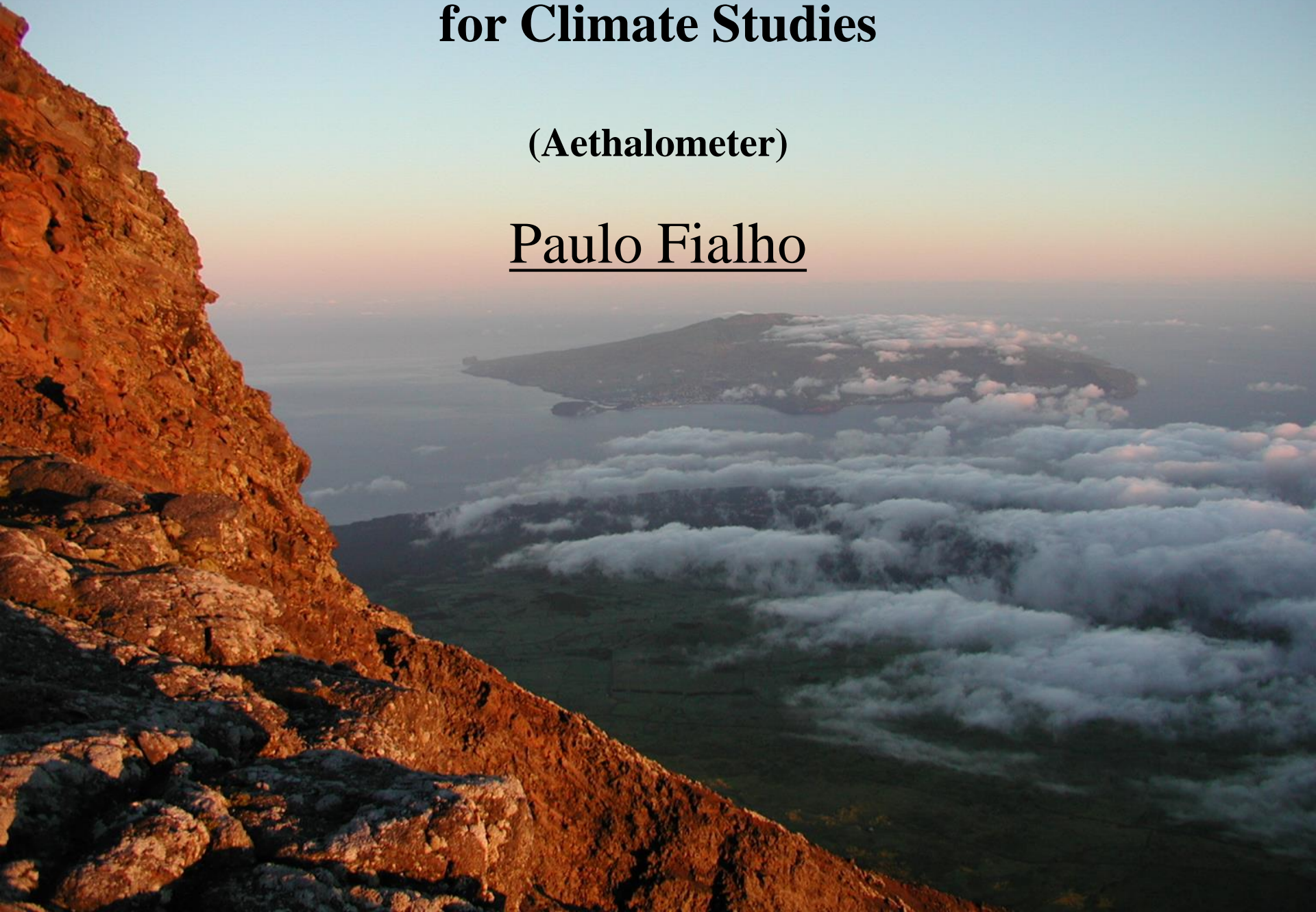
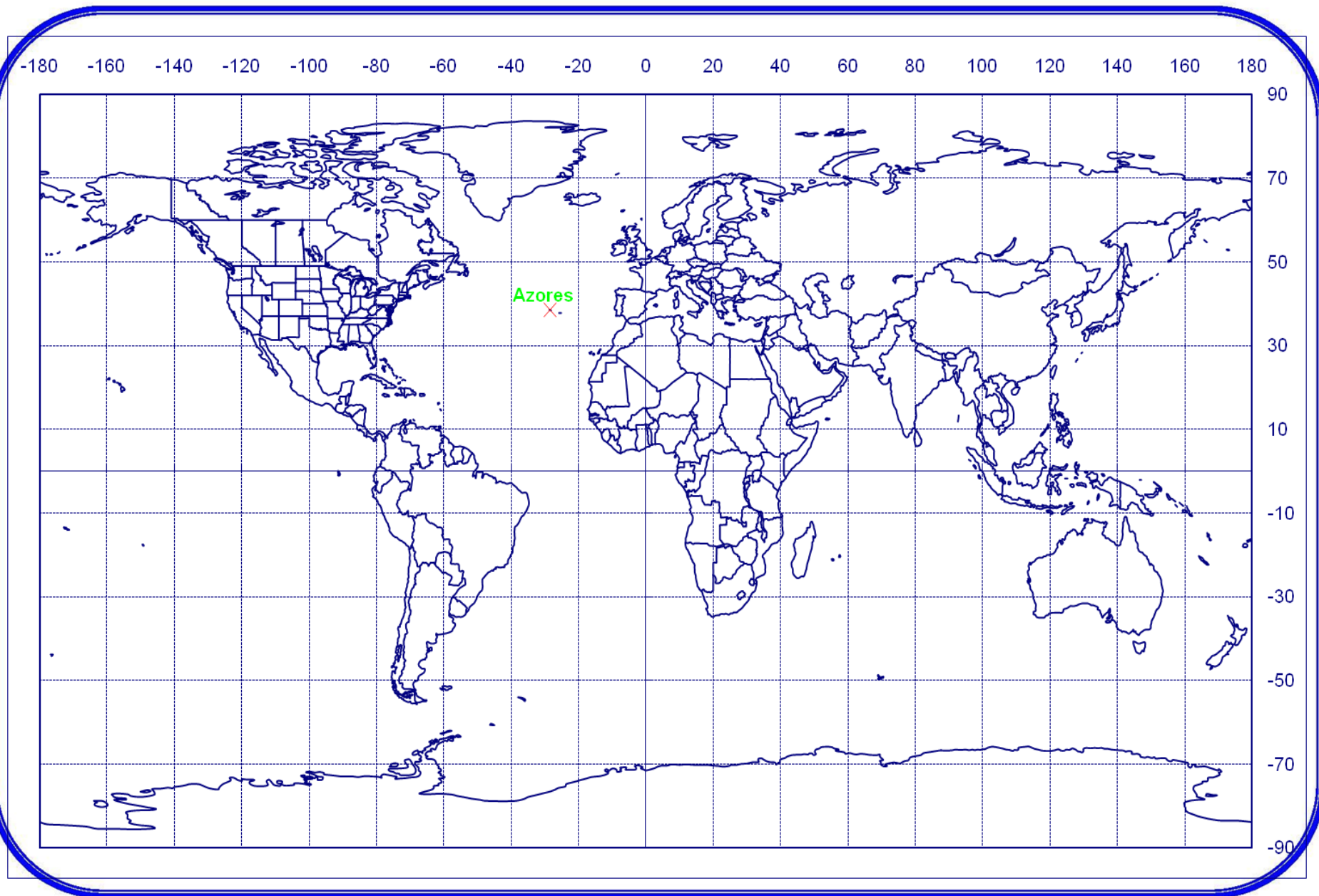


Optical Measurement and Aerosol Filter Loading for Climate Studies

(Aethalometer)

Paulo Fialho







Azores Archipelago – Central Group





Objectives

- Develop methodologies to compensate for apparent absorption caused by scattering and shadow due to the use of a filter matrix support.
 - Development of an improved compensation technique for the AE's attenuation coefficient, $\sigma_{ANT-comp}$.

$$\sigma_{ATN-comp}(\lambda, t) = f(ATN, \lambda, t) \times \sigma_{abs}(\lambda, t)$$

- Correlation of the $\sigma_{ANT-comp}$, with MAAP's absorption coefficient measurements, σ_{abs} , to evaluate the AE's C_{ref} (shadow effect) and R (scattering) corrections for the sampled aerosol.

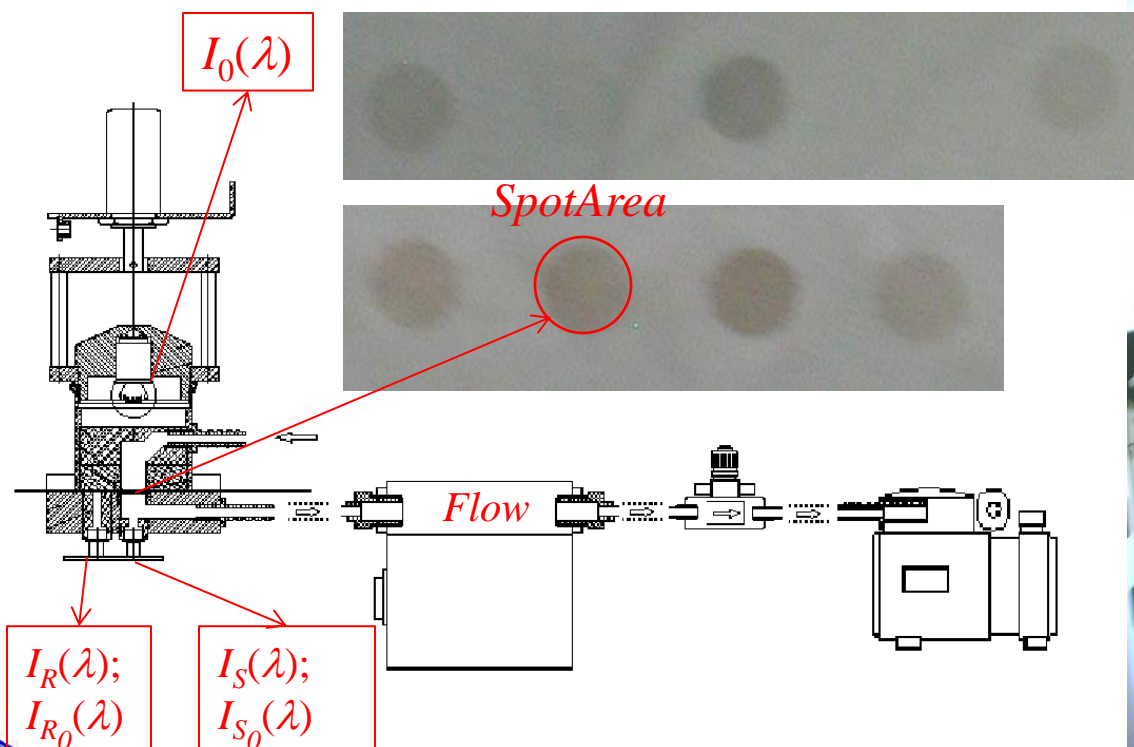
$$\sigma_{abs}(\lambda, t) = \frac{\sigma_{ATN-comp}(\lambda, t)}{C_{ref} \times R}$$

Aethalometer

$$ATN_S(\lambda) = -\ln\left(\frac{I_S(\lambda) - I_{S_0}(\lambda)}{I_0(\lambda)}\right) \text{ and } ATN_R(\lambda) = -\ln\left(\frac{I_R(\lambda) - I_{R_0}(\lambda)}{I_0(\lambda)}\right)$$

