Lire la première partie de la thèse
Chapitre 5

Implementation in SURFEX

Contents

5.1 Introduction .......................................................... 109
5.2 Impact of changing albedo ............................................ 110
  5.2.1 Description of experiment ..................................... 110
  5.2.2 Results of changing albedo on energy flux components .... 111
5.3 Joint Assimilation of LAI, SSM and albedo ....................... 120
  5.3.1 Study station, model and observations ....................... 120
  5.3.2 Data Assimilation Scheme and Experiment setup .......... 120
  5.3.3 Results .......................................................... 123
5.4 Conclusion ........................................................... 130

5.1 Introduction

Surface albedo is an important parameter of surface model influencing energy balance. The impact of changing albedo on energy balance and hydrology components is worth to test. McCumber and Pielke (1981) performed sensitivity test (24-h simulations) in which soil albedo was free to vary as a function of surface moisture (Idso et al., 1975). Depending on the soil type, the authors reported a shift of the simulated surface temperature ranging between 1°C and +2.5°C. Cedilnik et al. (2012) found that change in surface albedo from climatology to daily analysed satellite products infers a modification of the surface temperature that can reach 1K in average over certain regions. The coupling bare soil albedo with soil moisture is tested using ORCHIDEE model (Gascoin et al., 2009a). It is demonstrates that implementing the effect of soil moisture on bare soil albedo importantly influences the surface fluxes at the monthly and annual scale. For example, the mean annual evaporation rate was increased by +12%. But even in the latest surface models, bare soil albedo dependence on soil moisture is not correctly accounted for. Herein, the dependence function of bare soil albedo with soil wetness developed in previous chapter is considered to test the impact of changing soil albedo on energy components.
Hitherto, soil moisture and biomass/LAI assimilation has been achieved through a SEKF(Simple Ensemble Kalman Filter) scheme developed at Meteo-France with ISBA-A-gs land surface model (Barbu et al., 2011; Draper et al., 2011; Mahfouf et al., 2009; Rüdiger et al., 2010). It can be expected that adding albedo as an extra observation might better constrain model status. In fact since it represents a flux, surface albedo products have higher precision comparing with LAI and SSM whose variations have an impact on surface albedo measurements. However, up-to-date ISBA-A-gs merely offers an albedo climatology, whose temporal variation is only driven by LAI in the context of ECOCLIMAP (Masson et al., 2003). Hence, a prognostic albedo is urgently required to fill the cap to capture the signals observed by satellite.

To meet such above requirements, a 2-stream radiative transfer scheme is employed as observation operator to build the bridge. Both Black Sky Albedo (BSA) and White Sky Albedo (WSA) can be simulated at VIS and NIR spectral range. They depend on (1) canopy structure parameter : Leaf Area Index (LAI), average leaf inclination angle (ALA) ; (2) leaf optical property : leaf reflectance ($\rho_l$), leaf transmittance ($\tau_l$) ; (3) surface soil moisture (SSM) ; (4) solar zenith angle (SZA) (only for BSA).

The novel prognostic albedo is assessed through comparing with MODIS and SEVIRI albedo product over France from 2007 to 2010. A joint assimilation strategy based on SEKF is proposed by digesting satellite observed albedo, LAI, soil moisture products into ISBA-A-gs model.

### 5.2 Impact of changing albedo

#### 5.2.1 Description of experiment

The objective of this experiment is to evaluate the impact of using alternative parameterization scheme of bare soil albedo in SURFEX with emphasis on soil moisture component. Through incorporating a ‘albedo-soil moisture’ dependence in SURFEX, it is expected to improve its modelling ability for energy balance. The relationship between surface albedo and moisture is represented by a set of three coefficients representing the best calibration between daily SEVIRI albedo product and in-situ soil moisture record at 12 SMOSMANIA stations. This relationship is extended to the whole France using the calibration from a representative station ‘Condom’ as it appeared to be a solid relationship well representative of south-western France. It is clearly deemed not necessarily appropriate for certain regions of France but the idea is rather here to conduct impact studies rather than searching for an accurate time evolving surface albedo pixel-based. The skin surface moisture is used, which is defined over the depth of bare soil evaporation.

In this respect, the impact of changing surface albedo on energy budget (net radiation, sensible heat, latent heat), surface moisture and surface temperature are evaluated via some dedicated model simulations. ISBA-A-gs model is running at a 6 hour step from 2007/08/01 to 2010/07/31, driven by the French forcing dataset SAFRAN. It yields totally 8602 points over France Metropolitan at SIM (Safran-Isba-Modcou) grid, within which each point represents around a circle with 8km radius. The initial condition is generated for the simulation through a spin-up, which is conducted during one year previously to the study period (from 2006/08/01 to 2007/07/31) until
equilibrium is reached. The principle equations relative to soil moisture and biomass evolution in SIM model can be found in Annexe B. Six outputs are evaluated over France, namely: (1) total albedo (TALB), (2) surface soil moisture (WG1), (3) Surface Temperature (TG1), (4) net radiation (RN), (5) sensible heat (H), and (6) latent heat (LE).

In the following, two experiments are conducted: (1) a reference case (hereafter denoted as 'REFE') using the default soil albedo climatology, and (2) a new case applying the changing albedo-moisture relationship (hereafter named as 'NEWS'). In the two cases, the same forcing, the same initial conditions and parameterization options are used, the only difference is the chosen soil albedo scheme, which would be the unique source causing the output difference.

5.2.2 Results of changing albedo on energy flux components

5.2.2.1 Spatial distribution over France

![Figure 5.1](image)

Figure 5.1 – Impact assessment on (a) TALB, (b) WG1, (c) TG1, (d) RN, (e) H, (f) LE over France. Scenario at 12:00 UTC on Aug 1, 2007 is rendered as illustration.
Spatial distribution of the impact is rendered in Fig. 5.1 for a selected day Aug 1, 2007. Since it has a diurnal variation with a peak around local solar noon, a scenario at 12:00 UTC is enhance the potential maximal influence. First, it can be observed some opposite tendencies between NEWS and REFE surface albedo values according roughly western and eastern part of France 5.1(a), highlighting sandy regions like the Landes forest near Atlantic ocean. Those geographical patterns are highly correlated with soil moisture WG1 5.1(d), as expected. Difference in albedo can vary up to 0.1 in absolute value whereas 0.05 is more common. As a remind, the quantity 0.05 falls within the GCOS specification for surface albedo, meaning that the climate models are not to day ready to accept satellite albedo of such precision. No distinct patterns are noticeable for the net radiation (RN), latent heat flux (LE) and even the surface temperature, probably because WG1 values are not high enough. However, sparse distribution of deviations between -0.1 and 0.1 W/m² for RN and LE reveal some impact with no systematic bias. Interestingly, the sensible heat flux (H) indicates marked spatial pattern negatively correlated with surface albedo. The explanation is that a wet surface albedo infers a cooling that changes the gradient of temperature between the surface and low atmosphere, which is however not so noti-
Impact assessment on (a) TALB, (b) WG1, (c) TG1, (d) RN, (e) H, (f) LE over France. Scenario at 12:00 UTC on Aug 1, 2007 is rendered as illustration.

5.2.2.2 Seasonal and Daily Variation

There is a value to assess the temporal variations of the impact of changing surface albedo on both daily and seasonally basis. A point with index 0001 is illustrated as an example (Fig. 5.2). It can be noticed that the time evolving bare soil albedo is decreased by 0.03-0.04 in absolute value around the year compared to the climatology value used in REFE. The NEWS RN is above REFE RN along the whole year, yielding a positive bias around 10 W/m². Moreover, H and LE show also the same trend that RN in respect to the use of NEWS or REFE scenario, but the difference is smaller compared to RN. However, the changing albedo has limited influence on surface moisture and surface temperature.

The temporal variation of the impact is can be evaluated daily and seasonally. A point with index 0001 is illustrated as an example (Fig. 5.2). It can be noticed that after changing, soil albedo is lower by 0.03-0.04 around the year than climatology value used in ‘REFE’. The ‘NEWS’
RN is obvious higher than ‘REFE’ along the whole year, yielding around 10 W/m\(^2\) difference. H and LE has the same trend causing higher values of ‘NEWS’ than ‘REFE’, while the difference is smaller comparing to RN. However, the changing albedo has limited influence on surface moisture and surface temperature.

Daily averaged variations of the different fields (Fig. 5.3) tell more compared to monthly averaged variations. As the remind, sensible heat (H) is caused by conduction and convection and with a warm surface and a cooler atmosphere, then the boundary layer heat will be conducted into the atmosphere. Thus, a slightly negative sensible heat as observed in the present situation would mean that it is being drawn from the surface to evaporate water, which appears here rather independent of the surface albedo (wet or dry) and of course more significant on TG1. But it is more usual to see positive sensible heat during the daytime as the surface warms the lower levels of the atmosphere. Interestingly, the major noticeable differences between NEWS
and REFE H and LE values are when values reach a peak. In fact, the rate of heat penetration (e.g. into the soil) is dependent on the thermal diffusivity, which is a combination of two factors (thermal conductivity and heat capacity, i.e. heat it takes to increase the temperature of the

---

**Figure 5.3** – Same as Fig. 5.2 but showing daily average instead of monthly average.
Same as Fig. 5.2 but showing daily average instead of monthly average.

