The INFN Raman LIDAR aerosol measurements at CTA North and its future deployment at CTA South

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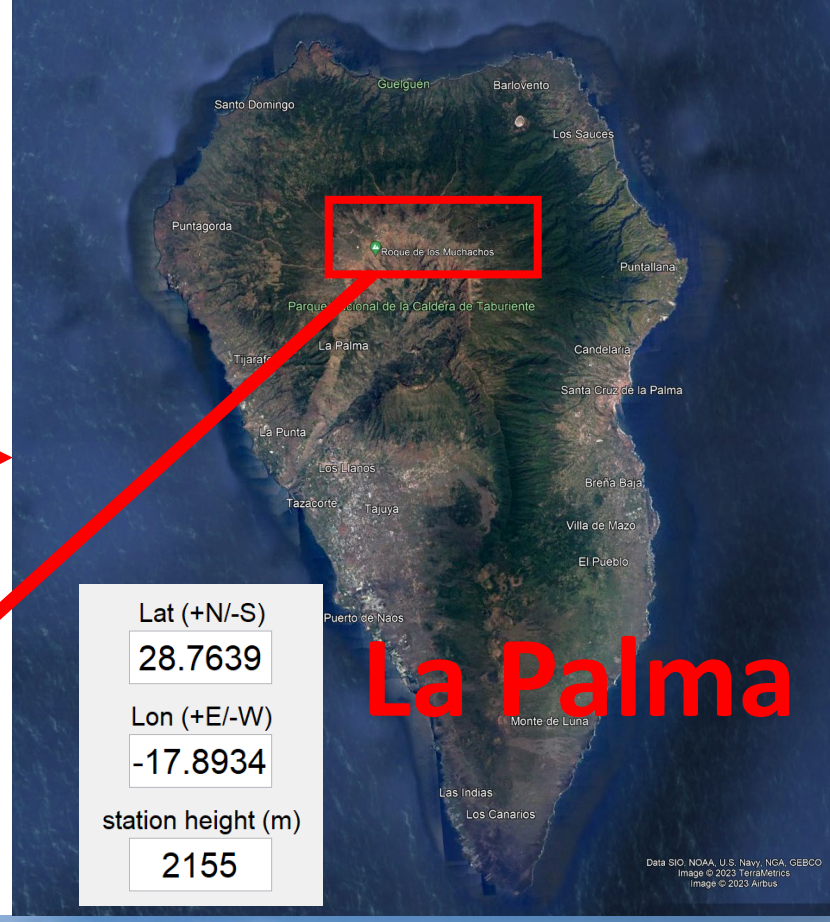
Outline:

- 5 Ws: What/Who/Where/When/Why
- Brief overview of the Lidar System
- Data
- Conclusions


Canary islands
Arrecife
Puerto del Carmen
Corralejo
Puerto del Rosario
Los Llanos
Santa Cruz de Tenerife
Puerto de la Cruz
CANARIAS
Costa Calma
Morro Jable
Las Palmas de Gran Canaria
Teide
Gran Canaria
Maspalomas
Villa de Valverde
La Frontera
La Restinga


Guelguén
Barlovento
Santo Domingo
Los Sauces
Puntagorda
Roque de los Muchachos
Puntallana
Parque Nacional de la Caldera de Taburiente
La Palma
Tijarafe
Candelaria
Santa Cruz de la Palma
La Punta
Los Llanos
Breña Baja
Tazacorte
Tajuya
Villa de Mazo
El Pueblo
Puerto de Naos
Monte de Luna
Las Indias
Los Canarios
Lat (+N/-S)
28.7639
Lon (+E/-W)
-17.8934
station height (m)
2155
La Palma
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2023 TerraMetrics
Image © 2023 Airbus


We were here

The Cherenkov Telescope Array (CTA) is the next generation of ground-based very high energy gamma-ray instruments based on Imaging Astronomical Cherenkov Telescopes (IACTs).
The CTA Observatory will consist of two separate arrays, one located in the Northern Hemisphere **(Observatorio Roque de Los Muchachos - ORM, 2300m a.s.l. La Palma, Canary Islands, Spain)** and one in the Southern Hemisphere (Cerro Armazones, close to Paranal, Chile), to ensure full sky coverage.

cta
cherenkov telescope array

The CTA Observatory

The development of the Extensive Air Showers generated by gamma primaries is greatly influenced by the atmosphere.

The variable atmospheric properties affect the observations of the Cherenkov light in multiple ways, contributing **significantly to the systematic uncertainty on the primary energy and flux determination**. **The atmosphere plays a double role, being responsible at the same time for the production of the Cherenkov light and also for its attenuation when it travels towards the telescopes.**

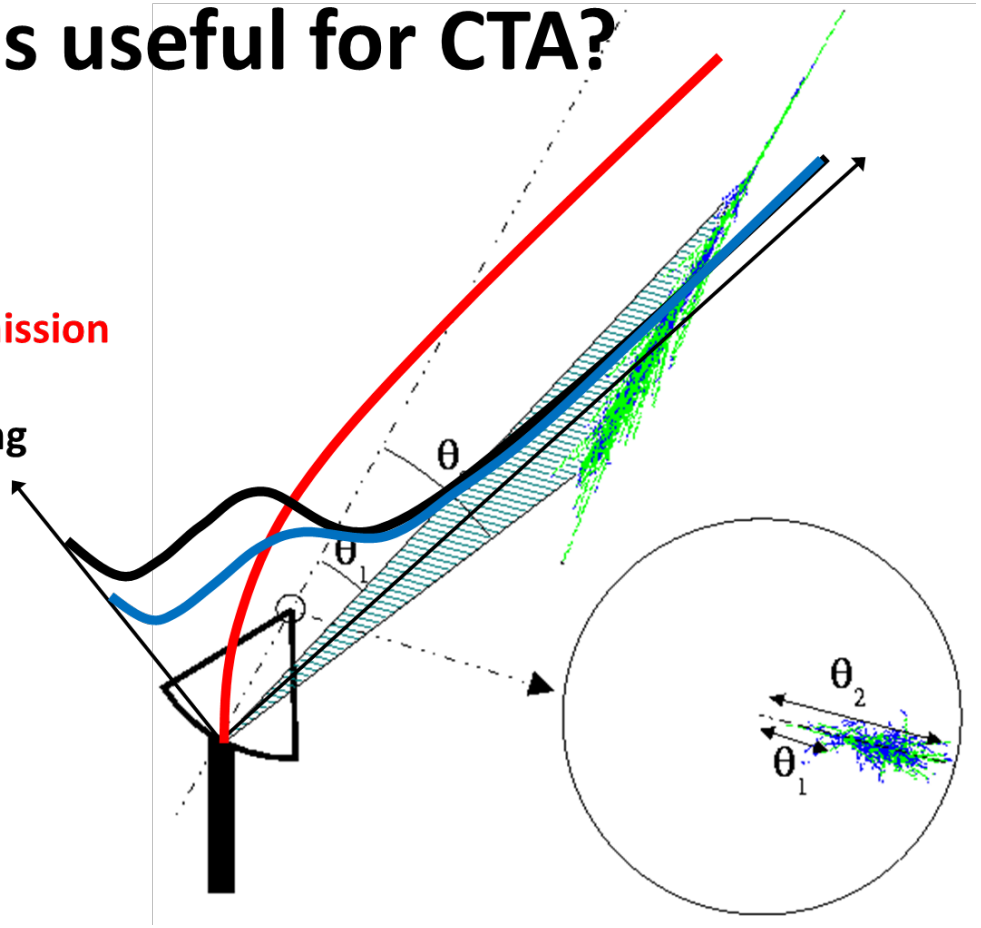
In particular, the production of Cherenkov light depends on the molecular profile, while the rapidly changing aerosol profile affects its attenuation. In the CTA, high quality of the data will be ensured by a constant monitoring of the local optical properties of the atmosphere during data taking with the aim to correct the collected data.

How a Raman lidar is useful for CTA?

aerosol optical depth -> light transmission

aerosol backscatter -> light scattering

water vapour -> air refractive index



Measurements:

- the vertical profiles of the aerosol optical properties at 355 nm: the **aerosol backscatter coefficient and optical depth (AOD)** up to 4000 m above ground level; the statistical error affecting the aerosol backscatter is between 3 and 50 %, the AOD indetermination (correlated and uncorrelated) is below 0.005.

- the vertical profile of **the water vapour mixing ratio**.

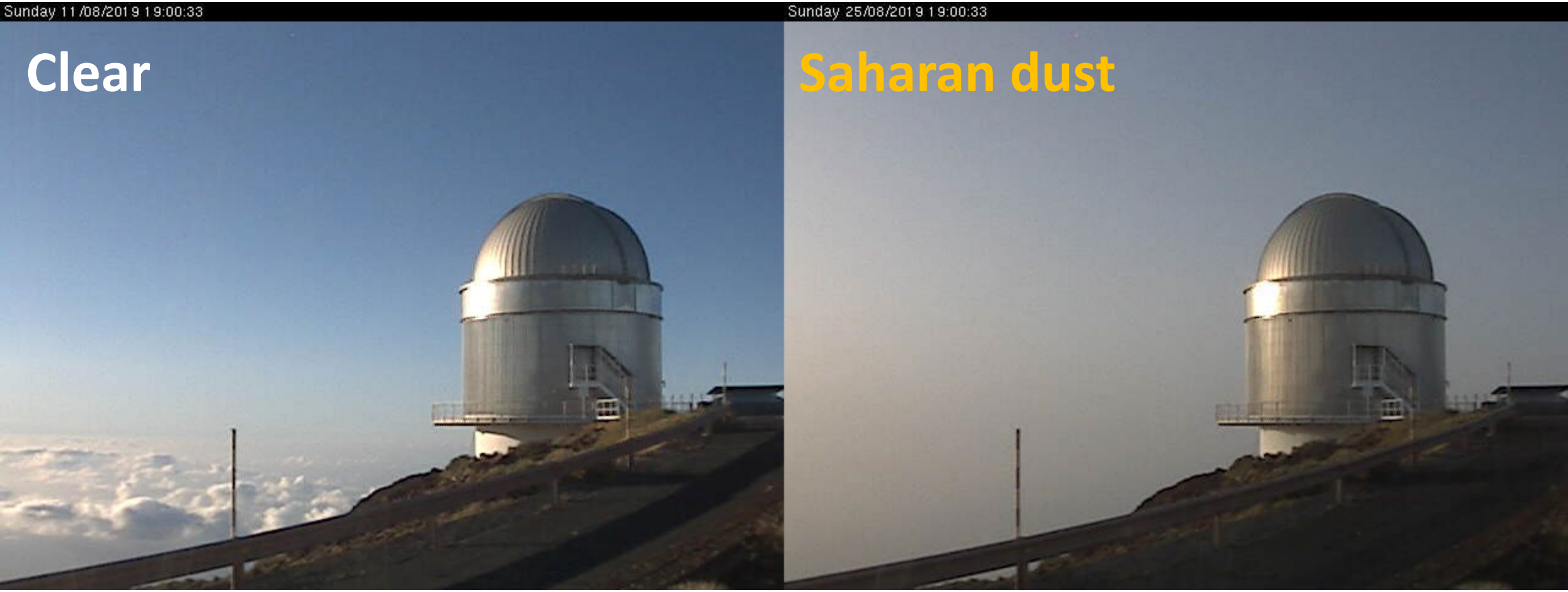
The CTA Observatory

The development of the Extensive Air Showers generated by gamma primaries is greatly influenced by the atmosphere.

The variable atmospheric properties affect the observations of the Cherenkov light in multiple ways, contributing **significantly to the systematic uncertainty on the primary energy and flux determination. The atmosphere plays a double role, being responsible at the same time for the production of the Cherenkov light and also for its attenuation when it travels towards the telescopes.**

INFN Raman Lidar for the aerosol contents/local climatology.

In particular, the production of Cherenkov light depends on the molecular profile, while the rapidly changing aerosol profile affects its attenuation. In the CTA, high quality of the data will be ensured by a constant monitoring of the local optical properties of the atmosphere during data taking with the aim to correct the collected data.



NOT telescope web camera

Cumbre Vieja 19 September to 13 December 2021

The Lidar system

The Lidar system

LIDAR dismounted in October 2023

CASSA #1 High=156 cm Large=192 cm Depth=117 cm – about 3.7 m^3 (including the pallet)

CASSA #2 High=100 cm Large=147 cm Depth=97 cm – about 1.6 m^3 (including the pallet)

LIDAR back in lab in February 2024

• LIDAR Performances & Measurements

Past activities

Measurements (automated & unattended):

- **Schedule: two 15min measurements per day (before dawn and after sunset)**
- **85% of days covered with at least one measurement session in the period Nov. 2018 - Dec. 2022**

Results

- **Characterization of aerosol component of atmospheric transmission in UV completed**
- **Incidence of sporadic events (volcanic eruptions and/or Saharan dust outbreaks) spotted**

Next activities

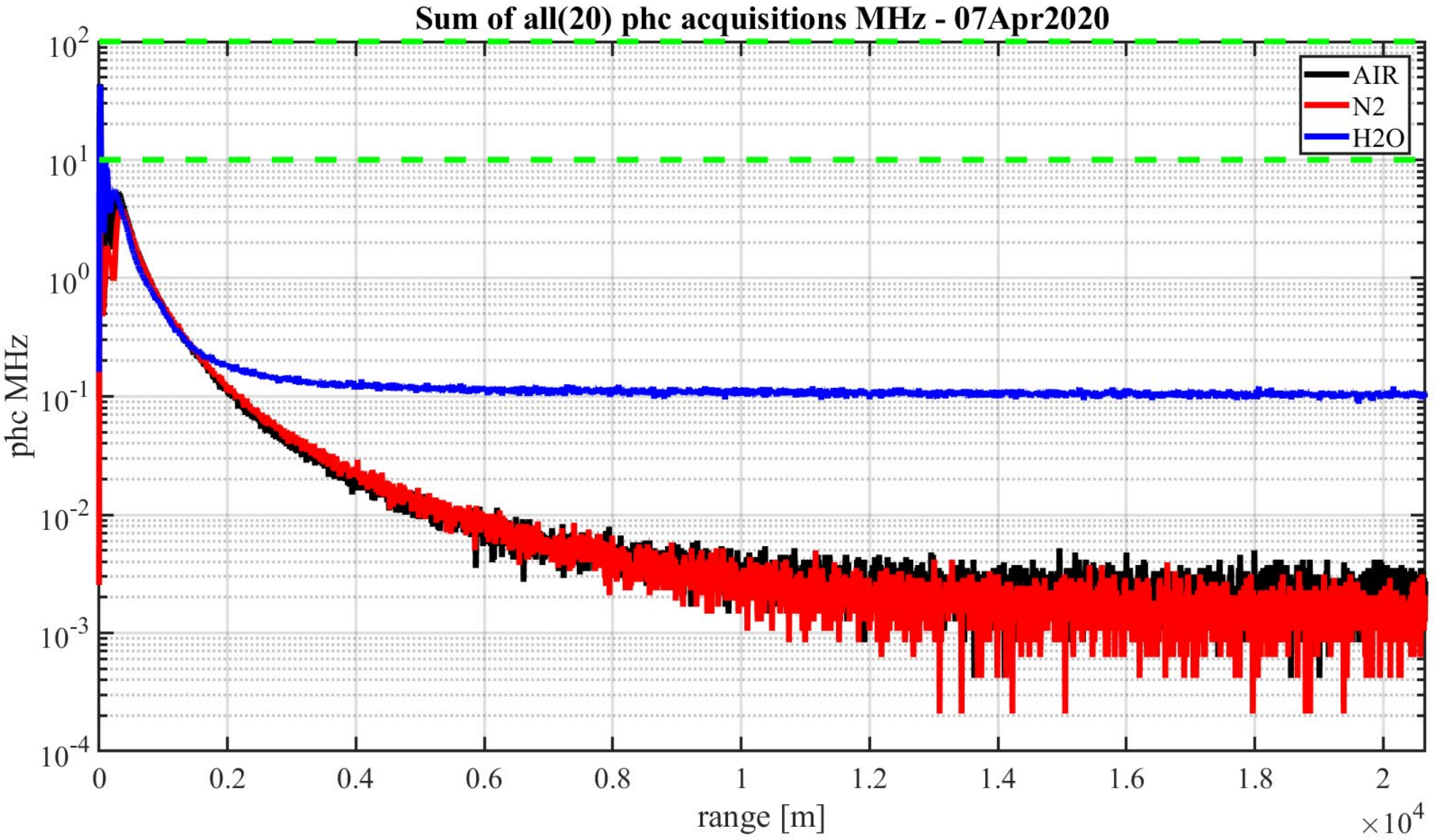
- **Preparation of a general paper on system performance and measurements (i.e., Jinst)**
- **System back in the lab for major refurbishment in september 2023 (funded)**
- **2024 possible participation in the ESO site characterization campaign (discussion on going)**

• Performances & Measurements status (problems)

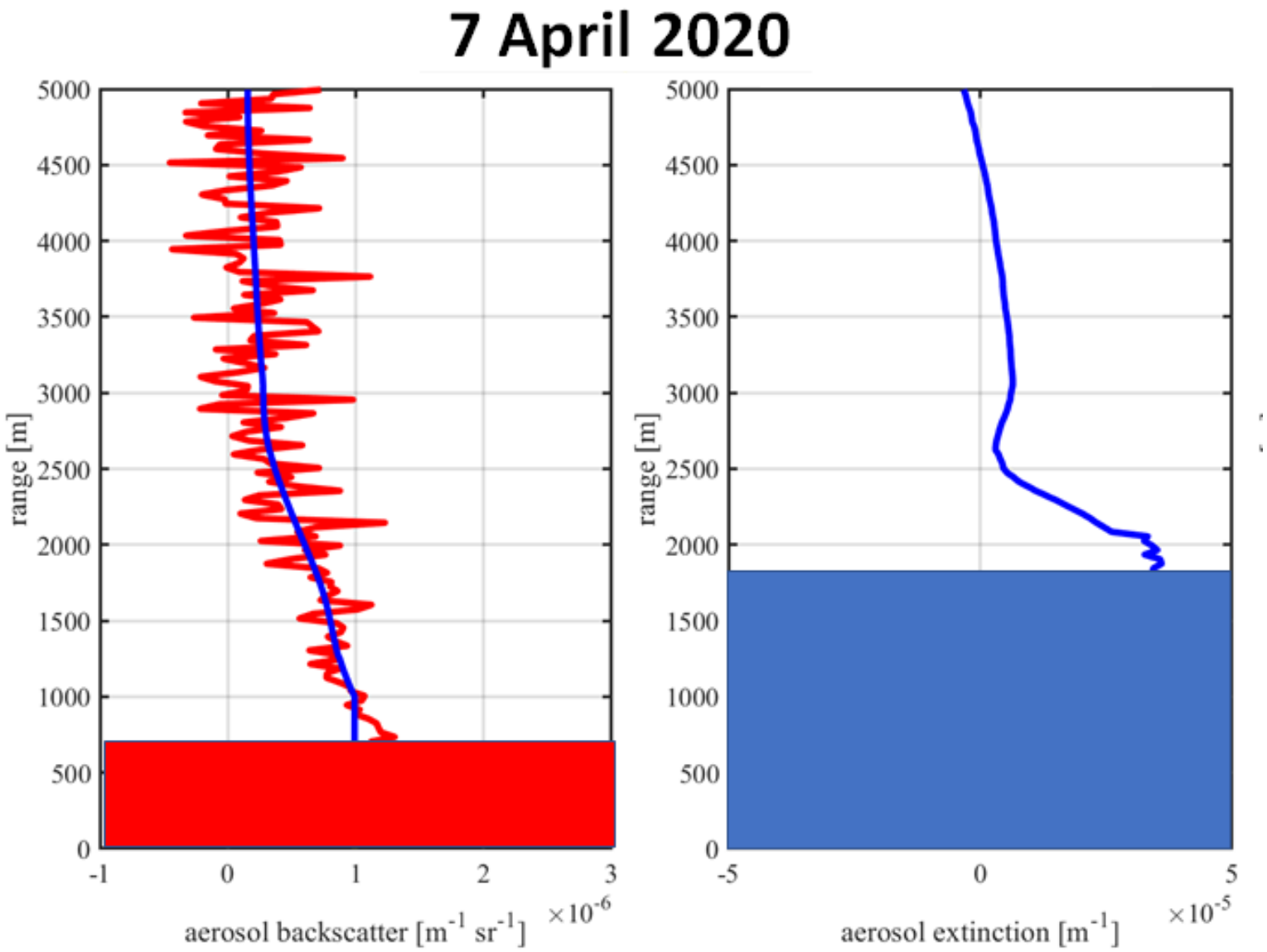
- No measurements causes:
  - Mainly bad weather (fog/rain: automatic no measurements)
  - Computer malfunctions.
  - Network problems.
- Measurement done does not means "good" data (ex. Because dirty exit window, Low level clouds, other hardware problems etc…).

- Required "on site" services not done. Consequences:
  - Raman channels off since 2021
  - Elastic channel (mainly) ok but SNR no more idea
  - Other problems to be fixed only "on site".

