Distinguishing between cloud and aerosol layers in the TROPOMI/Sentinel-5P measurements

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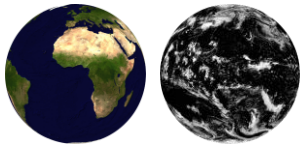
TROPOMI operational CLOUD retrieval algorithm

L1b radiances

Band 3/4

OCRA (Optical Cloud Recognition Algorithm)

RGB color space
UV VIS (NIR)



- Precomputed cloud-free composite maps are now based on a monthly basis TROPOMI measurements.
- The output is the radiometric cloud fraction (Lutz et al., 2016).

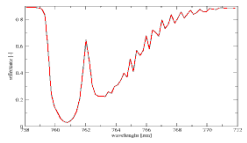
CF > 5 %

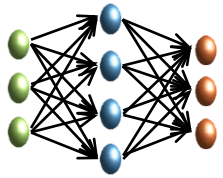
Co-registration of OCRA cloud fraction from Band 3/4 to Band 6 (Argyrouli et al., in review)

Band 6

ROCINN (Retrieval of Cloud Information using Neural Networks) CAL & CRB

O2 A-Band, NIR





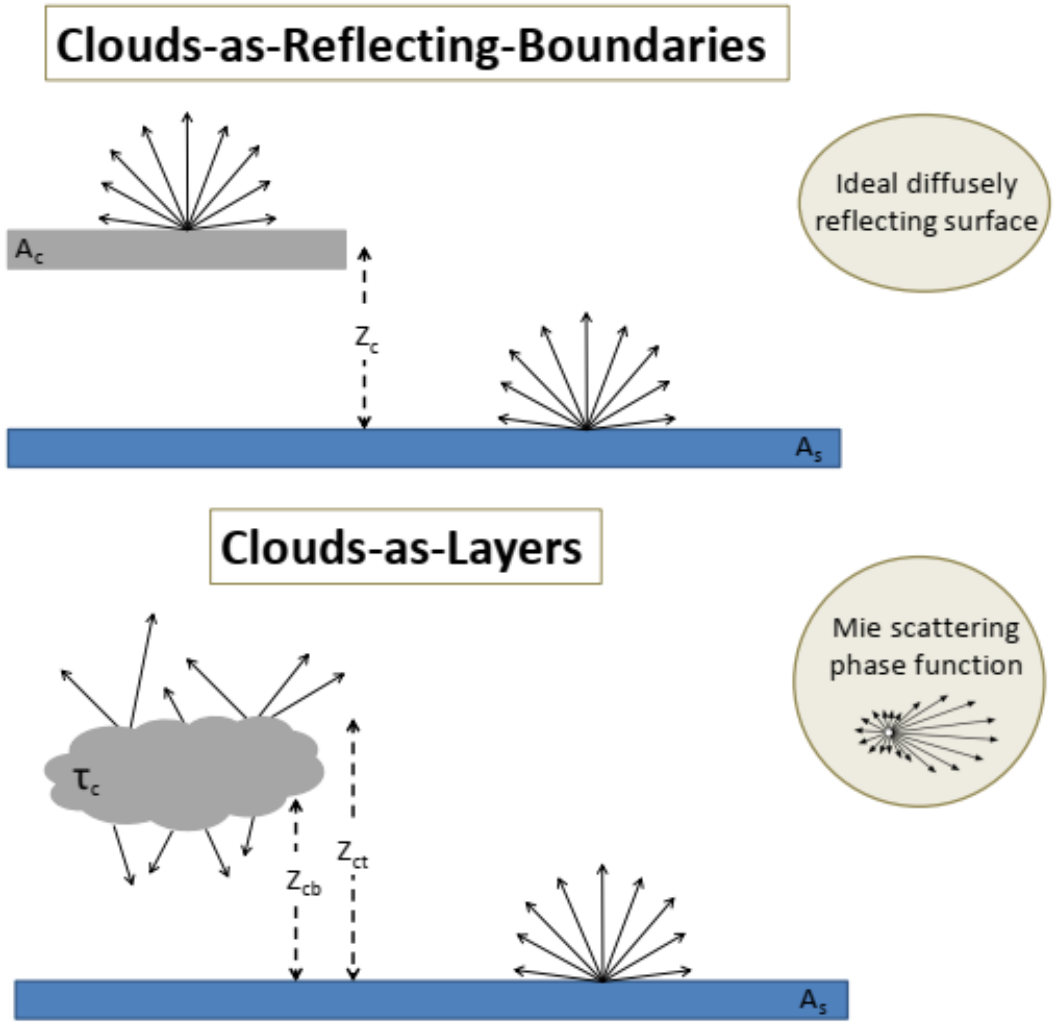
forward model neural network

- Tikhonov inversion using regularization technique is applied to retrieve cloud top height/cloud optical thickness (CAL) and cloud height and cloud albedo (CRB)(Loyola et al., 2018).

TROPOMI operational cloud product reprocessed with version 2.4.1. Since November 2023, the cloud operational data are generated with version 2.6.1.

DLR

CLOUD retrieval algorithm - ROCINN models



- In the simplified CRB model, the cloud is parametrized as an **ideal diffusely reflecting surface** (identical to the ground). The unknown properties of cloud is the **height from the ground** and the **albedo**.
- In the more realistic CAL model, the cloud is a **layer consisting of liquid-water spherical droplets**. Its scattering phase function is calculated from Mie theory. The unknown properties of the cloud are the **top height from the ground** and the **optical thickness**. The geometrical thickness is assumed constant.
- The information about the surface properties is known in the ROCINN fitting window from the G3_LER (Global Gapless Geometry-dependent LER) (Loyola et al., 2019).

Aerosol contamination in the TROPOMI cloud product

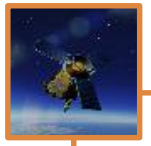
When should we consider the TROPOMI cloud product as “contaminated” with aerosols?

a) when there is a pure aerosol layer, shown in the TROPOMI cloud product. Usually, this is the case when OCRA gives a falsely elevated cloud fraction under clear-sky/cloudless conditions. Then, ROCINN is triggered and returns some cloud properties which “correspond” to the detected aerosol layer.

b) co-existence of cloud and aerosols in the same TROPOMI footprint. Aerosols above clouds are included in the TROPOMAER product. TROPOMAER is a NASA aerosol product for retrieving aerosol information in the UV (Torres et al., 2020).

Cloud / Aerosol information from TROPOMI and ground-based instruments

TROPOMI UVN spectrometer



TROPOMI CLOUD L2 product

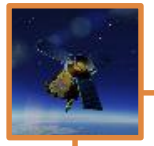
- OCRA cloud fraction
- CRB cloud parameters (cloud height, cloud albedo)
- CAL cloud parameters (cloud-top height, cloud optical thickness)

VIIRS imager re-gridded to TROPOMI footprints

TROPOMI S5P-NPP product

- Cloud fraction
- Cloud top height (from Nov. 2023)
- Cloud base height (from Nov. 2023)
- Cloud optical thickness (from Nov. 2023)
- Aerosol optical depth@550nm (from Nov. 2023)

TROPOMI UVN spectrometer



TropOMAER product

- UV Aerosol Index (UV AI)
- Aerosol Type (“smoke”, “dust” and “urban/industrial”)
- AOD @ wavelengths 354, 388 and 500nm.