In fact, the lower the value of the thermal diffusivity the lower the temperature rise further into the substance. So heat does get 10x further into wet soil compared to dry soil which may explain the differences noticed here. Worth recalling it is only a case study here and a more
realistic parameterization between soil albedo and wetness accounting for the soil texture could even amplify the observed features.

5.2.2.3 Diurnal variation
Figure 5.4 – Diurnal variation of bare soil albedo impact on (a) TALB, (b) WG1, (c) TG1, (d) RN, (e) H, (f) LE in 10 days since Aug 1, 2009.
Bare soil albedo impact on (a) TALB, (b) WG1, (c) TG1, (d) RN, (e) H, (f) LE in 10 days since Aug 1, 2009.
The same features noticed over France in average are observed here for the SMOSMANIA station of Condom (CDM). It can be noticed that a wet albedo yields a significant impact on RN, LE and H. The bias is positive with NEWS version of surface albedo for both RN and H. On the other hand, alternatively positive and negative bias are obtained for LE. Incidentally, a negative value of LE happening in mid-December indicate a net release of latent energy back into the environment because of the possible condensation or freezing of water. In general, it is observed here more signal for CDM station than over France. This is not surprising as the relationship between soil albedo and moisture was calibrated for CDM and it is thus a priori the more appropriate here.

5.3 Joint Assimilation of LAI, SSM and albedo

The objective of this study is two folded:
(1) to verify the addictive value and to what extent of albedo observation, it is required to improve assimilating the state variables LAI and SSM,
(2) to compare and evaluate the assimilation results using different combinations of observations.

5.3.1 Study station, model and observations

In this study, assimilation is performed at SMOSREX site, which is a long-term study station located near Toulouse, France. Within an 8-km circle around, the Plant Function Type (PFT) is dominated by grassland, with 33.25% SAND and 29.25% CLAY fraction according to HWSD. The station was initially designed for micro-wave validation of SMOS mission, therefore frequent in-situ soil moisture measurements are available from surface to root-zoon at 4 layers.

ISBA-A-gs land surface model with 'NIT' (nitrogen) option for photosynthesis is used to evolve surface parameters. Such configuration in fact allows for having an interactive LAI through the constrain of the behaviour of stoma to assimilate CO₂. The surface moisture is using a 3-L buck model, replying on a force restore equations to depict the evolution process. Detailed descriptions can be found in Annexe C.

The present assimilation scenario considers three input variables of observation: LAI, surface soil moisture(SSM) and set of albedo products. BioPAR LAI dataset is a product generated from SPOT/VEGETATION of 1km spatial resolution each 10 days. ASCAT soil moisture product is distributed at 12.5km resampled resolution each day, representing the status of satellite pass around local time 09:00H. SEVIRI sensor offers a daily surface albedo product on MSG geostationary grid, which is a retrieval using cloudless high-quality slots each 30min.

5.3.2 Data Assimilation Scheme and Experiment setup

SEKF scheme is a popular technique used for surface application due to its feasibility for non-linear model and efficiency. In this study, the framework proposed by Mahlouf et al. (2009)
is adopted to sustain an assimilation of LAI, SSM and albedo products. The whole process for propagation and analysis is illustrated in a flow chart (Fig. 5.5). The notion and associated errors for state and observation variables are listed in table 5.2.

The first step is propagation of the state variables. It consists in an update of the state variables achieved using land surface model ISBA-A-gs, that is integrated in the modelling platform SURFEX. The model is running offline at the SMOSMANIA grid point using SAFRAN as forcing. Integration step is set to be 24 hours for simulation output, and the temporal node is set to be 06:00 UTC. Initial conditions are obtained through one year spin-up for 2007/01/01. The updating process is represented by the following equation:

$$X_b^t = M(X_b^{t-1})$$

Here, $M$ is the matrix standing for model propagation through SURFEX, which is capable to evolve state variable at temporal node $(t-1)$ : $X_b^{t-1}$ to $t$ : $X_b^t$. It is a non-linear complicated model representing many interactive biophysical and hydrological processes. Since it is difficult
to obtain an explicit expression for the adjoint model, TLM (Tangent Linear Model) is used for the sake of linearization. A perturbation is given for each state variable in order to generate 'perturbed' simulation.

\[ X_b = [LAI, SSM]^T \]  

(5.2)

In this experiment, only LAI and SSM are considered as state variables. The initial corresponding background error covariance \( B \) can be represented by a diagonal matrix, omitting the interactions between the two:

\[ B = \begin{bmatrix} 0.2^2 & 0 \\ 0 & 0.04^2 \end{bmatrix} \]  

(5.3)

The second step is analysis. This process combines the observations and background information, and derive an analysis solution for state variables using the background error and observation error matrix, which can be represented as follows:

\[ X_a^t = X_b^t + K(y - H(X_b^t)) \]  

(5.4)

where, \( y \) denotes observation, \( H \) is the observation operator, \( K \) represents the gain. \( X_a^t \) and \( X_b^t \) are analysed and background state variable vectors, respectively.

The observations \( y \) is defined in this experiment as:

\[ y = [LAI, SSM, DH_{VI}, DH_{NI}, DH_{BB}, BH_{BB}]^T \]  

(5.5)

Observation operator \( H \) is correspondingly described as:

<table>
<thead>
<tr>
<th>Obs Annotation</th>
<th>Physical Meaning</th>
<th>Range</th>
<th>Sigma (Obs error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAI</td>
<td>leaf area index</td>
<td>( \mathbb{R}[0.0,10.0] )</td>
<td>0.20</td>
</tr>
<tr>
<td>WG1</td>
<td>surface water content</td>
<td>( \mathbb{R}[0.0,1.0] )</td>
<td>0.04</td>
</tr>
<tr>
<td>DH_VI</td>
<td>visible black sky albedo</td>
<td>( \mathbb{R}[0.0,1.0] )</td>
<td>0.05</td>
</tr>
<tr>
<td>DH_NI</td>
<td>nir-infrared black sky albedo</td>
<td>( \mathbb{R}[0.0,1.0] )</td>
<td>0.05</td>
</tr>
<tr>
<td>DH_BB</td>
<td>shortwave black sky albedo</td>
<td>( \mathbb{R}[0.0,1.0] )</td>
<td>0.05</td>
</tr>
<tr>
<td>BH_BB</td>
<td>shortwave white sky albedo</td>
<td>( \mathbb{R}[0.0,1.0] )</td>
<td>0.05</td>
</tr>
</tbody>
</table>
The observation operator is identity matrix for LAI and SM, while being non-linear for albedos. Here, $f_{DH\_VI}$, $f_{DH\_NI}$, $f_{DH\_BB}$, $f_{BH\_BB}$ are the functions linking WSA and BSA with state variables (LAI, SSM). They can be simulated through a radiative transfer model for different spectral range. Similarly to the model, TLM is again used for linearization.

The gain $K$ is calculated as:

$$K = BH^T(HBH^T + R)^{-1}$$  \hspace{1cm} (5.7)

Here, $R$ is the error covariance matrix for observations. It is set by experience as follow:

$$R = \begin{bmatrix}
0.2^2 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.04^2 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.05^2 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.05^2 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.05^2 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.05^2
\end{bmatrix}$$  \hspace{1cm} (5.8)

Background error covariance can be evolved through:

$$B_t = MB_tM^T + Q$$  \hspace{1cm} (5.9)

Here, $Q$ denotes the model representation error. Due to the difficulty to estimate, it is omitted in this study. $M$ is the matrix corresponding to TLM for the model.

Various possible combinations of observations are tested for their efficiency to constrain state variables. This leads to 4 experiments as listed in table 5.2.

### 5.3.3 Results

Assimilated LAI is found to be between observation and simulation for all situations except Experiment 3 (fig. 5.6). Actually, this seems to indicate that knowledge of WG1 is mandatory to achieve a realistic simulation. Furthermore, now replacing LAI by WG1 (purpose of Experiment 2), which means no state variable LAI included, has poor effect as SIMU and ASSI LAI values are quite close. Hence, the error compared to OBS LAI is the largest. This just translates the fact that albedo is constraining state variable LAI not as well as LAI observation, as somewhat
Table 5.2 – Presentation of the four experimental scenarios for assimilation.

<table>
<thead>
<tr>
<th>VAR/EXP</th>
<th>EXP1</th>
<th>EXP2</th>
<th>EXP3</th>
<th>EXP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WG1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>LAI</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DH_VI</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>DH_NI</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>DH_BB</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>BH_BB</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: 1 means that the type of observation is selected, while 0 denotes not.

Figure 5.6 – Comparison between the 4 experiments for LAI assimilation.

Expected. Worth recalling here that LAI and albedo are issued from different projects, which could have some effect in regard to their degree of consistency. But LAI BioPAr is likely the best offer in term of spatial resolution while the albedo time frequency from SEVIRI is well answering
the needs of assimilation exercise. Compared to the actual assimilation of reference (Experiment 4 without any albedo), Experiment 1 (with albedo) aims at raising LAI values at the onset of the cycle. This yields a positive effect particularly in 2009 while it seems to slightly degrade the situation for other years. Generally speaking, this can be deemed promising since an impact is noticeable whereas more investigation is probably needed.

As for SSM (Fig. 5.7), the outcomes from visual inspection is less conspicuous than for LAI. The best result is nonetheless obtained fro Experiment 1 with albedo consideration in addition to the assimilation of reference classically implemented (Experiment 4 with SSM and LAI only).

