,21E-03	624	629449	4184807	1,10E-03
579	634949	4183807	4,56E-03	625	629949	4184807	1,24E-03
580	635449	4183807	5,66E-03	626	630449	4184807	1,50E-03
581	635949	4183807	5,39E-03	627	630949	4184807	1,40E-03
582	636449	4183807	3,78E-03	628	631449	4184807	9,50E-04
583	636949	4183807	1,92E-03	629	631949	4184807	5,59E-04
584	637449	4183807	6,89E-04	630	632449	4184807	4,54E-04
585	637949	4183807	3,86E-05	631	632949	4184807	5,33E-04
586	638449	4183807	0,00E+00	632	633449	4184807	6,37E-04
587	638949	4183807	0,00E+00	633	633949	4184807	8,37E-04
588	639449	4183807	0,00E+00	634	634449	4184807	1,37E-03
589	625949	4184307	0,00E+00	635	634949	4184807	2,28E-03
590	626449	4184307	6,50E-04	636	635449	4184807	3,13E-03
591	626949	4184307	4,40E-03	637	635949	4184807	3,25E-03
592	627449	4184307	5,30E-03	638	636449	4184807	2,47E-03
593	627949	4184307	4,89E-03	639	636949	4184807	1,34E-03
594	628449	4184307	3,73E-03	640	637449	4184807	5,15E-04
595	628949	4184307	2,49E-03	641	637949	4184807	5,18E-05
596	629449	4184307	1,75E-03	642	638449	4184807	0,00E+00

643	638949	4184807	0,00E+00	689	633949	4185807	1,14E-03
644	639449	4184807	0,00E+00	690	634449	4185807	1,91E-03
645	625949	4185307	0,00E+00	691	634949	4185807	2,53E-03
646	626449	4185307	8,42E-04	692	635449	4185807	2,66E-03
647	626949	4185307	3,16E-03	693	635949	4185807	2,22E-03
648	627449	4185307	3,01E-03	694	636449	4185807	1,43E-03
649	627949	4185307	2,29E-03	695	636949	4185807	7,02E-04
650	628449	4185307	1,43E-03	696	637449	4185807	2,52E-04
651	628949	4185307	8,10E-04	697	637949	4185807	5,91E-05
652	629449	4185307	6,05E-04	698	638449	4185807	0,00E+00
653	629949	4185307	7,62E-04	699	638949	4185807	0,00E+00
654	630449	4185307	9,65E-04	700	639449	4185807	0,00E+00
655	630949	4185307	9,06E-04	701	625949	4186307	0,00E+00
656	631449	4185307	6,01E-04	702	626449	4186307	0,00E+00
657	631949	4185307	3,09E-04	703	626949	4186307	1,66E-03
658	632449	4185307	1,91E-04	704	627449	4186307	1,10E-03
659	632949	4185307	2,27E-04	705	627949	4186307	9,12E-04
660	633449	4185307	3,86E-04	706	628449	4186307	4,20E-04
661	633949	4185307	7,25E-04	707	628949	4186307	1,56E-04
662	634449	4185307	1,30E-03	708	629449	4186307	8,52E-05
663	634949	4185307	2,02E-03	709	629949	4186307	1,04E-04
664	635449	4185307	2,56E-03	710	630449	4186307	1,34E-04
665	635949	4185307	2,53E-03	711	630949	4186307	1,29E-04
666	636449	4185307	1,87E-03	712	631449	4186307	9,33E-05
667	636949	4185307	1,01E-03	713	631949	4186307	7,74E-05
668	637449	4185307	3,86E-04	714	632449	4186307	1,49E-04
669	637949	4185307	4,91E-05	715	632949	4186307	3,97E-04
670	638449	4185307	0,00E+00	716	633449	4186307	9,25E-04
671	638949	4185307	0,00E+00	717	633949	4186307	1,75E-03
672	639449	4185307	0,00E+00	718	634449	4186307	2,65E-03
673	625949	4185807	0,00E+00	719	634949	4186307	3,13E-03
674	626449	4185807	1,46E-04	720	635449	4186307	2,88E-03
675	626949	4185807	2,32E-03	721	635949	4186307	2,05E-03
676	627449	4185807	2,08E-03	722	636449	4186307	1,12E-03
677	627949	4185807	1,37E-03	723	636949	4186307	4,64E-04
678	628449	4185807	7,32E-04	724	637449	4186307	1,46E-04
679	628949	4185807	3,59E-04	725	637949	4186307	2,83E-05
680	629449	4185807	2,57E-04	726	638449	4186307	0,00E+00
681	629949	4185807	3,35E-04	727	638949	4186307	0,00E+00
682	630449	4185807	4,32E-04	728	639449	4186307	0,00E+00
683	630949	4185807	4,07E-04	729	625949	4186807	0,00E+00
684	631449	4185807	2,69E-04	730	626449	4186807	0,00E+00
685	631949	4185807	1,39E-04	731	626949	4186807	5,14E-05
686	632449	4185807	1,07E-04	732	627449	4186807	0,00E+00
687	632949	4185807	2,18E-04	733	627949	4186807	3,60E-05
688	633449	4185807	5,41E-04	734	628449	4186807	1,55E-04

735	628949	4186807	7,72E-05	781	637949	4187307	6,75E-06
736	629449	4186807	2,62E-05	782	638449	4187307	1,57E-07
737	629949	4186807	2,44E-05	783	638949	4187307	0,00E+00
738	630449	4186807	3,50E-05	784	639449	4187307	0,00E+00
739	630949	4186807	4,71E-05	785	625949	4187807	0,00E+00
740	631449	4186807	6,89E-05	786	626449	4187807	0,00E+00
741	631949	4186807	1,34E-04	787	626949	4187807	0,00E+00
742	632449	4186807	3,20E-04	788	627449	4187807	0,00E+00
743	632949	4186807	7,31E-04	789	627949	4187807	0,00E+00
744	633449	4186807	1,41E-03	790	628449	4187807	0,00E+00
745	633949	4186807	2,23E-03	791	628949	4187807	0,00E+00
746	634449	4186807	2,91E-03	792	629449	4187807	0,00E+00
747	634949	4186807	3,09E-03	793	629949	4187807	2,88E-06
748	635449	4186807	2,59E-03	794	630449	4187807	9,86E-05
749	635949	4186807	1,67E-03	795	630949	4187807	3,11E-04
750	636449	4186807	8,10E-04	796	631449	4187807	6,49E-04
751	636949	4186807	2,94E-04	797	631949	4187807	1,06E-03
752	637449	4186807	7,92E-05	798	632449	4187807	1,52E-03
753	637949	4186807	1,28E-05	799	632949	4187807	2,01E-03
754	638449	4186807	0,00E+00	800	633449	4187807	2,40E-03
755	638949	4186807	0,00E+00	801	633949	4187807	2,43E-03
756	639449	4186807	0,00E+00	802	634449	4187807	7,89E-04
757	625949	4187307	0,00E+00	803	634949	4187807	1,75E-04
758	626449	4187307	0,00E+00	804	635449	4187807	9,85E-05
759	626949	4187307	0,00E+00	805	635949	4187807	2,96E-05
760	627449	4187307	0,00E+00	806	636449	4187807	1,20E-04
761	627949	4187307	0,00E+00	807	636949	4187807	4,57E-06
762	628449	4187307	0,00E+00	808	637449	4187807	3,26E-06
763	628949	4187307	1,31E-06	809	637949	4187807	2,41E-06
764	629449	4187307	1,85E-06	810	638449	4187807	1,41E-07
765	629949	4187307	8,42E-06	811	638949	4187807	0,00E+00
766	630449	4187307	3,64E-05	812	639449	4187807	0,00E+00
767	630949	4187307	9,79E-05	813	625949	4188307	0,00E+00
768	631449	4187307	2,09E-04	814	626449	4188307	0,00E+00
769	631949	4187307	3,90E-04	815	626949	4188307	0,00E+00
770	632449	4187307	7,07E-04	816	627449	4188307	0,00E+00
771	632949	4187307	1,24E-03	817	627949	4188307	0,00E+00
772	633449	4187307	1,91E-03	818	628449	4188307	0,00E+00
773	633949	4187307	2,43E-03	819	628949	4188307	0,00E+00
774	634449	4187307	2,55E-03	820	629449	4188307	0,00E+00
775	634949	4187307	2,33E-03	821	629949	4188307	0,00E+00
776	635449	4187307	1,67E-03	822	630449	4188307	2,18E-05
777	635949	4187307	6,92E-04	823	630949	4188307	3,14E-04
778	636449	4187307	4,78E-04	824	631449	4188307	1,40E-03
779	636949	4187307	1,24E-04	825	631949	4188307	2,31E-03
780	637449	4187307	3,24E-05	826	632449	4188307	2,89E-03

827	632949	4188307	3,14E-03	873	627949	4189307	0,00E+00
828	633449	4188307	2,90E-03	874	628449	4189307	0,00E+00
829	633949	4188307	1,16E-03	875	628949	4189307	0,00E+00
830	634449	4188307	0,00E+00	876	629449	4189307	0,00E+00
831	634949	4188307	0,00E+00	877	629949	4189307	0,00E+00
832	635449	4188307	0,00E+00	878	630449	4189307	0,00E+00
833	635949	4188307	0,00E+00	879	630949	4189307	0,00E+00
834	636449	4188307	0,00E+00	880	631449	4189307	0,00E+00
835	636949	4188307	0,00E+00	881	631949	4189307	2,42E-03
836	637449	4188307	0,00E+00	882	632449	4189307	1,86E-03
837	637949	4188307	4,73E-07	883	632949	4189307	4,30E-03
838	638449	4188307	3,01E-08	884	633449	4189307	1,15E-03
839	638949	4188307	0,00E+00	885	633949	4189307	0,00E+00
840	639449	4188307	0,00E+00	886	634449	4189307	0,00E+00
841	625949	4188807	0,00E+00	887	634949	4189307	0,00E+00
842	626449	4188807	0,00E+00	888	635449	4189307	0,00E+00
843	626949	4188807	0,00E+00	889	635949	4189307	0,00E+00
844	627449	4188807	0,00E+00	890	636449	4189307	0,00E+00
845	627949	4188807	0,00E+00	891	636949	4189307	0,00E+00
846	628449	4188807	0,00E+00	892	637449	4189307	0,00E+00
847	628949	4188807	0,00E+00	893	637949	4189307	0,00E+00
848	629449	4188807	0,00E+00	894	638449	4189307	0,00E+00
849	629949	4188807	0,00E+00	895	638949	4189307	0,00E+00
850	630449	4188807	0,00E+00	896	639449	4189307	0,00E+00
851	630949	4188807	0,00E+00	897	625949	4189807	0,00E+00
852	631449	4188807	5,55E-04	898	626449	4189807	0,00E+00
853	631949	4188807	3,56E-03	899	626949	4189807	0,00E+00
854	632449	4188807	4,40E-03	900	627449	4189807	0,00E+00
855	632949	4188807	4,29E-03	901	627949	4189807	0,00E+00
856	633449	4188807	1,76E-03	902	628449	4189807	0,00E+00
857	633949	4188807	0,00E+00	903	628949	4189807	0,00E+00
858	634449	4188807	0,00E+00	904	629449	4189807	0,00E+00
859	634949	4188807	0,00E+00	905	629949	4189807	0,00E+00
860	635449	4188807	0,00E+00	906	630449	4189807	0,00E+00
861	635949	4188807	0,00E+00	907	630949	4189807	0,00E+00
862	636449	4188807	0,00E+00	908	631449	4189807	0,00E+00
863	636949	4188807	0,00E+00	909	631949	4189807	1,23E-04
864	637449	4188807	0,00E+00	910	632449	4189807	0,00E+00
865	637949	4188807	0,00E+00	911	632949	4189807	2,46E-03
866	638449	4188807	0,00E+00	912	633449	4189807	1,39E-04
867	638949	4188807	0,00E+00	913	633949	4189807	0,00E+00
868	639449	4188807	0,00E+00	914	634449	4189807	0,00E+00
869	625949	4189307	0,00E+00	915	634949	4189807	0,00E+00
870	626449	4189307	0,00E+00	916	635449	4189807	0,00E+00
871	626949	4189307	0,00E+00	917	635949	4189807	0,00E+00
872	627449	4189307	0,00E+00	918	636449	4189807	0,00E+00

919	636949	4189807	0,00E+00
920	637449	4189807	0,00E+00
921	637949	4189807	0,00E+00
922	638449	4189807	0,00E+00
923	638949	4189807	0,00E+00
924	639449	4189807	0,00E+00
925	625949	4190307	0,00E+00
926	626449	4190307	0,00E+00
927	626949	4190307	0,00E+00
928	627449	4190307	0,00E+00
929	627949	4190307	0,00E+00
930	628449	4190307	0,00E+00
931	628949	4190307	0,00E+00
932	629449	4190307	0,00E+00
933	629949	4190307	0,00E+00
934	630449	4190307	0,00E+00
935	630949	4190307	0,00E+00

936	631449	4190307	0,00E+00
937	631949	4190307	0,00E+00
938	632449	4190307	0,00E+00
939	632949	4190307	0,00E+00
940	633449	4190307	0,00E+00
941	633949	4190307	0,00E+00
942	634449	4190307	0,00E+00
943	634949	4190307	0,00E+00
944	635449	4190307	0,00E+00
945	635949	4190307	0,00E+00
946	636449	4190307	0,00E+00
947	636949	4190307	0,00E+00
948	637449	4190307	0,00E+00
949	637949	4190307	0,00E+00
950	638449	4190307	0,00E+00
951	638949	4190307	0,00E+00
952	639449	4190307	0,00E+00

Fogo ET vent opening			
ID	Longitude	Latitude	Probability
1	625949	4173807	0,00E+00
2	626449	4173807	0,00E+00
3	626949	4173807	0,00E+00
4	627449	4173807	0,00E+00
5	627949	4173807	0,00E+00
6	628449	4173807	0,00E+00
7	628949	4173807	0,00E+00
8	629449	4173807	0,00E+00
9	629949	4173807	0,00E+00
10	630449	4173807	0,00E+00
11	630949	4173807	0,00E+00
12	631449	4173807	0,00E+00
13	631949	4173807	0,00E+00
14	632449	4173807	0,00E+00
15	632949	4173807	0,00E+00
16	633449	4173807	0,00E+00
17	633949	4173807	0,00E+00
18	634449	4173807	0,00E+00
19	634949	4173807	0,00E+00
20	635449	4173807	0,00E+00
21	635949	4173807	0,00E+00
22	636449	4173807	0,00E+00
23	636949	4173807	0,00E+00
24	637449	4173807	0,00E+00
25	637949	4173807	0,00E+00
26	638449	4173807	0,00E+00
27	638949	4173807	0,00E+00
28	639449	4173807	0,00E+00
29	625949	4174307	0,00E+00
30	626449	4174307	0,00E+00
31	626949	4174307	0,00E+00
32	627449	4174307	0,00E+00
33	627949	4174307	0,00E+00
34	628449	4174307	0,00E+00
35	628949	4174307	0,00E+00
36	629449	4174307	0,00E+00
37	629949	4174307	0,00E+00
38	630449	4174307	0,00E+00
39	630949	4174307	0,00E+00
40	631449	4174307	4,14E-05
41	631949	4174307	0,00E+00
42	632449	4174307	0,00E+00
43	632949	4174307	0,00E+00
44	633449	4174307	0,00E+00
45	633949	4174307	0,00E+00

46	634449	4174307	0,00E+00
47	634949	4174307	0,00E+00
48	635449	4174307	0,00E+00
49	635949	4174307	0,00E+00
50	636449	4174307	0,00E+00
51	636949	4174307	0,00E+00
52	637449	4174307	0,00E+00
53	637949	4174307	0,00E+00
54	638449	4174307	0,00E+00
55	638949	4174307	0,00E+00
56	639449	4174307	0,00E+00
57	625949	4174807	0,00E+00
58	626449	4174807	0,00E+00
59	626949	4174807	0,00E+00
60	627449	4174807	0,00E+00
61	627949	4174807	0,00E+00
62	628449	4174807	0,00E+00
63	628949	4174807	0,00E+00
64	629449	4174807	0,00E+00
65	629949	4174807	0,00E+00
66	630449	4174807	0,00E+00
67	630949	4174807	8,28E-05
68	631449	4174807	2,80E-04
69	631949	4174807	2,83E-04
70	632449	4174807	1,46E-04
71	632949	4174807	0,00E+00
72	633449	4174807	0,00E+00
73	633949	4174807	0,00E+00
74	634449	4174807	0,00E+00
75	634949	4174807	0,00E+00
76	635449	4174807	0,00E+00
77	635949	4174807	0,00E+00
78	636449	4174807	0,00E+00
79	636949	4174807	3,00E-06
80	637449	4174807	5,94E-06
81	637949	4174807	0,00E+00
82	638449	4174807	0,00E+00
83	638949	4174807	0,00E+00
84	639449	4174807	0,00E+00
85	625949	4175307	0,00E+00
86	626449	4175307	0,00E+00
87	626949	4175307	0,00E+00
88	627449	4175307	0,00E+00
89	627949	4175307	0,00E+00
90	628449	4175307	0,00E+00
91	628949	4175307	0,00E+00

92	629449	4175307	4,35E-05	138	638449	4175807	1,67E-04
93	629949	4175307	8,60E-05	139	638949	4175807	0,00E+00
94	630449	4175307	4,67E-05	140	639449	4175807	0,00E+00
95	630949	4175307	2,67E-04	141	625949	4176307	0,00E+00
96	631449	4175307	3,17E-04	142	626449	4176307	0,00E+00
97	631949	4175307	3,35E-04	143	626949	4176307	0,00E+00
98	632449	4175307	3,29E-04	144	627449	4176307	0,00E+00
99	632949	4175307	2,58E-04	145	627949	4176307	0,00E+00
100	633449	4175307	9,51E-05	146	628449	4176307	4,97E-05
101	633949	4175307	1,25E-05	147	628949	4176307	2,09E-04
102	634449	4175307	2,91E-05	148	629449	4176307	2,95E-04
103	634949	4175307	2,71E-04	149	629949	4176307	3,21E-04
104	635449	4175307	2,03E-04	150	630449	4176307	3,50E-04
105	635949	4175307	1,07E-04	151	630949	4176307	3,81E-04
106	636449	4175307	1,44E-04	152	631449	4176307	4,14E-04
107	636949	4175307	2,77E-04	153	631949	4176307	4,47E-04
108	637449	4175307	2,61E-04	154	632449	4176307	4,79E-04
109	637949	4175307	1,79E-04	155	632949	4176307	5,09E-04
110	638449	4175307	5,96E-05	156	633449	4176307	5,33E-04
111	638949	4175307	0,00E+00	157	633949	4176307	5,50E-04
112	639449	4175307	0,00E+00	158	634449	4176307	5,56E-04
113	625949	4175807	0,00E+00	159	634949	4176307	5,51E-04
114	626449	4175807	0,00E+00	160	635449	4176307	5,35E-04
115	626949	4175807	0,00E+00	161	635949	4176307	5,10E-04
116	627449	4175807	0,00E+00	162	636449	4176307	4,79E-04
117	627949	4175807	0,00E+00	163	636949	4176307	4,44E-04
118	628449	4175807	0,00E+00	164	637449	4176307	4,07E-04
119	628949	4175807	1,32E-05	165	637949	4176307	3,72E-04
120	629449	4175807	2,43E-04	166	638449	4176307	3,10E-04
121	629949	4175807	2,89E-04	167	638949	4176307	5,56E-05
122	630449	4175807	3,12E-04	168	639449	4176307	0,00E+00
123	630949	4175807	3,36E-04	169	625949	4176807	0,00E+00
124	631449	4175807	3,61E-04	170	626449	4176807	0,00E+00
125	631949	4175807	3,86E-04	171	626949	4176807	0,00E+00
126	632449	4175807	4,09E-04	172	627449	4176807	0,00E+00
127	632949	4175807	4,30E-04	173	627949	4176807	5,17E-05
128	633449	4175807	4,38E-04	174	628449	4176807	2,50E-04
129	633949	4175807	4,01E-04	175	628949	4176807	2,96E-04
130	634449	4175807	4,56E-04	176	629449	4176807	3,25E-04
131	634949	4175807	4,57E-04	177	629949	4176807	3,58E-04
132	635449	4175807	4,46E-04	178	630449	4176807	3,94E-04
133	635949	4175807	4,29E-04	179	630949	4176807	4,34E-04
134	636449	4175807	4,06E-04	180	631449	4176807	4,77E-04
135	636949	4175807	3,81E-04	181	631949	4176807	5,23E-04
136	637449	4175807	3,55E-04	182	632449	4176807	5,69E-04
137	637949	4175807	3,28E-04	183	632949	4176807	6,12E-04

184	633449	4176807	6,50E-04	230	628449	4177807	3,17E-04
185	633949	4176807	6,76E-04	231	628949	4177807	3,53E-04
186	634449	4176807	6,87E-04	232	629449	4177807	3,95E-04
187	634949	4176807	6,80E-04	233	629949	4177807	4,43E-04
188	635449	4176807	6,56E-04	234	630449	4177807	5,01E-04
189	635949	4176807	6,18E-04	235	630949	4177807	5,68E-04
190	636449	4176807	5,72E-04	236	631449	4177807	6,45E-04
191	636949	4176807	5,21E-04	237	631949	4177807	7,35E-04
192	637449	4176807	4,71E-04	238	632449	4177807	8,33E-04
193	637949	4176807	4,24E-04	239	632949	4177807	9,37E-04
194	638449	4176807	3,81E-04	240	633449	4177807	1,04E-03
195	638949	4176807	1,59E-04	241	633949	4177807	1,11E-03
196	639449	4176807	0,00E+00	242	634449	4177807	1,15E-03
197	625949	4177307	0,00E+00	243	634949	4177807	1,14E-03
198	626449	4177307	0,00E+00	244	635449	4177807	1,08E-03
199	626949	4177307	1,42E-05	245	635949	4177807	9,75E-04
200	627449	4177307	1,32E-04	246	636449	4177807	8,58E-04
201	627949	4177307	2,64E-04	247	636949	4177807	7,44E-04
202	628449	4177307	2,93E-04	248	637449	4177807	6,42E-04
203	628949	4177307	3,24E-04	249	637949	4177807	5,54E-04
204	629449	4177307	3,59E-04	250	638449	4177807	4,81E-04
205	629949	4177307	3,98E-04	251	638949	4177807	2,17E-04
206	630449	4177307	4,44E-04	252	639449	4177807	0,00E+00
207	630949	4177307	4,96E-04	253	625949	4178307	0,00E+00
208	631449	4177307	5,54E-04	254	626449	4178307	5,13E-05
209	631949	4177307	6,17E-04	255	626949	4178307	1,76E-04
210	632449	4177307	6,84E-04	256	627449	4178307	2,78E-04
211	632949	4177307	7,50E-04	257	627949	4178307	3,08E-04
212	633449	4177307	8,09E-04	258	628449	4178307	3,43E-04
213	633949	4177307	8,53E-04	259	628949	4178307	3,84E-04
214	634449	4177307	8,73E-04	260	629449	4178307	4,33E-04
215	634949	4177307	8,64E-04	261	629949	4178307	4,92E-04
216	635449	4177307	8,26E-04	262	630449	4178307	5,63E-04
217	635949	4177307	7,66E-04	263	630949	4178307	6,50E-04
218	636449	4177307	6,94E-04	264	631449	4178307	7,55E-04
219	636949	4177307	6,20E-04	265	631949	4178307	8,81E-04
220	637449	4177307	5,49E-04	266	632449	4178307	1,03E-03
221	637949	4177307	4,85E-04	267	632949	4178307	1,20E-03
222	638449	4177307	4,28E-04	268	633449	4178307	1,37E-03
223	638949	4177307	2,10E-04	269	633949	4178307	1,52E-03
224	639449	4177307	0,00E+00	270	634449	4178307	1,61E-03
225	625949	4177807	0,00E+00	271	634949	4178307	1,59E-03
226	626449	4177807	2,51E-05	272	635449	4178307	1,47E-03
227	626949	4177807	2,03E-04	273	635949	4178307	1,28E-03
228	627449	4177807	2,60E-04	274	636449	4178307	1,08E-03
229	627949	4177807	2,87E-04	275	636949	4178307	9,00E-04

276	637449	4178307	7,52E-04	322	632449	4179307	1,61E-03
277	637949	4178307	6,33E-04	323	632949	4179307	2,07E-03
278	638449	4178307	5,38E-04	324	633449	4179307	2,68E-03
279	638949	4178307	2,21E-04	325	633949	4179307	3,40E-03
280	639449	4178307	0,00E+00	326	634449	4179307	4,00E-03
281	625949	4178807	0,00E+00	327	634949	4179307	4,10E-03
282	626449	4178807	0,00E+00	328	635449	4179307	3,41E-03
283	626949	4178807	0,00E+00	329	635949	4179307	2,46E-03
284	627449	4178807	1,10E-04	330	636449	4179307	1,76E-03
285	627949	4178807	3,22E-04	331	636949	4179307	1,31E-03
286	628449	4178807	3,68E-04	332	637449	4179307	1,01E-03
287	628949	4178807	4,16E-04	333	637949	4179307	8,03E-04
288	629449	4178807	4,73E-04	334	638449	4179307	5,46E-04
289	629949	4178807	5,44E-04	335	638949	4179307	0,00E+00
290	630449	4178807	6,32E-04	336	639449	4179307	0,00E+00
291	630949	4178807	7,42E-04	337	625949	4179807	0,00E+00
292	631449	4178807	8,82E-04	338	626449	4179807	0,00E+00
293	631949	4178807	1,06E-03	339	626949	4179807	0,00E+00
294	632449	4178807	1,28E-03	340	627449	4179807	0,00E+00
295	632949	4178807	1,56E-03	341	627949	4179807	0,00E+00
296	633449	4178807	1,88E-03	342	628449	4179807	5,12E-05
297	633949	4178807	2,20E-03	343	628949	4179807	2,12E-04
298	634449	4178807	2,41E-03	344	629449	4179807	3,02E-04
299	634949	4178807	2,41E-03	345	629949	4179807	6,32E-04
300	635449	4178807	2,14E-03	346	630449	4179807	7,76E-04
301	635949	4178807	1,75E-03	347	630949	4179807	9,44E-04
302	636449	4178807	1,38E-03	348	631449	4179807	1,18E-03
303	636949	4178807	1,09E-03	349	631949	4179807	1,51E-03
304	637449	4178807	8,77E-04	350	632449	4179807	2,00E-03
305	637949	4178807	7,18E-04	351	632949	4179807	2,75E-03
306	638449	4178807	5,92E-04	352	633449	4179807	3,92E-03
307	638949	4178807	7,86E-05	353	633949	4179807	5,64E-03
308	639449	4178807	0,00E+00	354	634449	4179807	7,34E-03
309	625949	4179307	0,00E+00	355	634949	4179807	7,75E-03
310	626449	4179307	0,00E+00	356	635449	4179807	5,72E-03
311	626949	4179307	0,00E+00	357	635949	4179807	3,39E-03
312	627449	4179307	0,00E+00	358	636449	4179807	2,17E-03
313	627949	4179307	8,48E-05	359	636949	4179807	1,52E-03
314	628449	4179307	3,71E-04	360	637449	4179807	1,13E-03
315	628949	4179307	4,48E-04	361	637949	4179807	8,81E-04
316	629449	4179307	5,14E-04	362	638449	4179807	3,86E-04
317	629949	4179307	5,97E-04	363	638949	4179807	0,00E+00
318	630449	4179307	7,04E-04	364	639449	4179807	0,00E+00
319	630949	4179307	8,42E-04	365	625949	4180307	0,00E+00
320	631449	4179307	1,02E-03	366	626449	4180307	0,00E+00
321	631949	4179307	1,27E-03	367	626949	4180307	0,00E+00