Ground-based LIDAR

PollyXT target classification product

- Target classification (with 12 classes for aerosols and clouds)

Ground-based sun-photometer

AERONET product

- Aerosol optical depth at 340, 380 and 500nm

Where to look for the "contaminated" clouds?

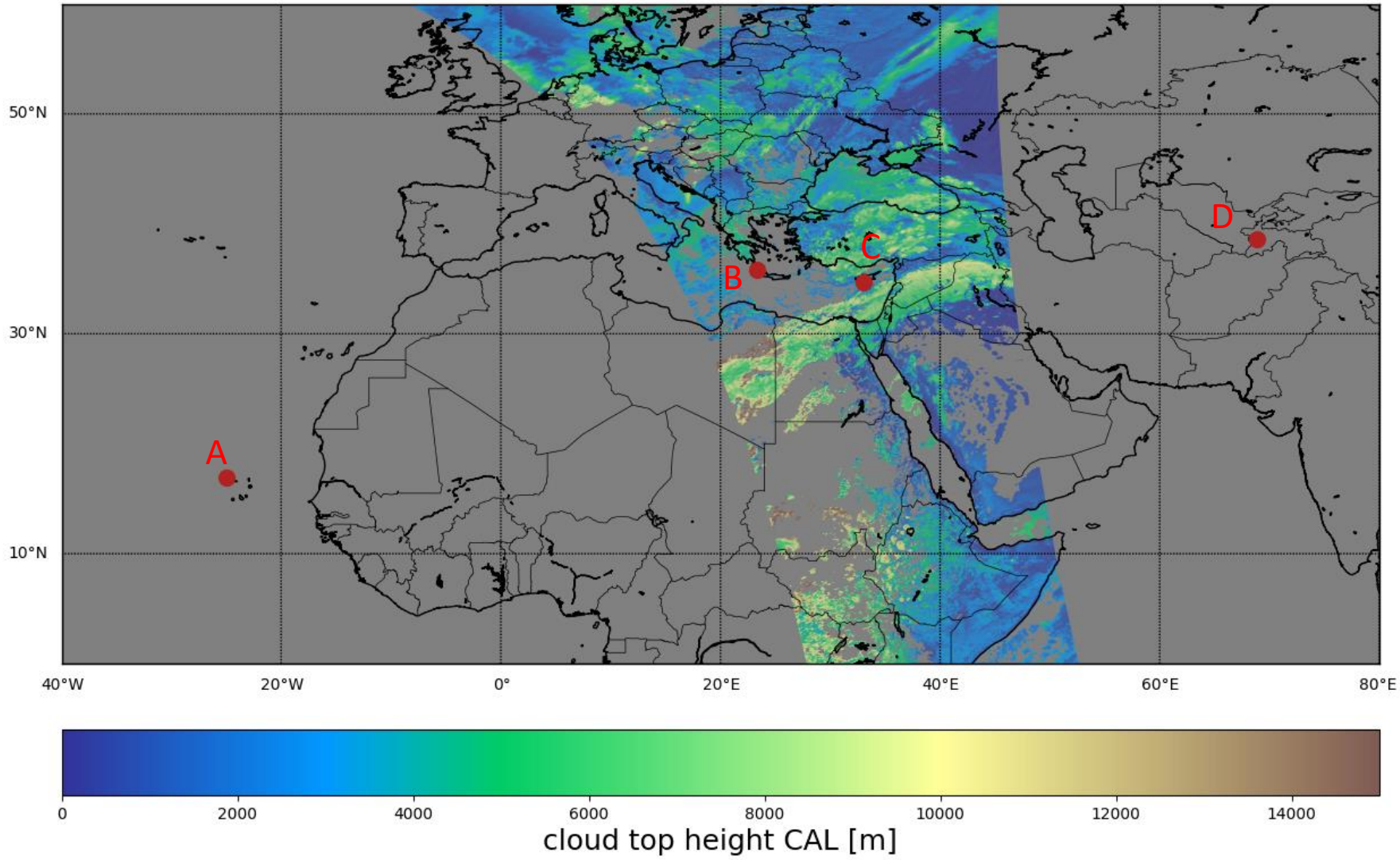
Over the following ground-based observation sites equipped with multiwavelength-Raman-polarization lidars, the so-called PollyXT, developed at the Leibniz Institute for Tropospheric Research (TROPOS). The aerosol products can be visualized on the PollyNET website.

- Station A "Mindelo" @ Cape Verde (Latitude 16.877772, Longitude -24.995374)

- Station B "Antikythera" @ Greece (Latitude 35.86, Longitude 23.31)

- Station C "Limassol" @ Cyprus (Latitude 34.67667, Longitude 33.04417)

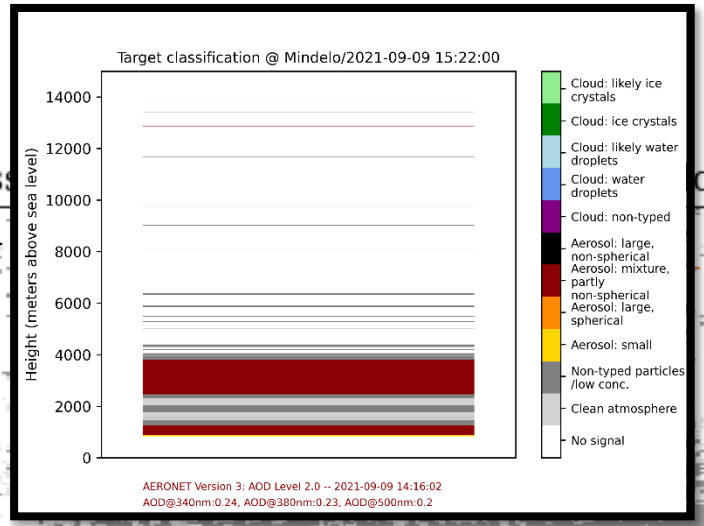
- Station D "Dushanbe" @ Tajikistan (Latitude 38.559386, Longitude 68.856086)