Using albedo values for diagnostic (Fig. 5.8), assimilation with scenario of Experiment 1 (albedo consideration) always provide best statistical results of comparison. Not surprisingly, this means with actual state variables (LAI SSM), the construction of a prognostic albedo is not relevant if it is accompanied by an assimilation scheme of the satellite observed surface albedo.

Figure 5.7 – Same as Fig. 5.6 for SSM.
This is proven to be valid here for all broadband spectral albedos.

At the end of this exercise, one key question is the best choice of the observations. Also what is the difference among various combinations of observations? To answer these two questions, the RMSEs of each variable for the four experiments are listed in table 5.3 referring an open-loop simulation. Generally every assimilation leads to a lower rmse comparing to simulation, which confirms the benefit of integrating observations to constrain surface variables. Further, it can be found that Experiment 1 achieves lower rmse for most variables, which might indicate this combination is better than the others. Experiment 3 is losing constrain for albedo, which can be identified from Fig. 5.8, Fig. 5.9, Fig. 5.10, Fig. 5.11.
Figure 5.9 – Same as Fig. 5.6 for DH_NI.

Table 5.3 – Summary of RMSE results for the 4 experiments.

<table>
<thead>
<tr>
<th>RMSE</th>
<th>SIMU</th>
<th>EXP1</th>
<th>EXP2</th>
<th>EXP3</th>
<th>EXP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WGI</td>
<td>0.0514</td>
<td>0.0504</td>
<td>0.0506</td>
<td>0.0510</td>
<td>0.0507</td>
</tr>
<tr>
<td>LAI</td>
<td>0.8878</td>
<td>0.5489</td>
<td>0.7525</td>
<td>0.6999</td>
<td>0.5068</td>
</tr>
<tr>
<td>DH_VI</td>
<td>0.0187</td>
<td>0.0182</td>
<td>0.0207</td>
<td>0.0277</td>
<td>0.0209</td>
</tr>
<tr>
<td>DH_NI</td>
<td>0.0513</td>
<td>0.0385</td>
<td>0.0553</td>
<td>0.0827</td>
<td>0.0522</td>
</tr>
<tr>
<td>DH_BB</td>
<td>0.0307</td>
<td>0.0256</td>
<td>0.0322</td>
<td>0.0457</td>
<td>0.0312</td>
</tr>
<tr>
<td>BH_BB</td>
<td>0.0319</td>
<td>0.0359</td>
<td>0.0247</td>
<td>0.0373</td>
<td>0.0284</td>
</tr>
</tbody>
</table>
Figure 5.10 – Same as Fig. 5.6 for DH_BB.
Figure 5.11 – Same as Fig. 5.6 for BH_BB.
5.4 Conclusion

The relationship between soil albedo and soil moisture calibrated from in-situ measurements (Chapter 4) has been integrated into SURFEX. The impact of the change of the surface albedo parameterization for bare soil patch is tested using the forcing SAFRAN database. The energy fluxes (net radiation, sensible heat, latent heat) as well as surface temperature were simulated for two versions (REFE for dry soil albedo and NEWS for possible wet soil albedo) were compared over France and then SMOSREX station near Toulouse.

Daily variations of energy fluxes are examined at 12:00H local time during one year 2007, which show a clear difference between REFE and NEWS. Diurnal variation is also examined for these energy components and surface temperature, which shows an enhanced difference around noon.

These results confirm the importance of accurate surface albedo description in surface model for a better determination of energy fluxes and surface temperature. The impact of integrating ‘surface albedo-moisture’ relationship will improve the water cycle. However, comparison of in-situ measurements should be more investigated to verify whether the time evolving surface albedo will provide the flux values more approaching the reality. Since the change of energy exchange, surface temperature and moisture have a feedback effect to atmosphere, coupled surface and atmosphere model would give a more physical-correct simulation comparing to offline.

The advent of accurate albedo satellite datasets is in favor of an assimilation into surface model of this state variable provided it well combines the model and observations. Herein, a SEKF method is employed over one station SMOSREX at 8 km scale as proof of concept of assimilating SEVIRI spectral albedos into ISBA-A-gs model. LAI and SSM are treated as state variables in this case, while a Radiative Transfer Model (RTM) is applied to derive TOC albedo. It is found that the assimilation with state variables LAI and SSM only. More insight is needed but this first initiative offers interesting perspectives.
Chapitre 6

Conclusion and Perspectives

Albedo climatology used by ISBA-A-gs land surface model is assessed with daily MODIS and SEVIRI satellite products over France. Daily MODIS albedo is generated from MODIS 8 day BRDF/Albedo standard product and daily directional reflectance after a series of processing. The comparison of the three datasets at 8km spatial resolution and daily temporal scale reveals that: (1) daily MODIS is comparing favorably with SEVIRI product although it is sometimes higher at winter and early spring period, (2) albedo climatology used by ISBA-A-gs model has distinct difference with both MODIS and SEVIRI daily albedo products. This conclusion encourages the improvement of albedo parameterization to generate a prognostic albedo in ISBA-A-gs.

For parameterization in land surface models, soil and vegetation albedo are commonly requested to be separated. To fulfill this requirement, two types of methods are explored to generate soil background albedo and vegetation albedo from satellite products: static method and dynamic method. Two global soil background albedo datasets generated using the former method are compared: CNRM and SWANSEA. Spatial patterns are found to be consistent. A dynamic retrieval method is proposed using 2-stream model, soil background albedo and leaf single scattering reflectance are retrieved over France.

Daily SEVIRI albedo is found to be sensitive to in-situ surface moisture measurement, which might serve as proxy. Using the exponential function, this daily albedo is used to do parameterization with surface soil moisture at 12 SMOSMANIA stations at south-western France. Regression show a promising fulfill of observation and exponential empirical model. Calibrated coefficients are further linked to soil texture.

Canopy vegetation albedo is linked with leaf chlorophyll content through calibration of PROSAIL model. It is found that in VIS domain, canopy albedo can be parameterized as a simple function depending merely on LAI and Cab. This parameterization adds the dynamic effect due to chlorophyll absorption, therefore is expected to better capture the temporal variation due to leaf color change, particularly during germinate and senescence stage. Moreover, leaf chlorophyll content is found to be closely related to leaf nitrogen content, which can be predicted by
land surface model. If the relationship of canopy albedo and leaf nitrogen content can be established at ecosystem level, it is possible to evolve leaf chlorophyll content through model prediction.

Finally, a prognostic total albedo based on surface soil moisture and leaf chlorophyll content is introduced. This parameterization scheme is verified using satellite products and in-situ measurements at Majadas station. The 'surface albedo-soil moisture' relationship is calibrated with SEVIRI albedo product and in-situ soil moisture, which shows robust satisfaction using exponential function. Vegetation canopy albedo is linked with Leaf Chlorophyll Content using MERIS albedo at 560nm and field measured Cab.

Following the confirmation at site-level validation, the impact of this new albedo scheme is evaluated in SURFEX over France running offline with SAFRAN as forcing. Through incorporation on an 'albedo-soil moisture' dependence in SURFEX, improvements are shown for its modeling ability for energy balance. The energy fluxes (net radiation, sensible heat, latent heat) and surface temperature simulated by the model through these two schemes are showing distinct seasonal and daily variation.

With the coming of the prognostic albedo in SURFEX, it is foreseen to assimilate satellite albedo products into land surface model as ISBA-A-gs. Soil moisture and biomass/LAI assimilation has been achieved through a Simple Extended Kalman Filter (SEKF) scheme developed at Meteo-France with ISBA-A-gs. Adding albedo as an extra observation might better constrain model status since albedo products commonly have higher precision comparing with LAI and SSM. Moreover, the inter-link of bare soil albedo with surface soil moisture, as well as the chlorophyll incorporation might add to the feedback existing between hydrology, energy transfer processes.

Improved observations are expected to be provided by next generation satellites of Sentinel family, which is designed by ESA serving for Global Monitoring for Environment and Security (GMES) program. This constellation consists of a series of earth-observing satellites as a success of ERS-1, ERS-2 and Envisat, offering long term data records for climate studies. The high spatial resolution (10m scale) and adequate temporal resolution would benefit the sub-pixel parameterization and improve the description of temporal variation in land surface model. Assimilation of such datasets would better constrain the relative state variables (e.g. albedo, LAI, soil moisture) and define its uncertainty. A prototype of this assimilation system is shown by Lewis et al. (2012).

Analysed surface variables are important for Numerical Weather Prediction and climate studies. Through coupling the land surface model and NWP model, the change in near surface fields as 2m Humidity and 2m Wind Speed is worth to be examined. For climate model, surface albedo is an important variable for long-term energy balance. With the updated scheme, it is expected to alter energy flux estimation in climate models.
Chapitre 7
Conclusion et Perspectives

Dans cette étude, l’albédo climatologique utilisé dans le modèle de surface ISBA-A-gs a tout d’abord été évalué sur le domaine France au travers d’une comparaison avec les produits d’albédo journalier du satellite géostationnaire SEVIRI à 4km et du satellitaire polaire MODIS à 1km, ce dernier étant constitué à partir d’une méthode originale inhérente à ce travail. En effet, ils ont été réalisés à partir des albédos standard MODIS à 8 jours qui sont mis à disposition au même titre que le produit BRDF (Bidirectional Reflectance Distribution Function). La réactualisation quotidienne de ce produit albédo a été faite à partir de la radiométrie issue des passages d’orbite MODIS. La comparaison des 3 produits rééchantillonnés sur une grille de 8km - pour être compatibles avec la finesse du modèle ISBA-A-gs, a permis d’en tirer les enseignements suivants : (1) l’albédo MODIS journalier se compare favorablement avec le produit SEVIRI bien qu’il se situe sensiblement au dessus durant les périodes hivernales et préprintanières, la raison étant due à une géométrie solaire différente ; (2) l’albédo climatologique utilisé ce jour dans le modèle ISBA-A-gs montre clairement des différences avec les 2 produits satellitaires. Cet état de fait plaide en faveur d’une amélioration de la paramétrisation de l’albédo de surface dans ISBA-A-gs afin d’obtenir un albédo pronostique plus proche des observations spatiales.

