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Validation of MERIS/AATSR synergy algorithm for aerosol retrieval against globally distributed AERONET observations and comparison with MODIS aerosol product

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ABSTRACT

A new synergy algorithm has been recently developed, to retrieve Aerosol Optical Thickness (AOT) in high spatial resolution (1 km × 1 km), which may improve the study of aerosols at local scale. The algorithm combines spectral and angular information provided by the MERIS and the AATSR sensors, respectively, offering improved characterization of aerosol properties. In the present study, the MERIS/AATSR synergy algorithm was validated by comparing the retrieved AOT with the respective AOT values observed at AERONET stations globally, considering different land cover types. Spatial patterns and differences between the MERIS/AATSR and the MODIS derived AOT were also investigated. Results indicated that the MERIS/AATSR synergy algorithm substantially improves the spatial resolution of the derived AOT and it is capable of retrieving AOT for most land cover types, with a good correlation relative to AERONET station measurements (R^2 ranges between 0.60 and 0.90, depending on the land cover type).

1. Introduction

Atmospheric aerosols are a crucial parameter in studies of the Earth-Atmosphere system. Through their impacts in atmospheric radiation fluxes, they constitute an important factor that can have impacts on climate change, along with greenhouse gases (Battrick, 2006; IPCC, 2007). However, the quantification of the aerosol effects is more complex compared to greenhouse gases, due to their high spatial and temporal variability. In local scale, aerosols can also affect air quality and human health. The local scale variability is caused primarily by a huge number of different aerosol local sources, combined with their relatively short life time (e.g. Kaufman et al., 2002) and the modification processes which change their properties.

The study of aerosols is based on two different approaches, namely ground measurements and satellite remote sensing. The most widely used ground data come from the Aerosol Robotic Network (AERONET), a network of ground based stations which provides a long term and continuous database of aerosol optical, microphysical and radiative properties (Holben et al., 1998). However, this database is limited only over land and specifically over regions where stations are available and operational. Furthermore, station point measurements provide no information on possible aerosol spatial patterns of the wider station area. Satellite remote sensing of aerosols has been performed for over three decades (Nagaraja Rao et al., 1989; Kaufman et al., 1997; King et al., 1999; Deuze et al., 2001; Yu et al., 2006; Lee et al., 2009; Bréon et al., 2011). Although the advantage of aerosol remote sensing compared to station measurements is obvious (global spatial coverage), the spatial and temporal resolution of satellite retrieved aerosols remains a drawback in case of local scale studies (Hadjimitsis, 2008; Al-Hamdan et al., 2009; Chrysoulakis et al., 2010; Retalis and Sifakis, 2010; van Donkelaar et al., 2010; Lee et al., 2011; Wang et al., 2013).

Although early aerosol monitoring from space used data from sensors that were designed for other purposes (e.g. Advanced Very High Resolution Radiometer (AVHRR)) (Holben et al., 1992;

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Mishchenko et al., 1999) and Total Ozone Mapping Spectrometer (TOMS) (Torres et al., 2002), modern satellite aerosol products include Aerosol Optical Thickness (AOT), as well as other aerosol properties, in multiple wavelengths in the ultraviolet through the thermal infrared, and at spatial resolutions reaching up to 10 km × 10 km. These products include NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) Level 2 aerosol data products (Levy et al., 2010) and the GlobAEROSOL product, which aims to produce a 10-year global aerosol data set from European satellite radiometers (Thomas et al., 2006).

Most of the modern aerosol products are based on data from instruments with a single sampling of the angular domain. The main problem in AOT and other aerosol properties retrieval is to decouple the signal contributed by atmospheric scattering from that contributed by surface reflectance. The separation of the surface contribution to the received radiance at the sensor is always based on a priori knowledge about the spectral properties of the surface and it is based on identification of dark pixels, spectral mixing and a priori assumptions based on existence of an independent estimate of surface reflectance from other instruments (Themistocleous et al., 2012). Generally these methods are suitable only for dark targets with relatively low spectral variability, thus giving a sparse estimate of AOT, and are normally inappropriate for bright surfaces such as arid or snow covered land (e.g. North et al., 2009). Use of multiple view-angle imagery allows an additional constraint to be placed, since the same area of surface is viewed through different atmospheric path lengths. The principal advantage of a multiple view-angle approach is that no a priori information of the surface spectrum is required and aerosol properties can be retrieved over all surface types. A limitation of the angular approach is that the algorithms require accurate co-registration of the images acquired from multiple view angles. Several multi-angle approaches for aerosol retrieval have been developed in the past (e.g. Diner et al., 2009; Martonchik et al., 1998; Leroy et al., 1997; Grey et al., 2006; Frankenberg et al., 2012). Most of them use data from MISR (Multi-angle Imaging SpectroRadiometer), POLDER (POLarization and Directionality of the Earth's Reflectances) and AATSR (Advanced Along-track Scanning Radiometer) sensors.

