Cloud retrievals from the TROPOMI UV/VIS/NIR measurements with aerosol signature

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(3) NASA Goddard Space Flight Center
(4) National Observatory of Athens (NOA)

O2 workshop, 30 May 2024

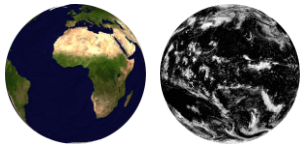
TROPOMI operational CLOUD retrieval algorithm

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).

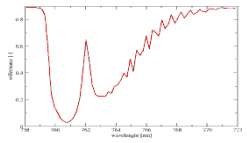
CF > 5 %

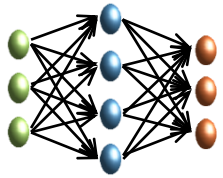
Co-registration of OCRA cloud fraction from Band 3/4 to Band 6 (Argyrouli et al., in review)

Band 6

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

O2 A-Band, NIR





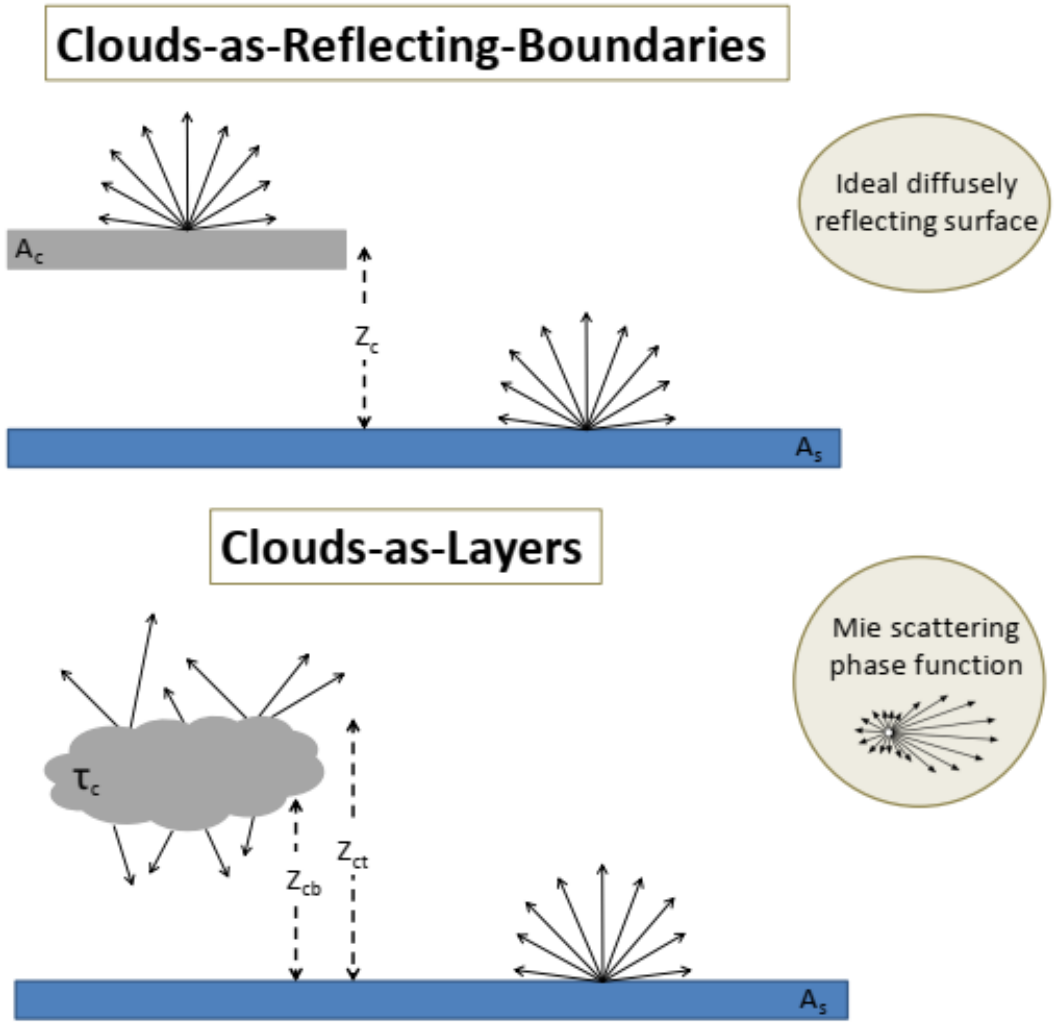
forward model neural network

- 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

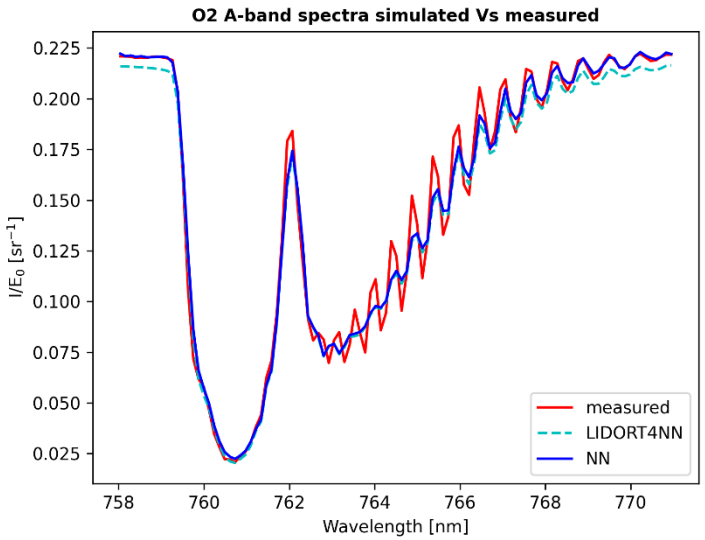


- In the simplified CRB model, the cloud is parametrized as an **ideal diffusely reflecting surface** (identical to the ground). The unknown properties of cloud is the **height from the ground** and the **albedo**.
- In the more realistic CAL model, the cloud is a **layer consisting of liquid-water spherical 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).

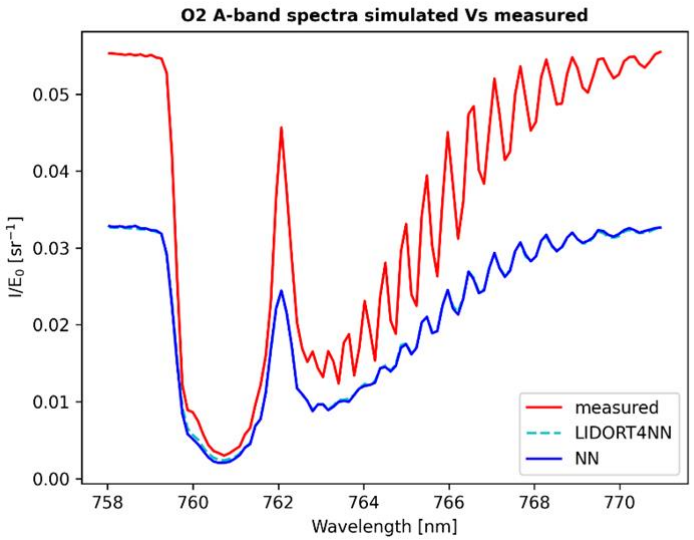
TROPOMI cloud product can be contaminated from aerosols

What is the reason that we need to know when aerosols are detected by OCRA/ROCINN instead of clouds? Should we care when TROPOMI cloud product is "contaminated" with aerosols?

The answer is YES. When aerosol is detected falsely instead of cloud, our NN will never manage to reproduce the L1b measurement and the ROCINN retrieved properties "correspond" to the detected aerosol layer.



Aerosols are present but TROPOMI cloud product is not contaminated



Aerosols are present and TROPOMI cloud product **is contaminated**

TROPOMI cloud product can be contaminated from aerosols

What is the reason that we need to know when aerosols are detected by OCRA/ROCINN instead of clouds? Should we care when TROPOMI cloud product is "contaminated" with aerosols?

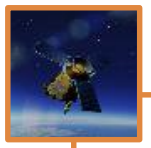
The answer is YES. When aerosol is detected falsely instead of cloud, our NN will never manage to reproduce the L1b measurement and the ROCINN retrieved properties "correspond" to the detected aerosol layer.

What happens when there is an aerosol layer in the atmosphere?

- OCRA might give a falsely elevated cloud fraction under clear-sky/cloudless conditions. Often this OCRA cloud fraction is small but still above 5% to trigger ROCINN.
- The trace gases are corrected for clouds and the accuracy of the cloud retrievals for small cloud fractions < 20% is important. This is the region where OCRA would give us those false alarms.

Cloud / Aerosol information from TROPOMI and ground-based instruments

TROPOMI UVN spectrometer



TROPOMI CLOUD L2 product

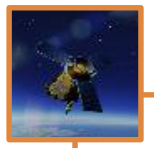
- OCRA cloud fraction
- CRB cloud parameters (cloud height, cloud albedo)
- CAL cloud parameters (cloud-top height, cloud optical thickness)

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)

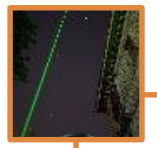
TROPOMI UVN spectrometer



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 aerosol signature in the TROPOMI CLOUD product?

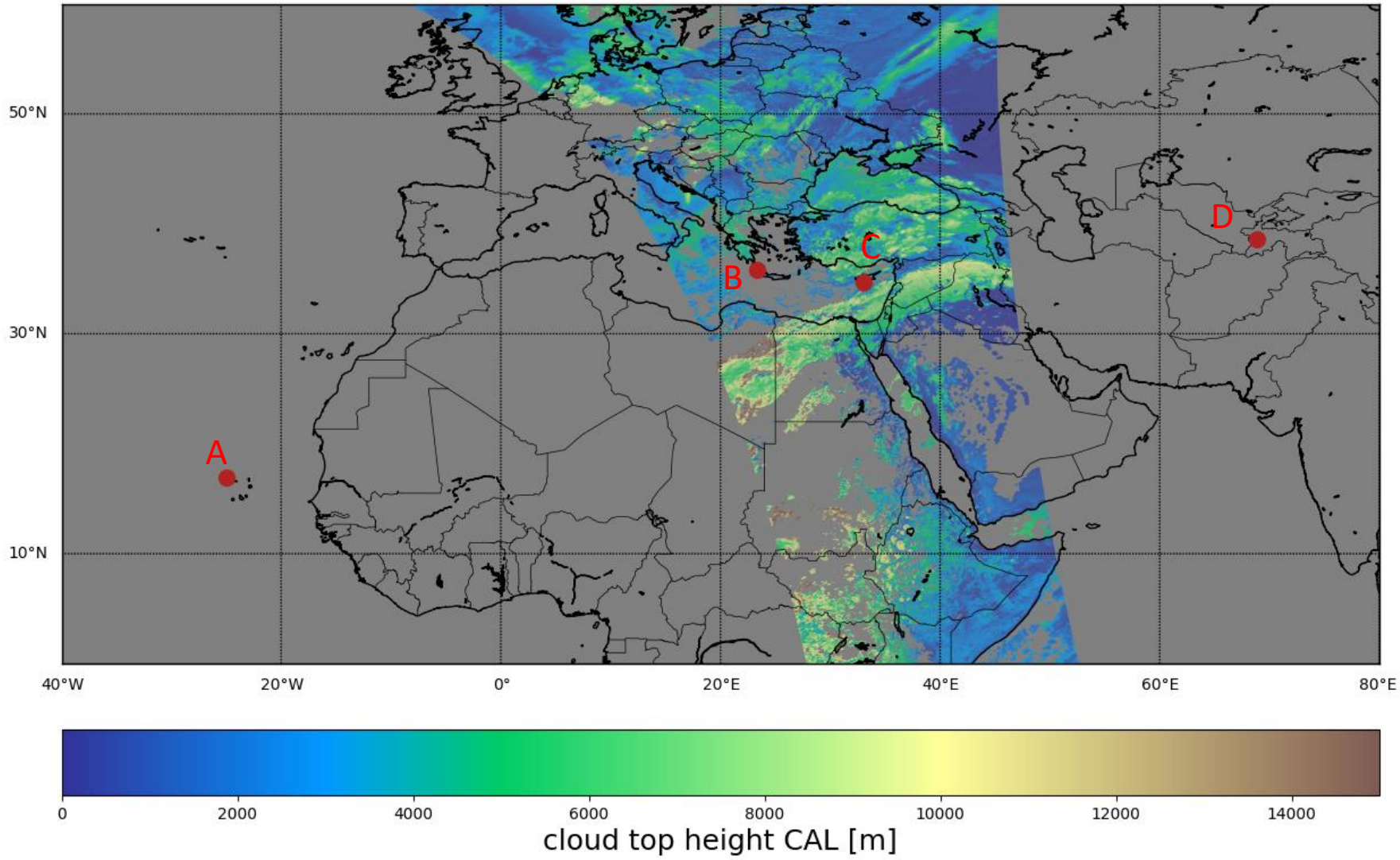
Over the following ground-based observation sites equipped with multiwavelength-Raman-polarization lidars, the so-called PollyXT, developed at the Leibniz Institute for Tropospheric Research (TROPOS). The aerosol products can be visualized on the PollyNET website.

- 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)

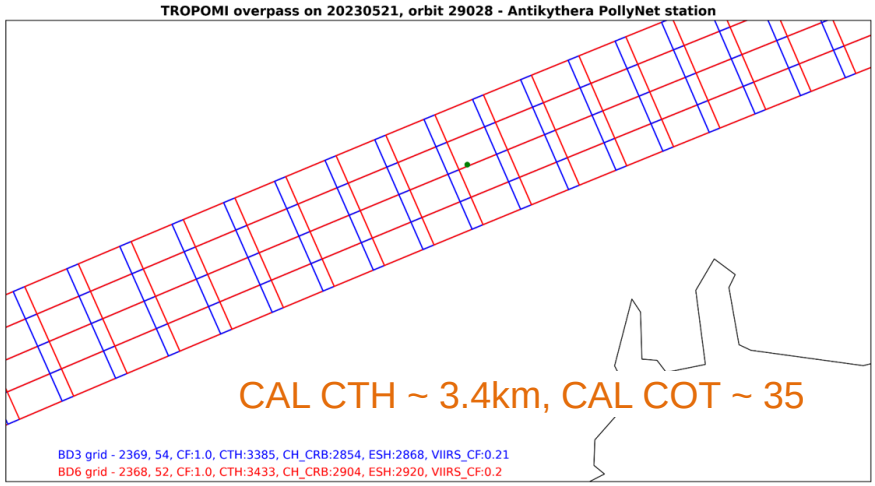


DLR

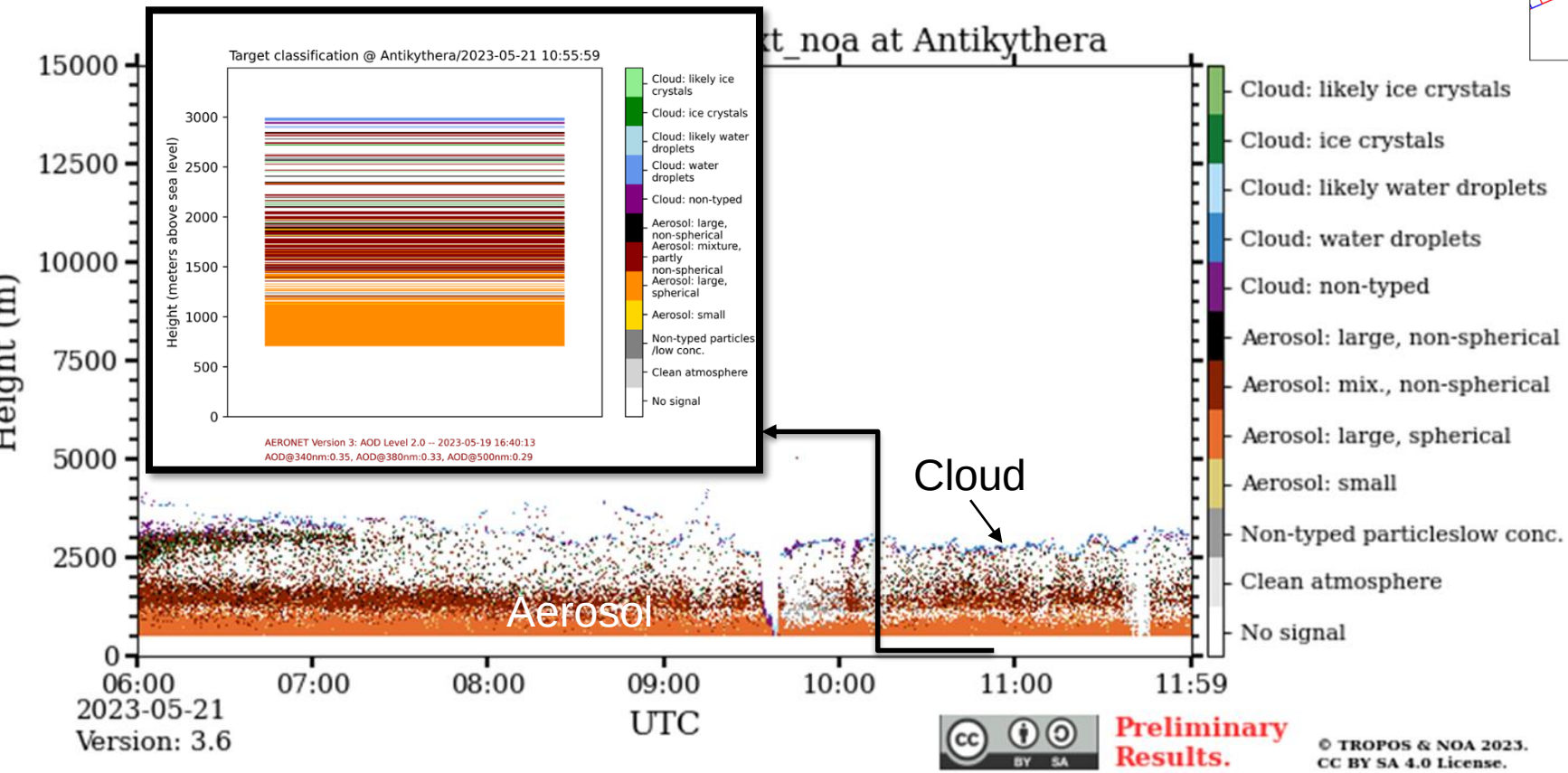
Over Antikythera, Greece

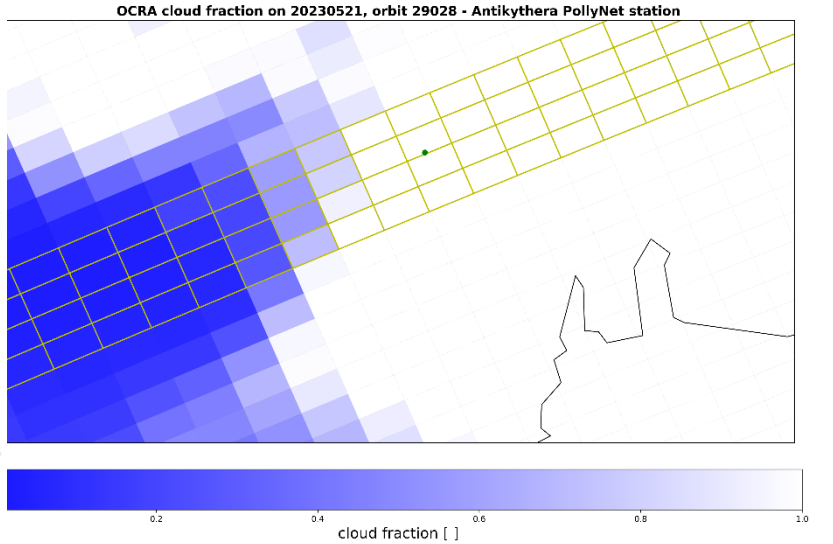
Cloud above Aerosols

- 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)