When the Lidar is in a good shape…



… nevertheless, we have the limitations caused by overlap function…

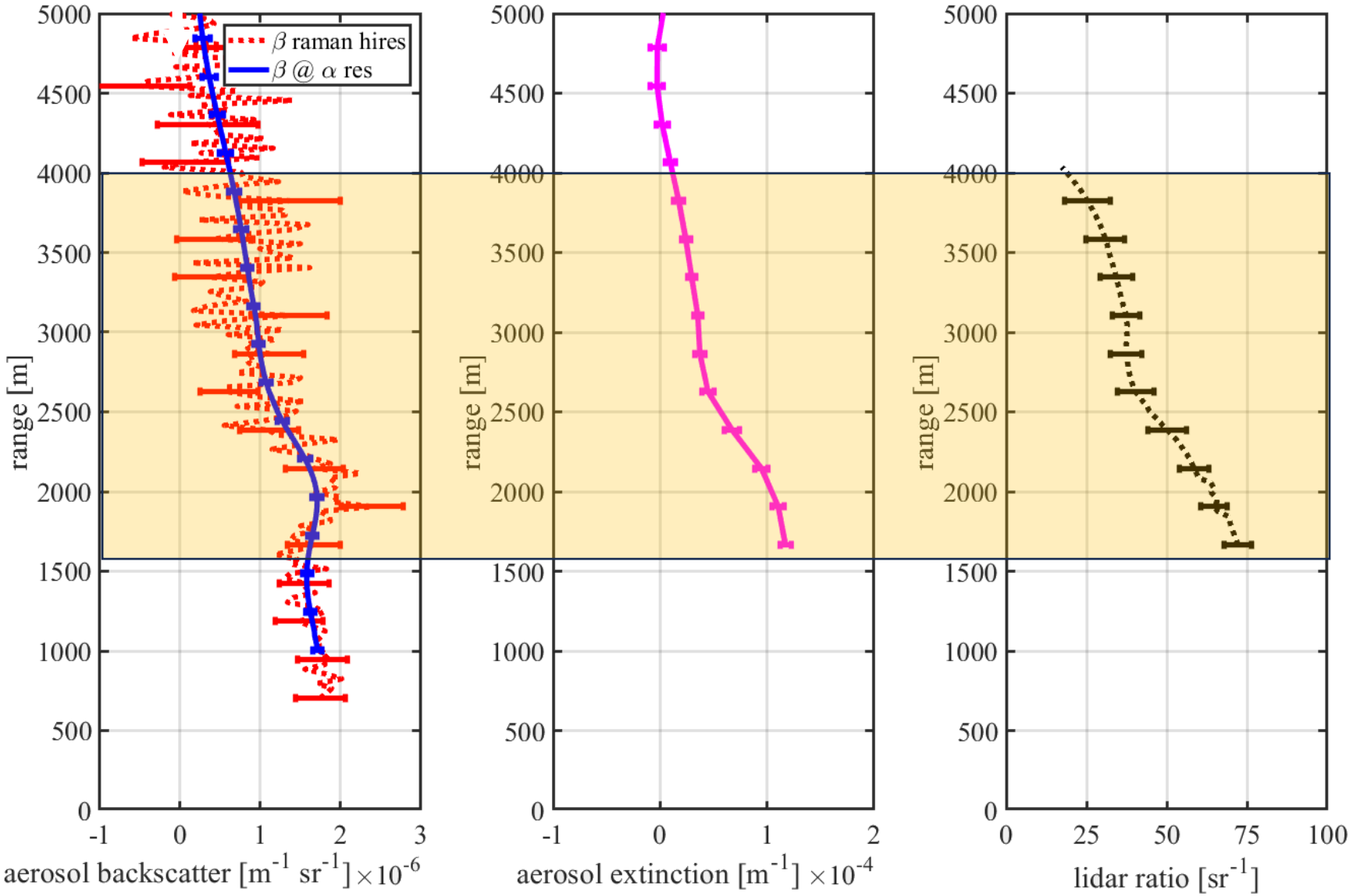


Data

Saharan dust

25 August 2019 20UT – Saharan dust case

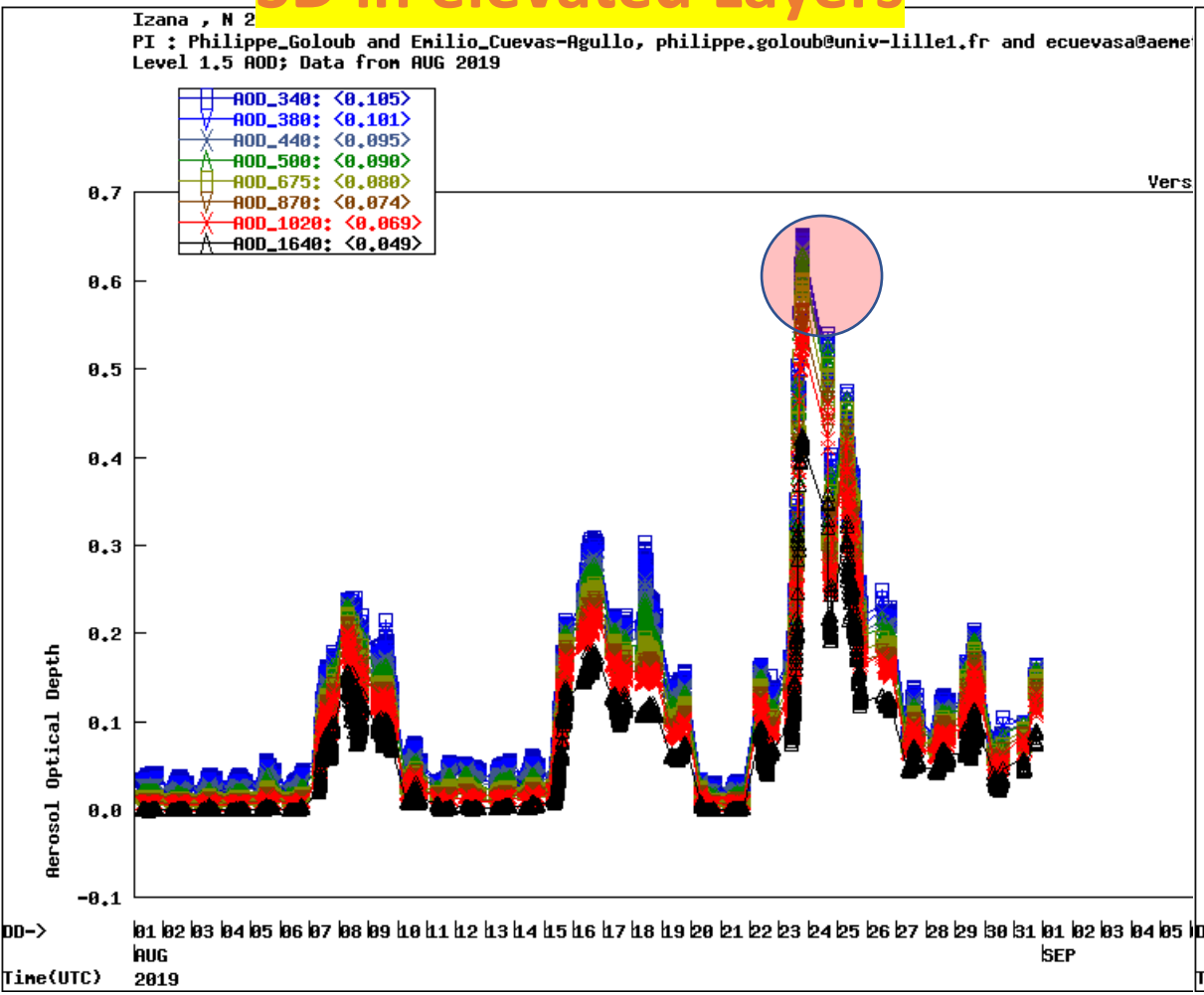
SD in elevated layers

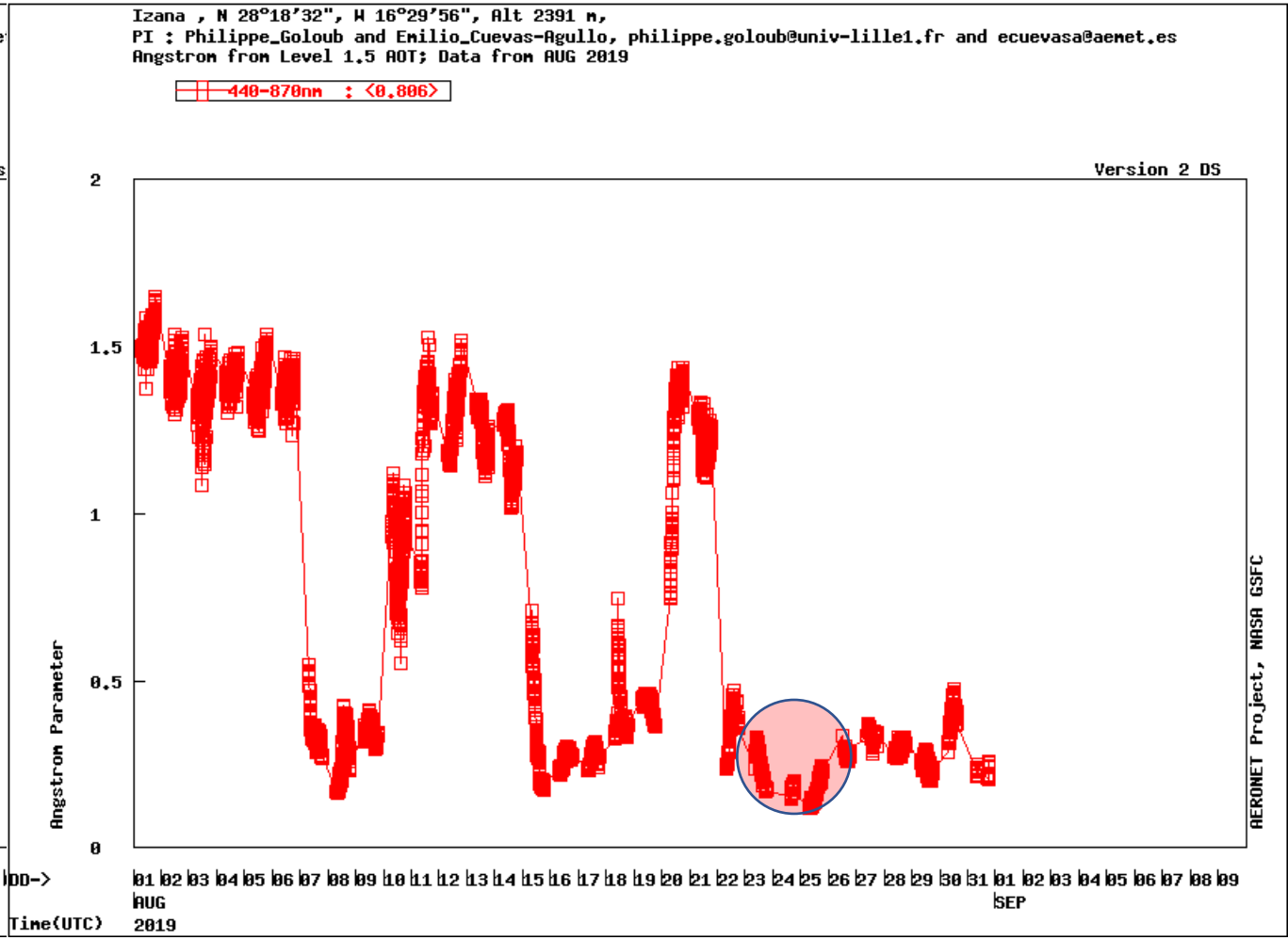


Data

AERONET

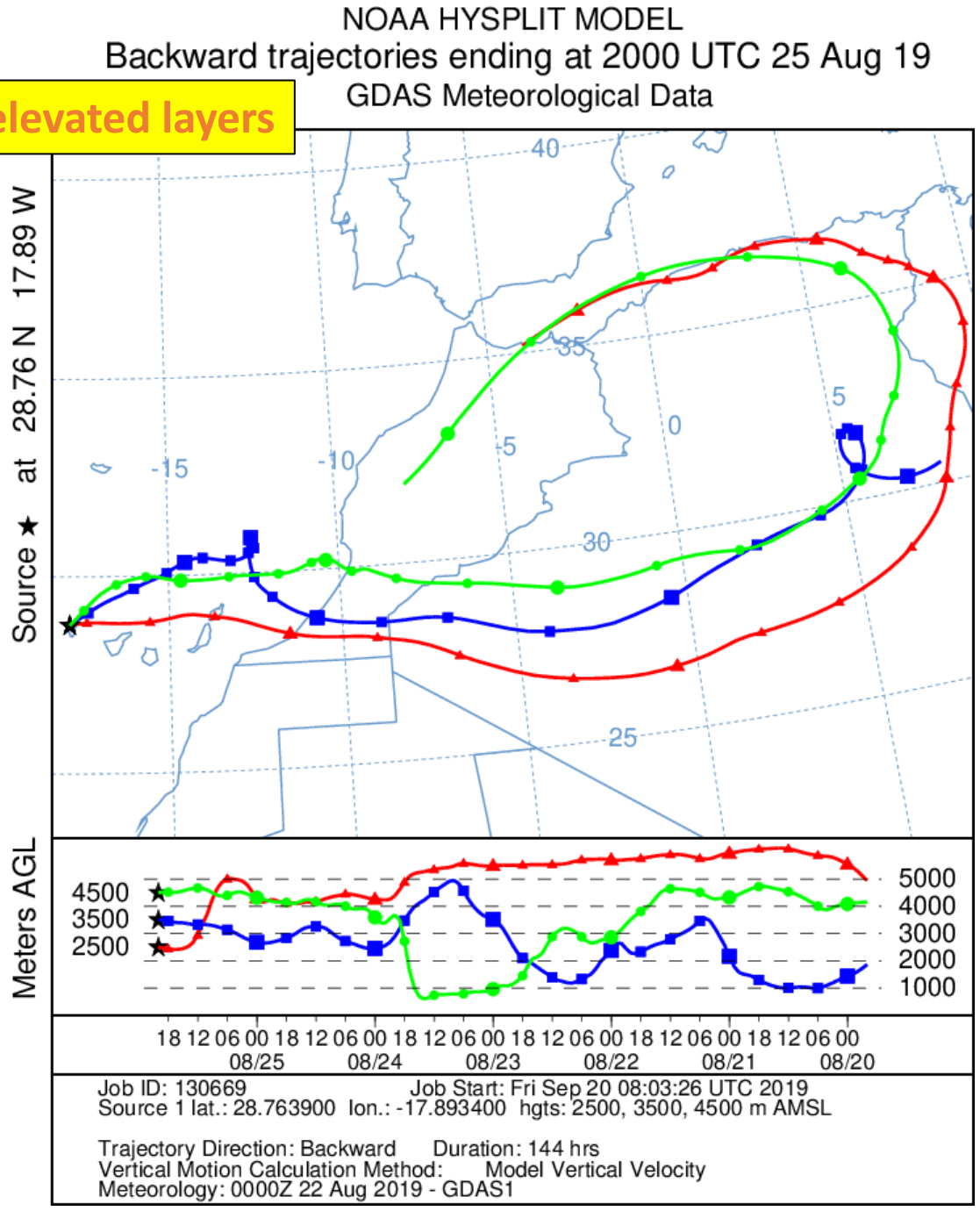
SD in elevated Layers

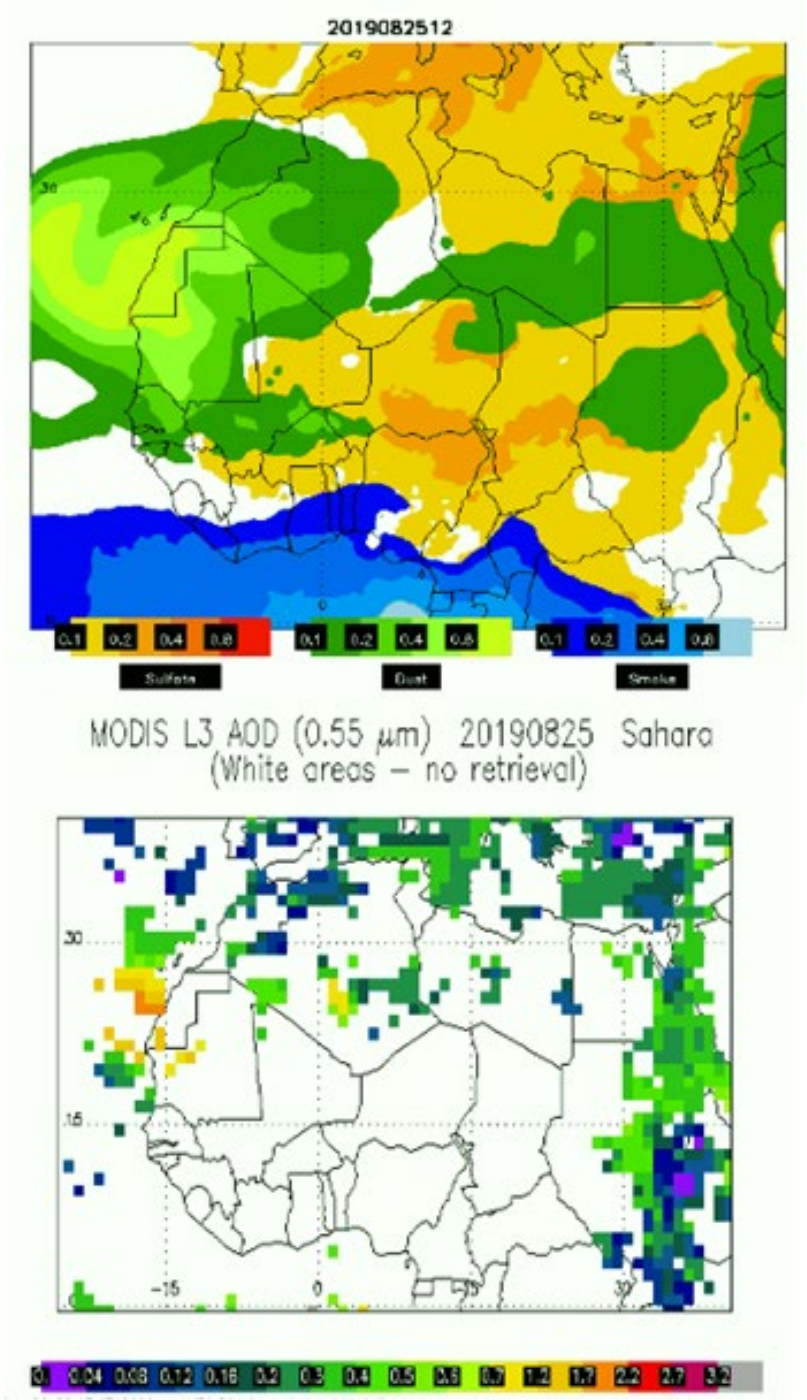




Data

SD in elevated layers





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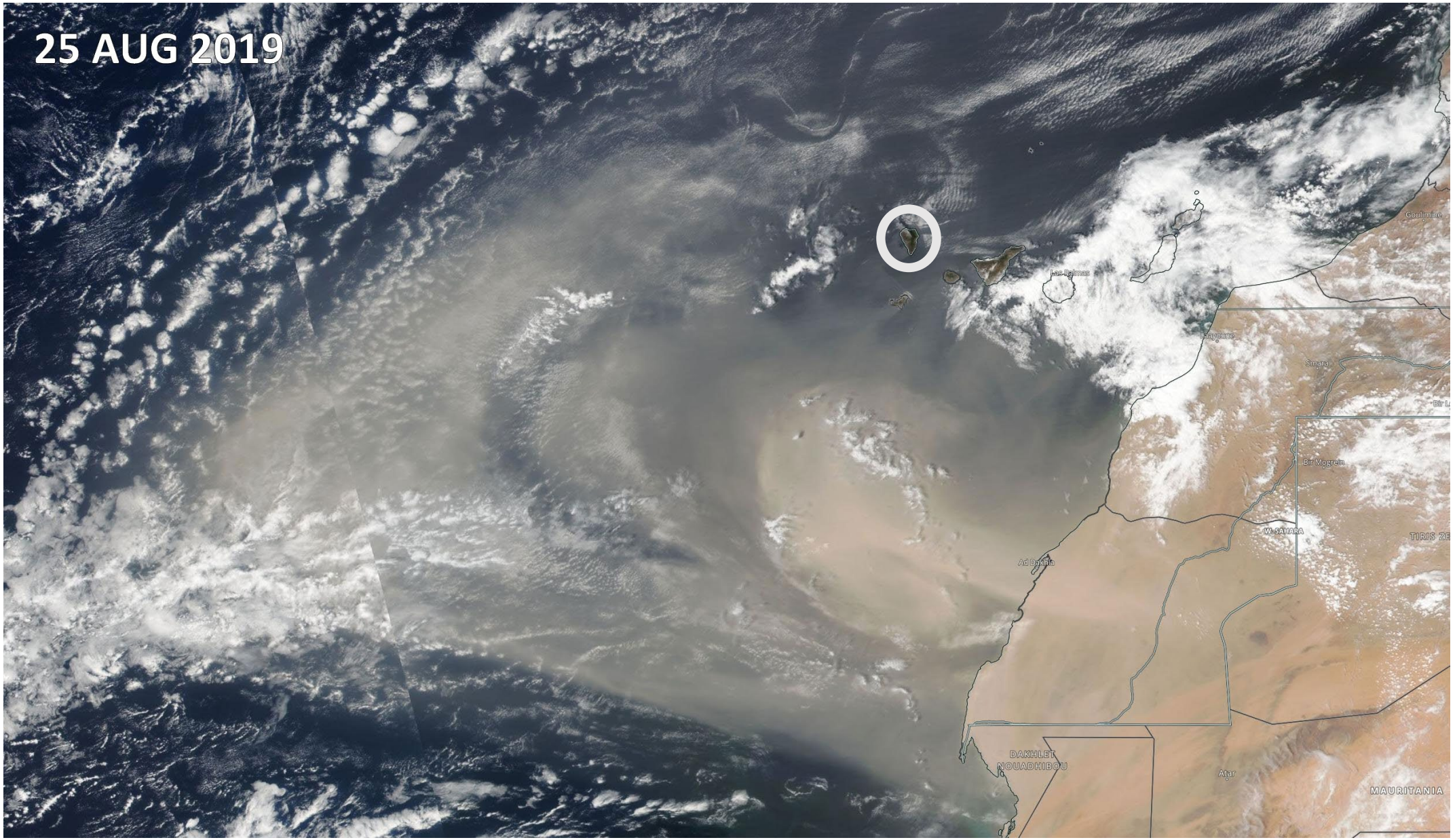
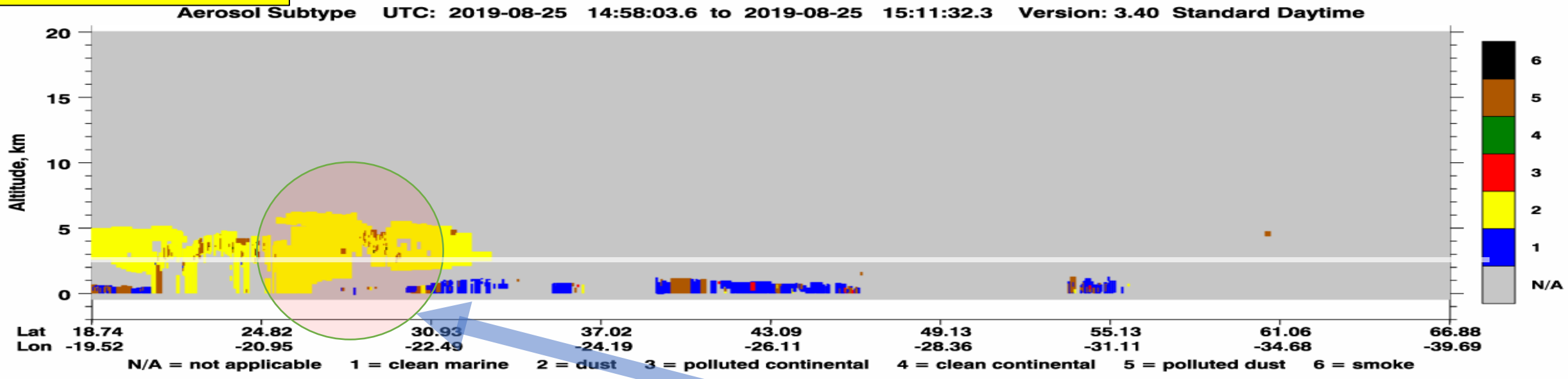
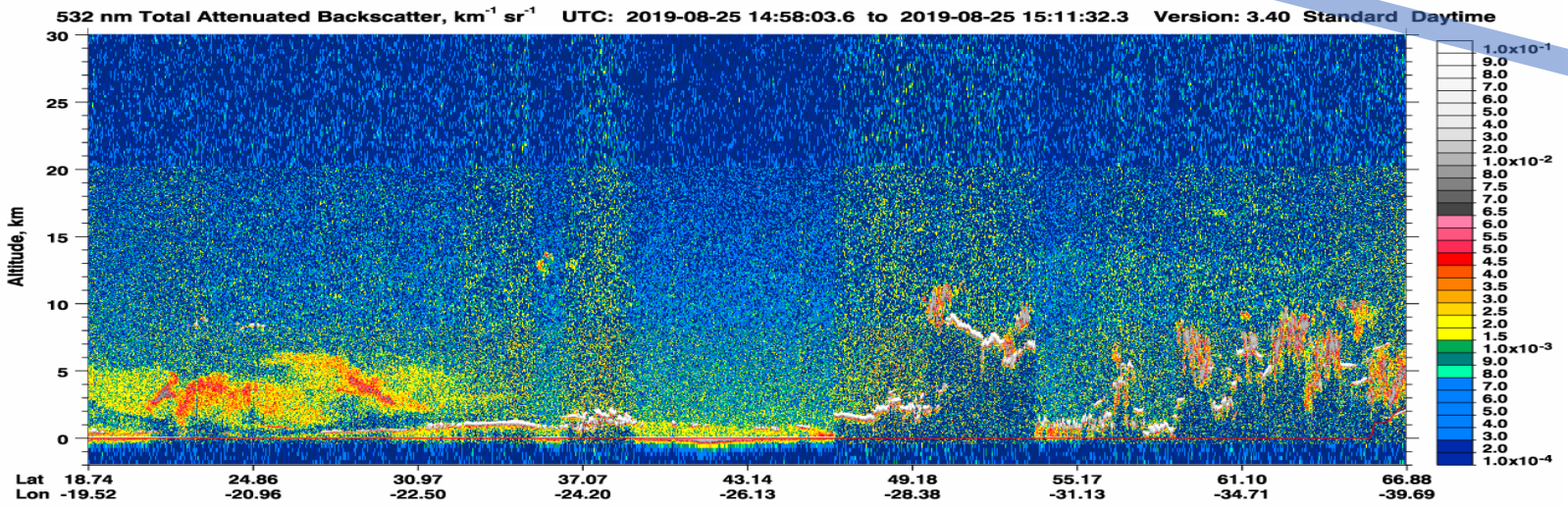
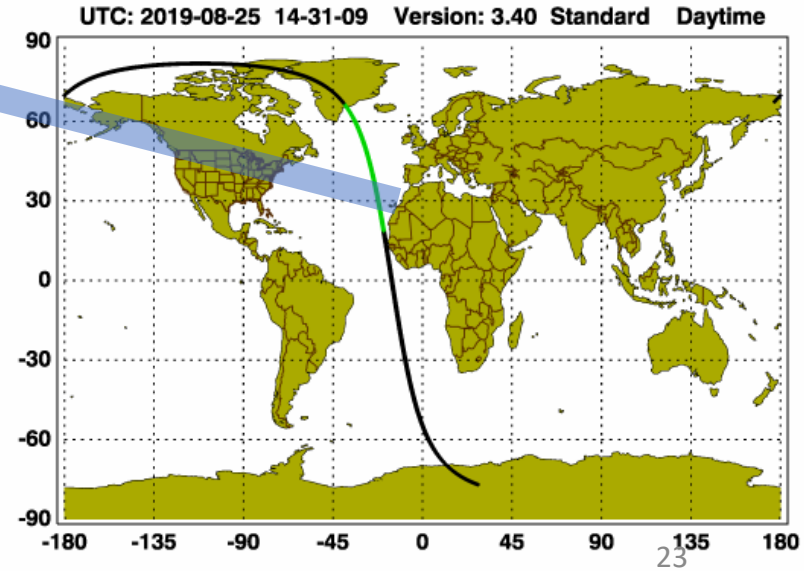

