The use of infrasound in volcano monitoring. Contribution for future application in the Azores Islands

Dissertação de Mestrado

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOGRAPHIES

LIST OF ACRONYMS

ABL - Atmospheric Boundary Layer

ARISE2 – Atmospheric dynamics Research InfraStructure in Europe

CEA/DASE – Commissariat à l'energie atomique et aux energies alternatives, Departement Analyse, Surveillance, Environnement

CMSCG - Santa Cruz da Graciosa Municipality

CRF - Central Recording Facility

CTBT - Comprehensive Nuclear-Test-Ban Treaty

CTBTO - Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization

CVARG - Centre of Volcanology and Geological Risks Assessment

DFT - Discrete Fourier Transform

DTFT - Discrete-Time Fourier Transform

DTK-GPMCC – Dase Tool Kit - Graphical Progressive Multi-Channel Correlation

EU - European Union

EUp- Eurasian plate

FD / TD - Frequency Domain / Time-Domain

FFT - Fast Fourier Transform

GCI - Global Communication Infrastructure

GPS - Global Positioning System

GVS - Grímsvötn Volcanic System

IDC - International Data Centre

I**FFT** - Inverse Fast Fourier Transform

IMS - International Monitoring System

INGV - Istituto Nazionale di Geofisica e Vulcanologia

IP - Infrasonic Parameter

IS – Infrasound Station

IVAR - Instituto de Investigação em Vulcanologia e Avaliação de Riscos

JTA - Triple Junction of the Azores

LKO - Outside temperature long period instrument channel code

LP - Long Period

LVDT - Linear Variable Displacement Transducer

MAR – Mid-Atlantic Ridge

NAp - North American plate

NDC - National Data Centre

NUp – Nubia/African plate

OSI - On-Site Inspections

PBL - Planetary Boundary Layer

PC – Personal computer

PDC - Pyroclastic Density Current

PMCC - Progressive Multi-Channel Correlation

PSD - Power Spectral Density

PTBT - Partial Test Ban Treaty

PTS - Provisional Technical Secretariat

SOFAR - SOund Fixing And Ranging

TLE - Transient Luminous Event

ULP - Ultra Long Period

UPS - Uninterruptible Power Supply

US –United States (of America)

VPN - Virtual Private Network

VSAT - Very Small Aperture Terminal

WNRS - Wind-Noise-Reducing System

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ABSTRACT

Infrasound is an atmospheric pressure perturbation associated both to natural or man-made sources. Among the natural causes are the atmospheric extreme events like severe weather, avalanches, earthquakes and volcanic eruptions. The major sources of anthropogenic sources are explosions related with mining, chemical production and nuclear tests. Due its low frequency (<20 Hz) they can travel long distance in atmospheric waveguides and be recorded several thousand kilometres from the source.

Eruptions are processes in which volcanoes restore the equilibrium perturbed by rising magma in a chamber deep in the crust. When a volcano erupts, it releases energy in the form of pressure waves into the atmosphere, generally with low frequency, below the audible range of human hearing. The use of infrasound provides a valuable working tool for monitoring volcanic activity, both in the near- and far-field.

There are a variety of eruptive styles, and each one produces unique and different infrasound signals, most commonly related to explosions, tremor, eruptive column and degassing. Infrasound also enhances the efficacy of the volcanic hazard monitoring once the infrasonic pressure field may be directly associated with the flux rate of gas released.

Recently, infrasound studies from active volcanoes have permitted successful advances in volcanic hazards mitigation and in the understanding of volcanic source. On Etna volcano, infrasound array monitoring allowed to suggest a gas flow regime transition from slug to churn flow, driving lava fountains, with the two phases being reflected by different infrasonic signature.

The Instituto de Investigação em Vulcanologia e Avaliação de Riscos - IVAR operates an infrasound station (IS42) located in Graciosa island, which integrates the International Monitoring System (IMS) that operationalise the verification regime of the Comprehensive Test-Ban Treaty (CTBT). It also integrates the European Union ARISE project consortium, with the objective to develop collaborative research on infrasound regarding extreme events.