368	627449	4180307	0,00E+00	414	636449	4180807	2,54E-03
369	627949	4180307	0,00E+00	415	636949	4180807	1,74E-03
370	628449	4180307	0,00E+00	416	637449	4180807	1,28E-03
371	628949	4180307	0,00E+00	417	637949	4180807	8,33E-04
372	629449	4180307	0,00E+00	418	638449	4180807	8,45E-06
373	629949	4180307	5,16E-04	419	638949	4180807	0,00E+00
374	630449	4180307	8,45E-04	420	639449	4180807	0,00E+00
375	630949	4180307	1,04E-03	421	625949	4181307	0,00E+00
376	631449	4180307	1,33E-03	422	626449	4181307	0,00E+00
377	631949	4180307	1,75E-03	423	626949	4181307	0,00E+00
378	632449	4180307	2,42E-03	424	627449	4181307	0,00E+00
379	632949	4180307	3,59E-03	425	627949	4181307	0,00E+00
380	633449	4180307	5,68E-03	426	628449	4181307	1,05E-05
381	633949	4180307	9,21E-03	427	628949	4181307	4,06E-04
382	634449	4180307	1,26E-02	428	629449	4181307	6,57E-04
383	634949	4180307	1,13E-02	429	629949	4181307	7,84E-04
384	635449	4180307	7,35E-03	430	630449	4181307	9,59E-04
385	635949	4180307	4,02E-03	431	630949	4181307	1,21E-03
386	636449	4180307	2,45E-03	432	631449	4181307	1,57E-03
387	636949	4180307	1,67E-03	433	631949	4181307	2,14E-03
388	637449	4180307	1,22E-03	434	632449	4181307	3,07E-03
389	637949	4180307	9,41E-04	435	632949	4181307	4,79E-03
390	638449	4180307	2,33E-04	436	633449	4181307	8,28E-03
391	638949	4180307	0,00E+00	437	633949	4181307	1,28E-02
392	639449	4180307	0,00E+00	438	634449	4181307	1,48E-02
393	625949	4180807	0,00E+00	439	634949	4181307	1,11E-02
394	626449	4180807	0,00E+00	440	635449	4181307	6,35E-03
395	626949	4180807	0,00E+00	441	635949	4181307	3,80E-03
396	627449	4180807	0,00E+00	442	636449	4181307	2,48E-03
397	627949	4180807	0,00E+00	443	636949	4181307	1,73E-03
398	628449	4180807	0,00E+00	444	637449	4181307	1,28E-03
399	628949	4180807	2,90E-05	445	637949	4181307	8,89E-04
400	629449	4180807	4,71E-04	446	638449	4181307	1,19E-04
401	629949	4180807	7,46E-04	447	638949	4181307	0,00E+00
402	630449	4180807	9,08E-04	448	639449	4181307	0,00E+00
403	630949	4180807	1,13E-03	449	625949	4181807	0,00E+00
404	631449	4180807	1,46E-03	450	626449	4181807	0,00E+00
405	631949	4180807	1,97E-03	451	626949	4181807	0,00E+00
406	632449	4180807	2,81E-03	452	627449	4181807	0,00E+00
407	632949	4180807	4,41E-03	453	627949	4181807	4,83E-06
408	633449	4180807	7,73E-03	454	628449	4181807	3,52E-04
409	633949	4180807	1,25E-02	455	628949	4181807	5,83E-04
410	634449	4180807	1,50E-02	456	629449	4181807	6,81E-04
411	634949	4180807	1,12E-02	457	629949	4181807	8,13E-04
412	635449	4180807	6,80E-03	458	630449	4181807	9,97E-04
413	635949	4180807	4,02E-03	459	630949	4181807	1,26E-03

460	631449	4181807	1,66E-03	506	626449	4182807	0,00E+00
461	631949	4181807	2,28E-03	507	626949	4182807	0,00E+00
462	632449	4181807	3,27E-03	508	627449	4182807	6,64E-05
463	632949	4181807	4,85E-03	509	627949	4182807	4,72E-04
464	633449	4181807	7,17E-03	510	628449	4182807	5,48E-04
465	633949	4181807	1,02E-02	511	628949	4182807	6,17E-04
466	634449	4181807	1,32E-02	512	629449	4182807	7,10E-04
467	634949	4181807	1,01E-02	513	629949	4182807	8,39E-04
468	635449	4181807	5,62E-03	514	630449	4182807	1,02E-03
469	635949	4181807	3,42E-03	515	630949	4182807	1,30E-03
470	636449	4181807	2,30E-03	516	631449	4182807	1,74E-03
471	636949	4181807	1,66E-03	517	631949	4182807	2,51E-03
472	637449	4181807	1,25E-03	518	632449	4182807	3,98E-03
473	637949	4181807	9,77E-04	519	632949	4182807	6,73E-03
474	638449	4181807	2,04E-04	520	633449	4182807	8,93E-03
475	638949	4181807	0,00E+00	521	633949	4182807	7,00E-03
476	639449	4181807	0,00E+00	522	634449	4182807	5,31E-03
477	625949	4182307	0,00E+00	523	634949	4182807	4,21E-03
478	626449	4182307	0,00E+00	524	635449	4182807	3,19E-03
479	626949	4182307	0,00E+00	525	635949	4182807	2,38E-03
480	627449	4182307	0,00E+00	526	636449	4182807	1,81E-03
481	627949	4182307	2,09E-04	527	636949	4182807	1,41E-03
482	628449	4182307	5,28E-04	528	637449	4182807	5,35E-04
483	628949	4182307	6,01E-04	529	637949	4182807	0,00E+00
484	629449	4182307	6,98E-04	530	638449	4182807	0,00E+00
485	629949	4182307	8,31E-04	531	638949	4182807	0,00E+00
486	630449	4182307	1,02E-03	532	639449	4182807	0,00E+00
487	630949	4182307	1,30E-03	533	625949	4183307	0,00E+00
488	631449	4182307	1,72E-03	534	626449	4183307	0,00E+00
489	631949	4182307	2,41E-03	535	626949	4183307	0,00E+00
490	632449	4182307	3,58E-03	536	627449	4183307	2,70E-04
491	632949	4182307	5,54E-03	537	627949	4183307	5,27E-04
492	633449	4182307	7,53E-03	538	628449	4183307	5,73E-04
493	633949	4182307	7,95E-03	539	628949	4183307	6,33E-04
494	634449	4182307	8,00E-03	540	629449	4183307	7,17E-04
495	634949	4182307	6,43E-03	541	629949	4183307	8,36E-04
496	635449	4182307	4,29E-03	542	630449	4183307	1,01E-03
497	635949	4182307	2,89E-03	543	630949	4183307	1,27E-03
498	636449	4182307	2,06E-03	544	631449	4183307	1,70E-03
499	636949	4182307	1,54E-03	545	631949	4183307	2,47E-03
500	637449	4182307	1,02E-03	546	632449	4183307	4,11E-03
501	637949	4182307	3,52E-04	547	632949	4183307	7,24E-03
502	638449	4182307	0,00E+00	548	633449	4183307	8,06E-03
503	638949	4182307	0,00E+00	549	633949	4183307	5,64E-03
504	639449	4182307	0,00E+00	550	634449	4183307	4,02E-03
505	625949	4182807	0,00E+00	551	634949	4183307	3,14E-03

552	635449	4183307	2,51E-03	598	630449	4184307	9,32E-04
553	635949	4183307	2,00E-03	599	630949	4184307	1,12E-03
554	636449	4183307	1,60E-03	600	631449	4184307	1,40E-03
555	636949	4183307	1,30E-03	601	631949	4184307	1,84E-03
556	637449	4183307	6,78E-04	602	632449	4184307	2,49E-03
557	637949	4183307	0,00E+00	603	632949	4184307	3,23E-03
558	638449	4183307	0,00E+00	604	633449	4184307	3,40E-03
559	638949	4183307	0,00E+00	605	633949	4184307	2,99E-03
560	639449	4183307	0,00E+00	606	634449	4184307	2,57E-03
561	625949	4183807	0,00E+00	607	634949	4184307	2,24E-03
562	626449	4183807	0,00E+00	608	635449	4184307	1,94E-03
563	626949	4183807	1,21E-04	609	635949	4184307	1,66E-03
564	627449	4183807	5,39E-04	610	636449	4184307	1,40E-03
565	627949	4183807	5,75E-04	611	636949	4184307	1,16E-03
566	628449	4183807	6,05E-04	612	637449	4184307	9,69E-04
567	628949	4183807	6,51E-04	613	637949	4184307	1,74E-04
568	629449	4183807	7,20E-04	614	638449	4184307	0,00E+00
569	629949	4183807	8,24E-04	615	638949	4184307	0,00E+00
570	630449	4183807	9,77E-04	616	639449	4184307	0,00E+00
571	630949	4183807	1,21E-03	617	625949	4184807	0,00E+00
572	631449	4183807	1,57E-03	618	626449	4184807	3,89E-04
573	631949	4183807	2,21E-03	619	626949	4184807	8,64E-04
574	632449	4183807	3,47E-03	620	627449	4184807	8,48E-04
575	632949	4183807	5,56E-03	621	627949	4184807	7,80E-04
576	633449	4183807	5,77E-03	622	628449	4184807	7,24E-04
577	633949	4183807	4,17E-03	623	628949	4184807	7,05E-04
578	634449	4183807	3,14E-03	624	629449	4184807	7,25E-04
579	634949	4183807	2,55E-03	625	629949	4184807	7,85E-04
580	635449	4183807	2,12E-03	626	630449	4184807	8,84E-04
581	635949	4183807	1,76E-03	627	630949	4184807	1,03E-03
582	636449	4183807	1,46E-03	628	631449	4184807	1,24E-03
583	636949	4183807	1,21E-03	629	631949	4184807	1,52E-03
584	637449	4183807	9,94E-04	630	632449	4184807	1,87E-03
585	637949	4183807	1,16E-04	631	632949	4184807	2,20E-03
586	638449	4183807	0,00E+00	632	633449	4184807	2,39E-03
587	638949	4183807	0,00E+00	633	633949	4184807	2,41E-03
588	639449	4183807	0,00E+00	634	634449	4184807	2,35E-03
589	625949	4184307	0,00E+00	635	634949	4184807	2,23E-03
590	626449	4184307	1,10E-04	636	635449	4184807	2,02E-03
591	626949	4184307	5,99E-04	637	635949	4184807	1,72E-03
592	627449	4184307	6,51E-04	638	636449	4184807	1,42E-03
593	627949	4184307	6,51E-04	639	636949	4184807	1,16E-03
594	628449	4184307	6,53E-04	640	637449	4184807	9,56E-04
595	628949	4184307	6,74E-04	641	637949	4184807	1,95E-04
596	629449	4184307	7,22E-04	642	638449	4184807	0,00E+00
597	629949	4184307	8,05E-04	643	638949	4184807	0,00E+00

644	639449	4184807	0,00E+00	690	634449	4185807	3,69E-03
645	625949	4185307	0,00E+00	691	634949	4185807	4,34E-03
646	626449	4185307	3,71E-04	692	635449	4185807	3,98E-03
647	626949	4185307	1,41E-03	693	635949	4185807	2,76E-03
648	627449	4185307	1,26E-03	694	636449	4185807	1,81E-03
649	627949	4185307	9,99E-04	695	636949	4185807	1,28E-03
650	628449	4185307	8,22E-04	696	637449	4185807	9,68E-04
651	628949	4185307	7,41E-04	697	637949	4185807	6,50E-04
652	629449	4185307	7,28E-04	698	638449	4185807	0,00E+00
653	629949	4185307	7,63E-04	699	638949	4185807	0,00E+00
654	630449	4185307	8,38E-04	700	639449	4185807	0,00E+00
655	630949	4185307	9,53E-04	701	625949	4186307	0,00E+00
656	631449	4185307	1,11E-03	702	626449	4186307	0,00E+00
657	631949	4185307	1,31E-03	703	626949	4186307	4,12E-03
658	632449	4185307	1,54E-03	704	627449	4186307	1,97E-03
659	632949	4185307	1,80E-03	705	627949	4186307	1,44E-03
660	633449	4185307	2,06E-03	706	628449	4186307	9,72E-04
661	633949	4185307	2,34E-03	707	628949	4186307	7,75E-04
662	634449	4185307	2,62E-03	708	629449	4186307	7,12E-04
663	634949	4185307	2,73E-03	709	629949	4186307	7,15E-04
664	635449	4185307	2,51E-03	710	630449	4186307	7,62E-04
665	635949	4185307	2,04E-03	711	630949	4186307	8,43E-04
666	636449	4185307	1,56E-03	712	631449	4186307	9,57E-04
667	636949	4185307	1,21E-03	713	631949	4186307	1,11E-03
668	637449	4185307	9,60E-04	714	632449	4186307	1,31E-03
669	637949	4185307	2,88E-04	715	632949	4186307	1,60E-03
670	638449	4185307	0,00E+00	716	633449	4186307	2,13E-03
671	638949	4185307	0,00E+00	717	633949	4186307	3,33E-03
672	639449	4185307	0,00E+00	718	634449	4186307	5,79E-03
673	625949	4185807	0,00E+00	719	634949	4186307	7,34E-03
674	626449	4185807	1,21E-04	720	635449	4186307	6,50E-03
675	626949	4185807	2,75E-03	721	635949	4186307	3,61E-03
676	627449	4185807	2,14E-03	722	636449	4186307	2,00E-03
677	627949	4185807	1,31E-03	723	636949	4186307	1,31E-03
678	628449	4185807	9,25E-04	724	637449	4186307	9,58E-04
679	628949	4185807	7,71E-04	725	637949	4186307	5,21E-04
680	629449	4185807	7,26E-04	726	638449	4186307	0,00E+00
681	629949	4185807	7,41E-04	727	638949	4186307	0,00E+00
682	630449	4185807	7,98E-04	728	639449	4186307	0,00E+00
683	630949	4185807	8,90E-04	729	625949	4186807	0,00E+00
684	631449	4185807	1,02E-03	730	626449	4186807	0,00E+00
685	631949	4185807	1,18E-03	731	626949	4186807	1,37E-04
686	632449	4185807	1,38E-03	732	627449	4186807	0,00E+00
687	632949	4185807	1,65E-03	733	627949	4186807	7,31E-05
688	633449	4185807	2,05E-03	734	628449	4186807	5,35E-04
689	633949	4185807	2,72E-03	735	628949	4186807	7,25E-04

736	629449	4186807	6,82E-04	782	638449	4187307	7,42E-05
737	629949	4186807	6,86E-04	783	638949	4187307	0,00E+00
738	630449	4186807	7,31E-04	784	639449	4187307	0,00E+00
739	630949	4186807	8,09E-04	785	625949	4187807	0,00E+00
740	631449	4186807	9,23E-04	786	626449	4187807	0,00E+00
741	631949	4186807	1,08E-03	787	626949	4187807	0,00E+00
742	632449	4186807	1,28E-03	788	627449	4187807	0,00E+00
743	632949	4186807	1,57E-03	789	627949	4187807	0,00E+00
744	633449	4186807	2,09E-03	790	628449	4187807	0,00E+00
745	633949	4186807	3,27E-03	791	628949	4187807	0,00E+00
746	634449	4186807	5,67E-03	792	629449	4187807	0,00E+00
747	634949	4186807	6,80E-03	793	629949	4187807	5,79E-05
748	635449	4186807	5,64E-03	794	630449	4187807	6,04E-04
749	635949	4186807	3,29E-03	795	630949	4187807	7,72E-04
750	636449	4186807	1,88E-03	796	631449	4187807	9,25E-04
751	636949	4186807	1,24E-03	797	631949	4187807	1,16E-03
752	637449	4186807	9,12E-04	798	632449	4187807	1,48E-03
753	637949	4186807	4,74E-04	799	632949	4187807	1,82E-03
754	638449	4186807	0,00E+00	800	633449	4187807	2,01E-03
755	638949	4186807	0,00E+00	801	633949	4187807	2,10E-03
756	639449	4186807	0,00E+00	802	634449	4187807	7,91E-04
757	625949	4187307	0,00E+00	803	634949	4187807	2,75E-04
758	626449	4187307	0,00E+00	804	635449	4187807	1,70E-04
759	626949	4187307	0,00E+00	805	635949	4187807	1,04E-04
760	627449	4187307	0,00E+00	806	636449	4187807	5,69E-04
761	627949	4187307	0,00E+00	807	636949	4187807	3,33E-05
762	628449	4187307	0,00E+00	808	637449	4187807	2,13E-04
763	628949	4187307	2,74E-05	809	637949	4187807	5,79E-04
764	629449	4187307	9,87E-05	810	638449	4187807	1,34E-04
765	629949	4187307	4,36E-04	811	638949	4187807	0,00E+00
766	630449	4187307	7,02E-04	812	639449	4187807	0,00E+00
767	630949	4187307	7,87E-04	813	625949	4188307	0,00E+00
768	631449	4187307	9,12E-04	814	626449	4188307	0,00E+00
769	631949	4187307	1,09E-03	815	626949	4188307	0,00E+00
770	632449	4187307	1,31E-03	816	627449	4188307	0,00E+00
771	632949	4187307	1,59E-03	817	627949	4188307	0,00E+00
772	633449	4187307	1,95E-03	818	628449	4188307	0,00E+00
773	633949	4187307	2,54E-03	819	628949	4188307	0,00E+00
774	634449	4187307	3,32E-03	820	629449	4188307	0,00E+00
775	634949	4187307	3,67E-03	821	629949	4188307	0,00E+00
776	635449	4187307	2,99E-03	822	630449	4188307	5,48E-05
777	635949	4187307	1,45E-03	823	630949	4188307	3,83E-04
778	636449	4187307	1,54E-03	824	631449	4188307	8,97E-04
779	636949	4187307	7,78E-04	825	631949	4188307	1,29E-03
780	637449	4187307	7,11E-04	826	632449	4188307	1,93E-03
781	637949	4187307	6,39E-04	827	632949	4188307	2,72E-03

828	633449	4188307	2,66E-03	874	628449	4189307	0,00E+00
829	633949	4188307	1,01E-03	875	628949	4189307	0,00E+00
830	634449	4188307	0,00E+00	876	629449	4189307	0,00E+00
831	634949	4188307	0,00E+00	877	629949	4189307	0,00E+00
832	635449	4188307	0,00E+00	878	630449	4189307	0,00E+00
833	635949	4188307	0,00E+00	879	630949	4189307	0,00E+00
834	636449	4188307	0,00E+00	880	631449	4189307	0,00E+00
835	636949	4188307	0,00E+00	881	631949	4189307	7,47E-04
836	637449	4188307	0,00E+00	882	632449	4189307	9,82E-04
837	637949	4188307	3,24E-04	883	632949	4189307	3,68E-03
838	638449	4188307	7,48E-05	884	633449	4189307	1,35E-03
839	638949	4188307	0,00E+00	885	633949	4189307	0,00E+00
840	639449	4188307	0,00E+00	886	634449	4189307	0,00E+00
841	625949	4188807	0,00E+00	887	634949	4189307	0,00E+00
842	626449	4188807	0,00E+00	888	635449	4189307	0,00E+00
843	626949	4188807	0,00E+00	889	635949	4189307	0,00E+00
844	627449	4188807	0,00E+00	890	636449	4189307	0,00E+00
845	627949	4188807	0,00E+00	891	636949	4189307	0,00E+00
846	628449	4188807	0,00E+00	892	637449	4189307	0,00E+00
847	628949	4188807	0,00E+00	893	637949	4189307	0,00E+00
848	629449	4188807	0,00E+00	894	638449	4189307	0,00E+00
849	629949	4188807	0,00E+00	895	638949	4189307	0,00E+00
850	630449	4188807	0,00E+00	896	639449	4189307	0,00E+00
851	630949	4188807	0,00E+00	897	625949	4189807	0,00E+00
852	631449	4188807	2,26E-04	898	626449	4189807	0,00E+00
853	631949	4188807	1,35E-03	899	626949	4189807	0,00E+00
854	632449	4188807	2,49E-03	900	627449	4189807	0,00E+00
855	632949	4188807	4,54E-03	901	627949	4189807	0,00E+00
856	633449	4188807	2,23E-03	902	628449	4189807	0,00E+00
857	633949	4188807	0,00E+00	903	628949	4189807	0,00E+00
858	634449	4188807	0,00E+00	904	629449	4189807	0,00E+00
859	634949	4188807	0,00E+00	905	629949	4189807	0,00E+00
860	635449	4188807	0,00E+00	906	630449	4189807	0,00E+00
861	635949	4188807	0,00E+00	907	630949	4189807	0,00E+00
862	636449	4188807	0,00E+00	908	631449	4189807	0,00E+00
863	636949	4188807	0,00E+00	909	631949	4189807	3,46E-05
864	637449	4188807	0,00E+00	910	632449	4189807	0,00E+00
865	637949	4188807	0,00E+00	911	632949	4189807	1,38E-03
866	638449	4188807	0,00E+00	912	633449	4189807	9,58E-05
867	638949	4188807	0,00E+00	913	633949	4189807	0,00E+00
868	639449	4188807	0,00E+00	914	634449	4189807	0,00E+00
869	625949	4189307	0,00E+00	915	634949	4189807	0,00E+00
870	626449	4189307	0,00E+00	916	635449	4189807	0,00E+00
871	626949	4189307	0,00E+00	917	635949	4189807	0,00E+00
872	627449	4189307	0,00E+00	918	636449	4189807	0,00E+00
873	627949	4189307	0,00E+00	919	636949	4189807	0,00E+00

920	637449	4189807	0,00E+00
921	637949	4189807	0,00E+00
922	638449	4189807	0,00E+00
923	638949	4189807	0,00E+00
924	639449	4189807	0,00E+00
925	625949	4190307	0,00E+00
926	626449	4190307	0,00E+00
927	626949	4190307	0,00E+00
928	627449	4190307	0,00E+00
929	627949	4190307	0,00E+00
930	628449	4190307	0,00E+00
931	628949	4190307	0,00E+00
932	629449	4190307	0,00E+00
933	629949	4190307	0,00E+00
934	630449	4190307	0,00E+00
935	630949	4190307	0,00E+00
936	631449	4190307	0,00E+00

937	631949	4190307	0,00E+00
938	632449	4190307	0,00E+00
939	632949	4190307	0,00E+00
940	633449	4190307	0,00E+00
941	633949	4190307	0,00E+00
942	634449	4190307	0,00E+00
943	634949	4190307	0,00E+00
944	635449	4190307	0,00E+00
945	635949	4190307	0,00E+00
946	636449	4190307	0,00E+00
947	636949	4190307	0,00E+00
948	637449	4190307	0,00E+00
949	637949	4190307	0,00E+00
950	638449	4190307	0,00E+00
951	638949	4190307	0,00E+00
952	639449	4190307	0,00E+00

Furnas BT vent opening			
ID	Longitude	Latitude	Probability
1	641549	4175707	0,00E+00
2	642049	4175707	0,00E+00
3	642549	4175707	0,00E+00
4	643049	4175707	0,00E+00
5	643549	4175707	0,00E+00
6	644049	4175707	0,00E+00
7	644549	4175707	0,00E+00
8	645049	4175707	0,00E+00
9	645549	4175707	0,00E+00
10	646049	4175707	0,00E+00
11	646549	4175707	0,00E+00
12	647049	4175707	0,00E+00
13	647549	4175707	0,00E+00
14	648049	4175707	0,00E+00
15	648549	4175707	0,00E+00
16	649049	4175707	0,00E+00
17	649549	4175707	0,00E+00
18	650049	4175707	0,00E+00
19	650549	4175707	0,00E+00
20	651049	4175707	0,00E+00
21	651549	4175707	0,00E+00
22	652049	4175707	0,00E+00
23	641549	4176207	0,00E+00
24	642049	4176207	0,00E+00
25	642549	4176207	0,00E+00
26	643049	4176207	0,00E+00
27	643549	4176207	0,00E+00
28	644049	4176207	0,00E+00
29	644549	4176207	8,21E-05
30	645049	4176207	6,19E-05
31	645549	4176207	0,00E+00
32	646049	4176207	0,00E+00
33	646549	4176207	0,00E+00
34	647049	4176207	0,00E+00
35	647549	4176207	0,00E+00
36	648049	4176207	0,00E+00
37	648549	4176207	0,00E+00
38	649049	4176207	0,00E+00
39	649549	4176207	0,00E+00
40	650049	4176207	0,00E+00
41	650549	4176207	0,00E+00
42	651049	4176207	0,00E+00
43	651549	4176207	0,00E+00
44	652049	4176207	0,00E+00
45	641549	4176707	0,00E+00

46	642049	4176707	0,00E+00
47	642549	4176707	0,00E+00
48	643049	4176707	0,00E+00
49	643549	4176707	0,00E+00
50	644049	4176707	1,73E-04
51	644549	4176707	9,41E-04
52	645049	4176707	8,32E-04
53	645549	4176707	4,55E-04
54	646049	4176707	1,92E-04
55	646549	4176707	1,05E-04
56	647049	4176707	8,91E-05
57	647549	4176707	1,66E-04
58	648049	4176707	2,52E-04
59	648549	4176707	1,10E-05
60	649049	4176707	0,00E+00
61	649549	4176707	0,00E+00
62	650049	4176707	0,00E+00
63	650549	4176707	0,00E+00
64	651049	4176707	0,00E+00
65	651549	4176707	0,00E+00
66	652049	4176707	0,00E+00
67	641549	4177207	0,00E+00
68	642049	4177207	0,00E+00
69	642549	4177207	0,00E+00
70	643049	4177207	0,00E+00
71	643549	4177207	1,21E-04
72	644049	4177207	1,98E-03
73	644549	4177207	2,56E-03
74	645049	4177207	2,18E-03
75	645549	4177207	1,37E-03
76	646049	4177207	6,86E-04
77	646549	4177207	4,43E-04
78	647049	4177207	6,03E-04
79	647549	4177207	9,11E-04
80	648049	4177207	1,04E-03
81	648549	4177207	6,50E-04
82	649049	4177207	2,42E-04
83	649549	4177207	1,89E-05
84	650049	4177207	0,00E+00
85	650549	4177207	0,00E+00
86	651049	4177207	0,00E+00
87	651549	4177207	0,00E+00
88	652049	4177207	0,00E+00
89	641549	4177707	0,00E+00
90	642049	4177707	0,00E+00
91	642549	4177707	0,00E+00

92	643049	4177707	0,00E+00	138	644049	4178707	7,60E-03
93	643549	4177707	1,66E-03	139	644549	4178707	6,92E-03
94	644049	4177707	4,40E-03	140	645049	4178707	4,84E-03
95	644549	4177707	4,76E-03	141	645549	4178707	2,83E-03
96	645049	4177707	3,88E-03	142	646049	4178707	1,99E-03
97	645549	4177707	2,40E-03	143	646549	4178707	2,52E-03
98	646049	4177707	1,28E-03	144	647049	4178707	3,66E-03
99	646549	4177707	1,02E-03	145	647549	4178707	4,38E-03
100	647049	4177707	1,46E-03	146	648049	4178707	4,00E-03
101	647549	4177707	2,02E-03	147	648549	4178707	2,71E-03
102	648049	4177707	2,13E-03	148	649049	4178707	1,33E-03
103	648549	4177707	1,60E-03	149	649549	4178707	4,81E-04
104	649049	4177707	8,26E-04	150	650049	4178707	1,41E-04
105	649549	4177707	2,41E-04	151	650549	4178707	4,03E-05
106	650049	4177707	3,53E-05	152	651049	4178707	1,18E-05
107	650549	4177707	3,28E-06	153	651549	4178707	1,67E-06
108	651049	4177707	0,00E+00	154	652049	4178707	0,00E+00
109	651549	4177707	0,00E+00	155	641549	4179207	0,00E+00
110	652049	4177707	0,00E+00	156	642049	4179207	0,00E+00
111	641549	4178207	0,00E+00	157	642549	4179207	0,00E+00
112	642049	4178207	0,00E+00	158	643049	4179207	1,02E-03
113	642549	4178207	0,00E+00	159	643549	4179207	6,48E-03
114	643049	4178207	0,00E+00	160	644049	4179207	7,56E-03
115	643549	4178207	4,24E-03	161	644549	4179207	6,47E-03
116	644049	4178207	6,49E-03	162	645049	4179207	4,23E-03
117	644549	4178207	6,48E-03	163	645549	4179207	2,46E-03
118	645049	4178207	4,95E-03	164	646049	4179207	2,08E-03
119	645549	4178207	2,98E-03	165	646549	4179207	2,93E-03
120	646049	4178207	1,78E-03	166	647049	4179207	4,17E-03
121	646549	4178207	1,81E-03	167	647549	4179207	4,86E-03
122	647049	4178207	2,63E-03	168	648049	4179207	4,47E-03
123	647549	4178207	3,35E-03	169	648549	4179207	3,16E-03
124	648049	4178207	3,24E-03	170	649049	4179207	1,71E-03
125	648549	4178207	2,28E-03	171	649549	4179207	7,71E-04
126	649049	4178207	1,13E-03	172	650049	4179207	3,40E-04
127	649549	4178207	3,87E-04	173	650549	4179207	1,49E-04
128	650049	4178207	9,24E-05	174	651049	4179207	5,79E-05
129	650549	4178207	1,64E-05	175	651549	4179207	7,17E-06
130	651049	4178207	1,60E-06	176	652049	4179207	0,00E+00
131	651549	4178207	1,68E-08	177	641549	4179707	0,00E+00
132	652049	4178207	0,00E+00	178	642049	4179707	0,00E+00
133	641549	4178707	0,00E+00	179	642549	4179707	0,00E+00
134	642049	4178707	0,00E+00	180	643049	4179707	7,01E-04
135	642549	4178707	0,00E+00	181	643549	4179707	5,67E-03
136	643049	4178707	6,02E-04	182	644049	4179707	6,77E-03
137	643549	4178707	6,27E-03	183	644549	4179707	5,91E-03

