Final Report

Instantaneous retrieval of aerosol optical depth from SEVIRI/MSG observations using the i-AERUS-GEO approach

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1. Summary

This Final Report (FR) summarizes the work that was carried out by the Centre National de Recherches Météorologiques from Météo-France in the project entitled “Instantaneous retrieval of aerosol properties from geostationary imagers” (EUM/RSP/SOW/17/963965) from EUMETSAT. The main goal was the retrieval of the instantaneous aerosol optical depth (i-AOD) from observations of the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board of Meteosat Second Generation (MSG). This work follows the research that was initiated in the Federated Activity LSA-SAF_2015-02. Four workpackages were defined in this project.

The first workpackage (WP1) consisted in the development of the first version (v1) of the algorithm i-AERUS-GEO, which derives whenever possible the i-AOD corresponding to each SEVIRI observation. This is achieved thanks to the robust inversion of an accurate radiative transfer-based parameterization of the satellite signal using (i) spatio-temporal constraints and (ii) accurate optical properties to describe the aerosol mixture. The strengths of i-AERUS-GEO combined with the high temporal frequency of SEVIRI allows the estimation of the evolution of the aerosol load along the day (i.e. the diurnal cycle). The i-AERUS-GEO approach is bridged with a modified version of the existing method working at the daily frequency (d-AERUS-GEO; Carrer et al., 2010), which provides the bi-directional reflectance distribution function (BRDF) of the surface. An Algorithm Theoretical Basis Document (ATBD) was written to describe the retrieval algorithm (i-AERUS-GEO/MF/ATBD/1.1).

WP2 focused on the processing of 10 years of SEVIRI data with i-AERUS-GEO. The d-AERUS-GEO approach was also run to provide the daily aerosol load (d-AOD). The data resulting from this exercise were delivered to EUMETSAT.

WP3 consisted in the evaluation of the aerosol load that is retrieved by the AERUS-GEO algorithms over land against ground measurements and other satellite products. Results highlighted the accuracy of the i-AOD retrievals (correlation of 0.79, bias of -0.02, and RMSE of 0.08) and the access to the diurnal cycle under suitable conditions (i.e. frequent clear sky conditions and mild aerosol activity). Less favorable conditions (e.g. intense aerosol activity due to non-continental aerosols and proximity to water bodies) could result in less accurate retrievals. Overall, i-AERUS-GEO gave promising estimates of i-AOD (correlation of 0.66, bias of -0.02, and RMSE of 0.12) if the most robust retrievals were selected thanks to the confidence measure provided by the algorithm. Furthermore, the i-AOD retrievals compared well with the GRASP/POLDER satellite product. Regarding the d-AOD retrievals, slightly better results were found (correlation of 0.69, bias of 0.01, and RMSE of 0.14) thanks to the higher number of observations available for the inversion. This evaluation exercise was described in detail in the Validation Report (i-AERUS-GEO/MF/VR/1.0).

Finally the workpackage WP4 resulted in the present FR, which summarizes the accomplished work and lists the limitations of the v1 of i-AERUS-GEO along with the road map for its further improvement. Furthermore, recommendations are given for the adaptation of i-AERUS-GEO to the Flexible Combined Imager (FCI) on board of the future Meteosat Third Generation - Imager (MTG-I) platform.

2. Introduction

Atmospheric aerosols are of pivotal importance for the study of climate, numerical weather prediction, air quality, hazards, and air transport. Most of studies on aerosols require accurate information describing the temporal and spatial variations of the properties of these particles. One property of major interest is the aerosol load, which is generally expressed through the aerosol optical depth (AOD).

Passive remote sensing from space gives an unique tool to detect, characterize, map, and monitor aerosols at the regional and global scales. The main difficulty to capture the aerosol signal from passive observations (operating in the visible and near-infrared wavelengths) is to perform an accurate separation between the signals from the atmosphere and the surface. The coupling existing between these two contributions can be solved by exploiting the different variations of aerosol and surface properties (e.g. with time, space, wavelength, or geometry). For example, the availability of several observations with different geometries may allow the estimation of the surface BRDF, which in turn may make possible the retrieval of the aerosol load. While this task may be challenging with polar orbiting satellites, it may become possible for geostationary platforms observing a given region of Earth several times along the day with a varying geometry. The existing AERUS-GEO method (Carrer et al., 2010; Carrer et al., 2014) exploits this strength to derive the daily-averaged AOD (d-AOD) and the surface BRDF from the observations acquired by the MSG satellite from EUMETSAT. This is done by inspecting the directional and temporal variations of the satellite signal through the use of a semi-empirical kernel-driven model for the surface/atmosphere coupled system.

The performances of the d-AOD derived by AERUS-GEO were assessed in various studies. For example, Xu et al. (2014) found that AERUS-GEO was as accurate with regard to AERONET measurements as other satellite AOD products (i.e. zero bias and RMSE of 0.2), namely MODIS Dark Target (DT; Remer et al., 2005), MODIS Deep Blue (DB; Hsu et al., 2004), and the MISR product (Diner et al., 2005). The ratio of days with a successful AOD retrieval was however found to be higher for AERUS-GEO with a value of 53% in comparison to MODIS DT (28%), MODIS DB (20%), and MISR (6%). Other studies confirmed the robustness and usefulness of the AERUS-GEO product (e.g. Sic et al., 2015; Nabat et al., 2015; Granados-Muñoz et al., 2016; Escribano et al., 2017; and Flaounas et al., 2017).

