THREE YEARS OF ENVISAT SYNERGETIC AEROSOL RETRIEVAL

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ABSTRACT

At DLR-DFD a synergetic aerosol retrieval method SYNAER [1, 2] was developed, which exploits the complementary information content of the radiometer AATSR and the spectrometer SCIAMACHY, both onboard ENVISAT. This combination of two instruments allows to retrieve aerosol optical depth at 550 nm and aerosol speciation from a choice of pre-defined aerosol types. In the meantime, 3 years of ENVISAT AATSR and SCIAMACHY level 1 nadir data have been acquired (2003-2005). Processing of these data over the MSG field of view (Europe, Africa, Atlantic) has been started within the ESA GSE project PROMOTE, where SYNAER contributes to the air quality monitoring service. SYNAER products are provided daily in near-real time since June 2005 as input for data assimilation into chemistry transport models, and as long-term evolving archive.

It is the goal of this paper to summarize the current status and results of this monitoring effort. The presented results range from examples of individual daily datasets to monthly mean maps. Whereas the daily datasets exhibit large data gaps due to the san patterns of the synergetic sensor pair (SCIAMACHY nadir limb switching, AATSR swath width) and cloudiness, the monthly mean datasets provide reduced temporal resolution, which is not sufficient for near-real time purposes. The mid-term perspective for the SYNAER products promises a long-term dataset ranging from 1995 with ERS-2 (ATSR-2 and GOME) to 2020 with METOP (AVHRR and GOME-2), as the algorithm development was always focused on applicability to all these 3 platforms (thus not using special features as e.g. SCIAMCHY mid infrared channels or ATSR dual view).

1. INTRODUCTION

Air pollution by solid and liquid particles suspended in the air, so-called aerosols is one of the major concerns in many countries on the globe. One focus of concern is related to aerosols from anthropogenic origin mainly by combustion processes (industry, vehicle transport, heating, biomass burning). In developed countries improved combustion and filtering methods have led to a general decrease of particle concentrations in total suspended matter but new concern arises from potential health impact of increasing numbers of smaller aerosols, so-called nano-particles in particular from diesel engines ([3]). [4] reports that 21 – 38 % of total excess deaths in the UK during the summer heatwave of 2003 are attributable to elevated ozone and particle concentrations. On the other hand developing countries suffer still from high total particle loads in the air. Furthermore, natural aerosols (mainly dust and sea salt) also contribute significantly to background and episodically severely increased particle concentrations. Dust can also act as carrier for long-range transport of diseases, e.g. from the Sahara to the Caribics or Western Europe ([5]), or even once around the globe ([6], as Chinese yellow sand was detected as far as the Swiss Alps. Also well known in principle are direct (by reflecting light back to space) and indirect (by acting as cloud condensation nuclei) climate effects of aerosols, although large uncertainties exist in the exact values of the forcing. Kaufman, et al. [7] point out, that the absorption behaviour of particles (mainly soot and minerals) needs to be known to assess their total climate effect (strongly absorbing particles can regionally reverse the sign of the aerosol forcing from cooling to heating).

In the light of this overall picture, climate monitoring, long-term air pollution monitoring as well as short term forecast of pollution levels need to take into account intercontinental transport processes and the composition of the atmospheric particle load. Satellite observations of the total aerosol mass have experienced significant improvements in the last few years thanks to improved instrumentation and enhanced retrieval algorithms. Thus they offer the potential to regularly monitor the global aerosol distribution and by assimilating these measurements into chemistry-transport-models to enhance particle forecasts especially for episodic severe pollution events. Furthermore, satellite data can contribute to deduce background and long-range transport patterns of aerosols. And finally, with the emerging capacity to separate

the total aerosol mass observed with optical observations into major components, a better understanding of the behaviour of different chemical and size classes is supported. Examples of a satellite-based data set of optical depth of major aerosol components over Europe / Africa are presented here which underline the potential of the synergetic aerosol retrieval.

After this brief introduction, the retrieval method as well as the status of its validation against AERONET spectral sun photometer measurements and other satellite observations are described in section 2. Section 3 describes the examples of the application of the synergetic method to data from 3 years of ENVISAT measurements. Sections 4 to 6 contain the summary, acknowledgements and references.