184	645049	4179707	3,98E-03	230	646049	4180707	4,93E-03
185	645549	4179707	2,56E-03	231	646549	4180707	5,32E-03
186	646049	4179707	2,40E-03	232	647049	4180707	5,39E-03
187	646549	4179707	3,25E-03	233	647549	4180707	5,30E-03
188	647049	4179707	4,35E-03	234	648049	4180707	5,15E-03
189	647549	4179707	5,06E-03	235	648549	4180707	4,72E-03
190	648049	4179707	4,93E-03	236	649049	4180707	4,12E-03
191	648549	4179707	3,87E-03	237	649549	4180707	3,55E-03
192	649049	4179707	2,50E-03	238	650049	4180707	2,80E-03
193	649549	4179707	1,49E-03	239	650549	4180707	1,85E-03
194	650049	4179707	8,93E-04	240	651049	4180707	1,18E-03
195	650549	4179707	4,77E-04	241	651549	4180707	4,78E-04
196	651049	4179707	2,18E-04	242	652049	4180707	0,00E+00
197	651549	4179707	4,21E-05	243	641549	4181207	0,00E+00
198	652049	4179707	0,00E+00	244	642049	4181207	0,00E+00
199	641549	4180207	0,00E+00	245	642549	4181207	0,00E+00
200	642049	4180207	0,00E+00	246	643049	4181207	0,00E+00
201	642549	4180207	0,00E+00	247	643549	4181207	1,06E-03
202	643049	4180207	1,47E-04	248	644049	4181207	3,60E-03
203	643549	4180207	4,31E-03	249	644549	4181207	4,30E-03
204	644049	4180207	5,71E-03	250	645049	4181207	5,00E-03
205	644549	4180207	5,48E-03	251	645549	4181207	6,31E-03
206	645049	4180207	4,26E-03	252	646049	4181207	7,63E-03
207	645549	4180207	3,30E-03	253	646549	4181207	7,81E-03
208	646049	4180207	3,25E-03	254	647049	4181207	6,69E-03
209	646549	4180207	3,88E-03	255	647549	4181207	5,30E-03
210	647049	4180207	4,65E-03	256	648049	4181207	4,49E-03
211	647549	4180207	5,22E-03	257	648549	4181207	4,15E-03
212	648049	4180207	5,28E-03	258	649049	4181207	3,93E-03
213	648549	4180207	4,58E-03	259	649549	4181207	3,64E-03
214	649049	4180207	3,49E-03	260	650049	4181207	3,02E-03
215	649549	4180207	2,61E-03	261	650549	4181207	2,18E-03
216	650049	4180207	1,85E-03	262	651049	4181207	1,66E-03
217	650549	4180207	1,11E-03	263	651549	4181207	9,60E-04
218	651049	4180207	5,95E-04	264	652049	4181207	0,00E+00
219	651549	4180207	1,85E-04	265	641549	4181707	0,00E+00
220	652049	4180207	0,00E+00	266	642049	4181707	0,00E+00
221	641549	4180707	0,00E+00	267	642549	4181707	0,00E+00
222	642049	4180707	0,00E+00	268	643049	4181707	0,00E+00
223	642549	4180707	0,00E+00	269	643549	4181707	7,48E-05
224	643049	4180707	0,00E+00	270	644049	4181707	2,65E-03
225	643549	4180707	2,60E-03	271	644549	4181707	3,62E-03
226	644049	4180707	4,60E-03	272	645049	4181707	5,24E-03
227	644549	4180707	4,97E-03	273	645549	4181707	7,97E-03
228	645049	4180707	4,65E-03	274	646049	4181707	1,03E-02
229	645549	4180707	4,56E-03	275	646549	4181707	1,02E-02

276	647049	4181707	7,82E-03	322	648049	4182707	2,04E-03
277	647549	4181707	5,08E-03	323	648549	4182707	1,21E-03
278	648049	4181707	3,56E-03	324	649049	4182707	8,59E-04
279	648549	4181707	3,13E-03	325	649549	4182707	6,34E-04
280	649049	4181707	2,99E-03	326	650049	4182707	4,78E-04
281	649549	4181707	2,76E-03	327	650549	4182707	4,29E-04
282	650049	4181707	2,31E-03	328	651049	4182707	5,04E-04
283	650549	4181707	1,82E-03	329	651549	4182707	3,46E-04
284	651049	4181707	1,64E-03	330	652049	4182707	0,00E+00
285	651549	4181707	1,18E-03	331	641549	4183207	0,00E+00
286	652049	4181707	0,00E+00	332	642049	4183207	0,00E+00
287	641549	4182207	0,00E+00	333	642549	4183207	0,00E+00
288	642049	4182207	0,00E+00	334	643049	4183207	0,00E+00
289	642549	4182207	0,00E+00	335	643549	4183207	0,00E+00
290	643049	4182207	0,00E+00	336	644049	4183207	0,00E+00
291	643549	4182207	0,00E+00	337	644549	4183207	2,53E-03
292	644049	4182207	1,06E-03	338	645049	4183207	6,05E-03
293	644549	4182207	2,99E-03	339	645549	4183207	7,86E-03
294	645049	4182207	5,11E-03	340	646049	4183207	8,47E-03
295	645549	4182207	8,40E-03	341	646549	4183207	7,80E-03
296	646049	4182207	1,10E-02	342	647049	4183207	6,21E-03
297	646549	4182207	1,06E-02	343	647549	4183207	4,20E-03
298	647049	4182207	7,70E-03	344	648049	4183207	2,40E-03
299	647549	4182207	4,47E-03	345	648549	4183207	1,21E-03
300	648049	4182207	2,61E-03	346	649049	4183207	5,81E-04
301	648549	4182207	1,99E-03	347	649549	4183207	2,78E-04
302	649049	4182207	1,77E-03	348	650049	4183207	1,49E-04
303	649549	4182207	1,53E-03	349	650549	4183207	1,22E-04
304	650049	4182207	1,25E-03	350	651049	4183207	1,54E-04
305	650549	4182207	1,06E-03	351	651549	4183207	7,64E-05
306	651049	4182207	1,11E-03	352	652049	4183207	0,00E+00
307	651549	4182207	6,12E-04	353	641549	4183707	0,00E+00
308	652049	4182207	0,00E+00	354	642049	4183707	0,00E+00
309	641549	4182707	0,00E+00	355	642549	4183707	0,00E+00
310	642049	4182707	0,00E+00	356	643049	4183707	0,00E+00
311	642549	4182707	0,00E+00	357	643549	4183707	0,00E+00
312	643049	4182707	0,00E+00	358	644049	4183707	0,00E+00
313	643549	4182707	0,00E+00	359	644549	4183707	3,18E-03
314	644049	4182707	0,00E+00	360	645049	4183707	7,47E-03
315	644549	4182707	2,23E-03	361	645549	4183707	8,52E-03
316	645049	4182707	5,06E-03	362	646049	4183707	8,21E-03
317	645549	4182707	7,81E-03	363	646549	4183707	7,50E-03
318	646049	4182707	9,60E-03	364	647049	4183707	6,72E-03
319	646549	4182707	9,10E-03	365	647549	4183707	5,47E-03
320	647049	4182707	6,66E-03	366	648049	4183707	3,73E-03
321	647549	4182707	3,89E-03	367	648549	4183707	2,08E-03

368	649049	4183707	9,41E-04	414	650049	4184707	1,26E-04
369	649549	4183707	3,38E-04	415	650549	4184707	0,00E+00
370	650049	4183707	9,90E-05	416	651049	4184707	0,00E+00
371	650549	4183707	3,43E-05	417	651549	4184707	0,00E+00
372	651049	4183707	2,51E-05	418	652049	4184707	0,00E+00
373	651549	4183707	1,41E-05	419	641549	4185207	0,00E+00
374	652049	4183707	0,00E+00	420	642049	4185207	0,00E+00
375	641549	4184207	0,00E+00	421	642549	4185207	0,00E+00
376	642049	4184207	0,00E+00	422	643049	4185207	0,00E+00
377	642549	4184207	0,00E+00	423	643549	4185207	0,00E+00
378	643049	4184207	0,00E+00	424	644049	4185207	0,00E+00
379	643549	4184207	0,00E+00	425	644549	4185207	0,00E+00
380	644049	4184207	0,00E+00	426	645049	4185207	1,99E-03
381	644549	4184207	3,08E-03	427	645549	4185207	2,43E-03
382	645049	4184207	7,28E-03	428	646049	4185207	2,36E-03
383	645549	4184207	7,82E-03	429	646549	4185207	2,76E-03
384	646049	4184207	7,24E-03	430	647049	4185207	3,75E-03
385	646549	4184207	6,85E-03	431	647549	4185207	4,66E-03
386	647049	4184207	6,96E-03	432	648049	4185207	4,57E-03
387	647549	4184207	6,64E-03	433	648549	4185207	3,32E-03
388	648049	4184207	5,30E-03	434	649049	4185207	1,75E-03
389	648549	4184207	3,36E-03	435	649549	4185207	6,53E-04
390	649049	4184207	1,63E-03	436	650049	4185207	6,58E-05
391	649549	4184207	5,91E-04	437	650549	4185207	0,00E+00
392	650049	4184207	1,45E-04	438	651049	4185207	0,00E+00
393	650549	4184207	3,26E-06	439	651549	4185207	0,00E+00
394	651049	4184207	0,00E+00	440	652049	4185207	0,00E+00
395	651549	4184207	0,00E+00	441	641549	4185707	0,00E+00
396	652049	4184207	0,00E+00	442	642049	4185707	0,00E+00
397	641549	4184707	0,00E+00	443	642549	4185707	0,00E+00
398	642049	4184707	0,00E+00	444	643049	4185707	0,00E+00
399	642549	4184707	0,00E+00	445	643549	4185707	0,00E+00
400	643049	4184707	0,00E+00	446	644049	4185707	0,00E+00
401	643549	4184707	0,00E+00	447	644549	4185707	2,86E-05
402	644049	4184707	0,00E+00	448	645049	4185707	7,40E-04
403	644549	4184707	3,03E-04	449	645549	4185707	7,92E-04
404	645049	4184707	4,95E-03	450	646049	4185707	8,15E-04
405	645549	4184707	5,23E-03	451	646549	4185707	1,12E-03
406	646049	4184707	4,88E-03	452	647049	4185707	1,77E-03
407	646549	4184707	5,02E-03	453	647549	4185707	2,43E-03
408	647049	4184707	5,86E-03	454	648049	4185707	2,52E-03
409	647549	4184707	6,44E-03	455	648549	4185707	1,88E-03
410	648049	4184707	5,79E-03	456	649049	4185707	9,99E-04
411	648549	4184707	4,00E-03	457	649549	4185707	3,41E-04
412	649049	4184707	2,05E-03	458	650049	4185707	1,07E-05
413	649549	4184707	7,59E-04	459	650549	4185707	0,00E+00

460	651049	4185707	0,00E+00	506	652049	4186707	0,00E+00
461	651549	4185707	0,00E+00	507	641549	4187207	0,00E+00
462	652049	4185707	0,00E+00	508	642049	4187207	0,00E+00
463	641549	4186207	0,00E+00	509	642549	4187207	1,69E-03
464	642049	4186207	0,00E+00	510	643049	4187207	4,20E-03
465	642549	4186207	0,00E+00	511	643549	4187207	3,69E-03
466	643049	4186207	2,59E-04	512	644049	4187207	2,73E-03
467	643549	4186207	7,86E-04	513	644549	4187207	1,82E-03
468	644049	4186207	8,72E-04	514	645049	4187207	1,04E-03
469	644549	4186207	7,00E-04	515	645549	4187207	4,98E-04
470	645049	4186207	4,40E-04	516	646049	4187207	3,59E-04
471	645549	4186207	2,74E-04	517	646549	4187207	5,44E-04
472	646049	4186207	2,42E-04	518	647049	4187207	7,67E-04
473	646549	4186207	3,75E-04	519	647549	4187207	7,47E-04
474	647049	4186207	6,60E-04	520	648049	4187207	4,87E-04
475	647549	4186207	9,42E-04	521	648549	4187207	2,14E-04
476	648049	4186207	9,85E-04	522	649049	4187207	6,52E-05
477	648549	4186207	7,33E-04	523	649549	4187207	2,97E-06
478	649049	4186207	3,84E-04	524	650049	4187207	0,00E+00
479	649549	4186207	9,83E-05	525	650549	4187207	0,00E+00
480	650049	4186207	0,00E+00	526	651049	4187207	0,00E+00
481	650549	4186207	0,00E+00	527	651549	4187207	0,00E+00
482	651049	4186207	0,00E+00	528	652049	4187207	0,00E+00
483	651549	4186207	0,00E+00	529	641549	4187707	0,00E+00
484	652049	4186207	0,00E+00	530	642049	4187707	2,20E-05
485	641549	4186707	0,00E+00	531	642549	4187707	2,70E-03
486	642049	4186707	0,00E+00	532	643049	4187707	3,60E-03
487	642549	4186707	3,25E-04	533	643549	4187707	3,16E-03
488	643049	4186707	3,36E-03	534	644049	4187707	2,48E-03
489	643549	4186707	3,05E-03	535	644549	4187707	1,81E-03
490	644049	4186707	2,13E-03	536	645049	4187707	1,11E-03
491	644549	4186707	1,29E-03	537	645549	4187707	6,33E-04
492	645049	4186707	6,81E-04	538	646049	4187707	6,26E-04
493	645549	4186707	3,07E-04	539	646549	4187707	1,01E-03
494	646049	4186707	1,87E-04	540	647049	4187707	1,36E-03
495	646549	4186707	2,66E-04	541	647549	4187707	1,27E-03
496	647049	4186707	4,14E-04	542	648049	4187707	7,94E-04
497	647549	4186707	4,81E-04	543	648549	4187707	3,27E-04
498	648049	4186707	4,05E-04	544	649049	4187707	8,86E-05
499	648549	4186707	2,50E-04	545	649549	4187707	5,42E-06
500	649049	4186707	1,14E-04	546	650049	4187707	0,00E+00
501	649549	4186707	2,39E-05	547	650549	4187707	0,00E+00
502	650049	4186707	0,00E+00	548	651049	4187707	0,00E+00
503	650549	4186707	0,00E+00	549	651549	4187707	0,00E+00
504	651049	4186707	0,00E+00	550	652049	4187707	0,00E+00
505	651549	4186707	0,00E+00	551	641549	4188207	0,00E+00

552	642049	4188207	4,70E-04	598	643049	4189207	4,82E-05
553	642549	4188207	1,94E-03	599	643549	4189207	1,54E-04
554	643049	4188207	2,14E-03	600	644049	4189207	1,85E-04
555	643549	4188207	1,89E-03	601	644549	4189207	2,38E-04
556	644049	4188207	1,56E-03	602	645049	4189207	4,18E-04
557	644549	4188207	1,23E-03	603	645549	4189207	8,80E-04
558	645049	4188207	8,60E-04	604	646049	4189207	1,49E-03
559	645549	4188207	6,93E-04	605	646549	4189207	1,81E-03
560	646049	4188207	9,38E-04	606	647049	4189207	1,60E-03
561	646549	4188207	1,44E-03	607	647549	4189207	1,14E-03
562	647049	4188207	1,77E-03	608	648049	4189207	7,34E-04
563	647549	4188207	1,55E-03	609	648549	4189207	4,55E-04
564	648049	4188207	9,38E-04	610	649049	4189207	2,47E-04
565	648549	4188207	3,84E-04	611	649549	4189207	3,90E-05
566	649049	4188207	1,07E-04	612	650049	4189207	0,00E+00
567	649549	4188207	1,66E-05	613	650549	4189207	0,00E+00
568	650049	4188207	0,00E+00	614	651049	4189207	0,00E+00
569	650549	4188207	0,00E+00	615	651549	4189207	0,00E+00
570	651049	4188207	0,00E+00	616	652049	4189207	0,00E+00
571	651549	4188207	0,00E+00	617	641549	4189707	0,00E+00
572	652049	4188207	0,00E+00	618	642049	4189707	0,00E+00
573	641549	4188707	0,00E+00	619	642549	4189707	0,00E+00
574	642049	4188707	9,74E-05	620	643049	4189707	0,00E+00
575	642549	4188707	5,68E-04	621	643549	4189707	0,00E+00
576	643049	4188707	8,71E-04	622	644049	4189707	0,00E+00
577	643549	4188707	7,79E-04	623	644549	4189707	6,70E-05
578	644049	4188707	6,78E-04	624	645049	4189707	3,09E-04
579	644549	4188707	5,95E-04	625	645549	4189707	7,58E-04
580	645049	4188707	5,71E-04	626	646049	4189707	1,29E-03
581	645549	4188707	7,93E-04	627	646549	4189707	1,49E-03
582	646049	4188707	1,29E-03	628	647049	4189707	1,28E-03
583	646549	4188707	1,74E-03	629	647549	4189707	1,03E-03
584	647049	4188707	1,80E-03	630	648049	4189707	9,50E-04
585	647549	4188707	1,41E-03	631	648549	4189707	8,41E-04
586	648049	4188707	8,22E-04	632	649049	4189707	4,29E-04
587	648549	4188707	3,63E-04	633	649549	4189707	0,00E+00
588	649049	4188707	1,27E-04	634	650049	4189707	0,00E+00
589	649549	4188707	2,51E-05	635	650549	4189707	0,00E+00
590	650049	4188707	0,00E+00	636	651049	4189707	0,00E+00
591	650549	4188707	0,00E+00	637	651549	4189707	0,00E+00
592	651049	4188707	0,00E+00	638	652049	4189707	0,00E+00
593	651549	4188707	0,00E+00	639	641549	4190207	0,00E+00
594	652049	4188707	0,00E+00	640	642049	4190207	0,00E+00
595	641549	4189207	0,00E+00	641	642549	4190207	0,00E+00
596	642049	4189207	0,00E+00	642	643049	4190207	0,00E+00
597	642549	4189207	0,00E+00	643	643549	4190207	0,00E+00

644	644049	4190207	0,00E+00	690	645049	4191207	0,00E+00
645	644549	4190207	0,00E+00	691	645549	4191207	0,00E+00
646	645049	4190207	3,23E-05	692	646049	4191207	0,00E+00
647	645549	4190207	1,87E-04	693	646549	4191207	0,00E+00
648	646049	4190207	6,57E-04	694	647049	4191207	5,86E-05
649	646549	4190207	9,05E-04	695	647549	4191207	6,09E-04
650	647049	4190207	8,97E-04	696	648049	4191207	9,75E-04
651	647549	4190207	1,03E-03	697	648549	4191207	1,04E-03
652	648049	4190207	1,32E-03	698	649049	4191207	1,02E-04
653	648549	4190207	1,34E-03	699	649549	4191207	0,00E+00
654	649049	4190207	7,22E-04	700	650049	4191207	0,00E+00
655	649549	4190207	0,00E+00	701	650549	4191207	0,00E+00
656	650049	4190207	0,00E+00	702	651049	4191207	0,00E+00
657	650549	4190207	0,00E+00	703	651549	4191207	0,00E+00
658	651049	4190207	0,00E+00	704	652049	4191207	0,00E+00
659	651549	4190207	0,00E+00	705	641549	4191707	0,00E+00
660	652049	4190207	0,00E+00	706	642049	4191707	0,00E+00
661	641549	4190707	0,00E+00	707	642549	4191707	0,00E+00
662	642049	4190707	0,00E+00	708	643049	4191707	0,00E+00
663	642549	4190707	0,00E+00	709	643549	4191707	0,00E+00
664	643049	4190707	0,00E+00	710	644049	4191707	0,00E+00
665	643549	4190707	0,00E+00	711	644549	4191707	0,00E+00
666	644049	4190707	0,00E+00	712	645049	4191707	0,00E+00
667	644549	4190707	0,00E+00	713	645549	4191707	0,00E+00
668	645049	4190707	0,00E+00	714	646049	4191707	0,00E+00
669	645549	4190707	0,00E+00	715	646549	4191707	0,00E+00
670	646049	4190707	0,00E+00	716	647049	4191707	0,00E+00
671	646549	4190707	2,44E-04	717	647549	4191707	2,40E-04
672	647049	4190707	5,22E-04	718	648049	4191707	4,44E-04
673	647549	4190707	9,22E-04	719	648549	4191707	2,06E-04
674	648049	4190707	1,38E-03	720	649049	4191707	0,00E+00
675	648549	4190707	1,45E-03	721	649549	4191707	0,00E+00
676	649049	4190707	5,81E-04	722	650049	4191707	0,00E+00
677	649549	4190707	0,00E+00	723	650549	4191707	0,00E+00
678	650049	4190707	0,00E+00	724	651049	4191707	0,00E+00
679	650549	4190707	0,00E+00	725	651549	4191707	0,00E+00
680	651049	4190707	0,00E+00	726	652049	4191707	0,00E+00
681	651549	4190707	0,00E+00	727	641549	4192207	0,00E+00
682	652049	4190707	0,00E+00	728	642049	4192207	0,00E+00
683	641549	4191207	0,00E+00	729	642549	4192207	0,00E+00
684	642049	4191207	0,00E+00	730	643049	4192207	0,00E+00
685	642549	4191207	0,00E+00	731	643549	4192207	0,00E+00
686	643049	4191207	0,00E+00	732	644049	4192207	0,00E+00
687	643549	4191207	0,00E+00	733	644549	4192207	0,00E+00
688	644049	4191207	0,00E+00	734	645049	4192207	0,00E+00
689	644549	4191207	0,00E+00	735	645549	4192207	0,00E+00

736	646049	4192207	0,00E+00
737	646549	4192207	0,00E+00
738	647049	4192207	0,00E+00
739	647549	4192207	5,42E-06
740	648049	4192207	8,98E-05
741	648549	4192207	0,00E+00
742	649049	4192207	0,00E+00
743	649549	4192207	0,00E+00
744	650049	4192207	0,00E+00
745	650549	4192207	0,00E+00
746	651049	4192207	0,00E+00
747	651549	4192207	0,00E+00
748	652049	4192207	0,00E+00
749	641549	4192707	0,00E+00
750	642049	4192707	0,00E+00
751	642549	4192707	0,00E+00
752	643049	4192707	0,00E+00
753	643549	4192707	0,00E+00

754	644049	4192707	0,00E+00
755	644549	4192707	0,00E+00
756	645049	4192707	0,00E+00
757	645549	4192707	0,00E+00
758	646049	4192707	0,00E+00
759	646549	4192707	0,00E+00
760	647049	4192707	0,00E+00
761	647549	4192707	0,00E+00
762	648049	4192707	0,00E+00
763	648549	4192707	0,00E+00
764	649049	4192707	0,00E+00
765	649549	4192707	0,00E+00
766	650049	4192707	0,00E+00
767	650549	4192707	0,00E+00
768	651049	4192707	0,00E+00
769	651549	4192707	0,00E+00
770	652049	4192707	0,00E+00

Furnas T vent opening			
ID	Longitude	Latitude	Probability
1	641549	4175707	0,00E+00
2	642049	4175707	0,00E+00
3	642549	4175707	0,00E+00
4	643049	4175707	0,00E+00
5	643549	4175707	0,00E+00
6	644049	4175707	0,00E+00
7	644549	4175707	0,00E+00
8	645049	4175707	0,00E+00
9	645549	4175707	0,00E+00
10	646049	4175707	0,00E+00
11	646549	4175707	0,00E+00
12	647049	4175707	0,00E+00
13	647549	4175707	0,00E+00
14	648049	4175707	0,00E+00
15	648549	4175707	0,00E+00
16	649049	4175707	0,00E+00
17	649549	4175707	0,00E+00
18	650049	4175707	0,00E+00
19	650549	4175707	0,00E+00
20	651049	4175707	0,00E+00
21	651549	4175707	0,00E+00
22	652049	4175707	0,00E+00
23	641549	4176207	0,00E+00
24	642049	4176207	0,00E+00
25	642549	4176207	0,00E+00
26	643049	4176207	0,00E+00
27	643549	4176207	0,00E+00
28	644049	4176207	0,00E+00
29	644549	4176207	1,73E-07
30	645049	4176207	3,41E-07
31	645549	4176207	0,00E+00
32	646049	4176207	0,00E+00
33	646549	4176207	0,00E+00
34	647049	4176207	0,00E+00
35	647549	4176207	0,00E+00
36	648049	4176207	0,00E+00
37	648549	4176207	0,00E+00
38	649049	4176207	0,00E+00
39	649549	4176207	0,00E+00
40	650049	4176207	0,00E+00
41	650549	4176207	0,00E+00
42	651049	4176207	0,00E+00
43	651549	4176207	0,00E+00
44	652049	4176207	0,00E+00
45	641549	4176707	0,00E+00

46	642049	4176707	0,00E+00
47	642549	4176707	0,00E+00
48	643049	4176707	0,00E+00
49	643549	4176707	0,00E+00
50	644049	4176707	9,15E-08
51	644549	4176707	1,79E-06
52	645049	4176707	9,38E-06
53	645549	4176707	3,32E-05
54	646049	4176707	8,48E-05
55	646549	4176707	2,19E-04
56	647049	4176707	2,72E-04
57	647549	4176707	4,70E-04
58	648049	4176707	6,78E-04
59	648549	4176707	2,81E-05
60	649049	4176707	0,00E+00
61	649549	4176707	0,00E+00
62	650049	4176707	0,00E+00
63	650549	4176707	0,00E+00
64	651049	4176707	0,00E+00
65	651549	4176707	0,00E+00
66	652049	4176707	0,00E+00
67	641549	4177207	0,00E+00
68	642049	4177207	0,00E+00
69	642549	4177207	0,00E+00
70	643049	4177207	0,00E+00
71	643549	4177207	1,71E-08
72	644049	4177207	9,49E-07
73	644549	4177207	6,76E-06
74	645049	4177207	3,41E-05
75	645549	4177207	1,30E-04
76	646049	4177207	3,84E-04
77	646549	4177207	8,85E-04
78	647049	4177207	1,60E-03
79	647549	4177207	2,25E-03
80	648049	4177207	2,41E-03
81	648549	4177207	1,51E-03
82	649049	4177207	6,22E-04
83	649549	4177207	5,39E-05
84	650049	4177207	0,00E+00
85	650549	4177207	0,00E+00
86	651049	4177207	0,00E+00
87	651549	4177207	0,00E+00
88	652049	4177207	0,00E+00
89	641549	4177707	0,00E+00
90	642049	4177707	0,00E+00
91	642549	4177707	0,00E+00