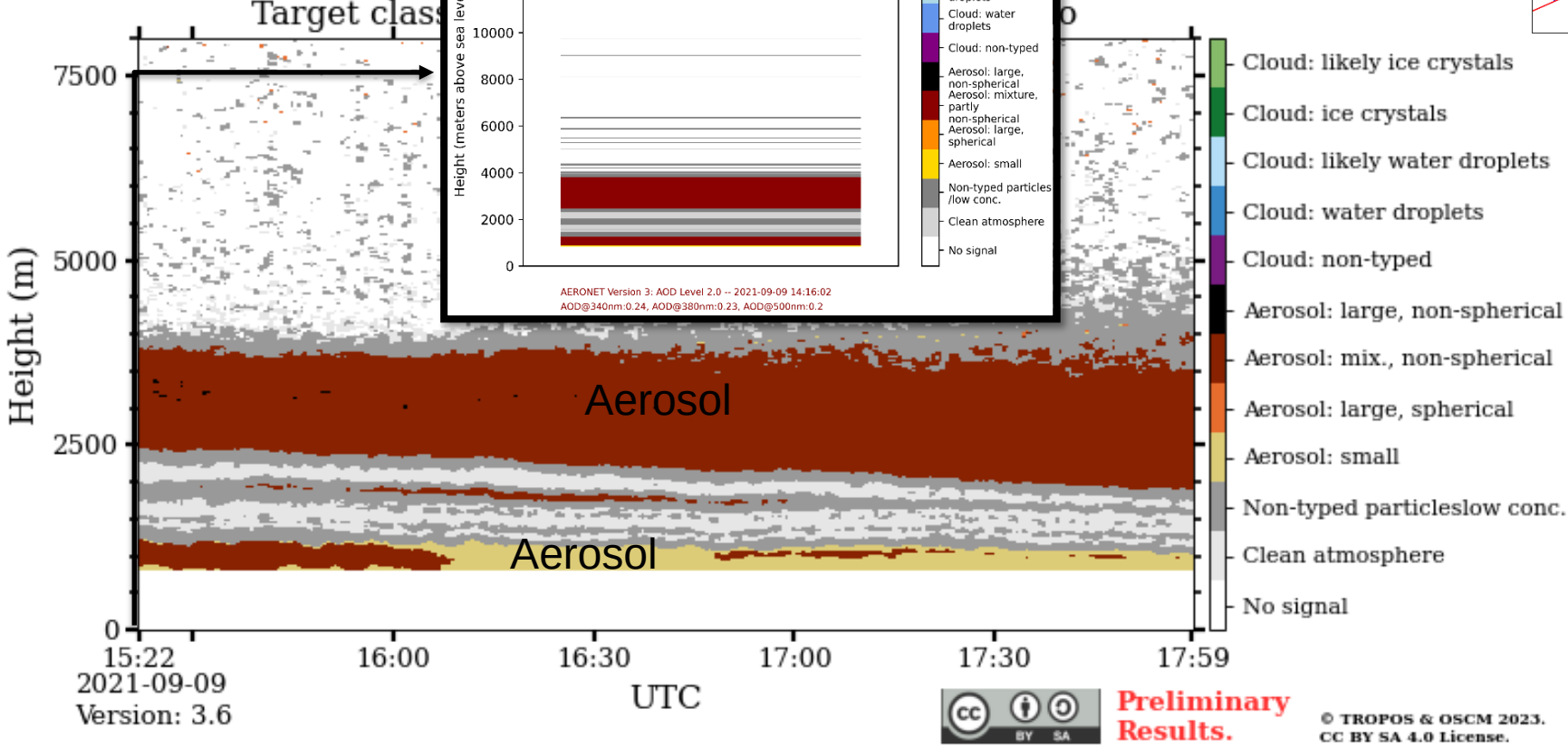


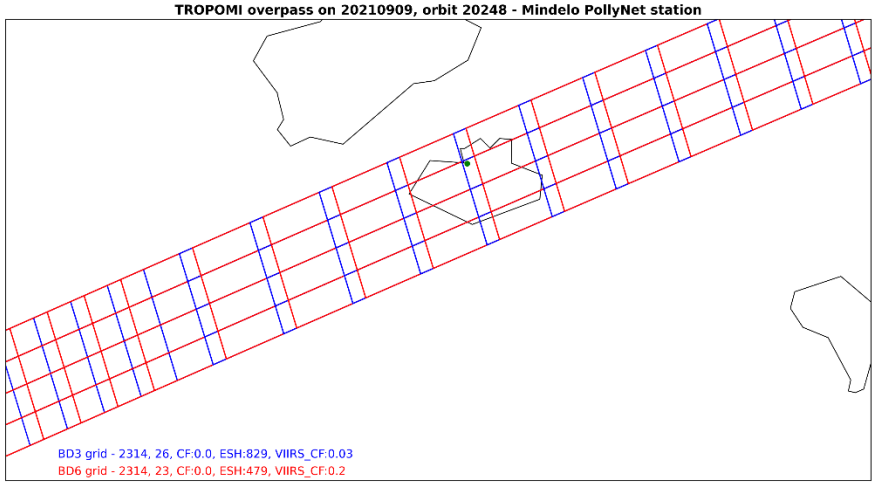
Over Mindelo, Cape Verde

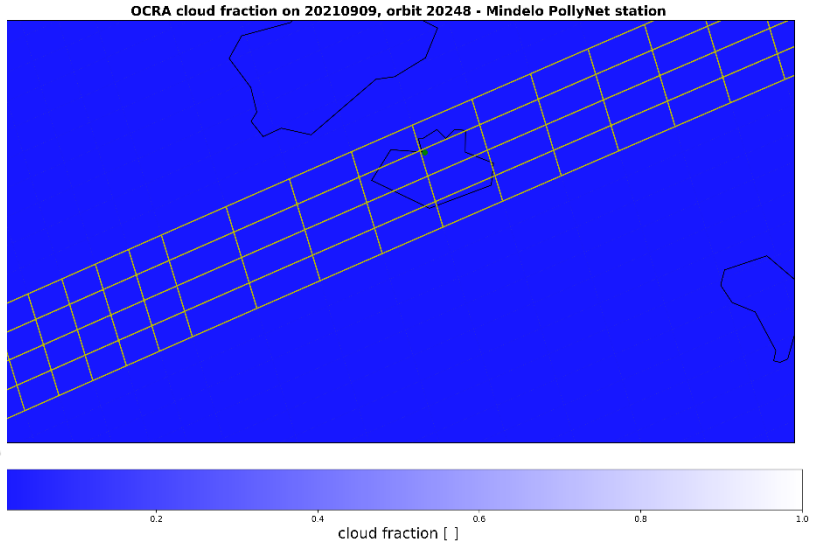
Only Aerosols

- Only Aerosol detected by the lidar up to 4km
- Aerosol type from TROPOMAER is “dust” and UV AI is < 1
- Low optical depths found by TROPOMAER and AERONET (AOD@388nm < 0.50)









OCRA CF = 0

Preliminary Results.