The major limitation of the currently available AERUS-GEO aerosol product resides in its daily frequency. The retrieved values of d-AOD do not provide information on the variation of the aerosol load along the day, which may be significant in some cases. For example, the departure of the i-AOD with regard to the d-AOD over the city of Beijing was estimated to be 30% in average by Xu et al., (2016). The diurnal cycle of the aerosol load is indeed of great importance for the study of sudden and rapid aerosol events and for the assimilation of aerosol data into chemical transport models, for example. Contrary to polar orbiting satellites, geostationary platforms may be valid to study the sub-daily variation of the aerosol load thanks to the combination of the high number of observations along the day and the use of an appropriate retrieval method .

3. Development of an algorithm for the instantaneous retrieval of AOD

The retrieval algorithm i-AERUS-GEO was developed to provide when possible an estimate of the i-AOD from each SEVIRI observation corresponding to clear sky conditions. The combination of the high temporal frequency of SEVIRI (i.e. one observation every 15 minutes) and the appropriateness of i-AERUS-GEO makes the aerosol diurnal cycle accessible. The major features of i-AERUS-GEO are:

- An accurate radiative transfer-based parameterization is used to model the SEVIRI observations based on two key elements. First, the Modified Sobolev Approximation (MSA; Katsev et al., 2010) models the aerosol contribution using a truncated phase function. The MSA allows the consideration of any mixture of aerosol particles provided that the corresponding optical properties are known. Second, the directionality of the reflectance of land surfaces is modeled using the Maignan's solution, which includes the scattering happening in backward geometries (i.e. the hot spot). Water surfaces are modeled using a Lambertian model. The resulting coupled model is able to reproduce the variations of the aerosol and surface signals with geometry and wavelength for most of the regions observed by SEVIRI.

- The parameterization detailed above is fed by a set of optical properties describing the extinction by aerosol particles (i.e. asymmetry parameter, single scattering albedo, and phase function). These properties are calculated by the tool MOPSMAP (Modeled Optical Properties of enSeMbles of Aerosol Particles; Gasteiger and Wiegner, 2018). The v1 of i-AERUS-GEO considers a mixture of continental aerosol particles for all the inversions.

- The i-AOD is estimated by using a robust inversion method that minimizes the error between the SEVIRI observations and the reflectance that is modeled by the radiative transfer-based parametrization. The inversion approach further constrains the retrieval by using spatio-temporal super-pixels for which the aerosol load is considered to be homogeneous. The goal of these constraints is to smooth the aerosol solution both in time and in space. Future slots are not considered in this process.

- Each retrieved value of i-AOD is provided with a confidence measure (CM) ranging from 0 (lowest confidence) to 4 (highest confidence). The CM is constructed at the time of the aerosol load retrieval based on the robustness of the inversion and the sensitivity of the SEVIRI observation to the aerosol signal, which is linked to the probability of performing an accurate retrieval.

The algorithm i-AERUS-GEO inherits some scientific and technical basis from the original d-AERUS-GEO algorithm. For example, i-AERUS-GEO is executed in two steps as it is illustrated in Figure 1. The first step carries out the molecular correction of SEVIRI observations in order to compensate for gaseous effects. This correction is done by the atmospheric correction code SMAC (Rahman and Dedieu, 1994), similarly to what is done in the original d-AERUS-GEO algorithm. The second step carries out the retrieval of the i-AOD as it is detailed above. The instantaneous and daily algorithms are bridged together through the use of the surface BRDF estimated by the daily method in order to estimate the instantaneous aerosol load. In particular, i-AERUS-GEO uses the last available estimate of surface BRDF, which is provided by a version of d-AERUS-GEO that was slightly modified to focus on the retrieval of the directionality of the surface reflectance. The bridging of the instantaneous and daily algorithms was proposed before in the Federated Activity LSA-SAF_2015-02 (Carrer et al., 2016).

Figure 1 summarizes the inputs that are used by i-AERUS-GEO including several data coming from SEVIRI (e.g. radiances, angles, land-space-water mask) as well as information on atmospheric composition coming from ECMWF (i.e. gas concentration) and from the SAF-NWC (i.e. cloud mask). Bias-corrected SEVIRI radiances were used to develop i-AERUS-GEO (Meirink et al., 2013), as they were found to provide a more accurate surface BRDF.

The outputs of i-AERUS-GEO include an estimate of the i-AOD for the three first channels of SEVIRI (VIS06, VIS08, and IR016). A confidence measure is also provided to classify the i-AOD retrievals according to their robustness. All output variables are calculated at the native SEVIRI grid and at a 15-minute frequency.