2. RETRIEVAL METHOD: OVERVIEW AND ITS VALIDATION STATUS

At the German Remote Sensing Data Center (DFD) the new aerosol retrieval method SYNAER (SYNergetic AErosol Retrieval) was developed ([1]) which delivers boundary layer aerosol optical depth (AOD) and type over both land and ocean. The type is given as percentage contribution of representative components from the OPAC (Optical Parameters of Aerosols and Clouds, [8]) dataset to AOD in the boundary layer. The high spatial resolution of the AATSR instrument (Advanced Along Track Scanning Radiometer) permits accurate cloud detection, AOD calculation over automatically selected and characterized dark pixels and surface albedo correction for a set of 40 different pre-defined boundary layer aerosol mixtures. After spatial integration to the larger pixels of the spectrometer SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY) these parameters are used to simulate SCIAMACHY spectra for the same set of different aerosol mixtures. A least square fit of these spectra to the measured spectrum delivers the correct AOD value and - if a uniqueness test is passed - the aerosol mixture. For humidity dependent components two models with 50% and 80% relative humidity have been included. Improvements in the definition of the aerosol model are described in [9]. SYNAER has been implemented for operational processing at the German Remote Sensing Data Center within the ESA GSE PROMOTE (Protocol Monitoring for the GMES Service Element; see also http://www.gse-promote.org) and delivers daily near-real time observations (within the same day) and an evolving archive of historic data.

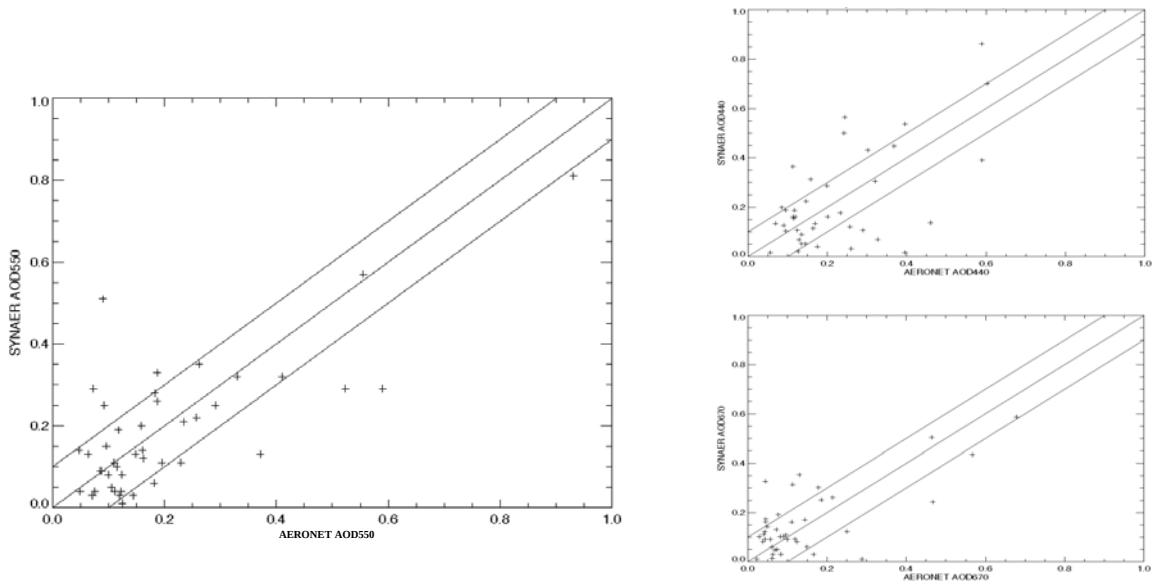

Fig. 1: SYNAER validation of data in the period 06 – 09 / 2005: The inter-comparison to AERONET sun photometer observations is shown for 43 pixels with the station inside the SYNAER pixel, a maximum time difference of one hour and a retrieved surface albedo at 670 nm lower than 0.15. The left image gives the inter-comparison at 550 nm; the right images show the validation at 440 (upper panel) and 670 nm (lower panel).

