Application of the Optimal Estimation Method to the Joint Retrieval of Aerosol Load and Surface Reflectance from MSG/SEVIRI Observations

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Abstract. The purpose of the presented new Land Daily Aerosol algorithm developed at EUMETSAT is to derive simultaneously the mean daily tropospheric aerosol load and the land surface reflectance from MSG/SEVIRI observations. The algorithm is based on the Optimal Estimation theory, where the forward radiative transfer model explicitly accounts for the surface anisotropy and its coupling with the atmosphere. A priori information on surface reflectance results from its temporal stability. Results of comparisons with AERONET data are presented to validate the modelling approach and the algorithm that resolves the inversion problem.

Keywords: optimal estimation, aerosols, land, SEVIRI, diagnostic tools
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1. INTRODUCTION

One of the major problems related to the retrieval of tropospheric aerosol load over land surfaces from space-borne imager observations consists in the discrimination of the contribution of the observed signal reflected by the surface from the one scattered by aerosols. It is equivalent to solving a radiative system composed of minimum two layers, where the upper layer(s) include(s) aerosols and the bottom one(s) represent(s) the surface. This problem is further complicated by the intrinsic anisotropic radiative behaviour of natural surfaces and its coupling with the atmosphere. The accuracy with which it is possible to retrieve aerosol properties is intimately related to the determination of the underlying surface characteristics. As the number of independent observations is not large enough to fully characterise the radiative properties of the observed medium, it is necessary to constrain the problem by providing some a priori knowledge on this medium. Typically, this additional knowledge concerns the lower layer(s), i.e., the surface properties, as the primary objective is to determine the characteristics of the upper aerosol layer [1]. An original method is proposed here where surface anisotropy and atmospheric scattering properties are characterised simultaneously, explicitly accounting for the radiative coupling between these two systems. The algorithm exploits the frequent Spinning Enhanced Visible and Infrared Imager (SEVIRI) observations to characterise the surface Bidirectional Reflectance Factor (BRF) and to derive the total column Aerosol Optical Depth (AOD). The use of a priori information, assuming that the surface radiative property temporal variations are much slower than aerosol ones is mathematically rigorously combined with the information derived from SEVIRI observations in the framework of the Optimal Estimation (OE) method [2]. The benefit of the a priori information has been assessed with some comparisons against AERONET observations.

1 Proceedings of The International Radiation Symposium (IRS2008), Current Problems in Atmospheric Radiation, Iguacu, Brazil, August 03-08, 2008, paper 1119.
2. RETRIEVAL METHOD

2.1. Forward model

The main objective of the Land Daily Aerosol (LDA) algorithm is to derive mean daily total column AOD over land surfaces for spherical and non-spherical aerosol classes derived from the clustering of AERONET data [3]. The aerosol properties are inferred from the inversion of a forward radiative transfer model against daily accumulated observations in the 0.6, 0.8 and 1.6 SEVIRI bands. This model expresses the Top-of-Atmosphere (TOA) BRF $y_m$ in a given spectral band as a sum of the atmospheric contribution and the contribution specifically due to surface scattering effects[4]. In addition, the gaseous absorption are treated separately from the molecular and aerosol scattering-absorbing effects, so that the system can be represented by a 3-layer model as in Fig. (1). The properties of this model, defined by the state vector $x$, include the surface reflectance in the three SEVIRI bands and the aerosol optical thickness normalised at $0.55 \mu m$. The surface reflectance is represented by the RPV model [5].

2.2. Measurement vector and associated error

The proposed algorithm capitalises on the capability of SEVIRI to acquire data every 15 minutes to perform an angular sampling of a same pixel under various solar geometries (Fig. 1). Using the principle of reciprocity applied to the three SEVIRI solar channels[6], the temporal accumulation is thus used to form a virtual multi-angular and multi-spectral measurement vector $y$ that can be used for retrieving simultaneously information on the atmospheric aerosol load, and the Earth surface reflectance. The reliable estimation of the measurement system error is one of the most critical aspect of the OE method as it strongly determines the likelihood of the solution. The measurement system total error covariance matrix $S_y$ is composed of the uncertainties related to the SEVIRI radiometric performance, the forward model, the model parameters and finally the assumptions of the retrieval algorithm.

