ABSTRACT

The Satellite Application Facility for Land Surface Analysis hosted by the Portuguese Meteorological Institute in Lisbon generates and distributes value added satellite products for numerical weather prediction and environmental applications in near-real time. Within the project consortium Météo-France is responsible for the land surface albedo and down-welling short-wave radiation flux products. Since the beginning of the year 2005 Meteosat Second Generation data are routinely processed by the Land-SAF operational system. In general the validation studies carried out so far show a good consistency with in-situ observations or equivalent products derived from other satellites. After one year of operations a summary of the product characteristics and performances is given.

Key words: Surface Albedo; Down-welling Radiation; Land-SAF.

1. INTRODUCTION

The land surface albedo and down-welling surface short-wave radiation flux (DSSF) products are both derived from the 0.6 \( \mu \)m, 0.8 \( \mu \)m, and 1.6 \( \mu \)m channels of the SEVIRI instrument. Albedo maps are provided once a day based on the most recent cloud-free observations available. Instantaneous estimates of the short-wave radiation flux are calculated with a temporal frequency of 30 minutes. The products are currently classified as “pre-operational” which signifies according to the relevant EUMETSAT terminology that they are “able to satisfy the majority of applicable requirements” and have been considered “suitable for early distribution to SAF users with documented limitations”. Four continental windows (Europe, North of Africa, South of Africa, and South America) are separately processed in the Land-SAF system. The product files are disseminated in the native MSG/SEVIRI projection with a specified timeliness of three hours via the Land-SAF website (http://landsaf.meteo.pt/) and by the EUMETSAT broadcast system EUMETCast.

2. SURFACE ALBEDO

The surface albedo quantifies the fraction of incident solar radiation that is reflected by the Earth’s surface. It constitutes an important element for characterising the surface energy balance. Since the albedo is “relatively close” to the physical measurements obtained by remote sensing one can expect to retrieve this quantity with a reasonable accuracy.

2.1. Methodology

The retrieval scheme comprises four successive steps: First the measured top-of-atmosphere radiances delivered by the satellite instrument are corrected for atmospheric effects in order to convert them into the corresponding top-of-canopy (TOC) reflectance factor values. The spectral TOC-reflectances then serve as the input quantities for the inversion of a linear model of the bi-directional reflectance distribution function (BRDF) which quantifies the dependence on the illumination and observation geometry. Spectral albedo values in the instrument channels are determined from the angular integrals of the model functions with the retrieved parameter values. Finally, a narrow- to broad-band conversion is performed with a linear regression formula.

Technically the processing chain comprises two distinct modules - one for atmospheric correction and one for model inversion and directional and spectral integration. The atmospheric correction module is applied separately on each image directly after acquisition. The inversion and albedo calculation module, on the other hand, operates on a set of TOC-reflectance images collected during one day. By using the previous inversion result as a priori information in a recursive scheme, a temporal composition of the information over a longer time period can be achieved in order to guarantee the coherence and completeness of the product while still preserving a rather high temporal resolution. The physical and mathematical background of the algorithm is explained in the Product User Manual [1] available on the project website. Relevant references are also listed in this document.

Figure 2. Left: Example for the uncertainty estimates (total broad-band directional-hemispherical). Right: The quality (or processing) flag for the 15th of February 2006. The processed areas appear in green, light blue (continental water), or grey (snow), and unprocessed areas in blue (ocean) and yellow.
2.2. Product Characteristics

The albedo product is generated on a daily basis. It comprises spectral albedo estimates corresponding to the three used SEVIRI channels as well as broad-band albedo estimates for the visible \([0.4 \, \mu m, 0.7 \, \mu m]\), near infrared \([0.7 \, \mu m, 4 \, \mu m]\), and total short-wave \([0.3 \, \mu m, 0.7 \, \mu m, 4 \, \mu m]\) intervals. Full disk example images generated by re-composing the four continental windows are shown in Fig. 1. The provided quantities include the directional-hemispherical (or ‘black-sky’) albedo at local solar noon and, for the spectral and total broad-band estimates, also the bi-hemispherical (or ‘white-sky’) albedo. The latter is relevant for a completely diffuse sky while the former corresponds to the presence of direct illumination only.

For each of the albedo quantities an uncertainty estimate is calculated by propagating estimates for the non-correlated (random) part of the input data errors through the model inversion (see the Product User Manual for details). The resulting values therefore quantify the contribution to the uncertainty due to random error sources and depend mainly on the number of observations available, the estimated TOC-reflectance errors, and the respective angular configuration. Sources of systematic errors, e.g. instrument calibration, are not taken into account in these uncertainty estimates. An example is depicted in Fig. 2. The quality flag also shown in this figure contains information about the land/water mask, the processed regions and potential snow cover.