25 AUG 2019
Las Palmas
Goulimine
Sayoune
Smara
Bir Mogrein
W. SAHARA
Ad Dakhla
DAKHLET
NOUADHIBOU
Atar
MAURITANIA

Data

SD in elevated layers

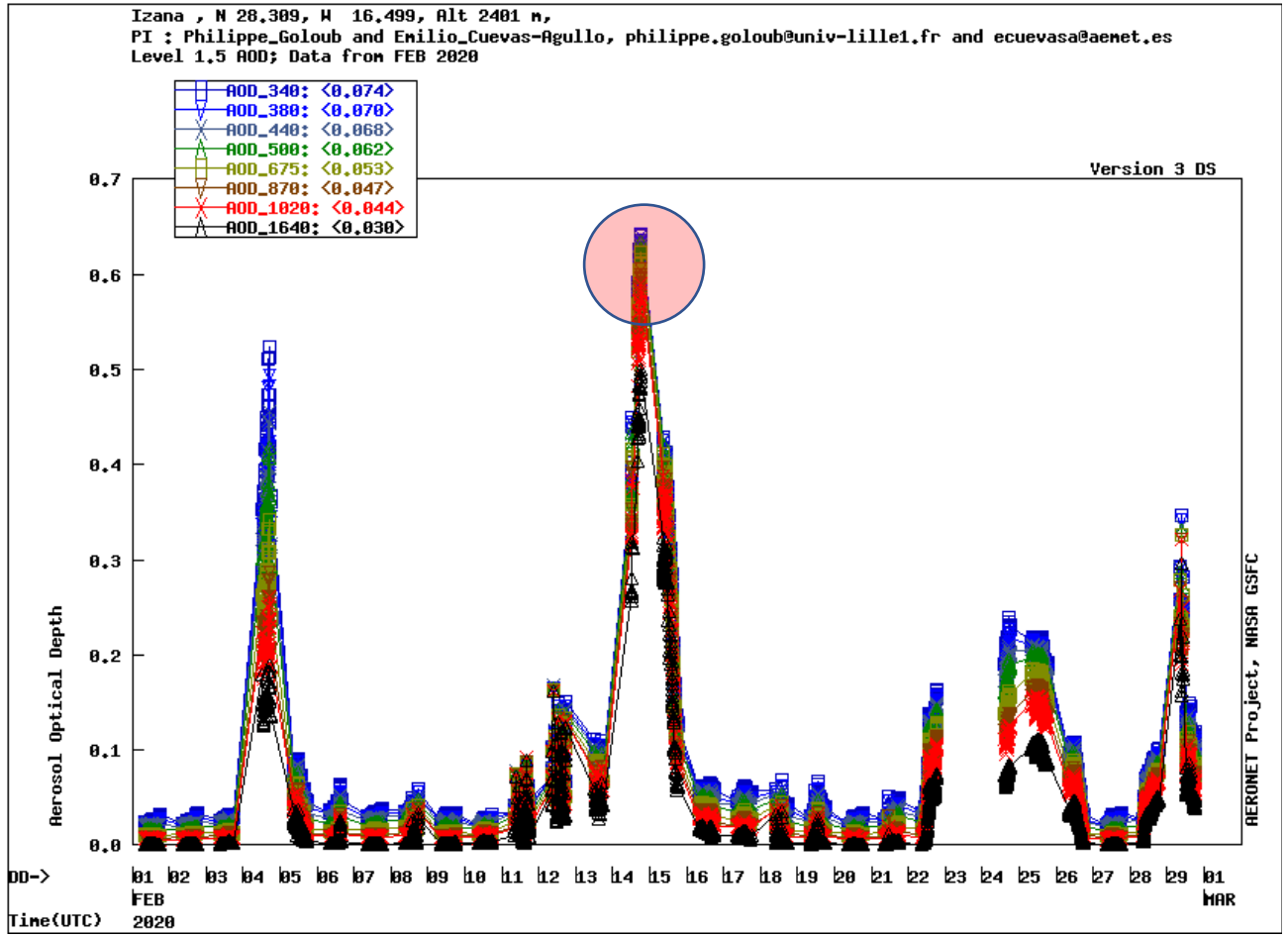


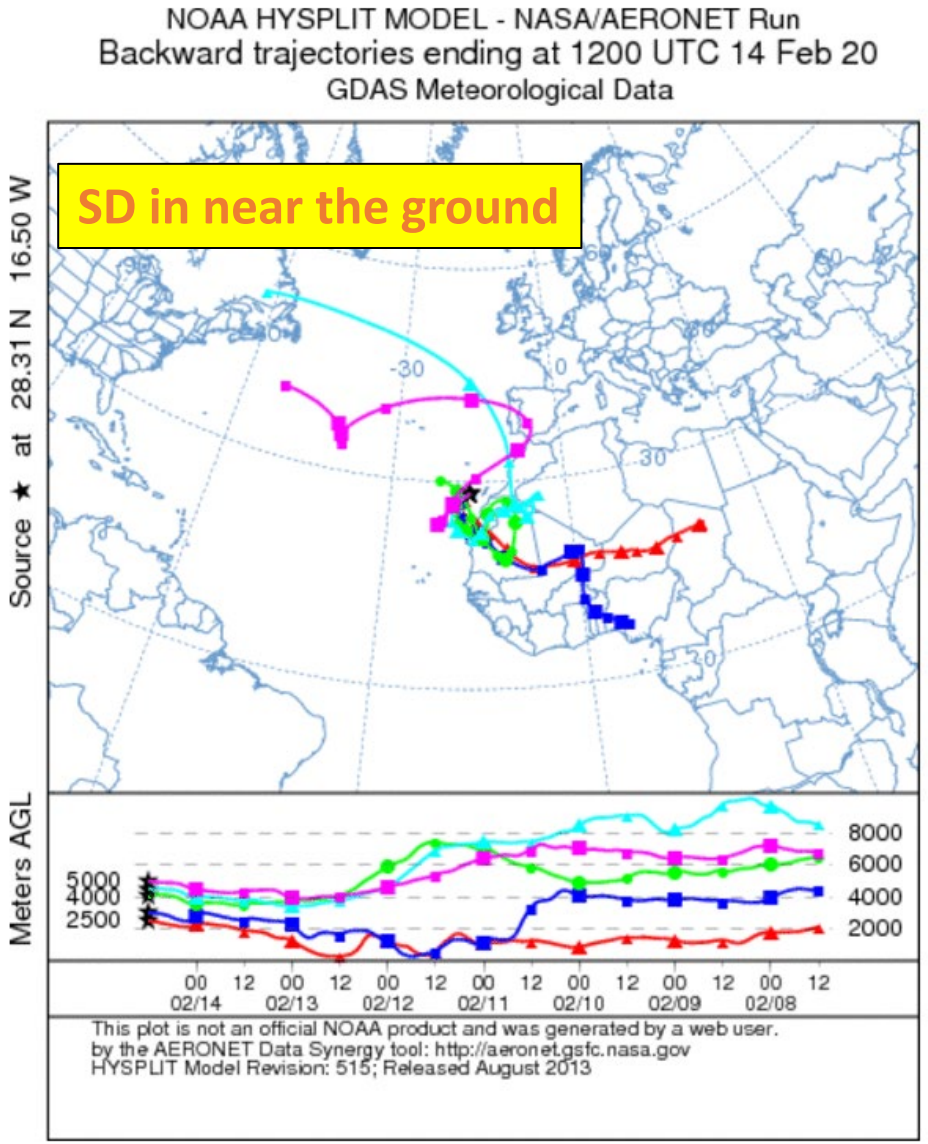




Data

14 FEB 2020 07UT – Saharan dust case

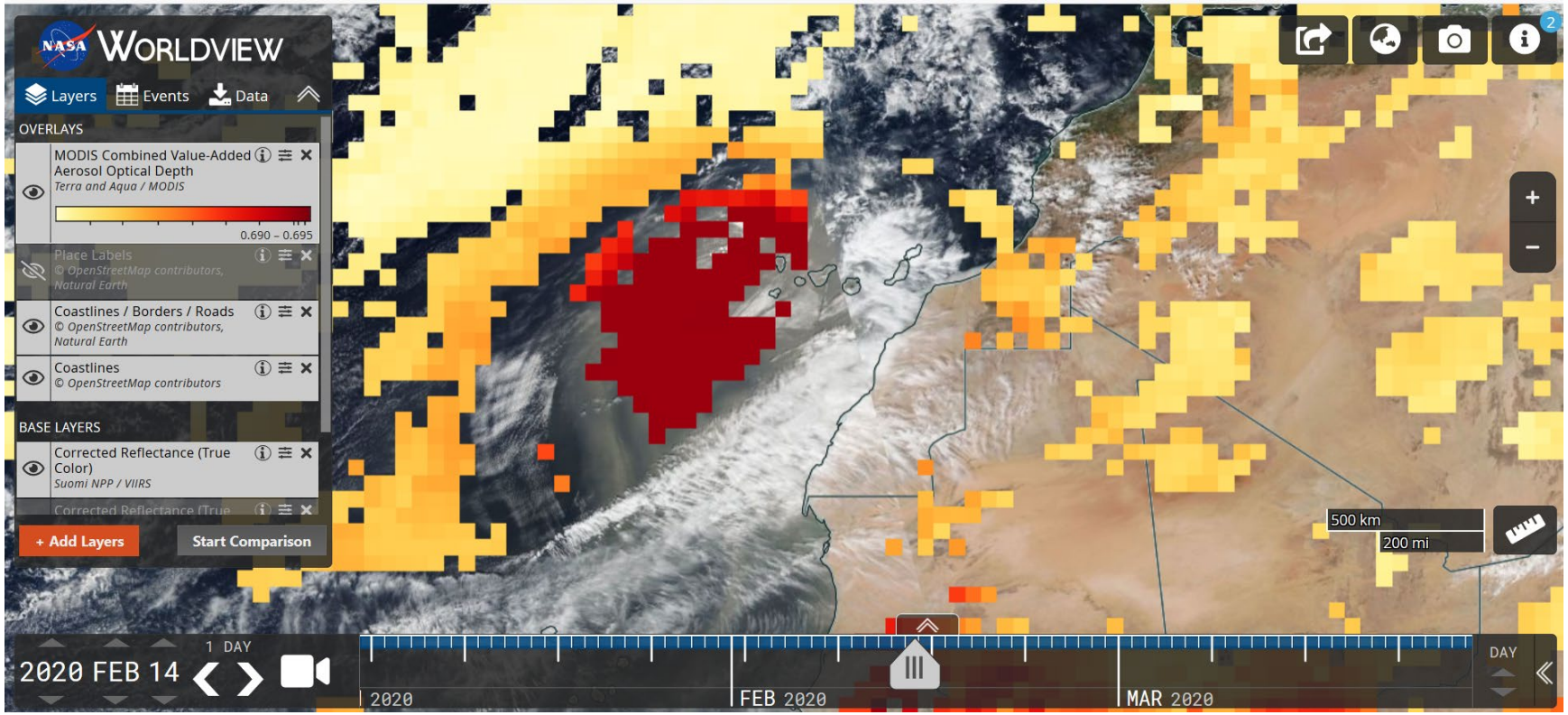


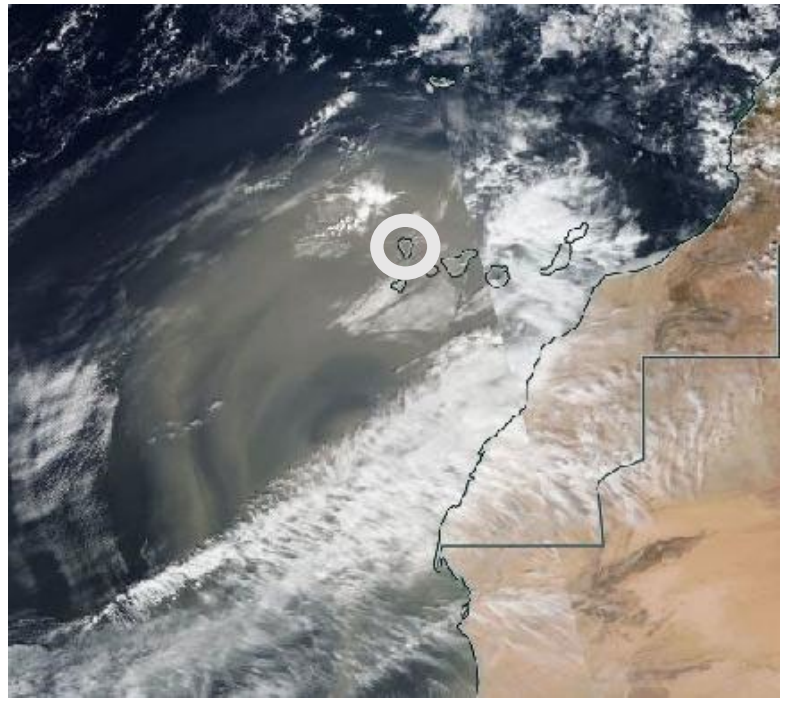


Data

14 FEB 2020 07UT – Saharan dust case

SD in near the ground





Data

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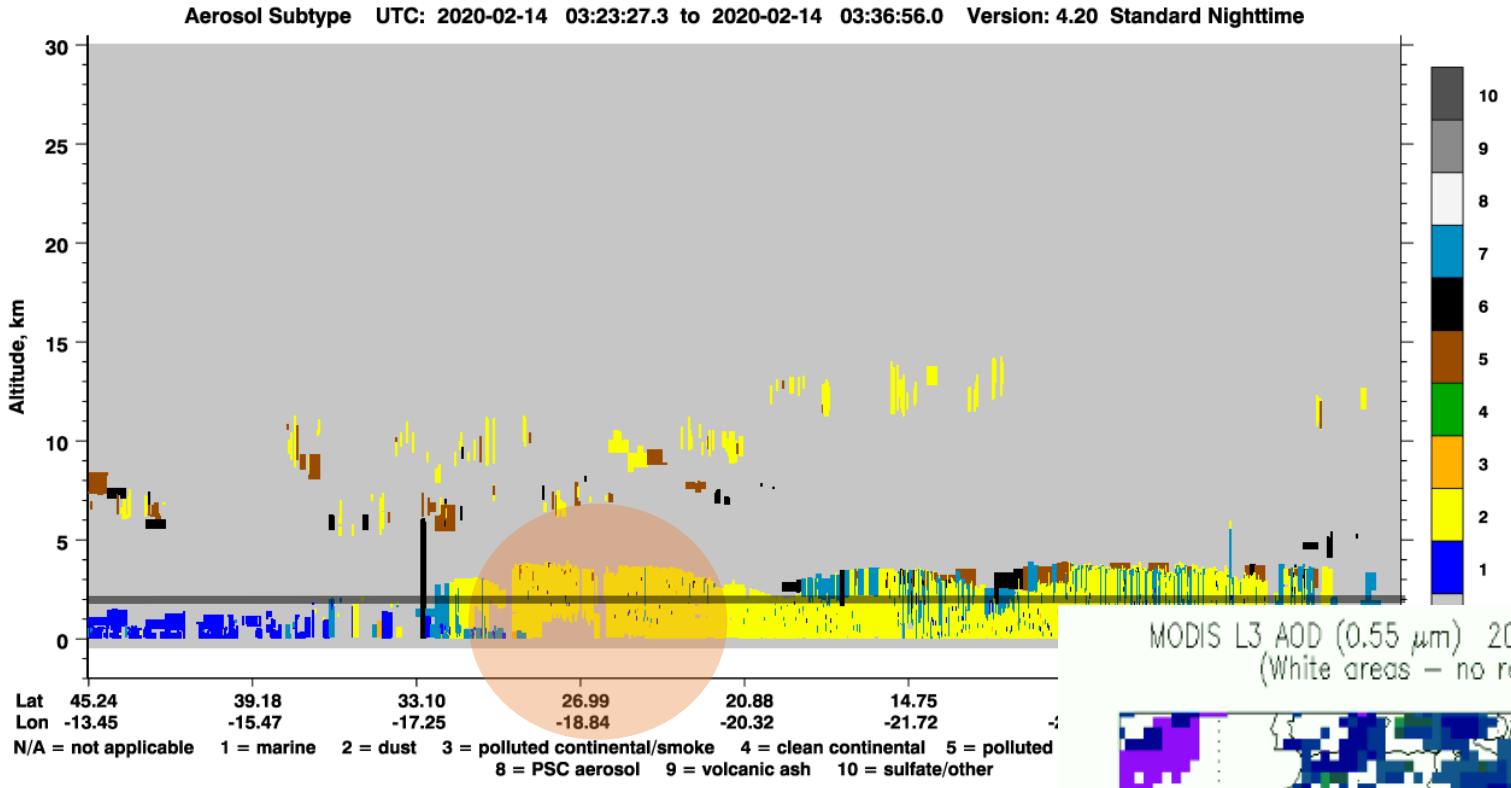
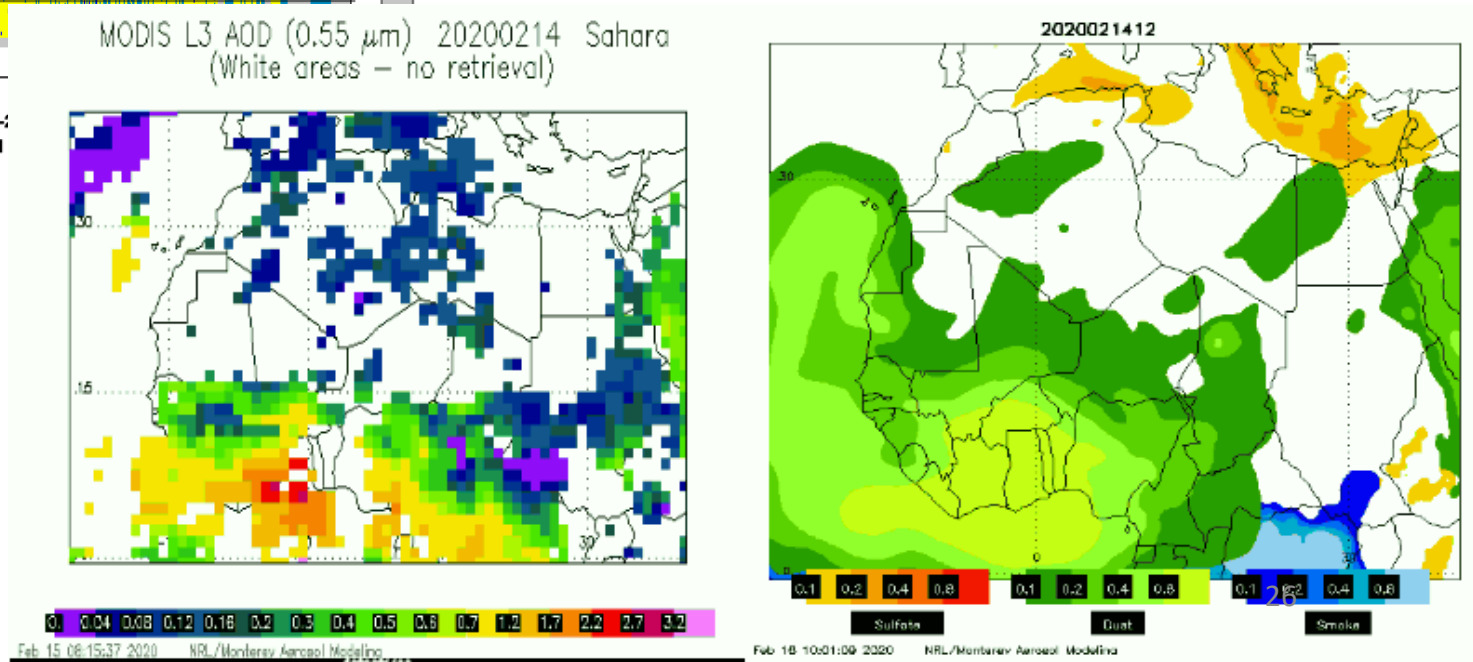