Pour la paramétrisation de l’albédo dans les modèles de surface, il est généralement requis que les albédos du sol nu et de la végétation soient séparés. Afin de répondre positivement à ce besoin, 2 méthodes ont été explorées afin de générer distinctement les albédos de sol nu et végétation à partir des observations spatiales : une méthode statique et une méthode dynamique. Pour le volet albédo statique, 2 jeux de données globaux ont été comparés, celui mis en œuvre dans cette étude et celui généré par l’université de SWANSEA. En règle générale, on retrouve les mêmes structures spatiales de façon consistante. Ensuite, pour le volet albédo dynamique, la méthode proposée repose sur un modèle physique du transfert radiatif à 2 flux, à partir duquel l’albédo du sol nu et l’albédo de simple diffusion des feuilles sont restitués sur le domaine France.

Le produit albédo journalier de SEVIRI se trouve être sensible à l’état d’humidité superficielle du sol nu, ce qui plairait en faveur de son utilisation comme proxy du contenu en eau. Il a ensuite été considéré une loi d’atténuation de type exponentielle pour l’albédo journalier en fonction de l’humidité du sol nu mesurée sur le réseau des 12 stations SMOSMANIA du sud-
7. Conclusion et Perspectives

ouest de la France. Une méthode d’étalonnage mise en place montre que l’évolution de l’albédo de sol nu ainsi simulé est très bien corrélée avec celle des albédos satellitaires, dans la limite d’une végétation faiblement ou nullement couvrante. Il semble qu’il existe alors des perspectives de relier les coefficients liant albédo et humidité avec la texture du sol mais il n’a pas été possible d’aller plus loin dans cette étude car cela dépend de l’échelle du paysage.

Une fois réglée la loi d’évolution de l’albédo du sol nu, il a été développé un albédo de la végétation dérivé de la chlorophylle via un étalonnage avec le modèle PROSAIL. On trouve pour le domaine visible que l’albédo du couvert végétal peut être paramétré à partir de fonctions simples dépendant du LAI et de la chlorophylle, ce qui a pu être validé dans cette étude à l’aide de vraies données. Cette paramétrisation ajoute un effet dynamique du à l’absorption par la chlorophylle. Plus loin, il est attendu de mieux capturer ensuite la variation temporelle due au changement de couleur de la feuille, particulièrement durant la germination et la sénescence. Le contenu en chlorophylle des feuilles est étroitement relié au contenu en azote, ce qui peut être prédit dans une certaine mesure par les modèles de surface. De fait, si les relations entre albédo de la canopée et azote des feuilles peuvent être établies à l’échelle de l’écosystème, il paraît possible de prévoir et mieux contrôler l’évolution de l’albédo de la végétation au travers du contenu en chlorophylle, ce qui ouvre des perspectives nouvelles intéressantes.

Au final, un albédo pronostique fondé sur l’humidité superficielle du sol et la chlorophylle de la feuille est développé pour être testé. Dans un premier temps, la validation est réalisée à partir de données à la fois in situ et satellitaires du site de Majadas (Espagne) qui représente l’écosystème naturel ‘deseha’ de grande échelle. La relation albédo de surface est alors calibrée avec SEVIRI pour l’humidité, de façon cohérente avec les lois d’atténuation exponentielle trouvées pour les stations SMOSMANIA du sud de la France. Ici, les mesures en chlorophylle réalisées permettent d’aller plus loin puisque la relation étalonnée entre l’albédo et la chlorophylle avec PROSAIL est validée en pratique avec la radiométrie de MODIS prise à 560nm.

Faisant suite à la confirmation d’une validation in situ, l’impact d’un nouveau schéma d’albédo est évalué dans SURFEX sur la France à l’aide de simulations offline et du forçage SAFRAN. Au travers de l’incorporation d’un albédo sol nu dépendant de l’humidité dans SURFEX, des améliorations sont mises en évidence au regard de la capacité du modèle à reproduire correctement le bilan d’énergie. Ces flux d’énergie (rayonnement net, chaleurs sensible et latente) et de température de surface sont simulés par le modèle SURFEX au travers de 3 schémas qui exhibent distinctement les tendances journalières et saisonnières.

Avec la formulation d’un albédo pronostique dans SURFEX, il a ensuite été réalisé une étude préliminaire (un seul site pilote étudié) afin d’assimiler les produits satellitaires d’albédo dans le schéma de surface ISBA-A-gs. L’humidité de surface et les paramètres biomasse/LAI sont assimilés à l’aide d’un Simple Extended Kalman Filter (SEKF) déjà existant pour ISBA-A-gs. L’ajout du produit albédo de surface joue comme étant une observation additionnelle permettant d’ajouter une meilleure contrainte au modèle car l’albédo en tant que flux est généralement d’une meilleure précision comparée au LAI et à l’humidité SSM. En conséquence, le lien étroit entre albédo du sol nu et humidité d’une part, et chlorophylle et végétation d’autre part, renforce les
effets retour positif avec l’hydrologie, et les processus de transfert d’énergie.

Une amélioration des observations est programmée avec la génération à venir des satellites de la famille des Sentinelles de l’ESA qui permettra notamment de renforcer la mise en place des services Copernicus. Cette constellation consiste en une série de satellites d’observation de la Terre tel les précurseurs ERS-1, ERS-2 et ENVISAT qui ont connu un vif succès, par lâme même offrant des séries long terme de données au bénéfice des études climatiques. La haute résolution spatiale prévue pour du global avec Sentinel-2 (pixel de 10m) avec une revisite fréquente va permettre de parfaire les paramétrisations sub-pixel et ainsi améliorer la description de la variation temporelle des modèles SVAT de la surface. En effet, l’assimilation de tels jeux de données servira à mieux contraindre les variables d’état qui en dépendent (i.e. albédo, LAI, humidité du sol) et ainsi mieux définir leur incertitude. Les variables de surface analysées sont importantes pour les modèles de type Numerical Weather Prediction (NWP) et l’étude du climat en général. Au travers du couplage entre modèle de surface et modèle NWP, les changements opérés près de la surface des champs d’humidité et de la température à 2m nécessiteront une nouvelle analyse. Au regard des modèles de climat, l’albédo de la surface est donc une variable clé déterminante pour le bilan d’énergie sur le long terme. Avec un schéma de surface amélioré grâce à des informations auxiliaires en plus grand nombre et de qualité croissante, il peut être raisonnablement espéré de progresser encore dans les prochaines années dans la connaissance et la détermination de l’estimation des flux d’énergie dans les modèles de climat.
Liste of Acronyms