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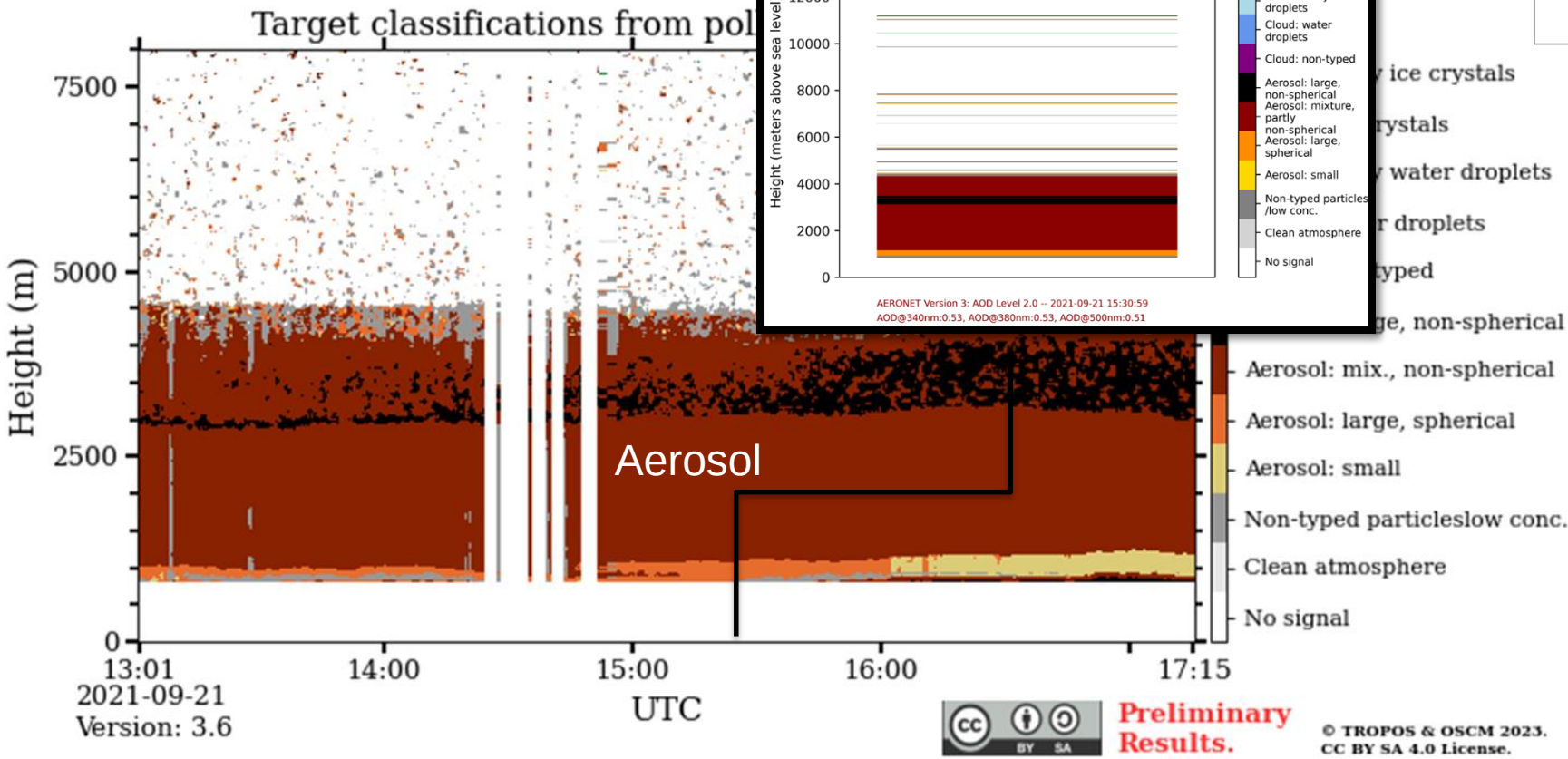
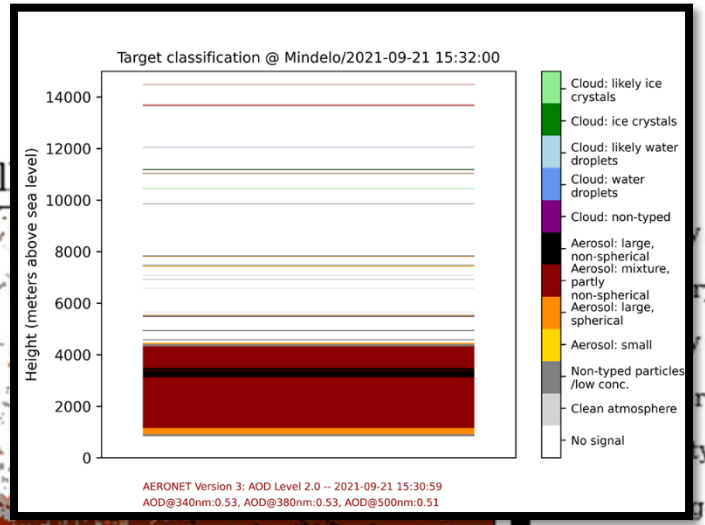
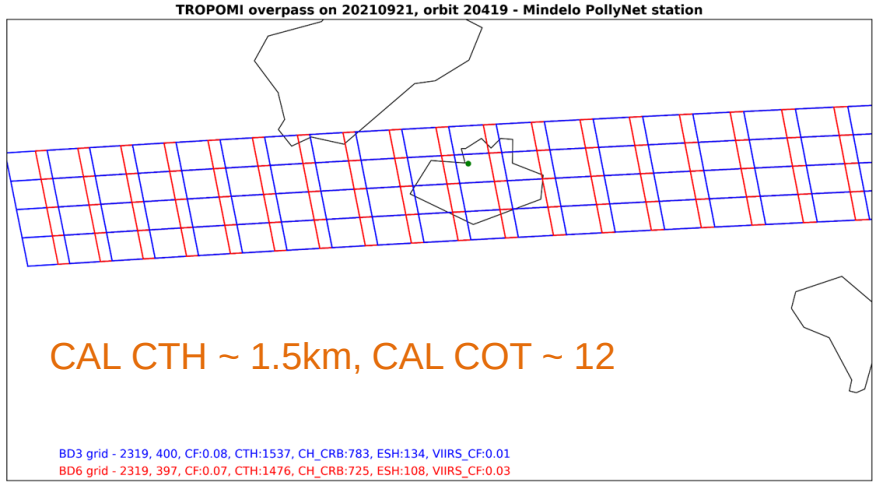
Over Mindelo, Cape Verde

Only Aerosols

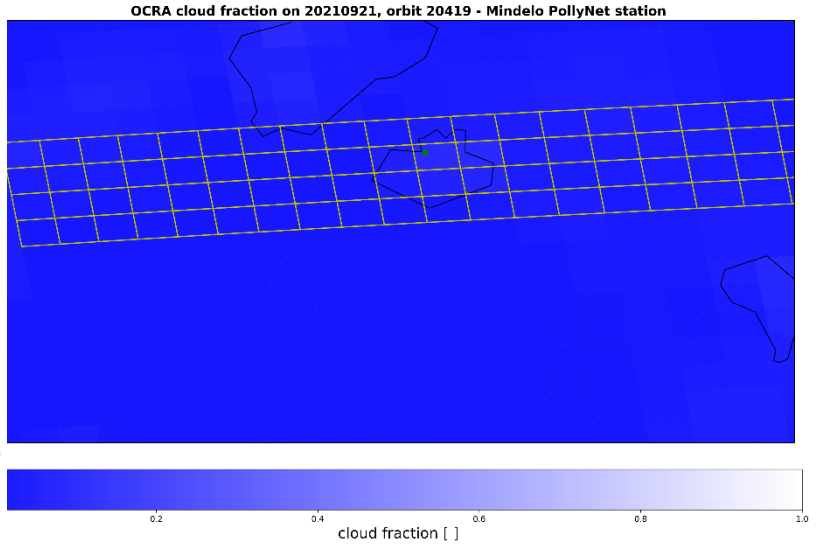
- Only Aerosol detected by the lidar up to 4.5 km
- Aerosol type from TROPOMAER is “dust” and UV AI is > 1
- Higher optical depths found by TROPOMAER and AERONET (AOD@388nm > 0.50)







CAL CTH ~ 1.5km, CAL COT ~ 12



OCRA CF = 0.08

Preliminary Results.