Accurate cloud detection is an important prerequisite for each aerosol retrieval. The well established APOLLO (AVHRR Processing Scheme Over CLoud Land and Ocean; [10]) software was adapted to AATSR data. The

capability of retrieving cloud cover in boxes of 1 km^2 means a significant strength of SYNAER because it reduces the erroneous aerosol detection due to the presence of sub pixel clouds significantly. It even allows the correction of partly cloudy SCIAMACHY pixels. However, a possible miss-interpretation of high AOD values in desert dust outbreaks over the ocean is still under investigation. First inter-comparisons of SYNAER-ENVISAT results to ground based sun-photometer measurements of the spectral aerosol optical depth from NASA's Aerosol Robotic Network (AERONET) at 43 locations with dark surface albedo (below 0.15 at 670nm) show a good agreement with bias values of about 0.02 and standard deviations of 0.18 (0.15, 0.14) at 550 (440, 670) nm as shown in fig. 1. This indicates to a correct assessment of the amount and type (namely the spectral dependence of extinction) of aerosol. This ground-based validation comprised data from Europe and Africa in several climate zones distributed over 3 months in the summer season of 2005 (see also http://wdc.dlr.de/data_and_products/aerosols/ENVISAT). A similar case study validation with 15 data pairs of AERONET and the predecessor satellite instruments ATSR-2/GOME onboard ERS-2 showed a similar agreement ([2]). Furthermore, a comparison of monthly mean results from SYNAER and other satellite aerosol retrievals as well as AERONET stations over ocean ([11]) showed a satisfactory agreement with the other datasets for a number of cases.

However, the currently ongoing validation exploiting the larger dataset becoming available also shows significant numbers of pixels with larger deviations, especially if pixels over brighter surfaces are included. The reasons behind this are under investigation. This will either lead to a more stringent quality/ambiguity test to refuse certain pixels or to corrections in the retrieval method for specific conditions. Another aspect, which needs further investigation, is the treatment of scaling effects in aerosol variability. Since typical horizontal variations of atmospheric aerosols (~10km or even less near densely populated areas) are smaller than the SYNAER pixel size of 60x30 km^2, the representativeness of each ground-based observation for the coincident SYNAER pixel must be thoroughly checked. Finally, the ambiguity test and quality control criteria need to be assessed with the now available larger data amount.

3. DATASET AND EXAMPLES

From the now available three years and four months of contemporary SCIAMACHY and AATSR data (January 2003 – April 2006) a subset has been processed with SYNAER. Since the SYNAER processor started routine operations in June 2005, daily aerosol products have been produced since then (but with gaps due to input failure or processing "childhood" errors) – the continuing processing leads to a further evolving data set. Additionally, reprocessing has been conducted with data of the months March and April as well as July to November 2003, and March / April 2004. This large data set will now be used for statistically significant validation and assessment of seasonal and geographical distribution of bias and noise in the SYNAER results. Furthermore, the limitations (as given in tab. 1 with preliminary threshold values) of the SYNAER method will be further investigated and quantified.

Tab. 1: limitation factors for SYNAER application

Limitation factor	Limiting effect	Preliminary threshold
surface albedo (670 nm)	Total aerosol and type sensitivity decreases with increasing brightness	below 0.15 for SCIAMACHY pixel below 0.08 for AATSR dark fields
Cloud fraction	Total aerosol and type sensitivity decreases with increasing cloudiness	below 0.35
Aerosol optical depth (550 nm)	Type retrieval becomes ambiguous for low aerosol loading	above 0.1
Solar zenith	Neglected non-spherical atmosphere leads to increasing AOD error	below 75°

As can be seen in the examples of daily SYNAER observations with ENVISAT in fig. 2, these limitation factors lead to a significant reduction of the data coverage. The instrument scan patterns (alternating nadir – limb pattern of SCIAMACHY; swath width limit of 512 km of AATSR) themselves lead to a revisit period over one location of about 12 days. Cloudiness, bright surface (deserts, snow cover) and low sun cause a further reduction of available observations especially in semi-arid regions and in winter times. The quicklooks in fig. 2 as they are available on the SYNAER website show the typical coverage and resolution with 2 – 3 orbits per day over Europe. As one feature in this example, elevated aerosol optical depth over the Iberian peninsula can be seen, which is mainly due to increased water-soluble and soot aerosols, as is the case for wildfires.