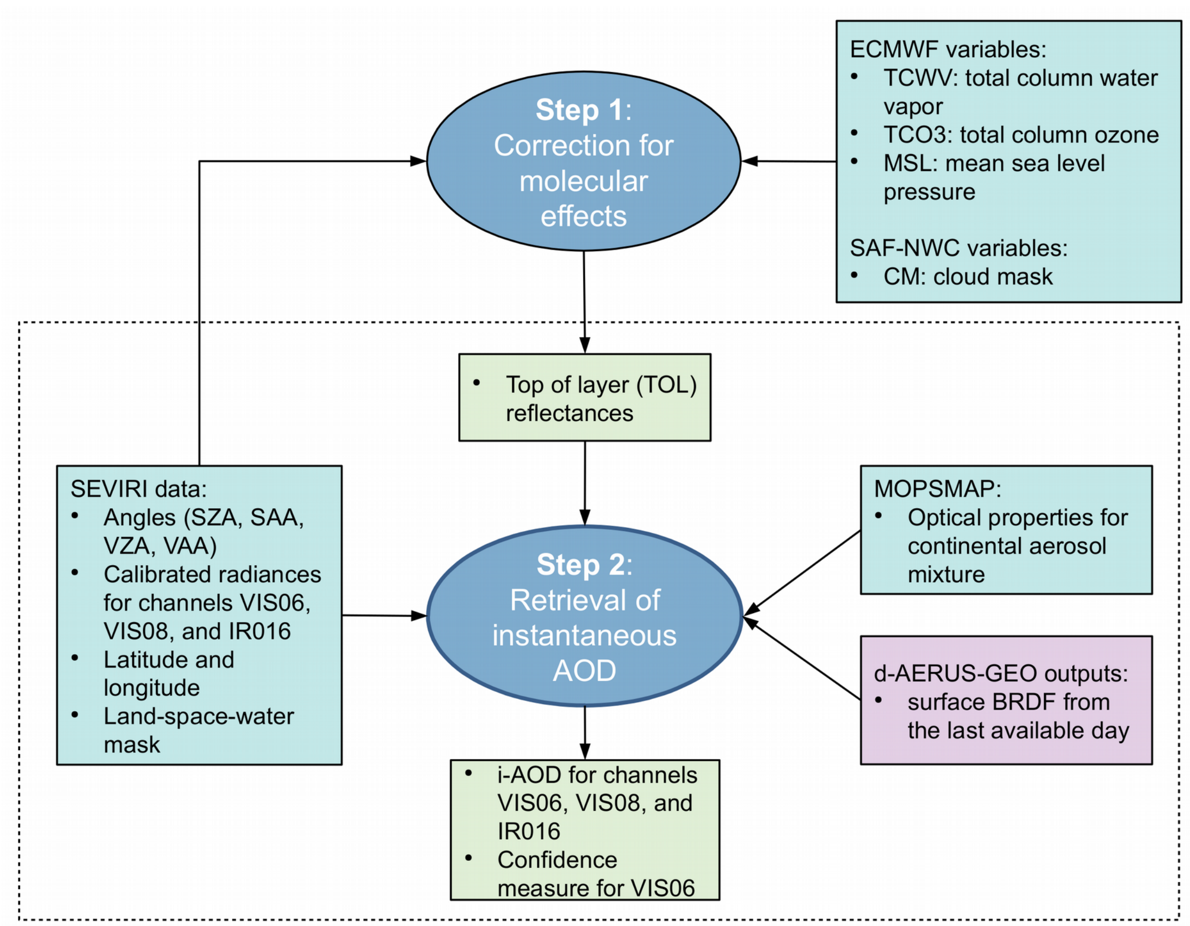

Figure 1 Flow chart summarizing the i-AERUS-GEO algorithm. Step 2 performing the i-AOD retrieval is framed by a dashed box. Input data are represented by pale blue boxes. A purple box is used for the input surface BRDF coming from d-AERUS-GEO. The two processing stages are shown by dark blue ovals. Output variables are represented by green boxes.

4. Processing of a long period of SEVIRI data

The i-AERUS-GEO algorithm was run for the 10-year period from 2007 to 2016. In parallel, the modified version of d-AERUS-GEO was also run to provide the surface BRDF that is necessary to estimate the i-AOD. This daily algorithm was launched at the beginning of 2006 in order to provide an accurate and stable estimate for the beginning of 2007 to be ingested by i-AERUS-GEO.

Furthermore, the original d-AERUS-GEO algorithm was also run on the 10-year data set to provide the d-AOD. The reason to use the original method is that the modified d-AERUS-GEO approach focuses on the retrieval of surface BRDF (and not the d-AOD). In the future an integrated version of the AERUS-GEO algorithm will provide all variables (i-AOD, d-AOD, and surface BRDF).

As it was agreed for this project, the AERUS-GEO algorithms were run only for the locations of the ground stations belonging to the AERONET network. This resulted in the processing of the 3×3 boxes of SEVIRI pixels centered over the coordinates of each AERONET ground station that is encompassed in the MSG disk (see Figure 2). Furthermore, the data processing was focused on the SEVIRI channel VIS06 centered at 635nm, making it the closest channel to the traditional wavelength used for aerosol remote sensing (i.e. 550nm). The information enclosed in the delivered data outputs for channels VIS08 and IR016 was not validated in the evaluation exercise and must be therefore handled with care.

The inputs and outputs resulting from this data processing were delivered to EUMETSAT. More details are found in the W2 report (i-AERUS-GEO/MF/WP2/1.0).

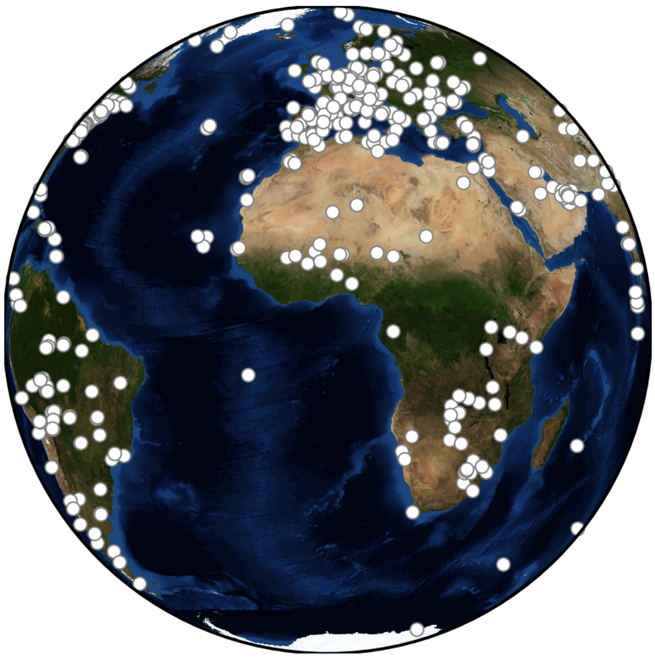

Figure 2 Location of the AERONET stations located in the MSG disk that were considered by the 10-year processing with i-AERUS-GEO and d-AERUS-GEO. Only stations with enough measurements were finally considered in the evaluation exercise.

