Aerosol Layer Height from ground based active remote sensing and satellite ALH product of S5P/TROPOMI

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Introduction

The aim of this study is to find a suitable method of validation for the satellite product ALH (Aerosol Layer Height) derived from passive remote sensing observation from S5P/TROPOMI, using ground based ceilometer measurements.

At present, daily global observations of aerosol height are not available on an operational basis. However, passive sensors on board satellites can scan the entire earth in a single day. On 13 October 2017 the Copernicus Sentinel 5 Precursor (S5P), the first of the European Sentinel satellites dedicated to monitoring of atmospheric composition, was launched with a single payload of TROPOspheric Monitoring Instrument (TROPOMI), a nadir viewing shortwave spectrometer that measures in the UV-visible wavelength range (270 – 500 nm), the near infrared (710 – 770 nm) and the shortwave infrared (2314 – 2382 nm). The ALH product is derived from measurements of the oxygen A-band in the near infrared region between 758 nm and 770 nm. It is focused on retrieval of vertically localized aerosol layers in the free troposphere, such as desert dust, biomass burning aerosol, or volcanic ash plumes (Nanda et al., 2020). Pixel size before August 2019 is 7 km x 3.5 km while after is 5.5 km x 3.5 km. Data are available through Copernicus hub (s5phub.copernicus.eu). S5P overpasses daily at around 12 UTC over mid latitude locations. Satellite data were selected based on quality flags of the available Level 2 data.

Active remote sensing techniques (such as ceilometers) can provide vertical profiles of the aerosol attenuated backscatter with vertical resolution of a few meters from ground up to 15 km. They are part of the coordinated European Network **e-profile**: (https://www.eumetnet.eu/activities/observations-programme/current-activities/e-profile/) and provide continuous vertical information for the aerosol load over Europe, but an operational algorithm for aerosol layer height assessment hasn't been implemented at the network level.

First ground based validation of satellite ALH but retrieved from GOME-2/MetOp observations was done using EARLINET lidar observations by Michailidis et al., 2021. They applied wavelet covariance transform to the lidar data in order extract geometrical characteristics (lofted layers and clouds). The method was able to obtain a significant number of collocated and coincident ground and satellite measurements due to long term satellite data based (12 years). S5P is orbiting only since 2017, therefore our study is focused on ceilometer measurements due to their continuous operation, near real time data availability and spread across Europe. Two methods were tested for aerosol layer detection: gradient method (Nicolae et al., 2018), and local minimum/maximum method (Adam et al.2020). The target requirement on the accuracy and precision of retrieved ALH is 0.5 km.

Results and discussion

Preliminary results of about 15 overpass-coincidences of S5P over Magurele, Romania (44.35N, 26.03E) during October 2017- April 2021 showed high variability of altitudes of the layers detected in a 50 km circle above Magurele for some scenes. The ALH retrieval algorithm implements a pixel selection scheme before committing to retrieving ALH satellite's estimates. The number of pixels varies from 10 to 127 for a particular scene.

Similar results were obtained when applying the two abovementioned methods to ceilometer data for aerosol heights, but there is a wide range of feature locations and backscatter intensities that can be encountered during a single day of measurements. Figure 1 is an example: three aerosol layer heights derived from ceilometer measurements in Magurele (blue, yellow, green) during 2 hours before and after the satellite overpass on 30.08.2018. The spatially averaged (in a 50 km circle above Magurele) S5P ALH is represented in black, with the error bar indicating the variability of the values. The question is now how to interpret this scene. Are these layers dust, biomass burning or volcanic ash? Using Hysplit backtrajectories (https://www.arl.noaa.gov/hysplit), dust modelling DREAM BSC (https://ess.bsc.es/bsc-dust-daily-forecast) and FIRMS (https://firms.modaps.eosdis.nasa.gov/) we were not able to specifically determine the source of these layers.

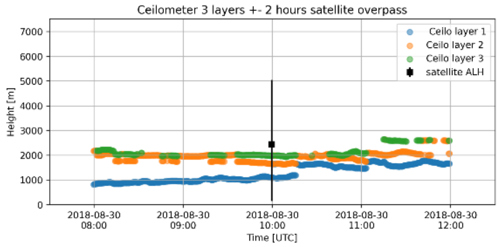

Figure 1. Aerosol layer heights derived from ceilometer measurements in Magurele (blue, yellow, green) during 30.08.2018 and derived from S5P(black)-spatially averaged (in a 50 km circle above Magurele)

On other days with similar scenes, we could identify that some layers were long range transported from Africa (e.g. a layer at 3.8 km on 5.10.2020; layers represented in Figure 2) and we could confirm as a validation case. When there is a well-developed and spatially well-spread aerosol layer then only questions related to how to average the satellite data are taken into account. On 5.10.2020 there were two satellite overpasses represented in Figure 2 in black, with error bars highlighting the variability of the satellite data.
The averaged satellite value for the first overpass it is very close the one derived from ceilometer and confirmed to be long range transported dust. For the second overpass only one pixel got a close value (3838m).

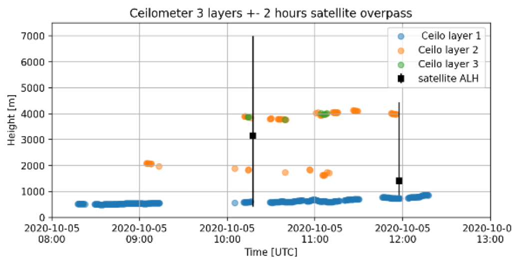

Figure 2. Aerosol layer heights derived from ceilometer measurements in Magurele (blue, yellow, green) during 05.10.2020 and derived from S5P(black)-spatially averaged (in a 50 km circle above Magurele)

The difference between the satellite pixel size and the point view of the ground-based observations is definitely a challenging issue in top of the ones related to different retrieving techniques. Several sensitivity studies have been performed but a lot of questions still remains:

- What is the best way to temporally average the ceilometer information to compare with a satellite overpassing once or twice per day?
- How to better choose which layer to take into consideration for comparison in a complex scene? Can this be done unsupervised by an automated algorithm?
- Can the satellite scene be considered as a proven case of existing layer?

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Challenges

The reported satellite ALH is the height of a single aerosol layer (Dust, Biomass burning or volcanic ash) for the entire atmospheric column within the scene measured by TROPOMI. During our study we have encountered several cases where distinctly separated elevated and boundary layer aerosols are present in the same scene.
Open questions: What could be the best approach in comparing aerosol layer heights from satellite passive remote sensing measurements and the ones from ground based active remote sensing data? Several specific cases will be brought to the community attention during the conference.

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