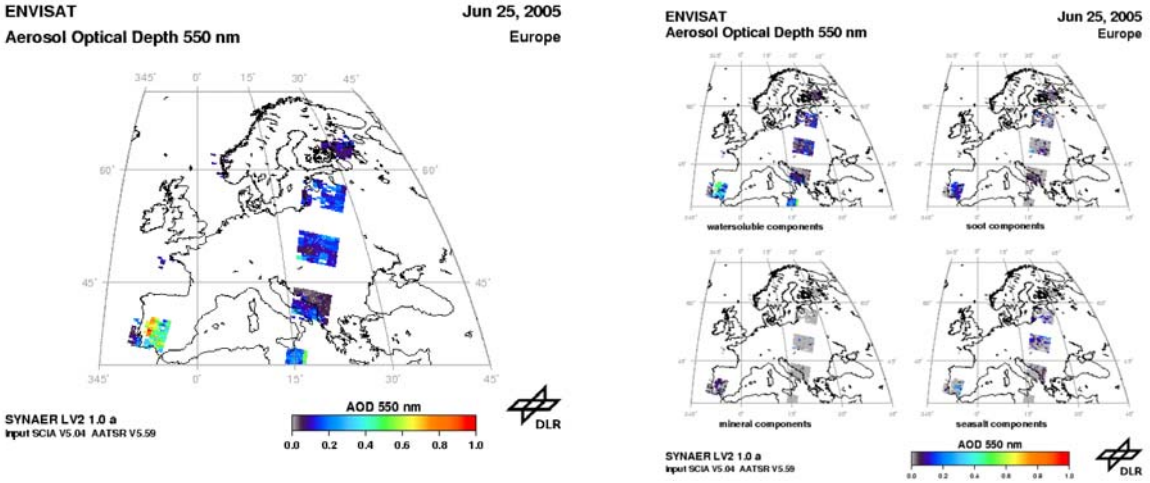

Fig. 2: example quicklooks of a daily SYNAER result over Europe for June 25, 2005: AOD (left) and AOD composition into the 4 major components (right) – clearly biomass burning soot can be seen over the Iberian peninsula.