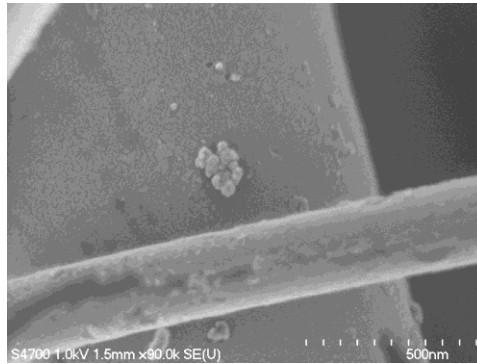
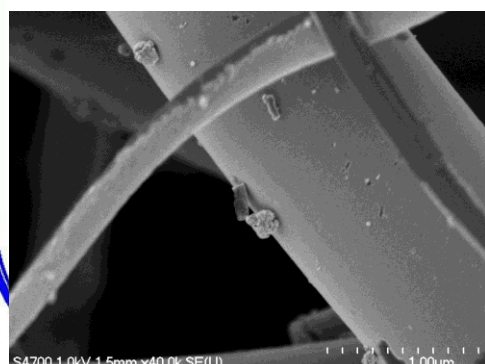
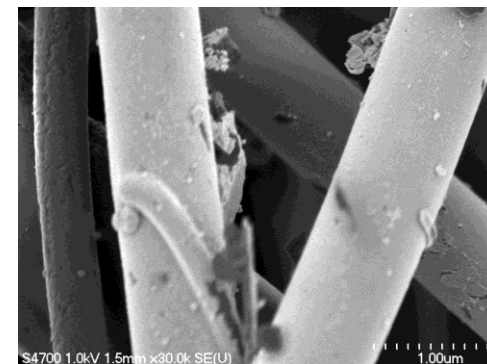
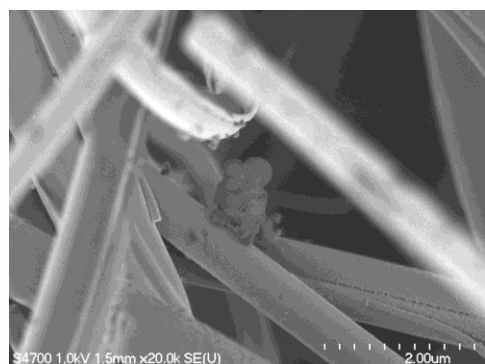
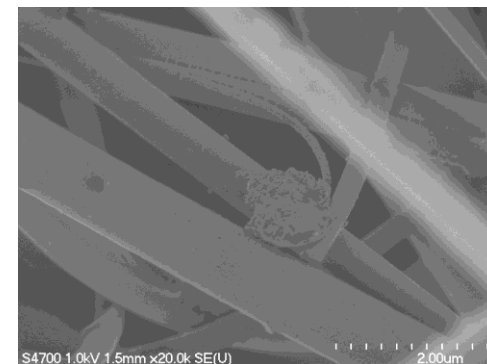
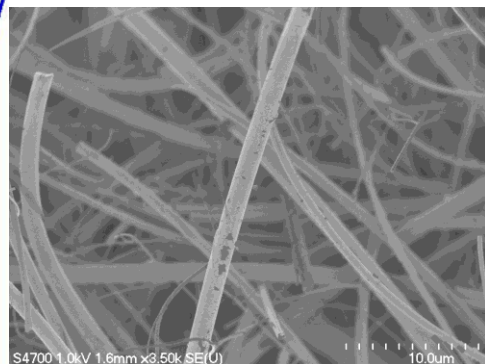
$$ATN(\lambda) = ATN_S(\lambda) - ATN_R(\lambda) \Rightarrow ATN(\lambda) = -\ln\left(\frac{I_S(\lambda) - I_{S_0}(\lambda)}{I_R(\lambda) - I_{R_0}(\lambda)}\right)$$

$$ATN(\lambda) = C_{aerosol} \times L \times S_{aerosol}(\lambda) \text{ where } L = \frac{\text{Flow}}{\text{SpotArea}}$$





Soot (Black Carbon) courtesy of Dr. Claudio Mazzoleni from MTU





Different Spot Time Loading Experiment Setup

- All the instruments used in the experiment sampled simultaneously from a common chamber with continuously refreshed dried ambient air.
 - **Four** High Sensitivity (HS) Aethalometers (AE)
(370, 470, 520, 590, 660, 880, 950 nm)
 - **Four** Extended Range (ER) Aethalometers (AE)
(370, 470, 520, 590, 660, 880, 950 nm)
 - **Three** Multi Angle Absorption Photometers (MAAP)
(637 nm)



Different Spot Time Loading Experiment Setup

- *Aethalometer's* were divided in three different groups sampling with a time difference of 3 hours but with the same flow rate.
 - **AE-31** – 4 dm³/min
 - HS#160; ER#408
 - HS#679; ER#427
 - HS#268; ER#945
- *MAAP's* where used as a secondary reference method for absorption coefficient, σ_{abs} (637 nm).
 - **MAAP-5012** – 10 dm³/min
 - #080; #012; #140



Working Equations

- Aethalometer (AE)

$$\sigma_{ATN}(\lambda, t) = \frac{SpotArea}{\langle Flow(\Delta t) \rangle} \times \frac{ATN(\lambda, t) - ATN(\lambda, t - \Delta t)}{\Delta t}$$

$$\sigma_{ATN}(\lambda, t; Mm^{-1}) = C_{BC}(t; ng.m^{-3}) \times S_{BC}(\lambda)$$

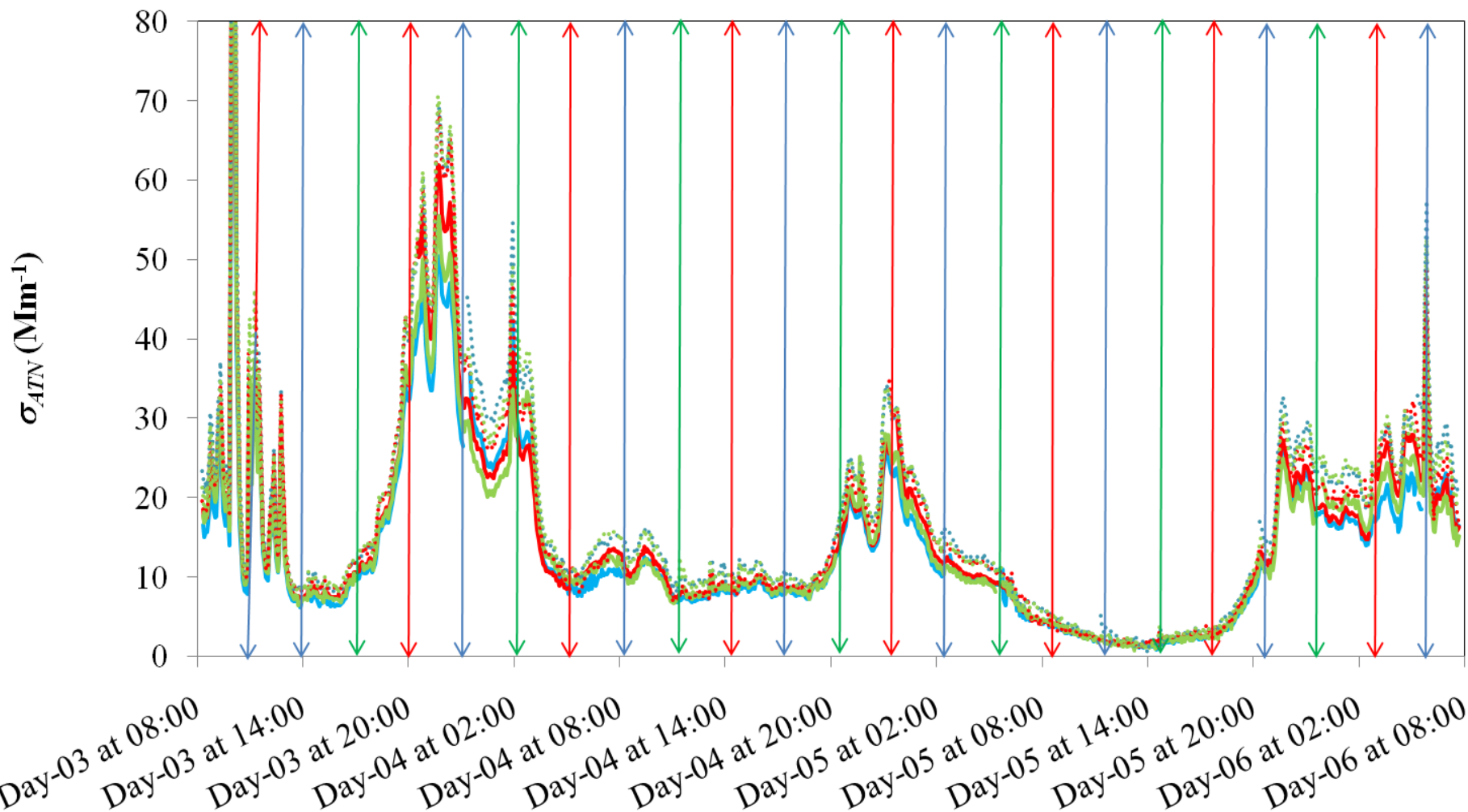
$$S_{BC}(\lambda) = \left(\frac{14.625(m^2 g^{-1} \mu m)}{\lambda(nm)} \right) \text{ is the } BC \text{ aerosol specific absorption cross - section}$$

- Multi Angle Absorption Photometer (MAAP)

$$\sigma_{abs}(Mm^{-1}) = \frac{C_{BC}(ng.m^{-3}) \times 6.5(m^2 / g)}{1000}$$

**Aethalometer's ($\lambda = 660 \text{ nm}$)**

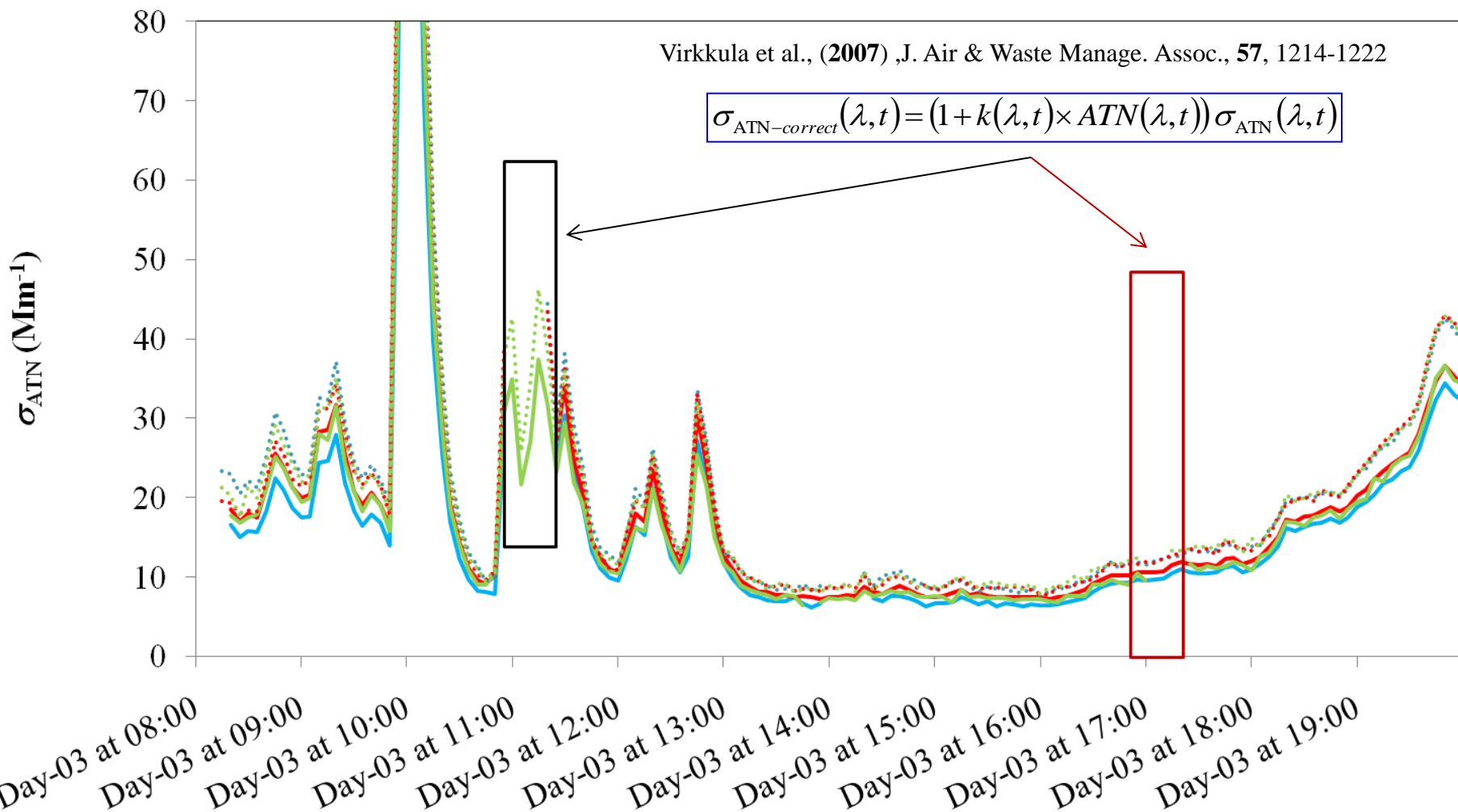
— HS#160 - NOAA — HS#679 - FMI — HS#268 - UAc
..... ER#408 - JRC ER#427 - ETS ER#945 - PSI