5. Evaluation against ground measurements and satellite products

The evaluation of the aerosol load retrieved by i-AERUS-GEO was first carried out by the comparison against ground measurements from the AERONET network. Two case studies were defined. First, the assessment was focused on a set of AERONET stations located in the Mediterranean basin during the summer 2012. This case study was defined to assess the performances of i-AERUS-GEO in front of suitable conditions for aerosol remote sensing. Indeed, clear sky observations are numerous in the Mediterranean summer, which is essential to characterize the surface reflectivity needed to estimate the aerosol load. Figure 3(left) shows the density scatter plot comparing the retrievals from i-AERUS-GEO and AERONET. A satisfactory agreement is observed (correlation of 0.79, bias of -0.02, and RMSE of 0.08) with an average of 13 successful retrievals per day and per station, making the diurnal cycle accessible. Figure 3(right) shows the homogeneity of the low RMSE over the region of study.

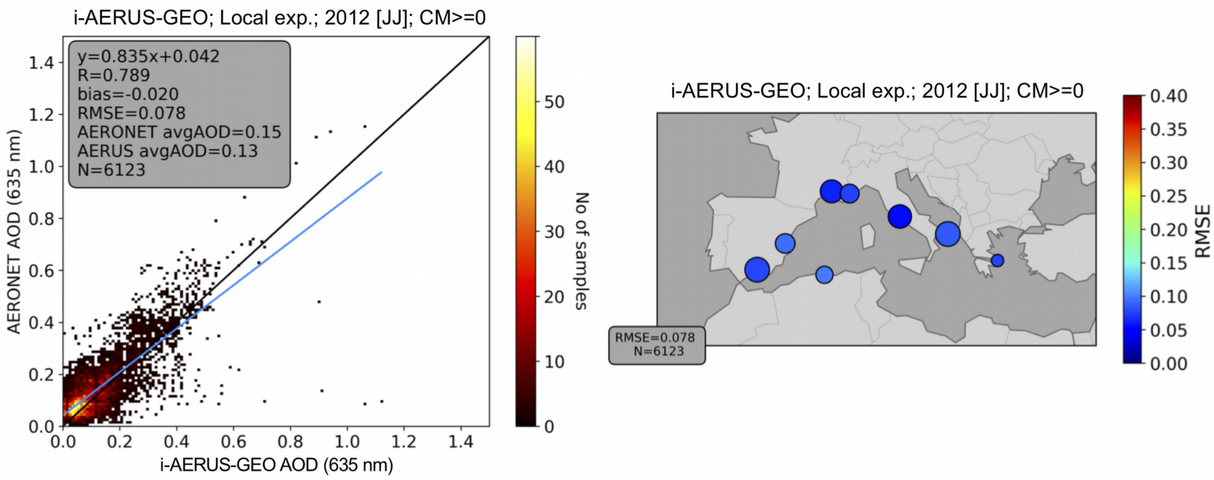

Figure 3 Density scatter plot (left) and map of RMSE (right) comparing two months of i-AERUS-GEO retrievals against measurements of eight AERONET stations.

Second, the evaluation was extended to the 10 years of the processed data and to all the AERONET stations encompassed by the MSG disk. This second case study resulted in the consideration of less convenient conditions for aerosol remote sensing with i-AERUS-GEO. Figure 4(left) confirms the increased difficulty according to the observed slight decrease in the performances (correlation of 0.64, bias of -0.01, and RMSE of 0.16). Figure 4(right) locates the highest errors for stations close to water bodies (i.e. on islands or along coastal areas) and in regions with an intense aerosol activity due to non-continental particles (e.g. dust and biomass burning aerosols). These stations are linked to a limited characterization of the surface reflectivity that results in less accurate aerosol retrievals. However, Figure 4(right) shows low errors (RMSE<0.1) for most of stations in Europe, the Mediterranean basin, South Africa, and a big part of South America. This confirms the validity of i-AERUS-GEO and the considered continental aerosol type in many situations. This second experiment was conducted after discarding the retrievals corresponding to a confidence measure equal to 0 with the goal of filtering the less robust retrievals from the comparison. The improvement of the scores in this case confirmed the usefulness of the CM as an indicator of the accuracy of the retrieved aerosol load (more details in i-AERUS-GEO/MF/VR/1.0).