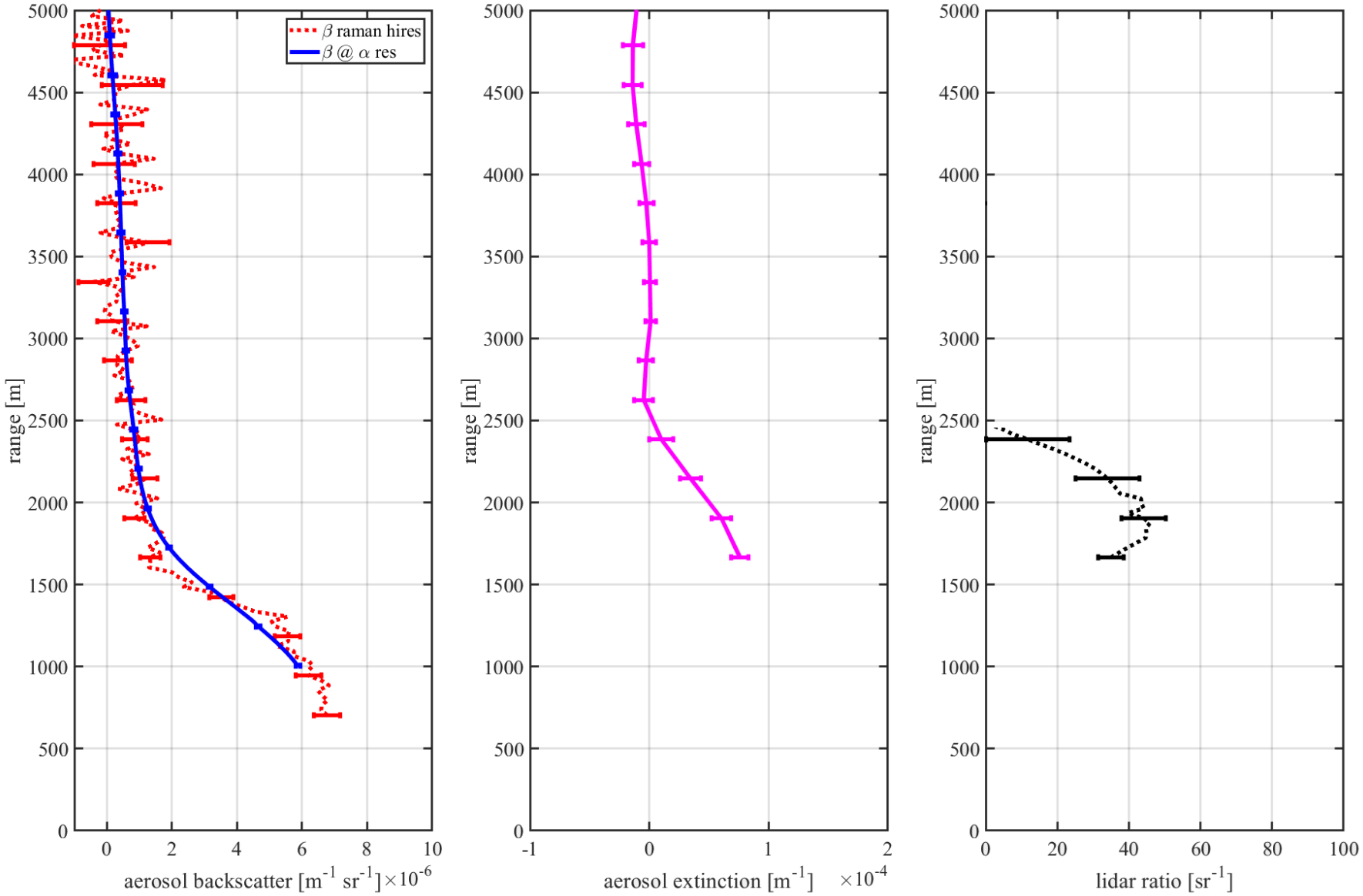
SD in near the ground



Data

14 FEB 2020 07UT – Saharan dust case

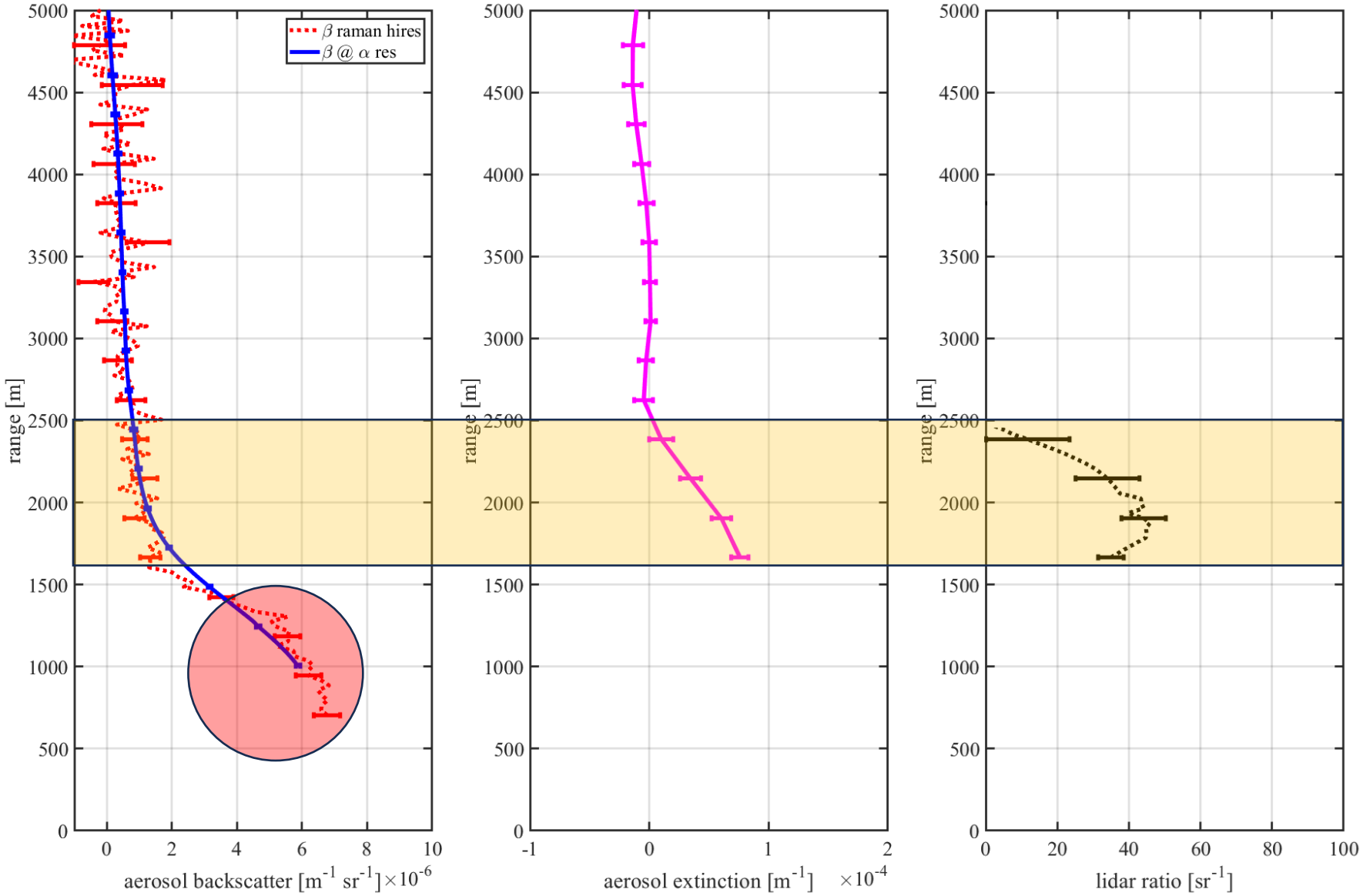
SD in near the ground



Data

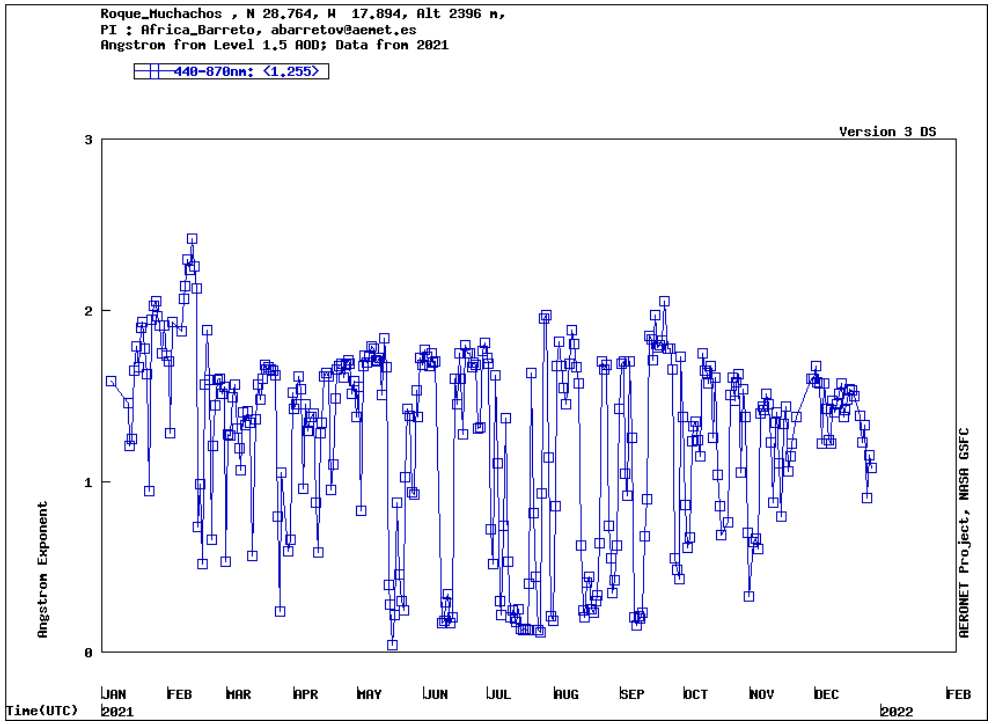
14 FEB 2020 07UT – Saharan dust case

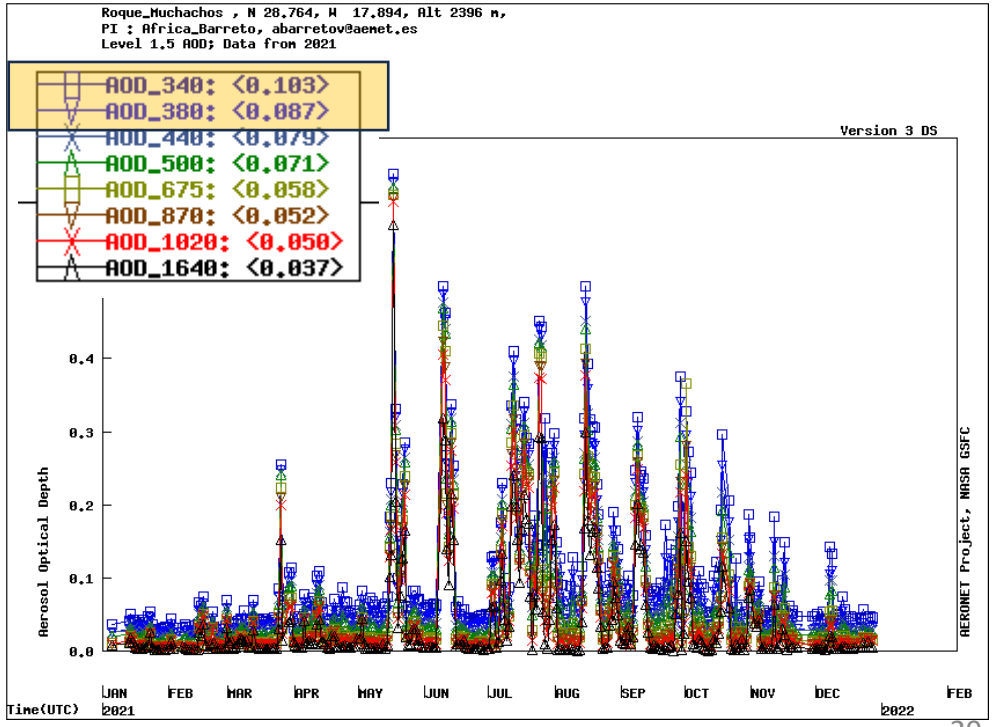
SD in near the ground



Roque_Muchachos AERONET site

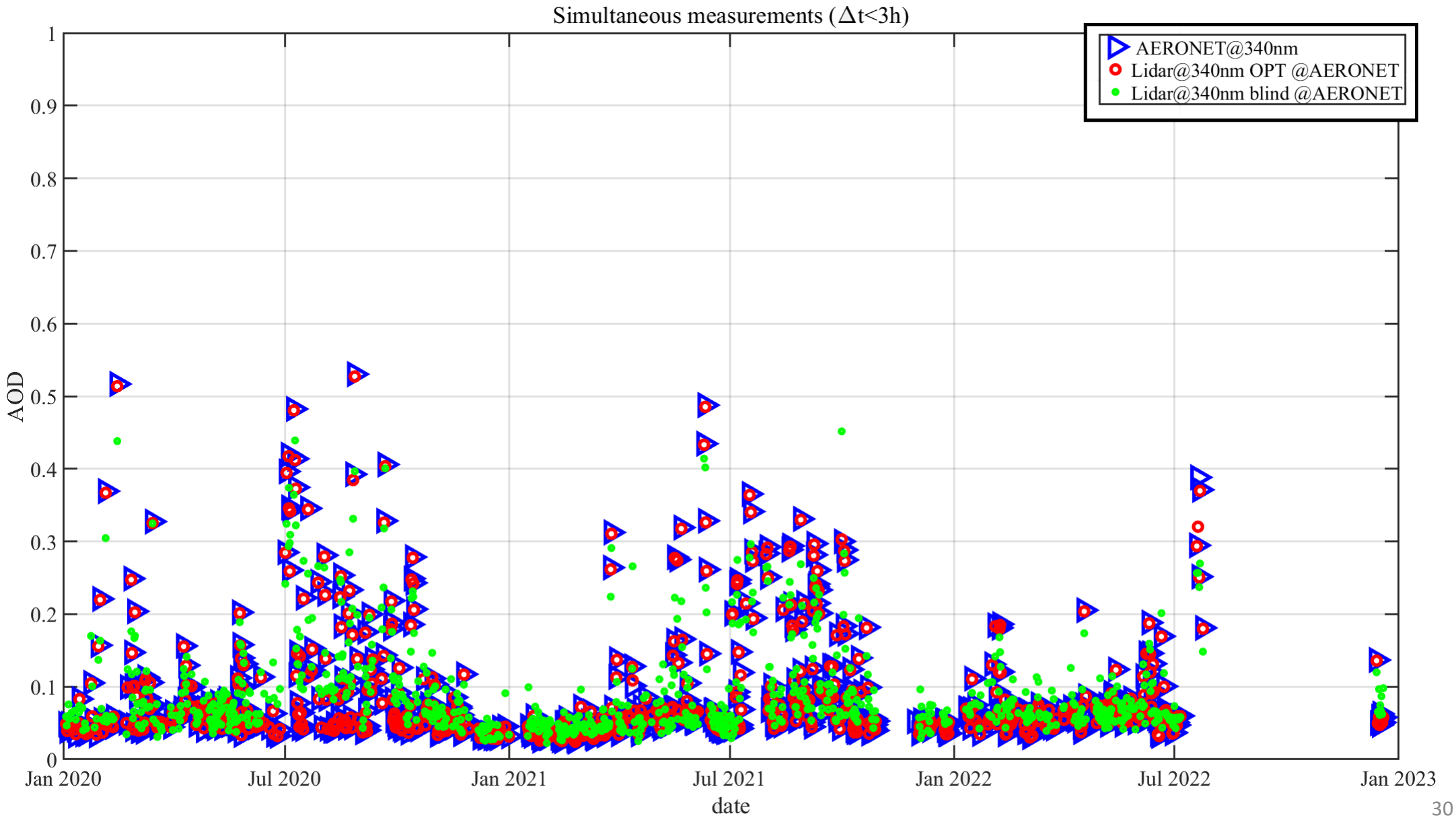
Site Coordinates and Elevation:	• Latitude: 28.76390° North • Longitude: 17.89390° West • Elevation: 2396.0 Meters
Site Description:	• Roque_Muchachos site is a high-mountain station located on the rim of the Taburiente National Park in the municipality of Garafía (La Palma). The photometer is installed at the Roque de los Muchachos Observatory, belonging to the Instituto de Astrofísica de Canarias (IAC). The site currently hosts the largest optical-infrared telescope in the world, along with twenty other telescopes and instruments for various kinds of studies, including nocturnal observations, robotic observing, solar physics, and high energy astrophysics.





Data

From elastic data



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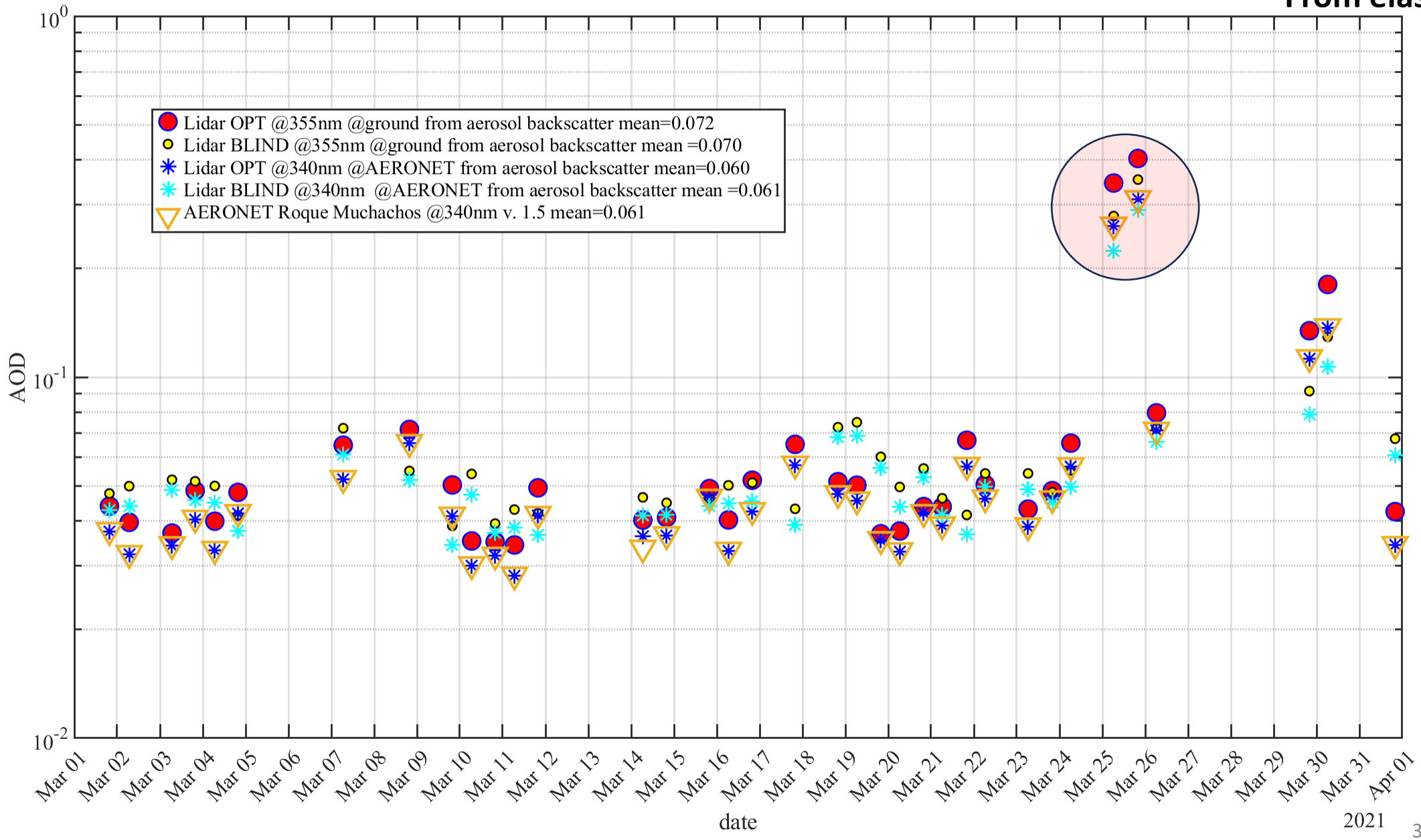
From elastic data