The work presented within the scope of this thesis has as objectives:

- (1) the verification of the capacity of the I42PT station to detect, locate and characterize infrasound waves originated from volcanic activity and propagated over long distances, showing as examples the eruption of the Grímsvötn volcano, Iceland, from 21st to 30th May 2011, and Mt. Etna volcano (Italy) paroxysmal eruptive episodes from May-August 2011 and eruptive activity between 16th to 22nd May2016.

-(2) to check the ability of the I42PT station to detect and characterize infrasonic waves originating from other extreme events in the North-Atlantic area.

RESUMO

Infrassons resultam de perturbações na pressão atmosférica associadas quer a fontes naturais quer antropogénicas. Entre as causas naturais estão eventos extremos que ocorrem na atmosfera, tais como tempestades, avalanches, sismos e erupções vulcânicas. As principais origens das fontes antropogénicas são explosões relacionadas com a atividade mineira, produção química e testes nucleares. Devido á sua baixa frequência (<20 Hz), podem percorrer longas distâncias através de correntes atmosféricas e serem registados a vários milhares de quilómetros de distância da fonte.

Erupções vulcânicas são processos através dos quais os sistemas vulcânicos restauram o equilíbrio perturbado pela ascensão de magma de um reservatório na profundidade da crosta. Quando um vulcão entra em erupção, liberta energia sob a forma de ondas de pressão para a atmosfera, geralmente de baixa frequência, abaixo da faixa audível para o ouvido humano. O uso de infrassons proporciona uma valiosa ferramenta de trabalho para monitorização da atividade vulcânica, tanto a nível local como a nível global.

Existe uma variedade de estilos eruptivos, e cada um produz inequívocos sinais de infrassons, normalmente relacionados com explosões, tremor, desenvolvimento da coluna eruptiva e desgaseificação. A utilização de infrassons aumenta a eficácia na monitorização da perigosidade vulcânica, uma vez que o campo de pressão dos infrassons pode estar diretamente relacionado com a taxa de fluxo de gás libertado.

Recentemente, o estudo de vulcões ativos através de infrassons, tem permitido, com sucesso, avanços na mitigação do risco vulcânico e na compreensão dos processos de origem vulcânica. No vulcão Etna, em Itália, a monitorização com recurso a um array de microbarómetros permitiu sugerir uma transição de fluxo de gás lento a impulsivo na génese de fontes de lava, com as duas fases a serem associadas a diferentes assinaturas dos sinais infrassónicos.

O Instituto de Investigação em Vulcanologia e Avaliação de Riscos - IVAR, opera uma estação de infrassons localizada na ilha da Graciosa, IS42, que integra o Sistema Internacional de Monitorização (IMS) que operacionaliza o regime de verificação do Tratado de Proibição Total de Ensaios Nucleares (CTBT). Integra também o consórcio do projeto ARISE da União Europeia, com o objetivo de desenvolver trabalhos de colaboração sobre a utilização de infrassons na observação de eventos extremos.

Inserido no tema, o trabalho apresentado no âmbito desta tese tem como objetivos, (1) a verificação da capacidade da estação I42PT de detetar, localizar e caraterizar ondas infrassónicas originadas por atividade vulcânica a longas distâncias, mostrando como exemplos a erupção do vulcão Grímsvötn, na Islândia, de 21 a 30 de maio de 2011, e episódios eruptivos paroxísticos de maio a agosto de 2011 e atividade eruptiva entre 16 a 22 de maio de 2016 do vulcão Mt. Etna em Itália; e (2) a verificação da capacidade da estação I42PT de detetar localizar e caraterizar ondas infrassónicas originadas por outros eventos extremos na área do Atlântico Norte.

Photo 1.1- Frank Perret (1867-1943) at the Campi Flegrei in Pozzuoli, Italy, with an improvised "geophone" in hopes of detecting magma's subterranean movements. Here, using a microphone to amplify the sounds from the earth interior, he connected a cable from the geophone to the loudspeaker on his ear.

Photo from "The Day's Work of a Volcanologist." The World's Work, V. 25, November 1907 (image in public domain).

