GLOBAEROSOL: A 12 YEAR GLOBAL AEROSOL DATASET FROM EUROPEAN SATELLITE INSTRUMENTS

Gareth E. Thomas[1], Caroline A. Poulsen[2], Richard Siddans[2], Andrew M. Sayer[1], Elisa Carboni[1], Óscar Pérez Navarro[3], Óscar Portela Arjona[3], R. Don Grainger[1], Brian Kerridge[2], and Simon Pinnock[4]

[1]*Atmospheric, Oceanic and Planetary Physics, University of Oxford, Oxford OX1 3PU, United Kingdom*
[2]*Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, United Kingdom*
[3]*GMV, 28760 Madrid, Spain*
[4]*ESA ESRIN, 00044 Frascati (RM), Italy*

ABSTRACT

GlobAEROSOL is an ESA Data User Element project to produce a global aerosol dataset from four separate European satellite radiometers: AATSR and MERIS, plus ATSR-2 (on board ERS-2) and SEVIRI (on the second generation Meteosats). Together these instruments provide a near continuous global dataset spanning 1995 - 2007. Aerosol parameters (optical depth, Angstrom coefficient and aerosol type) are being produced in a consistent format from each individual instrument, as well as in 'merged aerosol products' that combine the results from multiple instruments. Details of the GlobAEROSOL product set are given and results from the on-going validation of these products are presented, as well as an overview of the analysis algorithms.

Key words: DUE; GlobAEROSOL; aerosol.

1. INTRODUCTION

The fourth assessment report from the Intergovernmental Pannel on Climate Change [1] states that aerosols, both through their direct radiative impact and their influence on cloud properties, remain the largest source of uncertainty in our understanding of the climate system. This uncertainty is due to the high temporal and spatial variablity of aerosol properties and loading, combined with the complexity of their interactions with cloud. The requirement for long term, global datasets to aid in quantifying the radiative impact of aerosol is thus clear.

GlobAEROSOL is an ESA Data User Element product to produce a unified, global dataset of aerosol properties derived from European satellite sensors. A common set of aerosol properties is being produced from the Along Track Scanning Radiometer 2 (ATSR-2, on board ERS-2), the Advanced ATSR (AATSR, on board ENVISAT), the MEdium Resolution Imaging Spectrometer (MERIS, also on ENVISAT) and the Spinning Enhanced Visible and InfraRed Imager (SEVIRI, on board the Second Generation Meteosats). Data from each of these sensors is produced on a common 10 km sinusoidal grid and in a common NetCDF file format. Not only will data from each individual sensor be available, but products are also being produced which combine the retrievals from all sensors to provide a 'merged' dataset.

The basic set of products produced for GlobAEROSOL are aerosol optical depth at 550 and 870 nm, the Ångström exponent and an indication of the type of aerosol present. In addition, other parameters (detailed below) are included in the output, depending on the instrument from which the data has been derived. Three broad types of data product are being produced:

- "Orbit files" that contain all the retrieval output from a given sensor for orbit or scene. These files contain all data (including failed retrievals etc.) as well as quality control flags and indications of best aerosol type.
- "Daily files" that contain all the data for a given day, either for a single instrument or a range of instruments. These data have had quality control and speciation applied and where overlap occurs between different instruments, or between different swaths of the same instrument, the data are merged using an optimal estimator.
- "Composite files" these contain averaged fields, on a monthly basis and on a $1 \times 1^{\circ}$ latitude-longitude grid. These files are produced for each individual instrument as well as for the merged product.

Production of the first full year of GlobAEROSOL data has recently been completed. This will now be validated against the AERosol RObotic NETwork (AERONET) of ground based sun photometers and other Earth observation satellite products. Once this has been completed, and quality control and data merging parameters have been finalised, the full twelve year dataset will be produced. The full dataset should be available by mid-2009.