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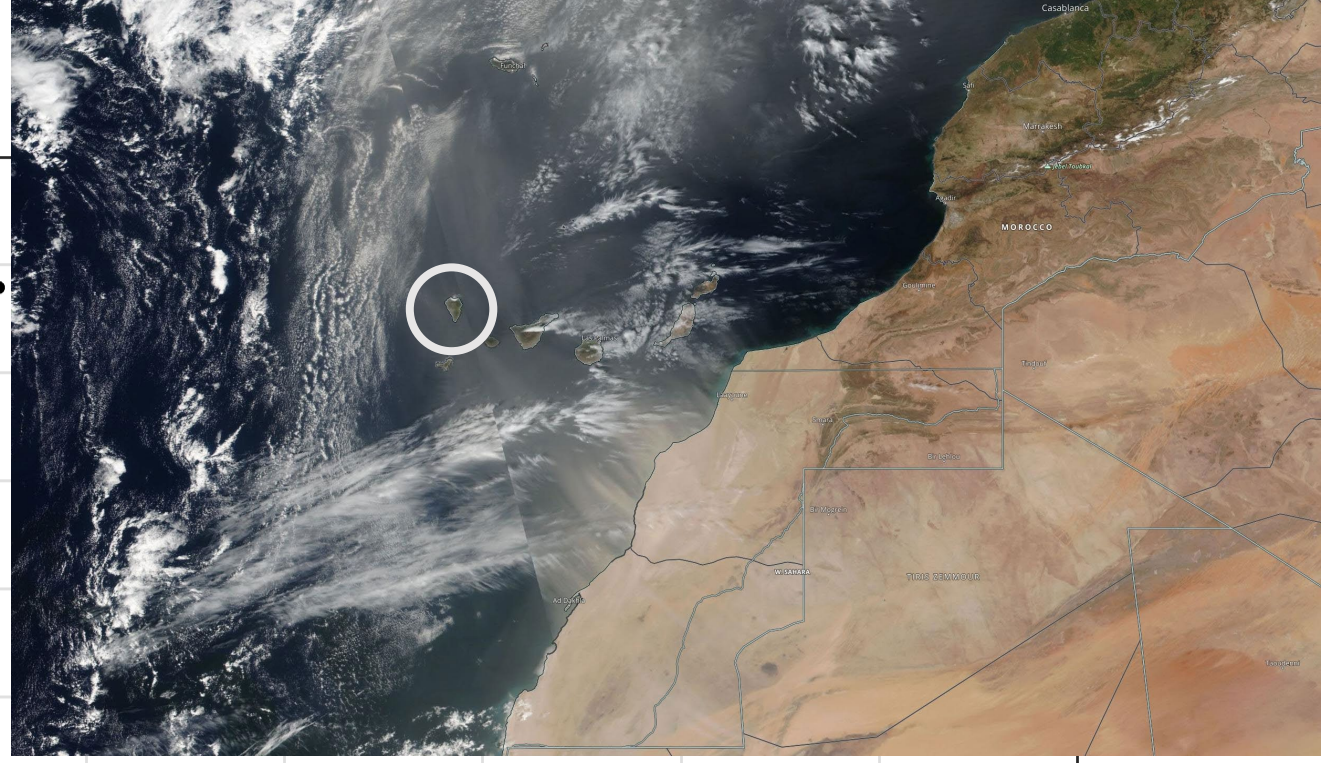
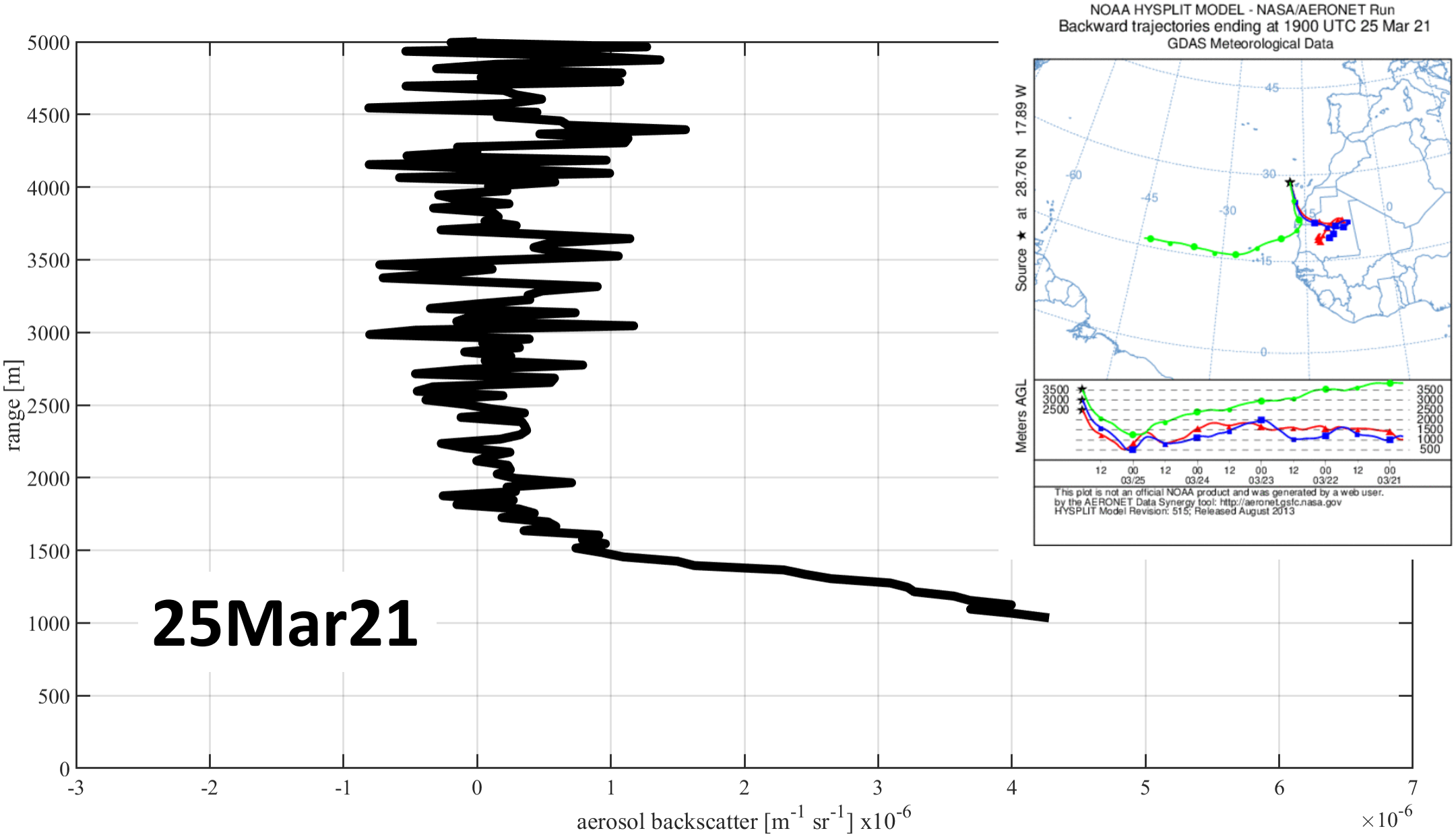
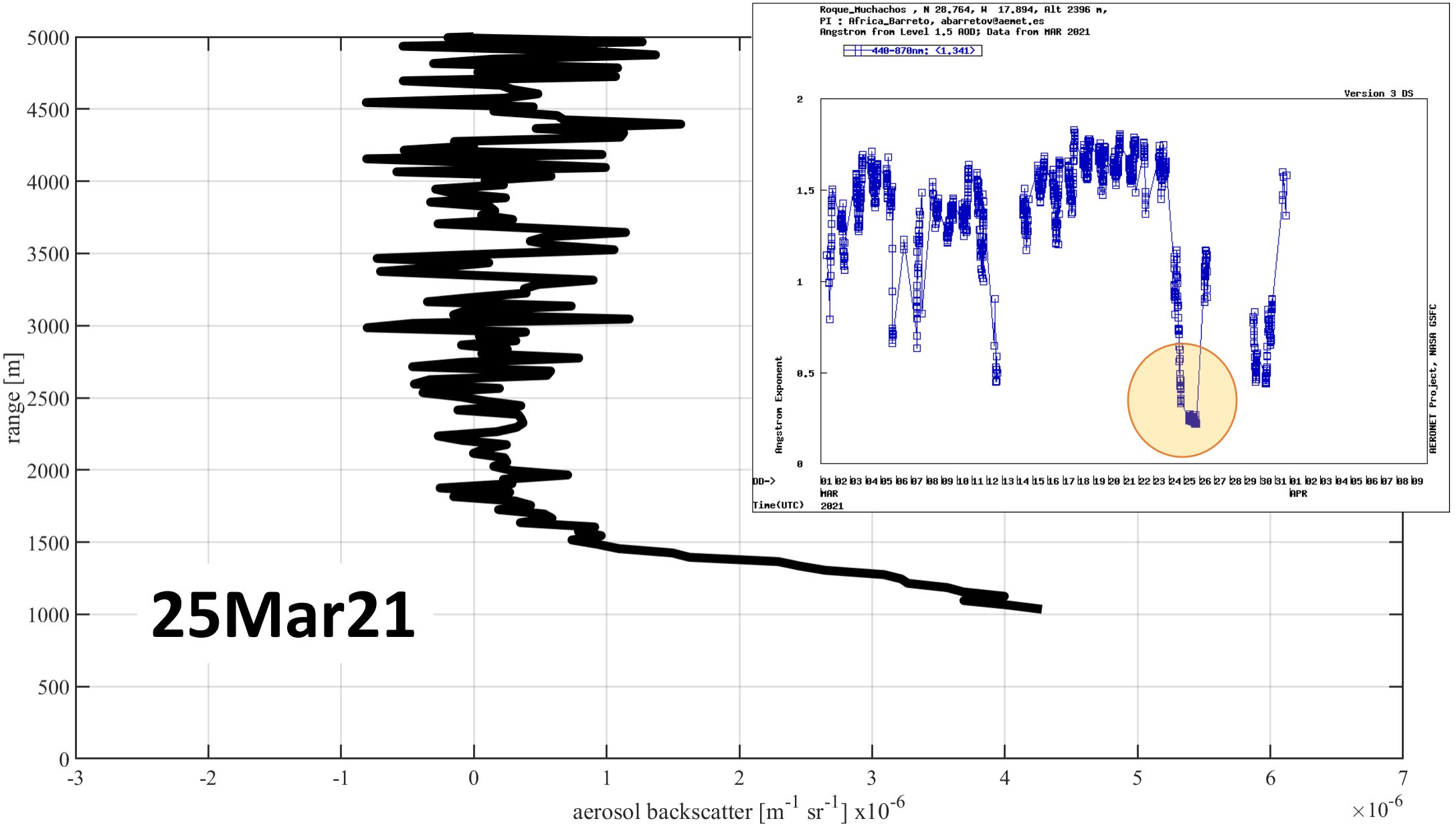

Casablanca
Marrakesh
MOROCCO
Agadir
Laayoune
Tindouf
TIZNIT ZEMMOUR

range [m]
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-3
-2
-1
0
1
2
3
4
5
6
7
aerosol backscatter [m-1 sr-1] x10-6
×10-6
25Mar21

Data

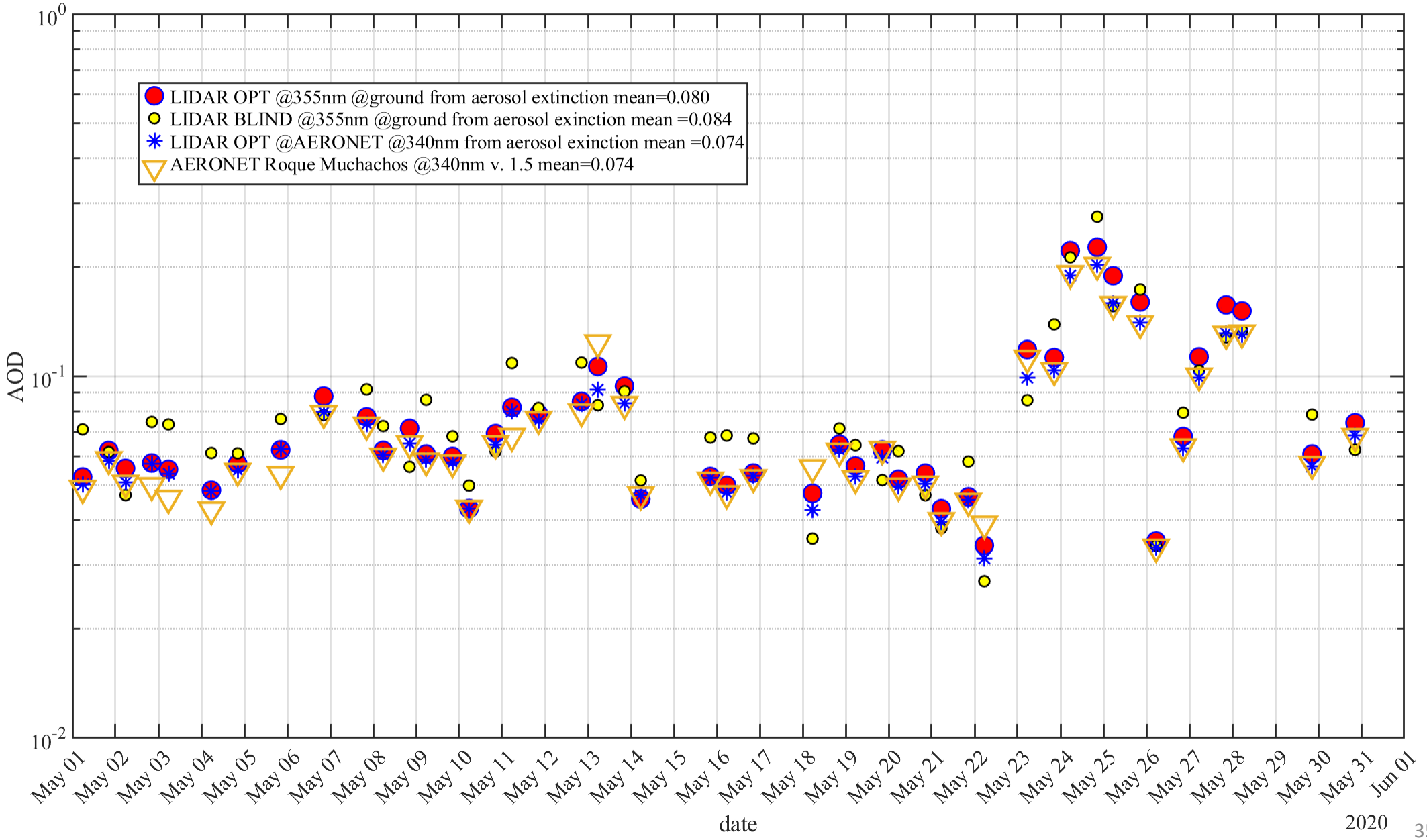

range [m]
aerosol backscatter [m^{-1} sr^{-1}] x10^{-6}
×10^{-6}
25Mar21
NOAA HYSPLIT MODEL - NASA/AERONET Run
Backward trajectories ending at 1900 UTC 25 Mar 21
GDAS Meteorological Data
Source ★ at 28.76 N 17.89 W
Meters AGL
This plot is not an official NOAA product and was generated by a web user.
by the AERONET Data Synergy tool: http://aeronet.gsfc.nasa.gov
HYSPLIT Model Revision: 515; Released August 2013

Data


range [m]
aerosol backscatter [m-1 sr-1] x10-6
×10-6
25Mar21
Roque_Muchachos , N 28.764, W 17.894, Alt 2396 m,
PI : Africa_Barreto, abarretov@aemet.es
Angstrom from Level 1.5 AOD; Data from MAR 2021
440-870nm: <1.341>
Version 3 DS
Angstrom Exponent
AERONET Project, NASA GSFC
DD->
Time(UTC)
MAR
APR
2021

Data

RAMAN - From aerosol extinction data…



Data

ARCADE Raman lidar

Report 15102021 – CTA-INFN Raman lidar [see also the previous reports in:

https://www.dropbox.com/sh/rccqafnecx9ri87/AABWPhyUaXx_ThXIX4PiF4M4a?dl=0

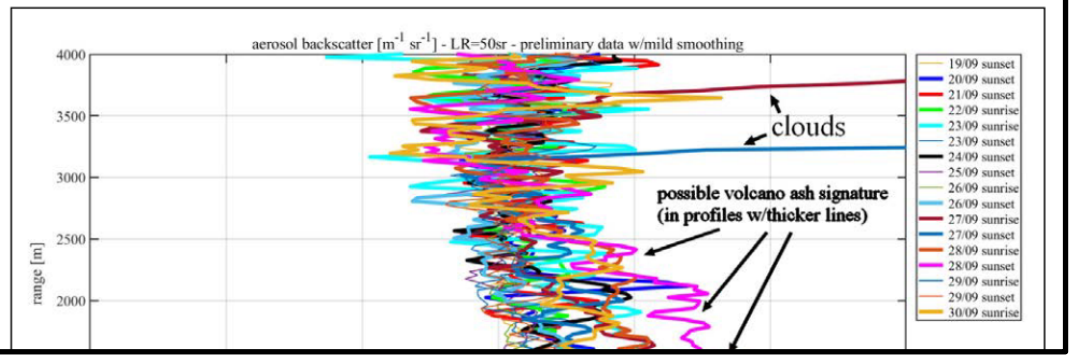
Cumbre Vieja volcano [lat. 28°36'57.85"N lon. 17°51'50.27"W 985 m a.s.l.] Eruption started on 19092021

This is a short report of the observations of the **CTA-INFN Raman lidar** located at Osservatorio del Roque de Los Muchachos (ORM) at lat. 28°45'49.77"N lon. 17°53'36.10"W 2155 m a.s.l..

The **CTA-INFN Raman lidar** is taking measurements in automatic mode, and, at the moment, the observations are scheduled around the sunset and the sunrise to override the possible interferences with other experiments at ORM.

The **CTA-INFN Raman lidar** signals can be used to retrieve the vertical profiles of the aerosol optical depth and of the aerosol volume backscatter coefficient; the latter quantity is less influenced by systematic uncertainties, and gives direct information about the aerosol location and relative concentration, especially in the cases of high aerosol load.

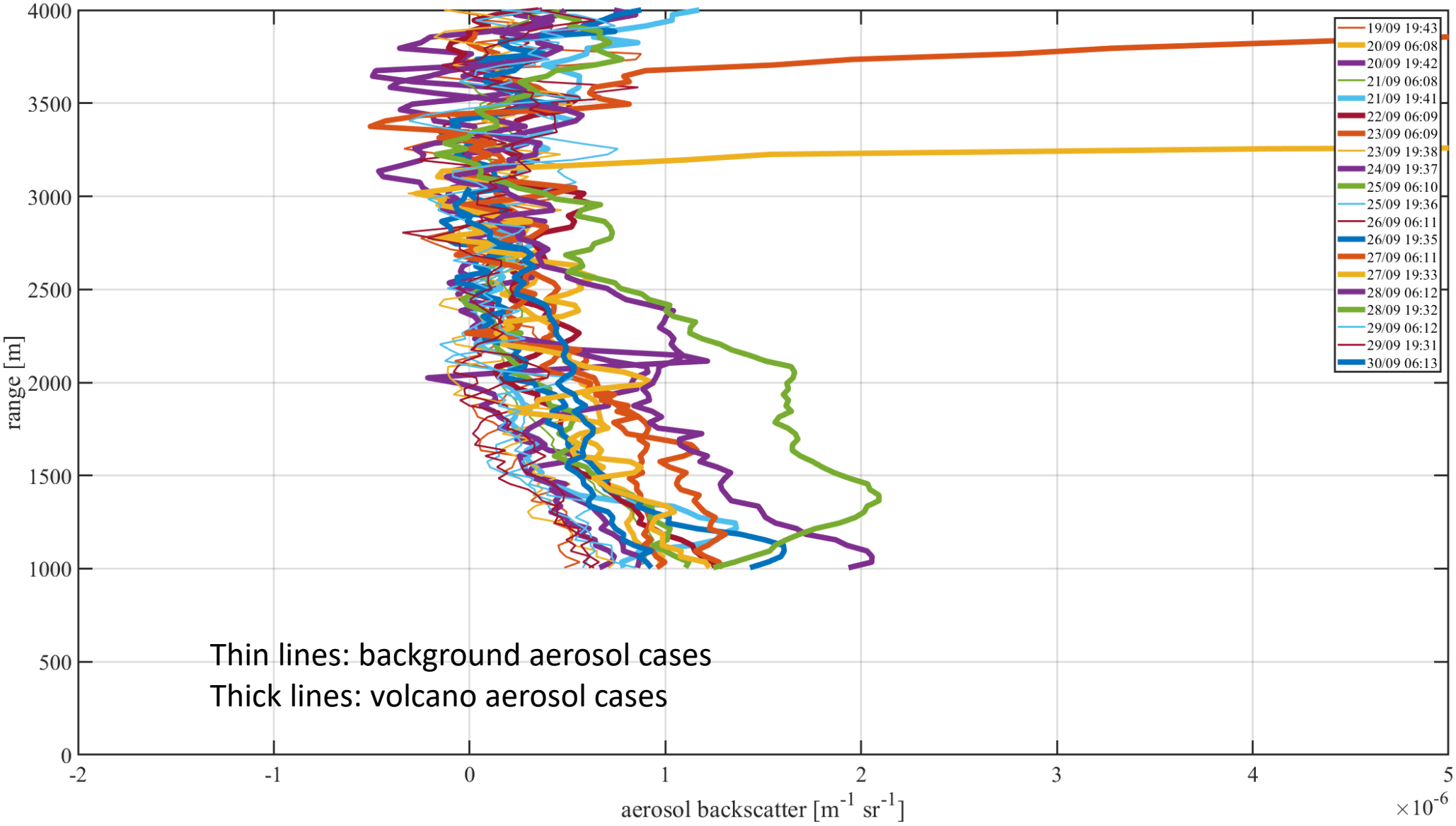
The (preliminary) vertical profiles of the **aerosol backscatter coefficients** up to 4000 m above ground level (a.g.l.) in the **period 19 – 30 September 2021** are shown in Figure 1. Several layers of the volcanic aerosols have been detected, and they show an aerosol concentration well above the background conditions (some



