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Evaluation of seven European aerosol optical depth retrieval algorithms for climate analysis

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ABSTRACT

Satellite data are increasingly used to provide observation-based estimates of the effects of aerosols on climate. The Aerosol-cci project, part of the European Space Agency's Climate Change Initiative (CCI), was designed to provide essential climate variables for aerosols from satellite data. Eight algorithms, developed for the retrieval of aerosol properties using data from AATSR (4), MERIS (3) and POLDER, were evaluated to determine their suitability for climate studies. The primary result from each of these algorithms is the aerosol optical depth (AOD) at several wavelengths, together with the Ångström exponent (AE) which describes the spectral variation of the AOD for a given wavelength pair. Other aerosol parameters which are possibly retrieved from satellite observations are not considered in this paper. The AOD and AE (AE only for Level 2) were evaluated against independent collocated observations from the ground-based AERONET sun photometer network and against “reference” satellite data provided by MODIS and MISR. Tools used for the evaluation were developed for daily products as produced by the retrieval with a spatial resolution of 10×10 km^2 (Level 2) and daily or monthly aggregates (Level 3). These tools include statistics for L2 and L3 products compared with AERONET, as well as scoring based on spatial and temporal correlations. In this paper we describe their use in a round robin (RR) evaluation of four months of data, one month for each season in 2008. The amount of data was restricted to only four months because of the large effort made to improve the algorithms, and to evaluate the improvement and current status, before larger data sets will be processed. Evaluation criteria are discussed. Results presented show the current status of the European aerosol algorithms in comparison to both AERONET and MODIS and MISR data. The comparison leads to a preliminary conclusion that the scores are similar, including those for the references, but the coverage of AATSR needs to be enhanced and further improvements are possible for most algorithms. None of the algorithms, including the references, outperforms all others everywhere. AATSR data can be used for the retrieval of AOD and AE over land and ocean. PARASOL and one of the MERIS algorithms have been evaluated over ocean only and both algorithms provide good results.

1. Introduction

Satellite-based radiometers and spectrometers have been used for the observation of aerosol properties from space since more than

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three decades (e.g., de Leeuw & Kokhanovsky, 2009; Lee, Li, Kim, & Kokhanovsky, 2009). The data have increasingly been used for purposes such as air quality assessment (Hoff & Christopher, 2009; van Donkelaar et al., 2010), emission estimates (Huneeus, Chevallier, & Boucher, 2012), forest fires applications (Kaufman et al., 1998; Labonne, Bréon, & Chevallier, 2007; Sofiev et al., 2009), atmospheric correction of oceanic (Müller et al., in this issue) and terrestrial (Zelazowski, Sayer, Thomas, & Grainger, 2011) observations. In this paper we focus on the use of satellite instruments to provide aerosol observations for climate and climate change studies. In particular eight aerosol retrieval algorithms using data from different instruments, or a combination of instruments, are evaluated for their suitability to produce climate-relevant aerosol parameters. This study was undertaken in the context of the European Space Agency (ESA) Climate Change Initiative (CCI) (Hollmann et al., 2013) project Aerosol-cci (Holzer-Popp et al., 2013). Aerosol-cci focuses on European instruments and the results are evaluated against non-European instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging SpectroRadiometer (MISR), and model predictions.

Below, a brief overview is presented of the Aerosol-cci project. Background information on aerosols, their effects on climate and the use of satellite-based instruments to obtain information on aerosols is presented in Appendix A. This information has been used to develop algorithms to obtain information on aerosol properties from satellite-based instruments. The eight aerosol retrieval algorithms which were evaluated as part of the Aerosol-cci project are presented in Table 1 and their characteristics are briefly summarized Appendix B. Recent improvements to these algorithms are described in detail in Holzer-Popp et al. (2013) and briefly summarized in Appendix C. The main focus of this paper is the validation and evaluation of the aerosol retrieval algorithms in a round-robin (RR) exercise. Methods used for validation and evaluation are presented in Section 2 and the protocol used in the RR exercise is outlined in Section 3. The results from this exercise are presented in Sections 3.1–3.3 and discussed in Section 4. Conclusions are presented in Section 5.

