Retrieving Essential Climate Variables over Land from Operational Surface Albedo Products

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Abstract – The main goal of this contribution is to help bridge the gap between available remote sensing products and large-scale global climate models. We present results from the application of an inversion method conducted using both MODIS and MISR derived broadband visible and near-infrared surface albedo products available during a full seasonal cycle. These results are derived for complex geophysical scenarios involving snow occurrence in mid and high-latitude 3-dimensional evergreen and deciduous forest canopy systems. Our results illustrate the capability of the inversion package to retrieve meaningful Essential Climate Variables (ECVs) over land complete with uncertainties along the year despite the rather high variability in the input products. This inversion package is able to cope with remote sensing flux products from different sources. Such a level of consistency between these fluxes is promising for future applications and promotes the design of integrated systems capable of assimilating various sources of information.

Keywords: Albedo, MERIS FAPAR; JRC-TIP; Assimilation.

1. INTRODUCTION

The accurate knowledge of the land processes controlling distribution and partition of solar radiant flux between the vegetation and the underneath soil layer is required to improve simulations of the soil-vegetation-atmosphere exchanges at various space and time scales of interest for climate, numerical weather prediction as well as carbon cycle models. The accuracy of the solutions to this radiation partitioning problem depends on the performance of the selected radiation transfer scheme, the availability of input remote sensing flux products and the quality of the retrieval procedure which makes optimal use of the available prior information.

Pinty etal. (2007) have devised and documented the performance of such a retrieval procedure on the basis of a set of applications conducted over mid-latitude sites. This procedure delivers a Gaussian approximation of the Probability Density Functions (PDFs) of the retrieved model parameter values together with a posterior covariance matrix. This information enables us to estimate the radiant fluxes simulated by a two-stream model (Pinty etal. 2006), including those that are not part of the measurement set, e.g., the fraction of radiation absorbed in the ground. The retrieval procedure known as the Joint Research Centre Two-stream Inversion Package (JRC-TIP) has been applied already against operational surface albedo products from MODIS, MISR on board the Terra platform and the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) product derived from the SeaWiFS and MERIS as well.

This contribution more specifically addresses the issue of the partitioning of solar radiation between the vegetation and soil layers in the more difficult but rather relevant case of tall spatially heterogeneous (3-D) forest canopies subject to significant changes in their background properties as a result, for instance, of the occurrence of snow in the winter and spring seasons (Pinty etal., 2008). Meanwhile, these changes offer challenging conditions to further test the JRC-TIP given that the main properties of the vegetation layer are expected to exhibit small (for environment dominated by evergreen forests) or smooth variations during the year (in the case of deciduous systems), unlike the albedo products which are quite sensitive to these drastic changes occurring on the forest floor. Our results illustrate the capability of the inversion package to retrieve meaningful Essential Climate Variables (ECVs) over land complete with uncertainties along the year despite the rather high variability in the input products.

2. OUTLINE OF THE JRC-TIP

Our formulation of the inverse problem is such that the solutions are combining all the available information, namely, 1) the prior knowledge on the PDFs of the model parameters with mean values and a covariance matrix expressing the uncertainty on this knowledge, 2) the physical constraints provided by the two-stream model and 3) the measurement set provided by remote sensing operational products, e.g., surface albedos.

The JRC-TIP delivers optimized solutions to the inverse problem in the form of posterior probability distribution for all parameters entering the two-stream model. These are approximated by Gaussian PDFs with mean values and covariance matrices. The latter are then propagated through the two-stream model to estimate the PDFs of flux quantities, i.e., the partitioning required to represent land surface processes. Technically, JRC-TIP relies on 1st and 2nd derivative information, which is efficiently provided via the automatic differentiation tool TAC++ (Voßbeck et al., 2008).