2.3. Optimal Estimation method

The basic principle of OE is to maximise the probability of the retrieved atmospheric state conditional on the value of the measurements and any a priori knowledge on the observed medium. Maximising probability is equivalent to minimizing a cost function which combines these two pieces of information. This function writes

$$J(x) = (y_m - y) S_y^{-1} (y_m - y)^T + (x - x_0) S_x^{-1} (x - x_0)^T$$

(1)
where $x$ is the state vector (retrieved model parameters), $y_m$ the modelled SEVIRI observations, $y$ the measurement vector, $S_y$ is the measurement error covariance matrix, $x_b$ the a priori knowledge, and $S_x$ the a priori error covariance matrix. The retrieval error is based on the OE theory, assuming a linear behaviour of $y_m$ in the vicinity of the solution $\hat{x}$. Under this condition, the Hessian $\nabla^2 J(\hat{x})$ at the minimum of $J$ approximates the inverse of the a posteriori error covariance matrix $S_\varepsilon$. This matrix provides information on the correlation between the retrieved model state variables of the solution state vector $\hat{x}$ extracted from a posteriori error covariance matrix. Comparison of the values in the a priori and a posteriori covariance matrices thus expresses the knowledge gain from the measurement system and its associated uncertainties.

### 2.4. a priori information definition

As already mentioned, one of the major issues in retrieving the aerosol load over land surfaces is to separate the aerosol contribution from the surface one. In LDA, prior knowledge $x_b$ on the surface relies on the assumption that the surface albedo temporal stability is higher than the aerosol load one. Hence, a time series analysis can be performed on the previous day retrievals to provide a priori information on the expected amplitude and shape of the surface BRF. LDA is able to detect a sudden change in the surface albedo (i.e., because of snow, or rain).

![Complete time series](image)

**FIGURE 2.** Effect of the a priori information on the AOD retrieval. Top RMSE time series analysis between retrieved aerosol optical thickness from SEVIRI observations and AERONET data without update of the a priori information on surface reflectance (black line with ◊ symbol) and with update of the a priori information (gray line with □ symbol). The dash-dotted lines correspond to the exponential fitting. Bottom Idem but for the bias between AERONET and LDA retrieval.

### 3. RESULTS

In order to evaluate the efficiency of the retrieval procedure and prior update mechanism, comparisons with AERONET [7] data were made over the time period extending from 15 February 2005 to 15 June 2005. A series of experiments are defined to evaluate the algorithm performance, comparing the retrieved aerosol optical thicknesses with those from the AERONET dataset. The reference experiment is made without updating the prior information on the surface. The default prior information is constant from a day to another and is given with a very large error covariance $S_x$ so that $x_b$ has no significant impact on $J(x)$. Sensitivity analysis is performed using, from a day to another, updated prior
information on the surface, as described in Section (2). The results of these retrievals are compared with the cases without prior update of the surface reflectance. A quantitative analysis is performed on the temporal evolution of the root mean square error (RMSE) and bias between LDA retrieval and AERONET data. Results are shown on Fig. (2). When no update of the a priori takes place (black line), the overall trend of the RMSE is to remain constant during the period of interest, despite sharp variations from a day to another. Conversely, when a priori information on the surface is provided, the RMSE decreases in time (gray line). This figure shows the positive impact of this mechanism, where the “memory” on the state of the surface is provided to the algorithm allowing reduction of the RMSE from 0.3 to about 0.2. The bias remains unaffected by the prior information. The overall impact is also analysed considering all AERONET observations available during the investigation period. This effect is further analysed in Fig. (3) considering now all AERONET stations in the MSG disc. On the average, the a priori mechanism improve the coefficient of the regression line from 0.58 to 0.75. The reason why LDA retrieval underestimates the AERONET observations still needs to be investigated.

![Figure 3](image-url)

**FIGURE 3.** AERONET versus LDA AOD for 0.1 bins using all station and all aerosol classes from 15 February 2005 to 15 June 2005. The symbol ◇ represents the reference experiment. The symbol □ represents the experiment with a priori update

### 4. CONCLUSIONS

An original method has been proposed to retrieve simultaneously AOD and surface reflectance, using daily accumulated SEVIRI observations. The algorithm has proved to be capable of separating the aerosol contribution from the surface one in the overall TOA observed signal. The method that has been put in place, based on OE, insures a rigorous control of the system errors, and allows a quality check on the retrieved information. Comparisons with AERONET time series over a period of four months have demonstrated the robustness of the algorithm. They have also shown the stabilisation effect on the surface properties of improving the a priori knowledge on the surface state variables, and the resulting improvement of the AOD retrieved values when compared to AERONET. The benefits in time of updating the prior can be summarised by the decreasing trend of the RMSE while the bias remains unchanged.

### REFERENCES