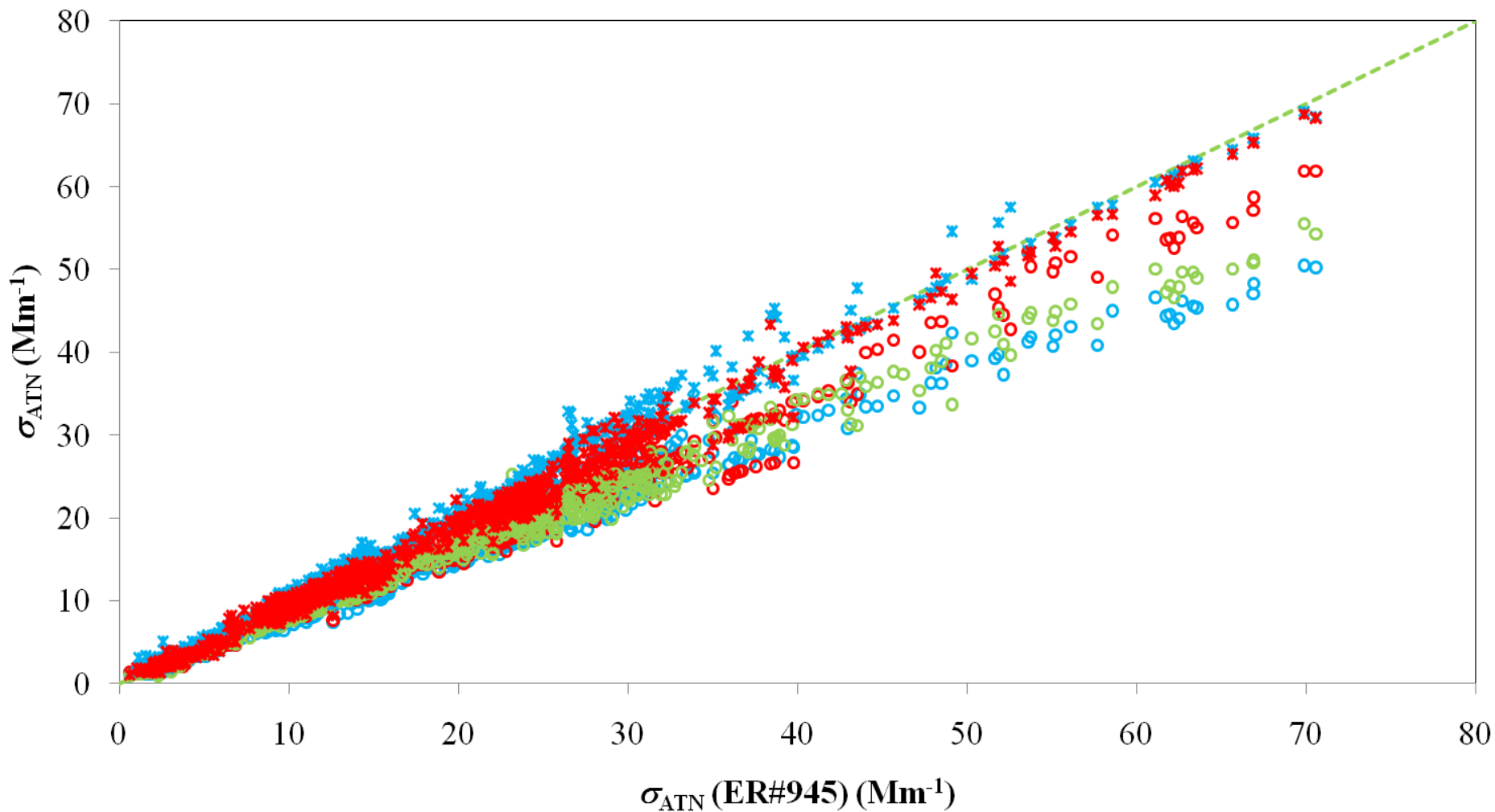
Aethalometer's ($\lambda = 660 \text{ nm}$)

— HS#160 - NOAA — HS#679 - FMI — HS#268 - UAc
..... ER#408 - JRC ER#427 - ETS ER#945 - PSI



**Aethalometer's ($\lambda = 660 \text{ nm}$)**

- HS#160 - NOAA ○ HS#679 - FMI ○ HS#268 - UAc
× ER#408 - JRC × ER#427 - ETS - - - Line 1:1





$$\sigma_{\text{ATN-Comp}}(\lambda, t) = f(\text{ATN}, \lambda, t) \times \sigma_{\text{ATN}}(\lambda, t)$$

$$f(\text{ATN}, \lambda, t) = 1 + k(\lambda) \times \text{ATN}(\lambda, t)$$

$$\sigma_{\text{ATN-Comp}}(\lambda, t, \text{Ref. AE}) = a_0(\text{AE\#}) (1 + k(\lambda) \times \text{ATN}(\lambda, t; \text{AE\#})) \sigma_{\text{ATN}}(\lambda, t; \text{AE\#})$$

$$\left\{ \begin{array}{l} \sigma_{\text{ATN-Comp}}(\lambda, t; \text{ER\#945}) = a_0(\text{ER\#945}) (1 + k(\lambda) \times \text{ATN}(\lambda, t; \text{ER\#945})) \sigma_{\text{ATN}}(\lambda, t; \text{ER\#945}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t; \text{ER\#945}) = a_0(\text{HS\#160}) (1 + k(\lambda) \times \text{ATN}(\lambda, t; \text{HS\#160})) \sigma_{\text{ATN}}(\lambda, t; \text{HS\#160}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t; \text{ER\#945}) = a_0(\text{HS\#268}) (1 + k(\lambda) \times \text{ATN}(\lambda, t; \text{HS\#268})) \sigma_{\text{ATN}}(\lambda, t; \text{HS\#268}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t; \text{ER\#945}) = a_0(\text{HS\#679}) (1 + k(\lambda) \times \text{ATN}(\lambda, t; \text{HS\#679})) \sigma_{\text{ATN}}(\lambda, t; \text{HS\#679}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t; \text{ER\#945}) = a_0(\text{ER\#408}) (1 + k(\lambda) \times \text{ATN}(\lambda, t; \text{ER\#408})) \sigma_{\text{ATN}}(\lambda, t; \text{ER\#408}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t; \text{ER\#945}) = a_0(\text{ER\#427}) (1 + k(\lambda) \times \text{ATN}(\lambda, t; \text{ER\#427})) \sigma_{\text{ATN}}(\lambda, t; \text{ER\#427}) \end{array} \right.$$

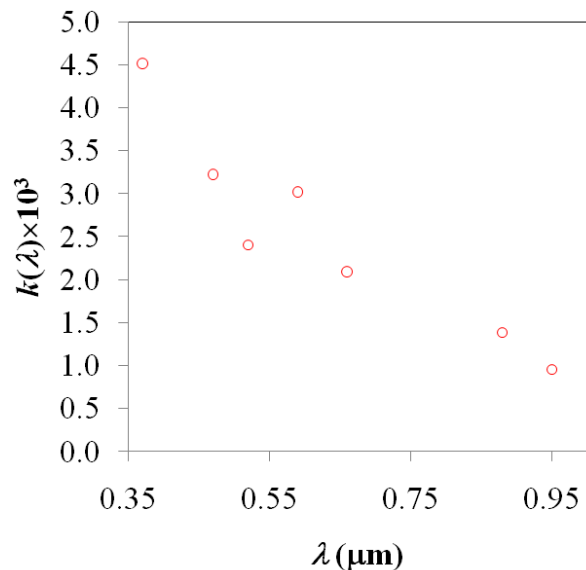
ER#945 was choose as the reference Aethalometer $\Rightarrow a_0(\text{ER\#945}) = 1.00$

λ (nm)	$k(\lambda) \times 10^3$
370	4.51
470	3.22
520	2.40
590	3.02
660	2.09
880	1.39
950	0.96

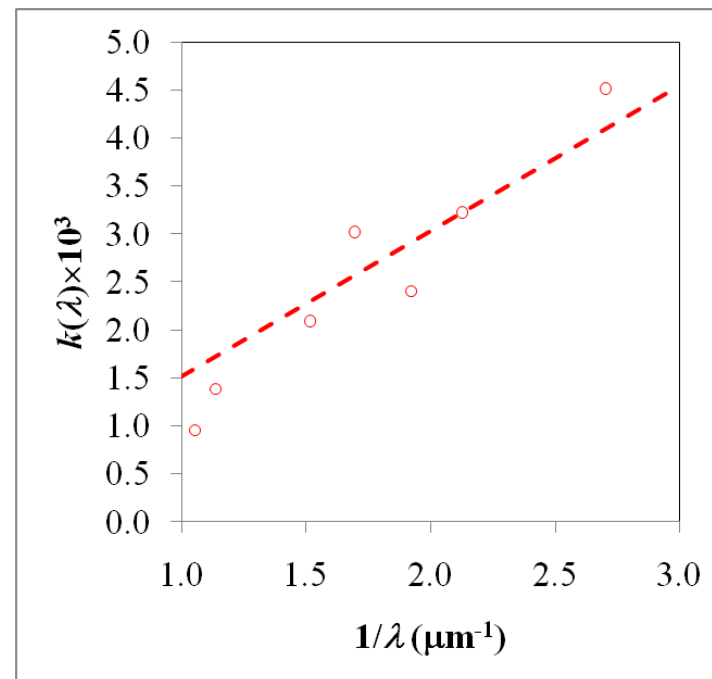
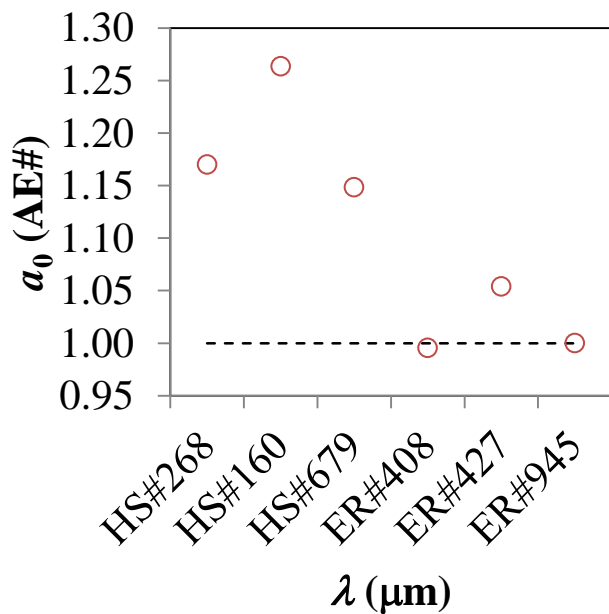
AE#	a_0 (AE#)
ER#945	1.00
HS#160	1.26
HS#268	1.17
HS#679	1.15
ER#408	1.00
ER#427	1.05

$N = 28154$

Standard Error = 1.5 Mm^{-1}



$$k(\lambda) = \frac{k}{\lambda} \quad \text{where } k = 1.49 \pm 0.09 \text{ nm} \quad r = 0.900$$





$$\sigma_{\text{ATN-Comp}}(\lambda, t; \text{Ref. AE}) = a_0(\text{AE\#}) \times f(\text{ATN}, \lambda, t; \text{AE\#}) \times \sigma_{\text{ATN}}(\lambda, t; \text{AE\#})$$

$$f(\text{ATN}, \lambda, t; \text{AE\#}) = \left(1 + k \times \frac{\text{ATN}(\lambda, t; \text{AE\#})}{\lambda} \right)$$

$$\left\{ \begin{array}{l} \sigma_{\text{ATN-Comp}}(\lambda, t, \text{ER\#945}) = a_0(\text{ER\#945}) \left(1 + k \times \frac{\text{ATN}(\lambda, t, \text{ER\#945})}{\lambda} \right) \sigma_{\text{ATN}}(\lambda, t, \text{ER\#945}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t, \text{ER\#945}) = a_0(\text{HS\#160}) \left(1 + k \times \frac{\text{ATN}(\lambda, t, \text{HS\#160})}{\lambda} \right) \sigma_{\text{ATN}}(\lambda, t, \text{HS\#160}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t, \text{ER\#945}) = a_0(\text{HS\#268}) \left(1 + k \times \frac{\text{ATN}(\lambda, t, \text{HS\#268})}{\lambda} \right) \sigma_{\text{ATN}}(\lambda, t, \text{HS\#268}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t, \text{ER\#945}) = a_0(\text{HS\#679}) \left(1 + k \times \frac{\text{ATN}(\lambda, t, \text{HS\#679})}{\lambda} \right) \sigma_{\text{ATN}}(\lambda, t, \text{HS\#679}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t, \text{ER\#945}) = a_0(\text{ER\#408}) \left(1 + k \times \frac{\text{ATN}(\lambda, t, \text{ER\#408})}{\lambda} \right) \sigma_{\text{ATN}}(\lambda, t, \text{ER\#408}) \\ \sigma_{\text{ATN-Comp}}(\lambda, t, \text{ER\#945}) = a_0(\text{ER\#427}) \left(1 + k \times \frac{\text{ATN}(\lambda, t, \text{ER\#427})}{\lambda} \right) \sigma_{\text{ATN}}(\lambda, t, \text{ER\#427}) \end{array} \right.$$