2.1 The Two-stream Model

The effective variables entering the two-stream model are, a spectrally invariant quantity, namely the Leaf Area Index (LAI) and, spectrally dependent parameters including the leaf reflectance and transmittance and background albedo. The effective LAI value expresses the capability of the vegetation layer to intercept direct radiation, and is thus associated with the probability distribution function of the canopy gaps. This quantity is generally measured

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in the field with standard optical devices. Accordingly, the two main parameters controlling the flux partitioning, i.e., the effective LAI and the true background albedo, can be estimated from in-situ measurements and this offers a practical means to evaluate the quality of the retrievals delivered by the inversion procedure.

2.3 The measurement set

The measurement set considered in the series of applications discussed here essentially includes the two broadband visible and near-infrared surface albedo products associated with both the MODIS (collection 4) and MISR (collection 6 from version 17 of the operational processor). The MODIS products are white sky albedos and only those delivered with good confidence levels are considered here. Surface albedo quantities similar to those from MODIS were generated at JRC from the MISR retrieved surface anisotropy parameters. All retrievals discussed here are based on the specification of an uncertainty of 5 % (relative) of the albedo products. Time-series of these 1 km resolution remote sensing products available for year 2005 over instrumented sites, e.g., Fluxnet, CarboEurope, exhibiting a variety of vegetation phenological cycles have been selected. In the present application, these sites are identified as Yakutsk (Russia; 62.25 N, 129.62 E), Hainich (Germany; 51.08 N, 10.45 E) and Le Bray (France; 44.72 N, 0.77 W) and they correspond to a deciduous needle leaf Larch forest, a deciduous broadleaf forest and an evergreen maritime pine forest, respectively.

3. RESULTS

The variability observed in the MODIS and MISR BHR values over the selected site (see Figures 1 to 3) is dominated by the occurrence of snow events at the end and beginning of the year. Under most of such conditions and as expected, the BHR values in the visible domain increase dramatically and reach a higher level than those estimated in the near-infrared domain. The good agreement between both MODIS and MISR derived product data sets is noticeable given the large variations depicted by the surface albedos, although some slight differences exist.

The FAPAR values estimated from the posterior model-parameter values are shown (open circles) together with their associated uncertainties inferred from the posterior covariance matrix (vertical lines). These figures reveal that :1) time-series in the retrieved FAPAR exhibit smooth variability as can be expected from the dominant vegetation type and cover and, consequently it shows that our inversion procedure is able to properly account for drastic changes in the measurement sets, i.e., the surface albedos, due to snow occurrence, 2) the FAPAR values retrieved from the MODIS and MISR albedos are in remarkable agreement with those delivered by the MERIS (violet crosses) operational processor (Gobron etal., 2007) as well as those generated from SeaWiFS (green crosses) using the JRC-FAPAR algorithm, 3) the FAPAR values generated by the operational MODIS (red crosses) processor exhibit a rather large and probably unrealistic intra-annual variability with 8-day composite values ranging from about 0.1 to 0.9, and finally 4) the values delivered by MISR (blue crosses) operational processor do not exibit any significant bias as is the case for MODIS but, in some instances, they show a large temporal variability and suddenly raise to high values, i.e., in the Spring time season.