Cumbre Vieja eruption

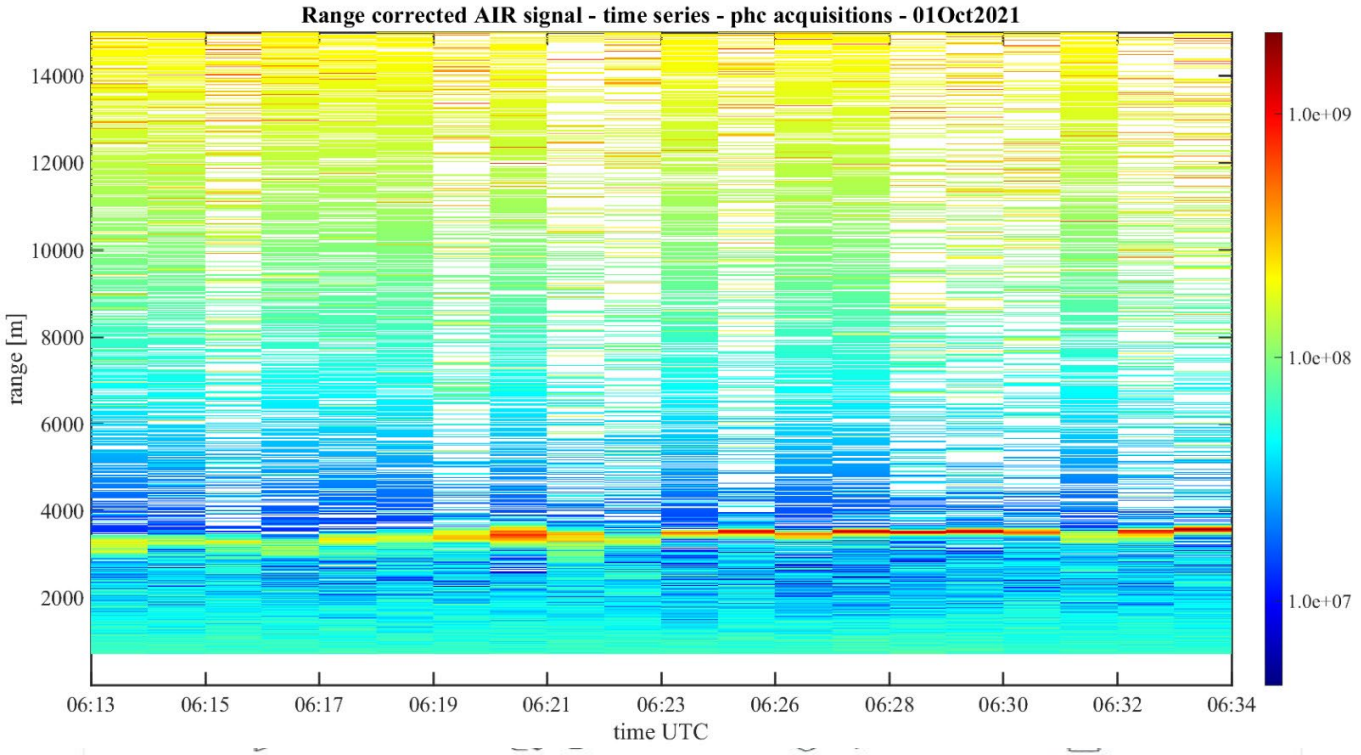
Data

Cumbre Vieja eruption



Data

Volcano plume direction toward lidar site



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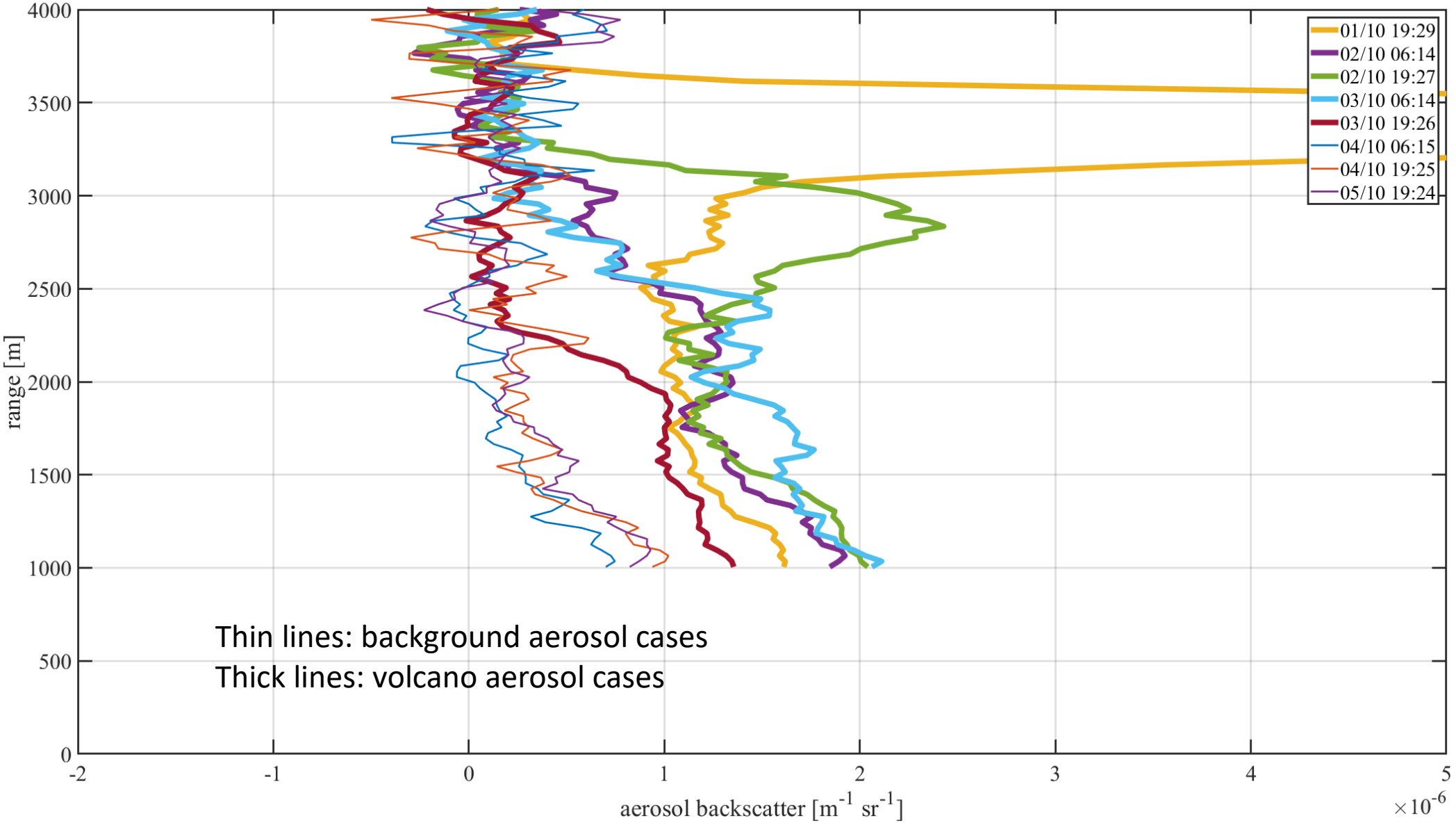
Cumbre Vieja eruption



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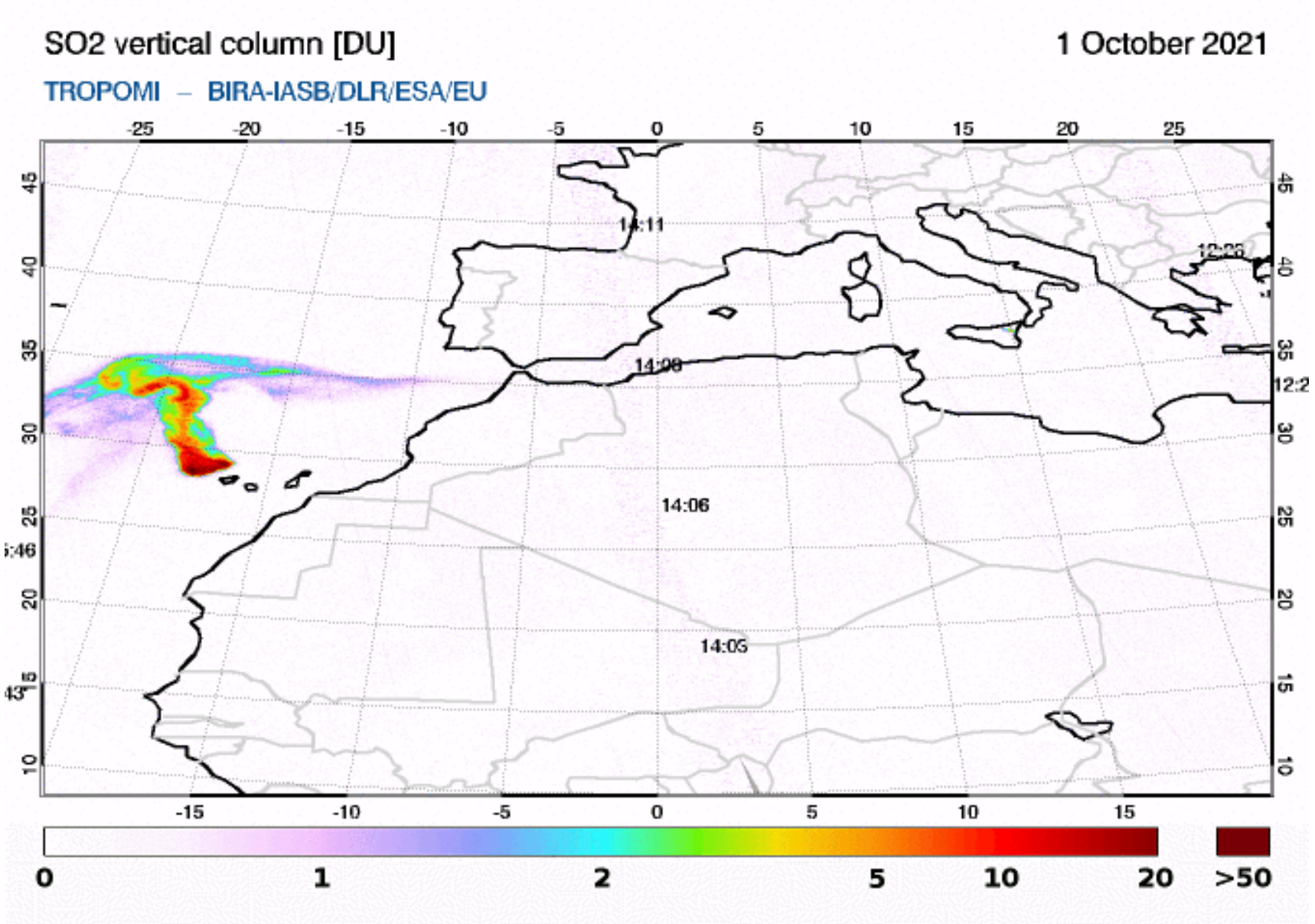
Cumbre Vieja eruption



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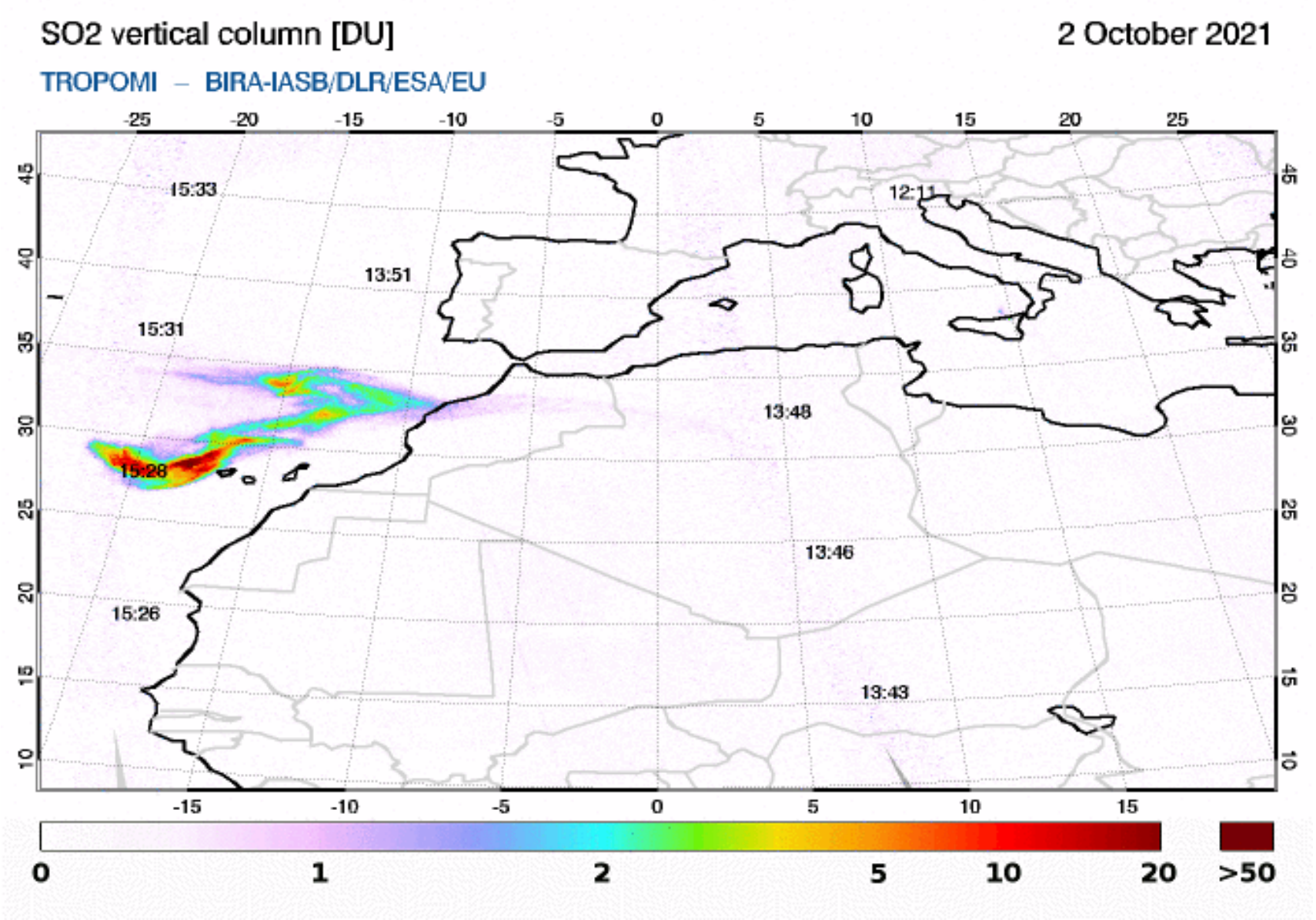
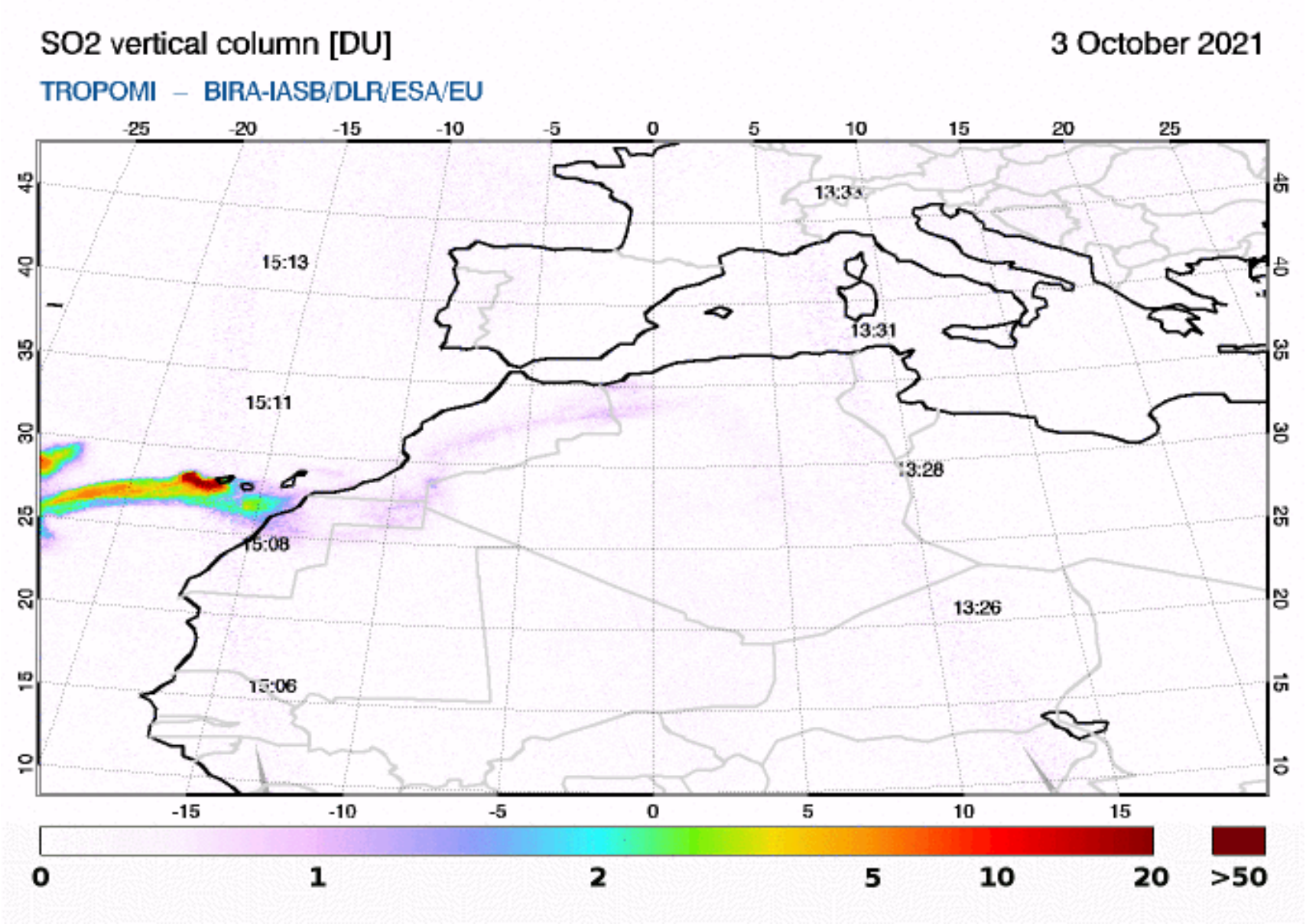
Cumbre Vieja eruption



Data

Cumbre Vieja eruption



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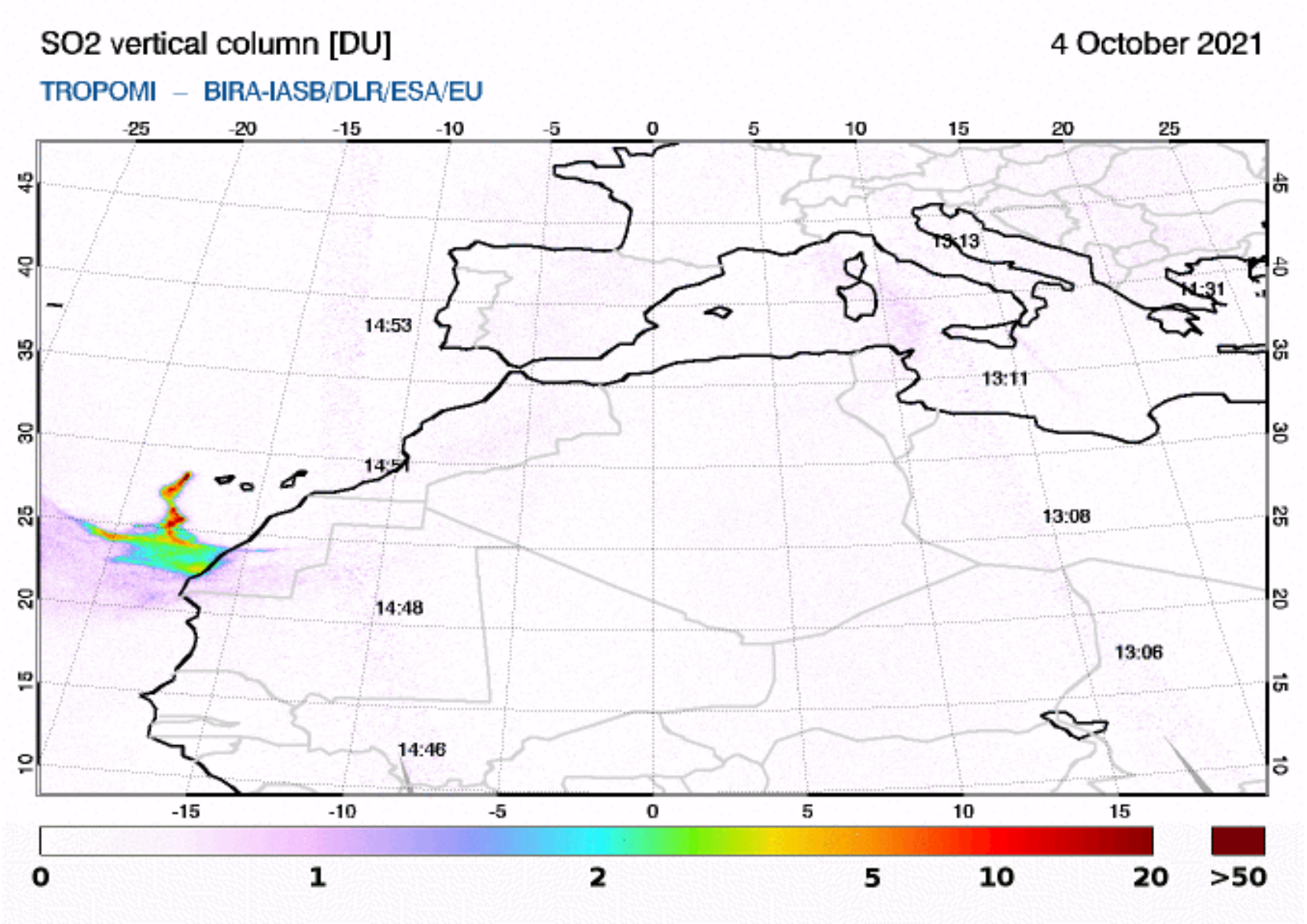
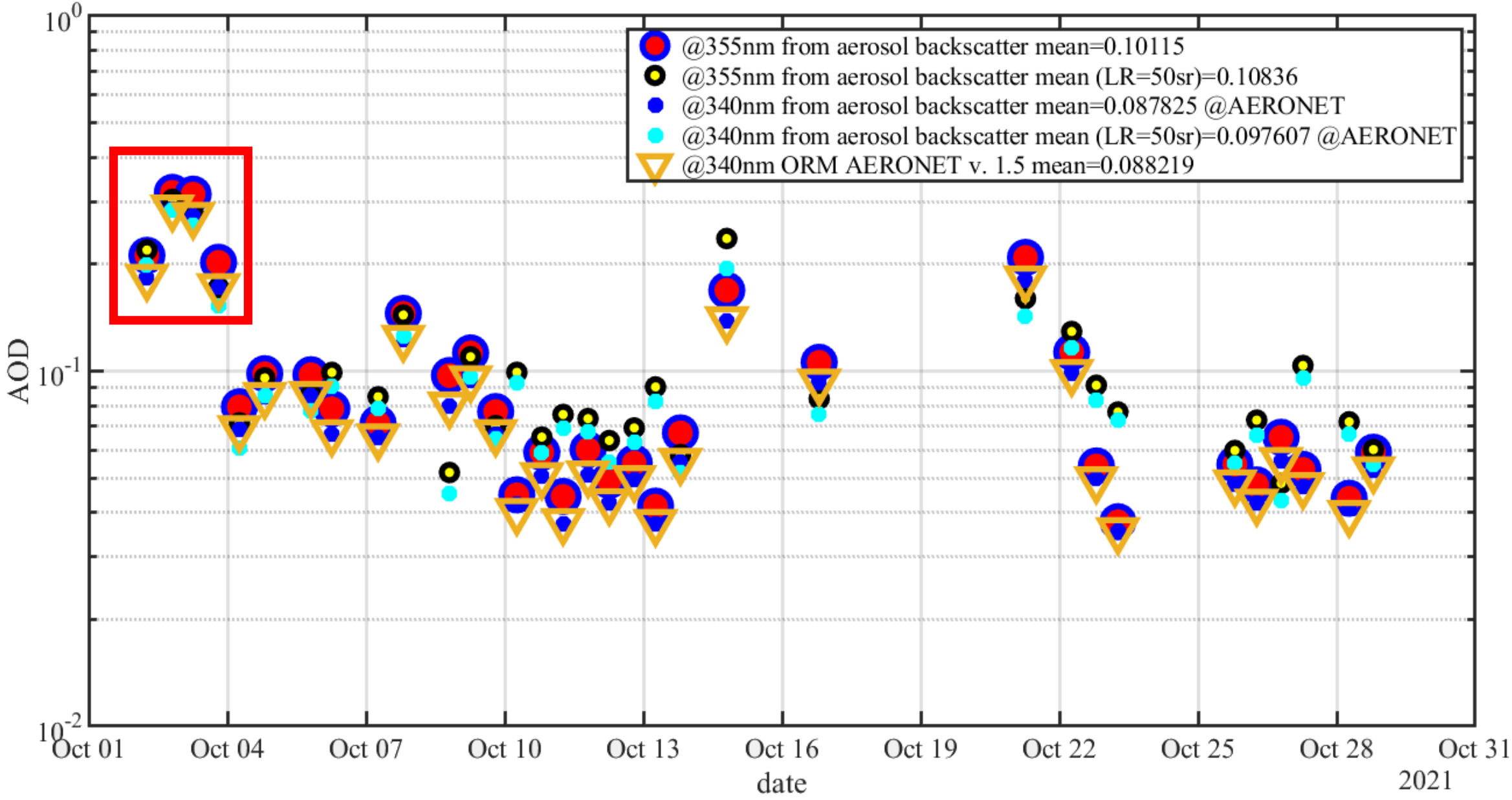
Cumbre Vieja eruption