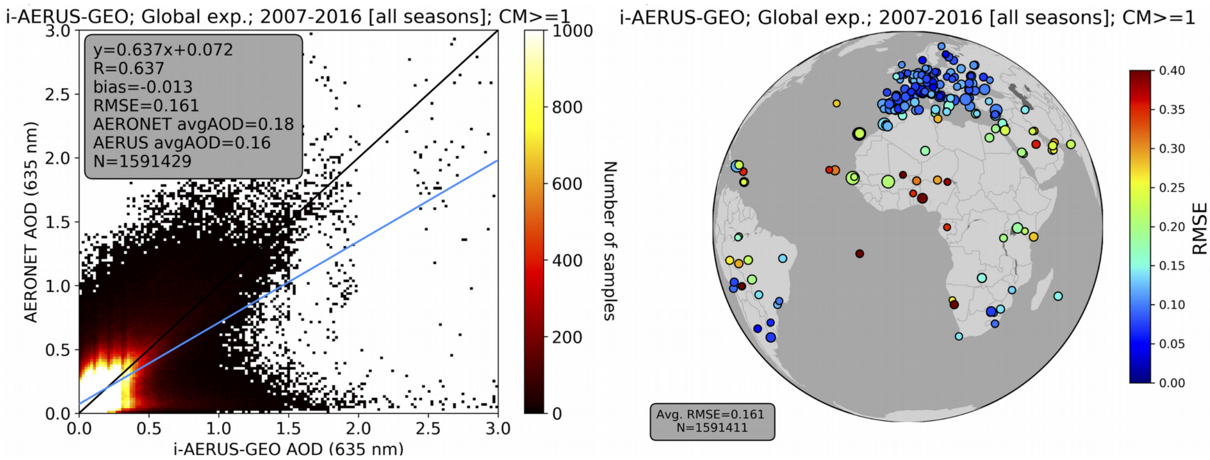

Figure 4 Density scatter plot (left) and map of RMSE (right) comparing 10 years of i-AERUS-GEO retrievals against AERONET measurements. Retrievals with CM=0 were discarded.

Figure 5 shows the temporal evolution of the aerosol load for some selected dates and AERONET stations. Three data sets are shown: the i-AOD retrieved by i-AERUS-GEO in magenta, the i-AOD counterpart measured by AERONET in black, and the d-AOD estimated by d-AERUS-GEO in orange. The times series of i-AERUS-GEO show a good temporal agreement with AERONET at the sub-daily and daily frequencies. Indeed, i-AERUS-GEO captures the diurnal cycle of AOD in numerous occasions and the aerosol events lasting a few days (e.g. July 27th in Avignon, June 20th in Tizi_Ouzou, and June 21st in Izaña). This good tracking of the AOD evolution with time is confirmed by the high correlation obtained for Avignon, Tizi_Ouzou, and Izaña with scores of 0.857, 0.781, and 0.895, respectively. Figure 5 also shows a lower quality of the retrieved diurnal cycle around noon for some stations (e.g. July 24th over Avignon). This limited accuracy comes from a lower sensitivity of SEVIRI to the aerosol signal because of a stronger aerosol-surface coupling. Indeed, both contributions correspond to a low reflectance at the scattering angles made available by SEVIRI around noon for this experiment. Finally, Figure 5 shows the good accuracy of the daily-average aerosol load estimated by d-AERUS-GEO (correlation between 0.77 and 0.91 combined with a low bias and a low RMSE). Gaps in the data (e.g. July 27th in Avignon) come from the non-convergence of the daily algorithm for these dates, thus not allowing the retrieval of the surface BRDF. In this case, i-AERUS-GEO uses the surface BRDF from the previous day.

The performances of the i-AERUS-GEO aerosol retrievals were further evaluated by a comparison against the state-of-the-art satellite product GRASP/POLDER. This experiment was conducted for the year 2012 and all AERONET stations in the MSG disk. Only the best retrievals from i-AERUS-GEO were considered (i.e. CM=4) to be in agreement with the fact that the GRASP/POLDER retrievals that were used in this experiment were quality-assured and post-filtered[1].

1 *The authors acknowledge the use of POLDER data (www.icare.univ-lille1.fr) processed with GRASP software (www.grasp-open.com)*