2. RETRIEVAL ALGORITHMS

The standard ESA level 2 product is the source for MERIS aerosol properties [2, 3], while the Oxford-RAL Aerosol and Cloud (ORAC) retrieval [4] scheme is used with the other three instruments. ORAC is an optimal estimation retrieval, which is applicable to visible-near IR instruments and supports the dual-view capability of the (A)ATSR series of instruments. The standard GlobAEROSOL product set consists of:

- Aerosol optical depth at 550 and 870 nm
- The Ångström exponent between these two wavelengths
- An indication of aerosol type

These products do not correspond to the MERIS level 2 product or native ORAC output. In the case of MERIS, the two optical depths are derived from the level 2 optical depth value using the retrieved Ångström exponent. There is no indication of aerosol type in MERIS level 2, thus this is not included in the corresponding GlobAEROSOL products.

In the case of ORAC, the retrieved parameters are the optical depth at 550 nm, the aerosol effective radius and surface albedo. The retrieval uses a set of five aerosol lookup tables based on different aerosol types:

1. Continental clean
2. Maritime clean
3. Desert dust
4. Urban
5. Biomass burning

Types 1–4 are derived from the OPAC database [6], while type 5 is based on the work of Dubovik [7]. The aerosol type which produces the best match to the observed radiances, subject to a priori constraints, defines the aerosol type for a given pixel.

The effective radius of each of these aerosol types is varied by altering the mixing ratios defined in literature. From the raw retrieval output, the optical depth at 870 nm is computed using a lookup table as a function of 550 nm optical depth and effective radius, and then the Ångström exponent is calculated between these two values.

The retrieval of surface reflectance within ORAC is different for the (A)ATSR and SEVIRI instruments. Both retrievals use an a priori surface BRDF based on the MODIS BRDF product over land and a sea-surface reflectance model over the ocean, and use full BRDF description of the surface in their forward modelling. In the case of (A)ATSR retrievals the ratio of the bidirectional reflectances are held at their a priori values, but the surface reflectance is retrieved in all channels. In the case of SEVIRI, which lacks the dual view capability of the (A)ATSR, the surface reflectance is only retrieved at 550 nm, while the ratio of the reflectance at each channel against the 550 nm value is held at the a priori value.

Another key difference between the (A)ATSR and SEVIRI retrievals used in GlobAEROSOL is the masking of cloud. The (A)ATSR retrieval uses the standard ESA cloud flag, including the improved land cloud flag developed by Birks et al. [8]. Post retrieval, any residual cloud is removed by the application of quality control measures to the retrieval output, including the quality of the fit to the measurements, consistency with a priori constraints and whether the retrieval converged at all. In the case of SEVIRI, no prior cloud flagging is done, with all cloud removal being done post retrieval using similar tests to those applied to the (A)ATSR results.

The final feature of the ORAC retrieval used in GlobAEROSOL is its ability to deal with missing values in the input data. Due to bandwidth limitations on the ERS-2 satellite, not all visible channel data is always available over the oceans. In particular, the 550 nm channel is often entirely missing in the forward view, and both 550 and 670 nm channels are in 'narrow swath mode' (where the edges of the swath are missing, resulting in only half the data begin available). ORAC is able to operate with or without these channels in a seamless way, and since aerosol retrieval over the dark ocean is inherently better constrained than over the land, there is no appreciable drop in data quality.

Most of extra data provided by ORAC, as well as the error estimates produced by the optimal estimation retrieval, are included in the relevant GlobAEROSOL products. In particular:

- Error estimates on all quantities quoted above, with the exception of aerosol type
- Aerosol effective radius
- White sky surface albedo at 550 nm

are included where applicable.

Merged GlobAEROSOL products are all presented at the nominal ENVISAT overpass time[1]. Where a pixel in a merged product contains measurements from more than one instrument, or from multiple measurements from the same instrument, a weighted mean is value calculated for the 550 nm and 870 nm optical depths, as well as other common retrieved values. This average takes error estimates (as given by the retrieval in the case of ORAC retrievals, and from estimates derived from validation results in the case of MERIS) for all input data, as well

[1]Except where only ATSR-2 data is available, where the ERS-2 overpass time is used.

as a temporal decorrelation coefficient, which weights against values which are further from the nominal ENVISAT overpass time for the given pixel. The speciation for a merged pixel is set by the instrument which generally gives the most reliable estimate for a given location – all individual products which go into a merged pixel therefore use consistent aerosol properties (with the exception of MERIS, for which no aerosol type information is available). The definition of the temporal decorrelation coefficient, MERIS uncertainty estimates and other merging parameters will be defined during the validation of the first year's test dataset.

