OPERATIONAL NEAR REAL-TIME DERIVATION OF LAND SURFACE ALBEDO AND DOWN-WELLING SHORT-WAVE RADIATION FROM MSG OBSERVATIONS

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ABSTRACT

In the framework of the EUMETSAT Satellite Application Facility for Land Surface Analysis (Land-SAF) we develop surface albedo and short-wave radiation products which will be generated in near real-time from observations provided by the MSG/SEVIRI instrument.

The albedo algorithm exploits the diurnal variation of the illumination angle, which provides information on the angular variation of reflectance, in order to invert a linear kernel-based bi-directional reflectance model. Several albedo variants are derived by adequately integrating the constrained model functions. In the case of poor angular sampling the achievable accuracy needs to be augmented by additional information, e.g. by using a static a priori information data base derived from measurements of instruments with multiple view angle capabilities.

The down-welling short-wave radiation at the surface essentially depends on cloud cover and hence to derive a reliable estimate of this quantity the cloud mask represents an important piece of information. Depending on the presence of clouds and potentially on cloud type different physically based parameterisation schemes are applied to approximate the radiative transfer problem.

Key words: Meteosat Second Generation; Land Surface Albedo; Down-welling Radiation.

1. INTRODUCTION

The European organization for meteorological satellites (EUMETSAT) hosts a number of decentralized processing centres [1] for specialized applications. The Satellite Application Facility for Land Surface Analysis (Land-SAF) is coordinated by the Portuguese meteorological institute [2]. Its objective is to provide near-real time estimates of land surface variables for the meteorological and environmental science communities with a particular emphasis on numerical weather prediction. The list of quantities that will be delivered includes land surface albedo, land surface temperature, down-welling surface short-wave and long-wave radiation fluxes, snow cover, leaf area index and the fraction of vegetation cover. In this contribution we present the albedo and short-wave radiation products developed by Météo-France.

2. LAND SURFACE ALBEDO

The operational processing scheme for land surface albedo comprises a number of successive steps which are briefly outlined in the following.

In a first step the measured top-of-atmosphere (TOA) radiances delivered by the SEVIRI instrument are corrected for atmospheric effects in order to convert them into the corresponding top-of-canopy (TOC) reflectance values. The atmospheric correction module is based on SMAC, a Simplified Method for the Atmospheric Correction of satellite measurements in the solar spectrum [4]. The method consists of a parameterisation of absorption and scattering processes with simple analytic functions whose coefficients depend on the spectral response of the respective channel considered. For our application the relevant coefficients corresponding to the MSG 0.6µm, 0.8µm, and 1.6µm channels were calculated by [5]. The operational Land-SAF system provides pressure and water vapour information obtained in near-real time from the ECMWF numerical weather prediction model. The aerosol optical thickness will be available as an internal product or will be taken from a climatology.

The spectral TOC-reflectances for different solar angles then serve as input quantities for the inversion of a linear kernel-driven BRDF model (e.g. [6]) which allows us to characterize the angular dependence of the reflectance factor. Kernel-based BRDF models consist of a linear combination of suitable basis functions \( f_i \), whose angular dependence is supposed to characterize representative features of scattering processes occurring in nature. For a fixed wavelength \( \lambda \) the reflectance factor \( \rho \) is expressed as

\[
\rho(\theta_v, \theta_s, \phi) = k_0 f_0 + k_1 f_1(\theta_v, \theta_s, \phi) + k_2 f_2(\theta_v, \theta_s, \phi),
\]

(1)
The numerical values of the parameters \( k \) can be considered as a description of the relative importance of the respective scattering mechanisms. The term \( f_0 \) is often chosen to be constant to represent an isotropic contribution to the reflectance factor.

In order to retrieve estimates for the parameters \( k \), a sufficient number of reflectance observations \( \rho \) under different angular conditions need to be collected during an appropriate time interval (or “composition period”). In general more observations than parameters are available (and required) and the corresponding linear equation system does not have an exact solution. We use standard numerical techniques to determine the “linear least squares” solution by employing a weight factor for the reflectance measurements specified as a function of illumination and viewing geometry. In addition to the parameters \( k = (k_0, k_1, k_2)^T \) we also obtain an estimate for their error covariance matrix \( C_X \).