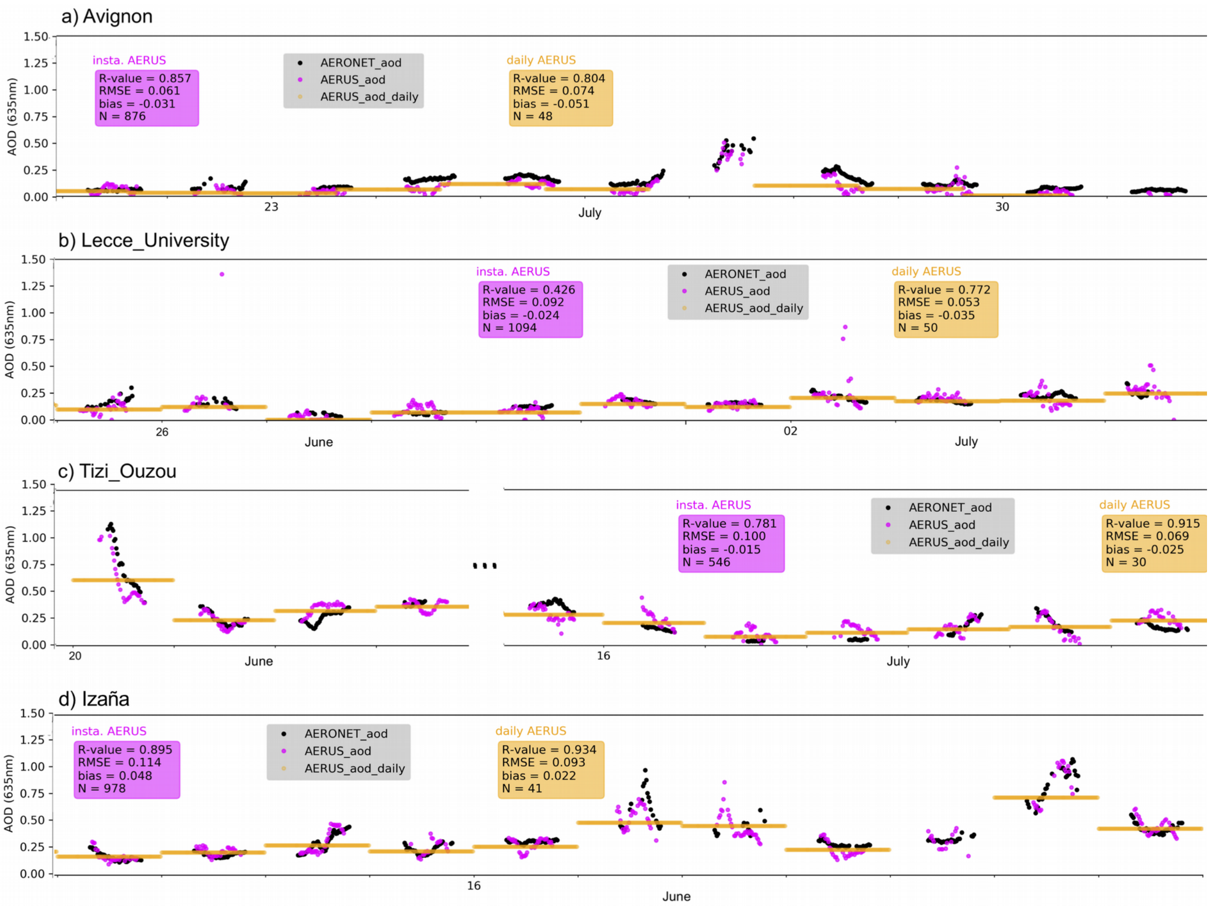

Figure 5 Time series of i-AOD from i-AERUS-GEO and AERONET over (a) Avignon, (b) Lecce_University, (c) Tizi_Ouzou, and (d) Izaña. Values of d-AOD are also shown.

Figure 6 shows the maps of RMSE and correlation corresponding to the comparison of the two satellite aerosol products against the AERONET ground measurements. In this experiment i-AERUS-GEO obtains a lower average RMSE than GRASP/POLDER (0.122 against 0.148). Figure 6(top) shows how the two satellite products obtain low RMSE values over Europe, the Mediterranean basin, a large part of South America, and South Africa. Higher errors are located in Northern Africa and Arabia for both products, which confirms the common challenges for aerosol remote sensing in these regions. In terms of correlation, GRASP/POLDER overcomes i-AERUS-GEO with an average score of 0.851 against 0.658. A satisfactory correlation is observed in Figure 6(bottom) for i-AERUS-GEO for many regions such as Europe, Africa, and some parts of South America. However, the proper tracking of aerosols seems to be more challenging in the borders of the MSG disk probably due to the presence of extreme geometries. It is important to note that the correlation score in the case of i-AERUS-GEO depends on the fidelity of the AOD variations at the daily frequency (as it is also the case for GRASP/POLDER) but also at the sub-daily frequency. Indeed, i-AERUS-GEO is able to provide information on the diurnal cycle thanks to the 50 times more retrievals than GRASP/POLDER, which is mainly limited by the polar orbit of PARASOL. This reduced number of retrievals is especially seen for stations on islands for which the GRASP/POLDER product is often not available. As it was discussed before, these stations close to water bodies correspond to some of the less accurate retrievals from i-AERUS-GEO.