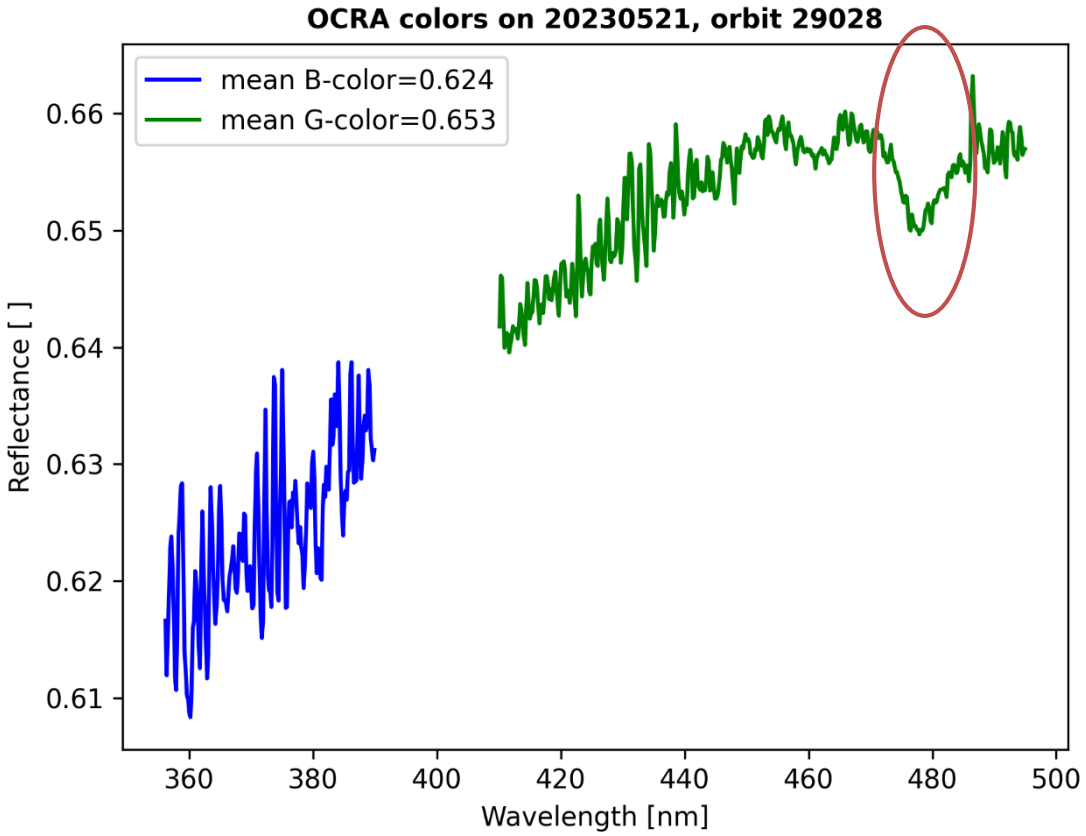
CAL CTH ~ 3.4km, CAL COT ~ 35

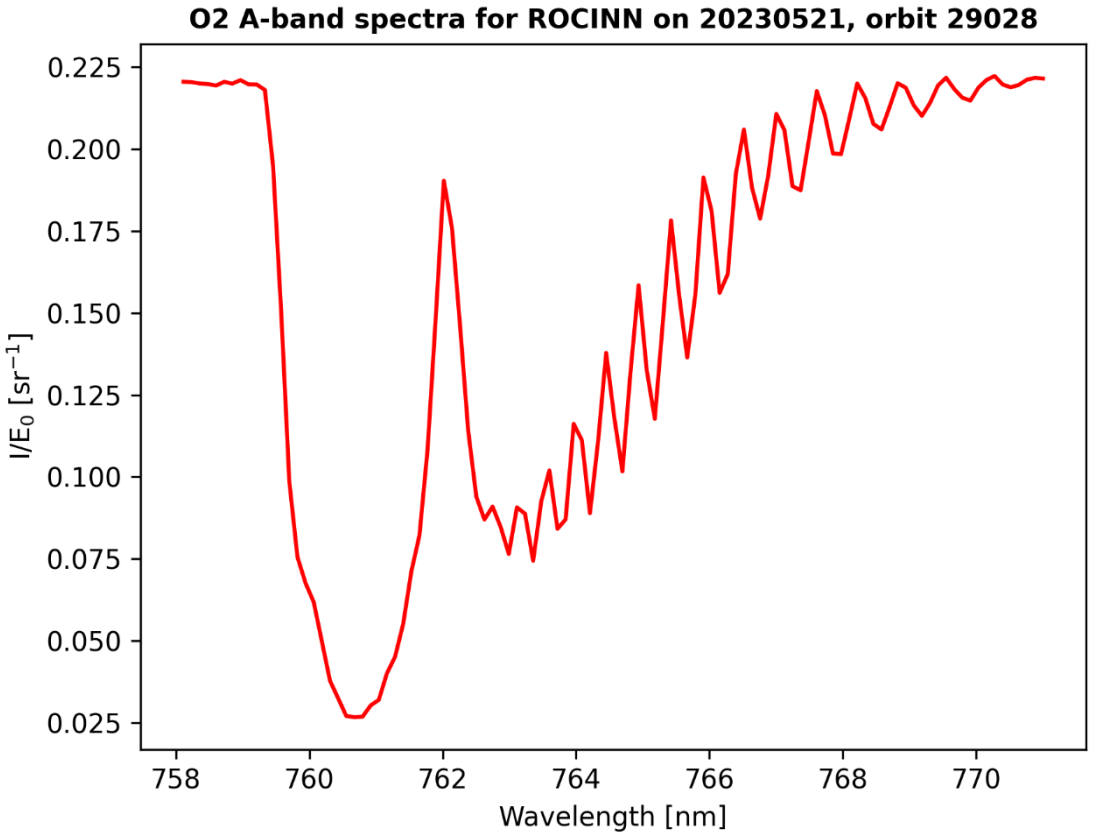




OCRA CF = 1

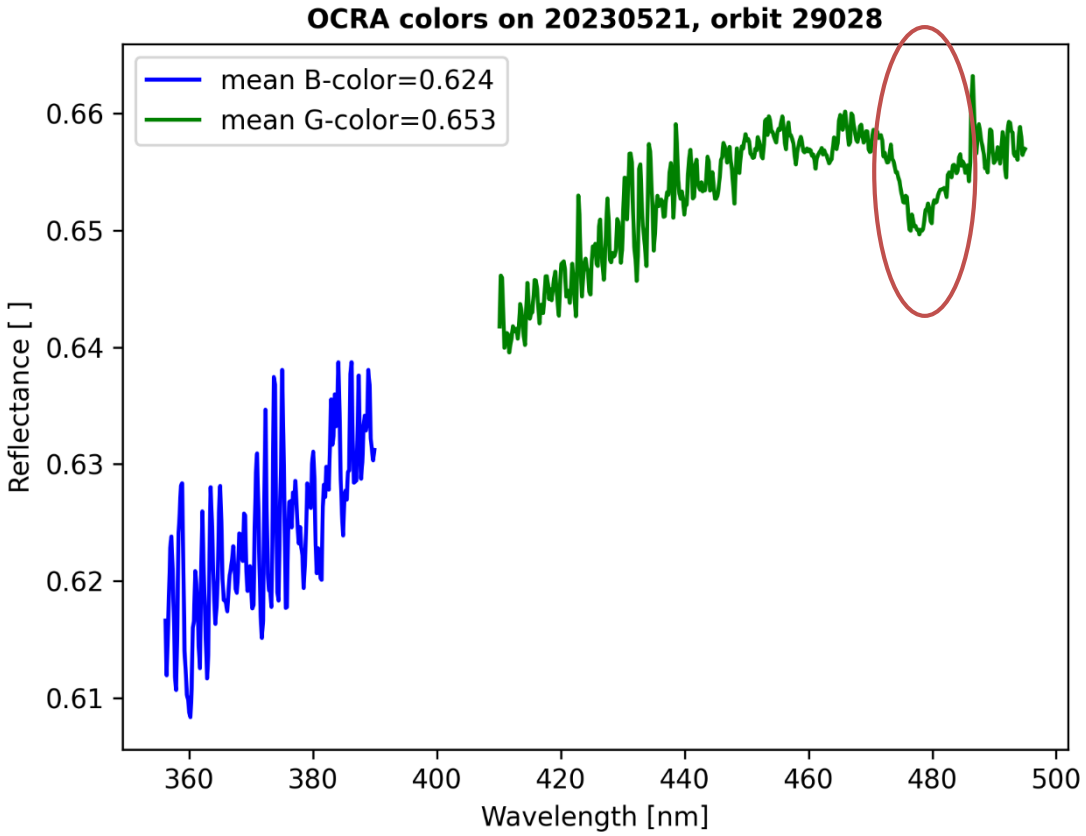
How do the L1b measurements look like?

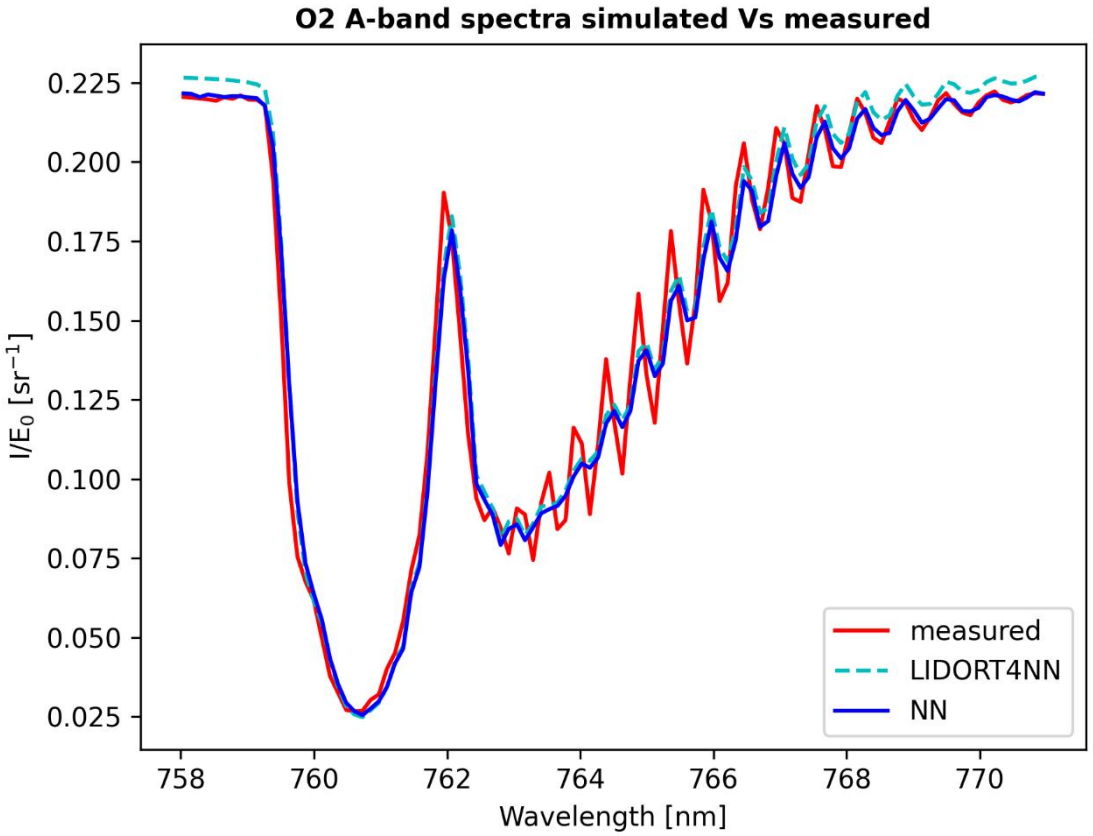




OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

How do the L1b measurements look like?





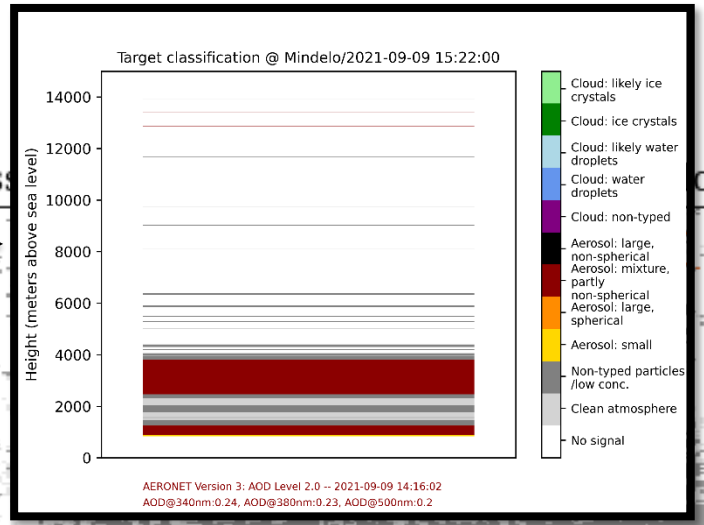
OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

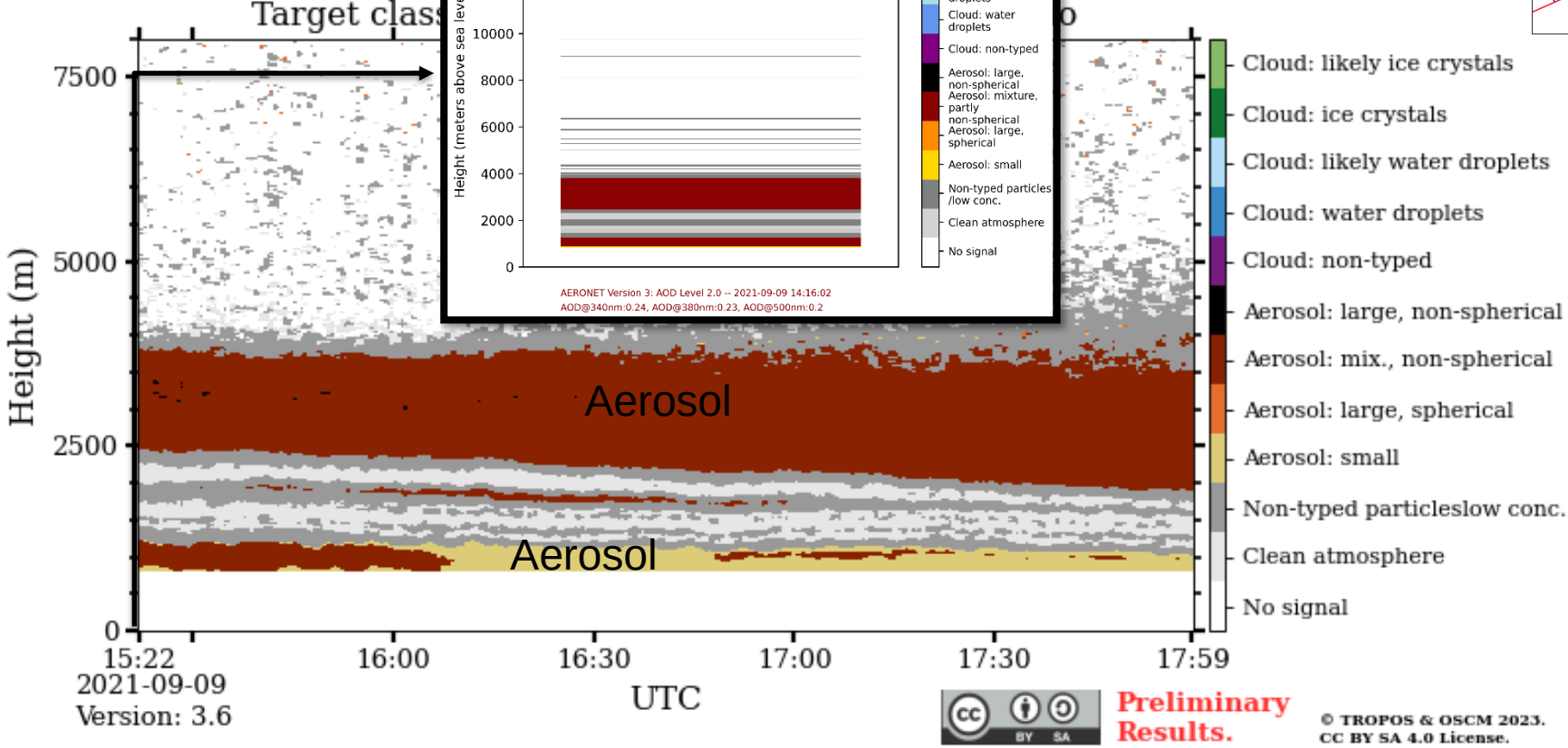
We learn that under cloudy scenes in aerosol layer presence below the cloud, the NN can reconstruct the measurement. When the aerosol layer is below the cloud, the aerosol signature **does not contaminate the TROPOMI L2 CLOUD product**!