92	643049	4177707	0,00E+00	138	644049	4178707	1,18E-05
93	643549	4177707	2,39E-07	139	644549	4178707	7,13E-05
94	644049	4177707	2,88E-06	140	645049	4178707	3,18E-04
95	644549	4177707	1,90E-05	141	645549	4178707	1,05E-03
96	645049	4177707	9,23E-05	142	646049	4178707	2,63E-03
97	645549	4177707	3,36E-04	143	646549	4178707	5,04E-03
98	646049	4177707	9,31E-04	144	647049	4178707	7,55E-03
99	646549	4177707	2,00E-03	145	647549	4178707	8,93E-03
100	647049	4177707	3,35E-03	146	648049	4178707	8,36E-03
101	647549	4177707	4,41E-03	147	648549	4178707	6,14E-03
102	648049	4177707	4,48E-03	148	649049	4178707	3,51E-03
103	648549	4177707	3,47E-03	149	649549	4178707	1,60E-03
104	649049	4177707	2,01E-03	150	650049	4178707	6,15E-04
105	649549	4177707	7,08E-04	151	650549	4178707	2,22E-04
106	650049	4177707	1,40E-04	152	651049	4178707	7,99E-05
107	650549	4177707	1,94E-05	153	651549	4178707	1,37E-05
108	651049	4177707	0,00E+00	154	652049	4178707	0,00E+00
109	651549	4177707	0,00E+00	155	641549	4179207	0,00E+00
110	652049	4177707	0,00E+00	156	642049	4179207	0,00E+00
111	641549	4178207	0,00E+00	157	642549	4179207	0,00E+00
112	642049	4178207	0,00E+00	158	643049	4179207	1,33E-07
113	642549	4178207	0,00E+00	159	643549	4179207	2,92E-06
114	643049	4178207	0,00E+00	160	644049	4179207	2,07E-05
115	643549	4178207	6,98E-07	161	644549	4179207	1,12E-04
116	644049	4178207	6,42E-06	162	645049	4179207	4,62E-04
117	644549	4178207	4,09E-05	163	645549	4179207	1,43E-03
118	645049	4178207	1,91E-04	164	646049	4179207	3,36E-03
119	645549	4178207	6,66E-04	165	646549	4179207	6,10E-03
120	646049	4178207	1,75E-03	166	647049	4179207	8,78E-03
121	646549	4178207	3,54E-03	167	647549	4179207	1,02E-02
122	647049	4178207	5,57E-03	168	648049	4179207	9,60E-03
123	647549	4178207	6,89E-03	169	648549	4179207	7,29E-03
124	648049	4178207	6,65E-03	170	649049	4179207	4,52E-03
125	648549	4178207	4,94E-03	171	649549	4179207	2,41E-03
126	649049	4178207	2,80E-03	172	650049	4179207	1,20E-03
127	649549	4178207	1,20E-03	173	650549	4179207	5,85E-04
128	650049	4178207	3,92E-04	174	651049	4179207	2,71E-04
129	650549	4178207	1,04E-04	175	651549	4179207	3,97E-05
130	651049	4178207	1,46E-05	176	652049	4179207	0,00E+00
131	651549	4178207	1,83E-07	177	641549	4179707	0,00E+00
132	652049	4178207	0,00E+00	178	642049	4179707	0,00E+00
133	641549	4178707	0,00E+00	179	642549	4179707	0,00E+00
134	642049	4178707	0,00E+00	180	643049	4179707	3,45E-07
135	642549	4178707	0,00E+00	181	643549	4179707	7,77E-06
136	643049	4178707	3,94E-08	182	644049	4179707	4,41E-05
137	643549	4178707	1,44E-06	183	644549	4179707	1,97E-04

184	645049	4179707	6,93E-04	230	646049	4180707	8,53E-03
185	645549	4179707	1,90E-03	231	646549	4180707	1,09E-02
186	646049	4179707	4,06E-03	232	647049	4180707	1,19E-02
187	646549	4179707	6,87E-03	233	647549	4180707	1,19E-02
188	647049	4179707	9,47E-03	234	648049	4180707	1,13E-02
189	647549	4179707	1,09E-02	235	648549	4180707	1,02E-02
190	648049	4179707	1,06E-02	236	649049	4180707	8,91E-03
191	648549	4179707	8,67E-03	237	649549	4180707	7,48E-03
192	649049	4179707	6,10E-03	238	650049	4180707	5,85E-03
193	649549	4179707	3,94E-03	239	650549	4180707	4,14E-03
194	650049	4179707	2,45E-03	240	651049	4180707	2,86E-03
195	650549	4179707	1,42E-03	241	651549	4180707	1,13E-03
196	651049	4179707	7,68E-04	242	652049	4180707	0,00E+00
197	651549	4179707	1,62E-04	243	641549	4181207	0,00E+00
198	652049	4179707	0,00E+00	244	642049	4181207	0,00E+00
199	641549	4180207	0,00E+00	245	642549	4181207	0,00E+00
200	642049	4180207	0,00E+00	246	643049	4181207	0,00E+00
201	642549	4180207	0,00E+00	247	643549	4181207	7,15E-05
202	643049	4180207	2,09E-07	248	644049	4181207	6,07E-04
203	643549	4180207	2,37E-05	249	644549	4181207	2,02E-03
204	644049	4180207	1,18E-04	250	645049	4181207	5,01E-03
205	644549	4180207	4,40E-04	251	645549	4181207	9,37E-03
206	645049	4180207	1,28E-03	252	646049	4181207	1,34E-02
207	645549	4180207	2,96E-03	253	646549	4181207	1,52E-02
208	646049	4180207	5,43E-03	254	647049	4181207	1,42E-02
209	646549	4180207	8,14E-03	255	647549	4181207	1,20E-02
210	647049	4180207	1,03E-02	256	648049	4181207	1,03E-02
211	647549	4180207	1,14E-02	257	648549	4181207	9,24E-03
212	648049	4180207	1,13E-02	258	649049	4181207	8,45E-03
213	648549	4180207	9,91E-03	259	649549	4181207	7,52E-03
214	649049	4180207	7,88E-03	260	650049	4181207	6,20E-03
215	649549	4180207	5,95E-03	261	650549	4181207	4,73E-03
216	650049	4180207	4,26E-03	262	651049	4181207	3,67E-03
217	650549	4180207	2,77E-03	263	651549	4181207	2,00E-03
218	651049	4180207	1,69E-03	264	652049	4181207	0,00E+00
219	651549	4180207	5,49E-04	265	641549	4181707	0,00E+00
220	652049	4180207	0,00E+00	266	642049	4181707	0,00E+00
221	641549	4180707	0,00E+00	267	642549	4181707	0,00E+00
222	642049	4180707	0,00E+00	268	643049	4181707	0,00E+00
223	642549	4180707	0,00E+00	269	643549	4181707	1,03E-05
224	643049	4180707	0,00E+00	270	644049	4181707	8,84E-04
225	643549	4180707	5,68E-05	271	644549	4181707	2,96E-03
226	644049	4180707	3,01E-04	272	645049	4181707	7,19E-03
227	644549	4180707	1,03E-03	273	645549	4181707	1,30E-02
228	645049	4180707	2,69E-03	274	646049	4181707	1,78E-02
229	645549	4180707	5,40E-03	275	646549	4181707	1,86E-02

276	647049	4181707	1,56E-02	322	648049	4182707	3,45E-03
277	647549	4181707	1,14E-02	323	648549	4182707	2,43E-03
278	648049	4181707	8,46E-03	324	649049	4182707	2,03E-03
279	648549	4181707	7,17E-03	325	649549	4182707	1,72E-03
280	649049	4181707	6,59E-03	326	650049	4182707	1,43E-03
281	649549	4181707	5,95E-03	327	650549	4182707	1,29E-03
282	650049	4181707	5,03E-03	328	651049	4182707	1,33E-03
283	650549	4181707	4,09E-03	329	651549	4182707	8,17E-04
284	651049	4181707	3,53E-03	330	652049	4182707	0,00E+00
285	651549	4181707	2,32E-03	331	641549	4183207	0,00E+00
286	652049	4181707	0,00E+00	332	642049	4183207	0,00E+00
287	641549	4182207	0,00E+00	333	642549	4183207	0,00E+00
288	642049	4182207	0,00E+00	334	643049	4183207	0,00E+00
289	642549	4182207	0,00E+00	335	643549	4183207	0,00E+00
290	643049	4182207	0,00E+00	336	644049	4183207	0,00E+00
291	643549	4182207	0,00E+00	337	644549	4183207	9,54E-04
292	644049	4182207	5,76E-04	338	645049	4183207	3,15E-03
293	644549	4182207	3,16E-03	339	645549	4183207	5,50E-03
294	645049	4182207	7,58E-03	340	646049	4183207	7,10E-03
295	645549	4182207	1,35E-02	341	646549	4183207	6,83E-03
296	646049	4182207	1,79E-02	342	647049	4183207	4,97E-03
297	646549	4182207	1,80E-02	343	647549	4183207	2,88E-03
298	647049	4182207	1,40E-02	344	648049	4183207	1,54E-03
299	647549	4182207	9,17E-03	345	648549	4183207	9,83E-04
300	648049	4182207	5,99E-03	346	649049	4183207	7,65E-04
301	648549	4182207	4,66E-03	347	649549	4183207	6,14E-04
302	649049	4182207	4,13E-03	348	650049	4183207	4,97E-04
303	649549	4182207	3,66E-03	349	650549	4183207	4,63E-04
304	650049	4182207	3,09E-03	350	651049	4183207	5,12E-04
305	650549	4182207	2,66E-03	351	651549	4183207	2,33E-04
306	651049	4182207	2,53E-03	352	652049	4183207	0,00E+00
307	651549	4182207	1,28E-03	353	641549	4183707	0,00E+00
308	652049	4182207	0,00E+00	354	642049	4183707	0,00E+00
309	641549	4182707	0,00E+00	355	642549	4183707	0,00E+00
310	642049	4182707	0,00E+00	356	643049	4183707	0,00E+00
311	642549	4182707	0,00E+00	357	643549	4183707	0,00E+00
312	643049	4182707	0,00E+00	358	644049	4183707	0,00E+00
313	643549	4182707	0,00E+00	359	644549	4183707	3,59E-04
314	644049	4182707	0,00E+00	360	645049	4183707	1,23E-03
315	644549	4182707	2,00E-03	361	645549	4183707	2,14E-03
316	645049	4182707	5,76E-03	362	646049	4183707	2,74E-03
317	645549	4182707	1,01E-02	363	646549	4183707	2,61E-03
318	646049	4182707	1,32E-02	364	647049	4183707	1,86E-03
319	646549	4182707	1,30E-02	365	647549	4183707	1,04E-03
320	647049	4182707	9,70E-03	366	648049	4183707	5,18E-04
321	647549	4182707	5,90E-03	367	648549	4183707	2,99E-04

368	649049	4183707	2,16E-04	414	650049	4184707	2,11E-06
369	649549	4183707	1,63E-04	415	650549	4184707	0,00E+00
370	650049	4183707	1,27E-04	416	651049	4184707	0,00E+00
371	650549	4183707	1,18E-04	417	651549	4184707	0,00E+00
372	651049	4183707	1,08E-04	418	652049	4184707	0,00E+00
373	651549	4183707	5,52E-05	419	641549	4185207	0,00E+00
374	652049	4183707	0,00E+00	420	642049	4185207	0,00E+00
375	641549	4184207	0,00E+00	421	642549	4185207	0,00E+00
376	642049	4184207	0,00E+00	422	643049	4185207	0,00E+00
377	642549	4184207	0,00E+00	423	643549	4185207	0,00E+00
378	643049	4184207	0,00E+00	424	644049	4185207	0,00E+00
379	643549	4184207	0,00E+00	425	644549	4185207	0,00E+00
380	644049	4184207	0,00E+00	426	645049	4185207	9,32E-05
381	644549	4184207	1,06E-04	427	645549	4185207	5,66E-05
382	645049	4184207	3,50E-04	428	646049	4185207	3,37E-05
383	645549	4184207	5,99E-04	429	646549	4185207	2,29E-05
384	646049	4184207	7,62E-04	430	647049	4185207	1,43E-05
385	646549	4184207	7,17E-04	431	647549	4185207	7,23E-06
386	647049	4184207	5,04E-04	432	648049	4185207	3,07E-06
387	647549	4184207	2,73E-04	433	648549	4185207	1,35E-06
388	648049	4184207	1,28E-04	434	649049	4185207	7,52E-07
389	648549	4184207	6,74E-05	435	649549	4185207	4,78E-07
390	649049	4184207	4,48E-05	436	650049	4185207	7,10E-08
391	649549	4184207	3,19E-05	437	650549	4185207	0,00E+00
392	650049	4184207	2,27E-05	438	651049	4185207	0,00E+00
393	650549	4184207	3,30E-06	439	651549	4185207	0,00E+00
394	651049	4184207	0,00E+00	440	652049	4185207	0,00E+00
395	651549	4184207	0,00E+00	441	641549	4185707	0,00E+00
396	652049	4184207	0,00E+00	442	642049	4185707	0,00E+00
397	641549	4184707	0,00E+00	443	642549	4185707	0,00E+00
398	642049	4184707	0,00E+00	444	643049	4185707	0,00E+00
399	642549	4184707	0,00E+00	445	643549	4185707	0,00E+00
400	643049	4184707	0,00E+00	446	644049	4185707	0,00E+00
401	643549	4184707	0,00E+00	447	644549	4185707	3,50E-05
402	644049	4184707	0,00E+00	448	645049	4185707	3,12E-04
403	644549	4184707	5,40E-06	449	645549	4185707	1,40E-04
404	645049	4184707	9,35E-05	450	646049	4185707	4,79E-05
405	645549	4184707	1,28E-04	451	646549	4185707	1,35E-05
406	646049	4184707	1,54E-04	452	647049	4185707	3,52E-06
407	646549	4184707	1,42E-04	453	647549	4185707	9,98E-07
408	647049	4184707	9,83E-05	454	648049	4185707	3,20E-07
409	647549	4184707	5,21E-05	455	648549	4185707	1,20E-07
410	648049	4184707	2,32E-05	456	649049	4185707	6,04E-08
411	648549	4184707	1,11E-05	457	649549	4185707	3,42E-08
412	649049	4184707	6,81E-06	458	650049	4185707	0,00E+00
413	649549	4184707	4,58E-06	459	650549	4185707	0,00E+00

460	651049	4185707	0,00E+00	506	652049	4186707	0,00E+00
461	651549	4185707	0,00E+00	507	641549	4187207	0,00E+00
462	652049	4185707	0,00E+00	508	642049	4187207	0,00E+00
463	641549	4186207	0,00E+00	509	642549	4187207	9,85E-04
464	642049	4186207	0,00E+00	510	643049	4187207	3,12E-03
465	642549	4186207	0,00E+00	511	643549	4187207	3,85E-03
466	643049	4186207	2,95E-04	512	644049	4187207	3,88E-03
467	643549	4186207	1,06E-03	513	644549	4187207	3,19E-03
468	644049	4186207	1,51E-03	514	645049	4187207	2,08E-03
469	644549	4186207	1,38E-03	515	645549	4187207	1,03E-03
470	645049	4186207	8,17E-04	516	646049	4187207	3,78E-04
471	645549	4186207	3,66E-04	517	646549	4187207	1,01E-04
472	646049	4186207	1,27E-04	518	647049	4187207	1,93E-05
473	646549	4186207	3,30E-05	519	647549	4187207	2,66E-06
474	647049	4186207	6,31E-06	520	648049	4187207	2,61E-07
475	647549	4186207	8,99E-07	521	648549	4187207	1,83E-08
476	648049	4186207	1,03E-07	522	649049	4187207	0,00E+00
477	648549	4186207	1,34E-08	523	649549	4187207	0,00E+00
478	649049	4186207	0,00E+00	524	650049	4187207	0,00E+00
479	649549	4186207	0,00E+00	525	650549	4187207	0,00E+00
480	650049	4186207	0,00E+00	526	651049	4187207	0,00E+00
481	650549	4186207	0,00E+00	527	651549	4187207	0,00E+00
482	651049	4186207	0,00E+00	528	652049	4187207	0,00E+00
483	651549	4186207	0,00E+00	529	641549	4187707	0,00E+00
484	652049	4186207	0,00E+00	530	642049	4187707	7,05E-06
485	641549	4186707	0,00E+00	531	642549	4187707	1,20E-03
486	642049	4186707	0,00E+00	532	643049	4187707	2,32E-03
487	642549	4186707	2,40E-04	533	643549	4187707	3,14E-03
488	643049	4186707	3,08E-03	534	644049	4187707	3,48E-03
489	643549	4186707	3,61E-03	535	644549	4187707	3,09E-03
490	644049	4186707	3,30E-03	536	645049	4187707	2,11E-03
491	644549	4186707	2,48E-03	537	645549	4187707	1,08E-03
492	645049	4186707	1,51E-03	538	646049	4187707	4,00E-04
493	645549	4186707	7,17E-04	539	646549	4187707	1,07E-04
494	646049	4186707	2,57E-04	540	647049	4187707	2,07E-05
495	646549	4186707	6,78E-05	541	647549	4187707	2,85E-06
496	647049	4186707	1,30E-05	542	648049	4187707	2,80E-07
497	647549	4186707	1,78E-06	543	648549	4187707	1,96E-08
498	648049	4186707	1,75E-07	544	649049	4187707	0,00E+00
499	648549	4186707	1,26E-08	545	649549	4187707	0,00E+00
500	649049	4186707	0,00E+00	546	650049	4187707	0,00E+00
501	649549	4186707	0,00E+00	547	650549	4187707	0,00E+00
502	650049	4186707	0,00E+00	548	651049	4187707	0,00E+00
503	650549	4186707	0,00E+00	549	651549	4187707	0,00E+00
504	651049	4186707	0,00E+00	550	652049	4187707	0,00E+00
505	651549	4186707	0,00E+00	551	641549	4188207	0,00E+00

552	642049	4188207	1,28E-04	598	643049	4189207	3,93E-05
553	642549	4188207	7,22E-04	599	643549	4189207	2,24E-04
554	643049	4188207	1,31E-03	600	644049	4189207	3,97E-04
555	643549	4188207	1,96E-03	601	644549	4189207	4,44E-04
556	644049	4188207	2,36E-03	602	645049	4189207	3,24E-04
557	644549	4188207	2,22E-03	603	645549	4189207	1,71E-04
558	645049	4188207	1,57E-03	604	646049	4189207	6,46E-05
559	645549	4188207	8,11E-04	605	646549	4189207	1,75E-05
560	646049	4188207	3,04E-04	606	647049	4189207	3,38E-06
561	646549	4188207	8,20E-05	607	647549	4189207	4,66E-07
562	647049	4188207	1,58E-05	608	648049	4189207	4,59E-08
563	647549	4188207	2,18E-06	609	648549	4189207	0,00E+00
564	648049	4188207	2,15E-07	610	649049	4189207	0,00E+00
565	648549	4188207	1,51E-08	611	649549	4189207	0,00E+00
566	649049	4188207	0,00E+00	612	650049	4189207	0,00E+00
567	649549	4188207	0,00E+00	613	650549	4189207	0,00E+00
568	650049	4188207	0,00E+00	614	651049	4189207	0,00E+00
569	650549	4188207	0,00E+00	615	651549	4189207	0,00E+00
570	651049	4188207	0,00E+00	616	652049	4189207	0,00E+00
571	651549	4188207	0,00E+00	617	641549	4189707	0,00E+00
572	652049	4188207	0,00E+00	618	642049	4189707	0,00E+00
573	641549	4188707	0,00E+00	619	642549	4189707	0,00E+00
574	642049	4188707	2,38E-05	620	643049	4189707	0,00E+00
575	642549	4188707	2,06E-04	621	643549	4189707	0,00E+00
576	643049	4188707	5,66E-04	622	644049	4189707	0,00E+00
577	643549	4188707	9,28E-04	623	644549	4189707	7,29E-05
578	644049	4188707	1,19E-03	624	645049	4189707	8,99E-05
579	644549	4188707	1,17E-03	625	645549	4189707	4,75E-05
580	645049	4188707	8,40E-04	626	646049	4189707	1,80E-05
581	645549	4188707	4,40E-04	627	646549	4189707	4,88E-06
582	646049	4188707	1,66E-04	628	647049	4189707	9,43E-07
583	646549	4188707	4,48E-05	629	647549	4189707	1,30E-07
584	647049	4188707	8,65E-06	630	648049	4189707	1,28E-08
585	647549	4188707	1,19E-06	631	648549	4189707	0,00E+00
586	648049	4188707	1,17E-07	632	649049	4189707	0,00E+00
587	648549	4188707	0,00E+00	633	649549	4189707	0,00E+00
588	649049	4188707	0,00E+00	634	650049	4189707	0,00E+00
589	649549	4188707	0,00E+00	635	650549	4189707	0,00E+00
590	650049	4188707	0,00E+00	636	651049	4189707	0,00E+00
591	650549	4188707	0,00E+00	637	651549	4189707	0,00E+00
592	651049	4188707	0,00E+00	638	652049	4189707	0,00E+00
593	651549	4188707	0,00E+00	639	641549	4190207	0,00E+00
594	652049	4188707	0,00E+00	640	642049	4190207	0,00E+00
595	641549	4189207	0,00E+00	641	642549	4190207	0,00E+00
596	642049	4189207	0,00E+00	642	643049	4190207	0,00E+00
597	642549	4189207	0,00E+00	643	643549	4190207	0,00E+00

644	644049	4190207	0,00E+00	690	645049	4191207	0,00E+00
645	644549	4190207	0,00E+00	691	645549	4191207	0,00E+00
646	645049	4190207	4,49E-06	692	646049	4191207	0,00E+00
647	645549	4190207	4,70E-06	693	646549	4191207	0,00E+00
648	646049	4190207	3,09E-06	694	647049	4191207	0,00E+00
649	646549	4190207	9,71E-07	695	647549	4191207	0,00E+00
650	647049	4190207	1,88E-07	696	648049	4191207	0,00E+00
651	647549	4190207	2,59E-08	697	648549	4191207	0,00E+00
652	648049	4190207	0,00E+00	698	649049	4191207	0,00E+00
653	648549	4190207	0,00E+00	699	649549	4191207	0,00E+00
654	649049	4190207	0,00E+00	700	650049	4191207	0,00E+00
655	649549	4190207	0,00E+00	701	650549	4191207	0,00E+00
656	650049	4190207	0,00E+00	702	651049	4191207	0,00E+00
657	650549	4190207	0,00E+00	703	651549	4191207	0,00E+00
658	651049	4190207	0,00E+00	704	652049	4191207	0,00E+00
659	651549	4190207	0,00E+00	705	641549	4191707	0,00E+00
660	652049	4190207	0,00E+00	706	642049	4191707	0,00E+00
661	641549	4190707	0,00E+00	707	642549	4191707	0,00E+00
662	642049	4190707	0,00E+00	708	643049	4191707	0,00E+00
663	642549	4190707	0,00E+00	709	643549	4191707	0,00E+00
664	643049	4190707	0,00E+00	710	644049	4191707	0,00E+00
665	643549	4190707	0,00E+00	711	644549	4191707	0,00E+00
666	644049	4190707	0,00E+00	712	645049	4191707	0,00E+00
667	644549	4190707	0,00E+00	713	645549	4191707	0,00E+00
668	645049	4190707	0,00E+00	714	646049	4191707	0,00E+00
669	645549	4190707	0,00E+00	715	646549	4191707	0,00E+00
670	646049	4190707	0,00E+00	716	647049	4191707	0,00E+00
671	646549	4190707	7,59E-08	717	647549	4191707	0,00E+00
672	647049	4190707	2,56E-08	718	648049	4191707	0,00E+00
673	647549	4190707	0,00E+00	719	648549	4191707	0,00E+00
674	648049	4190707	0,00E+00	720	649049	4191707	0,00E+00
675	648549	4190707	0,00E+00	721	649549	4191707	0,00E+00
676	649049	4190707	0,00E+00	722	650049	4191707	0,00E+00
677	649549	4190707	0,00E+00	723	650549	4191707	0,00E+00
678	650049	4190707	0,00E+00	724	651049	4191707	0,00E+00
679	650549	4190707	0,00E+00	725	651549	4191707	0,00E+00
680	651049	4190707	0,00E+00	726	652049	4191707	0,00E+00
681	651549	4190707	0,00E+00	727	641549	4192207	0,00E+00
682	652049	4190707	0,00E+00	728	642049	4192207	0,00E+00
683	641549	4191207	0,00E+00	729	642549	4192207	0,00E+00
684	642049	4191207	0,00E+00	730	643049	4192207	0,00E+00
685	642549	4191207	0,00E+00	731	643549	4192207	0,00E+00
686	643049	4191207	0,00E+00	732	644049	4192207	0,00E+00
687	643549	4191207	0,00E+00	733	644549	4192207	0,00E+00
688	644049	4191207	0,00E+00	734	645049	4192207	0,00E+00
689	644549	4191207	0,00E+00	735	645549	4192207	0,00E+00

736	646049	4192207	0,00E+00
737	646549	4192207	0,00E+00
738	647049	4192207	0,00E+00
739	647549	4192207	0,00E+00
740	648049	4192207	0,00E+00
741	648549	4192207	0,00E+00
742	649049	4192207	0,00E+00
743	649549	4192207	0,00E+00
744	650049	4192207	0,00E+00
745	650549	4192207	0,00E+00
746	651049	4192207	0,00E+00
747	651549	4192207	0,00E+00
748	652049	4192207	0,00E+00
749	641549	4192707	0,00E+00
750	642049	4192707	0,00E+00
751	642549	4192707	0,00E+00
752	643049	4192707	0,00E+00
753	643549	4192707	0,00E+00

754	644049	4192707	0,00E+00
755	644549	4192707	0,00E+00
756	645049	4192707	0,00E+00
757	645549	4192707	0,00E+00
758	646049	4192707	0,00E+00
759	646549	4192707	0,00E+00
760	647049	4192707	0,00E+00
761	647549	4192707	0,00E+00
762	648049	4192707	0,00E+00
763	648549	4192707	0,00E+00
764	649049	4192707	0,00E+00
765	649549	4192707	0,00E+00
766	650049	4192707	0,00E+00
767	650549	4192707	0,00E+00
768	651049	4192707	0,00E+00
769	651549	4192707	0,00E+00
770	652049	4192707	0,00E+00

Furnas ET vent opening			
ID	Longitude	Latitude	Probability
1	641549	4175707	0,00E+00
2	642049	4175707	0,00E+00
3	642549	4175707	0,00E+00
4	643049	4175707	0,00E+00
5	643549	4175707	0,00E+00
6	644049	4175707	0,00E+00
7	644549	4175707	0,00E+00
8	645049	4175707	0,00E+00
9	645549	4175707	0,00E+00
10	646049	4175707	0,00E+00
11	646549	4175707	0,00E+00
12	647049	4175707	0,00E+00
13	647549	4175707	0,00E+00
14	648049	4175707	0,00E+00
15	648549	4175707	0,00E+00
16	649049	4175707	0,00E+00
17	649549	4175707	0,00E+00
18	650049	4175707	0,00E+00
19	650549	4175707	0,00E+00
20	651049	4175707	0,00E+00
21	651549	4175707	0,00E+00
22	652049	4175707	0,00E+00
23	641549	4176207	0,00E+00
24	642049	4176207	0,00E+00
25	642549	4176207	0,00E+00
26	643049	4176207	0,00E+00
27	643549	4176207	0,00E+00
28	644049	4176207	0,00E+00
29	644549	4176207	0,00E+00
30	645049	4176207	0,00E+00
31	645549	4176207	0,00E+00
32	646049	4176207	0,00E+00
33	646549	4176207	0,00E+00
34	647049	4176207	0,00E+00
35	647549	4176207	0,00E+00
36	648049	4176207	0,00E+00
37	648549	4176207	0,00E+00
38	649049	4176207	0,00E+00
39	649549	4176207	0,00E+00
40	650049	4176207	0,00E+00
41	650549	4176207	0,00E+00
42	651049	4176207	0,00E+00
43	651549	4176207	0,00E+00
44	652049	4176207	0,00E+00
45	641549	4176707	0,00E+00