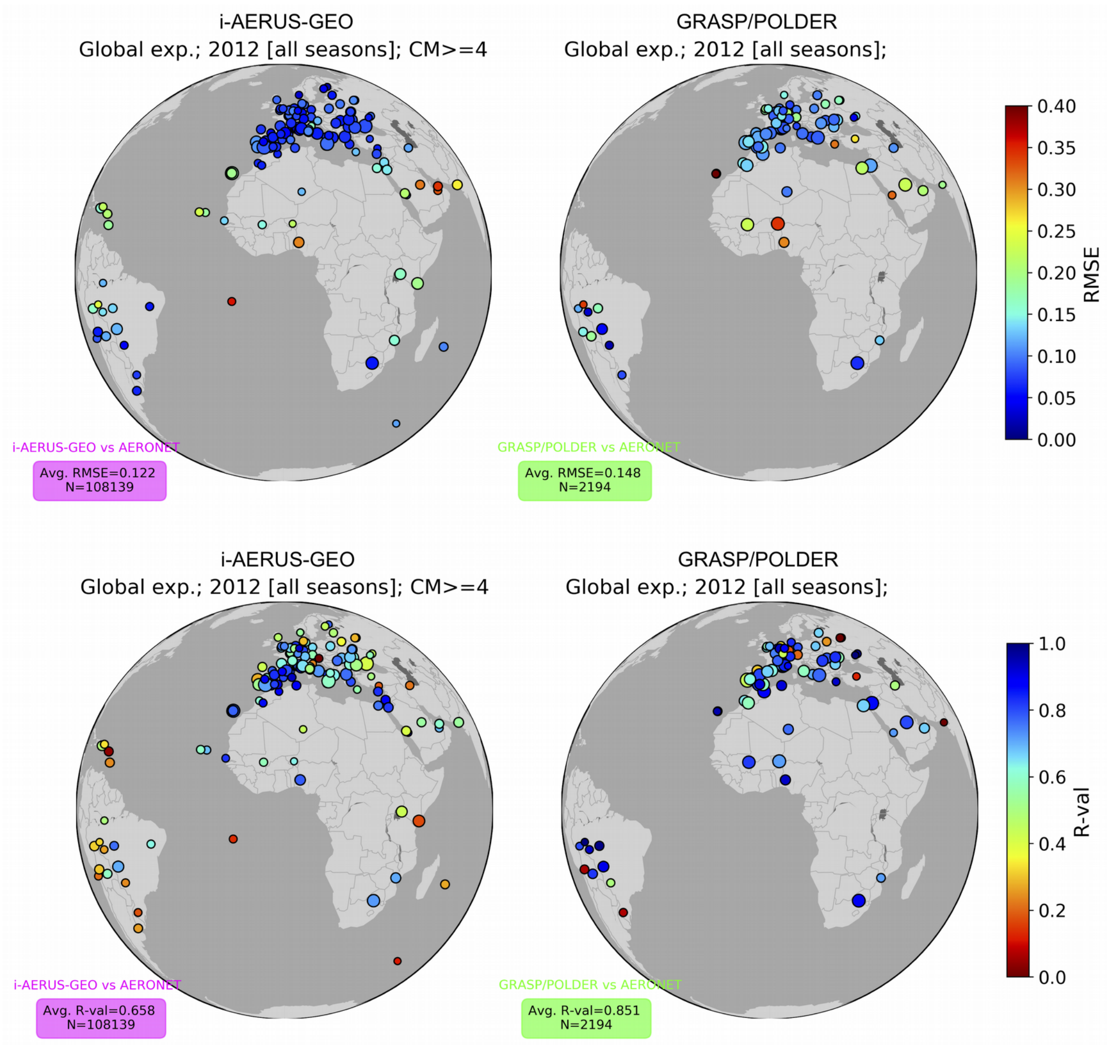

Figure 6 Maps of RMSE (top) and correlation (bottom) for the comparison of i-AERUS-GEO (left) and GRASP/POLDER (right) instantaneous AOD retrievals for 2012.

6. Limitations and future work

The main limitations of i-AERUS-GEO are listed below along with the road map for their improvement in the future versions of the algorithm.

1. **The fixed continental aerosol type.** The use of continental aerosol properties may result in significant bias in terms of the retrieved AOD if another aerosol mixture is present. The less accurate results obtained by i-AERUS-GEO over desert areas may partially come from this assumption. This limitation may be tackled by determining the appropriate aerosol type based on the spectral information provided by SEVIRI. In particular, the distinct spectral signature of each class of aerosol particles along the three channels of SEVIRI (VIS06, VIS08, and IR016) could be exploited for achieving such a goal. It is important to note that i-AERUS-GEO was designed to consider any aerosol type as long as the corresponding optical properties are available.

2. **The BRDF model for sea surfaces.** The Lambertian model that is currently used for the reflectance of water bodies does not reproduce accurately the particular directional properties of water surfaces. This is seen in the less accurate results obtained for stations on islands, for example. This limitation may be tackled by using a suitable BRDF model such as the one in Cox and Munk (1954). The presence of mixed pixels, both over land and water, should also be investigated.

3. **The limited accuracy of the surface BRDF in some cases**. Some situations (e.g. persistent cloudiness, rainfall or continuous high opacity due to aerosols) may result in a less accurate characterization of the surface BRDF. This will in turn decrease the accuracy of the aerosol solution. This limitation may be overcome by improving the retrieval of the surface BRDF by considering additional constraints such as the use of a climatology of surface BRDF.

4. **Retrieval over non-homogeneous regions.** The spatial heterogeneity of the surface may be sometimes wrongly assigned by the retrieval method to the aerosol signal, which is generally more homogeneous. This limitation should be overcome by the spatial smoothing included in i-AERUS-GEO. However, the processing of SEVIRI data corresponding to ground stations only did not allow a complete assessment of the spatial robustness and homogeneity of the retrieved i-AOD. This will be done when full disk SEVIRI images will be processed to produce maps of instantaneous aerosol load. The spatial smoothing will also be implemented in the daily algorithm d-AERUS-GEO.

5. **The presence of snow.** The v1 of i-AERUS-GEO is not designed to work over snow covered regions partially due to the unsuitability of the used surface BRDF model for this kind of surfaces. This limitation could be overcome to some extent by using an appropriate BRDF model. However, the benefits of such an improvement in front of the rapidly changing surface reflectance of this types of surfaces (i.e. snow fall, transformation and melt) should also be investigated.

7. Future adaptation to MTG-I/FCI

The flexibility of the algorithm i-AERUS-GEO may allow its adaptation to the upcoming FCI/MTG-I observations. Some evolutions could be implemented to exploit the better performances of FCI with respect to SEVIRI for a better characterization of the aerosols. The improvements of i-AERUS-GEO applied to FCI may include:

1. **Improved retrieval of the aerosol type.** The higher number of spectral bands of FCI in the visible and the near infrared may allow a better characterization of the aerosol mixture. For example, channels VIS04 and VIS05 should be sensitive to fine aerosol particles, while channel IR022 could be used to detect coarse particles (Aoun, 2016; Descheemaecker et al., 2019). The finer spectral resolution may also allow a better discrimination between similar aerosol types. The retrieval of this kind of information could in turn improve the estimation of the aerosol load. The aerosol type could be determined based on the characteristic spectral features of each aerosol type. The development of such a method could be performed together with the improvement of i-AERUS-GEO applied to SEVIRI data that is described in point 1 of Section 6.