The present study aims to validate the AOT of a multiple view-angle approach, developed to make a synergistic use of the AATSR and the Medium Resolution Imaging Spectrometer (MERIS) instruments (North et al., 2009). Both sensors are carried on board the Envisat satellite, launched in 2002, and provided until 2012, complementary information, encompassing different spectral domains and viewing geometries. Specifically, the input of the algorithm consist of Top of Atmosphere (TOA) reflectance data from 21 channels: the 4 solar reflective AATSR bands at both nadir and forward views (a total of 8 input channels), and 13 out of 15 MERIS bands (O_2 absorption band 11 and water vapor band 13 are excluded). This algorithm therefore combines the spectral information provided by MERIS with the angular information provided by AATSR. Its main advantage is the higher spatial resolution of the aerosol retrieval, compared to the 10 km × 10 km spatial resolution available from MODIS and GlobAEROSOL products. This spatial resolution offers new possibilities in discriminating aerosol spatial patterns, previously undetected by other satellite sensors or ground-based instruments, and generally studying spatial aerosol characteristics in areas of high interest, such as urban regions. Furthermore, it increases the potential of Earth Observation to support local level air quality studies, which include the conversion of AOT in particulate matter (PM) using remote sensing techniques, in order to further investigate urban air pollution patterns (e.g. Gupta and Christopher, 2009a,b; Yap and Hashim, 2013).

The objective of this study is to validate the MERIS/AATSR synergy algorithm for AOT against global-scale AERONET measurements and to compare its outputs with the MODIS aerosol product. In the next section, MERIS and AATSR instruments, as well as the synergy algorithm are presented in more detail. Section 3 describes the methodology and procedure used for the validation of the synergy algorithm output against corresponding AERONET and MODIS data. Results of the validation processes and the spatial distribution intercomparison are presented in Section 4, before the summary and conclusions.

2. The MERIS/AATSR synergy algorithm for aerosol retrieval

MERIS and AATSR instruments were launched on board the Envisat satellite on March 1st 2002. MERIS is a medium resolution imaging spectrometer, operating in the solar reflective spectral range and possessing 15 spectral bands between 390 nm and 1040 nm. Three of these bands are dedicated to the retrieval of aerosol properties. The instrument's field of view around nadir covers a swath width of 1150 km across-track. The Earth is imaged with a spatial resolution of 300 m × 300 m (Full Resolution data), while Reduced Resolution data pixel size covers an area of 1.2 km × 1.2 km (ESA, 2011). Only Fine Resolution data were used in this study.

AATSR is a scanning radiometer with seven spectral bands in the visible, reflective infrared and thermal infrared regions. Special features of the AATSR include its use of a conical scan to give a dual view of the Earth's surface, thus improving the capacity for atmospheric correction. The AATSR swath covers approximately half of the MERIS swath (~500 km), with pixel sizes of 1 km × 1 km at the center of the nadir swath and 1.5 km × 1.5 km at the center of the forward swath. For the AATSR Level 1 products, forward pixels are resampled to 1 km^2 resolution, in order to be the same size as the nadir pixels (ESA, 2007).

The MERIS/AATSR synergistic algorithm for retrieval of aerosol properties has been described in detail by North et al. (2009). It consists of three major procedures: in the first step, the MERIS and AATSR data collocation is performed, and a combined MERIS/AATSR Level 1b product is created, containing all the data that will be used as input to the algorithm. These data are resampled into the AATSR nadir view spatial resolution (1 km × 1 km) and cover the area where both data sets are available. The center of this area's swath coincides with the centers of the MERIS and AATSR swaths, while the width is equal to the AATSR swath width (~500 km). The second step of the algorithm consists of a cloud screening procedure applied to the collocated product, while in the third step the atmospheric correction and aerosol retrieval are performed. Specifically, a physical model of spectral change with view angle was developed to separate the angular effects of the surface into two components, a structural parameter that is dependent only on the viewing and illumination geometry and a spectral parameter that is dependent only on the wavelength. The angular reflectance of a wide variety of natural land surfaces