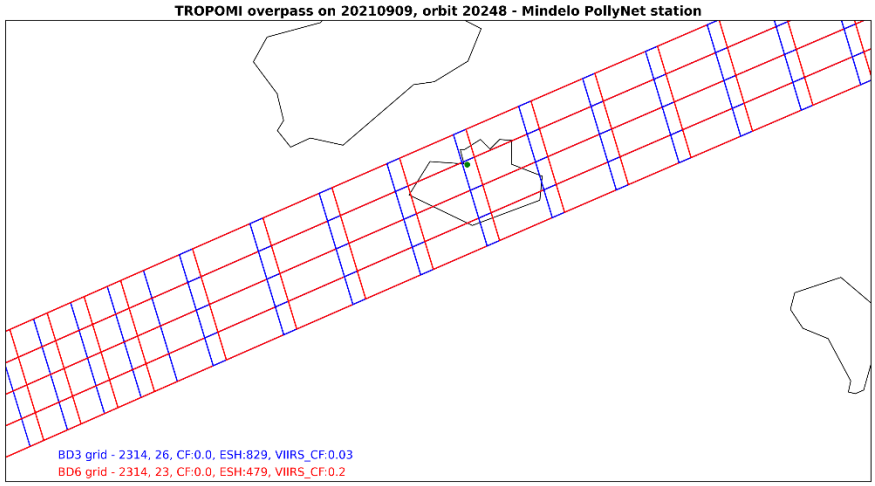
Over Mindelo, Cape Verde

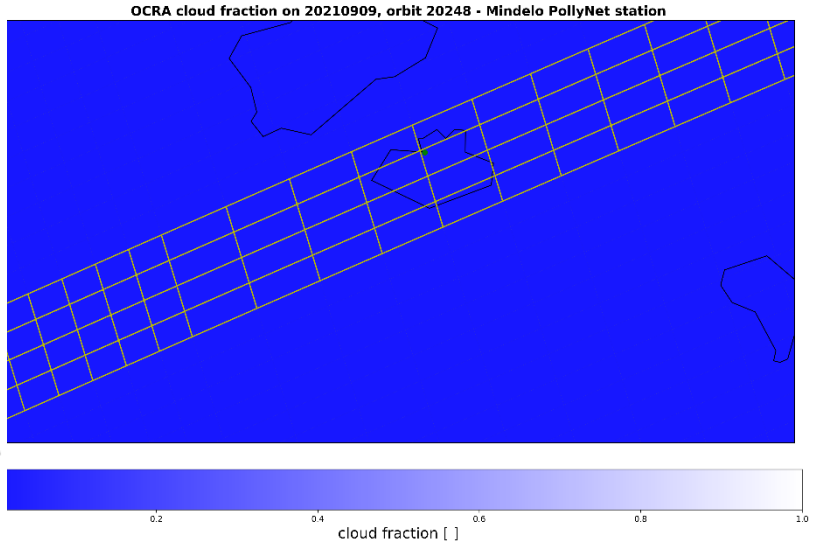
Only Aerosols

- 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)







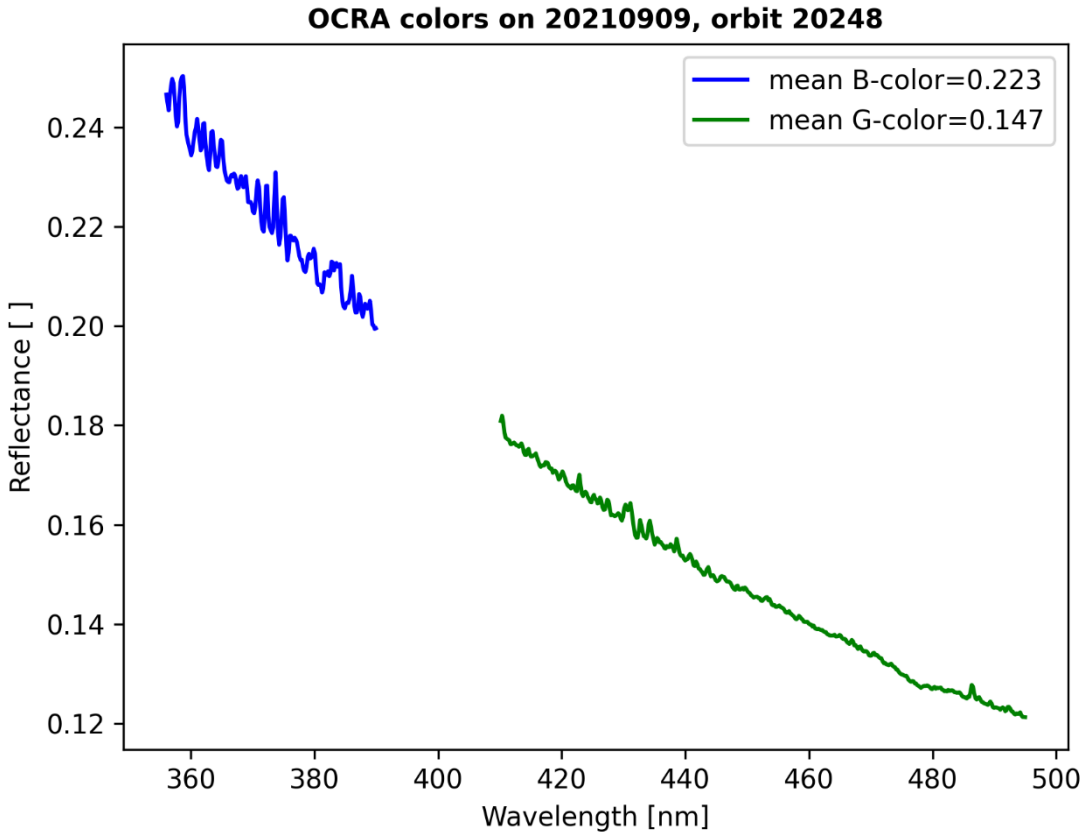


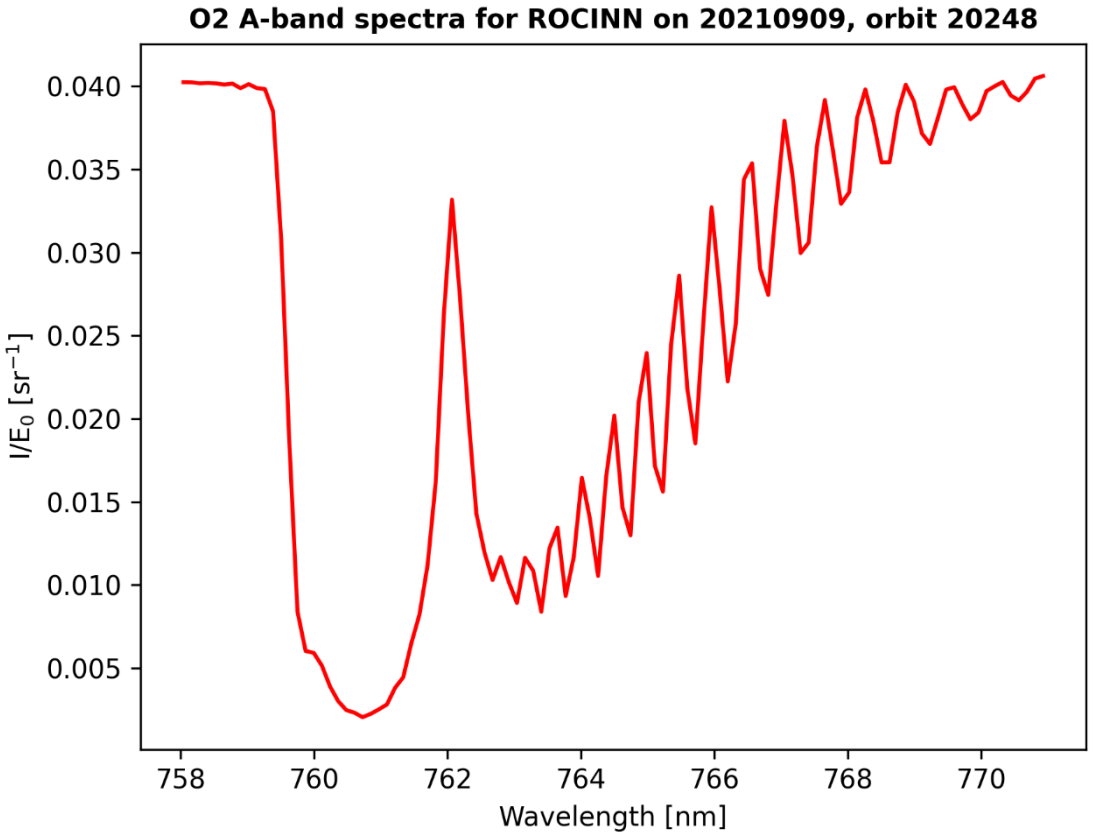
OCRA CF = 0

Preliminary Results.

DLR

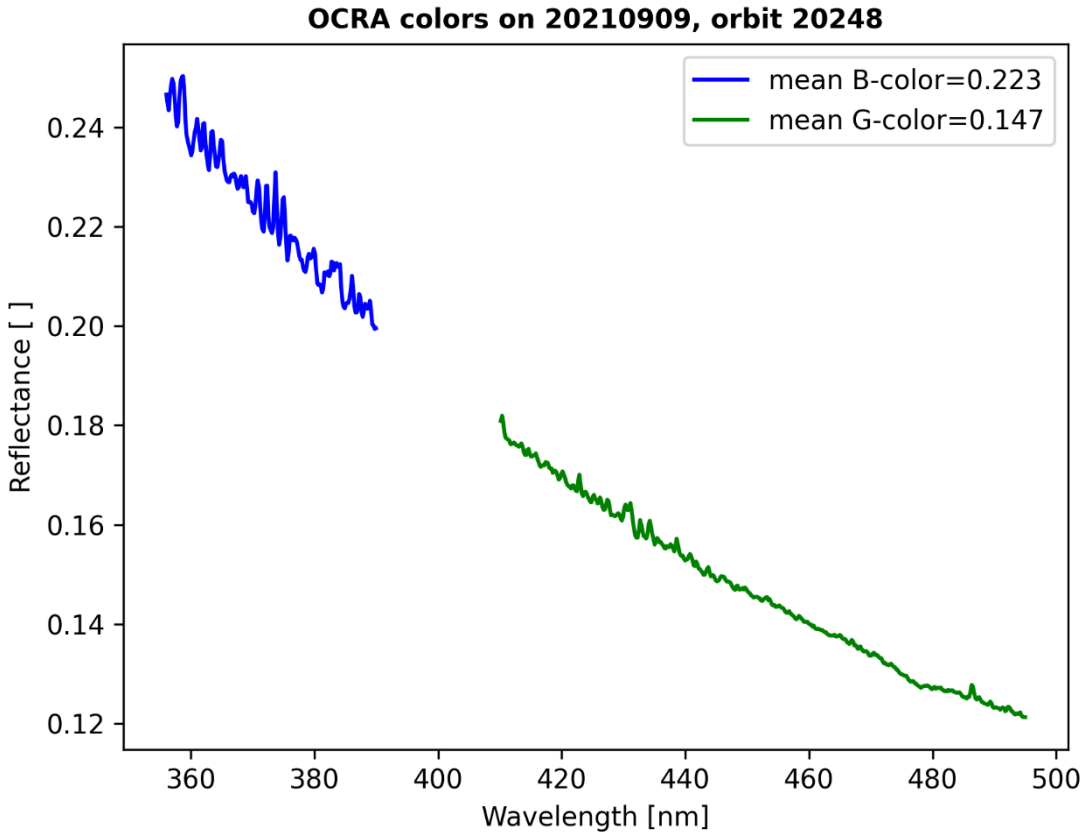
How do the L1b measurements look like?

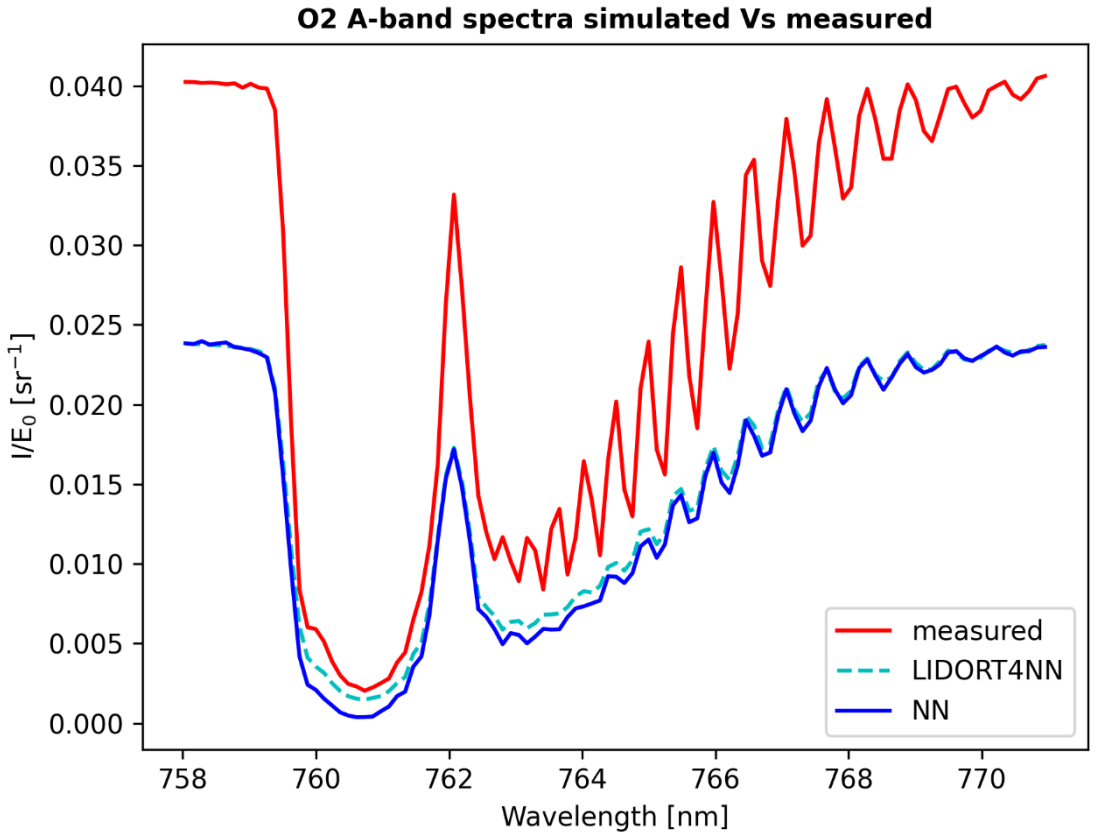




OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

How do the L1b measurements look like?





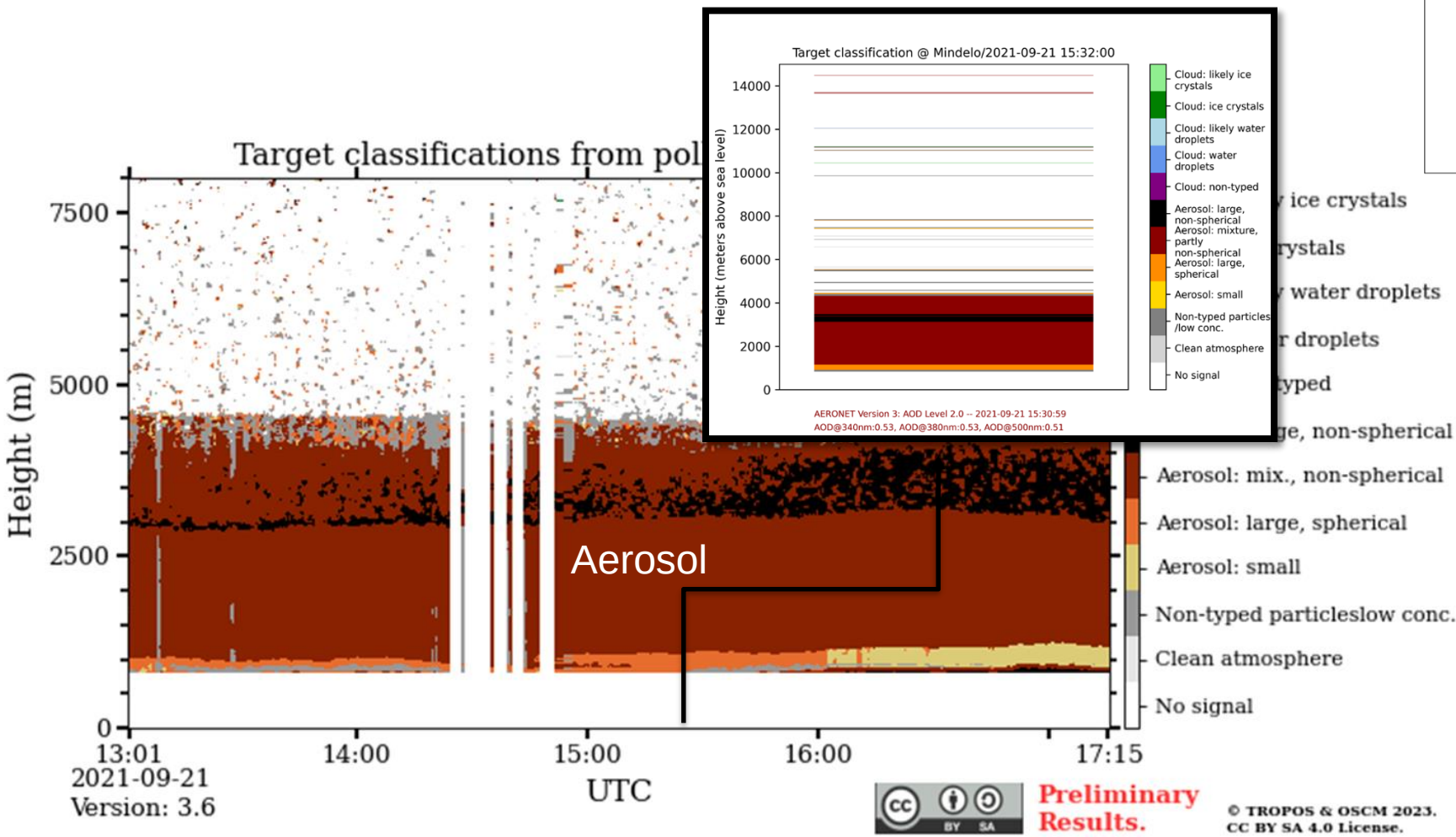
OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

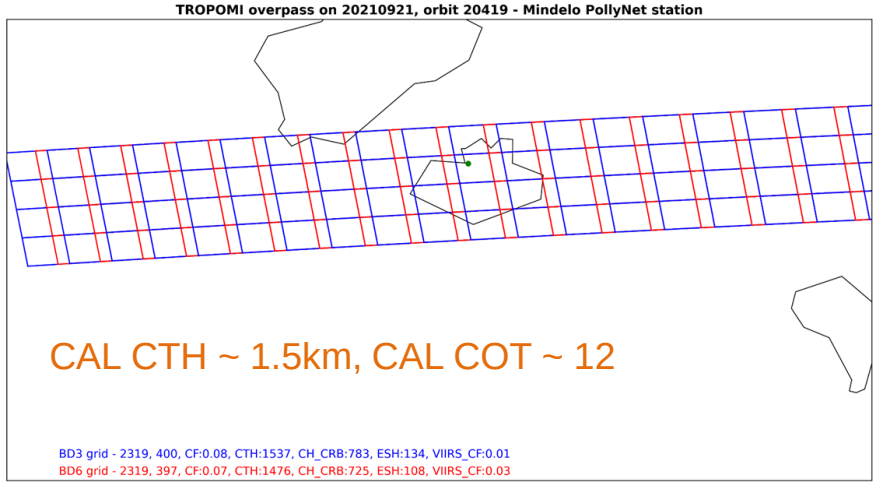
We learn that under cloud-free scenes in aerosol layer presence, the NN cannot reconstruct the measurement. The aerosol signature is weak and **does not contaminate the TROPOMI L2 CLOUD product**!

