

# VALIDATION OF NEW SATELLITE AEROSOL OPTICAL DEPTH RETRIEVAL ALGORITHM USING RAMAN LIDAR OBSERVATIONS AT RADIATIVE TRANSFER LABORATORY IN WARSAW

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## ABSTRACT

During an exceptionally warm September of 2016, the unique, stable weather conditions over Poland allowed for an extensive testing of the new algorithm developed to improve the Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infrared Imager (SEVIRI) aerosol optical depth (AOD) retrieval. The development was conducted in the frame of the ESA-ESRIN SAMIRA project. The new AOD algorithm aims at providing the aerosol optical depth maps over the territory of Poland with a high temporal resolution of 15 minutes. It was tested on the data set obtained between 11-16 September 2016, during which a day of relatively clean atmospheric background related to an Arctic air-mass inflow was surrounded by a few days with well increased aerosol load of different origin. On the clean reference day, for estimating surface reflectance the AOD forecast available on-line via the Copernicus Atmosphere Monitoring Service (CAMS) was used. The obtained AOD maps were validated against AODs available within the Poland-AOD and AERONET networks, and with AOD values obtained from the PollyXT-UW lidar of the University of Warsaw (UW).

## 1 INTRODUCTION

Despite considerable improvements in the past decades, Europe is still far from achieving levels of air quality that do not pose unacceptable hazards to humans and the environment. Inhabitants in urban areas still can experience significant health problems due to air pollution. Research on the air pollution issue on regional scale, is presently carried out in the frame of ESA-ESRIN founded project entitled SATEllite based Monitoring Initiative for Regional Air quality

(SAMIRA). The overall goal of the project is to improve regional and local air quality monitoring through synergistic use of data from present and upcoming satellite missions, traditionally used in-situ air quality monitoring networks, and output from chemical transport models.

Through collaborative efforts of Poland, Romania, the Czech Republic, and Norway, countries confronted with different but pressing air quality problems, the SAMIRA aims at both to support national monitoring obligations and to generate novel research in this area. In SAMIRA, the most relevant pollutants are being addressed; NO<sub>2</sub>, SO<sub>2</sub>, particulate matter PM<sub>2.5</sub> and PM<sub>10</sub>, as well as Aerosol Optical Depth (AOD). The latter can be directly retrieved or indirectly estimated from existing satellites sensors. The satellite retrieval of aerosol properties over land is challenging mainly due to the high surface reflectance, its temporal variability, and spatial inhomogeneity, but also due to anisotropic bi-directional reflectance of land surfaces, which induces higher uncertainties of retrieved parameters. For this paper we choose to exploit the geostationary SEVIRI/MSG sensor [1], as for air quality quasi-continuous, high temporal and spatial resolution monitoring is a necessity. The optimal interpolation approach to retrieve AOD from the SEVIRI data, initially developed by [2], was elaborated for the further improvement. A new version of algorithm was developed and tested on the data set collected between 11-16 September 2016. The obtained AOD values were validated against the next generation PollyXT-UW lidar in Warsaw [3,4], as well as by using the AOD data sets available within the Polish aerosol network Poland-AOD (<http://www.polandaod.pl/>) and AERONET (<https://aeronet.gsfc.nasa.gov/>).

## 2 METHODOLOGY

The modified AOD retrieval algorithm is fed with the high temporal and spatial resolution data from SEVIRI channel 1 (635 nm) and it allows for retrieving AOD at a spatial resolution of about 5×5 km at a frequency of 15 min. The most important parameter for the retrieval process is the surface reflectance. The surface properties are estimated during relatively cloud free reference days (cloud cover < 1/8) with a low AOD (< 0.1 at 500 nm), based on the Top-Of-Atmosphere reflectance measured by the SEVIRI detector. Even if the AOD is low, elimination of influence of atmospheric components, in particular atmospheric aerosols, on the reflectance measured by satellite is still essential. By applying the optimal interpolation method [5] and the additional ground based sources of AOD data the uncertainties related to the aerosol background estimation errors can be reduced to improve the AOD retrieval. For more details of the retrieval scheme refer to [2]. The main changes introduced in the new algorithm include following: I) CAMS AOD forecast data [6] are used as an AOD background information for a reference day; II) all Polish ground-based stations with a continuous AOD measurements are implemented in the code; and III) cloud screening process was improved. Favourable conditions in September 2016 allowed for tests and validation of the new version of algorithm.