Finally, Fig. 3 shows the resulting time series for two example sites. The largest albedo changes are provoked by snowfall and snowmelt. The seasonal evolution of vegetation and changes of soil humidity also induce temporal variability of the surface albedo. The product time series may still contain high frequency noise caused by uncorrected atmospheric effects (e.g. due to variations of the aerosol concentration on small time scales) or by potential problems in the elimination of observations affected by clouds or cloud shadows. The rapidly increasing uncertainty estimates that can be seen for example at the end of December reflect the lack of information during periods without useful observations due to persistent cloudiness.

2.3. Validation

The albedo product has been (indirectly) validated by comparing it to the respective product derived from observations of the MODIS instrument [2], which is generally considered as being of good quality and suitable as a reference quantity. We re-projected the higher resolution MODIS product to the MSG/SEVIRI grid within the European continental window. For each original MODIS pixel the “closest” SEVIRI pixel was determined and afterwards the albedo estimates for all MODIS pixels assigned to a given SEVIRI pixel were averaged. The MODIS product is generated with a temporal composition window of 16 days. In order to reproduce the temporal characteristics as closely as possible with the MSG data, the internal TOC-reflectance files provided by the operational system were re-processed to generate daily albedo estimates, which were then averaged over the relevant MODIS period. For expressing the validation results in a quantitative way we determine the bias - defined as the average of the difference between the two estimates - and the standard deviation of that difference. The temporal evolution of the validation statistics from June 2005 to March 2006 is visualised in Fig. 4. The position of the symbols in the graphs indicates the bias, and the length of the bars (from the centre to each end) corresponds to the standard deviation as defined above. The calculation of the statistics was restricted to those pixels for which the Land-SAF uncertainty estimate is below 0.10 and the MODIS quality flag indicates a high confidence.

Until the month of October, the biases between the Land-SAF and MODIS products are negligible for the near infrared and total short-wave ranges and in the order of \pm 0.015 for the visible range. The standard deviation in absolute units ranges between 0.015 for the visible and up to 0.03 for the near-infrared and total short-wave ranges. However, owing to the lower level of the albedo values, the discrepancies in relative units are the largest for the visible broad-band estimates. The results tend to deteriorate during winter, which may be related to the unfavourable observation conditions (clouds, low solar elevation), the smaller number of data points entering the validation statistics, and the different treatment of snow cover in the Land-SAF and MODIS algorithms. The validation studies will be pursued in more detail by considering the spectral albedo quantities and by investigating the performance as a function of season, geographic position, surface type, snow cover, precipitation, or atmospheric composition.
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 \( \mu \text{m}, 4.0 \mu \text{m} \)] 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.

3.1. Methodology

The method for the retrieval of DSSF currently implemented in the Land-SAF system largely follows previous developments achieved at Météo-France in the framework of the SAF on Ocean & Sea-Ice [3]. Separate algorithms are applied for clear sky and cloudy sky situations. In the presence of clouds, the down-welling radiation reaching the ground is considerably reduced. The DSSF is strongly anti-correlated with the observable top-of-atmosphere reflectances: The brighter the clouds appear on the satellite images, the more radiation is reflected by them and the less radiation reaches the surface. In this case the top-of-atmosphere albedo is first calculated from the observed directional reflectance values by applying a broad-band conversion and an angular dependence model. The top-of-atmosphere albedo then serves as the most important input information for a simple physical model of the radiation transfer in the cloud-atmosphere-surface system. In the clear sky method the DSSF estimate is directly determined with a parameterisation for the effective transmittance of the atmosphere as a function of the concentration of atmospheric constituents. A more detailed description is given in the Product User Manual [4].

3.2. Product Characteristics

The DSSF estimates are currently calculated at intervals of thirty minutes based on every second slot of MSG/SEVIRI images. The values are derived for the instantaneous acquisition time of each image line. The SEVIRI scans are performed from South to North. At the Northern edge of the image the reference time therefore deviates from the nominal slot time by up to twelve minutes.

The DSSF product files comprise the physical estimate as well as a quality flag. An example is given in Fig. 5. In the visualisation of the quality information the green colour refers to the regions for which the clear sky method was applied, the yellow colour indicates the application of the cloudy sky method, and the blue colour marks the ocean for which no estimates are derived. The other colours appearing in the legend refer to particular cases which do not occur very frequently. The detailed signification of the bit codes is explained in the Product User Manual.

3.3. Validation

Up to now the validation studies have been based on the Baseline Surface Radiation Network [5] stations of Carpentras (France) and Toravere (Estonia) for which data concomitant with our product time series were already available. In addition we had access to in-situ data from ground measurement stations run by the Land-SAF project in Evora (Portugal) and by Météo-France in Roissy (France).

In general a good agreement between the satellite estimates and the in-situ data is observed when comparing the daily time series. A few examples are shown in Fig. 6. In the unfavourable case depicted for Roissy with a rather large dispersion, the discrepancies cannot entirely be attributed to deficiencies of the retrieval method. The example also illustrates the limitation of the validation approach when the conditions are highly variable in space and time. At least part of the dispersion is a consequence of comparing a local measurement with an estimate for a rather extended image pixel.