Over Mindelo, Cape Verde

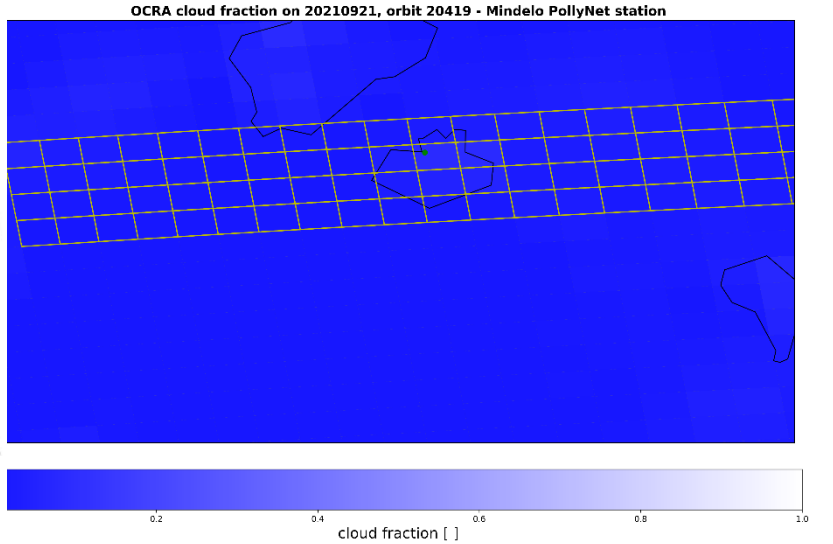
Only Aerosols

- 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

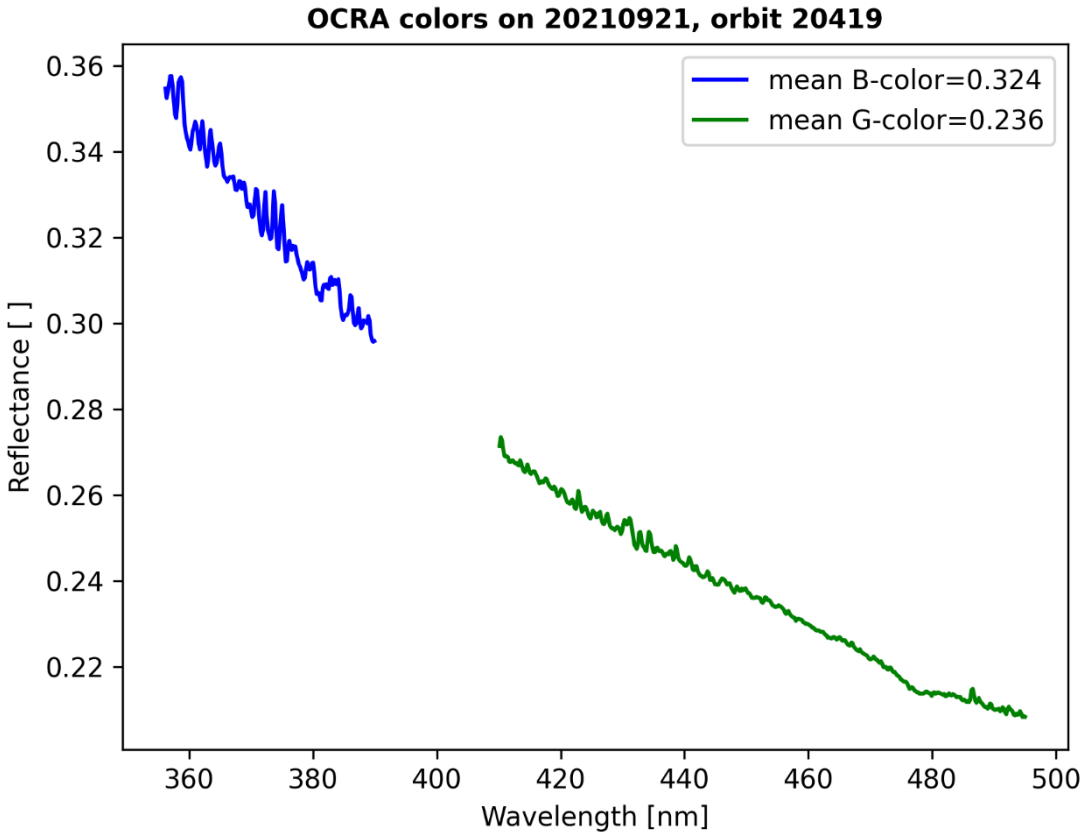


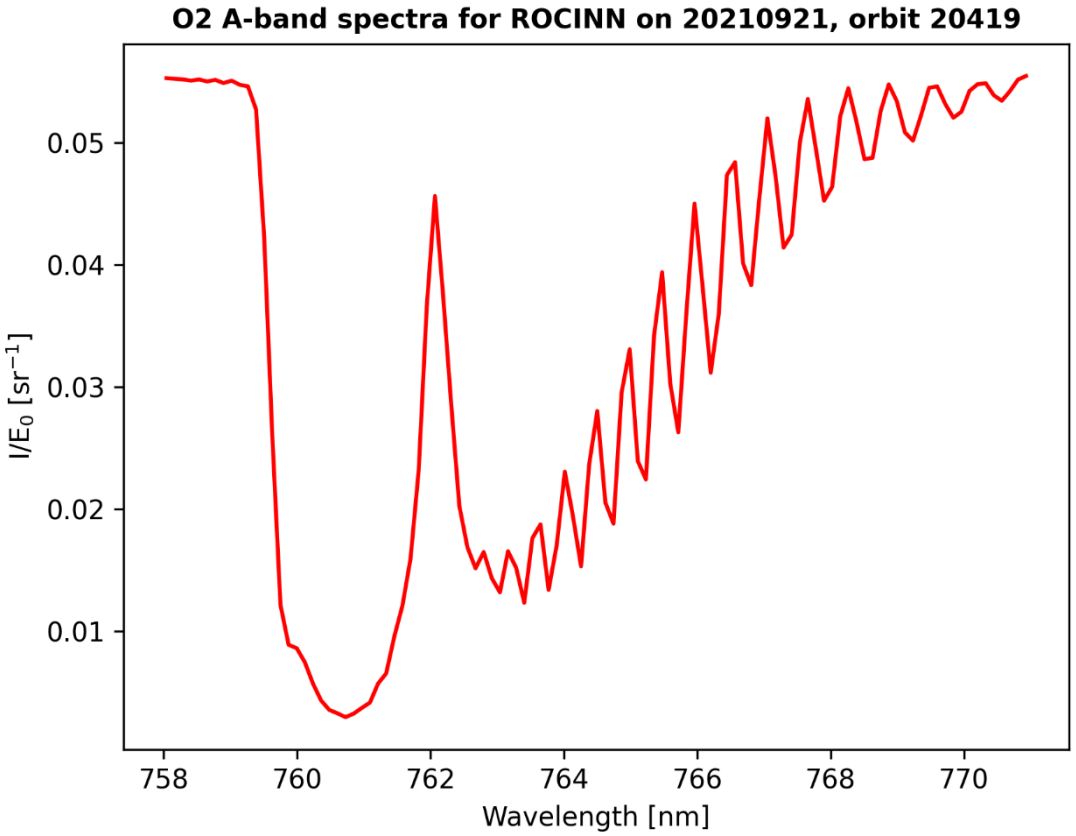
OCRA CF = 0.08

Preliminary Results.

DLR

How do the L1b measurements look like?





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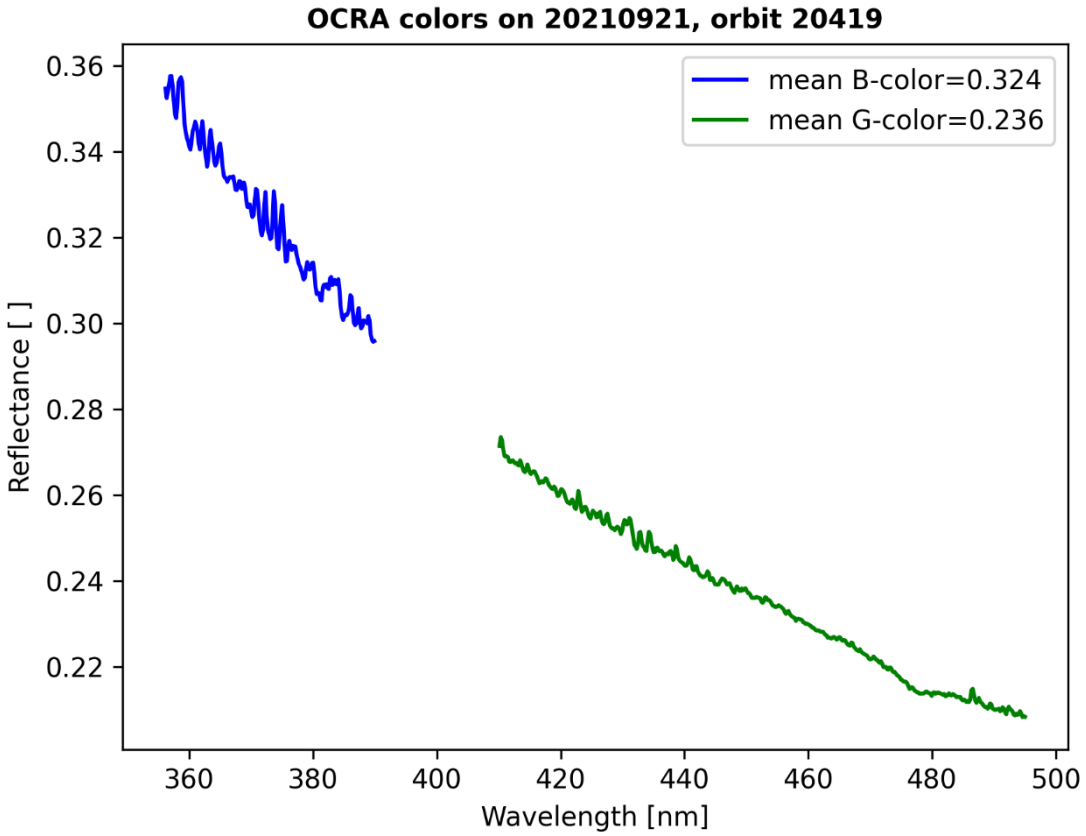
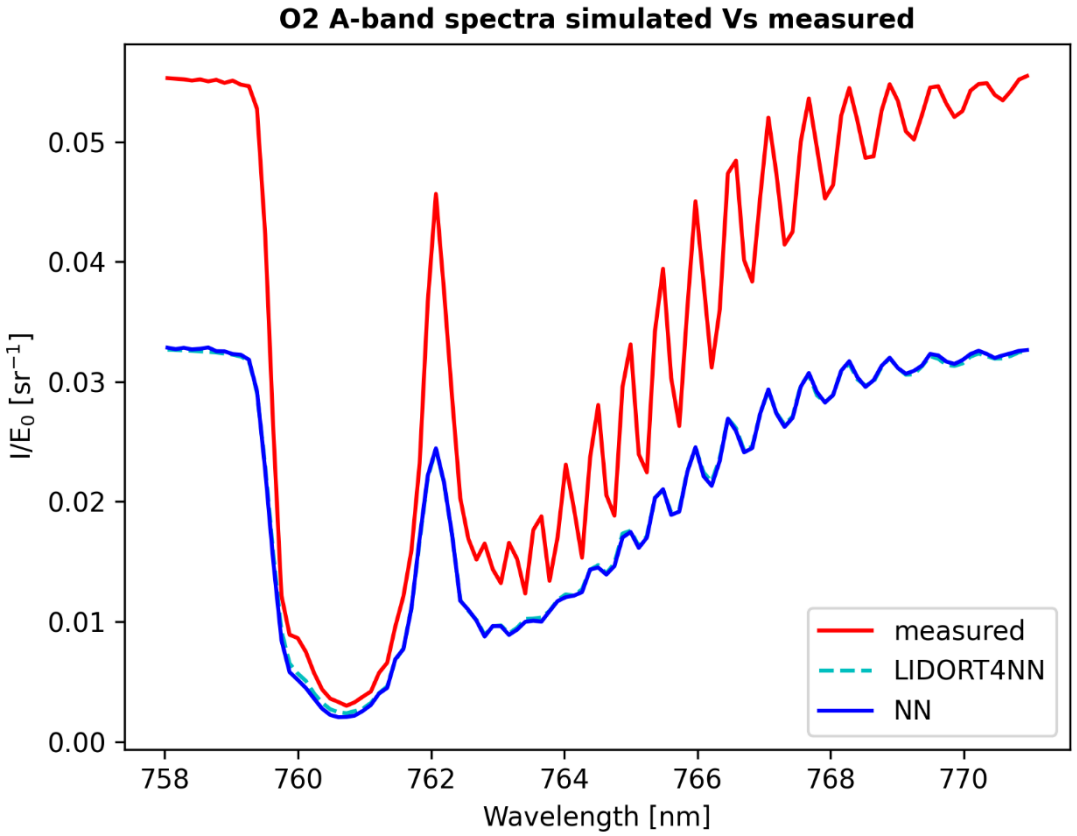
OCRA color G -> mean reflectance within the window 410-495 nm

How do the L1b measurements look like?





OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

The NN cannot reconstruct the measurement.
The aerosol signature is strong and **does contaminate the TROPOMI L2 CLOUD product**!

Summary and Conclusions

Scenes with clouds above aerosol layers: show high agreement with the ground-based measurements and the NN can reconstruct the measurement. **The aerosol signature does not contaminate the TROPOMI L2 CLOUD product.**

Scenes with only aerosols or co-existence of aerosols and clouds: **The aerosol signature can contaminate the TROPOMI L2 CLOUD product** and could affect the quality of the retrieved trace gases which require the cloud information for their correction.

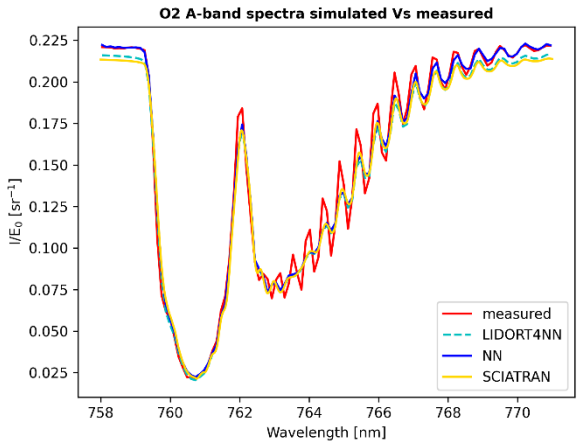
Possible solution in the short-term:

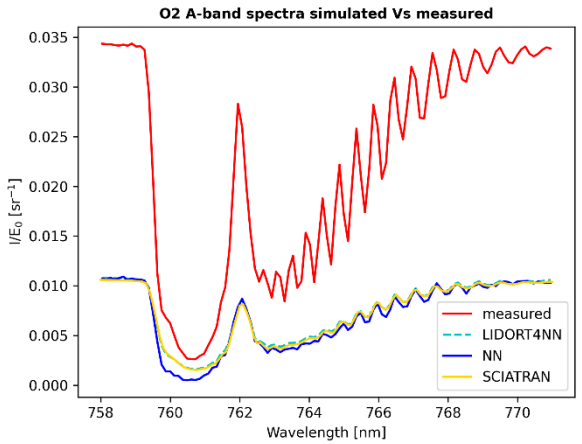
An aerosol-contamination flag can be introduced to the TROPOMI cloud product.

Long term solution:

(1) The OCRA clear sky maps could become adjustable to the aerosol presence conditions.

(2) Introduce the aerosol layer in the forward model.