Observations and calculations for two 2 days: 11<sup>th</sup> and 15<sup>th</sup> September are discussed. On these days, the PollyXT-UW lidar observations were taken at the Radiative Transfer Laboratory (RT-Lab) of the Institute of Geophysics, Faculty of Physics, University of Warsaw (Poland). The RT-Lab site located at central Warsaw (52.21° N 20.98° E, 112 m a.s.l.) joined the EARLINET [7] in March 2015, and is regularly contributing to the network activities. We use the 12-channel NeXT generation Polly XT system equipped with the photon-counting detection channels at 1064, 532, and 355 nm (elastic), 607 and 387 nm (N<sub>2</sub> Raman), 407 nm (H<sub>2</sub>O Raman), 532 and 355 nm (elastic cross). Since April 2016, lidar is equipped additionally with the Near Range Aerosol Lidar receiver (NARLa) at 532 and 355 nm (elastic), 607 and 387 nm (N<sub>2</sub> Raman), which significantly enhances lowermost range of lidar observations.

## 3 RESULTS AND DISCUSSION

On 11<sup>th</sup> September, which was a day with well increased aerosol load captured, the back-trajectories calculated using the HYSPLIT model [8], indicated possible occurrence and even accumulation of local pollution over Warsaw due to heat wave conditions (Fig. 1). Results of the NAAPS model simulations [9] suggest that sulphates were significant part of aerosol load on that day (Fig. 2). On the contrary, 15<sup>th</sup> September was characterized by significantly cleaner conditions, which were related to an Arctic air-mass inflow. Thus, this day was chosen to be used as a reference day for estimating the surface properties. The application of algorithm on SEVIRI data on 11<sup>th</sup> September provided the AOD maps over Poland with a temporal resolution of 15 minutes. An example of such a map is given in Fig. 3. The obtained AOD-SEVIRI values, (pixel regarded as representative for the Warsaw EARLINET site) were validated against the PollyXT-UW lidar. The lidar-derived AOD at 532nm was obtained from the extinction profiles. Additionally, the SEVIRI AOD data at 635nm were compared with the MFR-7 shadow-band radiometer observations of AOD at 614nm, showing generally a sufficient agreement.

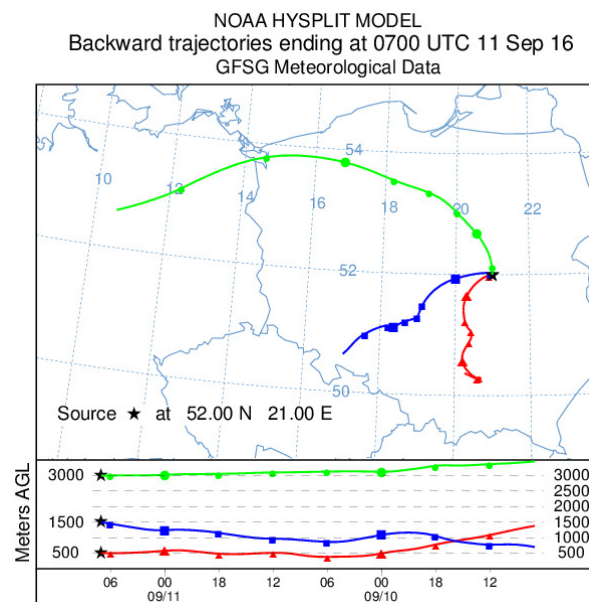


Figure 1 The HYSPLIT back-trajectories obtained for Warsaw at 7:00 UTC for 11<sup>th</sup> September. The model was run for 48 h with meteorological data from the Global Data Assimilation System (GDAS).

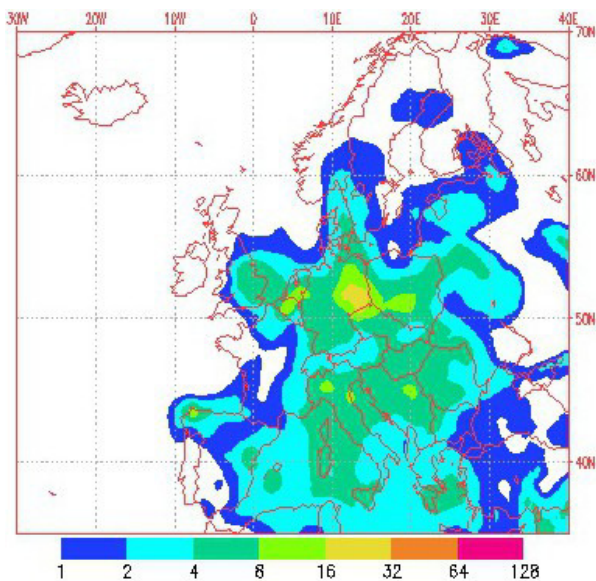


Figure 2 Sulfate surface concentration ( $\mu\text{g}/\text{m}^3$ ) on 11 September 2016, obtained from Navy Aerosol Analysis and Prediction System (NAAPS).

The AOD map (Fig. 3) at 635nm was calculated for data acquired at 7:00 UTC on 11<sup>th</sup> September 2016. Lack of data in northern and western areas of the map are due to the cloud cover. For pixel that covers Warsaw, the AOD SEVIRI for 15 min observations was 0.303. At the same time the AOD measured by the MFR-7 at the RT-Lab in Warsaw equalled 0.391 at 615nm and 0.52 at 500nm. In Figure 4, the daily evaluation of the range and background corrected lidar signal at 1064 nm on 11<sup>th</sup> September 2016 is shown. The aerosol load is visible up to 3 km, signatures of nocturnal and residual layers are pronounced. At 1-2, 12, and 13-14 UTC some clouds are captured.