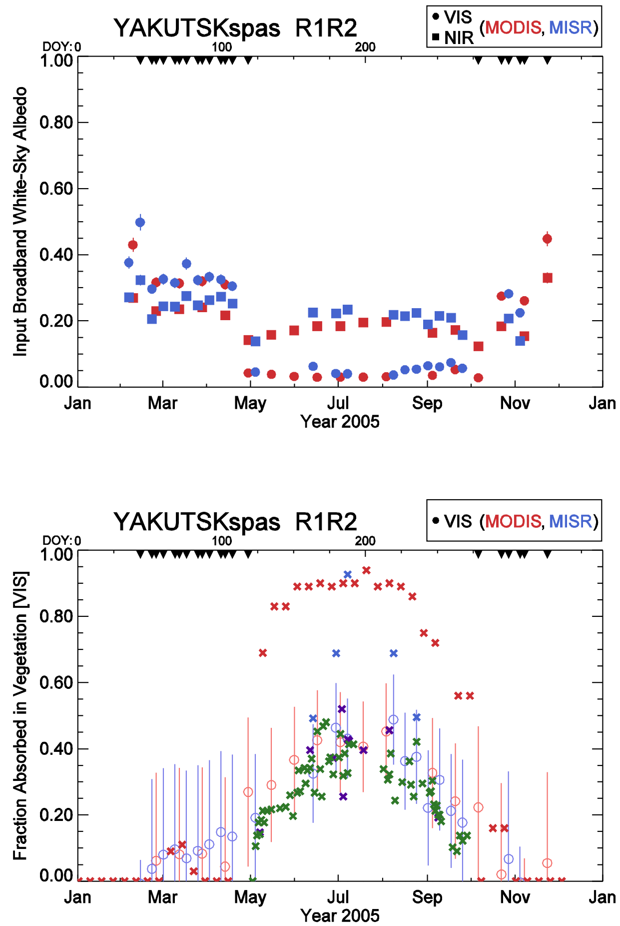

Figure 1. Top panel: time series of the surface albedo products. MODIS (MISR) derived values are featured in red (blue) color. Products estimated in the broadband visible (near-infrared) domain are depicted with full circles (squares). Triangles on the top axis mark snow events.
Bottom panel: time series of the fraction of absorbed radiation in vegetation by `green' material only in the visible domain (FAPAR) delivered by the JRC-TIP (open red and blue circles) and those generated from major operational products (crosses) for the sites identified as YAKUTSK. The red, blue, green and violet colors are for the MODIS 8-day composite, the daily MISR, the daily JRC-SeaWiFS and MERIS operational products, respectively. The open circles identify the values retrieved by the JRC-TIP using MODIS (red color) and MISR (blue color) broadband white sky albedos. The standard deviations associated with the PDF of the retrieved values are reported with vertical bars.

The performance of our inversion procedure to account properly for the temporal changes in the radiative properties of the forest background while maintaining smooth or no variation in LAI have been documented in Pinty etal. (2008). It was found that the background albedo values are capturing most of the variations observed in the surface albedo at the top of the canopy but with a

larger spectral contrast under occurrence of snow, i.e., the visible values get much larger than those retrieved in the broadband near-infrared domain. By contrast, in absence of snow, the leaf absorption (scattering) process in the visible (near-infrared) domain yields a much more limited, and even reversed, spectrally contrasted situation. These results have to be evaluated together with the retrieved LAI and associated uncertainties which, as pointed out before with the FAPAR product, show a very smooth temporal profile. The lack of retrieval or the retrieval of large unrealistic FAPAR values (such as in December over Le Bray) are generally a consequence of assigning too much weight on the prior information on the background spectral properties that probably turns out to be false i.e., snow covered versus snow-free conditions or conversely. It is noteworthy that, as a matter of fact, the JRC-TIP allows an evaluation of the snow conditions as well.
This ensemble of results illustrates our current ability to separate the radiation transfer processes controlling the relative contribution due to the vegetation layer from its background.

Figure 4 shows an RGB colored representation of outputs delivered by the JRC-TIP over Sicily from MODIS surface albedo products at the beginning of March (top panel), mid-April (middle panel) and mid-June (bottom panel) of year 2005, respectively. The three panels illustrate the capability of the JRC-TIP to deliver information of relevance for a number of remote sensing applications and, in particular, the monitoring of vegetation growth and decay over a full seasonal cycle.