Acknowledgements

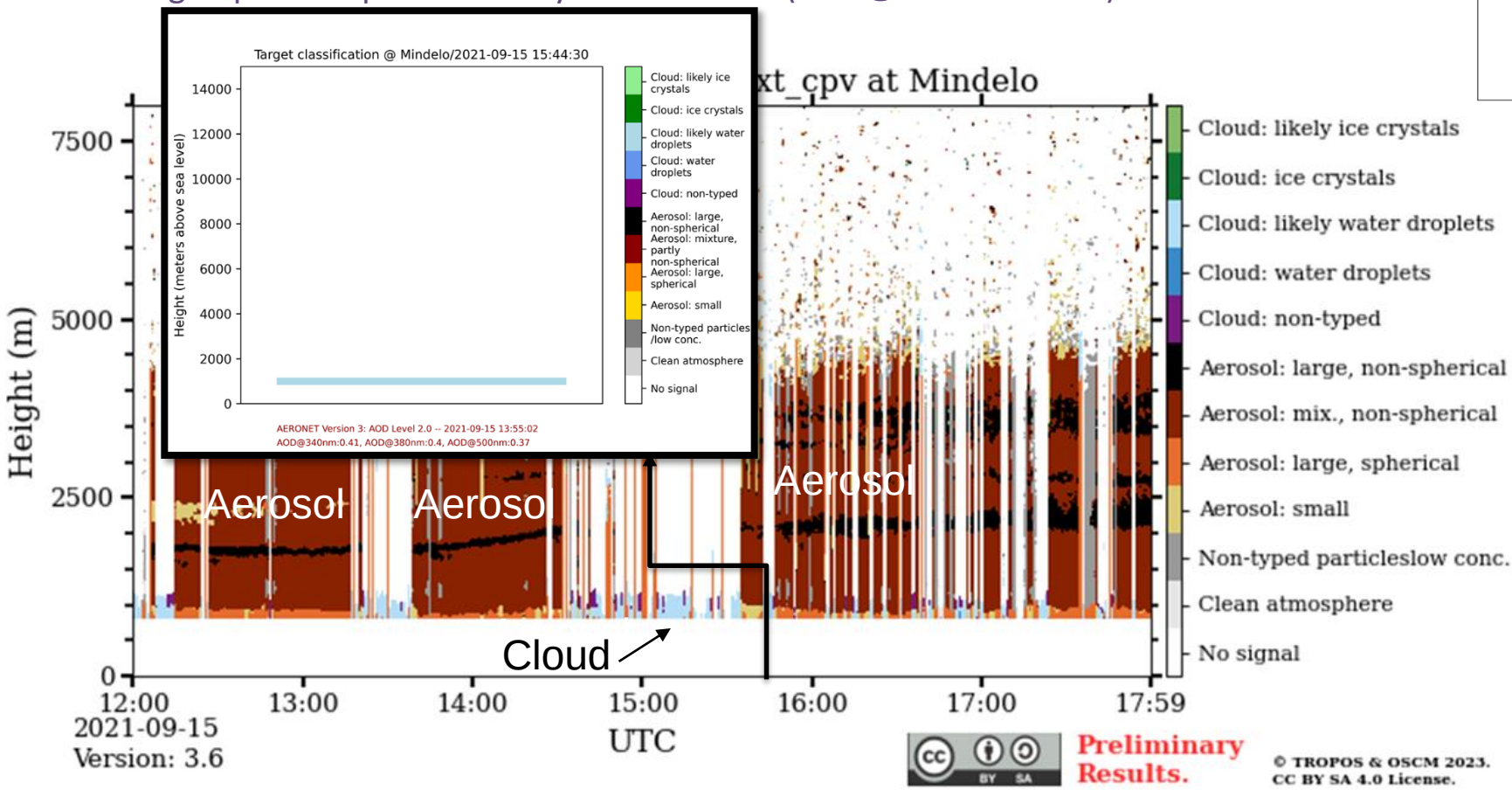
– Many thanks to the NOA colleagues Maria Tsichla, Peristera Paschou, Ioanna Tsikoudi for the lidar data provision and the scientific discussions.

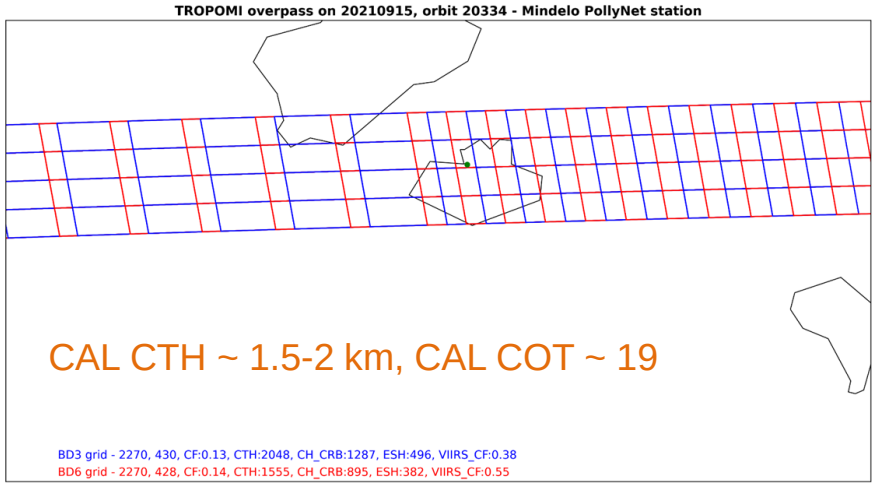
Supplementary Material

Over Mindelo, Cape Verde

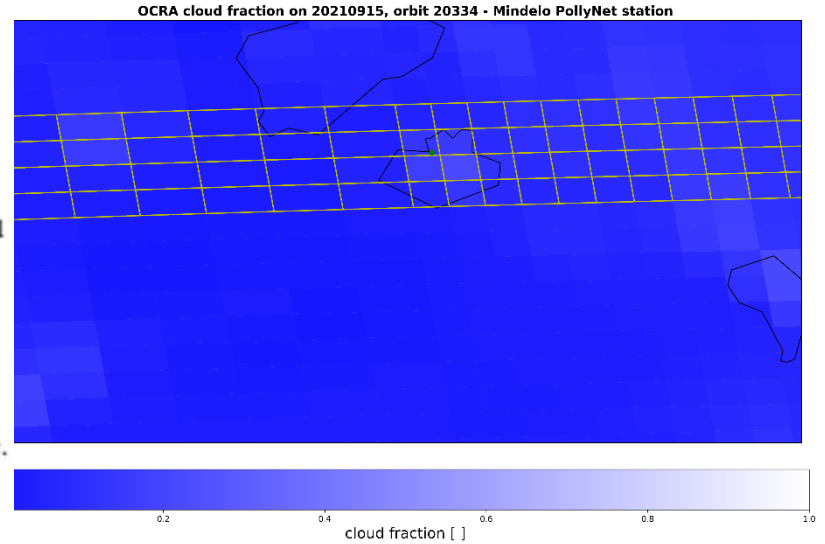
Cloud below Aerosols

- 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)



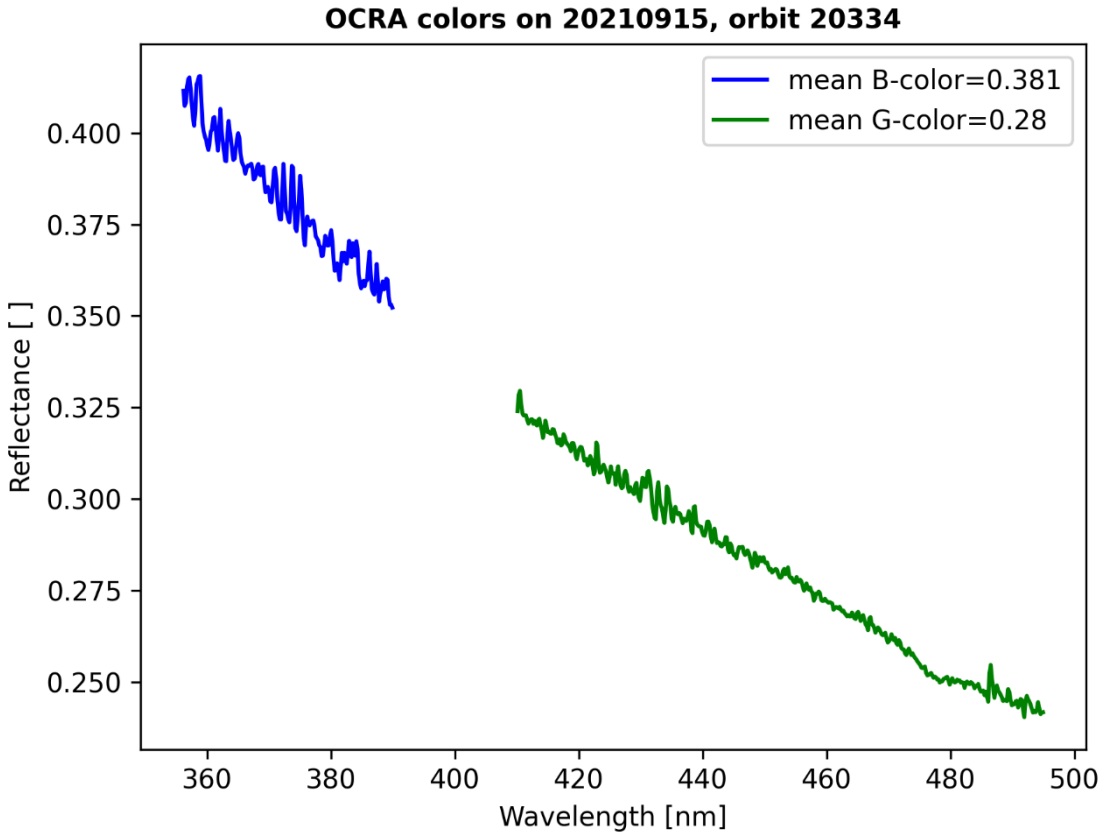


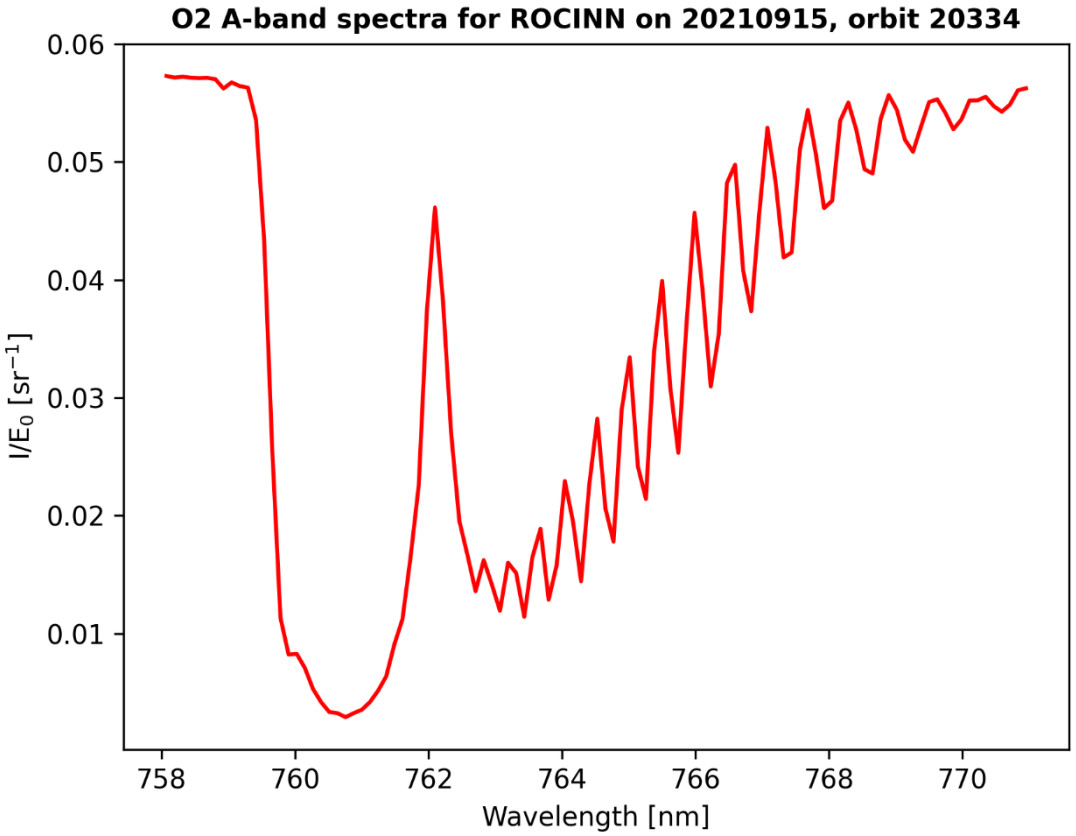
CAL CTH ~ 1.5-2 km, CAL COT ~ 19



OCRA CF = 0.13

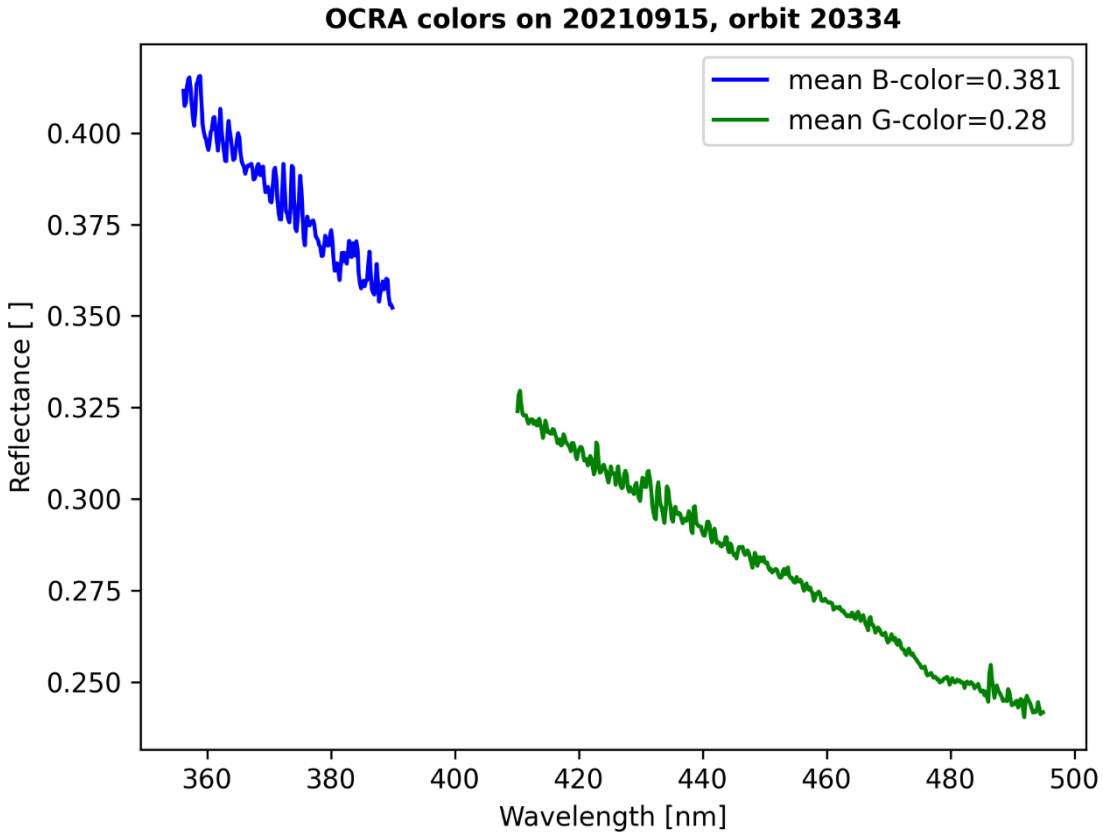
How do the L1b measurements look like?

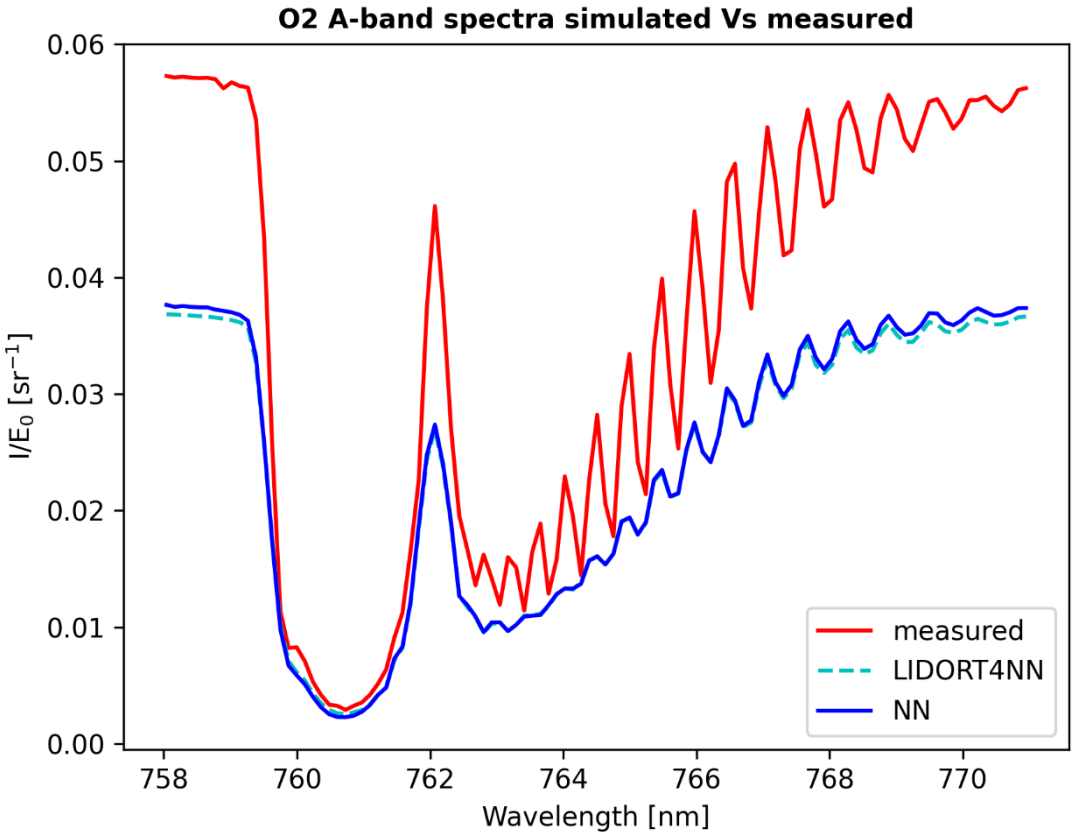




OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

How do the L1b measurements look like?