For validation purposes we also calculated daily averages of the Land-SAF DSSF product for the pixels corresponding to the validation sites. This is helpful for comparing the quantitative validation statistics to those

![Figure 4. Time series of the directional-hemispherical albedo validation statistics (in absolute units) from June 2005 to April 2006. Top: Visible broad-band. Middle: Near infrared broad-band. Bottom: Total short-wave broad-band.](image-url)
of other products which are not available as instantaneous estimates. The daily values are determined by averaging all available (day-time) Land-SAF DSSF estimates for a given day. For comparison only the in-situ measurements corresponding to the product time slots actually used for the determination of the “daily DSSF product” are then also averaged to obtain the corresponding “daily averaged in-situ measurement”. (Note that this prescription is useful only for our validation purposes, but not appropriate for generating a daily averaged DSSF product meant to be distributed and utilised. For this purpose the problems of temporal reference for the average and the treatment of missing data would have to be considered much more carefully.)

The temporal evolution of the statistical quantities - bias and standard deviation - for all four stations combined over the whole available validation period is shown in Fig. 7. Monthly sub-samples of the validation data points are considered in order to illustrate a possible temporal evolution of the product quality. From the top left to the bottom right the panels show the results for the data points processed with the clear sky method, for the cloudy sky method, for all processed day-time data points combined irrespective of the method applied, and for the daily averaged DSSF values which were calculated for validation purposes only as described above. The top left plot for clear sky also includes the bias values (but not the standard deviation) for morning and afternoon data points separately. Considering the whole validation period and all sites there is a small positive bias in the order of 5 Wm$^{-2}$ for both clear and cloudy sky situations. The standard deviation is in the order of 40 Wm$^{-2}$ for the clear sky and 115 Wm$^{-2}$ for the cloudy sky (instantaneous) estimates while it reduces to 30 Wm$^{-2}$ for the daily averaged values.

4. PERSPECTIVES

In general the validation results obtained so far show a good consistency with in-situ observations or equivalent products derived from other satellites. Nevertheless the present Initial Operational Phase still allows us to adjust the algorithms and implement some methodological improvements. In addition to continued validation studies we intend to test the application of the products in surface and NWP models in order to get a direct feedback for further development.

For the albedo algorithm minor adjustments of the narrow- to broad-band conversion relations may be required depending on the results of extended validation studies. In addition, the quality of the input information for the atmospheric correction scheme needs to be improved. In particular the presently employed climatology for the aerosol optical thickness should later be replaced by a dynamic aerosol product in order to remove from the surface albedo time series potential spurious fluctuations caused by unaccounted atmospheric variability.

The directional-hemispherical albedo is given for a reference angle corresponding to the local solar noon. We plan to provide a parameterisation which enables the user to calculate the diurnal albedo cycle. In addition to the currently available albedo product, which is suitable for near real time applications, we also envisage the implementation of a variant with different temporal characteristics based on the accumulation of the observations acquired within a “classical” temporal composition. Such an approach is appropriate for example for deriving a climatology of the variables characterising the surface properties.

After the launch of the first satellite of the MetOp series, the data acquired by the AVHRR instrument onboard will also be processed and exploited by the Land-SAF system. Owing to the complementary observation geometry resulting from the polar orbit, the additional information will be particularly beneficial for the albedo product - provided that technical problems such as geolocation and channel inter-calibration can be controlled with sufficient precision. It is planned to merge the data at the level of the TOC-reflectance factor by inverting the BRDF model with observations from both the SEVIRI and AVHRR instruments. Especially for high latitudes during winter this will significantly improve the constraints for model inversion and hence the quality of the result.

Concerning the DSSF estimates for cloudy sky conditions there is still some room for improvement by fine tuning and adapting some of the parameters used in the algorithm or by exploiting additional information such as the cloud type. For clear sky we envisage to re-formulate the currently applied parameterisation as a function of the aerosol optical thickness for which we expect that a dynamic estimate will be available in the near future in the framework of other projects.

In addition to the presently available instantaneous flux estimates it is planned to implement a daily averaged or integrated product during the forthcoming project phase. By taking into account the observations delivered by the polar-orbiting system this product could be improved and extended towards high latitudes beyond the region covered by the Meteosat disk.

REFERENCES

Figure 5. The DSSF estimate (left) and the corresponding quality (or processing) flag information (right) generated for the 15th of February 2006 at 12:00 UTC.

Figure 6. Examples for daily time series of DSSF estimates and in-situ measurements at the ground validation stations. The colour code of the dots is the same as for the quality flag in the previous figure.

Figure 7. Temporal evolution of bias and standard deviation between the Land-SAF DSSF estimates and ground measurements for all validation stations combined (Carpentras, Roissy, Evora, and Toravere).