46	642049	4176707	0,00E+00
47	642549	4176707	0,00E+00
48	643049	4176707	0,00E+00
49	643549	4176707	0,00E+00
50	644049	4176707	0,00E+00
51	644549	4176707	0,00E+00
52	645049	4176707	0,00E+00
53	645549	4176707	0,00E+00
54	646049	4176707	0,00E+00
55	646549	4176707	0,00E+00
56	647049	4176707	2,91E-04
57	647549	4176707	1,16E-03
58	648049	4176707	1,63E-03
59	648549	4176707	5,82E-05
60	649049	4176707	0,00E+00
61	649549	4176707	0,00E+00
62	650049	4176707	0,00E+00
63	650549	4176707	0,00E+00
64	651049	4176707	0,00E+00
65	651549	4176707	0,00E+00
66	652049	4176707	0,00E+00
67	641549	4177207	0,00E+00
68	642049	4177207	0,00E+00
69	642549	4177207	0,00E+00
70	643049	4177207	0,00E+00
71	643549	4177207	0,00E+00
72	644049	4177207	0,00E+00
73	644549	4177207	0,00E+00
74	645049	4177207	0,00E+00
75	645549	4177207	0,00E+00
76	646049	4177207	0,00E+00
77	646549	4177207	1,16E-04
78	647049	4177207	3,61E-03
79	647549	4177207	4,66E-03
80	648049	4177207	4,31E-03
81	648549	4177207	2,27E-03
82	649049	4177207	1,40E-03
83	649549	4177207	1,75E-04
84	650049	4177207	0,00E+00
85	650549	4177207	0,00E+00
86	651049	4177207	0,00E+00
87	651549	4177207	0,00E+00
88	652049	4177207	0,00E+00
89	641549	4177707	0,00E+00
90	642049	4177707	0,00E+00
91	642549	4177707	0,00E+00

92	643049	4177707	0,00E+00	138	644049	4178707	0,00E+00
93	643549	4177707	0,00E+00	139	644549	4178707	0,00E+00
94	644049	4177707	0,00E+00	140	645049	4178707	0,00E+00
95	644549	4177707	0,00E+00	141	645549	4178707	1,63E-03
96	645049	4177707	0,00E+00	142	646049	4178707	5,41E-03
97	645549	4177707	0,00E+00	143	646549	4178707	8,65E-03
98	646049	4177707	9,90E-04	144	647049	4178707	1,36E-02
99	646549	4177707	5,56E-03	145	647549	4178707	1,28E-02
100	647049	4177707	8,73E-03	146	648049	4178707	1,23E-02
101	647549	4177707	8,35E-03	147	648549	4178707	1,10E-02
102	648049	4177707	6,69E-03	148	649049	4178707	7,77E-03
103	648549	4177707	5,50E-03	149	649549	4178707	1,78E-03
104	649049	4177707	3,17E-03	150	650049	4178707	0,00E+00
105	649549	4177707	1,75E-03	151	650549	4178707	0,00E+00
106	650049	4177707	0,00E+00	152	651049	4178707	0,00E+00
107	650549	4177707	0,00E+00	153	651549	4178707	0,00E+00
108	651049	4177707	0,00E+00	154	652049	4178707	0,00E+00
109	651549	4177707	0,00E+00	155	641549	4179207	0,00E+00
110	652049	4177707	0,00E+00	156	642049	4179207	0,00E+00
111	641549	4178207	0,00E+00	157	642549	4179207	0,00E+00
112	642049	4178207	0,00E+00	158	643049	4179207	0,00E+00
113	642549	4178207	0,00E+00	159	643549	4179207	0,00E+00
114	643049	4178207	0,00E+00	160	644049	4179207	0,00E+00
115	643549	4178207	0,00E+00	161	644549	4179207	0,00E+00
116	644049	4178207	0,00E+00	162	645049	4179207	0,00E+00
117	644549	4178207	0,00E+00	163	645549	4179207	3,06E-03
118	645049	4178207	0,00E+00	164	646049	4179207	6,67E-03
119	645549	4178207	5,53E-04	165	646549	4179207	1,01E-02
120	646049	4178207	3,76E-03	166	647049	4179207	1,37E-02
121	646549	4178207	6,93E-03	167	647549	4179207	1,90E-02
122	647049	4178207	9,20E-03	168	648049	4179207	1,87E-02
123	647549	4178207	1,07E-02	169	648549	4179207	1,52E-02
124	648049	4178207	1,11E-02	170	649049	4179207	1,06E-02
125	648549	4178207	8,33E-03	171	649549	4179207	3,67E-03
126	649049	4178207	5,04E-03	172	650049	4179207	1,19E-03
127	649549	4178207	2,24E-03	173	650549	4179207	1,46E-04
128	650049	4178207	0,00E+00	174	651049	4179207	0,00E+00
129	650549	4178207	0,00E+00	175	651549	4179207	0,00E+00
130	651049	4178207	0,00E+00	176	652049	4179207	0,00E+00
131	651549	4178207	0,00E+00	177	641549	4179707	0,00E+00
132	652049	4178207	0,00E+00	178	642049	4179707	0,00E+00
133	641549	4178707	0,00E+00	179	642549	4179707	0,00E+00
134	642049	4178707	0,00E+00	180	643049	4179707	0,00E+00
135	642549	4178707	0,00E+00	181	643549	4179707	0,00E+00
136	643049	4178707	0,00E+00	182	644049	4179707	0,00E+00
137	643549	4178707	0,00E+00	183	644549	4179707	0,00E+00

184	645049	4179707	2,91E-05	230	646049	4180707	5,82E-03
185	645549	4179707	3,46E-03	231	646549	4180707	7,63E-03
186	646049	4179707	6,00E-03	232	647049	4180707	1,32E-02
187	646549	4179707	1,13E-02	233	647549	4180707	1,67E-02
188	647049	4179707	1,83E-02	234	648049	4180707	1,82E-02
189	647549	4179707	1,91E-02	235	648549	4180707	1,78E-02
190	648049	4179707	1,84E-02	236	649049	4180707	1,63E-02
191	648549	4179707	1,43E-02	237	649549	4180707	1,31E-02
192	649049	4179707	1,18E-02	238	650049	4180707	6,58E-03
193	649549	4179707	8,59E-03	239	650549	4180707	7,98E-03
194	650049	4179707	4,28E-03	240	651049	4180707	7,95E-03
195	650549	4179707	3,03E-03	241	651549	4180707	1,78E-03
196	651049	4179707	2,33E-04	242	652049	4180707	0,00E+00
197	651549	4179707	0,00E+00	243	641549	4181207	0,00E+00
198	652049	4179707	0,00E+00	244	642049	4181207	0,00E+00
199	641549	4180207	0,00E+00	245	642549	4181207	0,00E+00
200	642049	4180207	0,00E+00	246	643049	4181207	0,00E+00
201	642549	4180207	0,00E+00	247	643549	4181207	0,00E+00
202	643049	4180207	0,00E+00	248	644049	4181207	0,00E+00
203	643549	4180207	0,00E+00	249	644549	4181207	0,00E+00
204	644049	4180207	0,00E+00	250	645049	4181207	0,00E+00
205	644549	4180207	0,00E+00	251	645549	4181207	2,24E-03
206	645049	4180207	2,04E-04	252	646049	4181207	5,59E-03
207	645549	4180207	3,03E-03	253	646549	4181207	6,75E-03
208	646049	4180207	6,46E-03	254	647049	4181207	1,09E-02
209	646549	4180207	1,10E-02	255	647549	4181207	1,48E-02
210	647049	4180207	1,85E-02	256	648049	4181207	1,40E-02
211	647549	4180207	1,90E-02	257	648549	4181207	1,64E-02
212	648049	4180207	1,84E-02	258	649049	4181207	1,46E-02
213	648549	4180207	1,45E-02	259	649549	4181207	1,14E-02
214	649049	4180207	1,57E-02	260	650049	4181207	8,35E-03
215	649549	4180207	1,15E-02	261	650549	4181207	8,73E-03
216	650049	4180207	6,29E-03	262	651049	4181207	7,57E-03
217	650549	4180207	5,91E-03	263	651549	4181207	2,74E-03
218	651049	4180207	4,31E-03	264	652049	4181207	0,00E+00
219	651549	4180207	9,31E-04	265	641549	4181707	0,00E+00
220	652049	4180207	0,00E+00	266	642049	4181707	0,00E+00
221	641549	4180707	0,00E+00	267	642549	4181707	0,00E+00
222	642049	4180707	0,00E+00	268	643049	4181707	0,00E+00
223	642549	4180707	0,00E+00	269	643549	4181707	0,00E+00
224	643049	4180707	0,00E+00	270	644049	4181707	0,00E+00
225	643549	4180707	0,00E+00	271	644549	4181707	0,00E+00
226	644049	4180707	0,00E+00	272	645049	4181707	0,00E+00
227	644549	4180707	0,00E+00	273	645549	4181707	1,08E-03
228	645049	4180707	0,00E+00	274	646049	4181707	3,09E-03
229	645549	4180707	3,58E-03	275	646549	4181707	3,90E-03

276	647049	4181707	6,75E-03	322	648049	4182707	3,00E-03
277	647549	4181707	1,02E-02	323	648549	4182707	2,91E-03
278	648049	4181707	1,12E-02	324	649049	4182707	3,46E-03
279	648549	4181707	1,38E-02	325	649549	4182707	4,37E-03
280	649049	4181707	1,18E-02	326	650049	4182707	2,30E-03
281	649549	4181707	8,82E-03	327	650549	4182707	2,65E-03
282	650049	4181707	9,26E-03	328	651049	4182707	2,97E-03
283	650549	4181707	8,44E-03	329	651549	4182707	1,66E-03
284	651049	4181707	6,20E-03	330	652049	4182707	0,00E+00
285	651549	4181707	2,62E-03	331	641549	4183207	0,00E+00
286	652049	4181707	0,00E+00	332	642049	4183207	0,00E+00
287	641549	4182207	0,00E+00	333	642549	4183207	0,00E+00
288	642049	4182207	0,00E+00	334	643049	4183207	0,00E+00
289	642549	4182207	0,00E+00	335	643549	4183207	0,00E+00
290	643049	4182207	0,00E+00	336	644049	4183207	0,00E+00
291	643549	4182207	0,00E+00	337	644549	4183207	0,00E+00
292	644049	4182207	0,00E+00	338	645049	4183207	0,00E+00
293	644549	4182207	0,00E+00	339	645549	4183207	0,00E+00
294	645049	4182207	0,00E+00	340	646049	4183207	0,00E+00
295	645549	4182207	5,82E-05	341	646549	4183207	0,00E+00
296	646049	4182207	2,12E-03	342	647049	4183207	0,00E+00
297	646549	4182207	2,91E-03	343	647549	4183207	0,00E+00
298	647049	4182207	3,49E-03	344	648049	4183207	8,15E-04
299	647549	4182207	6,20E-03	345	648549	4183207	1,46E-03
300	648049	4182207	6,08E-03	346	649049	4183207	1,22E-03
301	648549	4182207	4,08E-03	347	649549	4183207	1,75E-04
302	649049	4182207	6,99E-03	348	650049	4183207	0,00E+00
303	649549	4182207	7,71E-03	349	650549	4183207	0,00E+00
304	650049	4182207	6,58E-03	350	651049	4183207	5,53E-04
305	650549	4182207	6,11E-03	351	651549	4183207	4,66E-04
306	651049	4182207	4,89E-03	352	652049	4183207	0,00E+00
307	651549	4182207	1,51E-03	353	641549	4183707	0,00E+00
308	652049	4182207	0,00E+00	354	642049	4183707	0,00E+00
309	641549	4182707	0,00E+00	355	642549	4183707	0,00E+00
310	642049	4182707	0,00E+00	356	643049	4183707	0,00E+00
311	642549	4182707	0,00E+00	357	643549	4183707	0,00E+00
312	643049	4182707	0,00E+00	358	644049	4183707	0,00E+00
313	643549	4182707	0,00E+00	359	644549	4183707	0,00E+00
314	644049	4182707	0,00E+00	360	645049	4183707	0,00E+00
315	644549	4182707	0,00E+00	361	645549	4183707	0,00E+00
316	645049	4182707	0,00E+00	362	646049	4183707	0,00E+00
317	645549	4182707	0,00E+00	363	646549	4183707	0,00E+00
318	646049	4182707	5,82E-05	364	647049	4183707	0,00E+00
319	646549	4182707	1,05E-03	365	647549	4183707	0,00E+00
320	647049	4182707	1,46E-03	366	648049	4183707	0,00E+00
321	647549	4182707	2,85E-03	367	648549	4183707	0,00E+00

368	649049	4183707	0,00E+00	414	650049	4184707	0,00E+00
369	649549	4183707	0,00E+00	415	650549	4184707	0,00E+00
370	650049	4183707	0,00E+00	416	651049	4184707	0,00E+00
371	650549	4183707	0,00E+00	417	651549	4184707	0,00E+00
372	651049	4183707	0,00E+00	418	652049	4184707	0,00E+00
373	651549	4183707	0,00E+00	419	641549	4185207	0,00E+00
374	652049	4183707	0,00E+00	420	642049	4185207	0,00E+00
375	641549	4184207	0,00E+00	421	642549	4185207	0,00E+00
376	642049	4184207	0,00E+00	422	643049	4185207	0,00E+00
377	642549	4184207	0,00E+00	423	643549	4185207	0,00E+00
378	643049	4184207	0,00E+00	424	644049	4185207	0,00E+00
379	643549	4184207	0,00E+00	425	644549	4185207	0,00E+00
380	644049	4184207	0,00E+00	426	645049	4185207	0,00E+00
381	644549	4184207	0,00E+00	427	645549	4185207	0,00E+00
382	645049	4184207	0,00E+00	428	646049	4185207	0,00E+00
383	645549	4184207	0,00E+00	429	646549	4185207	0,00E+00
384	646049	4184207	0,00E+00	430	647049	4185207	0,00E+00
385	646549	4184207	0,00E+00	431	647549	4185207	0,00E+00
386	647049	4184207	0,00E+00	432	648049	4185207	0,00E+00
387	647549	4184207	0,00E+00	433	648549	4185207	0,00E+00
388	648049	4184207	0,00E+00	434	649049	4185207	0,00E+00
389	648549	4184207	0,00E+00	435	649549	4185207	0,00E+00
390	649049	4184207	0,00E+00	436	650049	4185207	0,00E+00
391	649549	4184207	0,00E+00	437	650549	4185207	0,00E+00
392	650049	4184207	0,00E+00	438	651049	4185207	0,00E+00
393	650549	4184207	0,00E+00	439	651549	4185207	0,00E+00
394	651049	4184207	0,00E+00	440	652049	4185207	0,00E+00
395	651549	4184207	0,00E+00	441	641549	4185707	0,00E+00
396	652049	4184207	0,00E+00	442	642049	4185707	0,00E+00
397	641549	4184707	0,00E+00	443	642549	4185707	0,00E+00
398	642049	4184707	0,00E+00	444	643049	4185707	0,00E+00
399	642549	4184707	0,00E+00	445	643549	4185707	0,00E+00
400	643049	4184707	0,00E+00	446	644049	4185707	0,00E+00
401	643549	4184707	0,00E+00	447	644549	4185707	0,00E+00
402	644049	4184707	0,00E+00	448	645049	4185707	0,00E+00
403	644549	4184707	0,00E+00	449	645549	4185707	0,00E+00
404	645049	4184707	0,00E+00	450	646049	4185707	0,00E+00
405	645549	4184707	0,00E+00	451	646549	4185707	0,00E+00
406	646049	4184707	0,00E+00	452	647049	4185707	0,00E+00
407	646549	4184707	0,00E+00	453	647549	4185707	0,00E+00
408	647049	4184707	0,00E+00	454	648049	4185707	0,00E+00
409	647549	4184707	0,00E+00	455	648549	4185707	0,00E+00
410	648049	4184707	0,00E+00	456	649049	4185707	0,00E+00
411	648549	4184707	0,00E+00	457	649549	4185707	0,00E+00
412	649049	4184707	0,00E+00	458	650049	4185707	0,00E+00
413	649549	4184707	0,00E+00	459	650549	4185707	0,00E+00

460	651049	4185707	0,00E+00	506	652049	4186707	0,00E+00
461	651549	4185707	0,00E+00	507	641549	4187207	0,00E+00
462	652049	4185707	0,00E+00	508	642049	4187207	0,00E+00
463	641549	4186207	0,00E+00	509	642549	4187207	0,00E+00
464	642049	4186207	0,00E+00	510	643049	4187207	0,00E+00
465	642549	4186207	0,00E+00	511	643549	4187207	0,00E+00
466	643049	4186207	0,00E+00	512	644049	4187207	0,00E+00
467	643549	4186207	0,00E+00	513	644549	4187207	0,00E+00
468	644049	4186207	0,00E+00	514	645049	4187207	0,00E+00
469	644549	4186207	0,00E+00	515	645549	4187207	0,00E+00
470	645049	4186207	0,00E+00	516	646049	4187207	0,00E+00
471	645549	4186207	0,00E+00	517	646549	4187207	0,00E+00
472	646049	4186207	0,00E+00	518	647049	4187207	0,00E+00
473	646549	4186207	0,00E+00	519	647549	4187207	0,00E+00
474	647049	4186207	0,00E+00	520	648049	4187207	0,00E+00
475	647549	4186207	0,00E+00	521	648549	4187207	0,00E+00
476	648049	4186207	0,00E+00	522	649049	4187207	0,00E+00
477	648549	4186207	0,00E+00	523	649549	4187207	0,00E+00
478	649049	4186207	0,00E+00	524	650049	4187207	0,00E+00
479	649549	4186207	0,00E+00	525	650549	4187207	0,00E+00
480	650049	4186207	0,00E+00	526	651049	4187207	0,00E+00
481	650549	4186207	0,00E+00	527	651549	4187207	0,00E+00
482	651049	4186207	0,00E+00	528	652049	4187207	0,00E+00
483	651549	4186207	0,00E+00	529	641549	4187707	0,00E+00
484	652049	4186207	0,00E+00	530	642049	4187707	0,00E+00
485	641549	4186707	0,00E+00	531	642549	4187707	0,00E+00
486	642049	4186707	0,00E+00	532	643049	4187707	0,00E+00
487	642549	4186707	0,00E+00	533	643549	4187707	0,00E+00
488	643049	4186707	0,00E+00	534	644049	4187707	0,00E+00
489	643549	4186707	0,00E+00	535	644549	4187707	0,00E+00
490	644049	4186707	0,00E+00	536	645049	4187707	0,00E+00
491	644549	4186707	0,00E+00	537	645549	4187707	0,00E+00
492	645049	4186707	0,00E+00	538	646049	4187707	0,00E+00
493	645549	4186707	0,00E+00	539	646549	4187707	0,00E+00
494	646049	4186707	0,00E+00	540	647049	4187707	0,00E+00
495	646549	4186707	0,00E+00	541	647549	4187707	0,00E+00
496	647049	4186707	0,00E+00	542	648049	4187707	0,00E+00
497	647549	4186707	0,00E+00	543	648549	4187707	0,00E+00
498	648049	4186707	0,00E+00	544	649049	4187707	0,00E+00
499	648549	4186707	0,00E+00	545	649549	4187707	0,00E+00
500	649049	4186707	0,00E+00	546	650049	4187707	0,00E+00
501	649549	4186707	0,00E+00	547	650549	4187707	0,00E+00
502	650049	4186707	0,00E+00	548	651049	4187707	0,00E+00
503	650549	4186707	0,00E+00	549	651549	4187707	0,00E+00
504	651049	4186707	0,00E+00	550	652049	4187707	0,00E+00
505	651549	4186707	0,00E+00	551	641549	4188207	0,00E+00

552	642049	4188207	0,00E+00	598	643049	4189207	0,00E+00
553	642549	4188207	0,00E+00	599	643549	4189207	0,00E+00
554	643049	4188207	0,00E+00	600	644049	4189207	0,00E+00
555	643549	4188207	0,00E+00	601	644549	4189207	0,00E+00
556	644049	4188207	0,00E+00	602	645049	4189207	0,00E+00
557	644549	4188207	0,00E+00	603	645549	4189207	0,00E+00
558	645049	4188207	0,00E+00	604	646049	4189207	0,00E+00
559	645549	4188207	0,00E+00	605	646549	4189207	0,00E+00
560	646049	4188207	0,00E+00	606	647049	4189207	0,00E+00
561	646549	4188207	0,00E+00	607	647549	4189207	0,00E+00
562	647049	4188207	0,00E+00	608	648049	4189207	0,00E+00
563	647549	4188207	0,00E+00	609	648549	4189207	0,00E+00
564	648049	4188207	0,00E+00	610	649049	4189207	0,00E+00
565	648549	4188207	0,00E+00	611	649549	4189207	0,00E+00
566	649049	4188207	0,00E+00	612	650049	4189207	0,00E+00
567	649549	4188207	0,00E+00	613	650549	4189207	0,00E+00
568	650049	4188207	0,00E+00	614	651049	4189207	0,00E+00
569	650549	4188207	0,00E+00	615	651549	4189207	0,00E+00
570	651049	4188207	0,00E+00	616	652049	4189207	0,00E+00
571	651549	4188207	0,00E+00	617	641549	4189707	0,00E+00
572	652049	4188207	0,00E+00	618	642049	4189707	0,00E+00
573	641549	4188707	0,00E+00	619	642549	4189707	0,00E+00
574	642049	4188707	0,00E+00	620	643049	4189707	0,00E+00
575	642549	4188707	0,00E+00	621	643549	4189707	0,00E+00
576	643049	4188707	0,00E+00	622	644049	4189707	0,00E+00
577	643549	4188707	0,00E+00	623	644549	4189707	0,00E+00
578	644049	4188707	0,00E+00	624	645049	4189707	0,00E+00
579	644549	4188707	0,00E+00	625	645549	4189707	0,00E+00
580	645049	4188707	0,00E+00	626	646049	4189707	0,00E+00
581	645549	4188707	0,00E+00	627	646549	4189707	0,00E+00
582	646049	4188707	0,00E+00	628	647049	4189707	0,00E+00
583	646549	4188707	0,00E+00	629	647549	4189707	0,00E+00
584	647049	4188707	0,00E+00	630	648049	4189707	0,00E+00
585	647549	4188707	0,00E+00	631	648549	4189707	0,00E+00
586	648049	4188707	0,00E+00	632	649049	4189707	0,00E+00
587	648549	4188707	0,00E+00	633	649549	4189707	0,00E+00
588	649049	4188707	0,00E+00	634	650049	4189707	0,00E+00
589	649549	4188707	0,00E+00	635	650549	4189707	0,00E+00
590	650049	4188707	0,00E+00	636	651049	4189707	0,00E+00
591	650549	4188707	0,00E+00	637	651549	4189707	0,00E+00
592	651049	4188707	0,00E+00	638	652049	4189707	0,00E+00
593	651549	4188707	0,00E+00	639	641549	4190207	0,00E+00
594	652049	4188707	0,00E+00	640	642049	4190207	0,00E+00
595	641549	4189207	0,00E+00	641	642549	4190207	0,00E+00
596	642049	4189207	0,00E+00	642	643049	4190207	0,00E+00
597	642549	4189207	0,00E+00	643	643549	4190207	0,00E+00

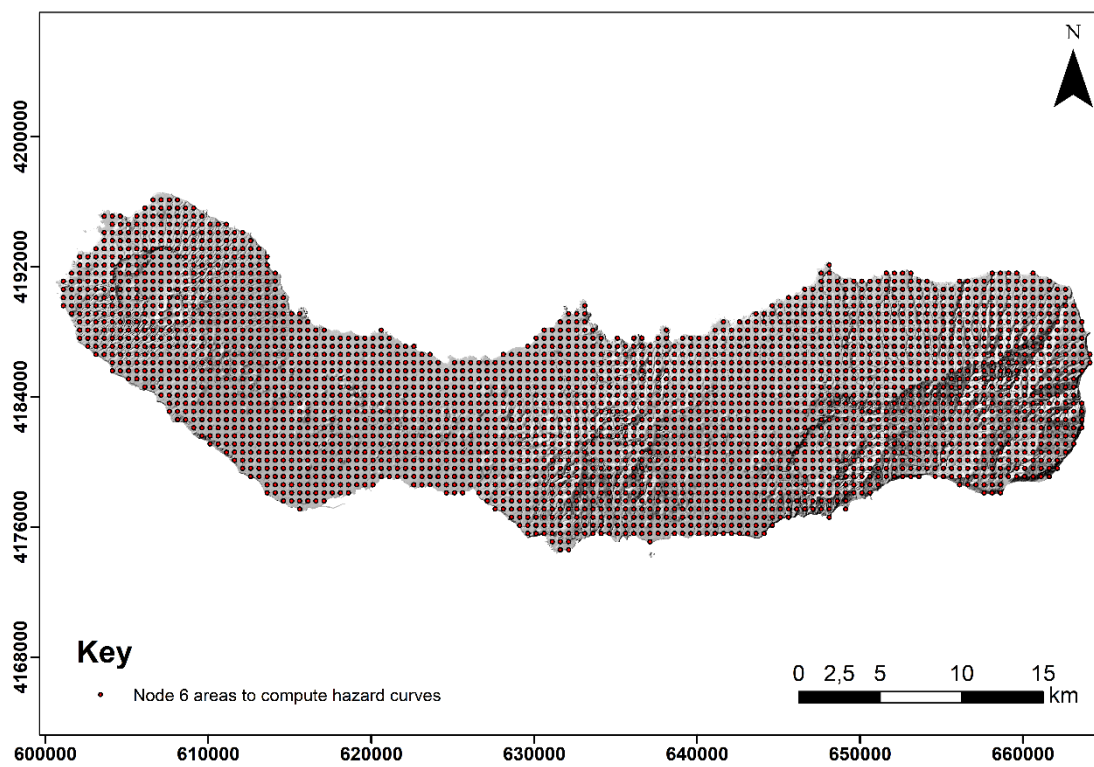
644	644049	4190207	0,00E+00	690	645049	4191207	0,00E+00
645	644549	4190207	0,00E+00	691	645549	4191207	0,00E+00
646	645049	4190207	0,00E+00	692	646049	4191207	0,00E+00
647	645549	4190207	0,00E+00	693	646549	4191207	0,00E+00
648	646049	4190207	0,00E+00	694	647049	4191207	0,00E+00
649	646549	4190207	0,00E+00	695	647549	4191207	0,00E+00
650	647049	4190207	0,00E+00	696	648049	4191207	0,00E+00
651	647549	4190207	0,00E+00	697	648549	4191207	0,00E+00
652	648049	4190207	0,00E+00	698	649049	4191207	0,00E+00
653	648549	4190207	0,00E+00	699	649549	4191207	0,00E+00
654	649049	4190207	0,00E+00	700	650049	4191207	0,00E+00
655	649549	4190207	0,00E+00	701	650549	4191207	0,00E+00
656	650049	4190207	0,00E+00	702	651049	4191207	0,00E+00
657	650549	4190207	0,00E+00	703	651549	4191207	0,00E+00
658	651049	4190207	0,00E+00	704	652049	4191207	0,00E+00
659	651549	4190207	0,00E+00	705	641549	4191707	0,00E+00
660	652049	4190207	0,00E+00	706	642049	4191707	0,00E+00
661	641549	4190707	0,00E+00	707	642549	4191707	0,00E+00
662	642049	4190707	0,00E+00	708	643049	4191707	0,00E+00
663	642549	4190707	0,00E+00	709	643549	4191707	0,00E+00
664	643049	4190707	0,00E+00	710	644049	4191707	0,00E+00
665	643549	4190707	0,00E+00	711	644549	4191707	0,00E+00
666	644049	4190707	0,00E+00	712	645049	4191707	0,00E+00
667	644549	4190707	0,00E+00	713	645549	4191707	0,00E+00
668	645049	4190707	0,00E+00	714	646049	4191707	0,00E+00
669	645549	4190707	0,00E+00	715	646549	4191707	0,00E+00
670	646049	4190707	0,00E+00	716	647049	4191707	0,00E+00
671	646549	4190707	0,00E+00	717	647549	4191707	0,00E+00
672	647049	4190707	0,00E+00	718	648049	4191707	0,00E+00
673	647549	4190707	0,00E+00	719	648549	4191707	0,00E+00
674	648049	4190707	0,00E+00	720	649049	4191707	0,00E+00
675	648549	4190707	0,00E+00	721	649549	4191707	0,00E+00
676	649049	4190707	0,00E+00	722	650049	4191707	0,00E+00
677	649549	4190707	0,00E+00	723	650549	4191707	0,00E+00
678	650049	4190707	0,00E+00	724	651049	4191707	0,00E+00
679	650549	4190707	0,00E+00	725	651549	4191707	0,00E+00
680	651049	4190707	0,00E+00	726	652049	4191707	0,00E+00
681	651549	4190707	0,00E+00	727	641549	4192207	0,00E+00
682	652049	4190707	0,00E+00	728	642049	4192207	0,00E+00
683	641549	4191207	0,00E+00	729	642549	4192207	0,00E+00
684	642049	4191207	0,00E+00	730	643049	4192207	0,00E+00
685	642549	4191207	0,00E+00	731	643549	4192207	0,00E+00
686	643049	4191207	0,00E+00	732	644049	4192207	0,00E+00
687	643549	4191207	0,00E+00	733	644549	4192207	0,00E+00
688	644049	4191207	0,00E+00	734	645049	4192207	0,00E+00
689	644549	4191207	0,00E+00	735	645549	4192207	0,00E+00