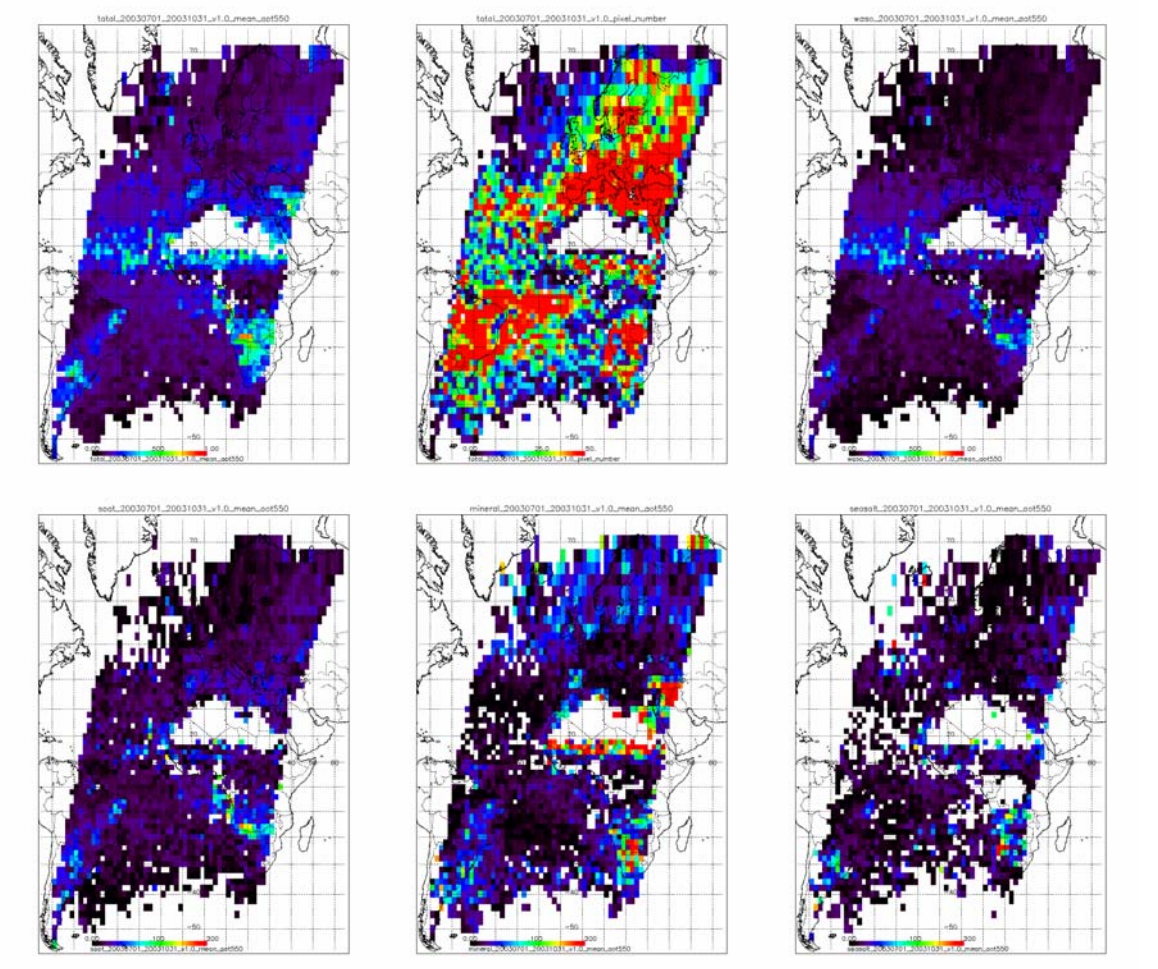

Fig. 3: examples of a 4-monthly average map based on SYNAER data of July – October 2003: upper line from left to right: total AOD at 550 nm, the number of contributing pixels per box, and component AOD at 550 nm of water-soluble aerosols; lower line from left to right: component AOD at 550 nm of soot, mineral, and sea salt aerosols. Note the different colour bars ranging from 0 – 50 for pixel number, from 0.0 to 1.0 for total and water-soluble AOD, and from 0.0 to 0.2 for components in the lower line.

Fig. 3 shows an example of the complete coverage of the currently available SYNAER dataset. Several well-known features can be clearly seen in the images. This dataset gives the 4-month average values for the period July – October 2003. In this time period a reasonable coverage in a 2x2 degree grid is achieved (as opposed to the earlier ERS-2 coverage [9], which needed one year of data for a similar pixel number on a 5x5 degree grid). Some values towards the edges of the covered region must be used with great caution, as there the exploited pixel numbers decrease significantly, so that a single episode can determine the "average" value. In the total aerosol optical depth distinct features are the tropical biomass burning regions in Africa and South America, the sub-tropical desertic regions (Sahara, Namib / Kalahari, Arabia, South America) and their plumes over the Atlantic. These are also to some extent visible in the water-soluble component, since this component contributes to all predefined aerosol types in SYNAER. However, AOD values in the regions with mineral and soot components are clearly reduced. The soot component has its peaks in the biomass burning regions, whereas mineral components concentrate around the desertic areas. No retrieval is possible inside the Sahara due to the bright surface. The sea salt component seems to be erroneous as the peaks occur inland. There seems to be a correlation with the mineral components. Thus, it must be concluded, that a separation of the different large particles (mineral, sea salt) is not successfully achieved so far.