$$k = 1.51 \pm 0.15 \text{ nm}$$

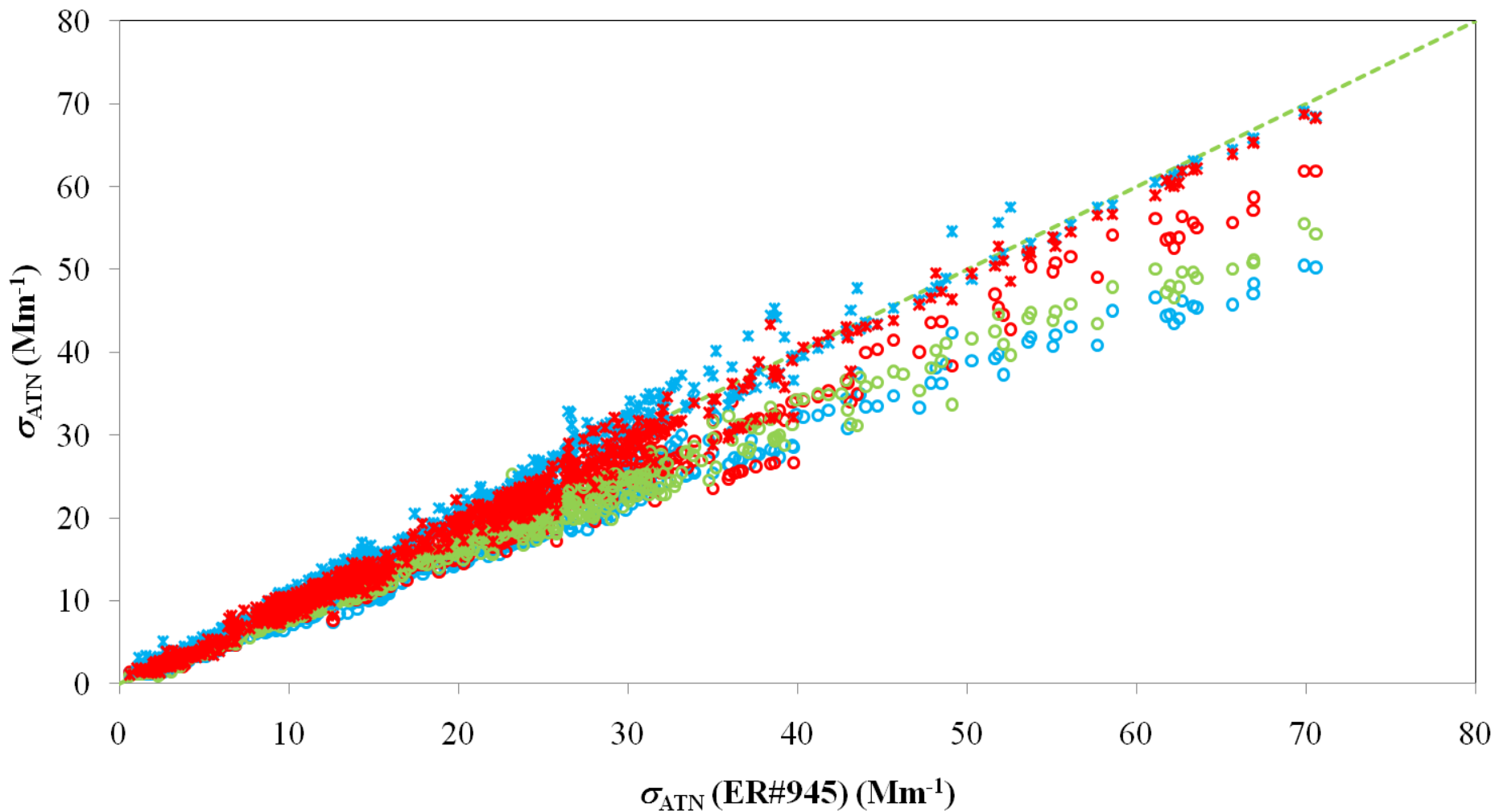
$$N = 28154$$

$$\text{Standard Error} = 1.5 \text{ Mm}^{-1}$$

AE#	$a_0(\text{AE\#})$ ± 0.004
ER#945	1.000
HS#160	1.260
HS#268	1.167
HS#679	1.146
ER#408	0.995
ER#427	1.054

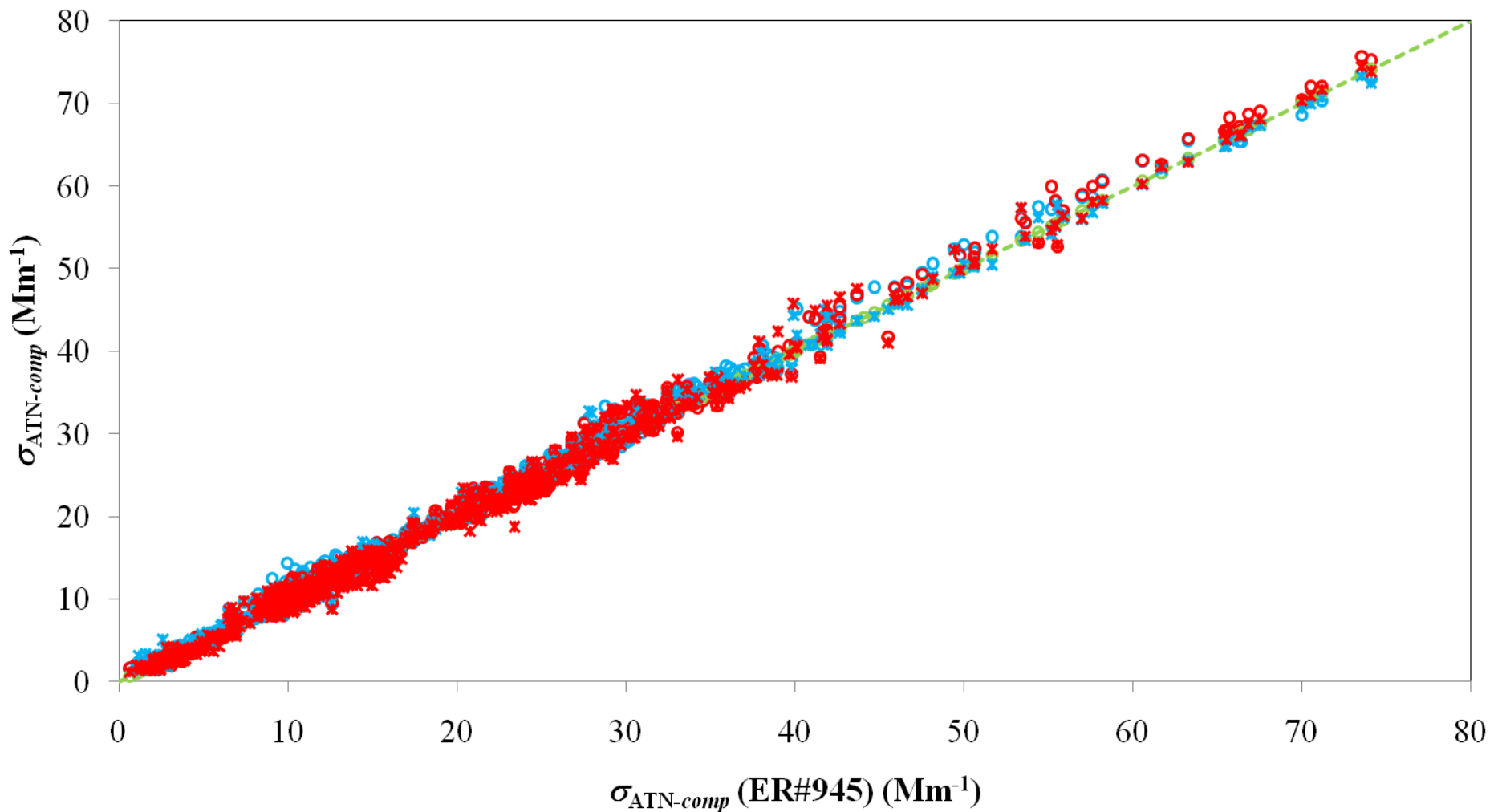
**Aethalometer's ($\lambda = 660 \text{ nm}$)**

- HS#160 - NOAA ○ HS#679 - FMI ○ HS#268 - UAc
× ER#408 - JRC × ER#427 - ETS - - - Line 1:1



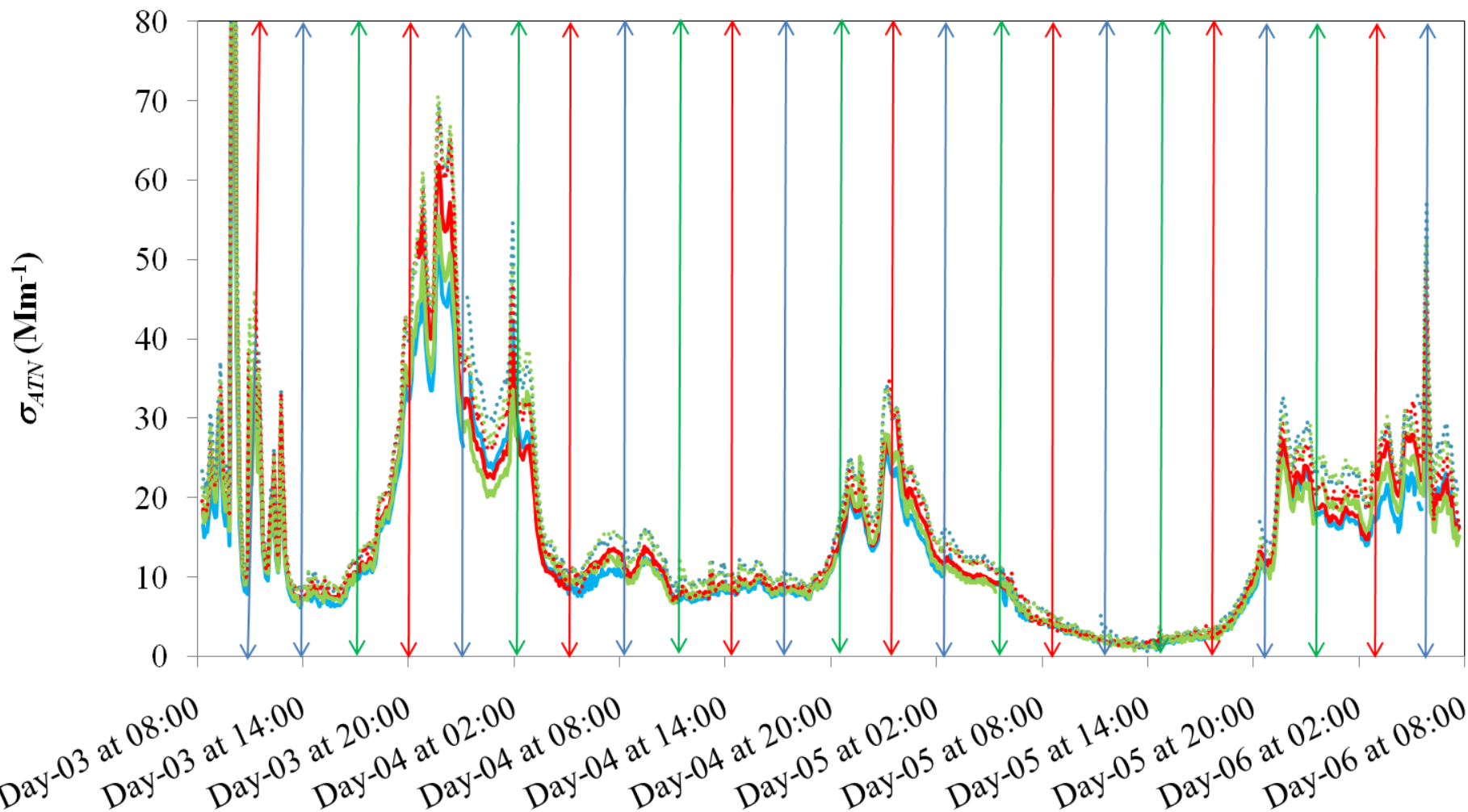
**Aethalometer's ($\lambda = 660 \text{ nm}$)**