ADEOS  Advanced Earth Observing Satellite
ALA    Average Leaf inclination Angle
AOD    Aerosol Optical Depth
ARPEGE Action de Recherche Petite Echelle Grande Echelle
ATBD   Algorithm Theoretical Basis Documents
AVHRR  Advanced Very High Resolution Radiometer
BB     Board Band
BHR    Bi-Directional Reflectance
BOREAS Boreal Ecosystem Atmosphere Study
BRDF   Bidirectional reflectance distribution function
BRFs   Bidirectional Reflectance Factors
BSA    Black Sky Albedo
BSRN   Boulder Science Resource Network
CCRS   Canada Centre for Remote Sensing
CCSM3  Community Climate System Model Version 3
CDRs   Climate Data Records
CEOS   Global Earth Observing System
CERES  Clouds and Earth’s Radiant Energy System
CGMS   Coordination Group for Meteorological Satellites
CLC    CORINE Land Cover
CLM    Common Land Model
CMG    Climate Modeling Grid
CNES   Centre National d’Etude Spatiales
CNRM   Centre National de Recherches Météorologiques
DART   Discrete Anisotropic Radiative Transfer Model
DVGM   Dynamic Global Vegetation Model
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EALCO</td>
<td>Ecological Assimilation of Land and Climate Observations</td>
</tr>
<tr>
<td>ECMWF</td>
<td>European Centre For Medium-Range Weather Forecasting</td>
</tr>
<tr>
<td>ECVs</td>
<td>Essential Climate Variables</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>European Environmental Satellite</td>
</tr>
<tr>
<td>EOS</td>
<td>Earth Observing System</td>
</tr>
<tr>
<td>ERBE</td>
<td>Earth Radiation Budget Experiment</td>
</tr>
<tr>
<td>ERS-1</td>
<td>European Remote Sensing Satellite 1</td>
</tr>
<tr>
<td>ERS-2</td>
<td>European Remote Sensing Satellite 2</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>ESM</td>
<td>Earth System Model</td>
</tr>
<tr>
<td>FAO</td>
<td>Food And Agriculture Organization</td>
</tr>
<tr>
<td>FIRS</td>
<td>Fourier Transform Infrared Sounder</td>
</tr>
<tr>
<td>FPAR</td>
<td>Fraction of Photosynthetically Active Radiation</td>
</tr>
<tr>
<td>GCOS</td>
<td>Global Climate Observing System</td>
</tr>
<tr>
<td>GEO</td>
<td>Geosynchronous Earth Orbit</td>
</tr>
<tr>
<td>GEWEX</td>
<td>Global Energy And Water Cycle Experiment</td>
</tr>
<tr>
<td>GIEC</td>
<td>Intergovernmental Panel on Climate</td>
</tr>
<tr>
<td>GLASS</td>
<td>Global Land Atmosphere System Study</td>
</tr>
<tr>
<td>GMES</td>
<td>Global Monitoring for Environment and Security</td>
</tr>
<tr>
<td>GMS</td>
<td>Geostationary Meteorological Satellite</td>
</tr>
<tr>
<td>GO</td>
<td>Geo-optical</td>
</tr>
<tr>
<td>HDF</td>
<td>Hierarchical Data Format</td>
</tr>
<tr>
<td>IGBP</td>
<td>International Geosphere-Biosphere Program</td>
</tr>
<tr>
<td>IGPO</td>
<td>International GEWEX Program Office</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel On Climate Change</td>
</tr>
<tr>
<td>IRR</td>
<td>Integrated Requirements Review</td>
</tr>
<tr>
<td>ISBA</td>
<td>Interaction Sol-Biosphère-Atmosphère</td>
</tr>
<tr>
<td>ISG</td>
<td>Integerized Sinusoidal Grid</td>
</tr>
<tr>
<td>ISIN</td>
<td>Integerized SINusoidal</td>
</tr>
<tr>
<td>ISLSCP</td>
<td>International Satellite Land Surface Climatology Project</td>
</tr>
<tr>
<td>JRC</td>
<td>Joint Research Centre</td>
</tr>
<tr>
<td>JULES</td>
<td>Joint UK Land Environment Simulator</td>
</tr>
<tr>
<td>KF</td>
<td>Kalman Filter</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf Area Index</td>
</tr>
<tr>
<td>LE</td>
<td>Latent Heat</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LSA-SAF</td>
<td>Land Surface Analysis Satellite Applications Facility</td>
</tr>
<tr>
<td>LSMs</td>
<td>Land Surface Models</td>
</tr>
<tr>
<td>LUT</td>
<td>Look Up Table</td>
</tr>
<tr>
<td>MACC</td>
<td>Monitoring Atmospheric Composition Climate</td>
</tr>
<tr>
<td>MERIS</td>
<td>Medium Resolution Imaging Spectrometer</td>
</tr>
<tr>
<td>MISR</td>
<td>Multiangle Imaging Spectro-Radiometer</td>
</tr>
<tr>
<td>MODIS</td>
<td>Moderate Resolution Imaging Spectrometer</td>
</tr>
<tr>
<td>MOSES</td>
<td>Meteorological Office Surface Exchange</td>
</tr>
<tr>
<td>MRPV</td>
<td>Modified-Rahman-Pinty-Verstaete</td>
</tr>
<tr>
<td>MRT</td>
<td>MODIS Reprojection Tool</td>
</tr>
<tr>
<td>MSG</td>
<td>Meteosat Second Generation</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NB</td>
<td>Narrow Band</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center For Atmospheric Research</td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
</tr>
<tr>
<td>NIR</td>
<td>Near InfraRed</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic And Atmospheric Administration</td>
</tr>
<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
</tr>
<tr>
<td>PAR</td>
<td>photosynthetically Active Radiation</td>
</tr>
<tr>
<td>PARASOL</td>
<td>Polarization Anisotropy of Reflectances for Atmospheric Sciences coupled</td>
</tr>
<tr>
<td></td>
<td>with Observations from a Lidar</td>
</tr>
<tr>
<td>PDF</td>
<td>Probability Density Functions</td>
</tr>
<tr>
<td>PFT</td>
<td>Plant Functional Type</td>
</tr>
<tr>
<td>PILPS</td>
<td>Program For Intercomparison Of Land Surface Parameterization Schemes</td>
</tr>
<tr>
<td>POLDER</td>
<td>POLarization and Directionality of the Earth’s Reflectances</td>
</tr>
<tr>
<td>QA</td>
<td>Quality Assurance</td>
</tr>
<tr>
<td>QC</td>
<td>Quality Control</td>
</tr>
<tr>
<td>RAMI</td>
<td>RAdition transfer Model Intercomparison</td>
</tr>
<tr>
<td>RF</td>
<td>Radiative Forcing</td>
</tr>
<tr>
<td>RMSE</td>
<td>Root Mean Square Error</td>
</tr>
<tr>
<td>RT</td>
<td>Radiative Transfer</td>
</tr>
<tr>
<td>SAFRAN</td>
<td>Système d’Analyse Fournissant des Reseignements Atmosphérique a la Neige</td>
</tr>
<tr>
<td>SEKF</td>
<td>Simple Extended Kalman Filter</td>
</tr>
<tr>
<td>SEVIRI</td>
<td>Spinning Enhanced Visible and Infrared Imager</td>
</tr>
<tr>
<td>SNORTEX</td>
<td>Snow Reflectance Transition Experiment</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>SORCE</td>
<td>Solar Radiation and Climate Experiment</td>
</tr>
<tr>
<td>SPOT</td>
<td>Satellite Pour l’Observation de la Terre</td>
</tr>
<tr>
<td>SSM</td>
<td>Surface Soil Moisture</td>
</tr>
<tr>
<td>SURFEX</td>
<td>SURFace EXternalisée</td>
</tr>
<tr>
<td>SURFRAD</td>
<td>SURFace RADiation Budget Network</td>
</tr>
<tr>
<td>SVAT</td>
<td>Surface Vegetation- Atmosphere Transfer</td>
</tr>
<tr>
<td>SVC</td>
<td>Spectra Vista Corporation</td>
</tr>
<tr>
<td>SW</td>
<td>Short Wave</td>
</tr>
<tr>
<td>SZA</td>
<td>Solar Zenith Angle</td>
</tr>
<tr>
<td>TOA</td>
<td>Top of Atmosphere</td>
</tr>
<tr>
<td>TOC</td>
<td>Top of Canopy</td>
</tr>
<tr>
<td>TSA</td>
<td>Total Sky Albedo</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Transverse Mercator</td>
</tr>
<tr>
<td>UVB</td>
<td>UltraViolet B</td>
</tr>
<tr>
<td>VIS</td>
<td>Visible</td>
</tr>
<tr>
<td>WCRP</td>
<td>World Climate Research Program</td>
</tr>
<tr>
<td>WGS</td>
<td>World Geodetic System</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
</tr>
<tr>
<td>WRCP</td>
<td>World Climate Research Programme</td>
</tr>
<tr>
<td>WSA</td>
<td>White Sky Albedo</td>
</tr>
</tbody>
</table>


Annexes
Annexe A

A parameterization of SEVIRI and MODIS daily surface albedo with soil moisture : Calibration and validation over southwestern France

A parameterization of SEVIRI and MODIS daily surface albedo with soil moisture: Calibration and validation over southwestern France

Siliang Liu a, Jean-Louis Roujean a,⁎, Armel Thibaut Kaptue Tchuente b, Xavier Ceamanos a, Jean-Christophe Calvet a

a CNRM-GAME, Météo-France, CNRS/UMR3589, 42, avenue Gaspard Coriolis, 31057 Toulouse, France
b Geographic Information Science Center of Excellence, South Dakota State University, USA

A R T I C L E   I N F O

Article history:
Received 21 June 2013
Received in revised form 4 November 2013
Accepted 19 January 2014
Available online 11 February 2014

Keywords:
Albedo
Satellite
Soil
Moisture

A B S T R A C T

In climate models, it is important to simulate the partitioning of the surface albedo into soil and vegetation albedo components because these latter address different processes that are time-scale dependent. Vegetation albedo primarily varies along with the growing season while soil albedo shows day-to-day variations caused by rainfall events. In this study, the objective is to disentangle soil albedo from surface albedo within the visible (VIS) and near infrared (NIR) spectral bands of MODIS and SEVIRI sensors in order to yield a calibration with surface soil moisture (SSM). In a first step, we derive global static maps of soil and vegetation albedos from MODIS products at the resolution of 0.05° over a 4-year period. In a second step, we estimate a daily MODIS white-sky albedo (WSA) by combining 8-day BRDF and TERRA/AQUA reflectance values for each orbit pass. These MODIS products are then projected on the SEVIRI grid of 4 km for further comparison. Then, a physical method is presented to get a daily soil albedo from both MODIS and SEVIRI data. Good correlations are obtained between satellite time series for 2007 and 2008 of retrieved soil albedo and in situ SSM measurements at the 12 SMOSMANIA stations located in southwestern France. A function of an exponential type between albedo and SSM, as supported by the theory, could be verified. As in the VIS domain, the goodness of fit r² is about 0.42 and 0.54 for Lahas and Ladanom, respectively. The Chi-Square test indicates that the relationship is significant with p-value < 0.01. Finally, it is shown that most anomalies of soil albedo correlate with anomalies of soil wetness, which yields crucial importance for studying the energy budget.

© 2014 Elsevier Inc. All rights reserved.