736	646049	4192207	0,00E+00
737	646549	4192207	0,00E+00
738	647049	4192207	0,00E+00
739	647549	4192207	0,00E+00
740	648049	4192207	0,00E+00
741	648549	4192207	0,00E+00
742	649049	4192207	0,00E+00
743	649549	4192207	0,00E+00
744	650049	4192207	0,00E+00
745	650549	4192207	0,00E+00
746	651049	4192207	0,00E+00
747	651549	4192207	0,00E+00
748	652049	4192207	0,00E+00
749	641549	4192707	0,00E+00
750	642049	4192707	0,00E+00
751	642549	4192707	0,00E+00
752	643049	4192707	0,00E+00
753	643549	4192707	0,00E+00

754	644049	4192707	0,00E+00
755	644549	4192707	0,00E+00
756	645049	4192707	0,00E+00
757	645549	4192707	0,00E+00
758	646049	4192707	0,00E+00
759	646549	4192707	0,00E+00
760	647049	4192707	0,00E+00
761	647549	4192707	0,00E+00
762	648049	4192707	0,00E+00
763	648549	4192707	0,00E+00
764	649049	4192707	0,00E+00
765	649549	4192707	0,00E+00
766	650049	4192707	0,00E+00
767	650549	4192707	0,00E+00
768	651049	4192707	0,00E+00
769	651549	4192707	0,00E+00
770	652049	4192707	0,00E+00

Appendix A.5

Node 7 areas



Areas to compute hazard curves		
ID	Longitude	Latitude
1	631619	4174601
2	632119	4174601
3	631119	4175101
4	631619	4175101
5	632119	4175101
6	637119	4175101
7	629619	4175601
8	630119	4175601
9	630619	4175601
10	631119	4175601
11	631619	4175601
12	632119	4175601
13	632619	4175601
14	633119	4175601
15	633619	4175601
16	634119	4175601

17	634619	4175601
18	635119	4175601
19	635619	4175601
20	636119	4175601
21	636619	4175601
22	637119	4175601
23	637619	4175601
24	638119	4175601
25	638619	4175601
26	639119	4175601
27	639619	4175601
28	640119	4175601
29	640619	4175601
30	641119	4175601
31	641619	4175601
32	642119	4175601
33	642619	4175601
34	643119	4175601
35	643619	4175601
36	644119	4175601
37	629119	4176101
38	629619	4176101
39	630119	4176101
40	630619	4176101
41	631119	4176101
42	631619	4176101
43	632119	4176101
44	632619	4176101
45	633119	4176101
46	633619	4176101
47	634119	4176101
48	634619	4176101
49	635119	4176101
50	635619	4176101
51	636119	4176101
52	636619	4176101
53	637119	4176101
54	637619	4176101
55	638119	4176101
56	638619	4176101
57	639119	4176101
58	639619	4176101
59	640119	4176101
60	640619	4176101
61	641119	4176101
62	641619	4176101

63	642119	4176101
64	642619	4176101
65	643119	4176101
66	643619	4176101
67	644119	4176101
68	644619	4176101
69	628619	4176601
70	629119	4176601
71	629619	4176601
72	630119	4176601
73	630619	4176601
74	631119	4176601
75	631619	4176601
76	632119	4176601
77	632619	4176601
78	633119	4176601
79	633619	4176601
80	634119	4176601
81	634619	4176601
82	635119	4176601
83	635619	4176601
84	636119	4176601
85	636619	4176601
86	637119	4176601
87	637619	4176601
88	638119	4176601
89	638619	4176601
90	639119	4176601
91	639619	4176601
92	640119	4176601
93	640619	4176601
94	641119	4176601
95	641619	4176601
96	642119	4176601
97	642619	4176601
98	643119	4176601
99	643619	4176601
100	644119	4176601
101	644619	4176601
102	645119	4176601
103	645619	4176601
104	648119	4176601
105	615619	4177101
106	627619	4177101
107	628119	4177101
108	628619	4177101

109	629119	4177101
110	629619	4177101
111	630119	4177101
112	630619	4177101
113	631119	4177101
114	631619	4177101
115	632119	4177101
116	632619	4177101
117	633119	4177101
118	633619	4177101
119	634119	4177101
120	634619	4177101
121	635119	4177101
122	635619	4177101
123	636119	4177101
124	636619	4177101
125	637119	4177101
126	637619	4177101
127	638119	4177101
128	638619	4177101
129	639119	4177101
130	639619	4177101
131	640119	4177101
132	640619	4177101
133	641119	4177101
134	641619	4177101
135	642119	4177101
136	642619	4177101
137	643119	4177101
138	643619	4177101
139	644119	4177101
140	644619	4177101
141	645119	4177101
142	645619	4177101
143	646119	4177101
144	646619	4177101
145	647119	4177101
146	647619	4177101
147	648119	4177101
148	649119	4177101
149	614619	4177601
150	615119	4177601
151	615619	4177601
152	616119	4177601
153	616619	4177601
154	617119	4177601

155	627119	4177601
156	627619	4177601
157	628119	4177601
158	628619	4177601
159	629119	4177601
160	629619	4177601
161	630119	4177601
162	630619	4177601
163	631119	4177601
164	631619	4177601
165	632119	4177601
166	632619	4177601
167	633119	4177601
168	633619	4177601
169	634119	4177601
170	634619	4177601
171	635119	4177601
172	635619	4177601
173	636119	4177601
174	636619	4177601
175	637119	4177601
176	637619	4177601
177	638119	4177601
178	638619	4177601
179	639119	4177601
180	639619	4177601
181	640119	4177601
182	640619	4177601
183	641119	4177601
184	641619	4177601
185	642119	4177601
186	642619	4177601
187	643119	4177601
188	643619	4177601
189	644119	4177601
190	644619	4177601
191	645119	4177601
192	645619	4177601
193	646119	4177601
194	646619	4177601
195	647119	4177601
196	647619	4177601
197	648119	4177601
198	648619	4177601
199	649119	4177601
200	613619	4178101

201	614119	4178101
202	614619	4178101
203	615119	4178101
204	615619	4178101
205	616119	4178101
206	616619	4178101
207	617119	4178101
208	617619	4178101
209	618119	4178101
210	618619	4178101
211	624619	4178101
212	625119	4178101
213	625619	4178101
214	626619	4178101
215	627119	4178101
216	627619	4178101
217	628119	4178101
218	628619	4178101
219	629119	4178101
220	629619	4178101
221	630119	4178101
222	630619	4178101
223	631119	4178101
224	631619	4178101
225	632119	4178101
226	632619	4178101
227	633119	4178101
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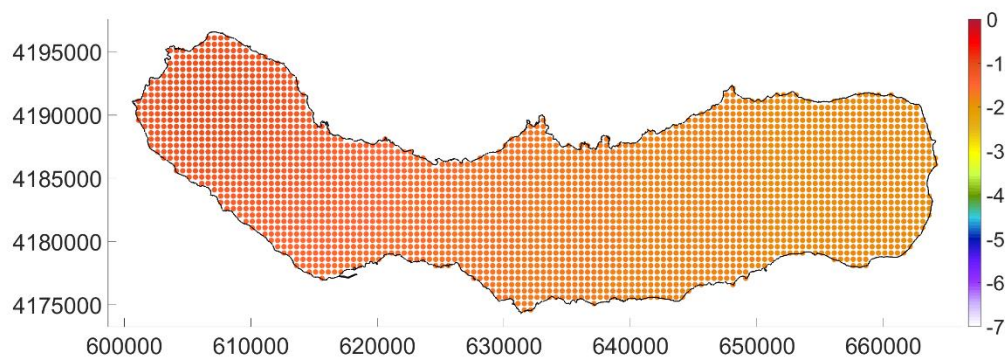
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Appendix A.6

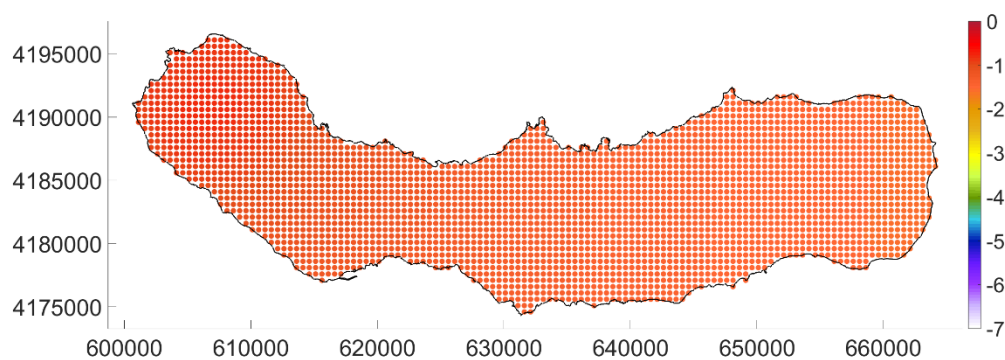
Absolute and conditional probability maps

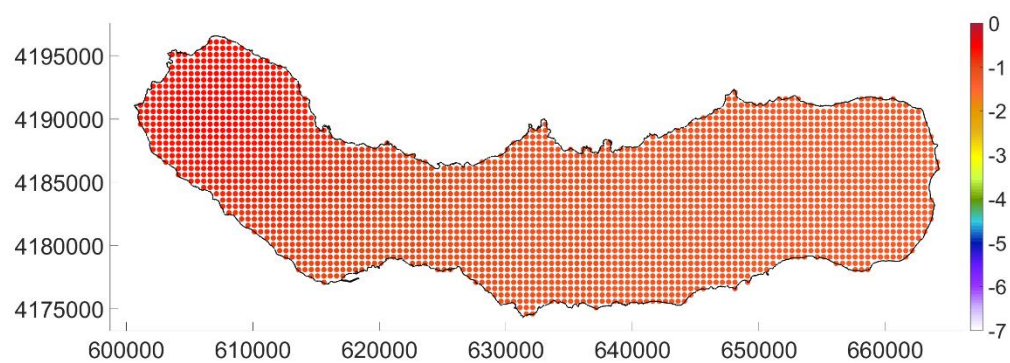
Sete Cidades Volcano absolute probability maps – 1 kg/m²

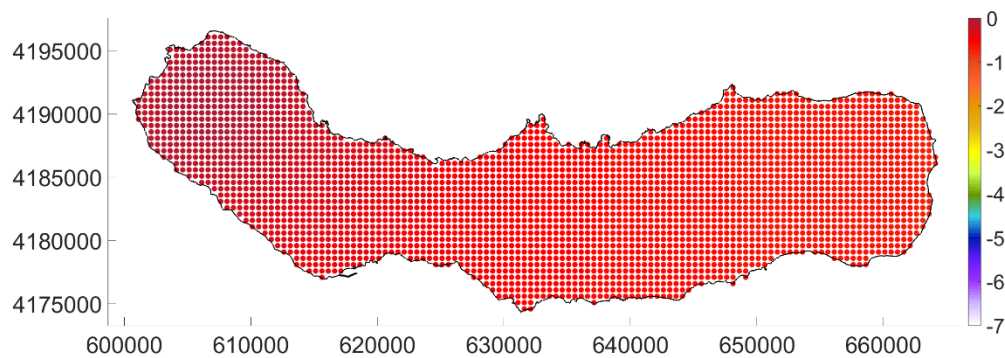
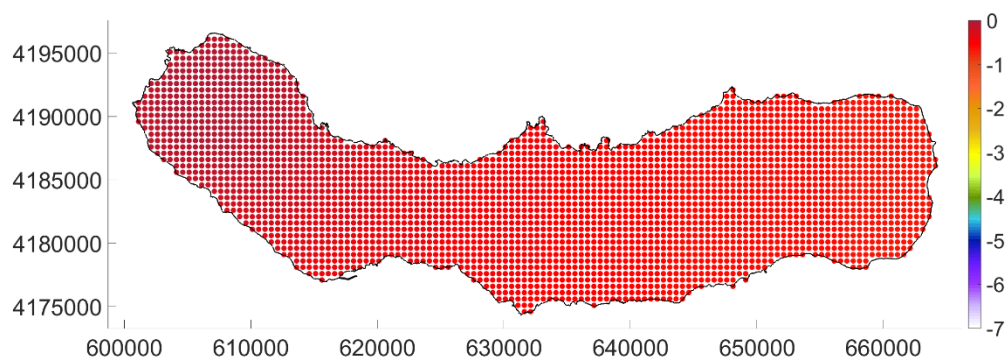
5th percentile

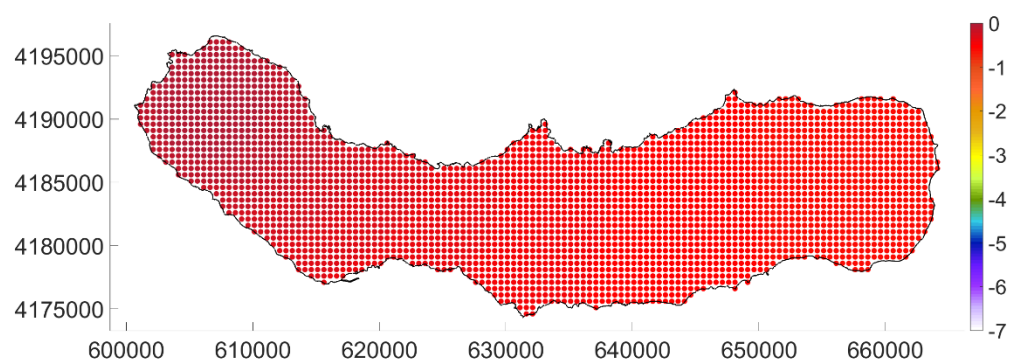


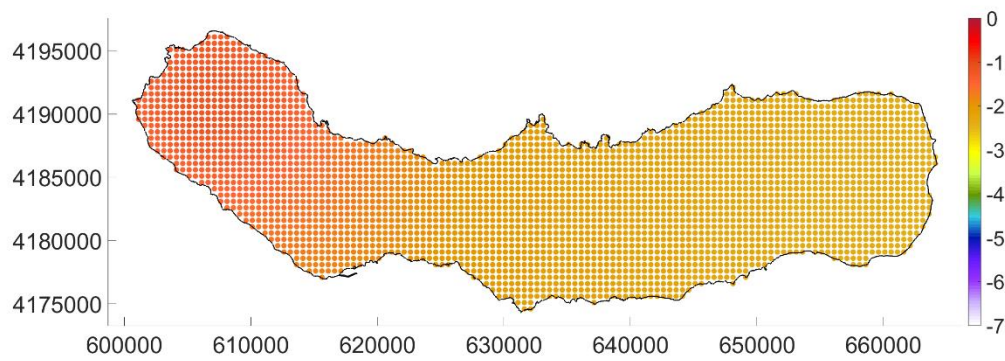
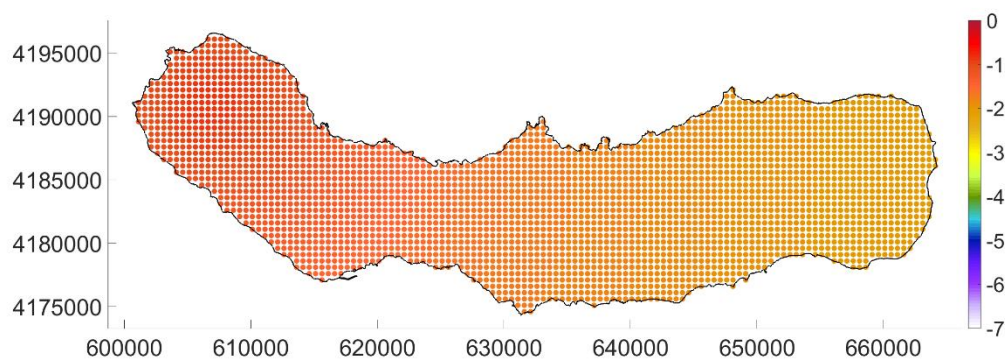
50th percentile

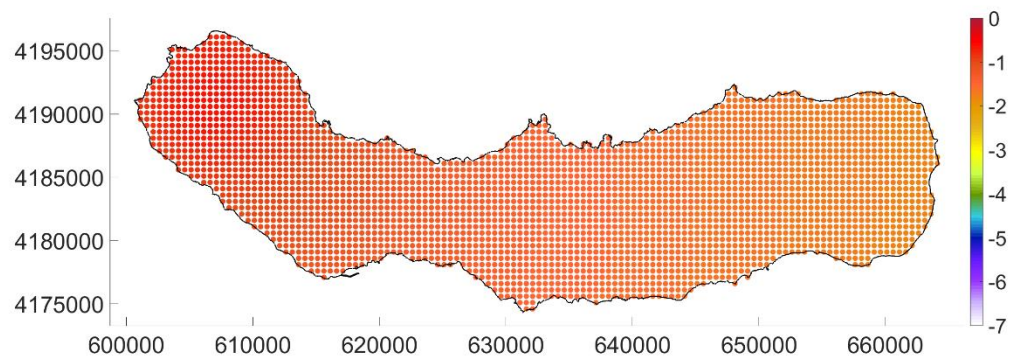


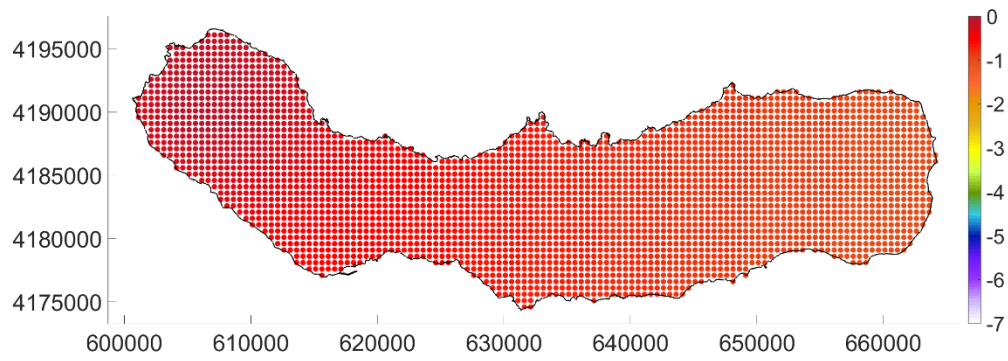
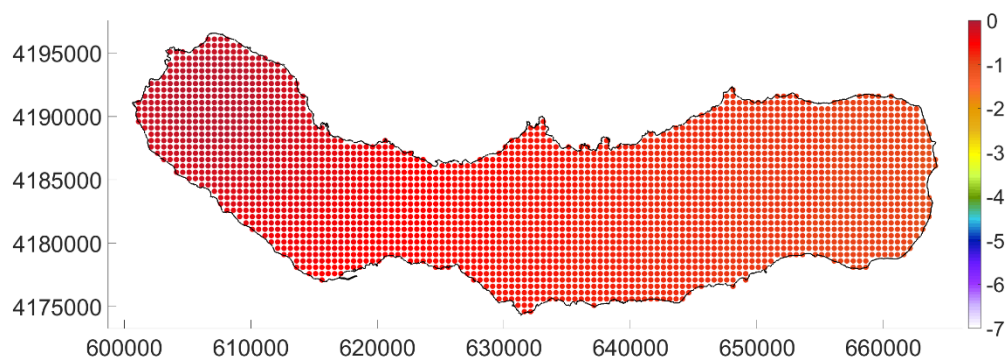
95th percentile

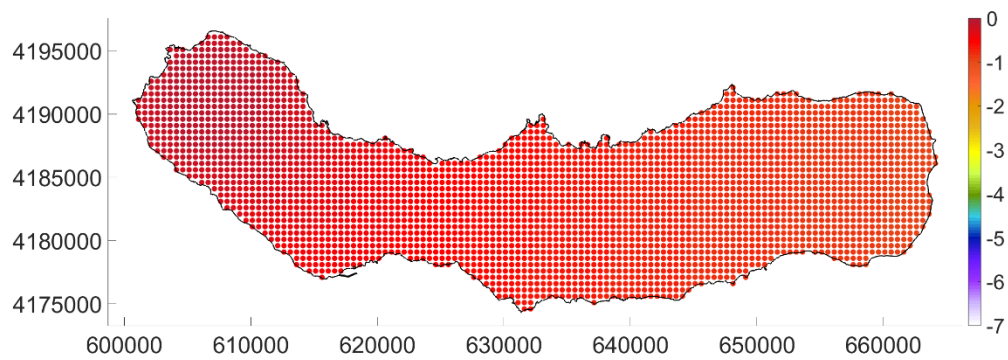
Sete Cidades Volcano conditional probability maps – 1 kg/m²5th percentile50th percentile

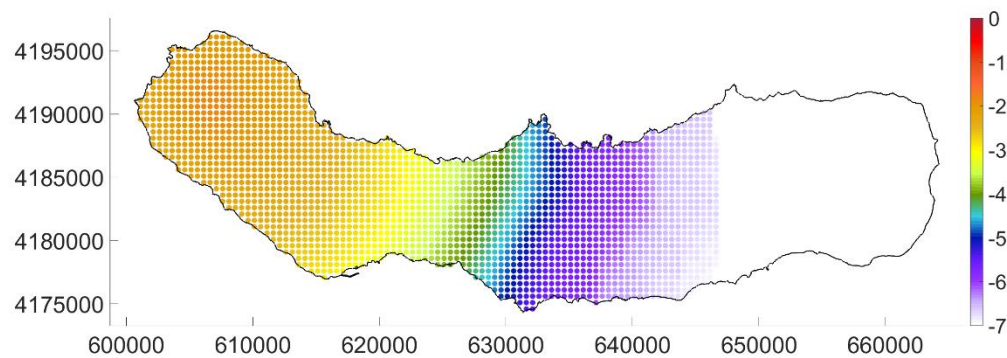
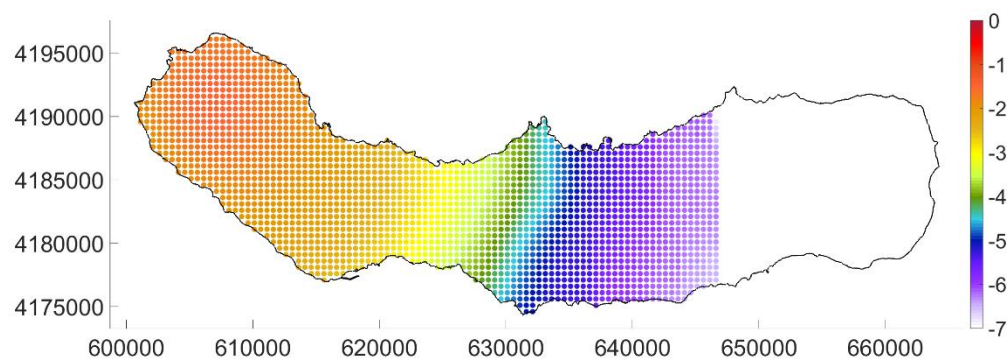
95th percentile

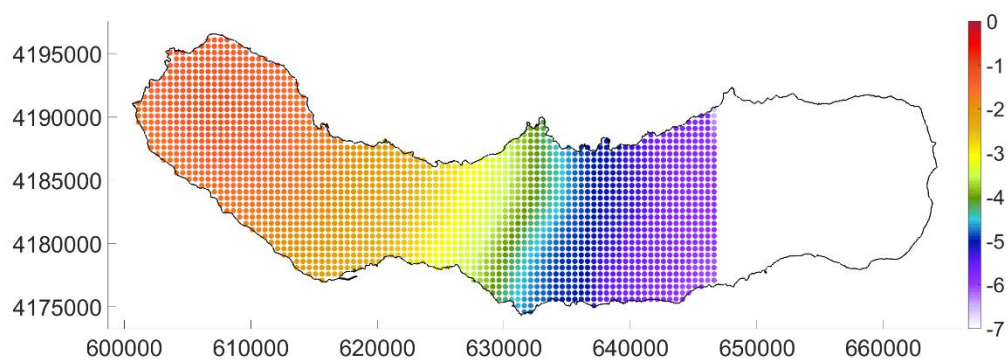
Sete Cidades Volcano absolute probability maps – 10 kg/m²5th percentile50th percentile

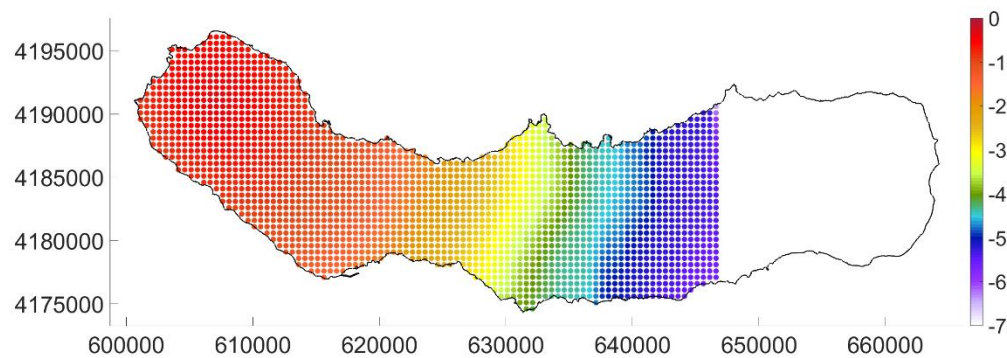
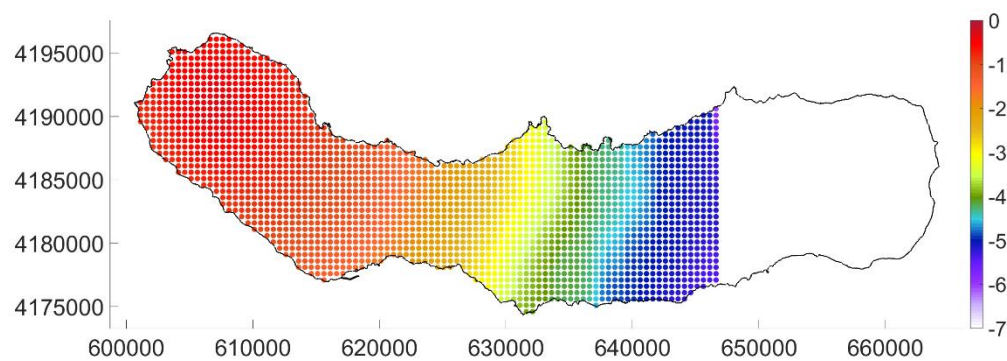
95th percentile