Often the restricted angular sampling geometry provided by the geostationary MSG satellite is unfavourable for albedo determination and consequently the error estimates are large. In this case additional information is required. Bayes’ Theorem provides the theoretical background for including a priori information (cp [9]) and for combining information \( X \) and \( Y \) from two different sensors. The a posteriori probability density distribution for the parameters \( k \) is given by:

\[
p(k|X, Y, a \ priori) \propto p(X|k) p(Y|k) p(k|a \ priori) .
\]  

We assume that the measurement errors follow a Gaussian distribution. Since the BRDF model applied is linear, the probability density distribution \( p(X|k) \) \( \{p(Y|k)\} \) interpreted as a function of \( k \) for a fixed set of observables \( X \) \( \{Y\} \) is also a Gaussian, whose properties are determined by the estimates for its first and second moments \( k_X \) and \( C_X \) \( \{k_Y \text{ and } C_Y\} \). For convenience we formulate potential a priori knowledge \( p(k|a \ priori) \) on the parameters also in terms of the first and second moments \( k_A \) and \( C_A \). In this case the a posteriori distribution remains Gaussian and its properties can be calculated as

\[
C^{-1} = C_X^{-1} + C_Y^{-1} + C_A^{-1} \quad \text{and} \quad k = C (C_X^{-1} k_X + C_Y^{-1} k_Y + C_A^{-1} k_A).
\]

For implementing this scheme various phases with increasing sophistication are envisaged. First, a priori knowledge could merely be used to exclude physically unreasonable solutions or to include BRDF information from a data base combined with a land cover classification map. (Related ideas have been developed by [10].) Furthermore, a kind of BRDF parameter climatology could be established as an a priori knowledge base, e.g. derived from a set of instruments including POLDER and VEGETATION in the framework of the CYCLOPES project [7].

In the future this problem will be alleviated by adding observations provided by the AVHRR instrument on board of the Metop satellites of the “European Polar System” which is planned to be included in the Land-SAF activities. In this scenario the pre-established data base mainly serves to complement missing information due to persistent cloud coverage.

The (spectral) directional-hemispherical (or black sky) albedo \( a_{bh}(\theta_s) \) is given by the integral of the reflectance factor in (1) over all view angles for a fixed illumination direction. The bi-hemispherical (or white sky) albedo \( a_{bh} \) corresponds to the case of completely diffuse lighting and is determined by an integration of the reflectance factor over all view and illumination directions. In both cases albedo can be expressed as a linear combination of the kernel integrals \( I_{1h}^{bh}(\theta_s) \) and \( I_{2h}^{bh} \), respectively, weighted with the retrieved parameter values. The kernel integrals can be pre-computed for the specific BRDF model employed. A theoretical error estimate for the albedo quantities is determined from the kernel integrals and the error covariance matrix of the model parameters ([8]):

\[
\sigma_a = \sqrt{I^T C I} \quad \text{with} \quad I = (I_0, I_1, I_2)^T .
\]  

For most of the applications the quantity of interest is the broadband rather than the spectral albedo. In order to transform the spectral albedo values determined for the three employed SEVIRI channels into broadband albedo estimates we make use of the linear regression equations suggested by [11] for various broadband wavelength ranges: total short-wave \((0.3 \mu m - 4 \mu m)\), visible \((0.4 \mu m - 0.7 \mu m)\), and near infrared \((0.7 \mu m - 4 \mu m)\). In contrast to spectral albedo, the broadband quantity is not a pure surface property since it slightly depends on atmospheric properties which influence the wavelength-dependence of the spectral weight factor irradiance appearing in its definition. Nevertheless the conversion relations are meant to be applicable under various atmospheric conditions for directional-hemispherical albedos irrespective of the solar illumination angle as well as for the bi-hemispherical quantity.

We applied the algorithm prototype to a limited test data set comprising six SEVIRI scenes acquired between 6:00 UTC and 18:00 UTC on 28 July 2003. Figure 1 shows the resulting spectral albedo maps as well as a broadband albedo estimate obtained as a linear combination

\[
a_{\lambda_1, \lambda_2} = c_0 + c_{0.6} a_{0.6} + c_{0.8} a_{0.8} + c_{1.6} a_{1.6}
\]

of the spectral quantities with regression coefficients as suggested by [11].

In the operational system the inversion scheme will be applied to all cloud-free reflectance observations available during one day. The information will also be accumulated over a longer time period in order to reduce the amount of missing data due to cloud cover. Appropriate techniques to achieve this will be tested once the operational Land-SAF system is fully integrated and data are processed on a regular basis.
Figure 1. Directional-hemispherical albedo estimates calculated from a series of six MSG/SEVIRI images acquired on 28 July 2003. The images on the left depict (from the top to the bottom) the spectral albedo in the 0.6μm, 0.8μm, and 1.6μm instrument channels. The top right image shows the corresponding total broadband albedo (0.3μm, 4.0μm), the middle right a provisional (theoretical) error estimate for the broadband albedo, and the bottom right a processing flag. In the latter the colour code indicates if the algorithm was successfully applied (green) or if the inversion was not performed due to missing observations (yellow).
3. DOWN-WELLING SURFACE SHORT-WAVE RADIATION

The down-welling surface short-wave radiation flux (DSSF) refers to the radiative energy in the wavelength interval [0.3\mu m, 4.0\mu m] reaching the Earth’s surface per time and surface unit. It essentially depends on the solar zenith angle, on cloud coverage, and to a lesser extent on atmospheric absorption and surface albedo. The method for the retrieval of DSSF that is implemented in the Land-SAF prototype largely follows previous developments achieved at Météo-France in the framework of the “SAF on Ocean and Sea-Ice” [12] [13].