3. VALIDATION

At the time of writing, the production of the first year of data, 2004, has just been completed and thus a full validation has yet to be performed. However, some preliminary results are available. A full validation of a one month test dataset was undertaken in 2007, and the results of this are available from the GlobAEROSOL website [5]:
`http://www.globaerosol.info`

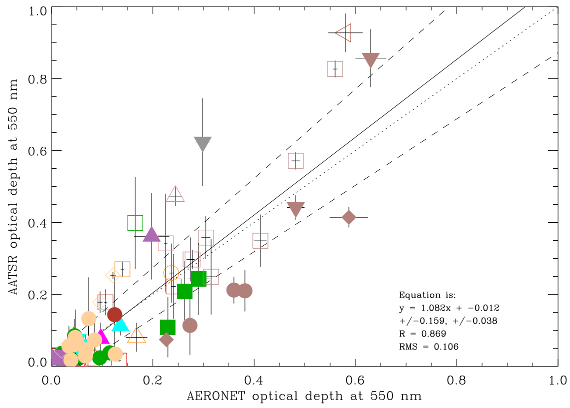
The primary source for validation data for aerosol datasets derived from satellite is the AERONET, which consists of a worldwide network of automated, standard sun photometers. Such measurements are the most direct way of determining the column aerosol optical depth and the common analysis and quality control of the AERONET database makes it a powerful validation tool. GlobAEROSOL data has been compared to a subset of station from the AERONET network, with only stations that are known to be both reliable and representative of their local region being used.

Fig. 1 shows a comparison between AATSR optical depth data, which has had preliminary quality control and speciation applied, and AERONET data for 2004. The two datasets show a high degree of correlation and a low RMS difference, especially at 550 nm. The bias seen in the 870 nm results can be attributed to errors in the spectral optical properties of the aerosol models used, as this value is derived from the 550 nm value, based on the retrieved effective radius and assumed aerosol properties. The relatively low number of matches is indicative of the high proportion of pixels that are affected by cloud in a dual-view instrument, along with overall poorer coverage of AATSR due the narrow swath width of the instrument.

Similar results for the MERIS results available at the time of writing (approximately 7 months: January – August 2004) are shown in Fig. 2. Again there is a high correlation between the two datasets, although it is lower than between AATSR and AERONET. Here there is little difference in the quality of fit at the two wavelengths, but the presence of points where MERIS has a strong positive bias suggest that cloud contamination is a problem.

Although, at the time of writing, data from SEVIRI has also been produced for 2004, it has yet to be speciated and

(a)



(b)

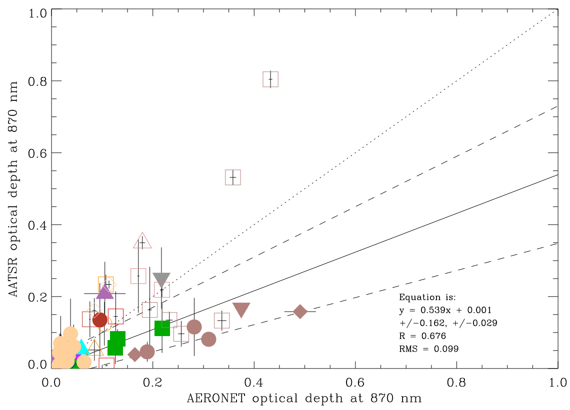


Figure 1. AATSR (a) 550 nm and (b) 870 nm optical depth versus AERONET for 2004. Error bars indicate the variability of the satellite data within 20 km of the site, and AERONET data within 30 minutes of the satellite overpass. The weighted least absolute deviation linear fit is shown with the solid line (with the equation noted at the bottom right of the figure). The 1σ uncertainty on this line is shown by the two dashed lines and the one-to-one line is shown by the dotted line. Each AERONET station has a unique symbol in the plot.