1. Introduction

Surface albedo is defined as the percentage of outgoing radiation to total incoming radiation on the Earth’s surface. It yields a major factor across a range of environmental processes, including photosynthesis, land–atmosphere heat and water exchange, and is identified as an Essential Climate Variable (ECV) (GCOS, 2006) product required in climate modelling and as a key variable to monitor climate change (IPCC, 2007). For instance, a change of 1% in Earth’s albedo would trigger a radiative forcing variation of about 3.4 W m−2. Characterizing the seasonal variation of surface albedo is also a key issue for evaluating deforestation in tropical regions (Coe et al., 2013) or quantifying black carbon deposition, which accelerates the melting of snow in boreal regions (Schwarz, Gao, Perring, Spackman, & Fahey, 2013). Thus improved observations of surface albedo would definitely improve our understanding of human–climate–water cycle interactions.

For modelling purpose, snow-free land surface albedo is commonly depicted from combined patches of vegetation and soil. The total surface albedo is formulated as the sum of soil and vegetation compounds weighted by the vegetation fraction cover. Soil albedo would more likely vary on an hourly-daily basis, as its main perturbing field is surface soil moisture. Amenable short-term variations of soil albedo connect to rainfall events, which must be accounted for in the energy budget closure.

A thorough examination of the numerous studies has been devoted to investigate a relationship between bare soil albedo and SSM (Duke & Guérif, 1998; Idso, Jackson, Reginato, Kimball, & Nakayama, 1975; Lobell & Asner, 2002; Roxy, Sumithranand, & Renuka, 2010; Weidong et al., 2002). There is a consensus on a non-linear exponential relationship between these two quantities. In the current generation of land surface models (LSM), bare soil albedo is either assumed stationary or weighted by an empirical factor related to SSM (Dickinson, Henderson-Sellers, Kennedy, & Wilson, 1986; Knorr, 1997; Noilhan & Mahfouf, 1996; Oleson & Bonan, 2010; Sellers, Mintz, Sud, & A.D., 1986). In the Joint UK Land Environment Simulator (JULES), which is based on the Meteorological Office Surface Exchange (MOSES) (e.g. Cox et al., 1999), soil albedo is taken from a soil atlas (Wilson & Henderson-Sellers, 1985). In the Common Land Model (CLM), SSM influences the soil albedo in a linear fashion with a set of parameters borrowed from the literature (Dai et al., 2003). In the Interaction between Soil, Biosphere, and Atmosphere (ISBA) model, bare soil albedo is reduced with humidity in an...
extent based on a number of in-situ measurements. All these LSM will undoubtedly benefit from a strategy to combine measurements of land surface albedo with SSM information rather than using static bare soil albedo. In this regard, Cenedlin, Carrer, Mahfouf, and Roujean (2012) initiated such a move, considering an analysed surface albedo based on satellite observations in substitution to the climatology.

In virtue of the advent of new generation of Earth observing satellites during the last two decades, various global and continental scale albedo data records were generated, from polar orbiting instruments like MODIS (Moderate Resolution Imaging Spectroradiometer), POLDER (Polarization and Directionality of Earth Reflectance) and VEGETATION onboard SPOT, and also from geostationary observing systems like SEVIRI (Spinning Enhanced Visible and Infrared Imager) onboard METEOSAT Second Generation (MSG). These data records are derived from well-calibrated reflectance by using well-suited pre-processing chains and consolidated physical algorithms. Climate and also weather forecast communities commonly argue that a 2–5% accuracy range is required for an observed surface albedo to be used in surface modelling. Various validation exercises showed the accuracy of the recent satellite-based albedo products, e.g. MODIS (Jin et al., 2003a), thereby justifying the efforts for refining the description of the surface albedo in land surface models (Oleson, 2003). The accumulation of observations over long time series, typically pluriannual, can be judged useful in order to establish climatology of soil and vegetation albedos. Recently a global soil background field for climate modelling using multi-annual time series of MODIS observations was produced by Houlcroft et al. (2009). But the dynamic effects due to SSM were not thoroughly investigated so far. In the case of polar orbiting sensors such as MODIS, a daily revisit may be severely hampered by the high frequency of cloudiness for certain regions. Therefore, monitoring the day-to-day surface albedo response to soil moisture may be a tough task for polar sensors. However, a trimmed analysis of time variations of surface albedo is now possible with the combination of polar and geostationary sensor systems. Apart from hazardous events (flood, storms, strong winds), short-term variations in surface albedo are driven by snow, by SSM, and by the vegetation growth and senescence periods. In this regard, the accumulation of decadal observations is suitable in order to establish solid climatology of soil and vegetation albedos.

The objective of this study is to investigate to what extent SSM can (1) explain the day-to-day variations of the surface albedo and (2) help disentangle bare soil and vegetation albedo components. An attempt is made to assess the dynamics of soil albedo, using both polar orbiting and geostationary satellite observations, by benefiting of in situ measurements of vertical profile of soil moisture at stations located in southwestern France. A methodology is proposed for the derivation of bare soil albedo from remotely sensed observations from MODIS and SEVIRI time series. The impact of SSM and of soil texture on the retrieved soil albedo values is assessed. An overview of the input datasets considered in this study is presented in Section 2, and the different methodological steps leading to a mapping of vegetation and bare soil albedos are described in Section 3. Results are presented in Section 4 while Section 5 summarizes the study along with a discussion and key conclusions.

2. Presentation of the datasets

2.1. Albedo and vegetation products from MODIS

MODIS is a NASA’s instrument for remote sensing of the Earth atmosphere, oceans and land. The MODIS instrument is operating onboard the TERRA satellite since 18 December 1999 and by the AQUA satellite since 4 May 2002. The downloaded products are at a spatial resolution of 500 m on Integerized Sinusoidal Grid (ISG) projection. Such products were tiled and resampled at the resolution of 1/224° and reprojected on a UTM (Universal Transverse Mercator) grid on the WGS 84 geoid. We consider herein merged TERRA and AQUA MODIS albedo/BRDF products (MCD43A1, MCD43B3) that are distributed on 8-day synthesis periods of clear sky data accumulation. Various solar/observation geometries are combined to adjust a BRDF kernel-driven model further serving to estimate albedo (Schaaf et al., 2002). When the inversion of the BRDF model fails due to missing data – at least seven observations have to be available – a back-up algorithm is activated. Three MODIS broadband albedo products are distributed: VIS (0.3–0.7 μm), NIR (0.7–5.0 μm), and SW (0.3–5.0 μm) along with QA indicators (flags), including a snow mask. Note that only best quality products are considered in the present study. The MODIS algorithm generates a directional–hemispherical reflectance or “black sky albedo” (BSA) and a bi-hemispherical reflectance or “white sky albedo” (WSA). The accuracy of these products is within 5% for the main algorithm (Jin et al., 2003b).

The MODIS LAI/FAPAR nominal algorithm relies on the inversion of a 3-D stochastic radiative transfer model based on a global 6-biome land cover map (grasses and cereal crops, shrubs, broadleaf crops, savannas, broadleaf forests and needle leaf forests) (Myneni et al., 2002). In Collection 5, the dissemination rate of LAI/FAPAR is 8 days. In case of failure of the main algorithm either due to saturation effect of the reflectance or to high aerosol load, a backup algorithm using the relationship between NDVI and LAI is activated. The MODIS LAI product is distributed with a Quality Control (QC) flag accounting for the influence of a number of factors like sun and view directions, biome type and observed red and near-infrared surface reflectance values along with their associated errors. This product was widely validated through a broad range of vegetation cover types (Shabanov et al., 2005). The accuracy of LAI is within 20%.

2.2. Albedo and vegetation products from SEVIRI

Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard METEOSAT Second Generation (MSG) offers a sub-track resolution of 3 km in the shortwave channels V106, V108 and SWIR1.6 centred on 0.6 μm, 0.8 μm and 1.6 μm respectively. The pixel resolution falls within the range 4–5 km over France. Using the three SEVIRI spectral bands, the LSA-SAF service (http://landsaf.meteo.pt/) (e.g. Trigo et al., 2011) generates directional–hemispherical reflectance (DHR) at solar noon as well as bi-hemispherical reflectance (BHR) over Europe, Africa, and eastern part of South America. Compiling slots on the same day leads to a daily derivation of BRDF (Bidirectional Reflectance Distribution Function) coefficients using the kernel-driven model of Roujean, Leroy, and Deschamps (1992). The disseminated products are broadband DHR and BHR in the visible (0.3–0.7 μm), near infrared (0.7–4.0 μm), and solar (0.3–4.0 μm) spectral domains (e.g. Geiger, Carrer, Franchistéguy, Roujean, & Meurey, 2008). Their quality was assessed through the comparison with the broadband MODIS albedo products and with albedo in situ observations (Carrer, Roujean, & Meurey, 2010a). As opposed to MODIS, a ground target is viewed by SEVIRI under quasi-similar inclinations but for various directional illuminations corresponding to the diurnal course of the sun at the frequency of 15 min. Observations from 30 min slots are accumulated during one day, from sunrise to sunset, for illumination angles lower than 85°. Snow and clouds are masked although the occurrence of residual effects is still possible. Quality Assessment (QA) for each observation includes information on cloud, snow, and algorithm inversion status. The pixels contaminated by clouds or snow are discarded. The required specification for LSA-SAF albedo has been fixed to 0.03 for albedo less than 0.15, and 20% for albedo greater than 0.15. Results of comparison show that the SEVIRI visible albedo is slightly overestimated compared to MODIS. This discrepancy is thought to be due by differences in the geometric kernel or the angular sampling handled to perform the directional correction.

Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Fraction of Vegetation Cover (FVC) products are also distributed within the framework of LSA-SAF. The retrieval algorithm relies on the use of BRDF parameters, which contains the
2.3. In situ soil moisture measurements from SMOSMANIA

SMOSMANIA is a ground network of automatic meteorological stations in southern France, able to measure soil moisture profiles, and spanning over an Atlantic–Mediterranean transect (Fig. 1). The main objective of SMOSMANIA is to offer a support to the validation of SSM remote sensing products, e.g. SMOS (Soil Moisture and Ocean Salinity) and ASCAT (Advanced Scatterometer) products (Albergel et al., 2008; Calvet et al., 2007). In this study, we consider the 12 SMOSMANIA stations set-up in 2006 in southwestern France. Most of these stations are located in low topography areas, for a variety of soil texture types, ranging from sandy locations (e.g. Sabres near the Atlantic coast) to relatively clayey (e.g. Narbonne near the Mediterranean coast). These stations are presented in Table 1. Since January 2007 they have been continuously measuring soil moisture at 12-minute intervals and 4 depths (5 cm, 10 cm, 20 cm and 30 cm) using one ThetaProbe sensor at each depth. The dataset is available through the International Soil Moisture Network (http://ismn.geo.tuwien.ac.at/).

In order to convert the voltage signal measured by the ThetaProbes into volumetric soil moisture content, site-specific calibration curves were developed using in situ gravimetric soil samples, for each station, and each depth, i.e. 48 calibrations curves (e.g. Albergel et al., 2008; Calvet et al., 2007).

3. Methodology

3.1. Derivation of a static MODIS albedo product

In order to produce a global static soil albedo estimate at the grid resolution of 0.05°, along with an associated uncertainty, four years (2007–2010) of 8-day MODIS albedo was archived. The method consists of steps on how to regress the MODIS total albedo products with the vegetation fraction cover, on a pixel-per-pixel basis. The soil albedo is disentangled from the vegetation albedo, according to:

\[ A_{tot} = A_{veg} \cdot veg + A_{soil} \cdot (1 - veg). \]

Here, \( A_{tot} \), \( A_{veg} \), and \( A_{soil} \) represent total, vegetation and soil albedos, respectively, and \( veg \) stands for the vegetation fraction cover. Eq. (1) is a formula with two unknown parameters (\( A_{veg} \) and \( A_{soil} \)). Based on the knowledge of \( A_{tot} \) and \( veg \) and using a linear model fit, the problem can be solved. The offset value of the regression line provides a direct estimation of \( A_{soil} \). Then, the latter is injected in the slope value estimate to obtain \( A_{veg} \). The method was successfully applied over African continent (Kaptue Tchuente, Roujean, & Faroux, 2010). In this method, soil albedo is assumed to be time invariant while vegetation albedo varies with the same time scale than the total albedo. In regions marked by the scarcity of rainfall, this retrieved soil albedo will be associated to dry conditions. In other areas, it should correspond to a statistical estimate, merging likely dry and wet soil conditions.

3.2. Derivation of a daily MODIS albedo product

Herein, an approach is proposed to generate a daily albedo using MODIS TERRA and AQUA reflectances (MOD09GA and MYD09GA, respectively) and MODIS albedo/BRDF products (MCD43A1, MCD43A2,
MCD43B3). The reflectance and BRDF products are used together in order to generate albedo estimates. MOD09GA and MYD09GA are tiled reflectance products distributed at the resolution of 500 m, along with granule time, cloud mask and information on geometry. They result from the composition of instantaneous atmosphere-corrected surface reflectances (MOD09AGG, MYD09AGG), thereby permitting the minimization of cloud effects. Relative QA values as well as observation geometry metrics are distributed along with this dataset as auxiliary information. Since a similar BRDF shape is noticed for a given land cover type (Luo, 2005), the BRDF shape is assumed invariant for a given pixel and within a 16-day period. Thus, the BRDF update will only consist in adapting the magnitude. Further, TERRA/AQUA reflectance on each day serves to estimate a daily albedo from 8-day BRDF.

The true albedo from in-situ measurements is equivalent to a blue-sky albedo integrating both direct and diffuse radiation components. For the sake of consistency, daily MODIS BSA and WSA for broadband were converted into Total Sky Albedo (TSA), summing them up weighted by a diffuse fraction. Carrer, Roujean, Hautecoeur, and Elias (2010b) proposed an approximate relationship to estimate the diffuse fraction from the aerosol optical depth. The latter is taken from the MACC-II (Monitoring Atmospheric Composition and Climate, http://www.gmes-atmosphere.eu/) project, which disseminates in near-real time a number of atmospheric products based on a transport model for atmospheric particles with dedicated identification of sources and sinks. The MACC-II aerosol optical depth closest (within 6 h) to the MODIS slot is retained. Then, narrow to broadband conversion of MACC-II aerosol optical depth is performed in order to obtain the diffuse contribution in the dedicated solar channel. The data processing chain is displayed in Fig. 2.

3.3. Derivation of a soil albedo product

The static soil albedo described in Section 3.1 should be perceived as a mean climatologic quantity. It could either serve for initialisation or as back-up of a prognostic soil albedo in weather forecast models. Herein, a novel method based on the principle of energy conservation is proposed to derive a dynamic soil albedo product. The method considers the different terms appearing in the radiative transfer equation: the total albedo $A_{\text{tot}}$, the absorptance $A_b$ – for the total solar spectrum, equivalent

<table>
<thead>
<tr>
<th>Station</th>
<th>Sand (%)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Vegetation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condom (CDM)</td>
<td>24</td>
<td>40</td>
<td>36</td>
<td>Dense crops</td>
</tr>
<tr>
<td>Crône d'Armagnac (CRI)</td>
<td>72</td>
<td>8</td>
<td>20</td>
<td>Forest &amp; herbaceous</td>
</tr>
<tr>
<td>Lahas (LHS)</td>
<td>23</td>
<td>41</td>
<td>36</td>
<td>Dense crops</td>
</tr>
<tr>
<td>Lézignan Corbieres (LZC)</td>
<td>51</td>
<td>17</td>
<td>32</td>
<td>Mediterranean grassland</td>
</tr>
<tr>
<td>Mouthoument (MTM)</td>
<td>42</td>
<td>22</td>
<td>36</td>
<td>Mediterranean crops</td>
</tr>
<tr>
<td>Montaut (MNT)</td>
<td>36</td>
<td>22</td>
<td>42</td>
<td>Dense crops</td>
</tr>
<tr>
<td>Narbonne (NBN)</td>
<td>25</td>
<td>45</td>
<td>30</td>
<td>Mediterranean crops</td>
</tr>
<tr>
<td>Peyrusse Grande (PRG)</td>
<td>23</td>
<td>41</td>
<td>36</td>
<td>Dense crops</td>
</tr>
<tr>
<td>Sabres (SBR)</td>
<td>87</td>
<td>4</td>
<td>9</td>
<td>Needle leaved forest</td>
</tr>
<tr>
<td>Saint Felix de Lauragais (SFL)</td>
<td>24</td>
<td>40</td>
<td>36</td>
<td>Mediterranean crops</td>
</tr>
<tr>
<td>Savenes (SVN)</td>
<td>36</td>
<td>22</td>
<td>42</td>
<td>Dense crops</td>
</tr>
<tr>
<td>Urgons (URG)</td>
<td>37</td>
<td>19</td>
<td>44</td>
<td>Irrigated crops</td>
</tr>
</tbody>
</table>

Table 1: Characteristics of the 12 SMOSMANIA stations. Soil information is taken from HWSD (Harmonized World Soil Database). Land cover type is from the nomenclature of ECOCLIMAP-II (Faroux et al., 2013).

Fig. 2. Flowchart of the processing chain implemented for producing daily MODIS albedo.
Fig. 3. Comparison of global static maps of WSA VIS and NIR bare soil albedo from CNRM and University of Swansea. Scatter-plots are also displayed.
to FAPAR for the PAR (Photosynthetically Active Radiation) range \( - \) and the transmittance factor \( T \).

\[
A_{\text{tot}} + A_b + T = 1 + A_{\text{soil}} \times T.
\]

The computation of the transmittance is based on an approximate relationship with LAI:

\[
T = 1 - \text{veg} = \exp \left( - \frac{G(\theta_s)}{\cos \theta_s} \text{LAI} \right).
\]

In Eq. (3), \( \theta_s \) represents the solar zenith angle, \( G(\theta_s) \) is the foliage distribution, and \( \text{veg} \) is the vegetation radiative fraction. We make first the reasonable assumption that the foliage is randomly oriented at coarse scale resolution, i.e. \( G(\theta_s) = 0.5 \). Further, considering our study area, a value of the solar zenith angle \( \theta_s = 60^\circ \) is retained as it represents an averaged quantity over the daily course of the sun.

\[
T = 1 - \text{veg} = \exp (-0.6 \times \text{LAI})
\]

In the visible band, the absorptance \( A_b \) is equivalent to FAPAR. \( A_{\text{soil}} \) can be directly estimated from Eq. (2). The accuracy of the products derived from this method can be related to the self-consistency of MODIS and SEVIRI respective biophysical products. Actually, this can be perceived as an additional criterion of evaluation for the quality of various satellite products through consistency. Incidentally, from Eq. (1), the vegetation albedo could be further obtained by assuming that the relationship with transmittance in Eq. (4) establishes an acceptable statement. Contrary to the VIS domain where FAPAR is available for quantifying the absorption, the determination of soil albedo in the NIR domain must adopt a different strategy. Actually, NIR soil albedo can be derived from the updated VIS albedo using the soil line approach with the relationship obtained with the climatologic-based product.