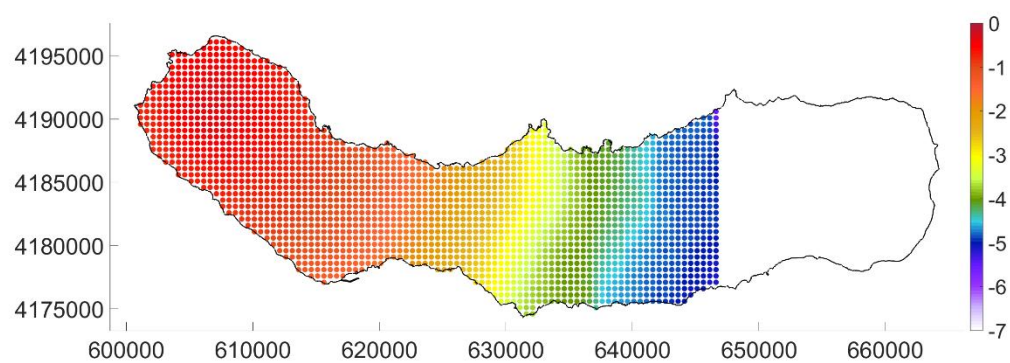
Sete Cidades Volcano conditional probability maps – 10 kg/m²5th percentile50th percentile

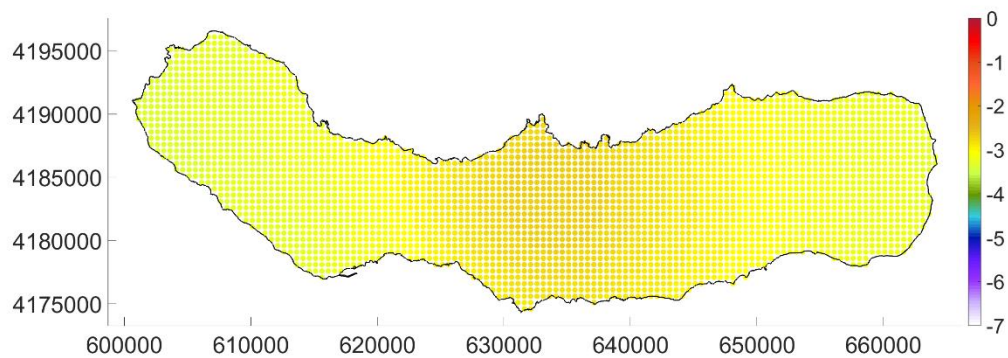
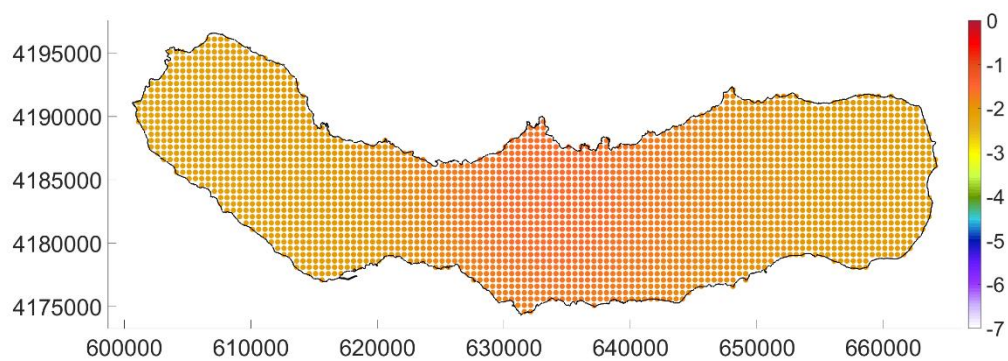
95th percentile

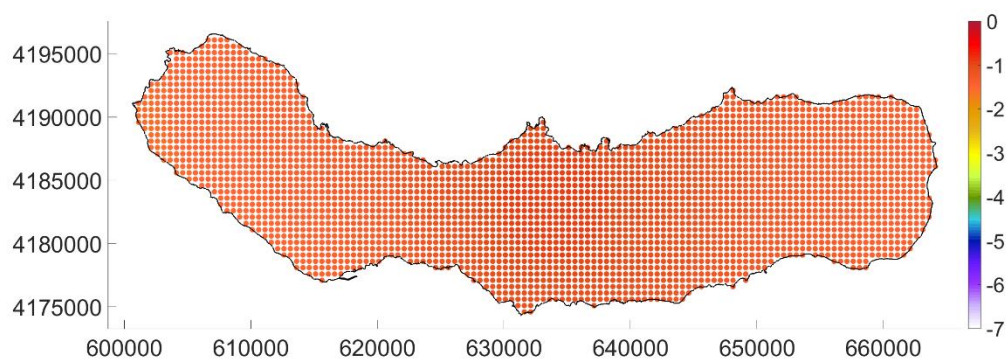
Sete Cidades Volcano absolute probability maps – 400 kg/m²5th percentile50th percentile

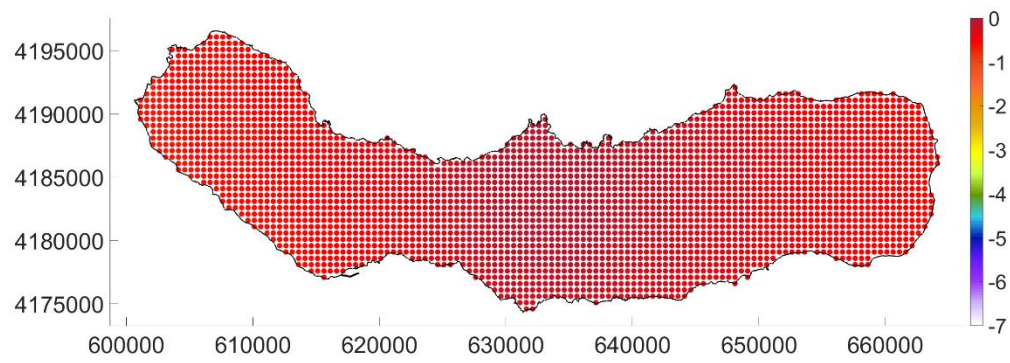
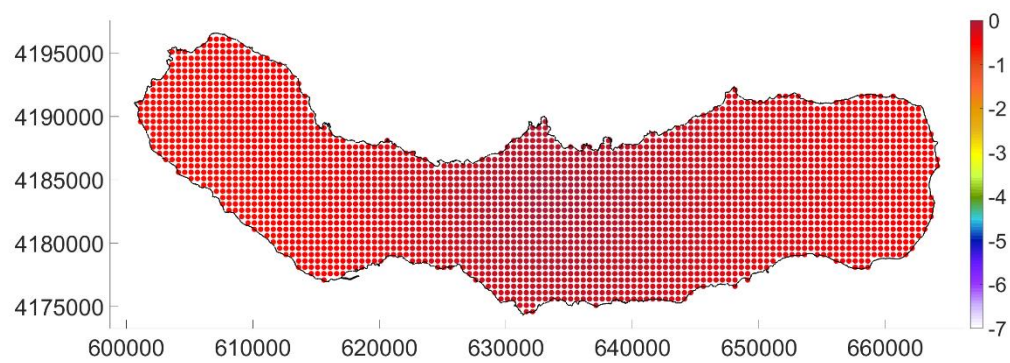
95th percentile

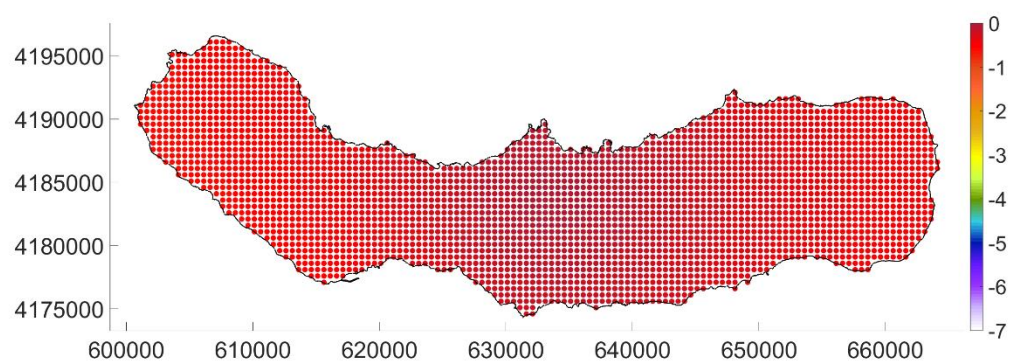
Sete Cidades Volcano conditional probability maps – 400 kg/m²5th percentile50th percentile

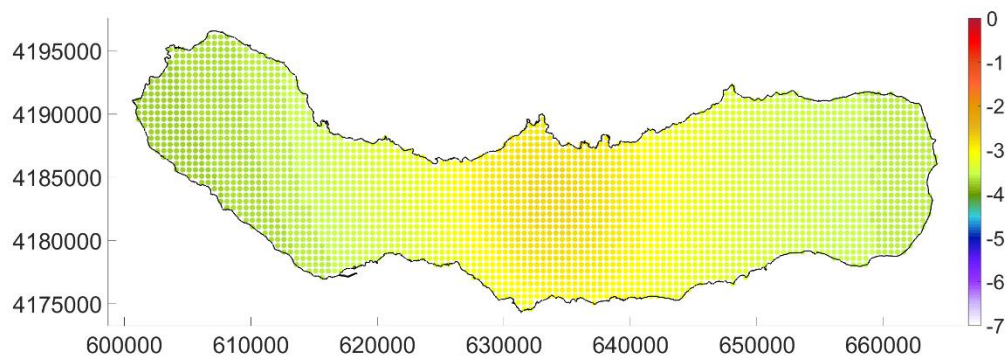
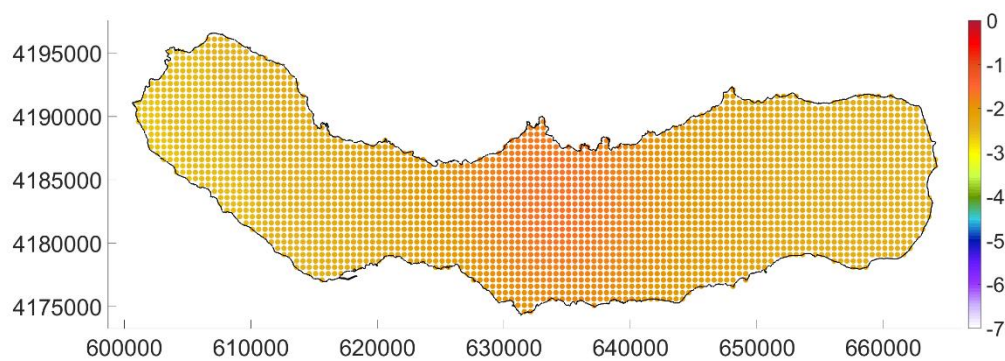
95th percentile

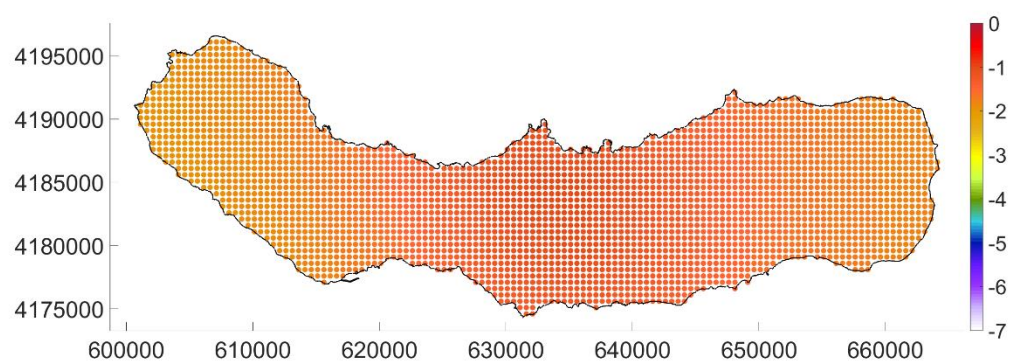
Fogo Volcano absolute probability maps – 1 kg/m²5th percentile50th percentile

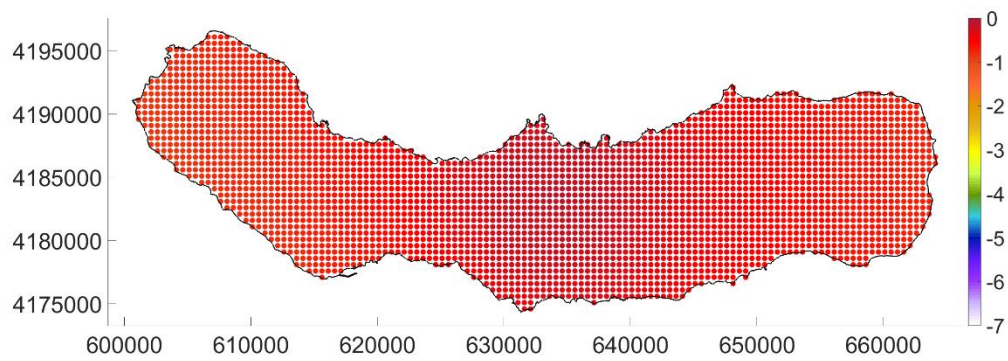
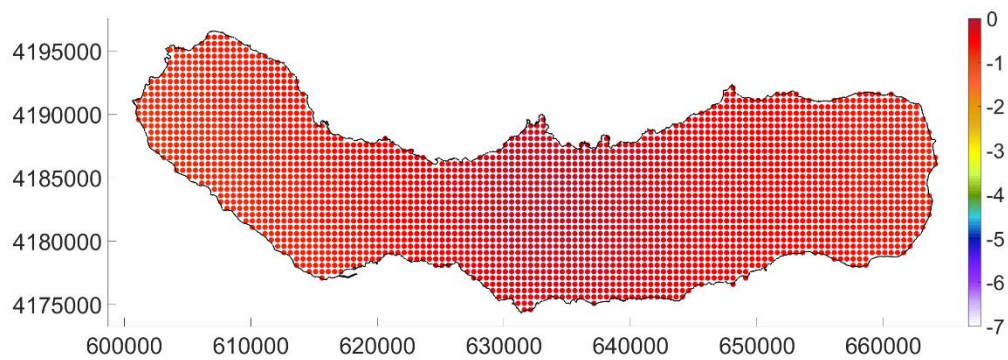
95th percentile

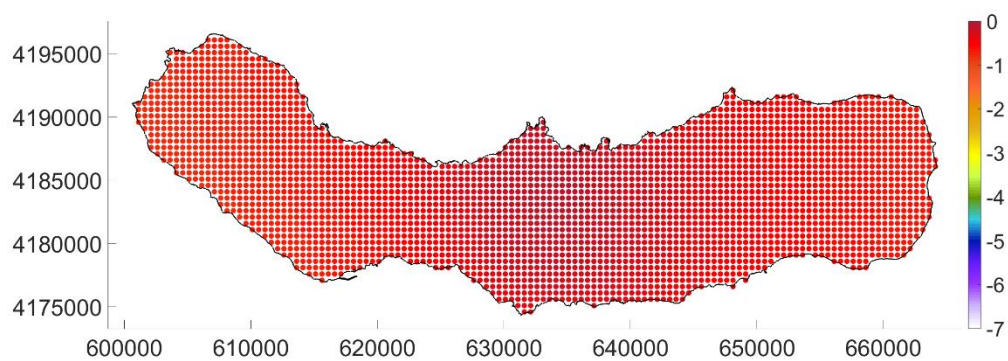
Fogo Volcano conditional probability maps – 1 kg/m²5th percentile50th percentile

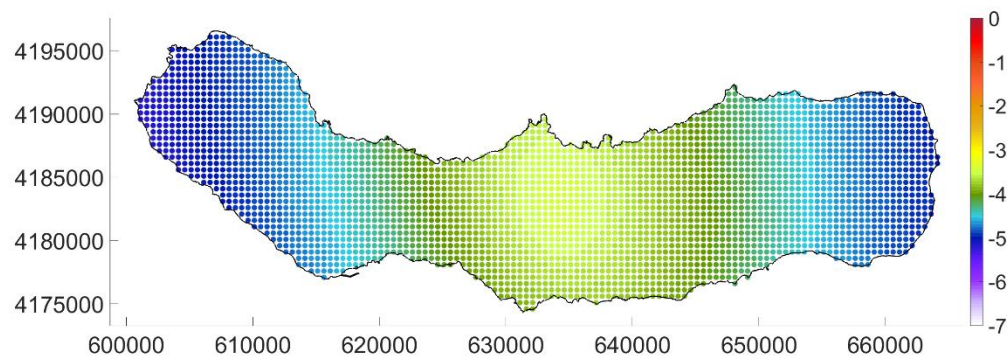
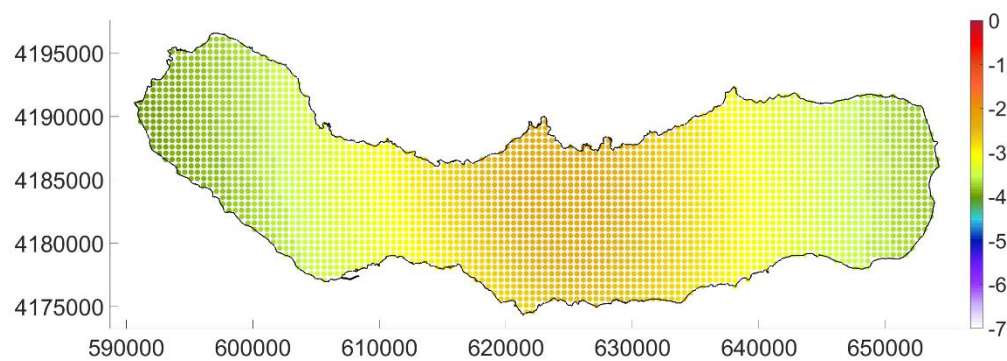
95th percentile

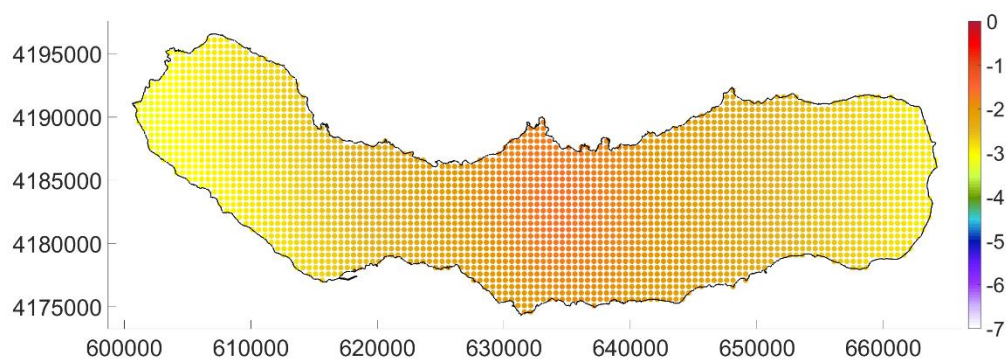
Fogo Volcano absolute probability maps – 10 kg/m²5th percentile50th percentile

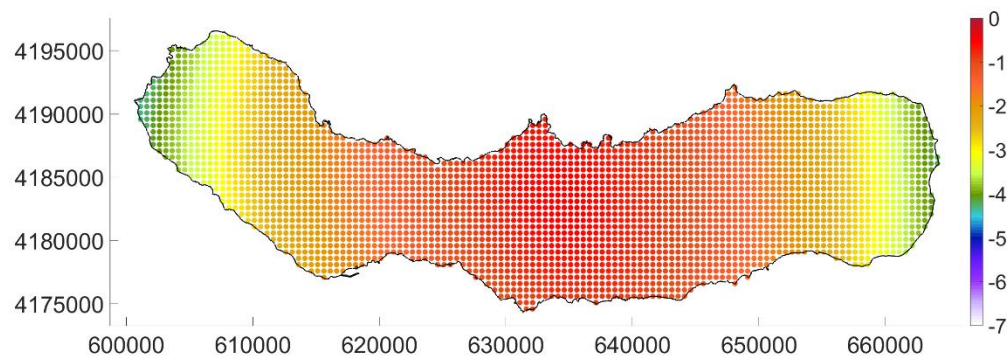
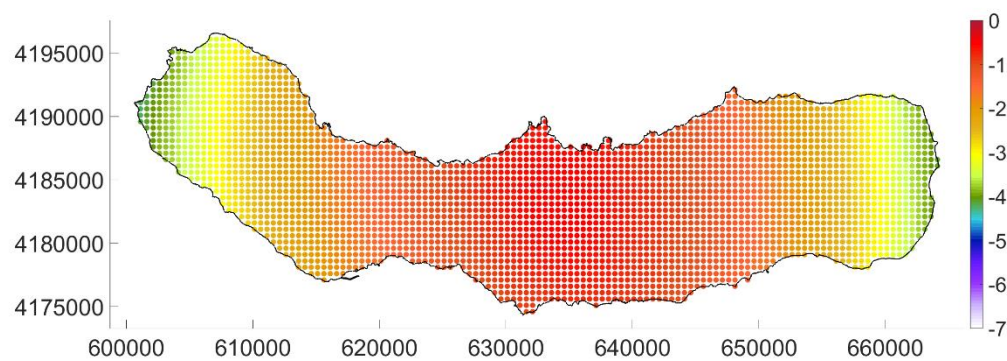
95th percentile

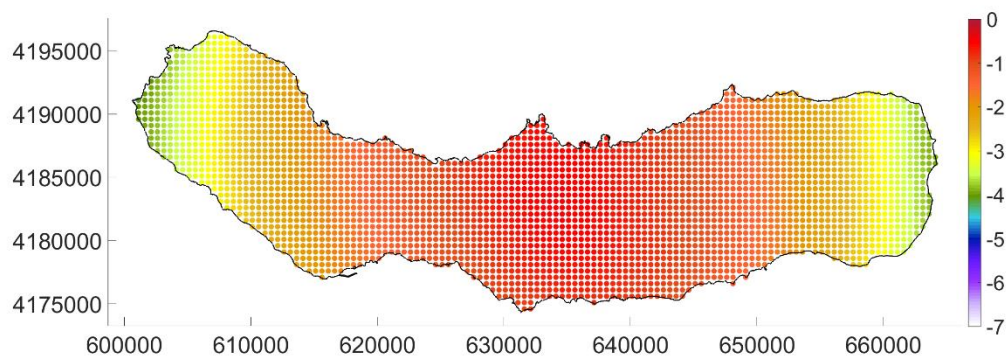
Fogo Volcano conditional probability maps – 10 kg/m²5th percentile50th percentile

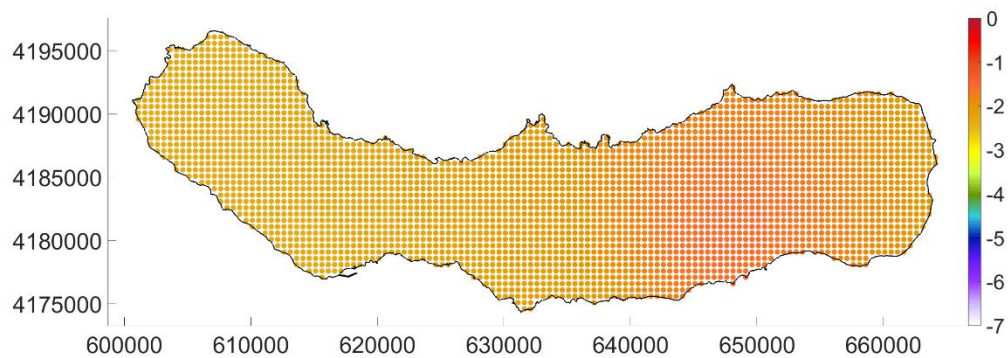
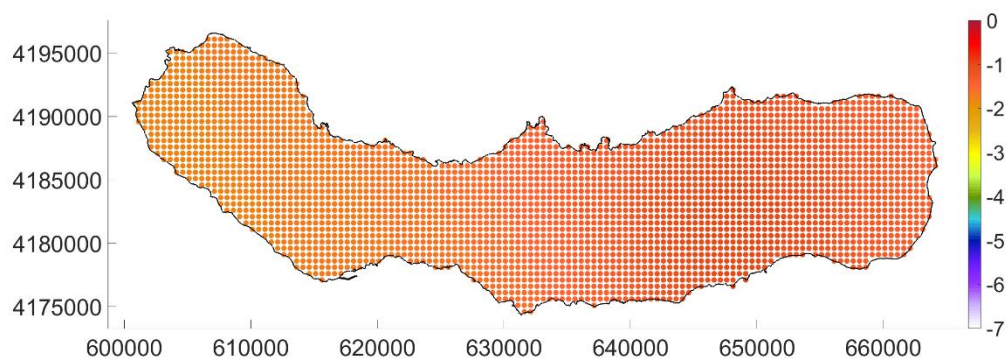
95th percentile

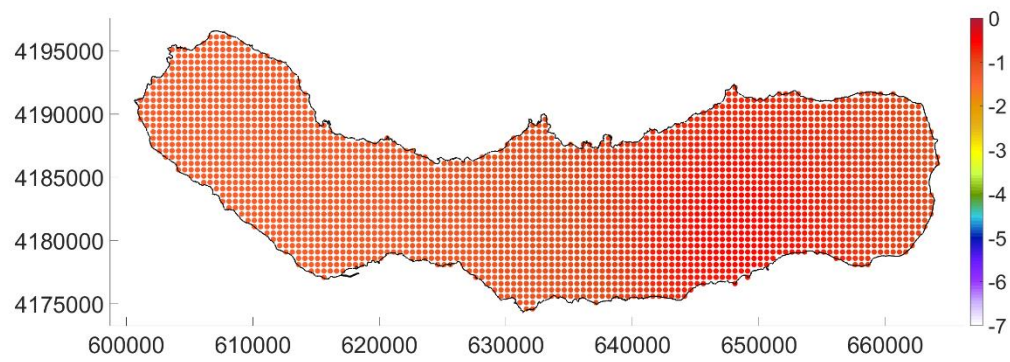
Fogo Volcano absolute probability maps – 400 kg/m²5th percentile50th percentile

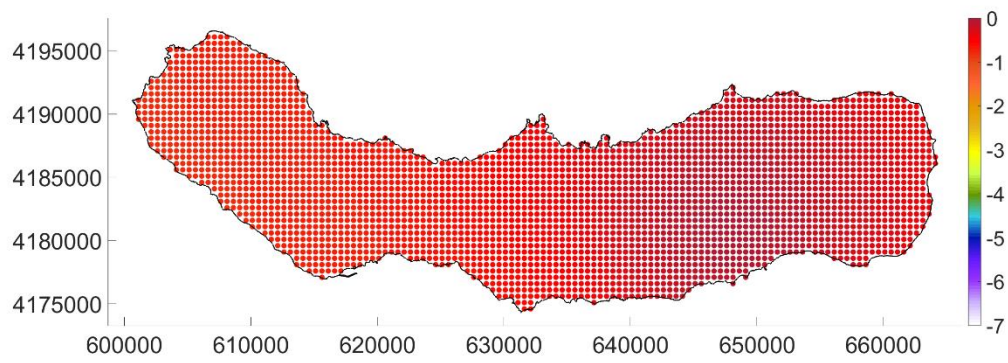
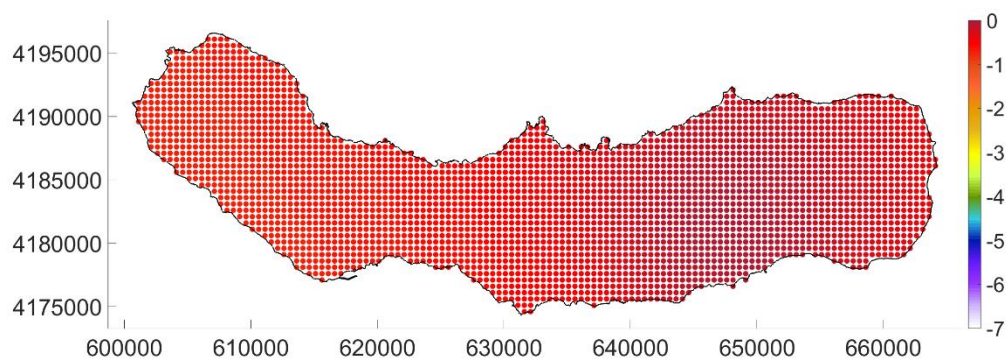
95th percentile