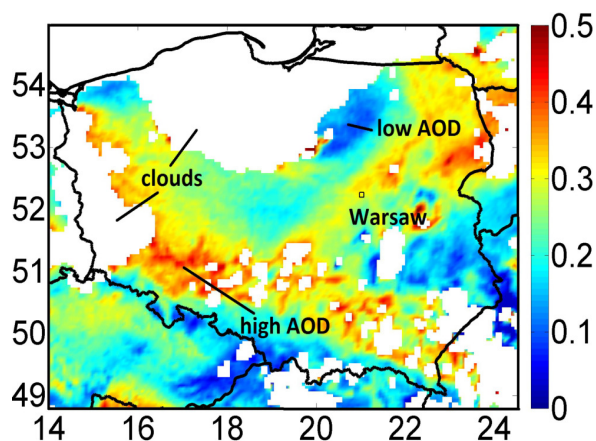


Figure 3 SEVIRI AOD at 635 nm calculated for 15 min at 7:00 UTC on 11 September 2016.

For the data collected at 7:00 UTC, the aerosol extinction and backscatter coefficient profiles at 355nm and 532nm were calculated using the classical Raman approach [10] for the 2h average with 81 points running mean smoothing.

The extinction retrieval was possible down to 400m, as we used the NARLa module. The near- and far-range profiles were calculated separately and combined afterwards. The missing values were interpolated with a constant extinction value at 400m. The maximum value of the particle extinction coefficient at 532 nm of about  $0.9 \text{ km}^{-1}$  was obtained at about 2 km. From the extinction profile the AOD of 0.113, 0.469, 0.545 was obtained by integration up to 1, 2 and 3 km, respectively. The latter value, was used for the comparison with the AOD-SEVIRI map pixel value for Warsaw.

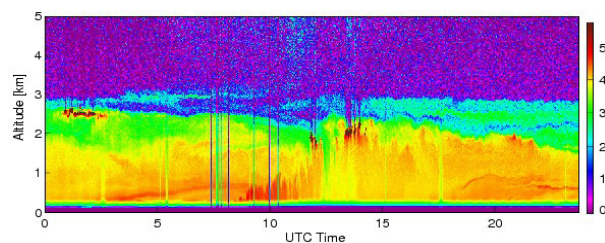


Figure 4 Lidar range corrected signal at 1064 nm on 11 September 2016. Measurements were taken with the PollyXT-UW lidar at the Radiative Transfer Laboratory RT-Lab in Warsaw.

The AOD SEVIRI in Warsaw was lower than the AOD obtained both from lidar and radiometric observations, although we keep in mind that this the data are not directly comparable. First of all, because the difference in the compared ADO-wavelength have to be taken into account. Secondly, because ground-based measurements are representative for a single point, while the SEVIRI data cover area of  $5 \times 5 \text{ km}$ , and thus the AOD is in fact a mean value for the whole pixel.

In the presented cases the obtained SEVIRI AOD was slightly underestimated in comparison to the lidar and radiometric observations. Such underestimation could be caused by an inaccurate estimation of the surface properties during the reference day (15<sup>th</sup> September). Analysis of lidar measurements allows to confirm that indeed this day was not a perfectly clean one (not a typical clean background for Warsaw [11]). Although the maximum value of the lidar particle extinction

coefficient at 532nm was nearly 10 times lower than the maximum value measured on 11<sup>th</sup> September, a closer look at the lidar derived intensive and extensive properties indicates an existence of small particles with Ångström Exponent (532/355) strongly oscillating around 2 within the ground and 2.4 km. This is accompanied with a very low linear polarization ratio of  $0.018 \pm 0.04$  at 532nm, lidar ratio of  $50 \pm 12$  sr at 532nm, and the AOD at 532nm of  $0.328 \pm 0.015$  (obtained from the ground up to 3 km). Thus, we interpret the lidar data set obtained on 15<sup>th</sup> September 2017 as typical for background conditions contaminated with a slight urban anthropogenic origin pollution.

#### 4 CONCLUSIONS

Presented in this paper AOD SEVIRI retrieval algorithm gives opportunity for quasi-continuous measurements providing AOD maps over Poland with high temporary resolution up to 15 min. Regarding the observed AOD differences between various sensors, the valuable information obtained from the lidar allowed for successful validation of the algorithm, as potential areas of problems were identified. Further algorithm adjustments will be undertaken, such as development of an additional procedure for a more appropriate choice of the reference day. The lidar validation of the SEVIRI pixel AOD for Warsaw data will be continued. We will also try to determine any relations of specific weather conditions to aerosol properties [11].

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