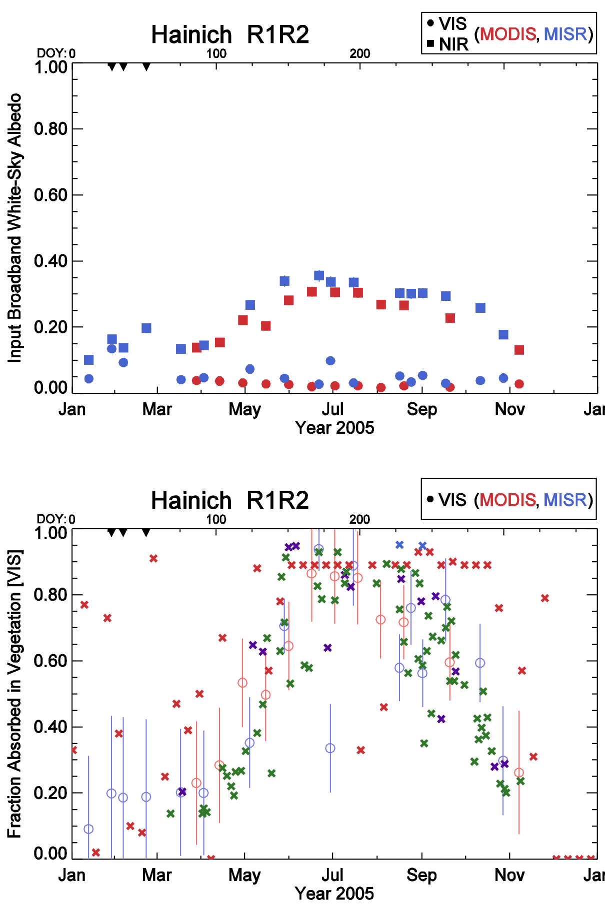

Figure 2. Same as Figure 1 but over the site of Hainich.

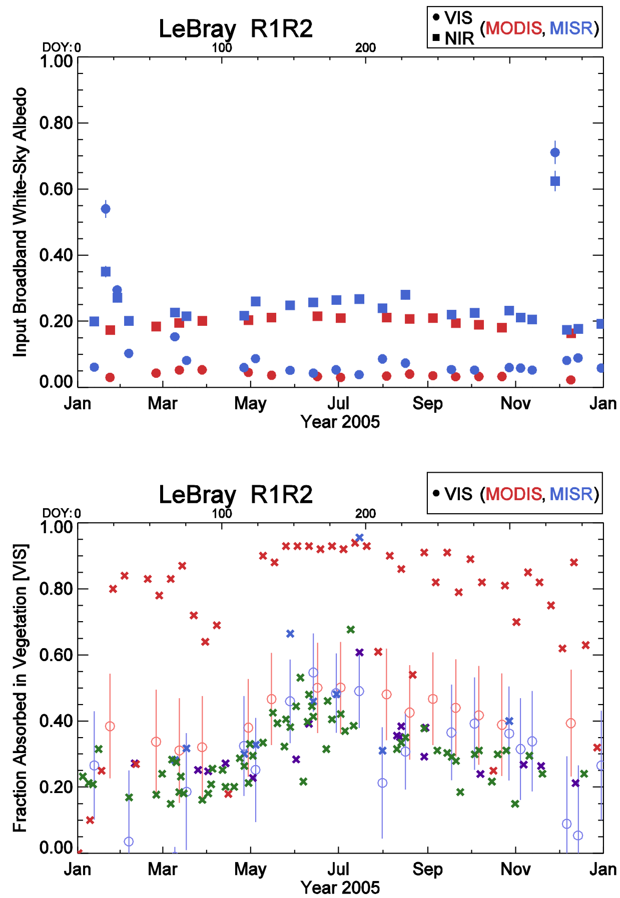

Figure 3. Same as Figure 1 but over the site of Le Bray.