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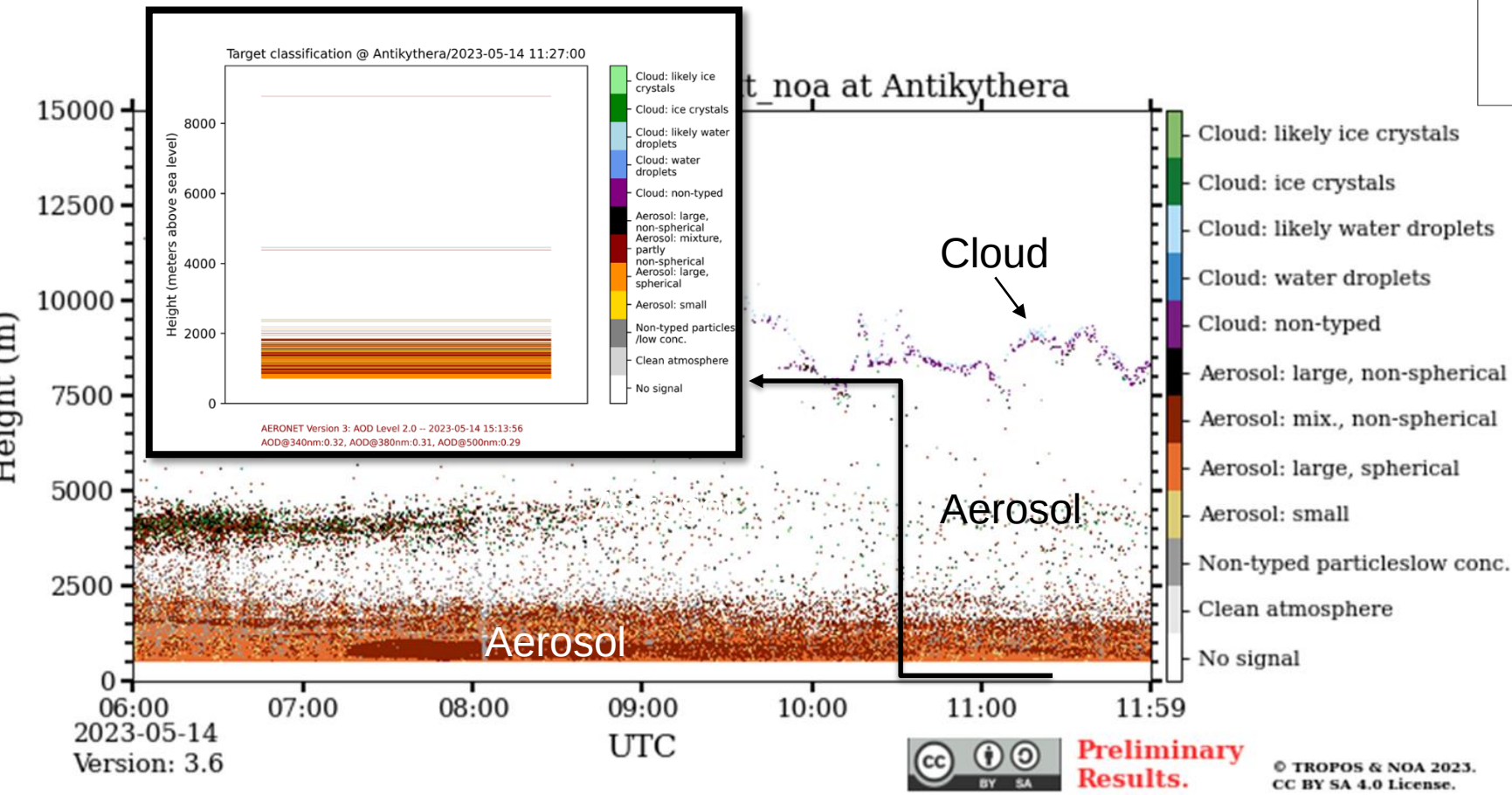
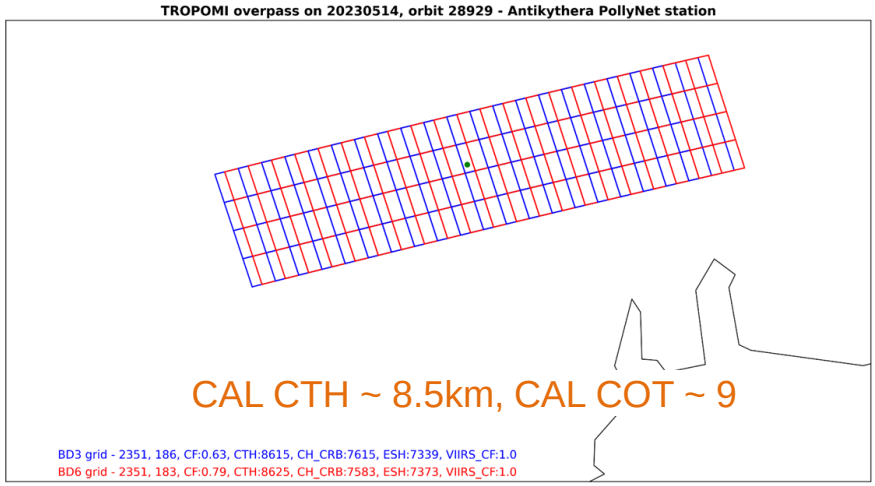
Over Antikythera, Greece

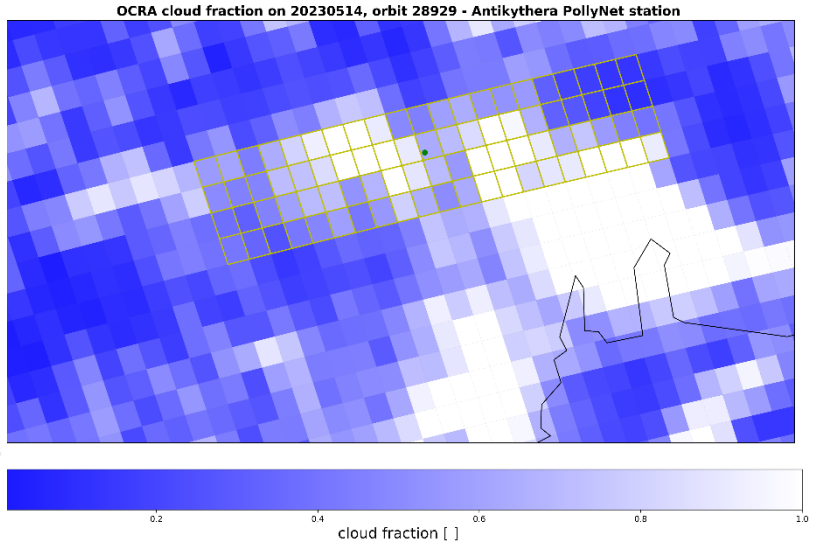
Cloud above Aerosols

- Aerosol detected by the lidar up to 2 km, thin aerosol layer ~ 4.5 km and thin cloud layer at 8.5 km
- Aerosol type from TROPOMAER is “urban/industrial” and UV AI is < 0
- Low optical depths found by AERONET (AOD@380nm < 0.50)