- HS#160 - NOAA ○ HS#679 - FMI ○ HS#268 - UAc
× ER#408 - JRC × ER#427 - ETS - - - Line 1:1



**Aethalometer's ($\lambda = 660 \text{ nm}$)**

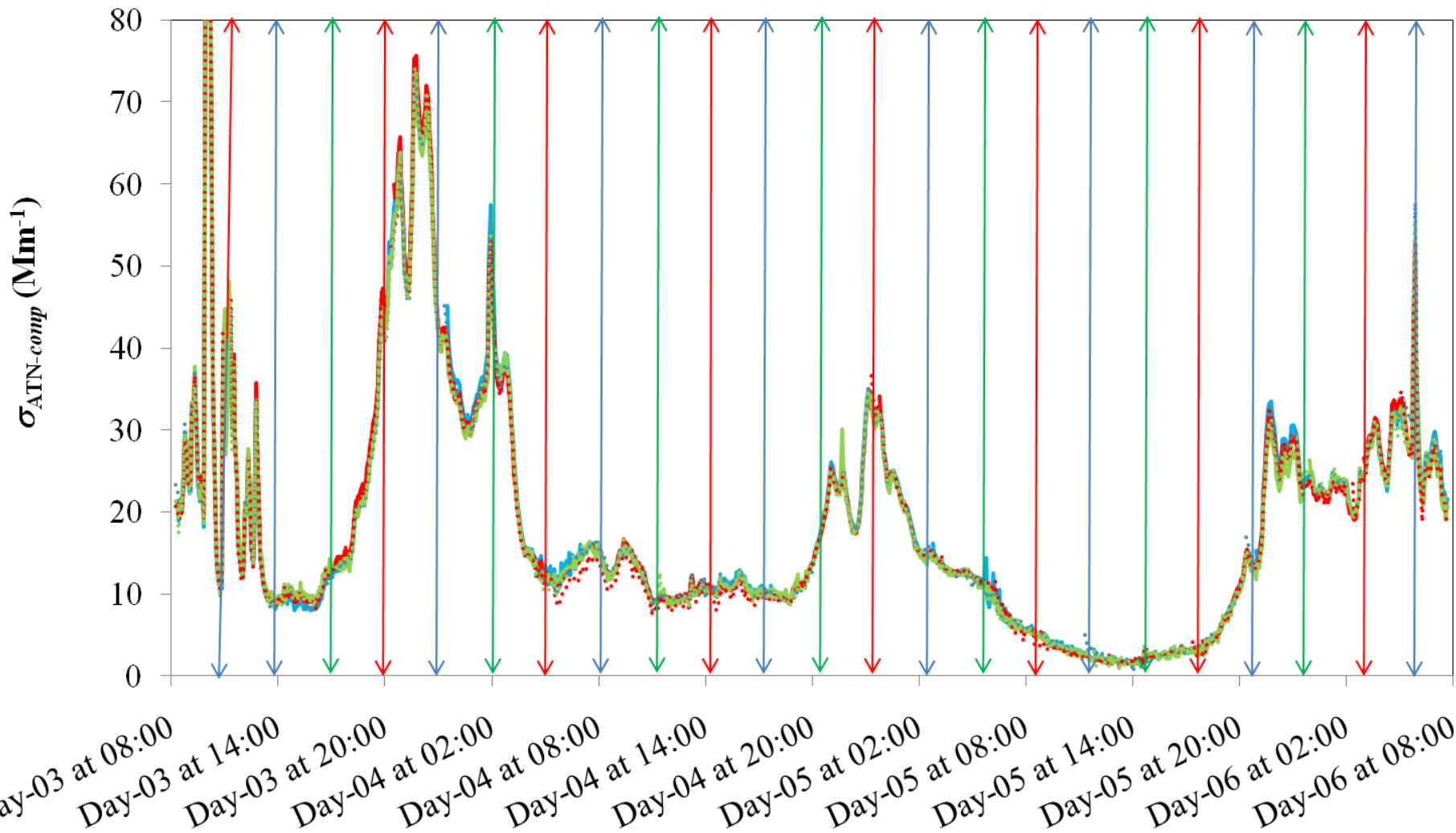
— HS#160 - NOAA — HS#679 - FMI — HS#268 - UAc
..... ER#408 - JRC ER#427 - ETS ER#945 - PSI





Aethalometer's ($\lambda = 660 \text{ nm}$)

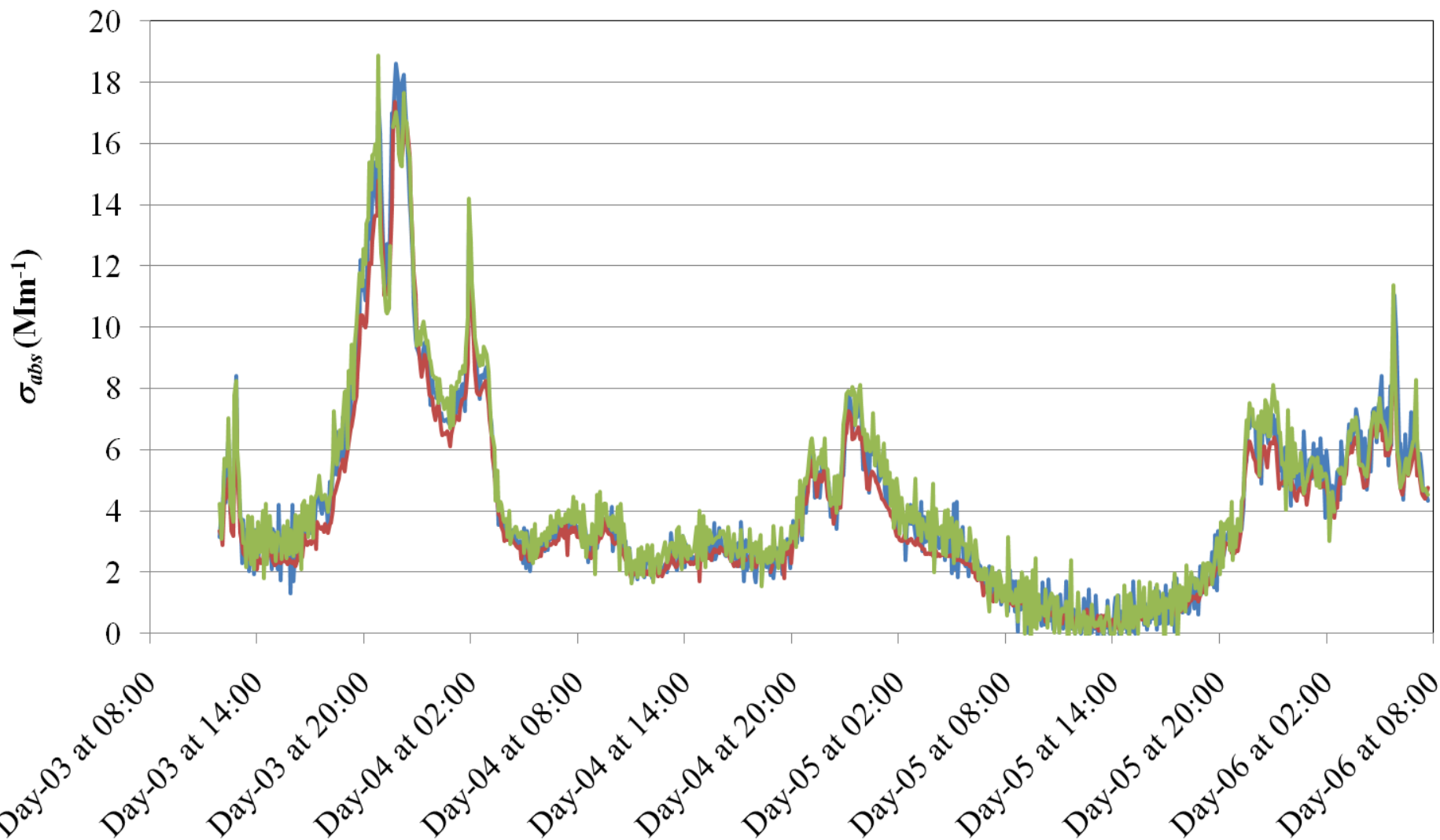
— HS#160 - NOAA — HS#679 - FMI — HS#268 - UAc
..... ER#408 - JRC ER#427 - ETS ER#945 - PSI





MAAP's ($\lambda = 637 \text{ nm}$)

— #140 — #012 — #080



MAAP's ($\lambda = 637 \text{ nm}$)

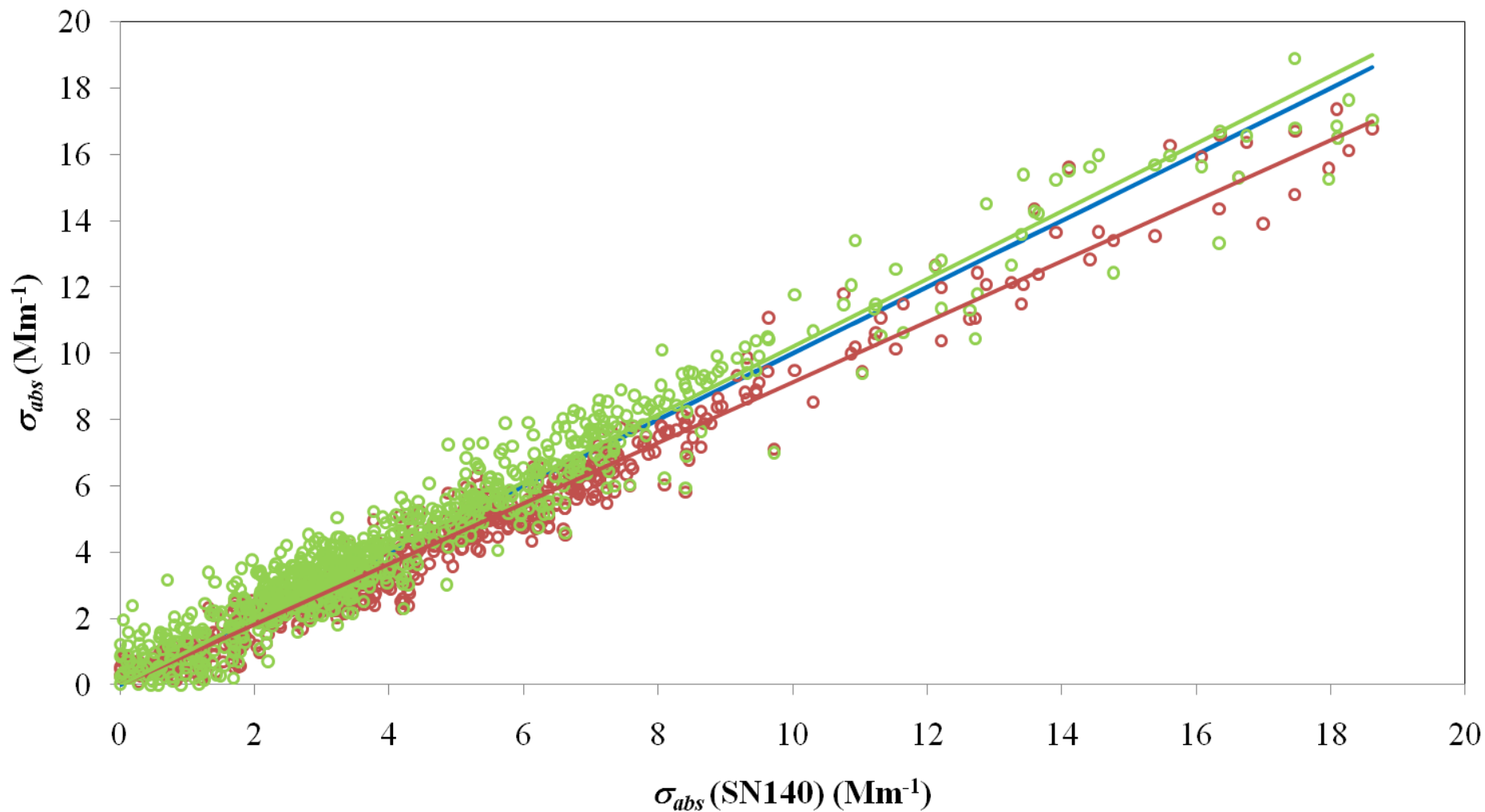
— Line 1:1

○ #012

○ #080

— Linear (#012)

— Linear (#080)