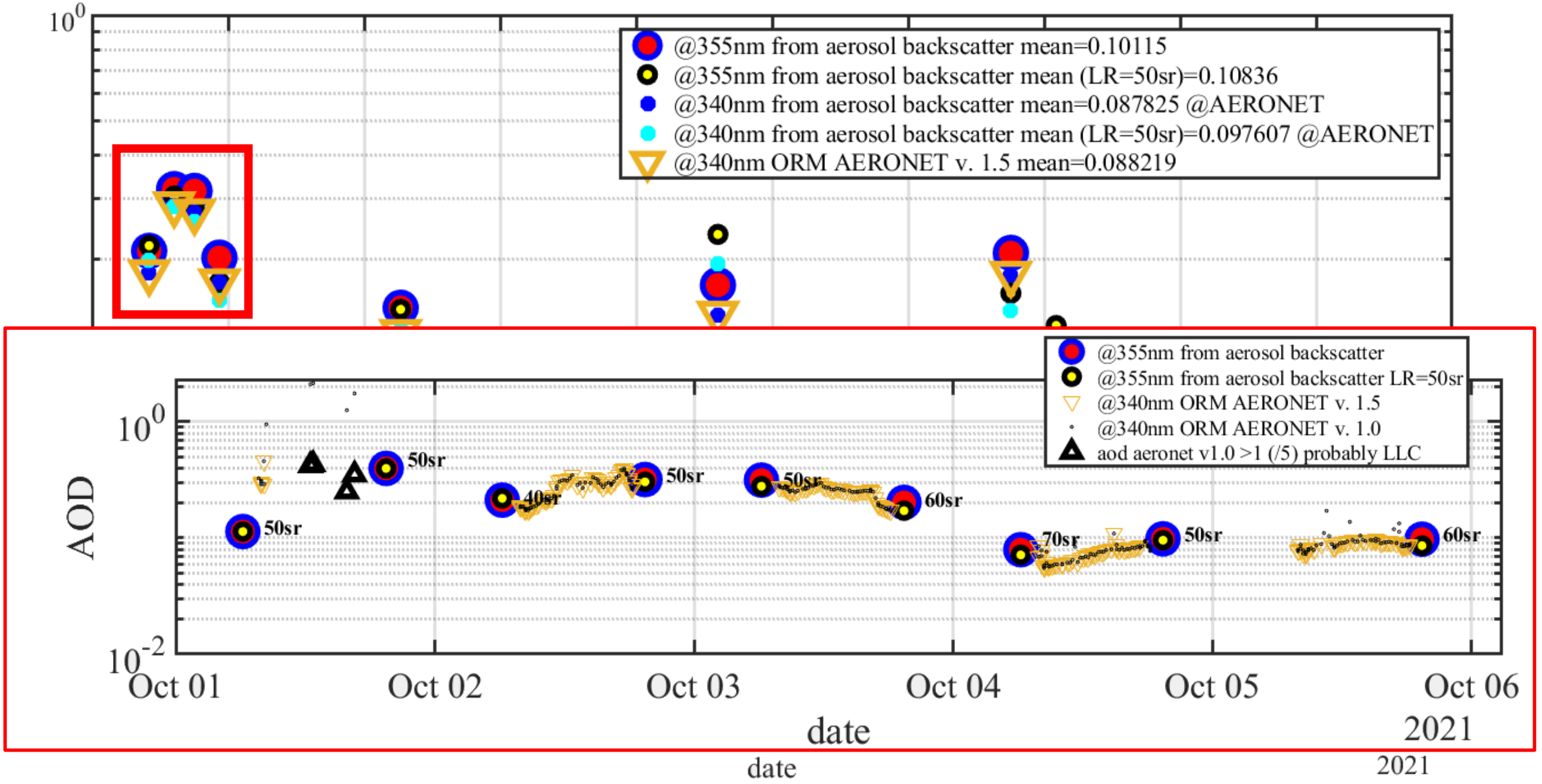
Data

Cumbre Vieja eruption



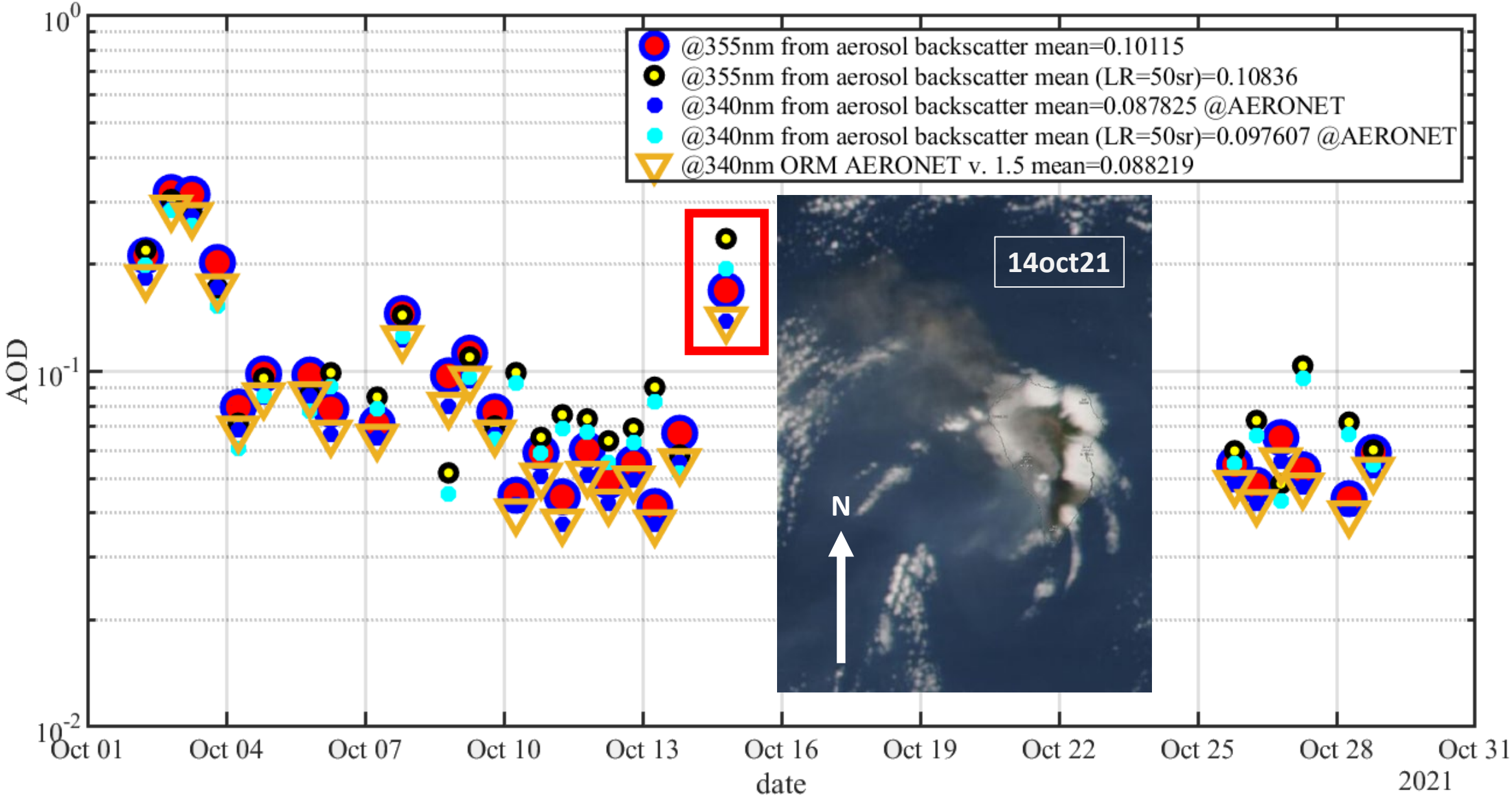
Data

Cumbre Vieja eruption



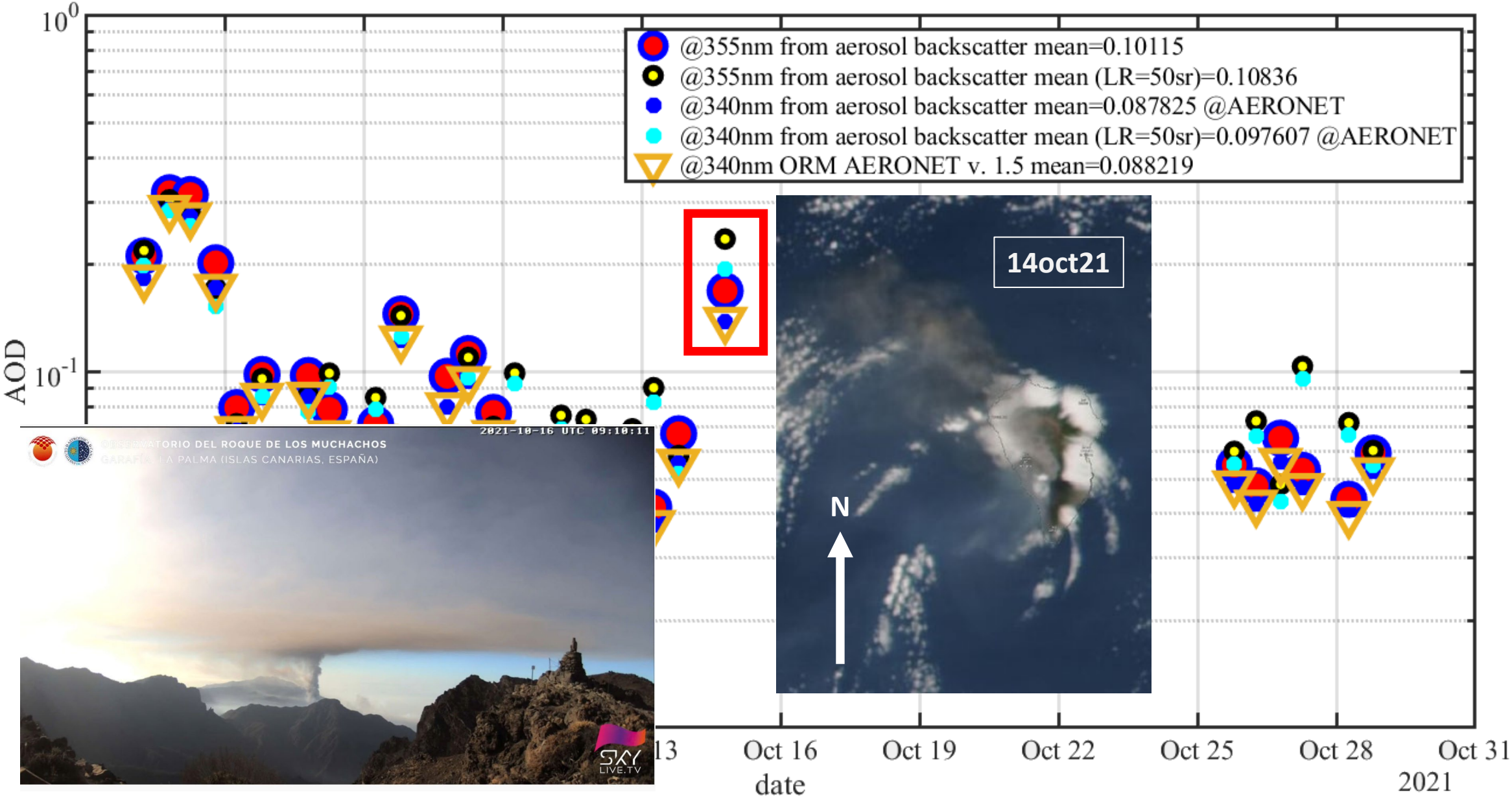
Data

Cumbre Vieja eruption



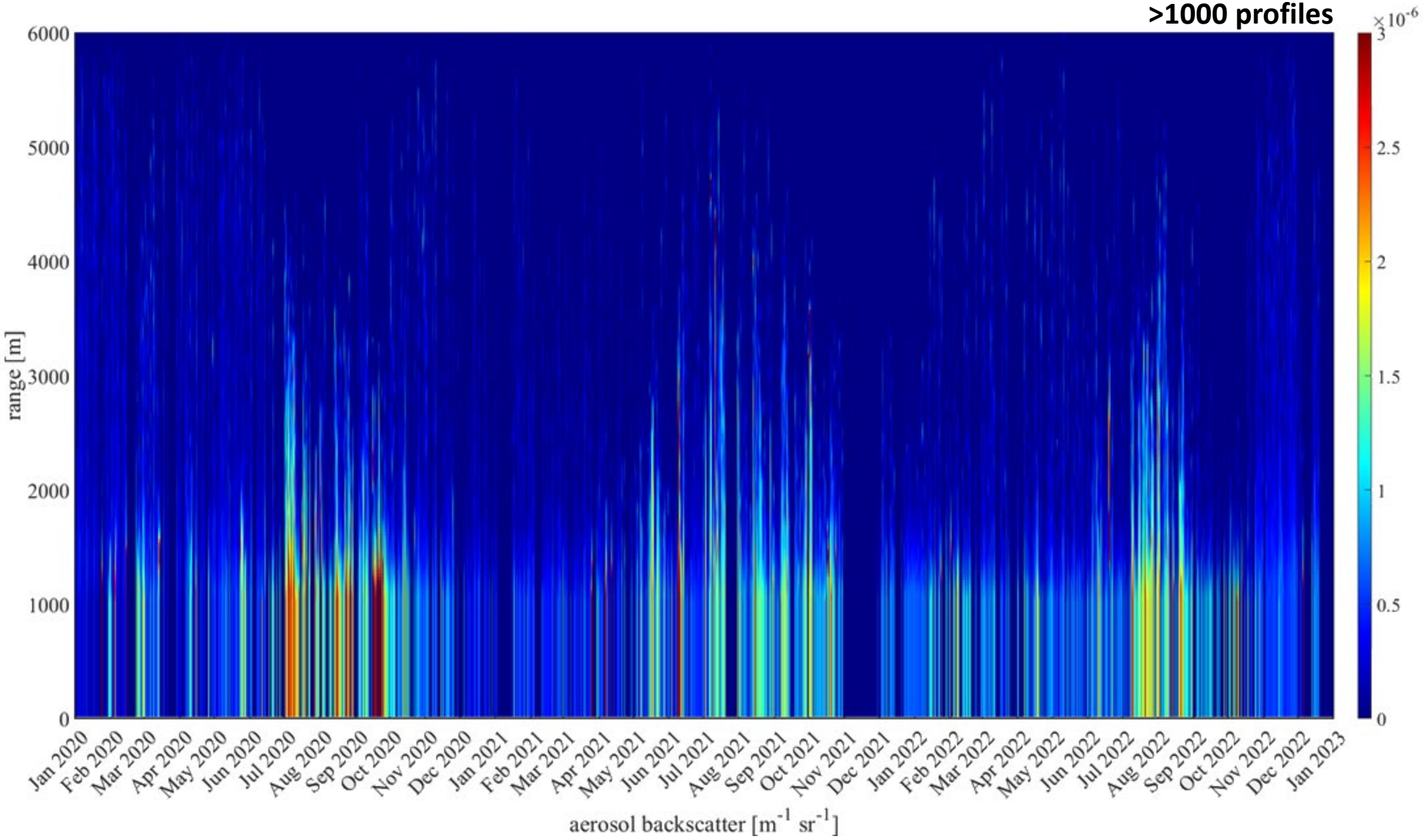
Data

Cumbre Vieja eruption



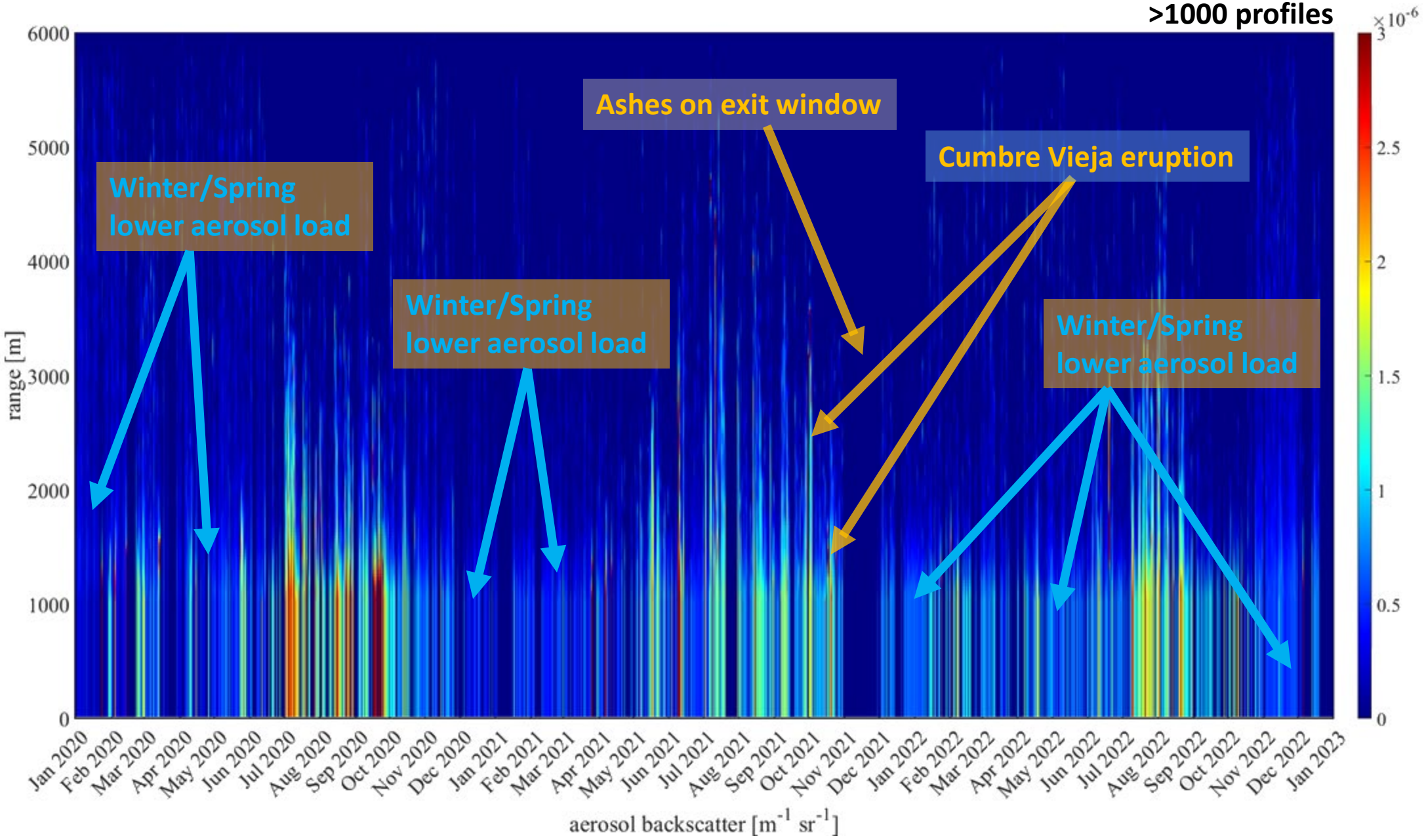
Data

>1000 profiles

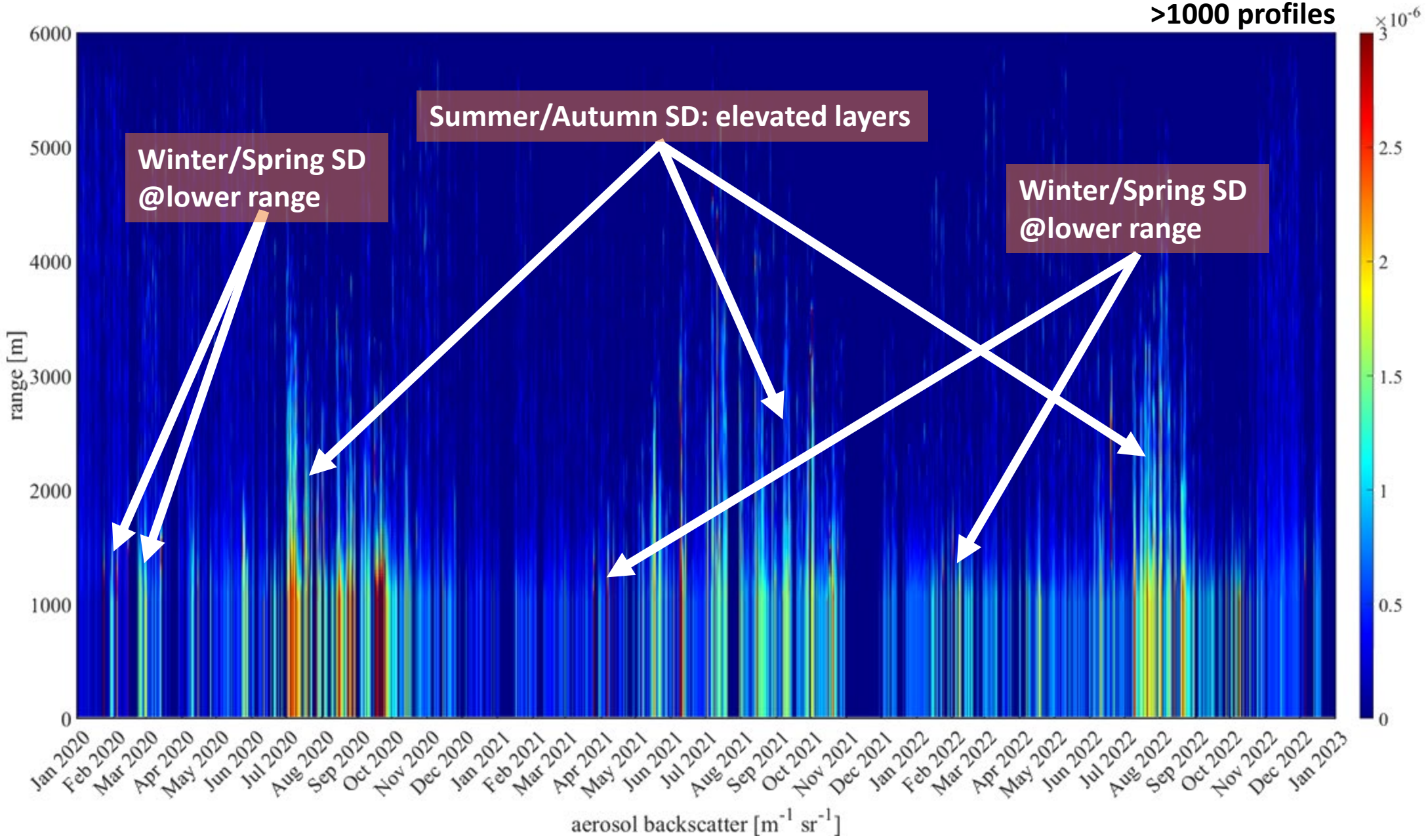


Data

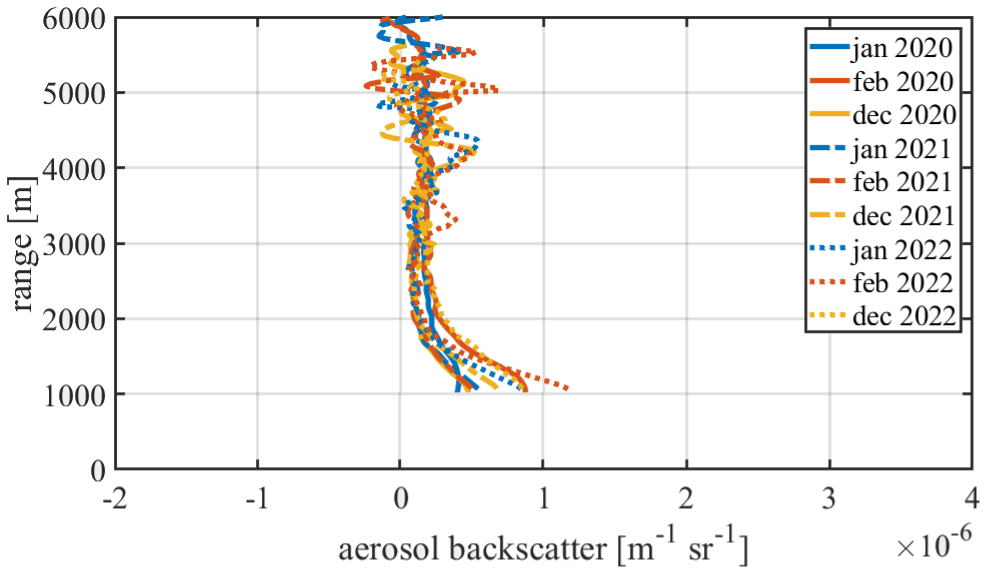
>1000 profiles

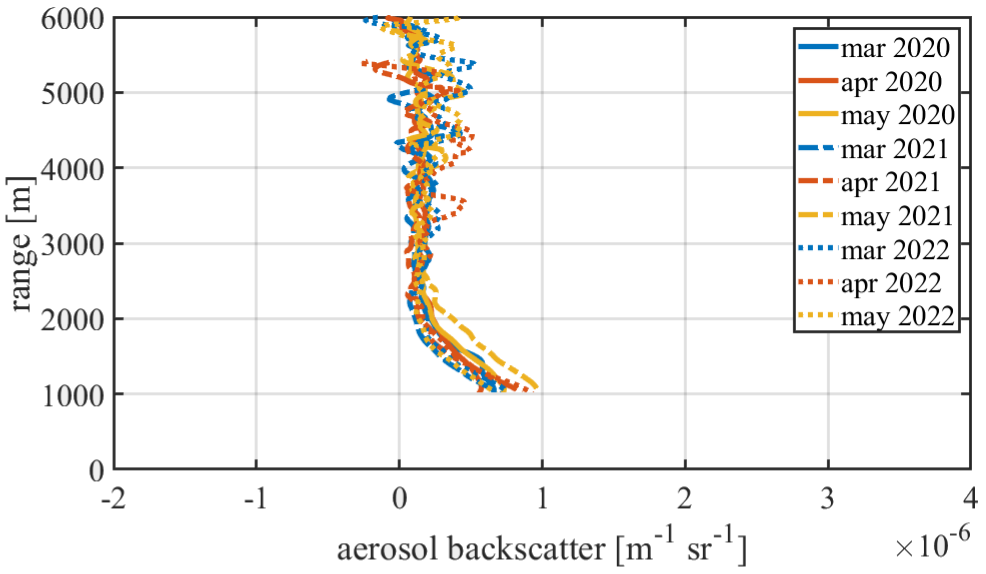


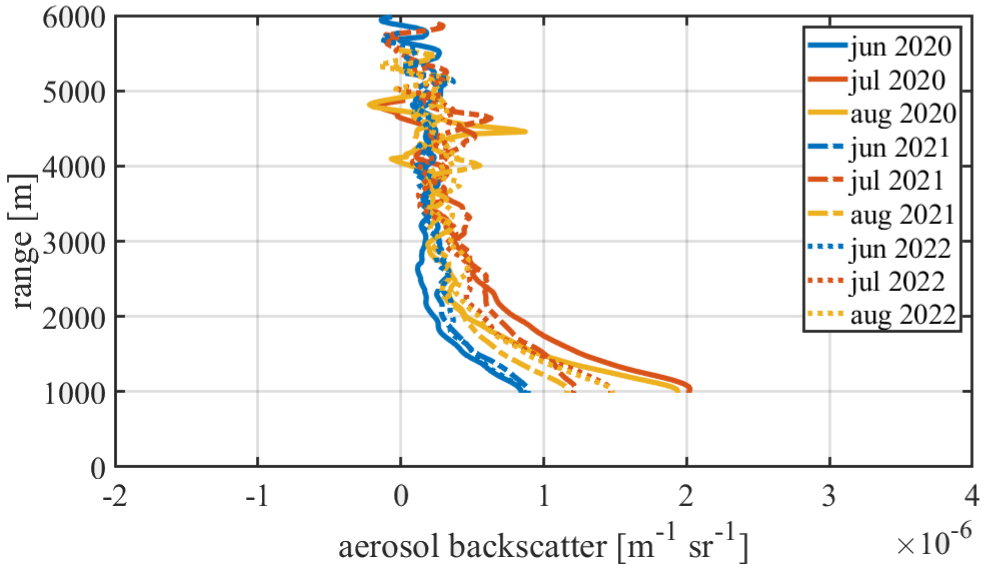
Data

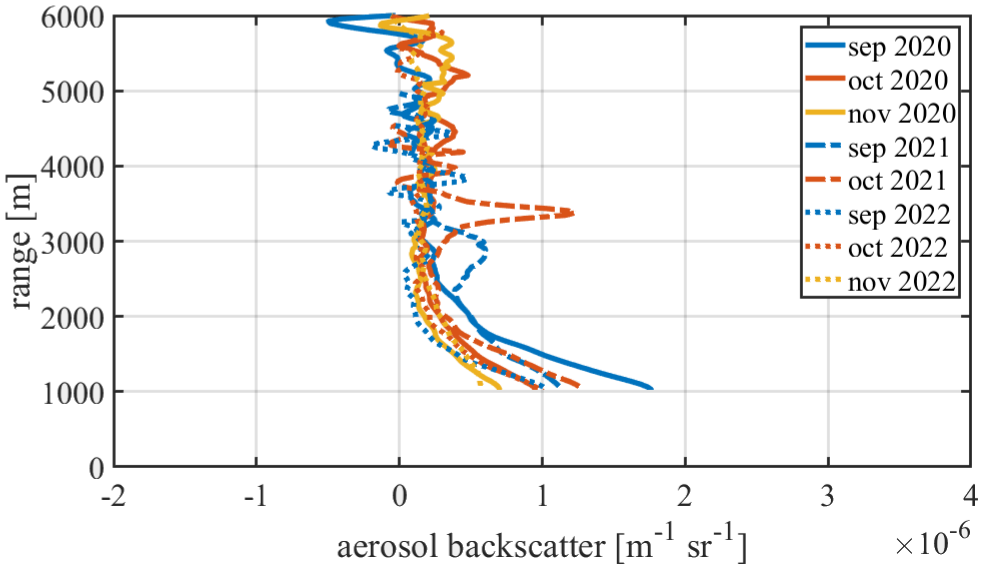

>1000 profiles
Summer/Autumn SD: elevated layers
Winter/Spring SD @lower range
Winter/Spring SD @lower range
range [m]
aerosol backscatter [m^{-1} sr^{-1}]
$\times 10^{-6}$

Data

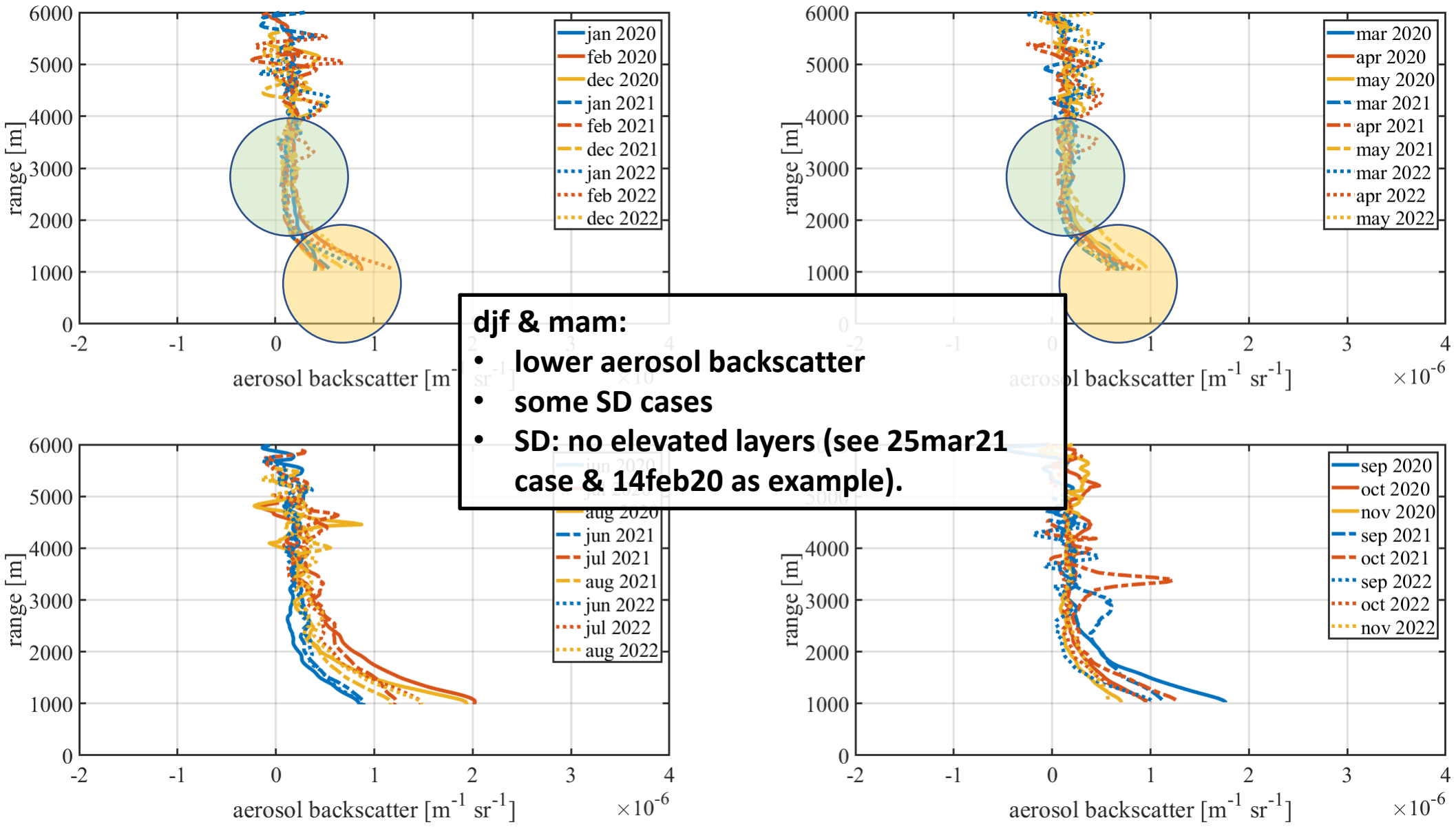

range [m]
aerosol backscatter [m^{-1} sr^{-1}]
$\times 10^{-6}$
jan 2020
feb 2020
dec 2020
jan 2021
feb 2021
dec 2021
jan 2022
feb 2022
dec 2022


range [m]
aerosol backscatter [m^{-1} sr^{-1}]
$\times 10^{-6}$
mar 2020
apr 2020
may 2020
mar 2021
apr 2021
may 2021
mar 2022
apr 2022
may 2022


range [m]
aerosol backscatter [m^{-1} sr^{-1}]
$\times 10^{-6}$
jun 2020
jul 2020
aug 2020
jun 2021
jul 2021
aug 2021
jun 2022
jul 2022
aug 2022


range [m]
aerosol backscatter [m^{-1} sr^{-1}]
$\times 10^{-6}$
sep 2020
oct 2020
nov 2020
sep 2021
oct 2021
sep 2022
oct 2022
nov 2022

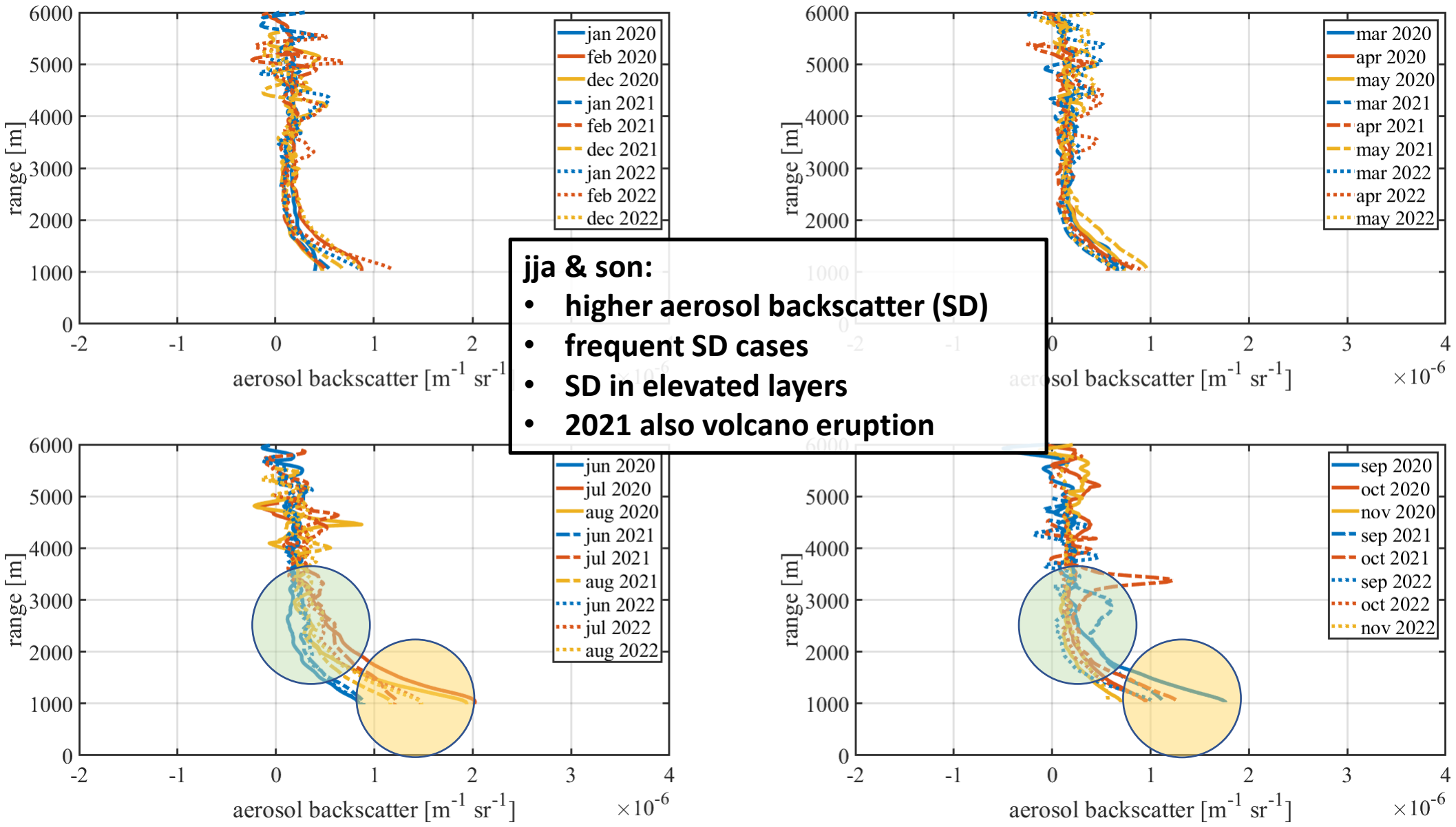
Data



djf & mam:

- **lower aerosol backscatter**
- **some SD cases**
- **SD: no elevated layers (see 25mar21 case & 14feb20 as example).**

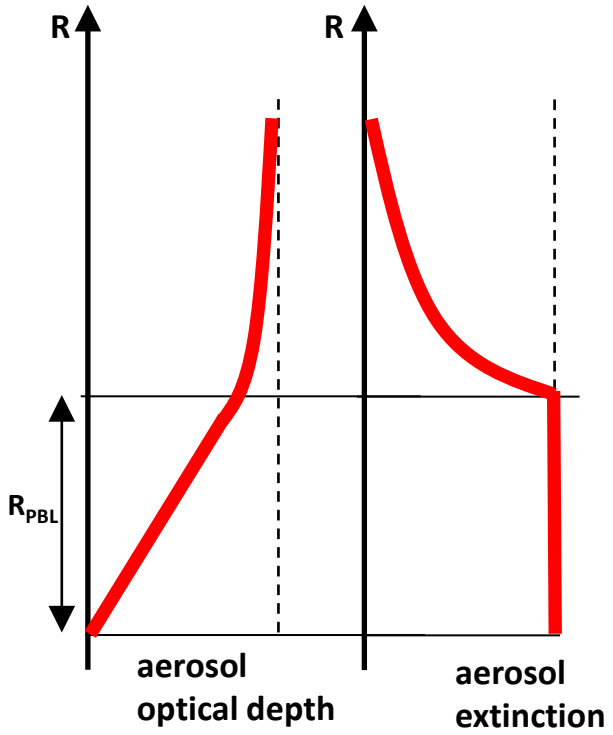
Data



jja & son:

- **higher aerosol backscatter (SD)**
- **frequent SD cases**
- **SD in elevated layers**
- **2021 also volcano eruption**

A LOCAL MODEL FOR THE VERTICAL AEROSOL OPTICAL DEPTH PROFILE?