OCRA color B -> mean reflectance within the window 356-390 nm
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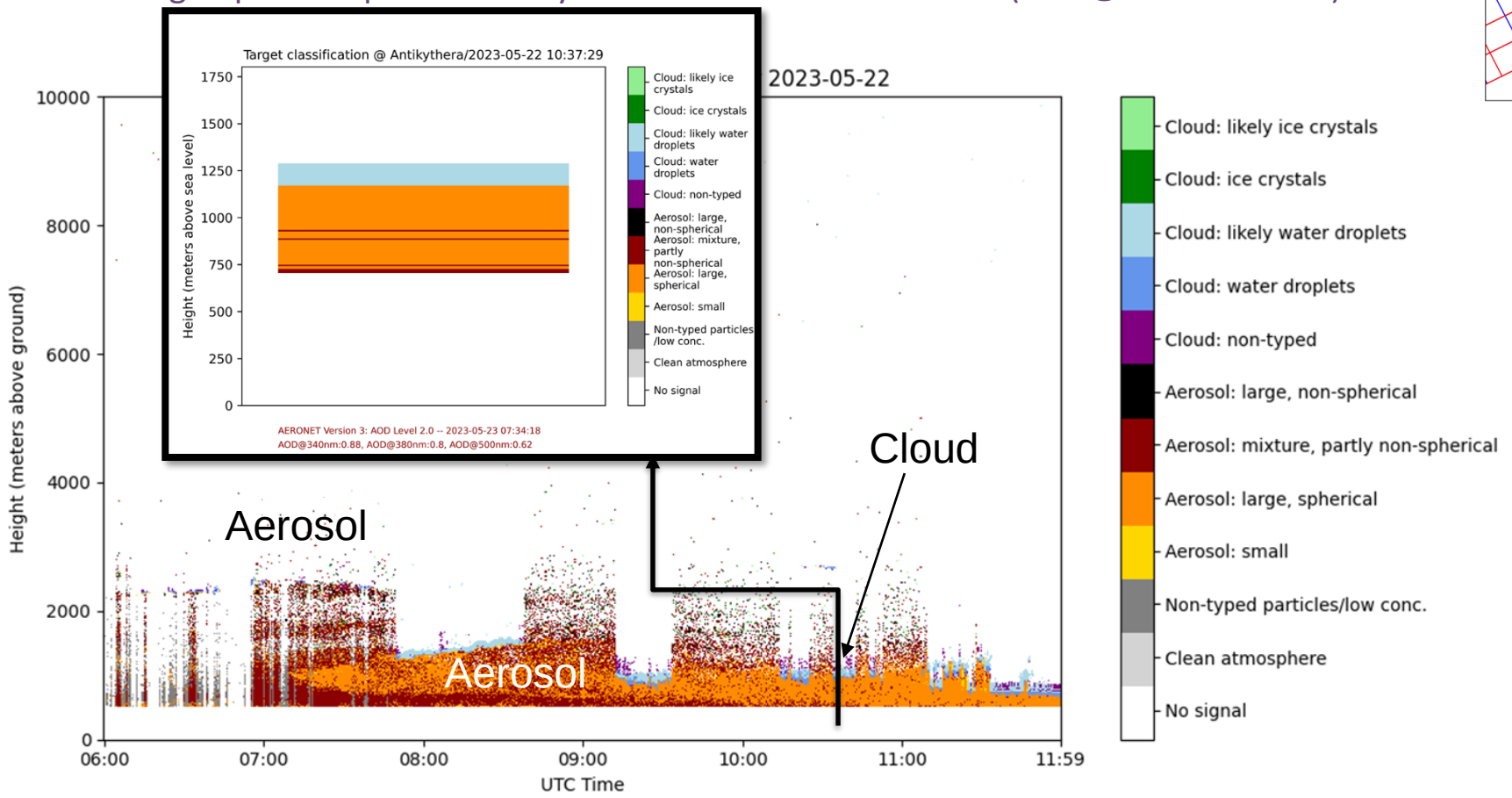
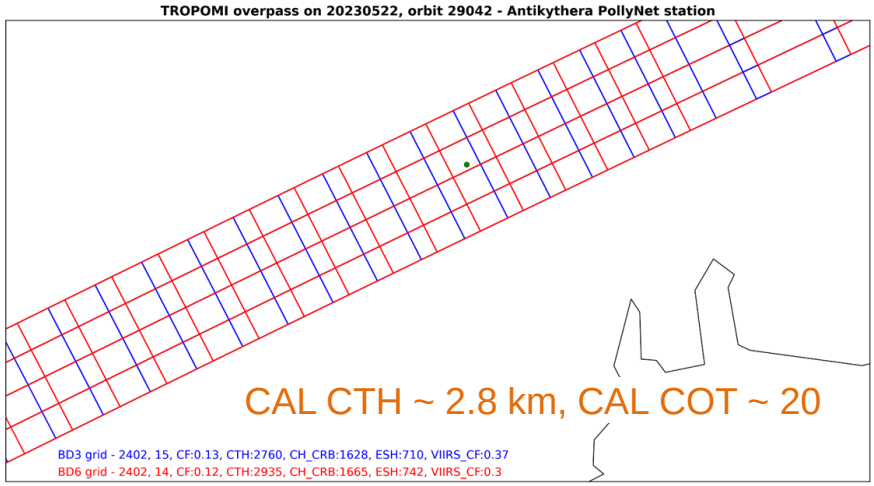
Over Antikythera, Greece

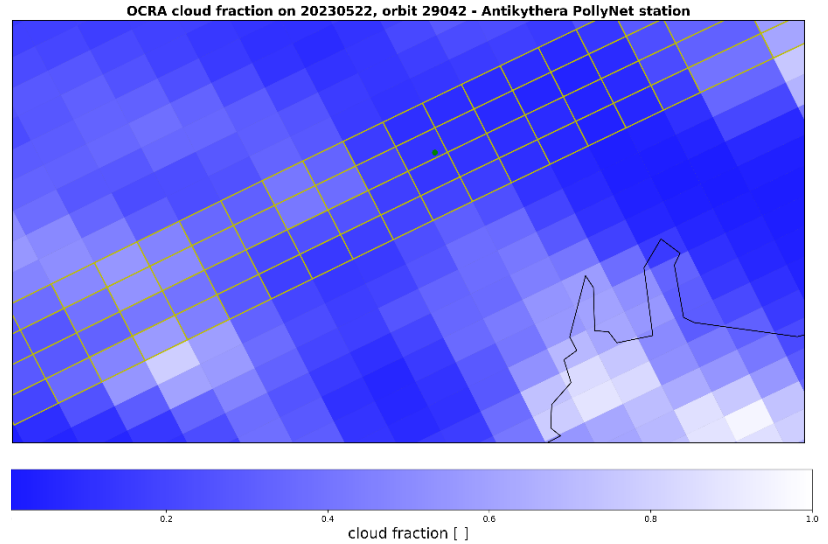
Cloud below Aerosols

- 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)



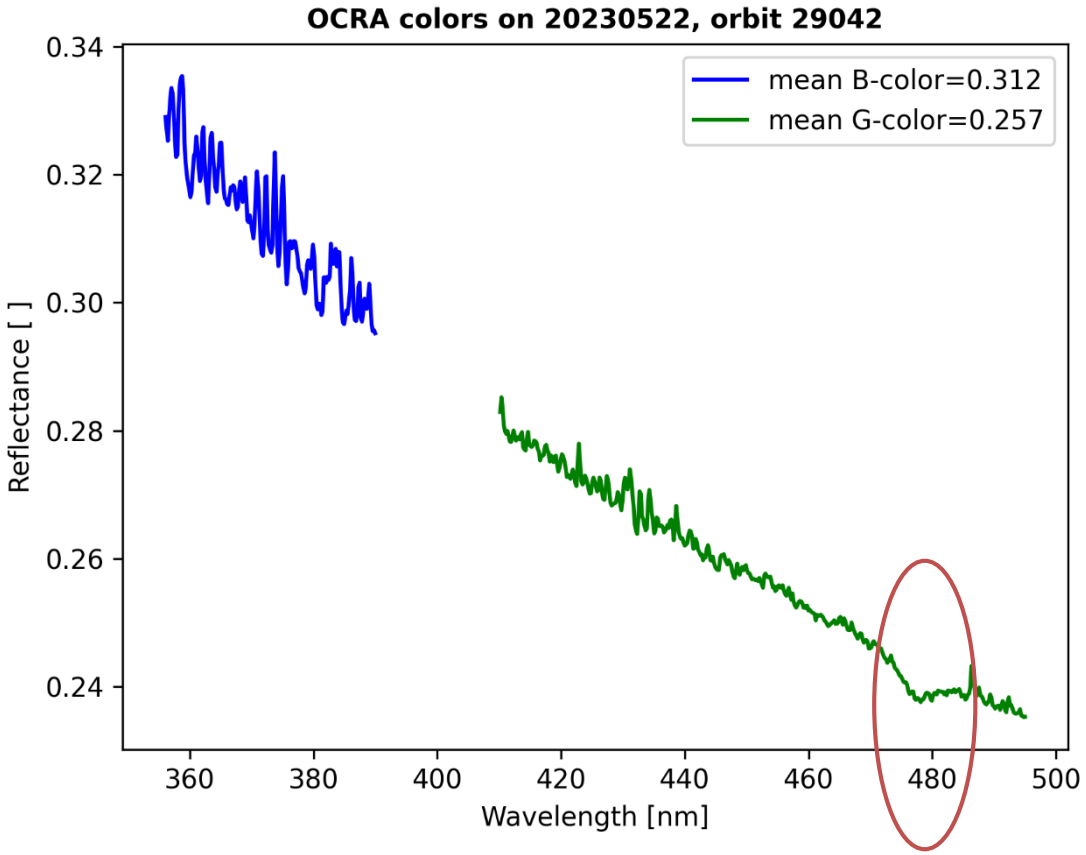


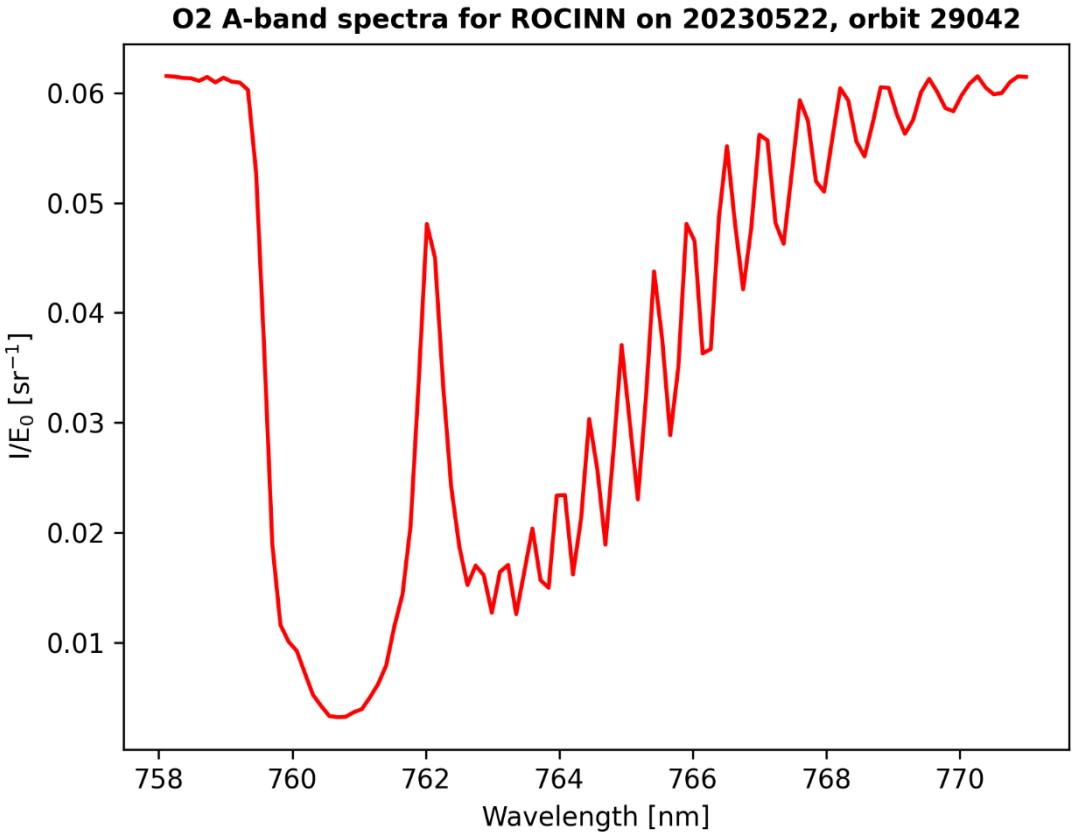
CAL CTH ~ 2.8 km, CAL COT ~ 20



OCRA CF = 0.13

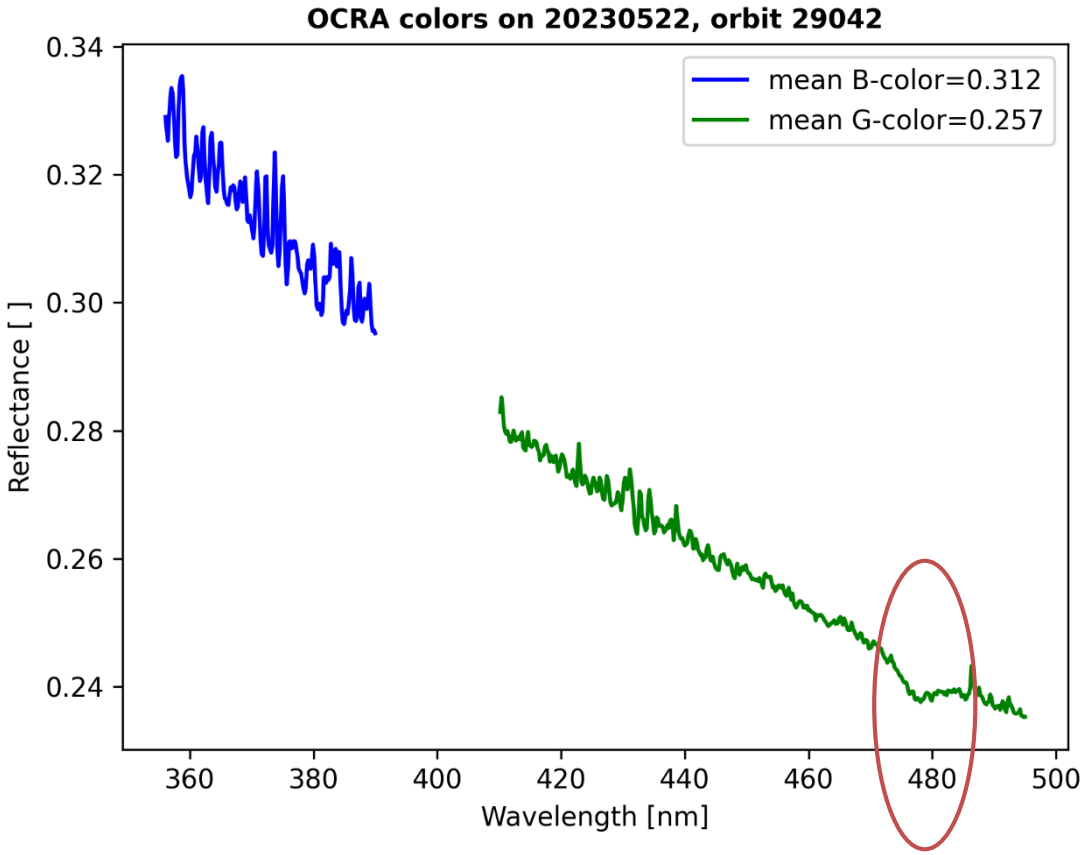
How do the L1b measurements look like?

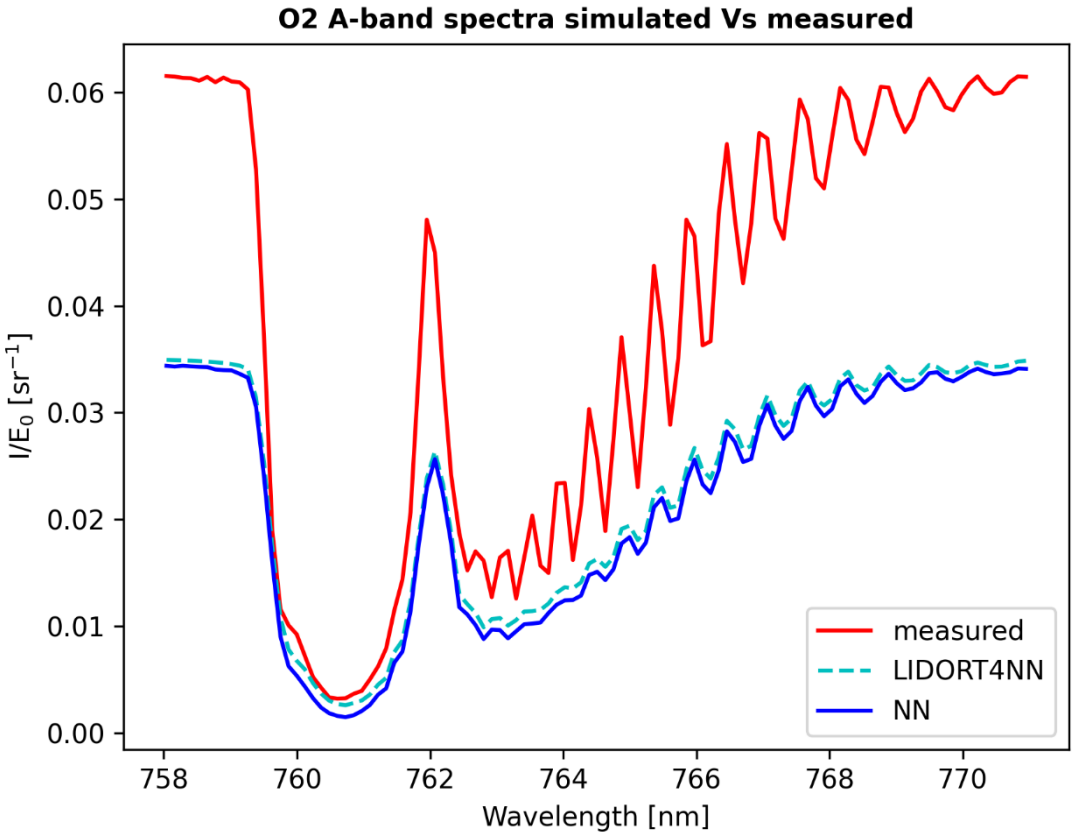




OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

How do the L1b measurements look like?