*slope = 0.913 ± 0.004**slope = 1.020 ± 0.005*



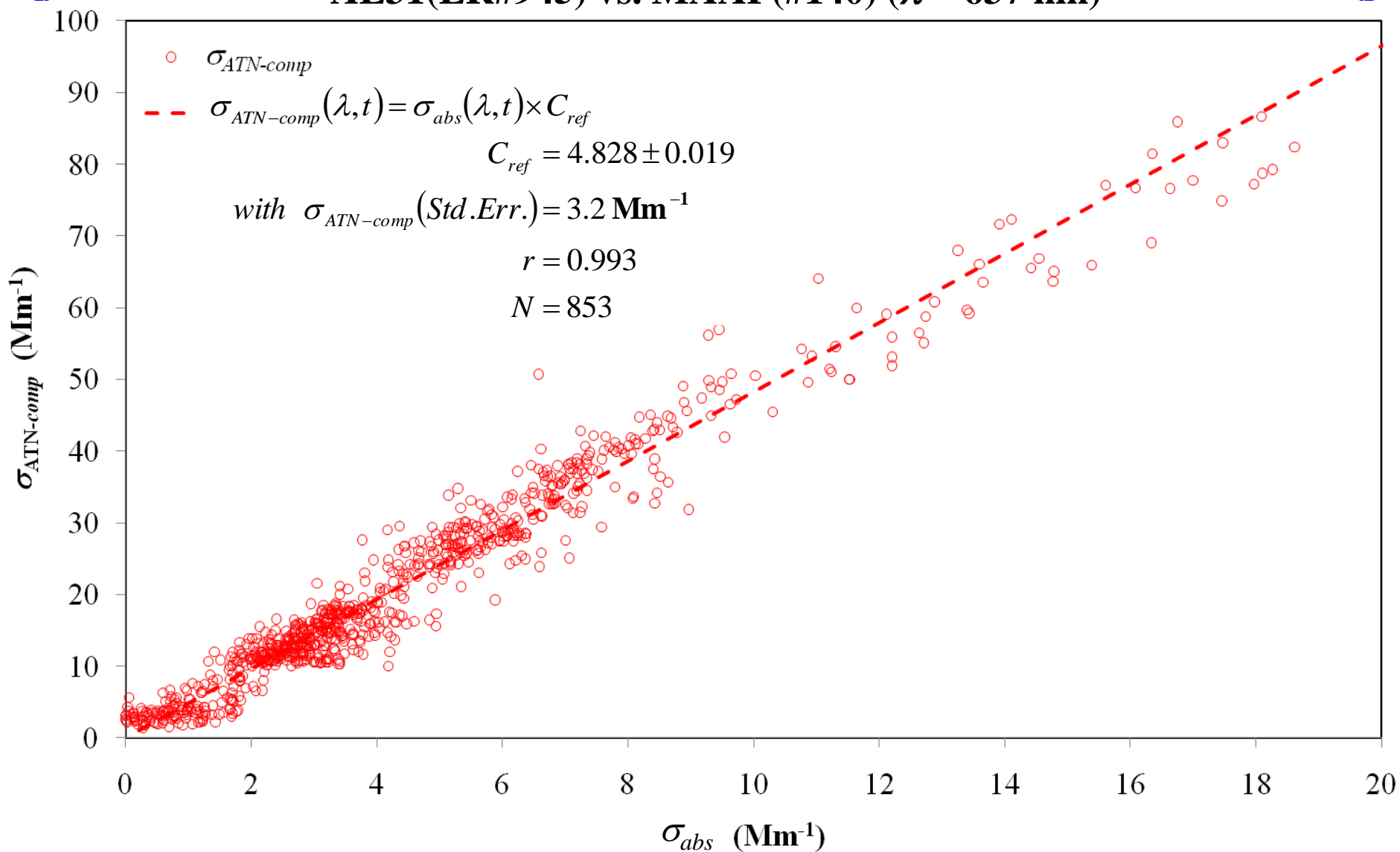
Correlating MAAP with AE

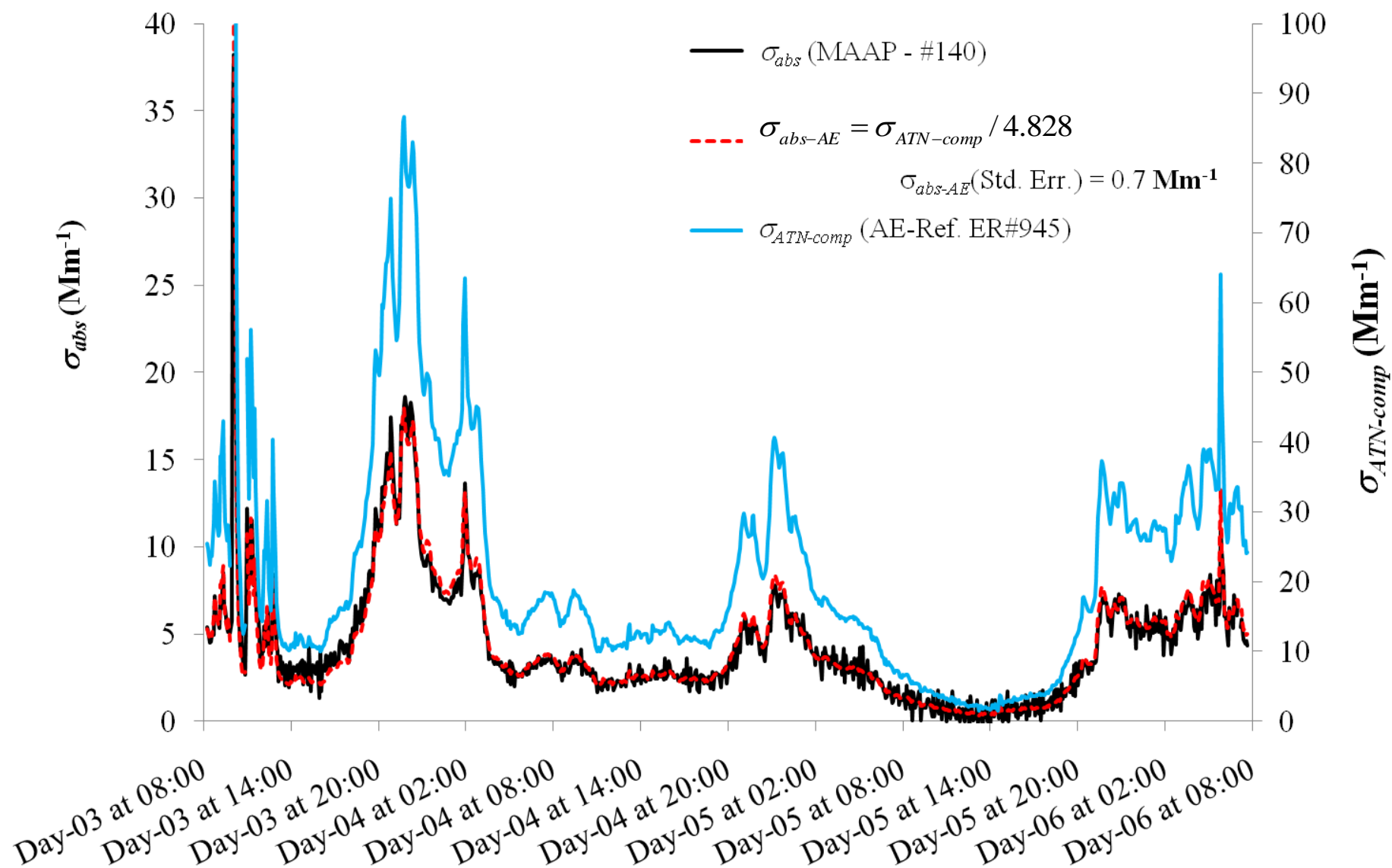
- MAAP #140 data was selected as the reference
 - Data in Standard Pressure (1013.25 mBar) and Temperature (273.15 K)
 - MAAP #080 is too noisy
 - MAAP #012 is slightly different from the other two and have less data than MAAP #140.
- AE31 ER#945 data is used as the reference
 - data was convert to 637 nm by using the relation,

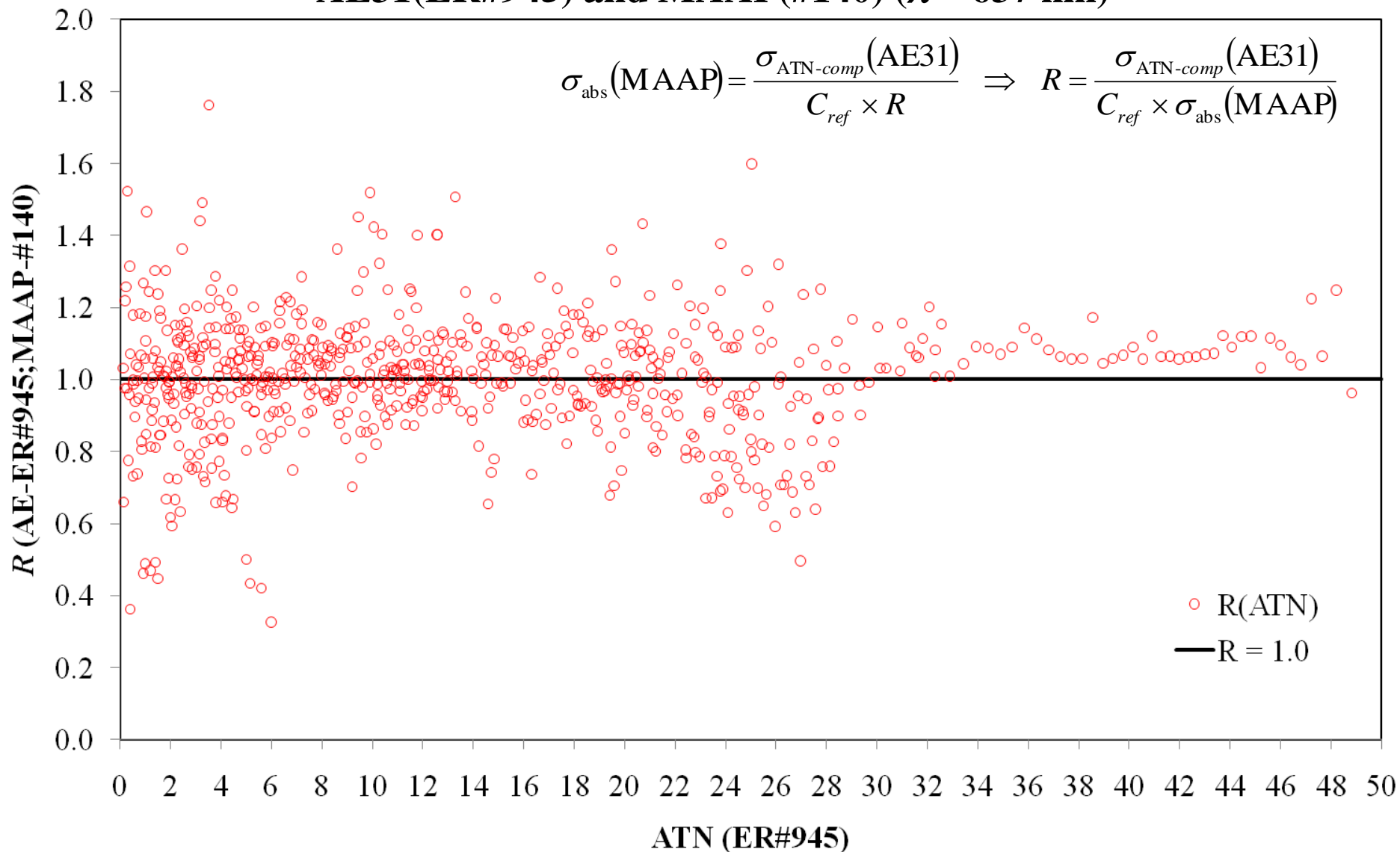
$$\sigma_{\text{ATN-comp}}(637) = \sigma_{\text{ATN-comp}}(660) \left(\frac{660}{637} \right)^\alpha$$

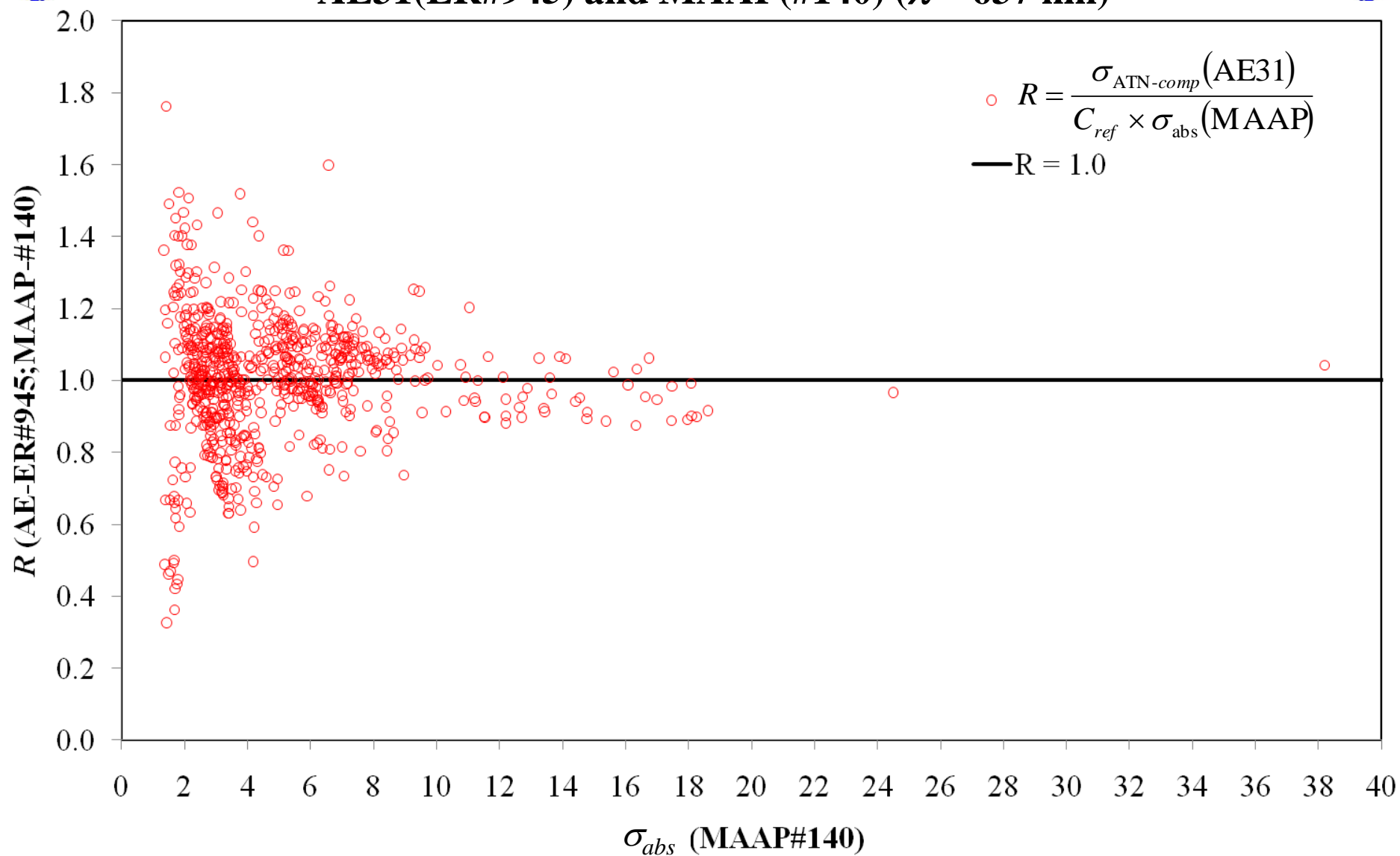
were, $\alpha = 1.11 \pm 0.15$

- scaled to Standard Pressure and Temperature.