2. **Better constrained inversion.** The increased spatial resolution (1km vs 3km) and temporal frequency (10min vs 15min) of FCI may allow a more robust inversion. This may be possible thanks to the higher number of observations that could form the spatio-temporal super-pixels used in i-AERUS-GEO.

3. **Improved detection of local and rapid aerosol events.** The higher spatial and temporal resolution of FCI may provide estimates of the aerosol load that should be more representative at the fine spatial and temporal scales.[2]

4. **Access to other optical properties.** The wealth of information provided by FCI may allow an improved characterization of the aerosol mixture. For instance, the aerosol content related to the coarse and the fine particles could be retrieved based on the improved spectral performances of FCI.

The adaptation of i-AERUS-GEO may encounter the following challenges:

1. **Limited molecular correction.** The compensation for gaseous effects carried out in the first step of i-AERUS-GEO assumes an absence of coupling between aerosols and gases. This assumption is valid for SEVIRI channels according to Rozanov and Kokhanovsky (2005), who quantified this coupling to be negligible for wavelengths greater than 600nm. However, this assumption will become invalid for FCI channels VIS04 and VIS05. The use of pre-calculated coupling terms could be considered to overcome this limitation.

2. **Absence of data today.** The few synthetic FCI images that are available today may not be enough to develop and test the evolution of i-AERUS-GEO to MTG-I. In this case, observations from the geostationary satellite Himawari could be used, as this satellite shares common features with the future MTG-I.

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2 Points 2 and 3 are not compatible simultaneously. The increase of spatial and temporal resolution can be used for either further constraining the inversion or increasing the resolution of the outputs.

8. Conclusions

The project entitled “Instantaneous retrieval of aerosol properties from geostationary imagers” (EUM/RSP/SOW/17/963965) from EUMETSAT was undertaken from September 2018 to August 2019 with the goal of proving the feasibility of retrieving the aerosol load from every observation acquired by the MSG/SEVIRI platform every 15 minutes. The results obtained by the CNRM from Météo-France during this project confirmed the viability of such a challenge. A retrieval algorithm was developed to perform the instantaneous retrieval of AOD based on the combination of an accurate radiative transfer-based parameterization and a robust inversion with spatio-temporal constraints. This newly developed algorithm, namely i-AERUS-GEO, is an evolution of the original AERUS-GEO algorithm that works at the daily frequency providing estimates of the daily-averaged aerosol load. The instantaneous and the daily algorithms are now bridged together by the use of the surface BRDF estimated by the latter in the instantaneous aerosol retrieval. The new i-AERUS-GEO method was evaluated thanks to the processing of 10 years of SEVIRI observations corresponding to the location of the AERONET stations that are encompassed by the MSG disk. Results confirmed the good performances of i-AERUS-GEO in providing accurate i-AOD retrievals (correlation of 0.79, bias of -0.02, and RMSE of 0.08) when suitable conditions are satisfied (i.e. frequent clear sky conditions and mild aerosol activity). In these situations, the combination of the high repetitivity of SEVIRI and the strengths of i-AERUS-GEO allows it to retrieve the diurnal cycle of the aerosol load, which is a key variable for many climate and weather studies. Some limitations exist today in the current version of i-AERUS-GEO such as the use of a fixed continental aerosol type or the characterization of the BRDF of ocean surfaces with a Lambertian model. These limitations may become important under some conditions (e.g. intense aerosol activity due to non-continental aerosols or proximity to water bodies), which may result in less accurate AOD retrievals. If all conditions are considered, i-AERUS-GEO gives promising estimates of i-AOD (correlation of 0.66, bias of -0.02, and RMSE of 0.12). These scores are obtained if the most robust retrievals are selected thanks to the confidence measure that is provided by the algorithm. In the future, the limitations of the current version of i-AERUS-GEO will be tackled in order to provide a new version of the algorithm that will aim the improvement of the accuracy of the retrieved AOD in all situations. Furthermore, the performances of i-AERUS-GEO on the spatial domain will be evaluated with the goal of providing robust and homogeneous maps of aerosol load. This future work will be carried out using available full disk observations of SEVIRI. Furthermore, the characteristics of the future FCI/MTG-I platform will be already taken into account in the corresponding developments. This will start the preparation of the adaptation of the current i-AERUS-GEO to the new generation of EUMETSAT geostationary satellites. In this regard, the improved spectral resolution and the increased number of bands of FCI could be exploited to perform a more accurate characterization of the aerosol mixture, which in turn should provide better estimations of the aerosol load and the surface BRDF. The next version of i-AERUS-GEO will include all these improvements and may be tested on observations of the geostationary platform Himawari/AHI, which shares many features with the upcoming MTG-I/FCI .

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Appendix A. Glossary

AERONET	Aerosol Robotic Network
AERUS-GEO	Aerosol and surface albedo retrieval using a directional splitting method-application to geostationary data
AOD	Aerosol Optical Depth
ATBD	Algorithm Theoretical Basis Document
BRDF	Bi-directional Reflectance Distribution Function
CNRM	Centre National de Recherches Météorologiques
DB	Deep Blue method
DT	Dark Target method
ECMWF	European Centre for Medium-Range Weather Forecast
EUMETSAT	European Meteorological Satellite Organisation
FCI	Flexible Combined Imager
METEOSAT	Meteorological Satellite
MF	Météo-France
MISR	Multiangle Imaging Spectroradiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MSA	Modified Sobolev Approximation
MSG	Meteosat Second Generation
MTG-I	Meteosat Third Generation – Imager
NWC-SAF	Nowcasting Satellite Application Facility
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SMAC	Simplified Method for Atmospheric Correction