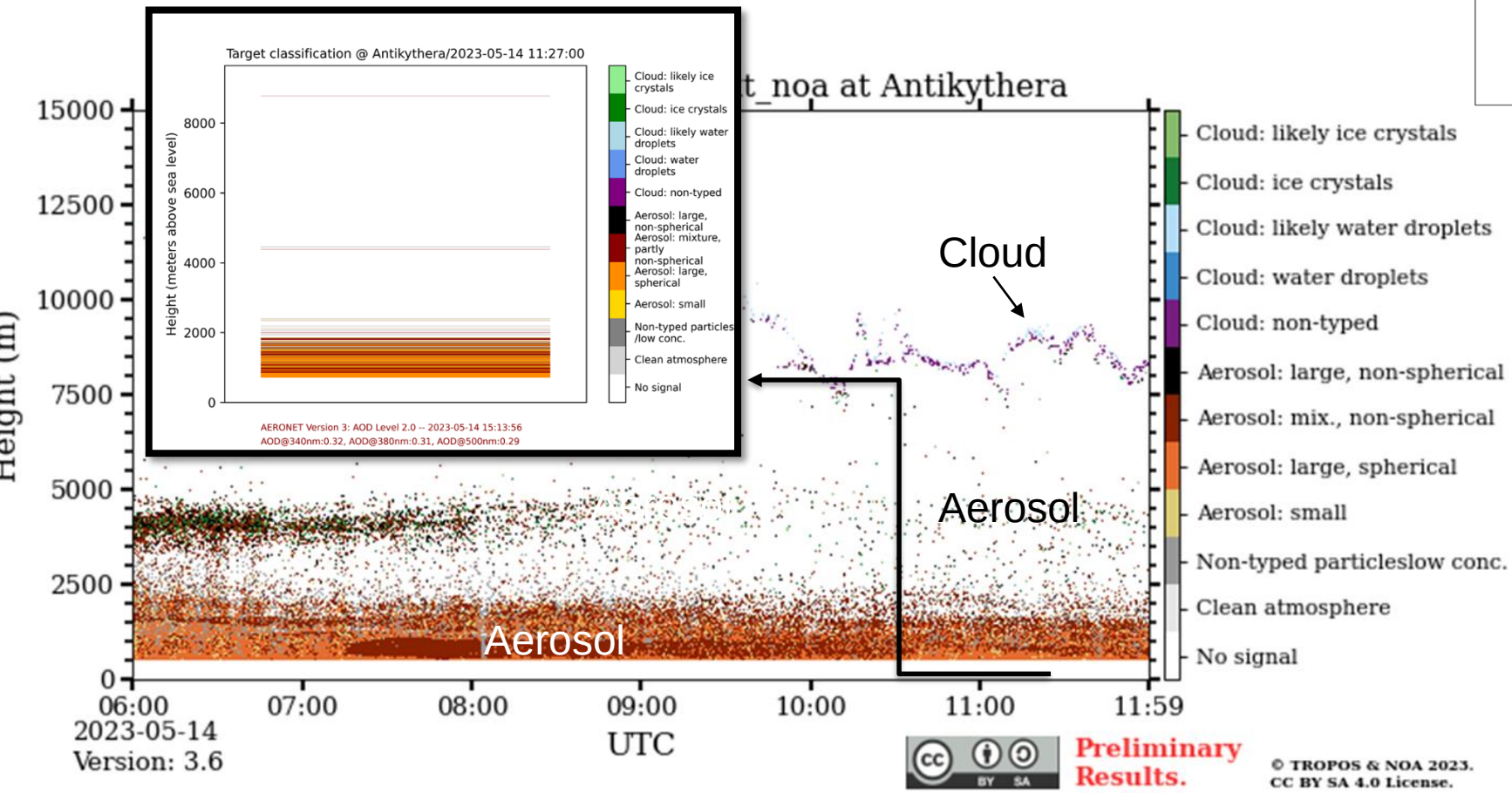


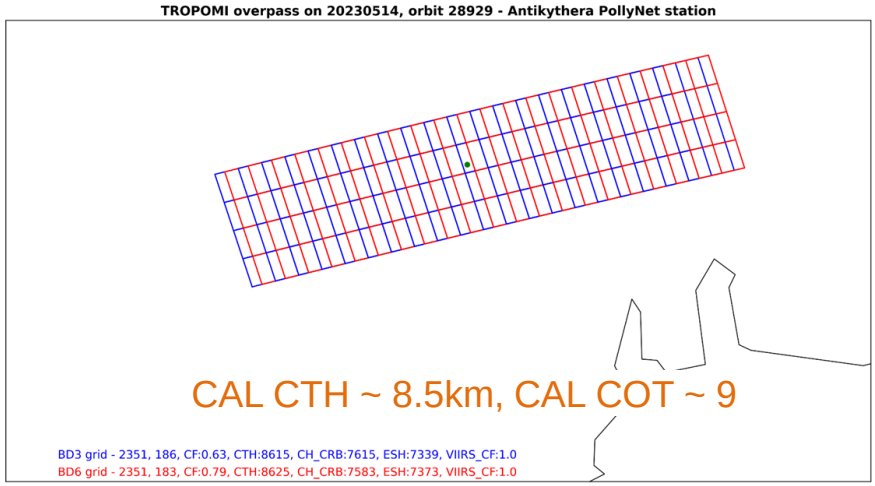
OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

Over Antikythera, Greece

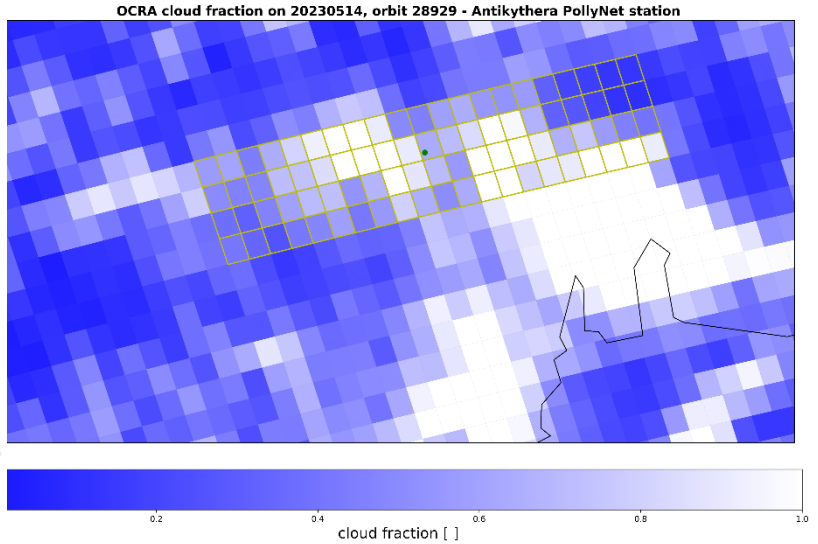
Cloud above Aerosols

- 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)



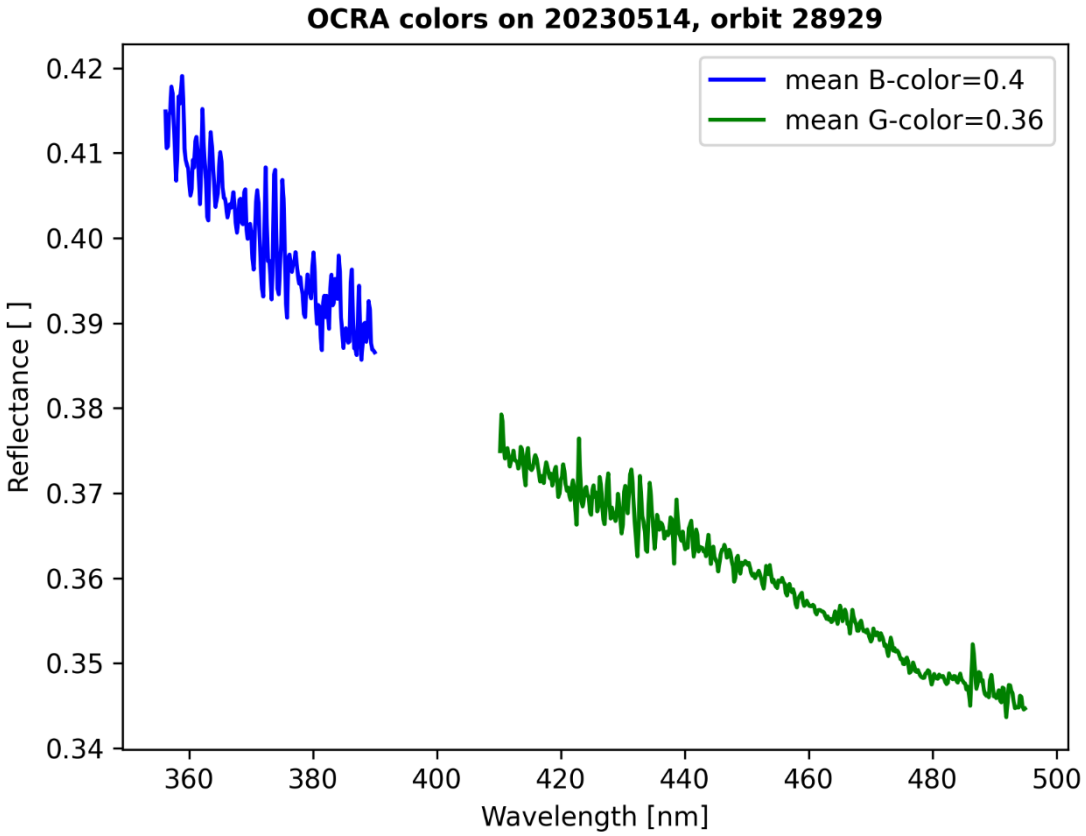


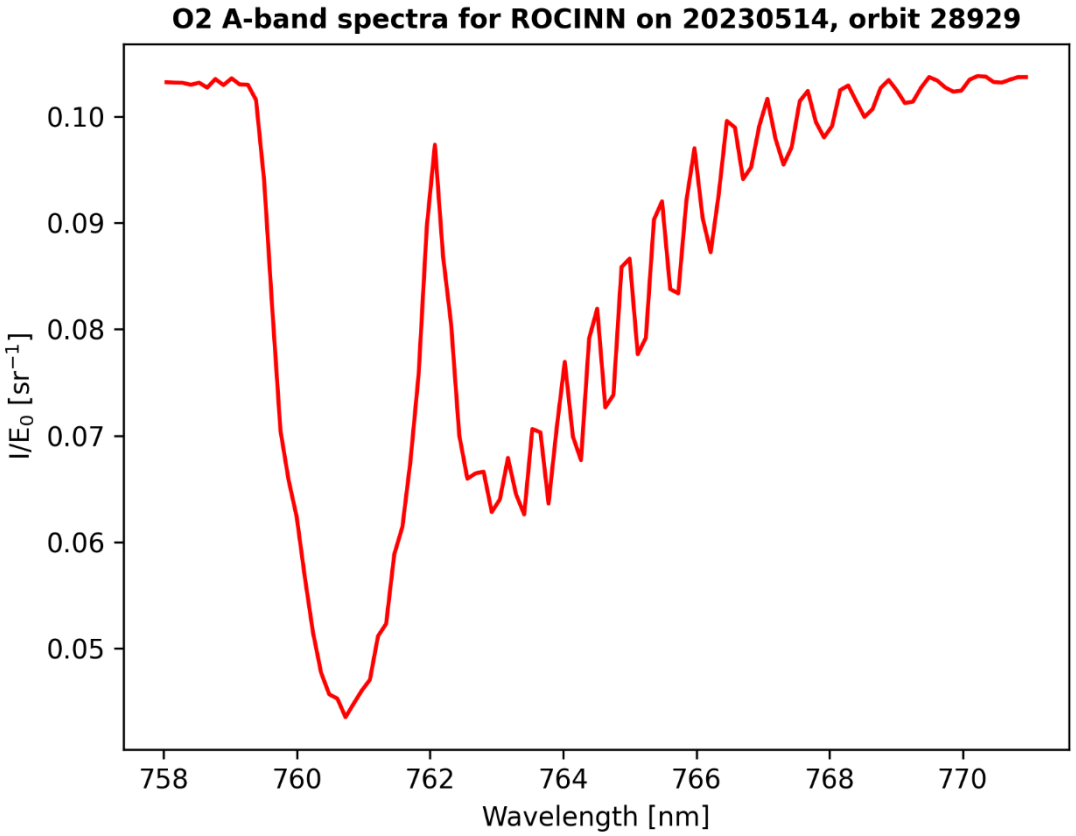
CAL CTH ~ 8.5km, CAL COT ~ 9



OCRA CF = 0.63

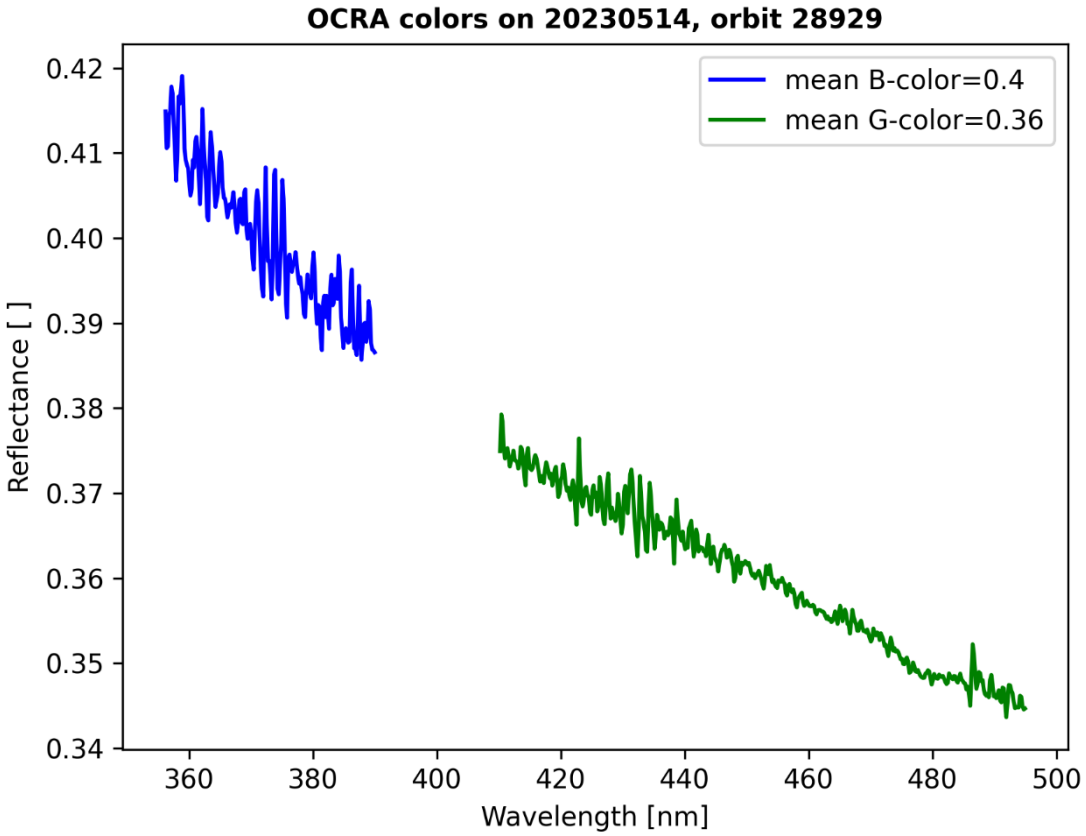
How do the L1b measurements look like?

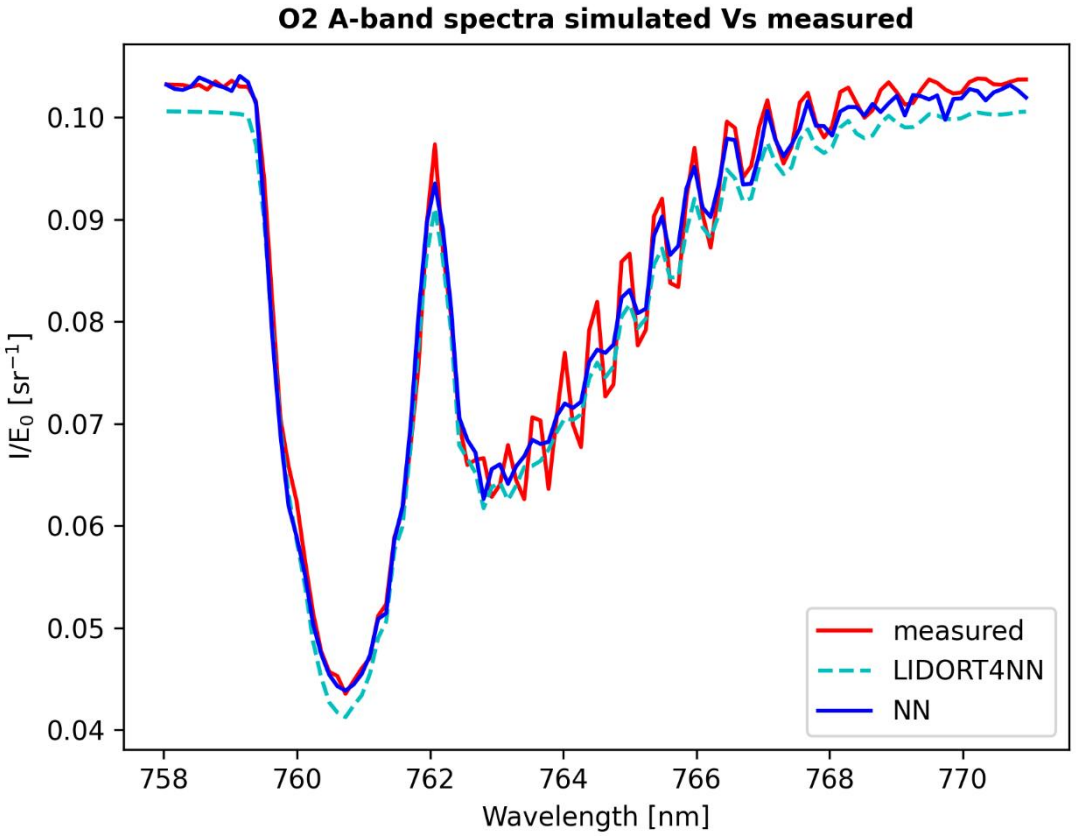




OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

How do the L1b measurements look like?