CHAPTER 1. INTRODUCTION

1.1. Framework and objectives of the work

1.1.1. Motivation

This work arises from the need to understand, analyse and characterize the potential of the IS42 infrasound station, for remote volcanic monitoring and to establish the rationale, routines and procedures to use infrasound as a relevant tool for the Azores seismovolcanic monitoring programme.

Located on the Graciosa Island, in the Azores archipelago, this station is part of an international network of 60 infrasound stations belonging to the International Monitoring System (IMS) of the Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO).

Based on a collaboration with the University of Florence under the ARISE2 project (EU - H2020 Program), this work aims to verify the capacity of detection of volcanic eruptions based on infrasound long distance observations, and the possibility of comparing data recorded near origin by a local infrasound station, with detections obtained by the IS42 station at identical time periods.

1.1.2. Study relevance

Due to its geodynamic location, the Azores islands play an important role in understanding the tectonics, magmatism and volcanism of North Atlantic tectonic triple junction, being a natural laboratory where geophysical processes are materialized by seismic and volcanic activity.

Due to its geographic location, the IS42 station covers a key region for the Comprehensive Nuclear-Test-Ban Treaty (CTBT) monitoring purposes, complementing the coverage of other infrasound stations in the North Atlantic. At the same time, it has a key position in the Atlantic for monitoring various types of infrasound sources (volcanic eruptions, explosions or extreme weather events).

1.1.3. Research objectives

The main objective of this work is to verify the capability of volcanic eruptions detections, based on long-distance observations of the IS42 infrasound station. In this context the present work aims to verify the I42PT station capability to support the location of sources and the characterisation of infrasound waves originated from volcanic activity over long distances. This work uses as examples the Mount Etna volcano (Italy) paroxysmal eruptive episodes from May-August 2011, as well the eruptive activity between 2016 May 16 to 22, and the eruption of the Grímsvötn volcano, in Iceland, from 21st to 30th May 2011.

1.1.4. Dissertation structure and organization

In order to reach the proposed objectives, the present work is structured accordingly with the following format:

Chapter 1. Introduction: chapter referring to the objectives and structure of the work, which describes the reason for its elaboration, its purpose, as well as its organizational structure.

Chapter 2. Infrasound: introduction chapter to the infrasound definition. Starts with an introductory chapter of the concept and characteristics of infrasound. The various types of sources and physical properties of infrasound are described. A subchapter is also included referring to the atmosphere, where its structure, its properties and its effects in the infrasound propagation are characterized.

Chapter 3. IMS Infrasound Stations: this chapter is divided into 4 subchapters. The first sub-chapters starts with a historical review of Comprehensive Nuclear-Test-Ban Treaty (CTBTO) and an introduction to IMS infrasound stations The third sub-chapter describes the basic components of an infrasound monitoring station and the later one present the general concepts in infrasound processing.

Chapter 4. Methodology: this chapter is divided into 4 subchapters. The first sub-chapter is related to introduction methodology. The second one describes the international station IS42, located in Graciosa Island, Azores archipelago, which data is the central base of the study of this work, and characterizes the geographical and geological framework of the area where the station was established. Next subchapter describes the ETN infrasound array near Etna Volcano and its characteristics. The later subchapter characterizes the data acquisition system and the data preparation, organization and processing.

Chapter 5. Results of long–range infrasound detections of volcanic activity by IS42 station: being one of the objectives of this work, this chapter is presented through the results obtained in the analysis of the detections. This chapter begin to make a brief introduction to the topic of volcanic monitoring using infrasound technics, followed by two subchapters corresponding to Mount Etna and Grímsvötn volcanoes, in which an introduction to the theme is presented in the first part and the framework of the study area is characterized. In the second part of each subchapter, results of the IS42 station are presented, in the time period corresponding to the eruption of the Mount Etna volcano between 2011 May - August lava-fountaining activity, on 16th- 22nd May 2016 Etna eruptive activity, and from Grímsvötn volcano, between May 21th to 28th, 2011 respectively.

Chapter 6. Discussion of the results: in this chapter we present the results of the detections potentially related to the Mount Etna volcano and the Grímsvötn volcano as well as the analysis and discussion of these same results.

Final considerations: resume the essential ideas retained and achieved by this project as well as the presents the perspectives of the work to be developed in the future.