AE31(ER#945) vs. MAAP(#140) ($\lambda = 637 \text{ nm}$)



**AE31(ER#945) and MAAP(#140) ($\lambda = 637 \text{ nm}$)**

**AE31(ER#945) and MAAP(#140) ($\lambda = 637 \text{ nm}$)**



Summary Information

$$\sigma_{\text{ATN-comp}}(\lambda) = \sigma_{\text{ATN}}(\lambda) \times f(\text{ATN}, \lambda)$$

$$f(\text{ATN}, \lambda) = \left(1 + k \times \frac{\text{ATN}(\lambda)}{\lambda} \right)$$

$$k = 1.51 \pm 0.15 \text{ nm}$$

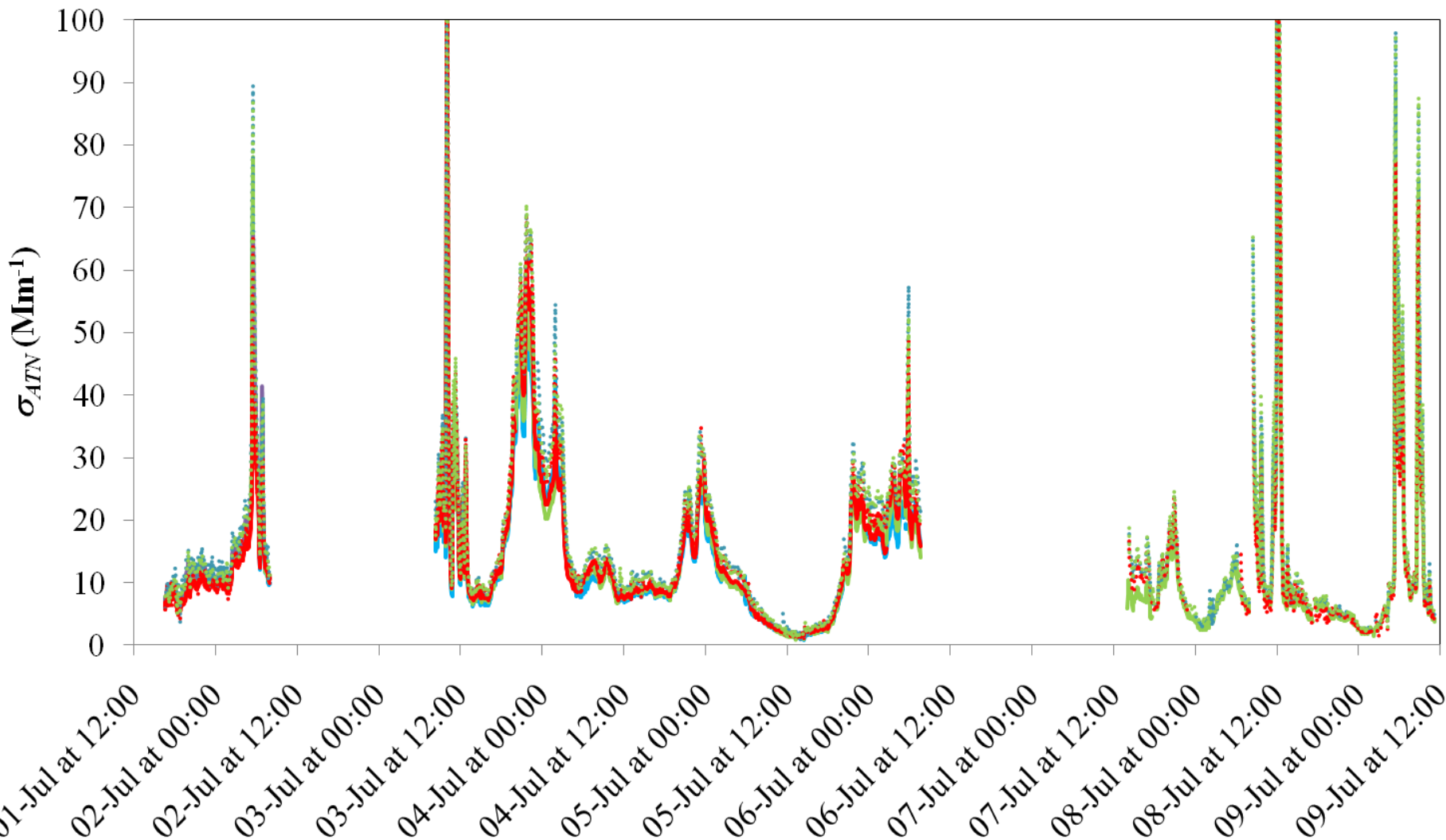
$$\sigma_{\text{abs-AE}}(\lambda) = \frac{\sigma_{\text{ATN-comp}}(\lambda)}{C_{\text{ref}}}$$

Aethalometer	C_{ref}
HS#160	3.821±0.019
HS#268	4.126±0.021
HS#496	4.477±0.023
HS#679	4.205±0.021
ER#408	4.851±0.026
ER#427	4.581±0.024
ER#945	4.828±0.026
Average	4.41±0.38 (9%)



Aethalometer's All Experiments ($\lambda = 660 \text{ nm}$)

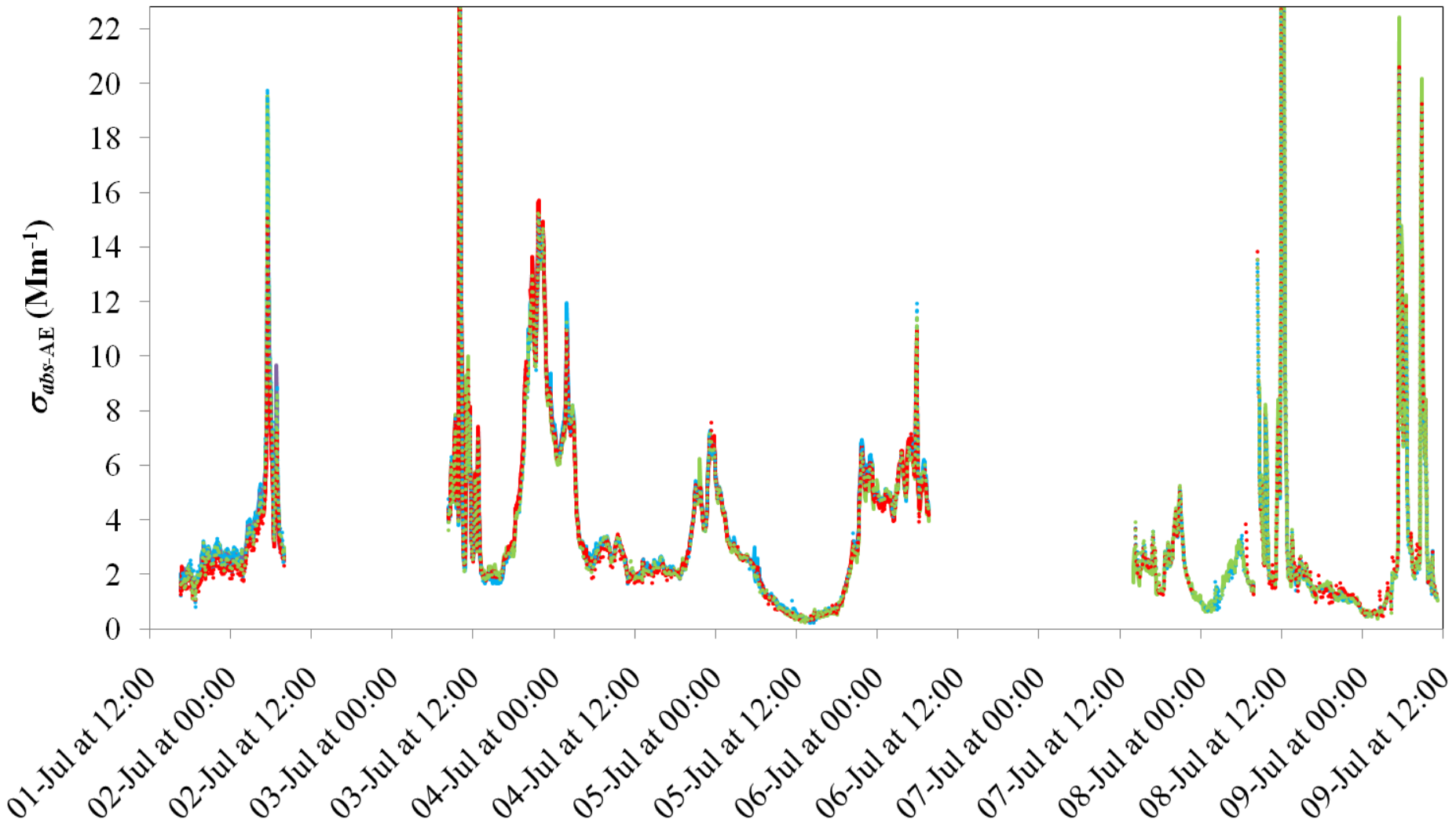
— HS#160 — HS#268 — HS#496 — HS#679 ···· ER#408 ···· ER#427 ···· ER#945





Aethalometer's All Experiments ($\lambda = 660 \text{ nm}$)

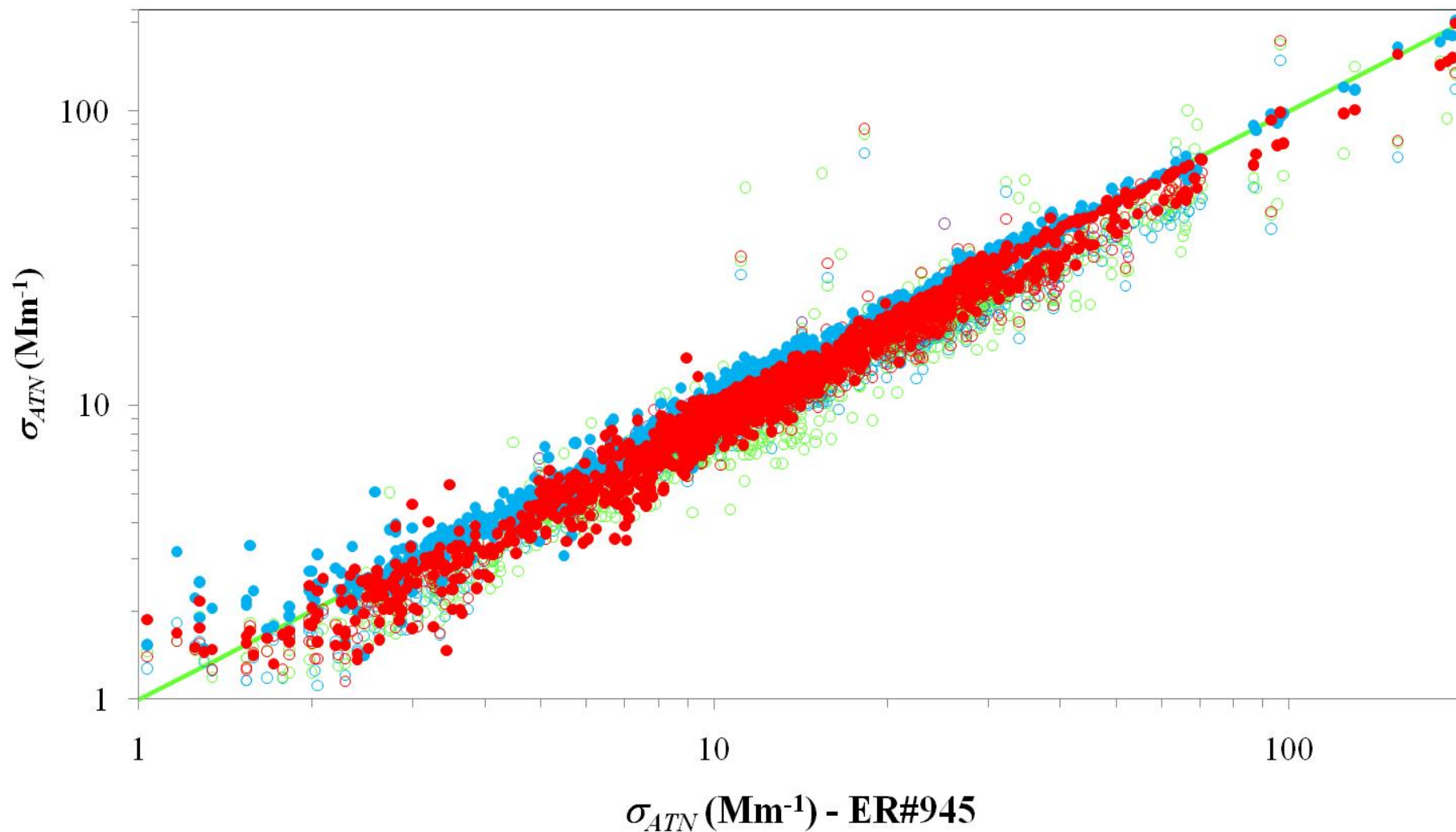
— HS#160 — HS#268 — HS#496 — HS#679 ···· ER#408 ···· ER#427 ···· ER#945





Aethalometer's All Experiments ($\lambda = 660 \text{ nm}$)