4. CONCLUDING REMARKS

We have shown that our inversion procedure is able to reconcile remote sensing flux products from different sources, i.e., surface albedos from MODIS and MISR with the MERIS FAPAR product in this application. Such a level of consistency between these fluxes is promising for future applications and promotes the design of integrated systems capable of assimilating a variety of sources of information. A first step in this direction has been already taken and discussed in Pinty etal. (2007) where both surface albedos from MODIS-MISR and FAPAR products from SeaWiFS are used jointly to reduce the uncertainties on the retrieved 2-stream model parameters and notably on the LAI. Here we have shown that, in addition, the availability of a snow indicator is beneficial to the analysis of products generated under Winter and early Spring seasons, especially at high latitudes. It is worthwhile emphasizing that our inversion package fulfills the stringent requirements imposed by operational processing such as, reliability, robustness and computer efficiency.

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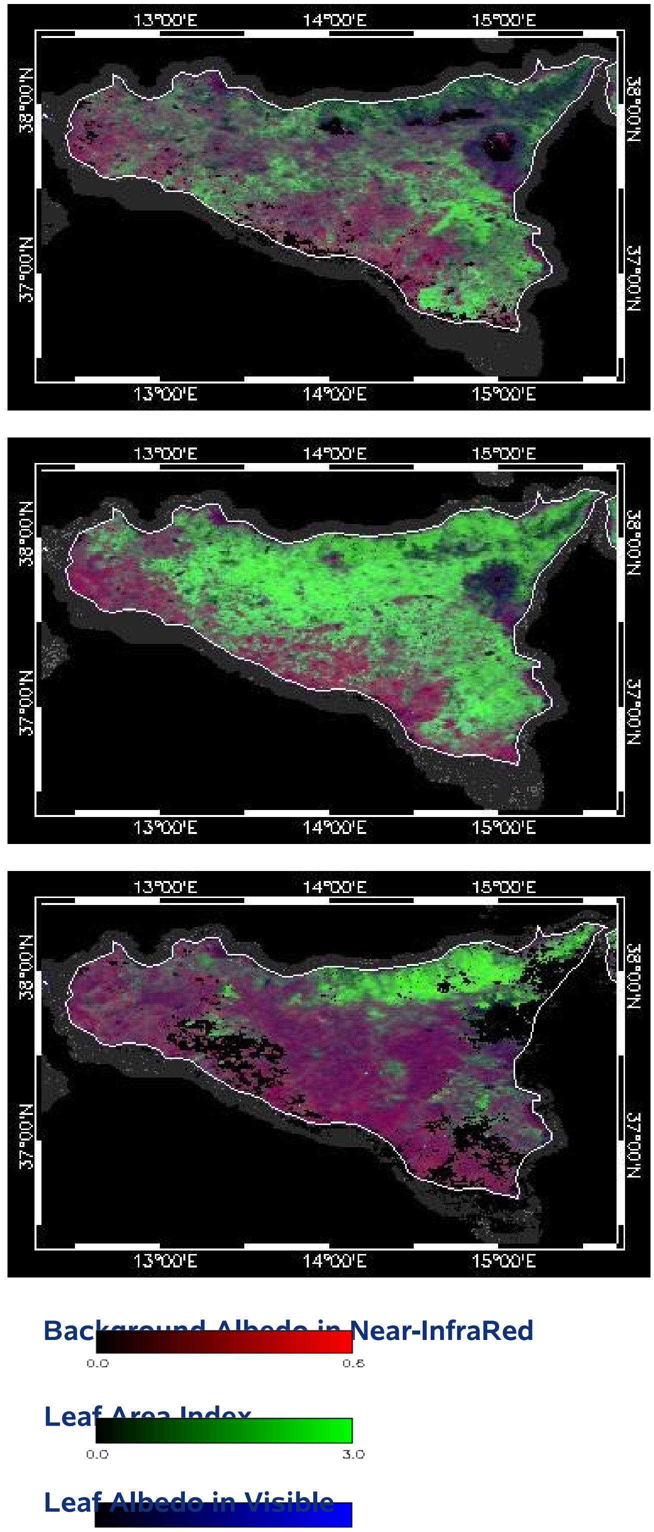

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