CAL CTH ~ 8.5km, CAL COT ~ 9

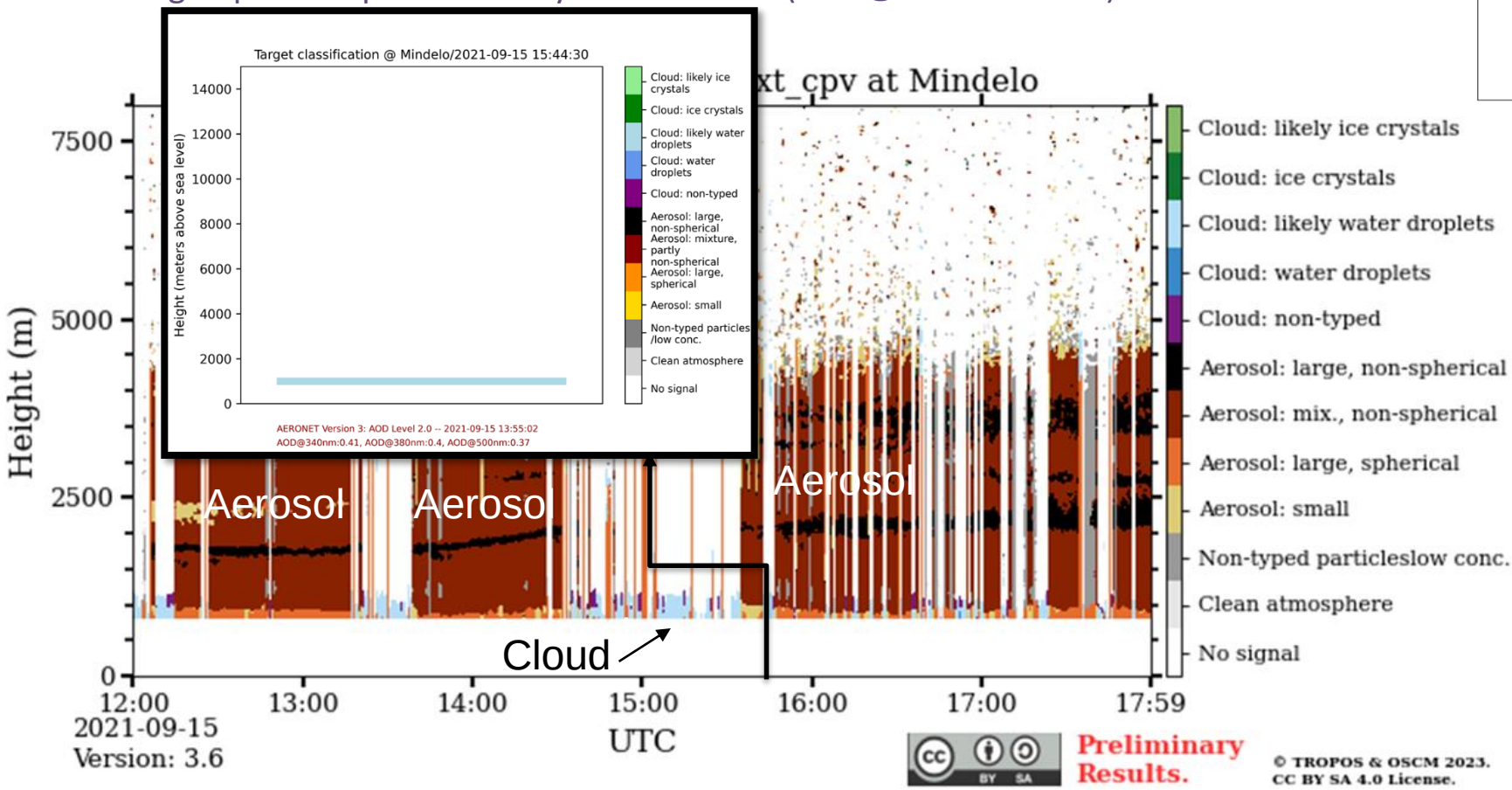


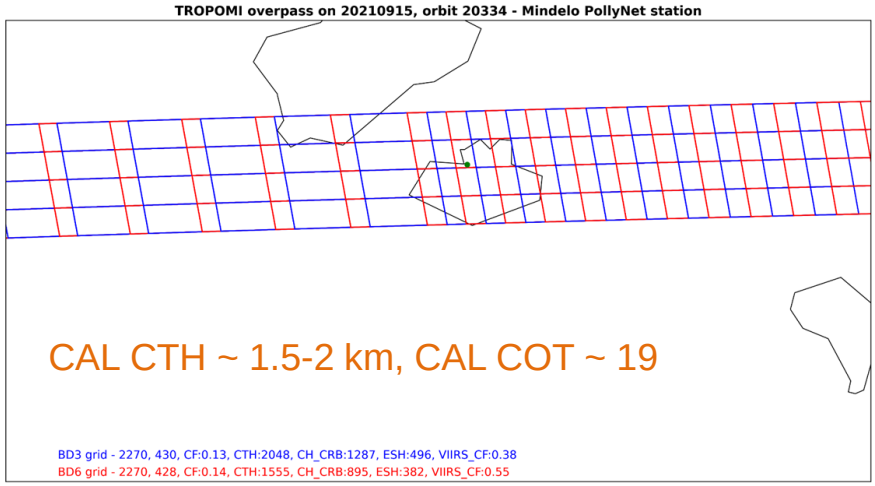
OCRA CF = 0.63

Over Mindelo, Cape Verde

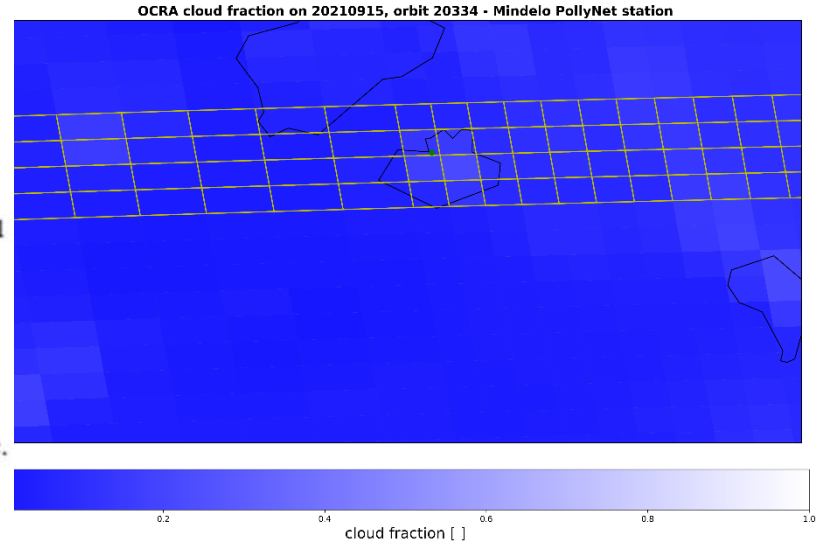
Cloud below Aerosols

- Aerosol detected by the lidar up to 4.5 km, when clouds are not in the lidar FOV. When a cloud is detected, the lidar does not capture any aerosol above the cloud (i.e., fully attenuated laser beam).
- Aerosol type from TROPOMAER is “dust” and UV AI is > 1
- High optical depths found by TROPOMAER (AOD@388nm > 0.50)





CAL CTH ~ 1.5-2 km, CAL COT ~ 19



OCRA CF = 0.13

Preliminary conclusions & future work

- With the synergy of the PollyXT multi-wavelength lidar and AERONET sun-photometer, we are able to gather “aerosol-contaminated cloud” cases. The regridded VIIRS data to the TROPOMI footprints are used complementary to the study.

- The newest S5P NPP cloud product contains cloud information (cloud top height, cloud optical thickness) and aerosol information (AOD at 550nm).

- Scenes with clouds above aerosol layers: **show high agreement with the ground-based measurements**.

- Only aerosols present in the atmosphere: TROPOMI cloud product is usually “clean”. For absorbing (UV AI>1) and in high concentrations (AOD>0.5) aerosol layers, OCRA cloud fraction **might be falsely elevated. Possible solution in the short-term: an aerosol-contamination flag can be introduced at the TROPOMI cloud product. As a future step, the OCRA clear sky maps could become adjustable to the aerosol presence conditions.**

- Scenes with aerosols above clouds: might appear with lower OCRA cloud fraction and less accurate ROCINN cloud top height and optical thickness. **Next step: Introduce an aerosol layer above the cloud layer in the forward model.**

Thank you !