$$VAOD(R) = \alpha_{aer}^{PBL} R, \qquad R < R_{PBL}$$

$$VAOD(R) = \alpha_{aer}^{PBL} R_{PBL} - \alpha_{aer}^{PBL} H_{aer} \left[e^{-\frac{(R - R_{PBL})}{H_{aer}}} - 1 \right], \qquad R \geq R_{PBL}$$

The system is moving for the Paranal Desert CTA site (?)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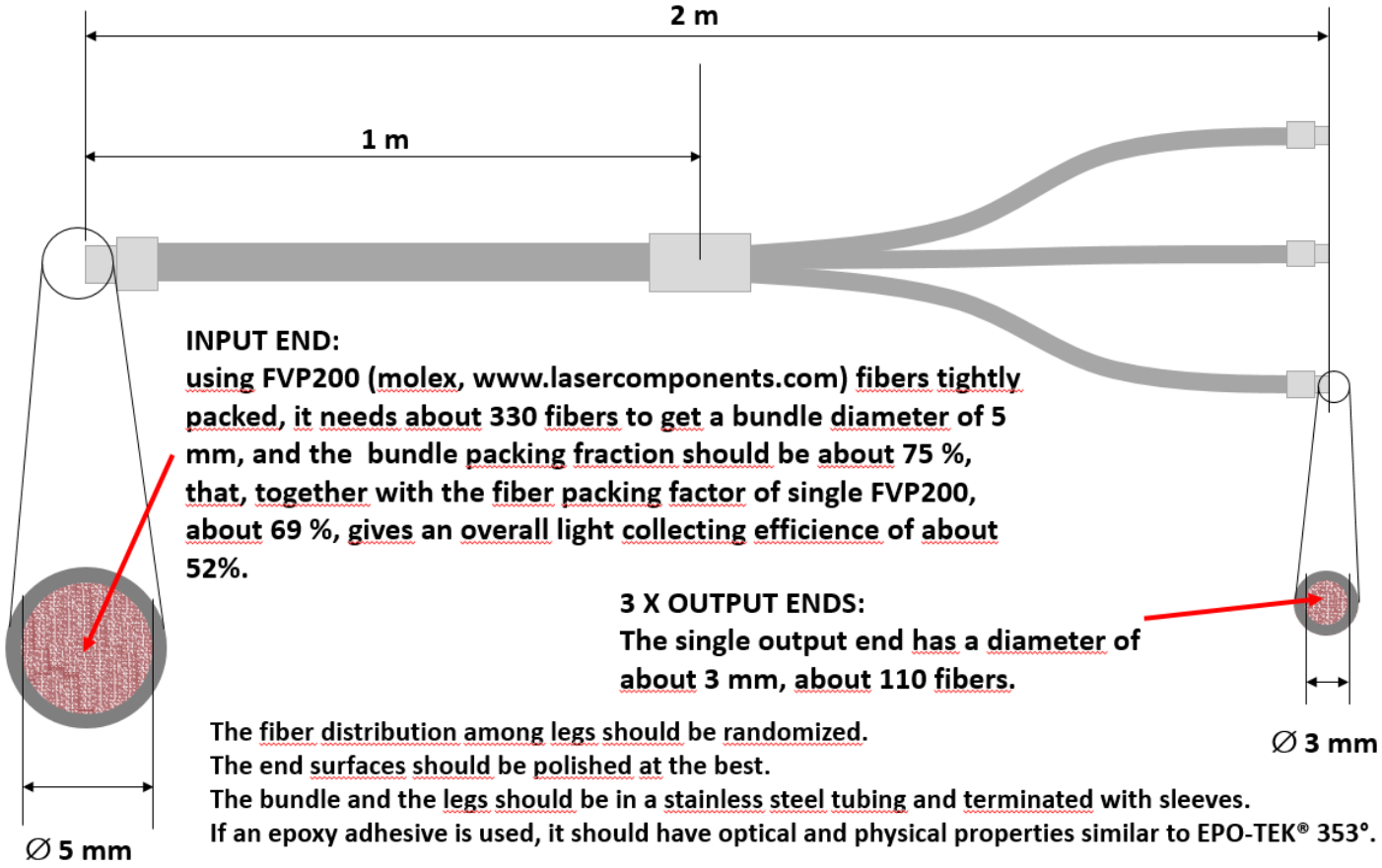
- **Future Upgrades**

- **Complete the cover/new beam exit: less stray lights, cleaner window.**
- **Change the telescope/receiver coupling from mirrors to optical fiber: improved optical stability/performances, better overlap function & lower systematics on data products.**

Optical fiber design



Conclusions [at ORM]

- **The Raman Lidar is robust**: in the last years it has collected of vertical profiles in automatic and unattended mode.
- **The Raman Lidar data appears of good quality** considering its characteristics and the operational constrains of the instrument.
- **The data analysis has been tested and improved** by the comparison with aerosol measurements taken by a nearly located **AERONET sunphotometer**.
- We were able to collect volcano plume data during the **Cumbre Veja eruption**.
- **The analysis of the profiles of the aerosol optical properties evidenced a seasonal cycle** linked to the **Saharan dust** events characteristics, superimposed to a generally low aerosol load.
- Although the **optimization** with AERONET data gives interesting results **(that requires further tuning and investigation) we want to provide independent results. This implies:**
  - **The Raman channels must be on (more "on site" services and/or local crew for simple tasks).**
  - **The overlap function must be significatively reduced (optical fiber).**

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Thanks!