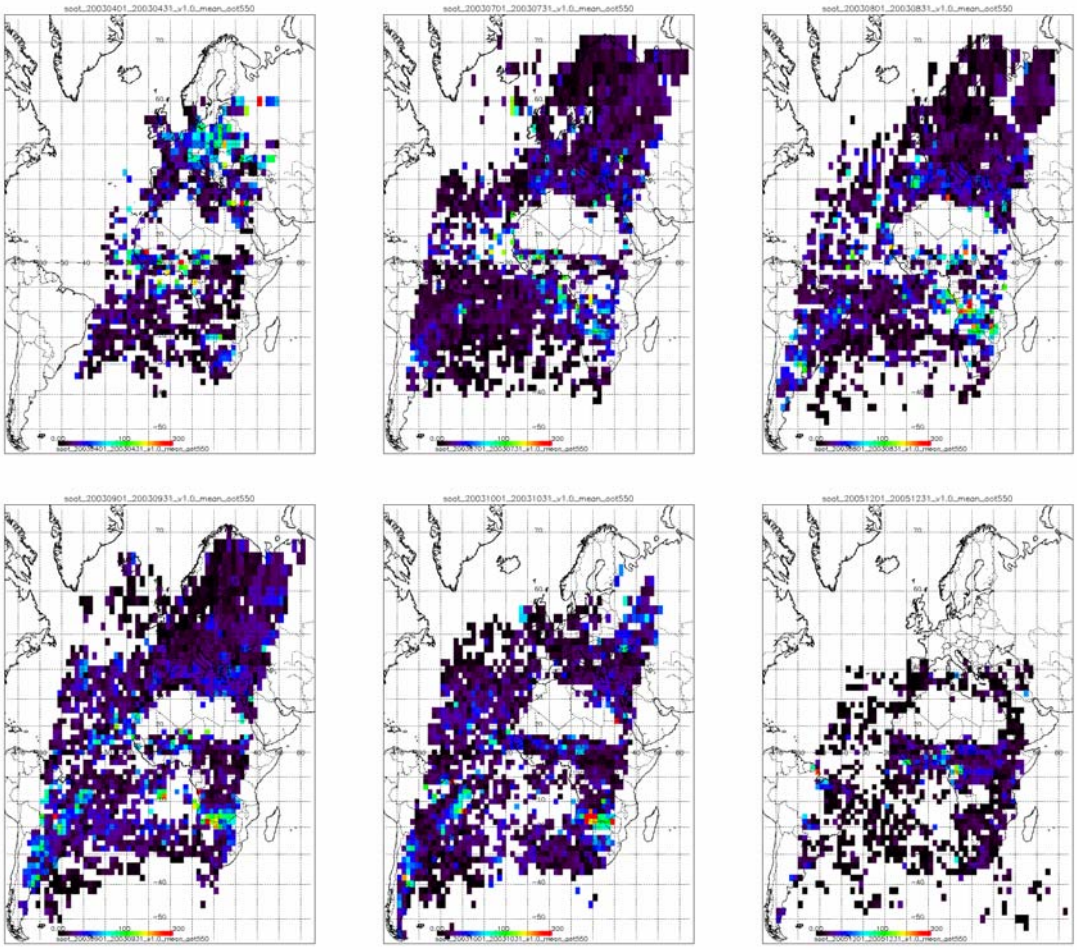

Fig. 4: seasonal variation of soot: monthly mean maps of soot AOD for the months April, July, August, September, October 2003, and December 2005 are shown from left to right / top to bottom.

The seasonal behaviour visible in the SYNAER data is shown in fig. 4 for the soot component. Here, three major features can be seen: From July to September the tropical African biomass burning moves South and East together with its plume over the Atlantic (which as slightly visible). The Amazonian biomass burning season mainly extends from August to October. Over large parts of Europe, no data are available in December (due to low sun, high cloudiness and snow cover). Highest European soot concentrations are detected, when observations are becoming available still in the heating season (April). Additionally, wildfires in August (hot summer 2003!) contribute to elevated soot over the Iberian peninsula. These features are precluded in the total aerosol optical depth due to other emissions; the water-soluble component shows correlated features as it is also partly linked to biomass burning emissions.

4. SUMMARY AND CONCLUSION

This paper has clearly demonstrated the potential in the ENVISAT SYNAER dataset to retrieve seasonal variability and composition of the atmospheric aerosol loading. Validation, quality control, and improvements are ongoing efforts. Based on the larger dataset now becoming available, these will be extended to a statistically significant and comprehensive assessment, especially of the retrieval of aerosol speciation. With the transfer to GOME-2 / AVHRR onboard METOP the daily coverage will be improved significantly (which is essential for near-real time data assimilation) and also the data record length can be extended to cover 25 years (1995 – 2020). Based on the SYNAER speciation information a systematic conversion of AOD into near-surface particle mass concentrations (PM values) has been demonstrated [12]. The promising perspective of these SYNAER derived pollution observations for air quality modelling and forecasting has been demonstrated by [13] and will be used within the ESA GMES Service Element PROMOTE to improve the treatment of episodic and gradually changing emission patterns in tropospheric chemistry transport models for air quality services.

5. ACKNOWLEDGEMENTS

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