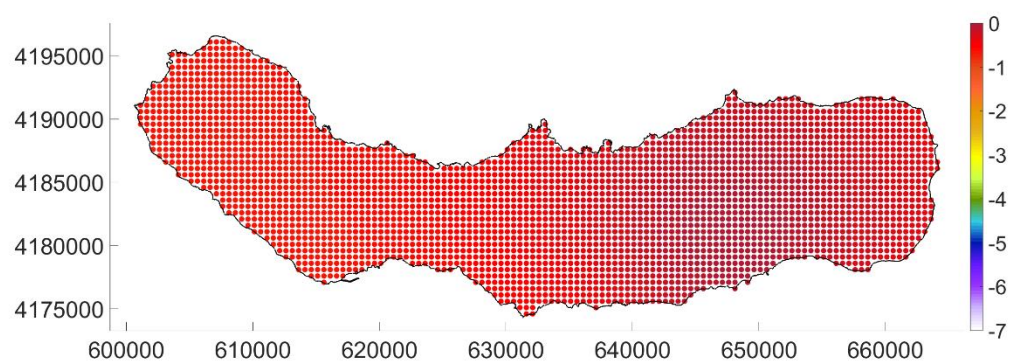
Fogo Volcano conditional probability maps – 400 kg/m²5th percentile50th percentile

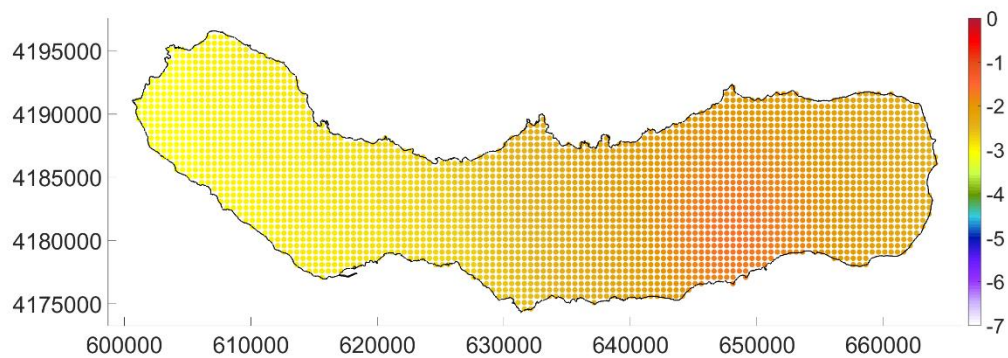
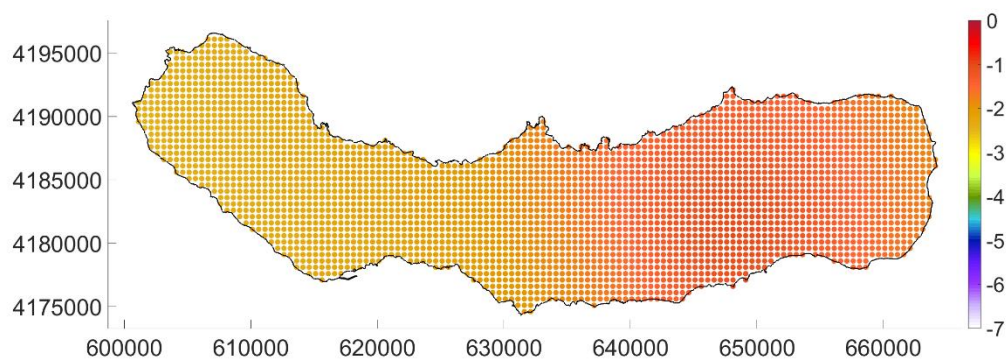
95th percentile

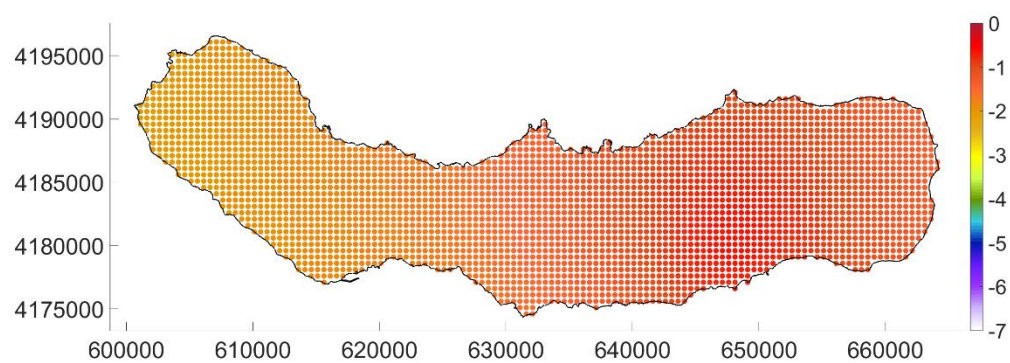
Furnas Volcano absolute probability maps – 1 kg/m²5th percentile50th percentile

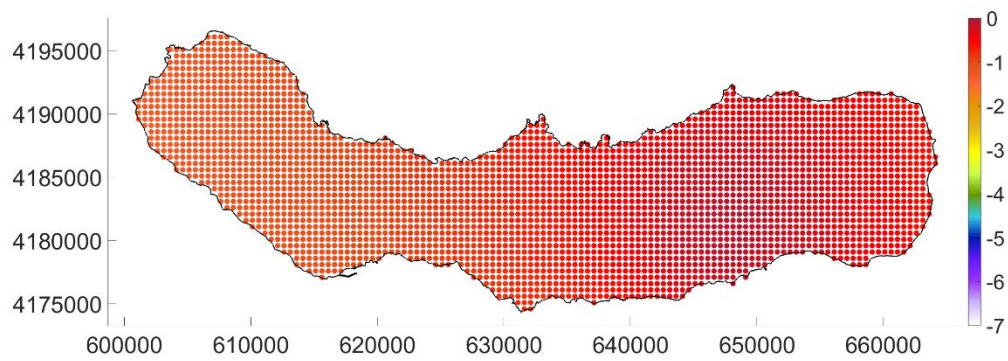
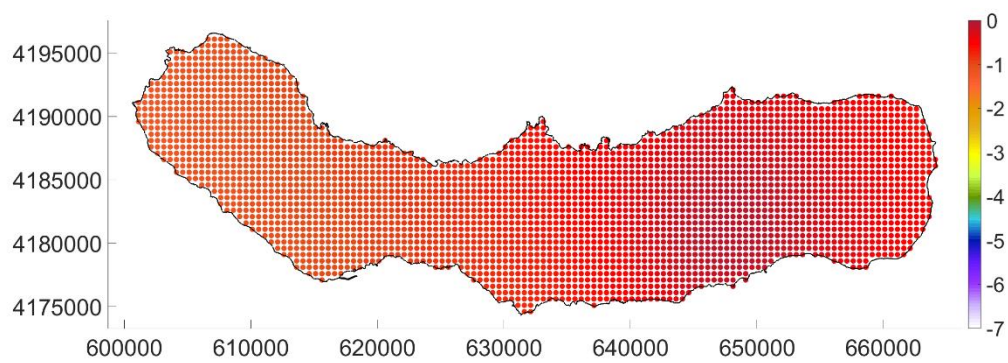
95th percentile

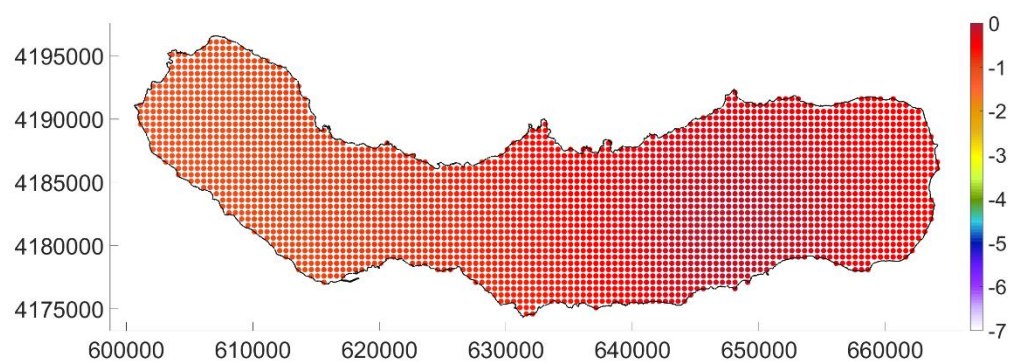
Furnas Volcano conditional probability maps – 1 kg/m²5th percentile50th percentile

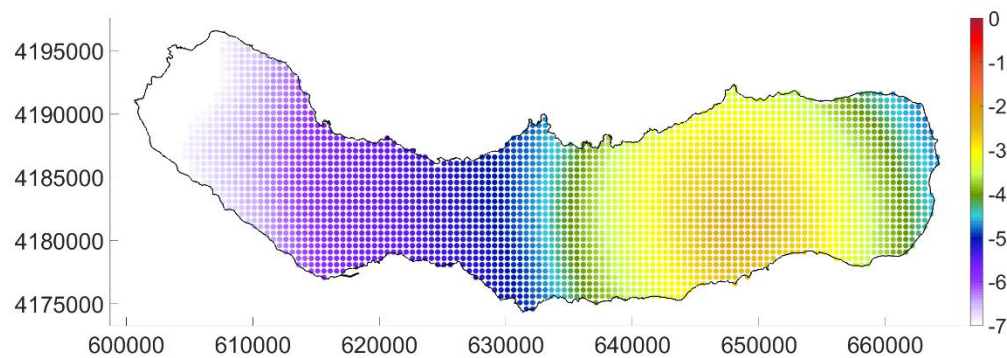
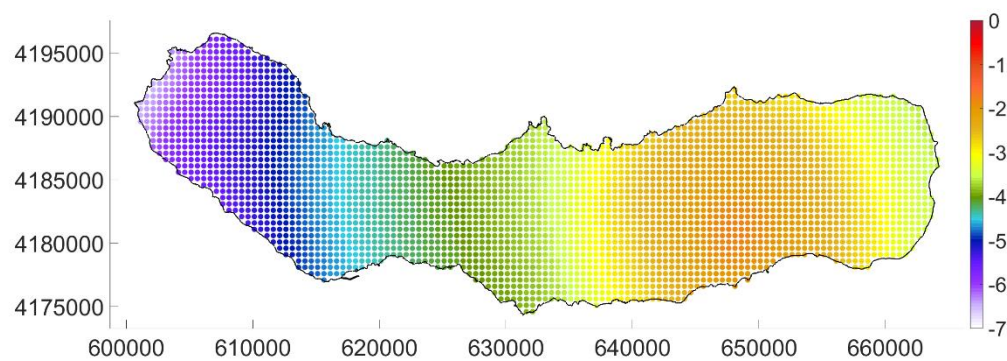
95th percentile

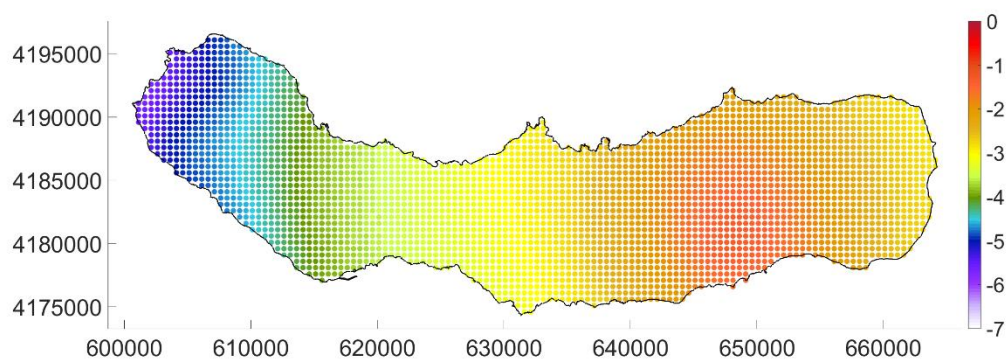
Furnas Volcano absolute probability maps – 10 kg/m²5th percentile50th percentile

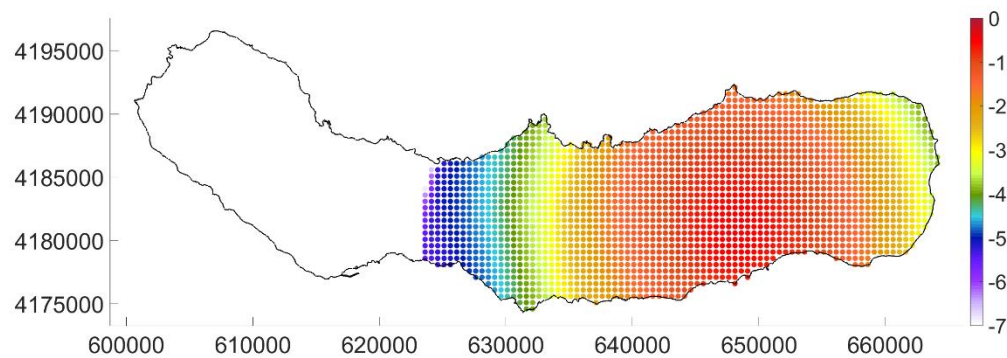
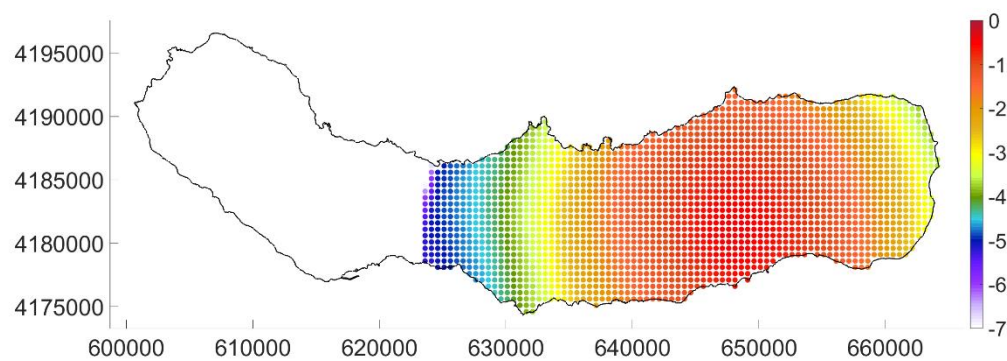
95th percentile

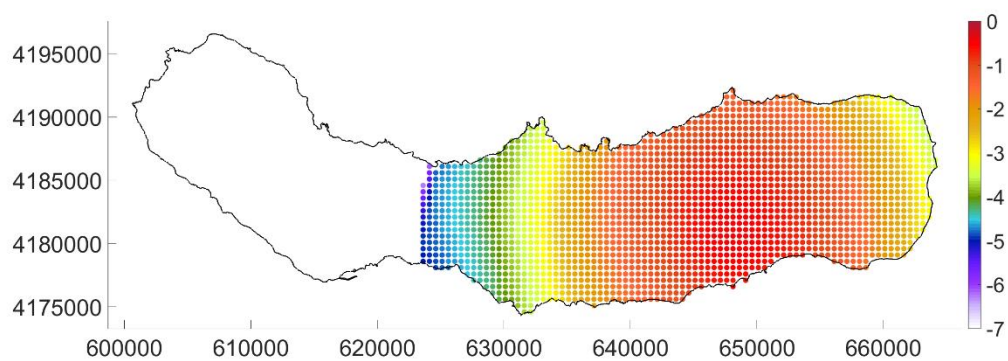
Furnas Volcano conditional probability maps – 10kg/m²5th percentile50th percentile

95th percentile

Furnas Volcano absolute probability maps – 400 kg/m²5th percentile50th percentile

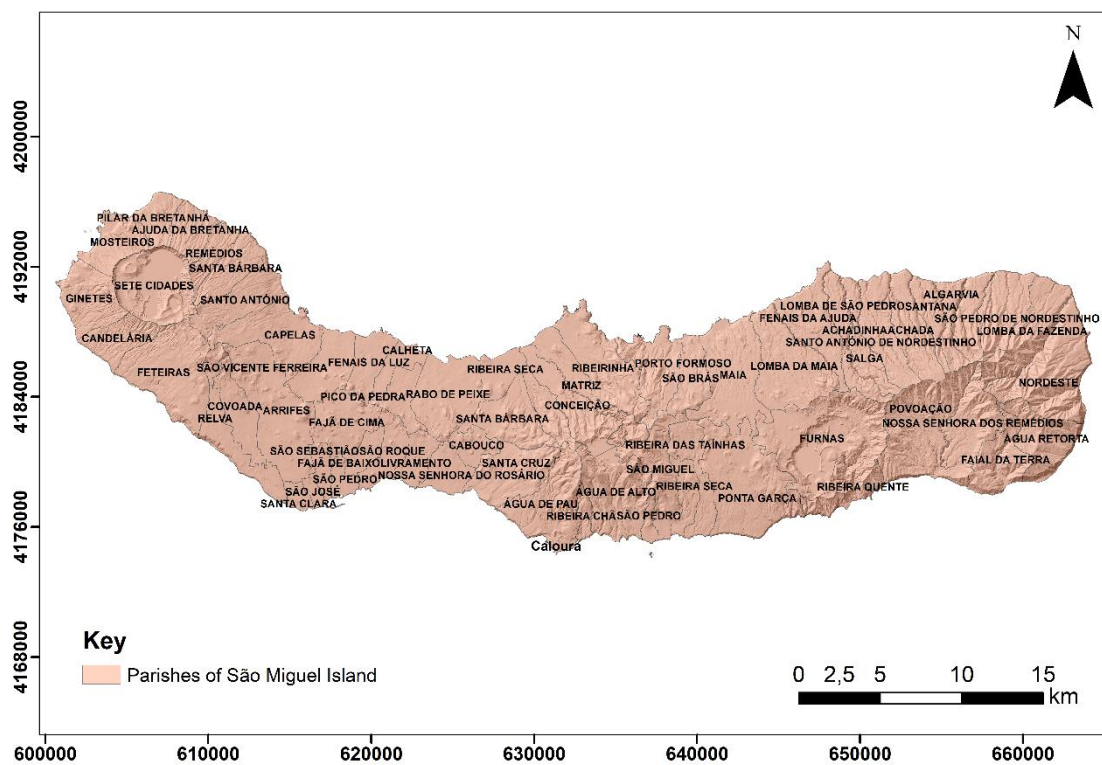
95th percentile

Furnas Volcano conditional probability maps – 400 kg/m²5th percentile50th percentile

95th percentile

Appendix A.7

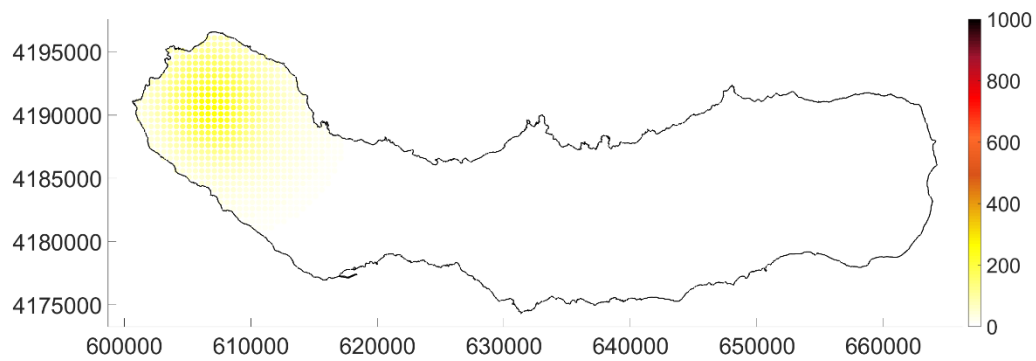
Geographical distribution of the parishes and locations of São Miguel Island



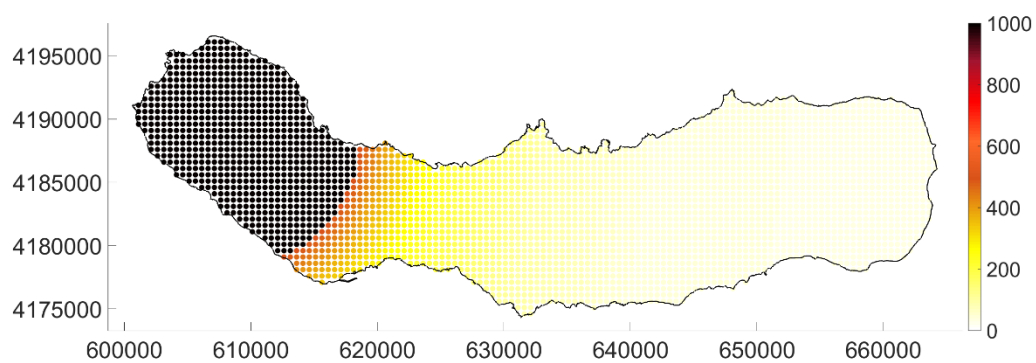
Appendix A.8

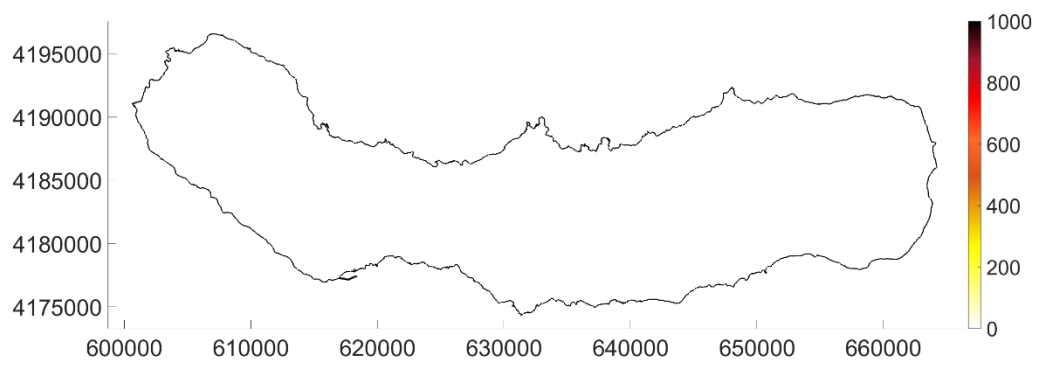
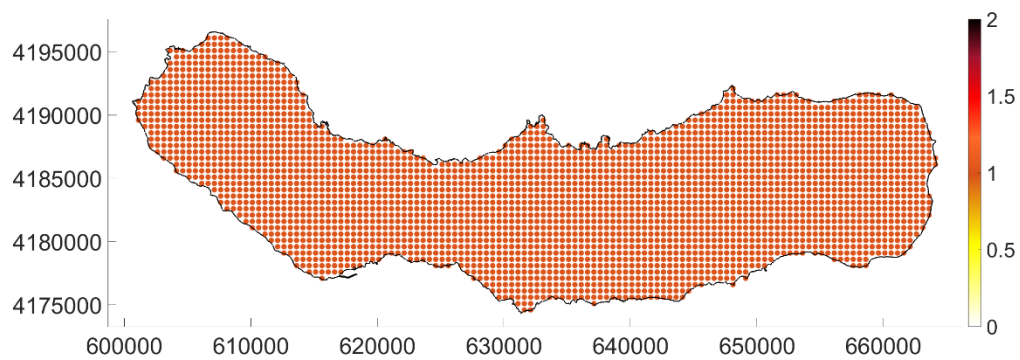
Absolute and conditional hazard maps

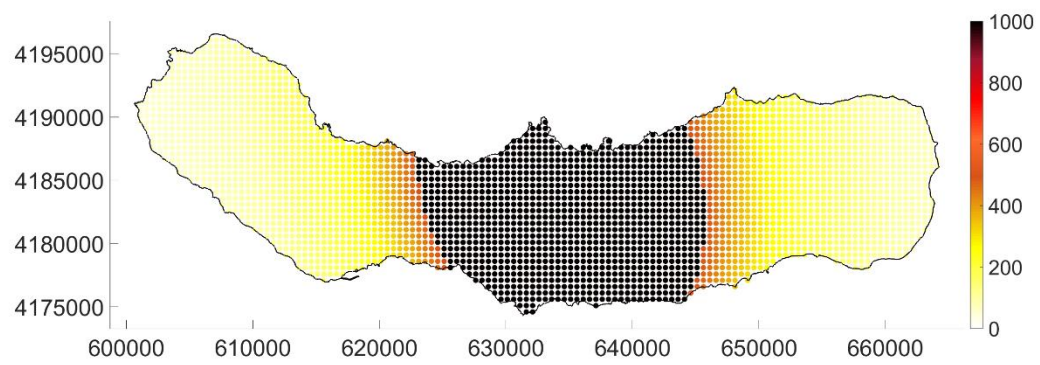
Sete Cidades Volcano absolute hazard map

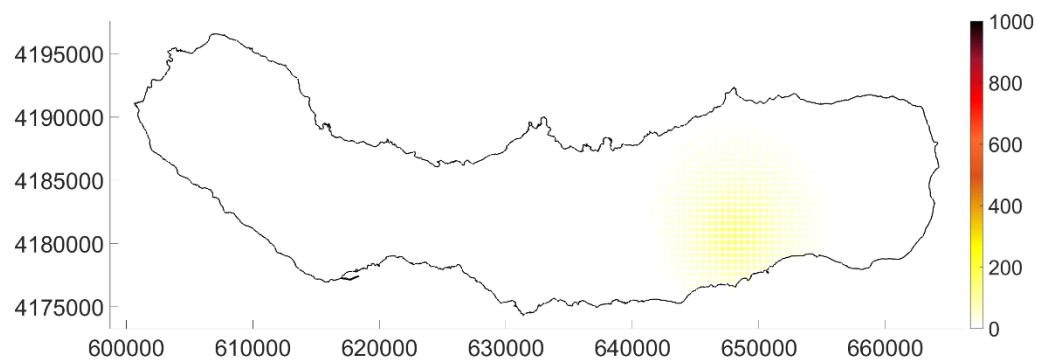
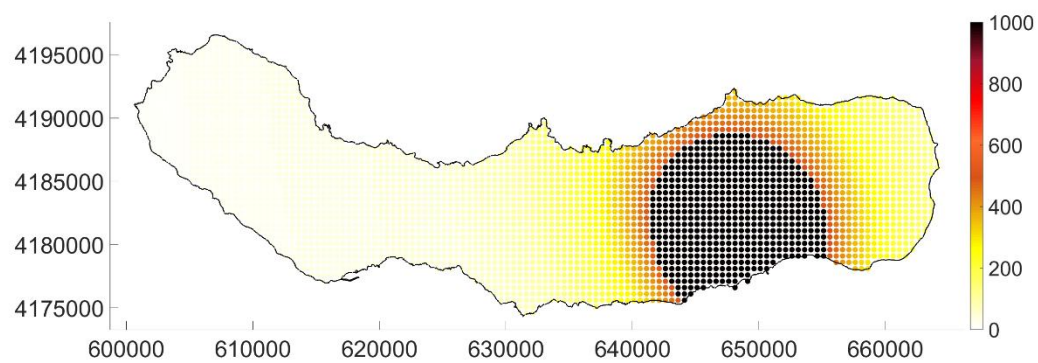


Sete Cidades Volcano conditional hazard map



Fogo Volcano absolute hazard map**Detailed scale**

Fogo Volcano conditional hazard map

Furnas Volcano absolute probability map**Furnas Volcano conditional probability map**

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2025

Assessment of volcanic hazards from explosive eruptions on islands

Simone Correia Aguiar