Acknowledgements

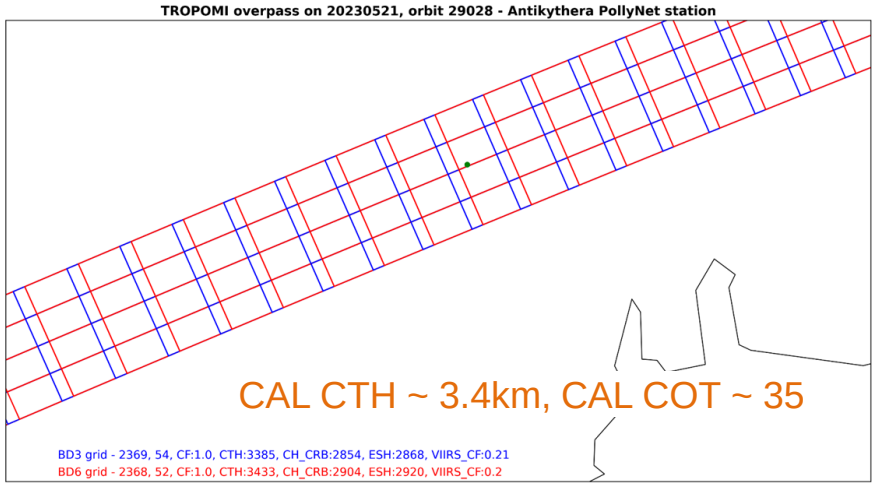
– Many thanks to the NOA colleagues Maria Tsichla, Peristera Paschou, Ioanna Tsikoudi for the lidar data provision and the scientific discussions.

Supplementary Material

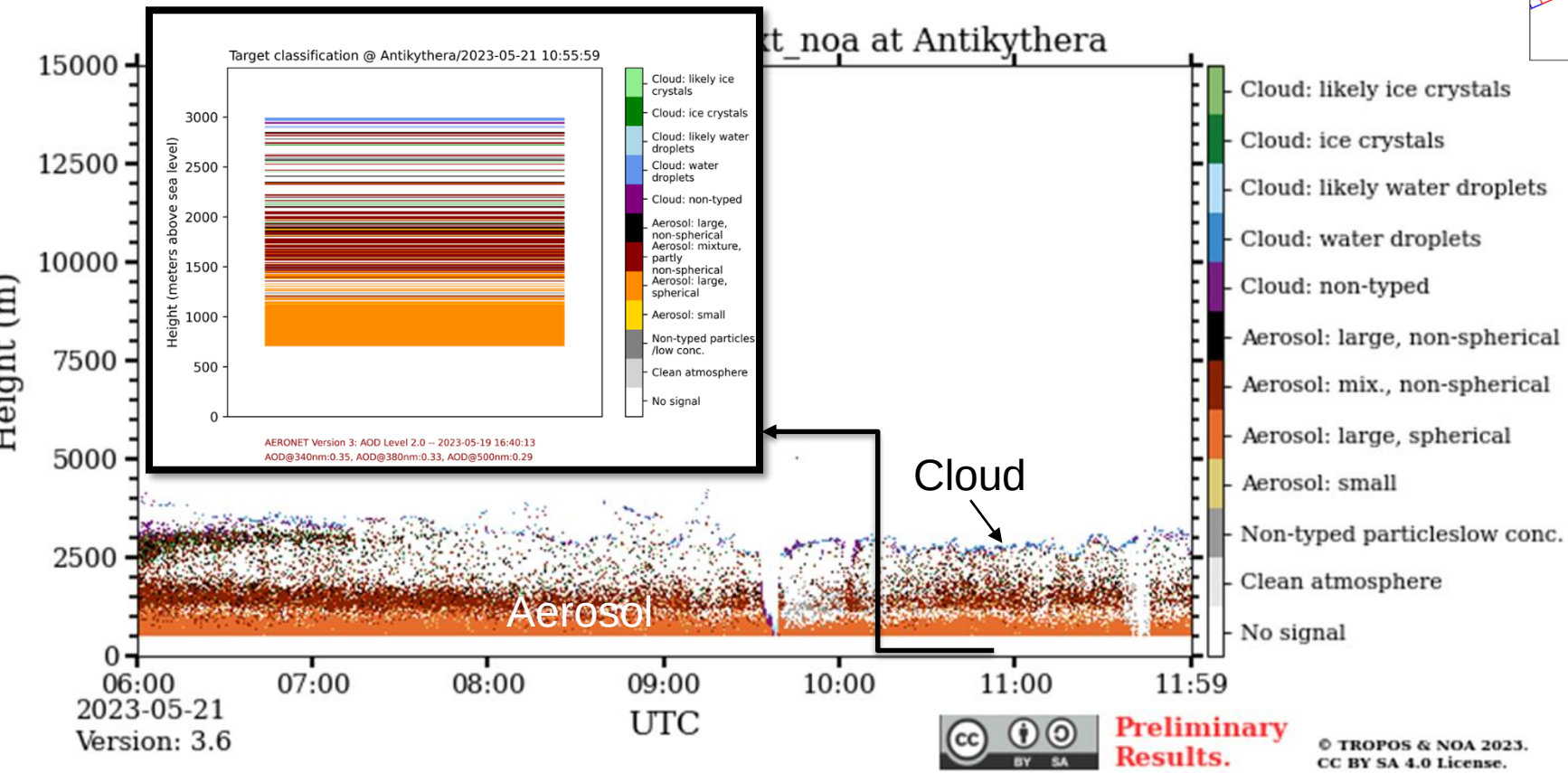
Over Antikythera, Greece

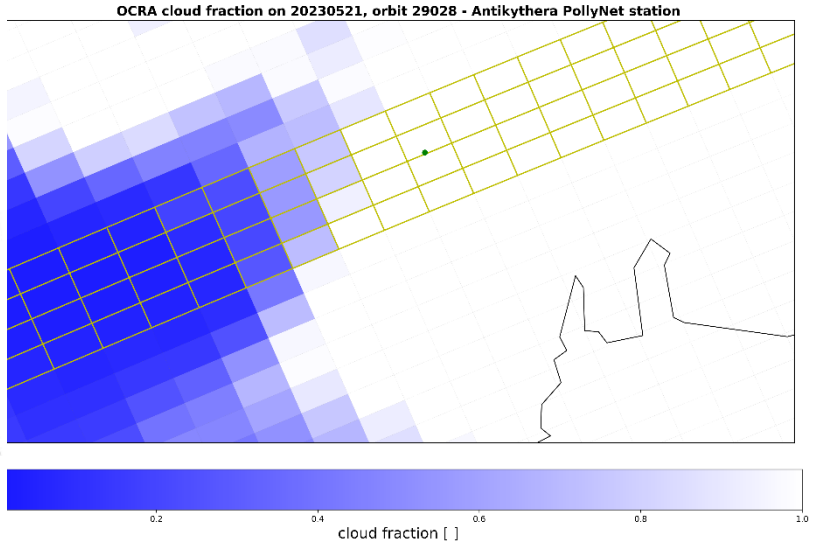
Cloud above Aerosols

- Aerosol detected by the lidar up the altitude of a cloud layer @ 3 km
- Aerosol type from TROPOMAER is “smoke” and UV AI is > 1
- Low optical depths found by TROPOMAER and AERONET (AOD@380nm < 0.50)