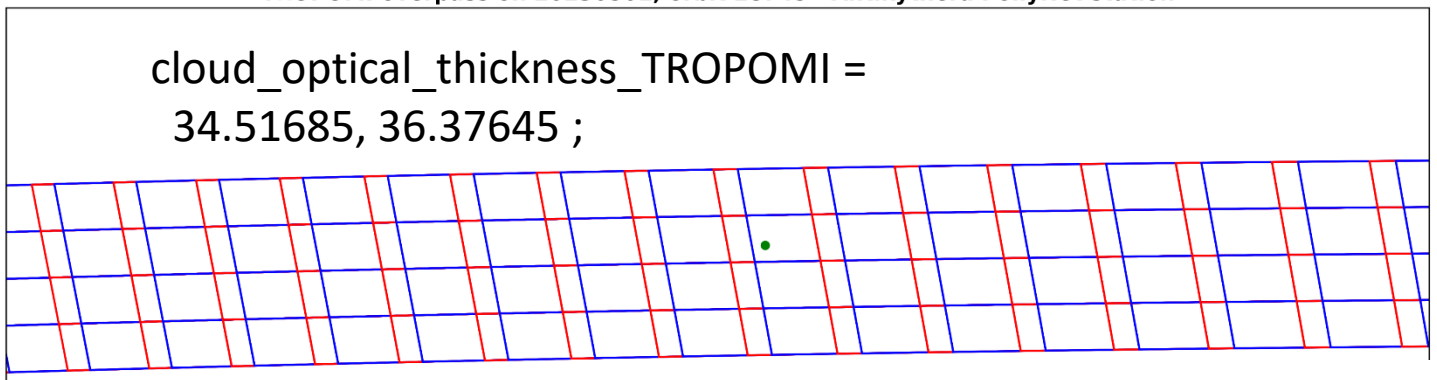




OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

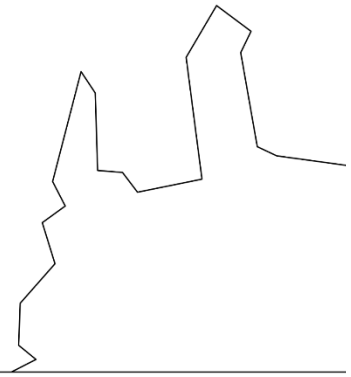
TROPOMI overpass on 20230501, orbit 28745 - Antikythera PollyNet station

cloud_optical_thickness_TROPOMI =
34.51685, 36.37645 ;



"urban/industrial"

UVAerosolIndex_TROPOMAER = 0.2758612 ;
CloudFraction_TROPOMAER = 1 ; **CloudOpticalDepth_TROPOMAER = 33.3869** ;
AerosolType_TROPOMAER = 3 ;

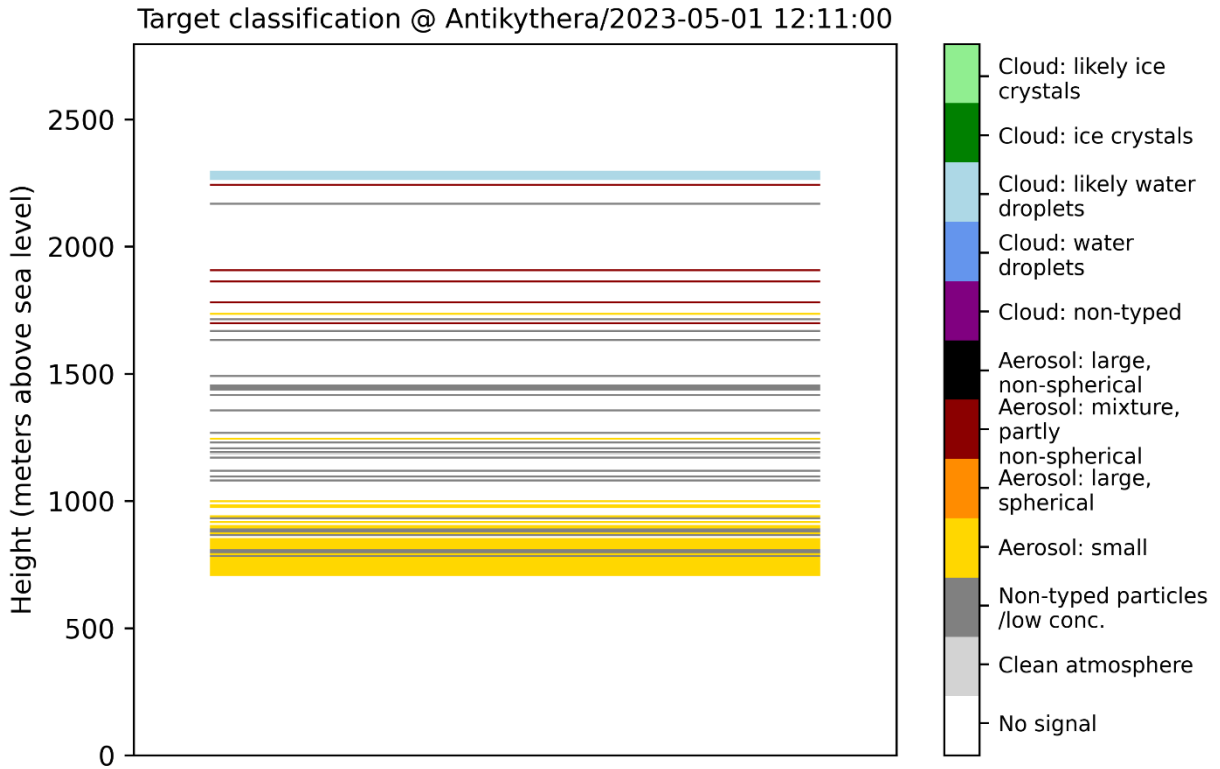


BD3 grid - 2400, 398, CF:1.0, CTH:3142, CH_CRB:2549, ESH:2575, VIIRS_CF:0.47
BD6 grid - 2400, 395, CF:1.0, CTH:3120, CH_CRB:2525, ESH:2551, VIIRS_CF:0.32

01-05-2023, orbit 28745

"Aerosol below cloud layer" ☺

Good agreement for cloudy

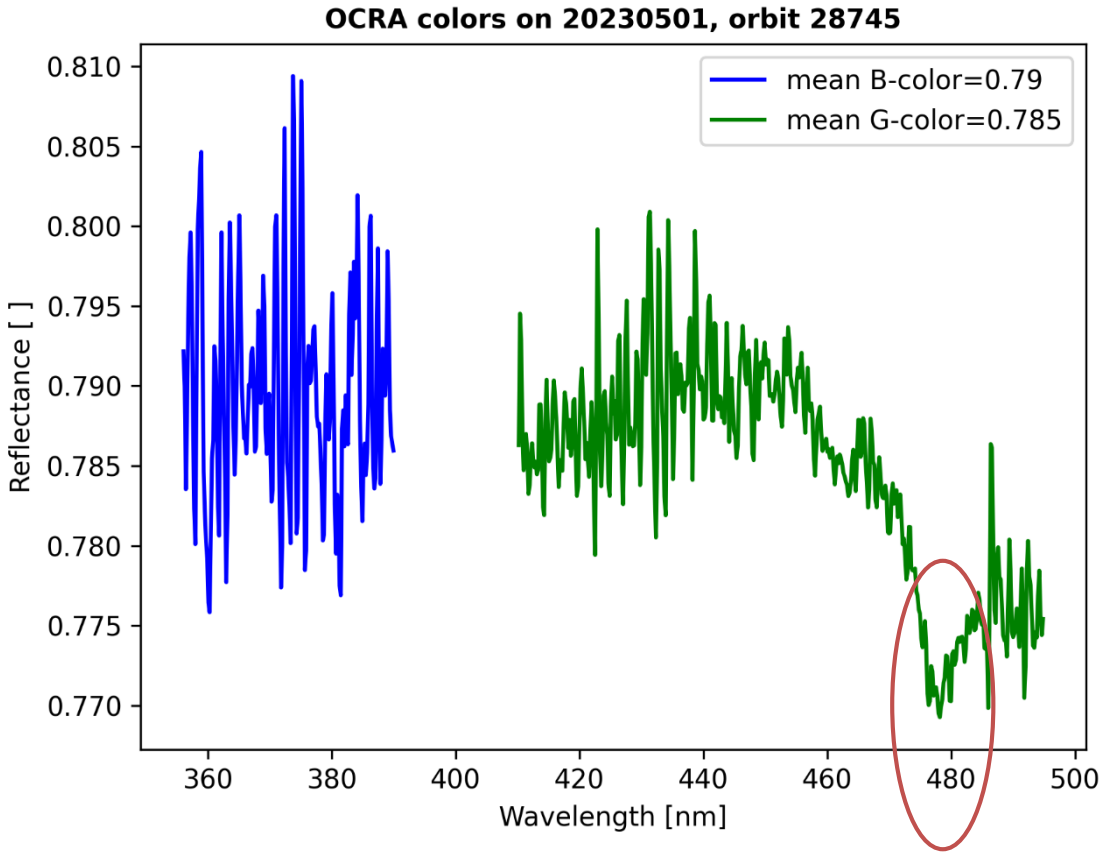


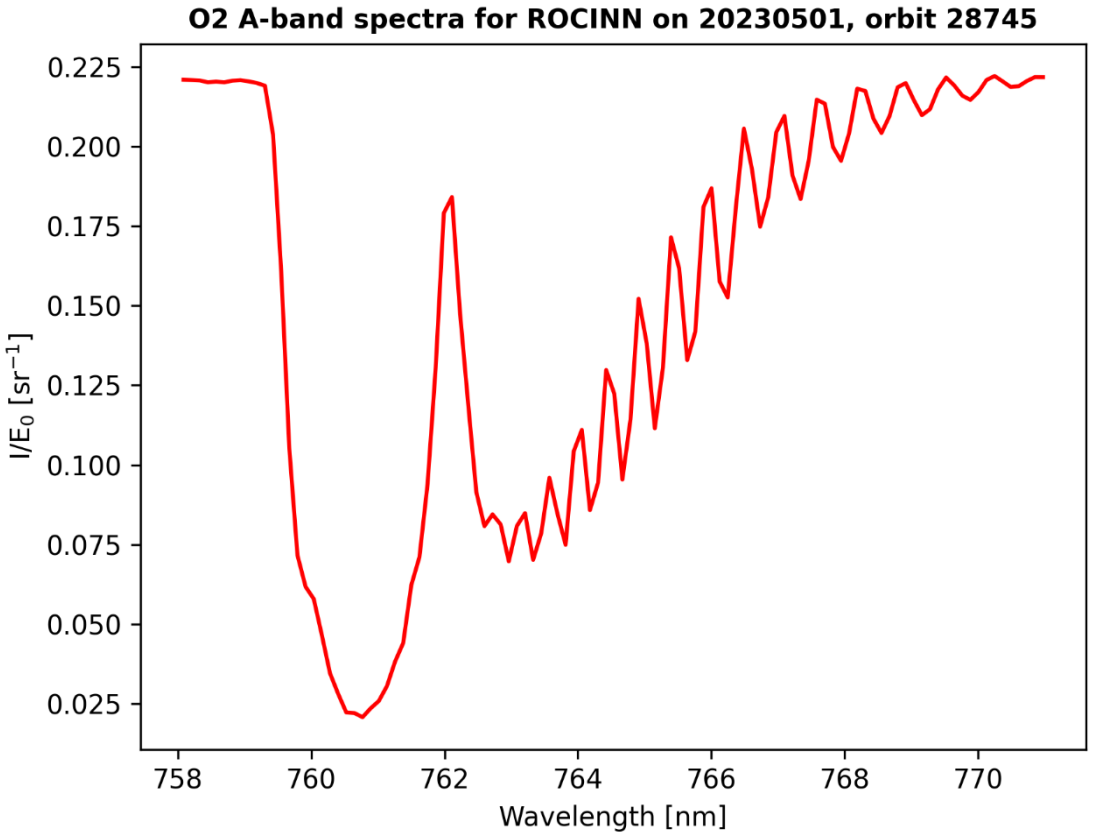
AERONET Version 3: AOD Level 2.0 -- 2023-05-03 04:20:44
AOD@340nm:0.39, AOD@380nm:0.36, AOD@500nm:0.29

Time difference with TROPOMI: 1 day, 16:09:33

DLR

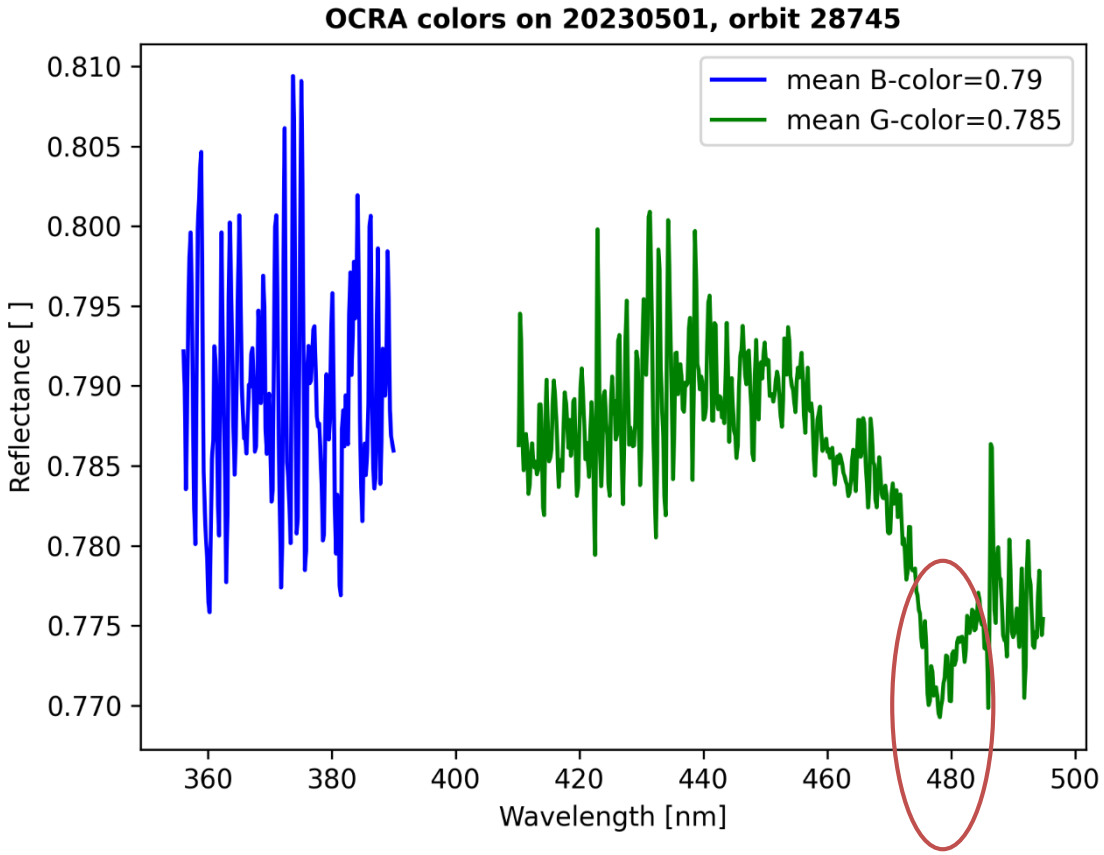
How do the L1b measurements look like?

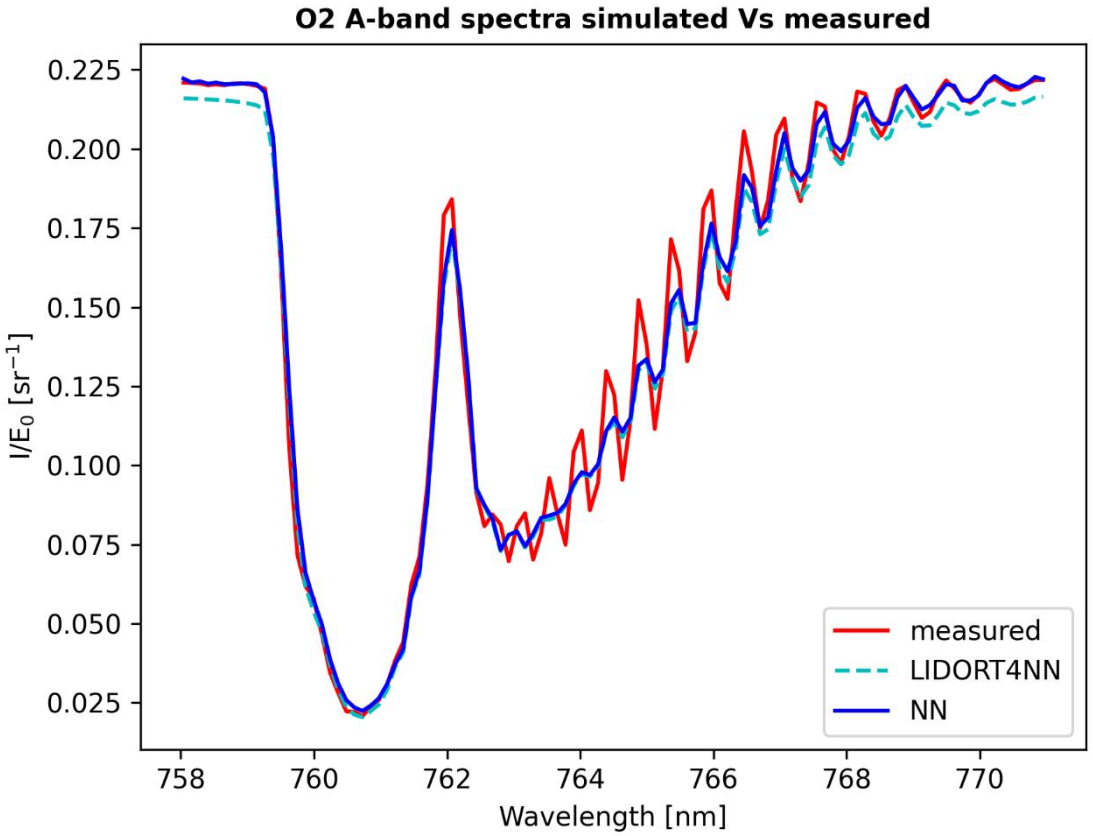




OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm

How do the L1b measurements look like?





OCRA color B -> mean reflectance within the window 356-390 nm
OCRA color G -> mean reflectance within the window 410-495 nm