Algorithms to retrieve aerosol properties from the radiance measured at the top of the atmosphere at different wavelengths, viewing angles and polarization, have been developed to optimally use the available information, based on different physical principles, cf. Kokhanovsky and de Leeuw (2009) and de Leeuw et al. (2011) for detailed descriptions of algorithms used for the retrieval of aerosol properties over land. However, the aerosol optical depth (AOD) obtained from different algorithms may vary widely and some algorithms may perform better than others, even when applied to the same data set from the same instrument. These differences are regionally dependent and there is no single algorithm that outperforms all others everywhere (cf. Kahn et al., 2009; van Donkelaar et al., 2010). The MODIS dark target algorithm (Levy, Remer, Mattoo, Vermote, & Kaufman, 2007) is most often used. It has been validated (Levy et al., 2010), provides two observations daily, each of them with near-global coverage, and the data are easy to access. Nevertheless, there are gaps, e.g., no data are available over bright surfaces such as deserts.

The basis for the assessment of aerosol retrieval algorithms is usually the comparison of the retrieval results, in particular AOD and the variation of AOD for a given pair of wavelengths expressed by the Ångström Exponent (AE), with independent data provided by AERONET, a federated network of ground-based sun photometers (Holben et al., 1998). Ground-based sun photometers provide accurate measurements of AOD (uncertainty ~0.01–0.02, Eck et al., 1999) because they directly observe the attenuation of solar radiation without interference from land surface reflections. The comparison of, e.g., MODIS and MISR AOD with AERONET data shows that the results from each instrument are within specification, and yet there are differences between them (Kahn et al., 2009). The performance of most of the European sensors prior to the start of the Aerosol-cci project was poorer than that of, e.g., MODIS or MISR, as indicated from a comparison of the AOD retrieved using the baseline algorithms with that obtained from either MODIS or MISR and with the AERONET AOD (Holzer-Popp et al., 2013). It is noted here that AERONET data is well screened for the presence of clouds so that a comparison of satellite-retrieved AOD with AERONET data does not provide a good test of the behavior of an algorithm in cases where cloudy pixels have not adequately been removed by cloud flagging.

The Aerosol-cci project was designed to provide essential climate variables (ECVs) for aerosols from satellite data (Holzer-Popp et al., 2013). To achieve this, the quality of current satellite aerosol products needed to be assessed and, when the quality was found to be insufficient, improved. Participating algorithms, focusing on European instruments, are listed in Table 1 and their most important characteristics are summarized in Appendix B. Aerosol parameters retrieved from other instruments such as MODIS or MISR were used for comparison, and this comparison provided a measure for the performance of the Aerosol-cci algorithms and their subsequent improvement. The initial focus of the Aerosol-cci project was on understanding differences between participating algorithms as a basis for their improvement. The baseline algorithms were those that existed at the start of the project and improvements were measured with respect to these, using several different methods described in Section 2. Tests were made for data from a single month (September 2008) as described in Holzer-Popp et al. (2013). The best version, as decided by each earth observation (EO) team for their own algorithm based on these tests, was used in a round robin (RR) test which encompassed four months in 2008

Table 1
Instruments and algorithms participating in the Aerosol-cci project. Providers, products and references for each algorithm are indicated. A brief description for each algorithm and references to full descriptions are provided in Appendix B.

Instrument	Algorithm	Provider	Products											
			Land	Ocean	AOD(n)	Type	FMF	Absorption	Dust	Uncertainty	Quality flag	Altitude	Surface reflectance	Cloud fraction
AATSR	ADV	FMI/UHEL	+	+	3/4	3	+	(+)	−	+	+	−	+	−
	ORAC	Univ Oxford/RAL	+	+	2	1	+	−	−	+	+	−	+	+
	SU	Univ Swansea	+	+	4	1	−	−	−	+	−	−	−	−
AATSR + SCHIAMACHY	SYNAER	DLR	+	+	4	3	+	+	+	+	+	−	+	+
MERIS	ESA standard (v8)	ESA	+	+	3	1	−	−	−	−	−	−	−	+
	BAER	Univ Bremen	+	+	1	0	+	−	−	−	+	−	−	+
	ALAMO	HYGEOS	−	+	2	1	+	−	−	−	−	+	−	−
POLDER	PARASOL	LOA	−	+	3	2	+	−	+	−	+	−	−	−

AATSR: Advanced Along-Track Scanning Radiometer.
SCHIAMACHY: SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY.
MERIS (MEdium Resolution Imaging Spectrometer).
POLDER: POLarization and Directionality of the Earth's Reflectances.
AOD(n), n = number of wavelengths.
Type: number of independent aerosol components which potentially can be retrieved.