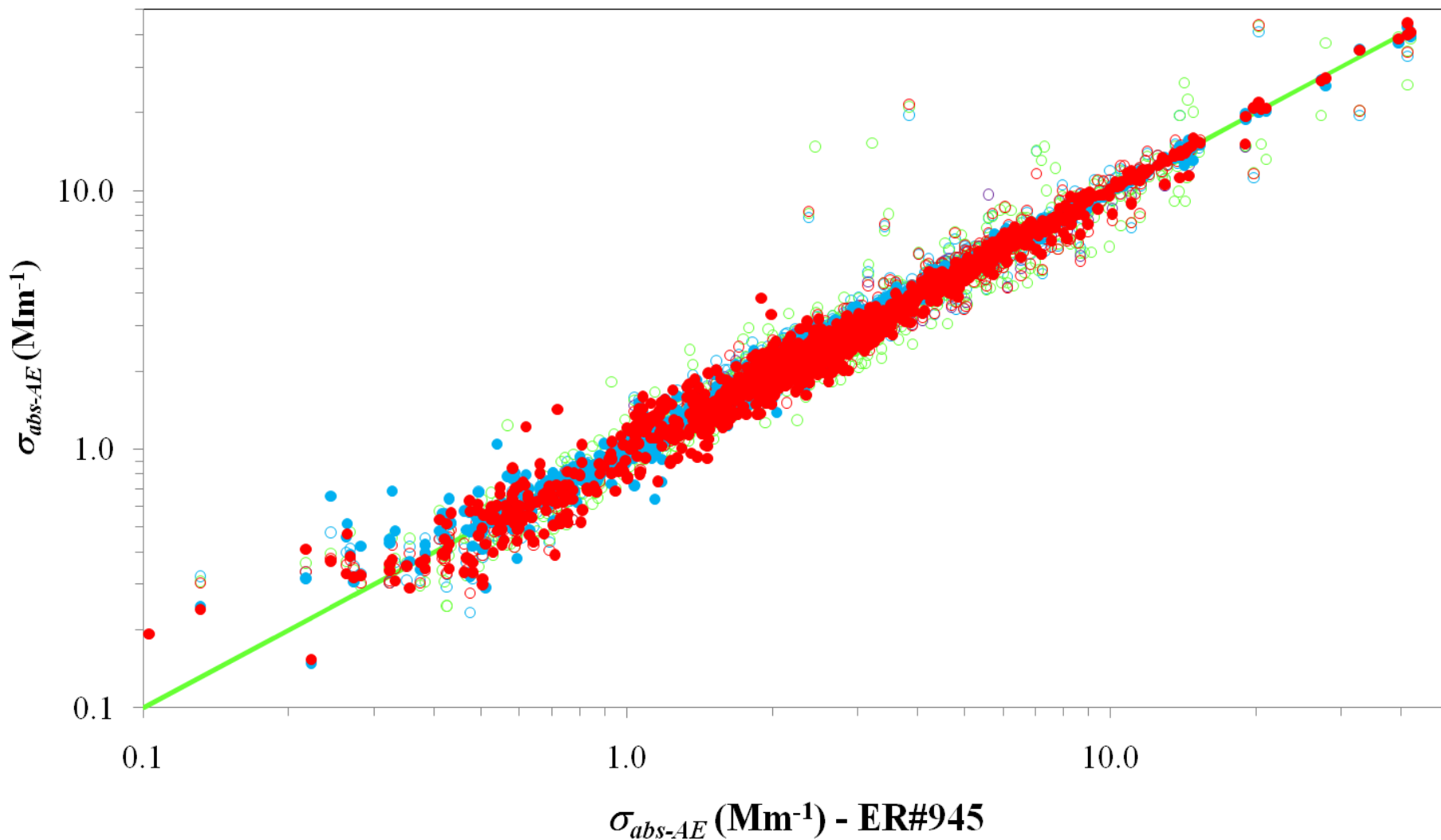
○ HS#160 ○ HS#268 ○ HS#496 ○ HS#679 ● ER#408 ● ER#427 — Line 1:1





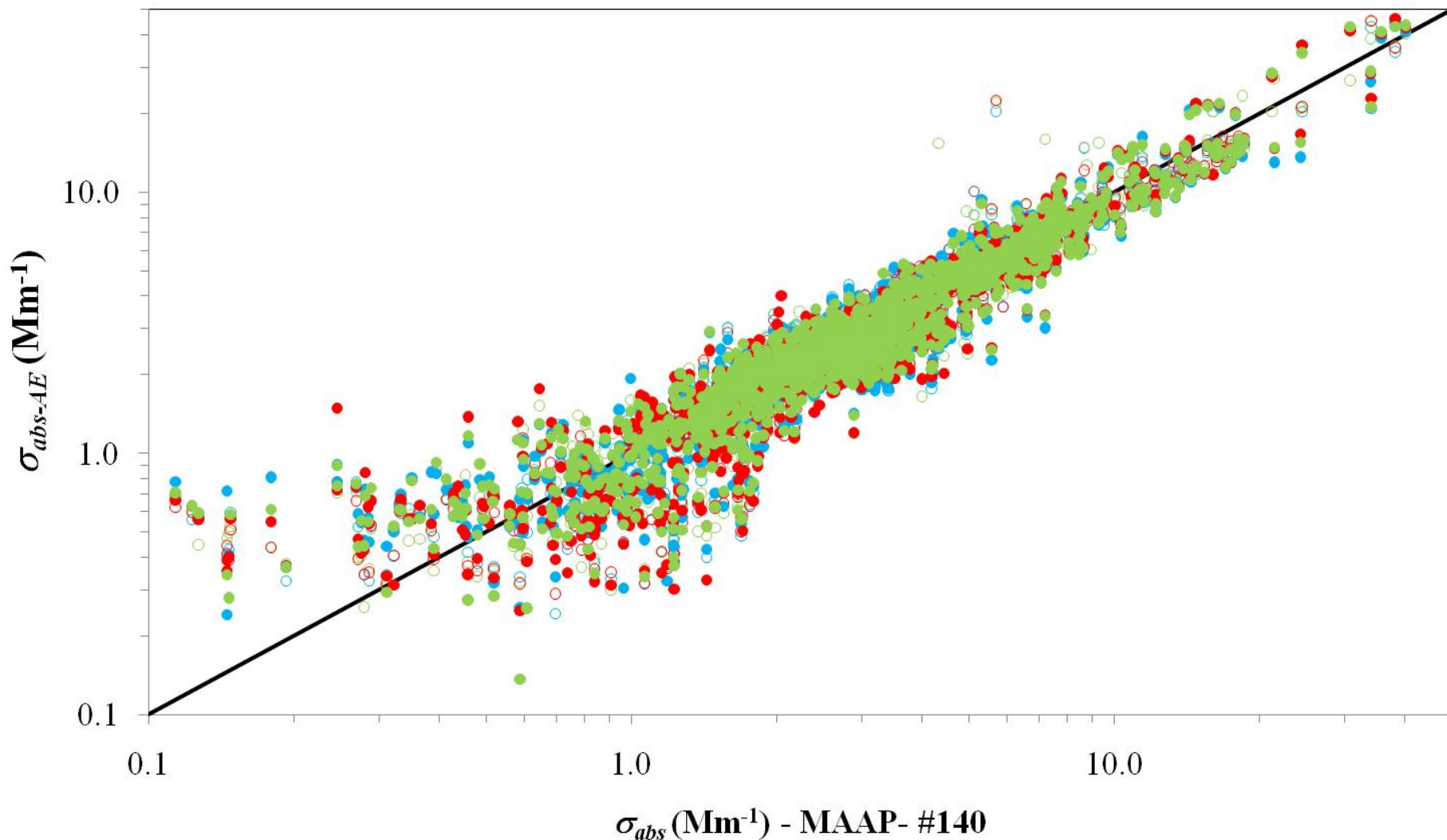
Aethalometer's All Experiments ($\lambda = 660 \text{ nm}$)

○ HS#160 ○ HS#268 ○ HS#496 ○ HS#679 ● ER#408 ● ER#427 — Line 1:1



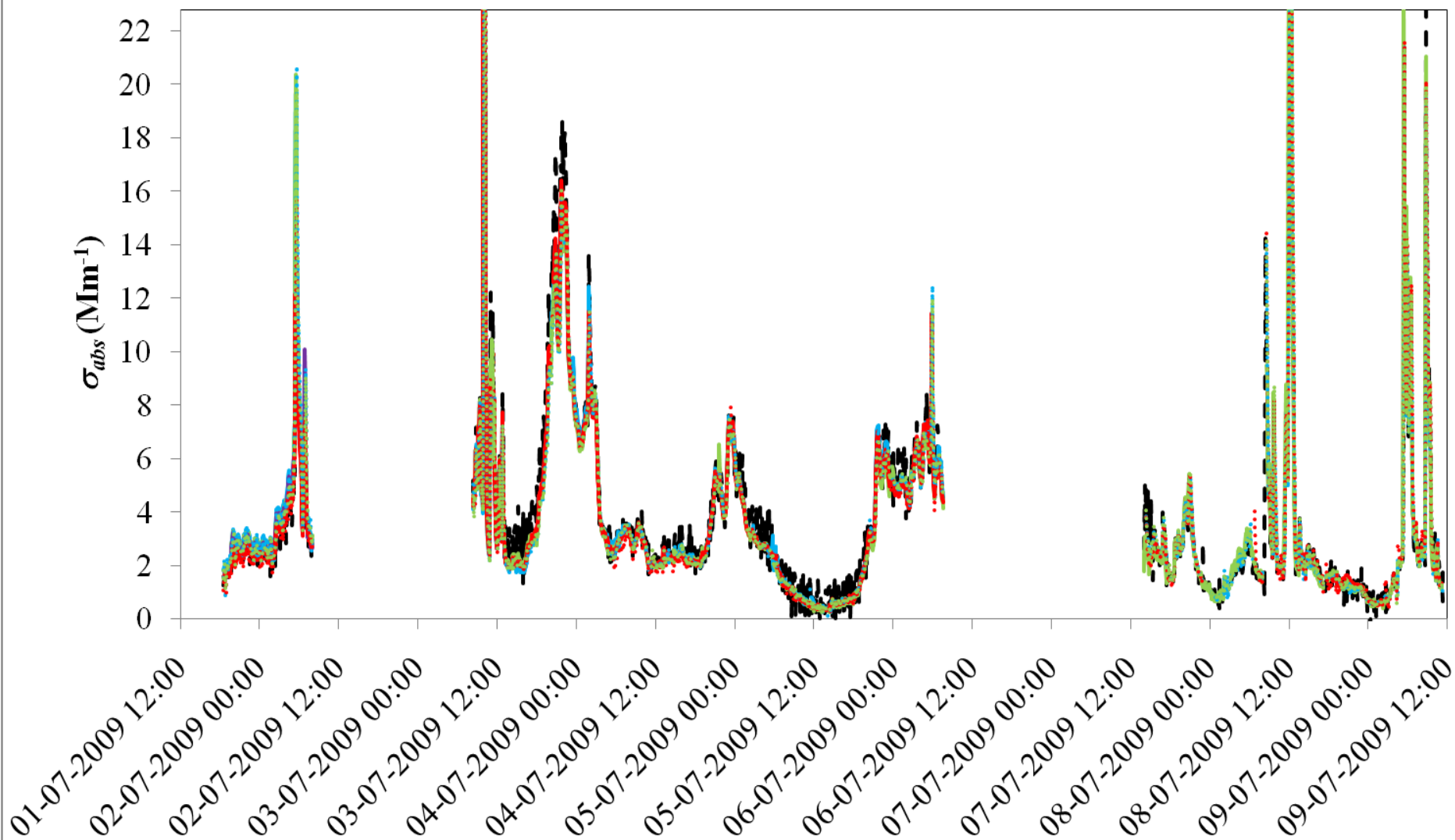
**Aethalometer's vs. MAAP#140 All Experiments ($\lambda = 637 \text{ nm}$)**

○ HS#160 ○ HS#268 ○ HS#496 ○ HS#679 ● ER#408 ● ER#427 ● ER#945 — Line 1:1



Time Series All Experiments ($\lambda = 637$ nm)

-- MAAP#140 — HS#160 — HS#268 — HS#496 — HS#679 ···· ER#408 ···· ER#427 ···· ER#945





Thank You for Your Attention

• Involved Institutions

- Aerosol d.o.o., Kamniska 41, SI-1000, Ljubljana, Slovenia
- Department of Optics and Quantum Electronics, University of Szeged, H-6701 Szeged, Hungary
- Environmental Radioactivity Laboratory, Institute of Nuclear Technology - Radiation Protection N.C.S.R. "Demokritos", 15310 Ag. Paraskevi Attiki, Greece
- Finnish Meteorological Institute, Climate Change Unit, Helsinki, Finland
- ISAC - CNR, Via Gobetti 101, 40129 Bologna, Italy
- JRC, Ispra site, via E. Fermi, 1, I - 21020 Ispra, Italy
- Leibniz Institute for Tropospheric Research, Leipzig, Germany
- Netherlands Organisation for Applied Scientific Research, TNO, 80015 Utrecht, The Netherlands
- University of Azores, P9701-851 Terra Cha, Portugal
- University of Helsinki, Dept of Physics, Helsinki, Finland

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