(a)

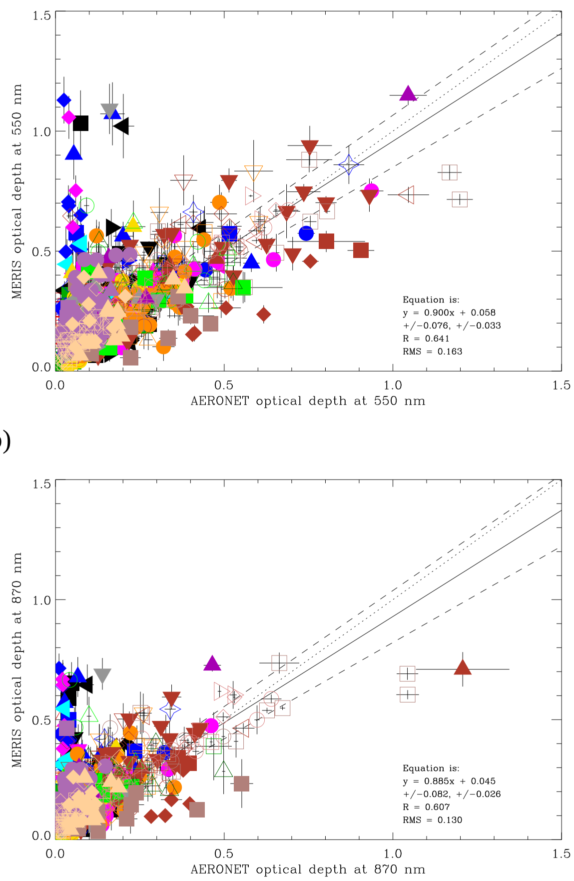


Figure 2. Similar to Fig. 1, but showing MERIS data for January to August 2004.

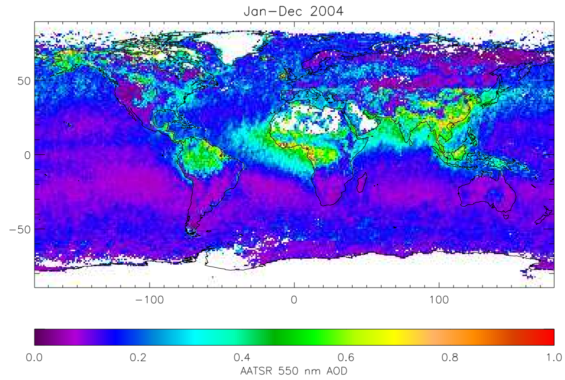


Figure 3. Mean aerosol optical depth for 2004, derived from AATSR. The data has been averaged onto a $1 \times 1^{\circ}$ *latitude-longitude grid.*

quality controls are not well optimised, so no quantitative AERONET comparison has yet to be done. Results from the test products produced in 2007 showed the retrieval to produce correlations with AERONET with values between those seen from AATSR and MERIS. SEVIRI also showed slightly higher correlations at 870 nm than at 550 nm, probably due to the fact that, although optical depth is retrieved at 550 nm, the instrument does not have a channel at this wavelength.

4. EXAMPLE PRODUCTS

Fig. 3 shows the mean 550 nm optical depth global mean for 2004 from the AATSR GlobAEROSOL product. The equivalent MERIS global mean is given in Fig. 4 (data from January – August 2004), while the SEVIRI result is shown in Fig. 5 (data from March – December).

It should be remembered that these plots are very preliminary: the quality control and speciation applied to the products has yet to be finalised, particularly in the case of SEVIRI. Despite this, the results are very encouraging. The distribution of optical depth is very much as expected for all three instruments and the magnitudes are reasonable. Although these figures are not strictly comparable, since they each cover differing time periods, there are certain observations that can be made from these figures. SEVIRI and AATSR show the greatest agreement, with very similar magnitudes and patterns of optical depth. SEVIRI has slightly higher optical depths over the ocean, but this could be due solely to the limitations of the speciation applied to the SEVIRI data.