The DSSF may be expressed as

\[ F_{\text{DSSF}} = E_0 \, v(t) \, \mu_0 \, T_x \, T_a \, T_c \, T_e, \]

where \( E_0 \) is the solar constant, \( v(t) \) a correction factor to take into account the varying distance of the sun, \( \mu_0 \) the cosine of the solar zenith angle, and \( T_a \) the transmittance of the atmosphere. For the factor \( T_x \), different expressions are used depending on whether a given pixel is marked as clear or cloudy. The information on cloud cover is provided by the cloud mask software which was developed by the “SAF in Support to Nowcasting and Very Short Range Forecasting” and which is integrated in the Land-SAF operational system. In addition to the static atmospheric constituents, variable water vapour and ozone contents are taken into account for calculating the atmospheric transmittance in analogy to the information provided for the atmospheric correction scheme.

In the case of clear pixels the factor \( T_x \) is specified as

\[ T_x = T_d = \frac{1}{1 - A_s(c_1 + \frac{c_2}{\mu})}, \]

where \( A_s \) is the broadband surface albedo, \( V \) the visibility, and \( c_1 \) and \( c_2 \) are constants. The term \( T_d \) is larger than one and represents the increase due to multiple scattering between the surface and the atmosphere which contributes to the diffuse component of the down-welling radiation. As described before surface albedo estimates are calculated by Land-SAF and are therefore readily available. The visibility parameter, on the other hand, is kept at a fixed value for the time being. Later it should be related to the aerosol optical depth which may either be taken from a climatology or be available as an internal product in the system.

For cloudy pixels the DSSF estimate relies on a simplified physical description of the radiative transfer in the cloud-atmosphere-surface system. In this case \( T_x \) represents the “cloud factor” \( T_{cl} \) which is given by

\[ T_x = T_{cl} = \frac{T_c}{1 - T_{bc} A_s A_c}. \]

The denominator has a similar significance as in the clear sky case and quantifies multiple scattering between the surface and the clouds. \( T_{bc} \) represents the atmospheric transmittance below the cloud, which is of minor importance, and \( A_c \) denotes the cloud albedo. The cloud transmittance is the decisive quantity in this expression. \( T_c \) and \( A_c \) are calculated by solving an equation system which follows from the radiation transfer parameterization. Details are omitted here for simplicity. The top-of-atmosphere broadband albedo turns out to be the most important input quantity for this equation system. It may be highly variable on small time scales depending on the daily evolution of the clouds. It is determined from the observed instantaneous reflectances in the 0.6\mu m, 0.8\mu m, and 1.6\mu m SEVIRI channels. For this purpose the spectral reflectances of an image scene are first transformed to broadband reflectance by applying a pre-defined set of conversion coefficients. Then the bi-directional reflectance model of [14] is used to convert the directional reflectance values into top-of-atmosphere albedo estimates. As an extension to the present method the cloud type, which is also delivered as a product by the Nowcasting-SAF software, may be added in the future as an additional piece of information for improving the employed parameterisation scheme.

The DSSF algorithm is planned to be applied to every image taken by the SEVIRI instrument. Figure 2 gives the results obtained with the prototype for the 28 July 2003 test data set. The evolution of the retrieved values for the cloud free regions mainly reflects the daily pattern owing to the solar geometry. In the presence of clouds, however, the down-welling radiation reaching the ground is considerably reduced. In this case the DSSF is strongly anti-correlated with the top-of-atmosphere reflectances: The brighter the clouds appear on the images, the more radiation is reflected by them and the less radiation reaches the ground.

4. PERSPECTIVES

The “Initial Operational Phase” of the Land-SAF project is foreseen to begin in early 2005. Albedo estimates will then be delivered on a daily basis and the down-welling radiation will be calculated every 15 minutes corresponding to the temporal frequency of the SEVIRI image acquisition. In this project phase the technical verification and the fine tuning of the algorithm interplay in the operational system will be emphasized. This may be a critical issue since the algorithms have only been tested in standalone mode up to now. Another important aspect will be the scientific validation of the results based on available ground measurements or by cross-comparison with other remote sensing data sets. At the development level the extension of the Land-SAF system and algorithms to the data provided by the AVHRR instrument on board of the Metop satellites of the future “European Polar System” will require major efforts. Thanks to the complementary geometrical configuration offered by the polar orbit its observations will be particularly valuable for constraining the BRDF model inversion and hence for improving the albedo product.
Figure 2. The series of images shows the evolution of the down-welling surface short-wave radiation on 28 July 2003 from 06:00 UTC (top left) to 18:00 UTC (bottom right). The middle right image depicts a processing flag corresponding to the result for 12:00 UTC. Here the green and yellow colours correspond to the cases in which, respectively, the clear and cloudy sky parameterisations were applied. For the latter the orange colour indicates a limiting condition in the solution of the equation system and most of the other colours listed in the legend correspond to special cases which do not occur frequently.
REFERENCES


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