CAL CTH ~ 3.4km, CAL COT ~ 35



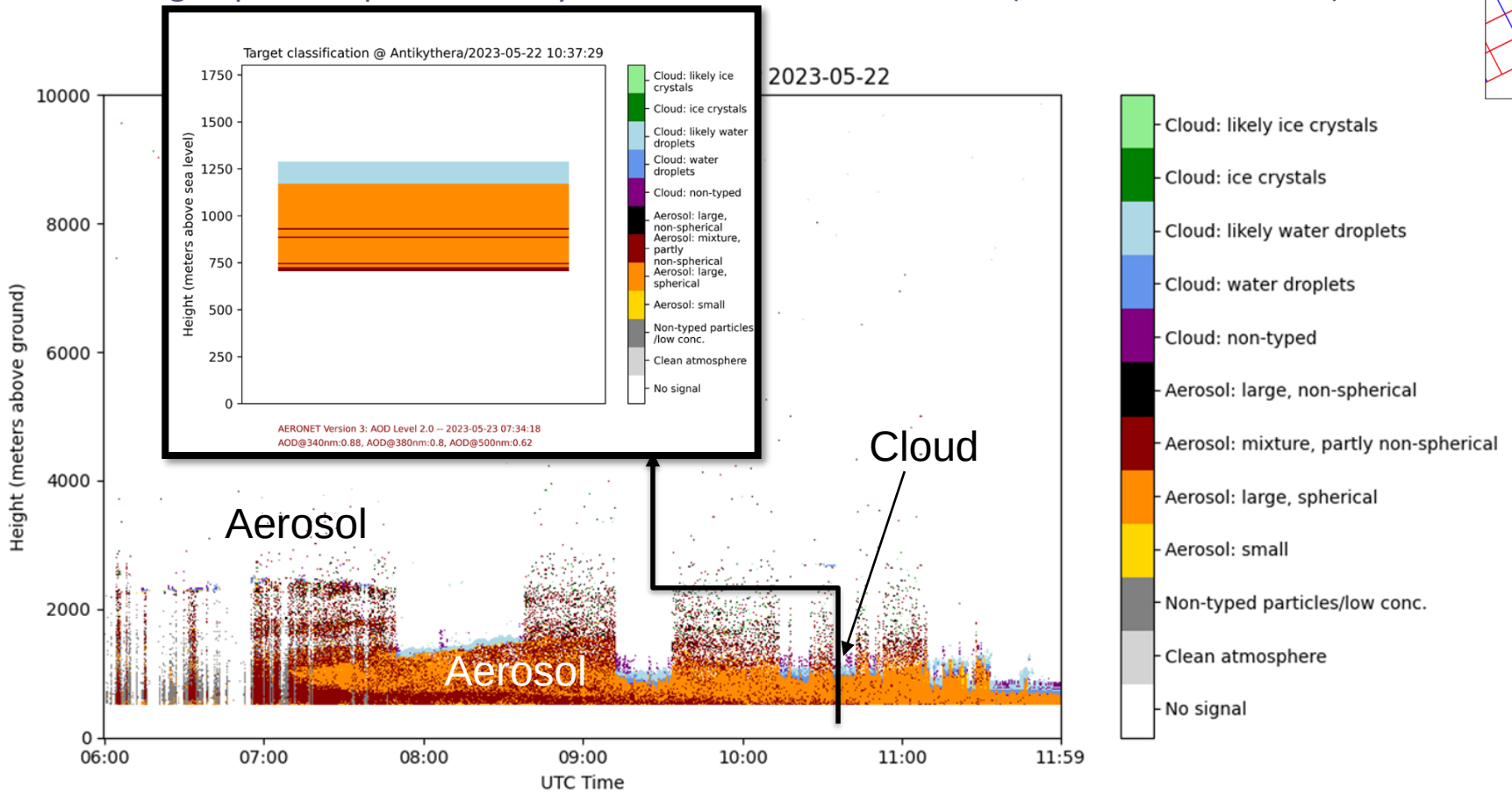


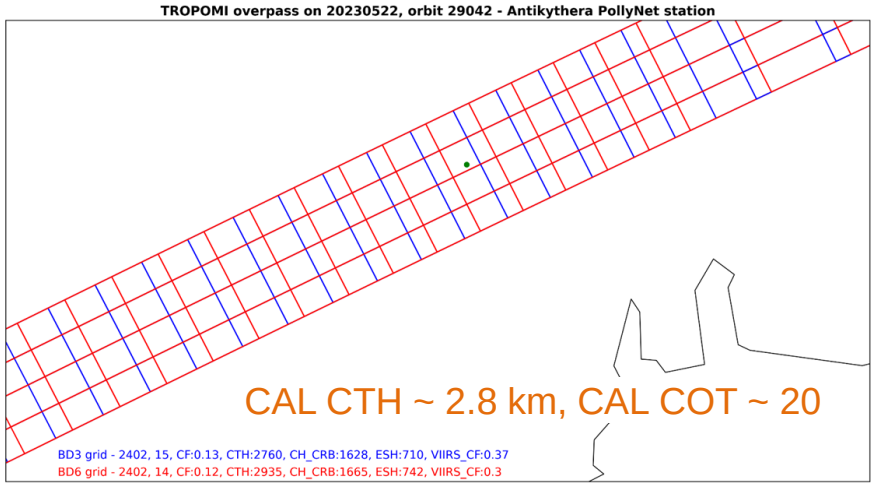
OCRA CF = 1

Over Antikythera, Greece

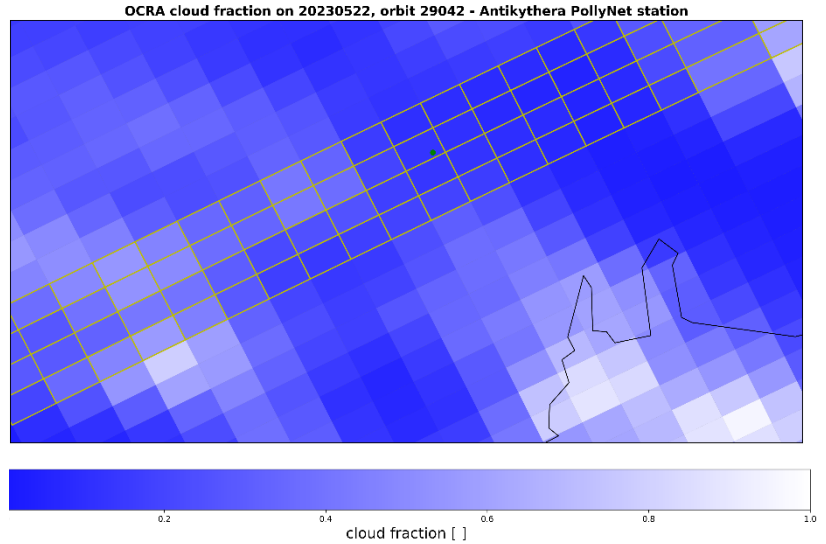
Cloud below Aerosols

- Aerosol detected by the lidar up to ~ 2 km, when clouds are not in the lidar FOV. When a cloud is detected, the lidar does not capture any aerosol above the cloud (i.e., fully attenuated laser beam). The cloud is seen below 1.5 km.
- Aerosol type from TROPOMAER is “smoke” and UV AI is > 1
- High optical depths found by TROPOMAER and AERONET (AOD@388nm > 0.50)





CAL CTH ~ 2.8 km, CAL COT ~ 20



OCRA CF = 0.13