MERIS shows the largest differences to the other two products. On average, the optical depth shows a significant positive over both land and sea, although the patterns of optical depth show good correspondence. As with the comparison with AERONET, the high bias is suggestive of cloud contamination in the MERIS product, but no firm conclusion can be drawn without further investiga-

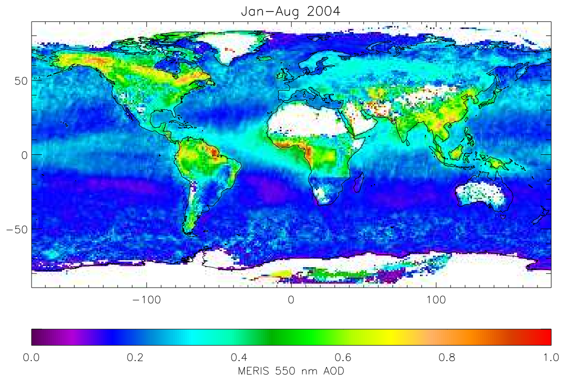


Figure 4. Mean aerosol optical depth for 2004, derived from MERIS. The data has been averaged onto a $1 \times 1°$ latitude-longitude grid.

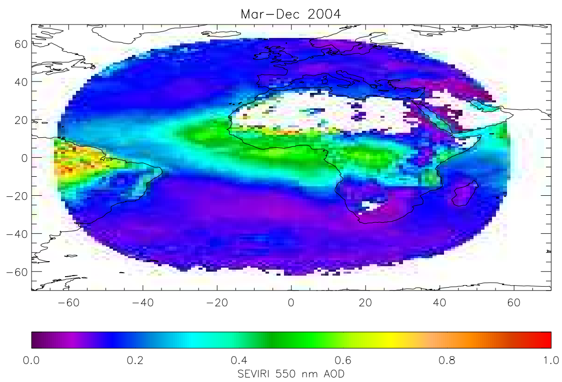


Figure 5. Mean aerosol optical depth for 2004, derived from SEVIRI. The data has been averaged onto a $1 \times 1°$ latitude-longitude grid.

tion. Another feature of the MERIS optical depth field is that regions of high optical depth over the ocean, the values tend to be lower than those seen in the AATSR and SEVIRI results: this is due to the fact that the MERIS algorithm does not allow the retrieval of optical depths higher than 0.5.

All three annual means also show a small number of artefacts and problematic regions within the data. Linear discontinuities in the AATSR and SEVIRI data (along the $45°$ latitude line in Fig. 3 and the $-15°$ latitude line in Fig. 5) can be attributed to the speciation applied to these products. There also some anomalously high pixels in the products, such as over Ireland in Fig. 3, which are could indicate regions where the cloud flagging is failing.

Overall, Figs. 3–5, indicate that even at this preliminary stage of data production, the quality of the GlobAEROSOL dataset is showing the high quality indicated by the preliminary validation carried out in 2007.

5. SUMMARY AND CONCLUSIONS

GlobAEROSOL data production is underway, with one full year processed. Once quality control and aerosol speciation settings have been finalised and a full validation of this year of data has been performed, the complete dataset will be produced, becoming available in mid-2009. This will provide a twelve year, fully validated, global aerosol dataset from four separate sensors.

The main remaining task remaining to the GlobAEROSOL consortium and and the scientific community as a whole is to utilise this dataset. The GlobAEROSOL dataset has some unique features which make it well suited to addressing some key questions. The excellent radiometric calibration and stability of the (A)ATSR sensors and the long dataset they provide makes them, and the GlobAEROSOL based on them, ideal for the study of long term trends. At the other end of the temporal, scale, the dense coverage and multiple daily measurements made by SEVIRI make it ideal for examining aerosol transport over and around the Atlantic basin.

The measurement of tropospheric aerosol from space is a fundamentally under constrained problem which requires many assumptions to be made about aerosol properties, the atmospheric state in general and the underlying surface. This leads to the situation where no one instrument or algorithm can meet all needs and only with a range of products can the strengths and weaknesses of each individual one be understood. On this basis alone, the addition of GlobAEROSOL to the pantheon of global aerosol datasets is an important step in improving our understanding of the role played by aerosols in the climate system.

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