### 3.4. Linking soil moisture to soil albedo

The relationship between the bare soil albedo and SSM is generally in the form (e.g. Guan, Huang, Guo, Bi, & Wang, 2009, for recent results):

\[
A_{\text{soil}} = a_0 + a_1 e^{-a_2 SSM}.
\]

This relationship is valid from visible to shortwave infrared, as the soil darkening effect is known to be spectrally bland with a rather low spectral dependence of water absorption. Since no in situ observation of albedo is routinely acquired over SMOSMANIA stations, we will only consider satellite-based albedo products to perform the calibration. The three unknown parameters of Eq. (5) are optimized to obtain the best fit between observations of albedo and SMOSMANIA in situ SSM for the year 2008. To mitigate vegetation impact on background soil beneath canopy, only observations during sparse vegetation periods are selected. A threshold of 1 on LAI is arbitrarily imposed as a separator between sparse-vegetated and dense-vegetated period. Further, to remove the outliers of albedo, a moving window abnormal detection method is applied to the whole time series based on calculated standard deviation value. Abnormal albedos too high or too low are filtered comparing to the mean values during each temporal window.

### 3.5. Intercomparison of albedo products

SEVIRI albedos from LSA-SAF at different slots from sunrise to sunset are compared with daily MODIS albedo. MODIS albedo WSA is first re-sampled at the resolution of 4 km and then re-projected on the METEOSAT grid using the nearest neighbour method. Further, MODIS

![Fig. 4. Static maps of bare soil albedo over France derived from MODIS with the associated uncertainties (STD) for a 4-year period (2007–2010).](image)
and SEVIRI pixels corresponding to SMOSMANIA stations are extracted. At this stage, snow and cloud contaminated MODIS pixels are discarded in order to only retain best pixel values. Note that this also serves to remove SEVIRI albedo pixels having possible residual contamination. The reliability between MODIS and SEVIRI is appraised through the broadband bi-hemispherical reflectance, either named WSA or BHR, as LSA-SAF does not distribute BH VIS and NIR albedo products.

Long-term records (2007–2010) of SSM from the 12 SMOSMANIA stations in southwestern France are re-sampled from 12-minute time intervals to one day to match with the frequency of the SEVIRI surface albedo. In the case of MODIS, SSM measurement the closest to the satellite overpass is retained. This is supported by the lack of significant variations within one day in most cases. Soil moisture measured at 5 cm is considered since it can be considered as representative of the SSM.

Two additional datasets are used for the validation: (1) the global albedo product of the University of Swansea (Houldcroft et al., 2009) which is derived from MODIS data and includes the separate soil and vegetation components (hereafter referred to as the Swansea product); and (2) in situ measurements from two FLUXNET forest sites in France: Fontainebleau and Le Bray.

FLUXNET (http://fluxnet.ornl.gov/) is a worldwide network of terrestrial ecosystem observations based on micrometeorological flux towers that use the eddy covariance method to measure the exchanges of carbon dioxide (CO₂), water vapour, and energy between the surface and the atmosphere. To be compliant with the defined protocol in FLUXNET, pyranometers measure incoming and outgoing radiation for SW range (280–2800 nm) at 3-minute intervals (Baldocchi et al., 2001). Albedo for these stations is thus calculated by dividing the upward solar radiation by the total downward solar radiation.

4. Results

4.1. Comparison of the static MODIS albedo with the Swansea product

The comparison with the Swansea static albedo product is displayed in Fig. 3 for the White Sky Albedo (WSA). Emerging feature is complete filled maps with our method. Our albedo estimates tend to display lower values than the Swansea product, with a negative mean bias of $-0.036$ in the visible band and a Root Mean Square Error (RMSE) equals to 0.055. In the near infrared, the agreement is improved and the bias is estimated to 0.029 even with the inclusion of outliers of the University of Swansea albedo products. An RMSE value equals to 0.076 is obtained in this case. Fig. 4 presents the obtained static maps of soil albedo over France. They are obtained using the regression method described in

![Comparison of TERRA/AQUA daily MODIS albedo with FLUXNET stations measurements for the whole year 2007 and on specific days revealing the diurnal cycle.](image-url)
Section 3.1. Values are lacking for some regions (white colour in Fig. 4) as a consequence of discarding pixels that are either non-vegetated or do not concentrate enough clear observations. The associated uncertainties are calculated considering (1) the errors induced by the regression process and (2) the errors in the input products. The uncertainty is in general higher when vegetation is dense (forests and grasslands), which is consistent with the fact that soil information is marginally contributing to the total albedo for the scenario of dense vegetation cover.

4.2. Comparison of daily MODIS albedo with FLUXNET observations

Fig. 5 shows for the 20–30 April 2007 period a comparison between the daily MODIS albedo generated by the scaling method and the in situ measurements for the two FLUXNET forest sites. It can be observed that FLUXNET albedo represents a typical U shape for diurnal variation while it is not symmetric before and after noon. In spite of the uncertainty due to the footprint size, hourly estimation from TERRA and AQUA catches the variation of albedo in relatively good agreement with the records.
from pyranometers. On the other hand, time series of ground-based and satellite daily albedos indicate a satisfactory matching.

4.3. Seasonal trends and anomalies in daily MODIS and SEVIRI albedos

Fig. 6 displays the seasonal evolution in 2007 of MODIS and SEVIRI albedo products over four SMOSMANIA stations (see Table 1). SEVIRI albedo product includes a gap-filling process. In the case of failure of the algorithm, either due to technical issues or persistent cloud coverage, the latest albedo value is prescribed with the associated uncertainty represented by an error bar (Fig. 6). The magnitude of this uncertainty increases with the time elapsed from the date of acquisition of the last albedo estimate. A characteristic time scale was fixed to 5 days, which explains the loss of confidence on the product rapidly after a few days. In particular, this occurs during snowfall episodes materialized by high albedo values. SEVIRI albedo shows more seasonality than MODIS albedo with a marked depletion in winter. During that period of time, discrepancies exist with MODIS. In other seasons, conspicuous agreement is observed, in particular during summer and fall periods. This will be further investigated in Section 5.1.

The prototyping test shown in Fig. 7 for the site of Condom (CDM) reveals the lack of consistency between albedo, LAI, and FAPAR products during certain periods of the year, which jeopardizes the criterion of energy conservation. In the case of MODIS, the residue of the radiation budget equation falls beyond 1, as it should be, but in excess (values of about 1.2 are observed at wintertime), which precludes possible retrieval of bare soil albedo. At the opposite, SEVIRI indicates a residue slightly less than 1, especially at springtime, for low transmittance values corresponding to dense vegetation. Therefore, for seasons with sparse vegetation (e.g. wintertime), SEVIRI products appear more dependable than MODIS to retrieve soil albedo.

4.4. Evaluation of the relationship between SSM and daily albedos

As illustrated in Figs. 8 and 9, the mathematical form of Eq. (5) is confirmed for both MODIS and SEVIRI VIS and NIR surface albedo. A better level of confidence and precision is obtained for VIS albedo, which indicates a lesser influence of vegetation scattering in the VIS

![Fig. 7. Consistency check of various MODIS and SEVIRI products for Condom SMOSMANIA station in VIS band in 2008: albedo (orange for VIS, red for NIR) FAPAR, VIS transmittance for LAI, and residue of radiation budget equation are displayed quantities.](image_url)

![Fig. 8. Calibration of MODIS soil albedo with soil moisture during sparse vegetated periods in 2008 for the stations of Lahas (LHS), Condom (CDM) and Montaut (MNT). Filtered outliers are shown in small black dots.](image_url)
domain. The values of the coefficients of Eq. (5) are shown in Table 2 for SEVIRI for a four-years (from 2007 to 2010) calibration. These values will be considered in the following.

The Lahas and Condom stations are both located in a region dominated by croplands. For these two stations, it can be seen in Fig. 9 that SEVIRI albedo and in situ soil moisture are highly correlated for 2008. As for the exponential function fit in the VIS domain, the goodness of fit \( r^2 \) is about 0.42 and 0.54 for Lahas and Condom, respectively. The Chi-Square test indicates that the relationship is significant with \( p \)-value < 0.01. When applying this relationship to the other three years (2008, 2009, 2010), it is also found that they generally fit Eq. (5) very well with a relatively low variability in coefficients, as long soil properties remain the same.

The chronology of SEVIRI albedo and surface soil moisture was compared for the 12 SMOSMANIA stations. Fig. 10 illustrates the results for the stations of Lahas (LHS) and Condom (CDM) during the whole year 2008. Surface soil moisture impact on surface albedo can be obviously discerned from comparing these two time series. Generally, contrasting variation trends can be observed, particularly in sparse vegetation seasons as winter and early spring. For instance, both for LHS and CDM, during Julian Days 36 to 60, as soil moisture gradually decreases, both VIS and NIR surface albedo increase accordingly.

The in situ observations of SSM can be used to simulate the day-to-day variations of the soil albedo. The total albedo can then be simulated using Eq. (1), where the value of vegetation albedo is taken from the climatology previously established, and is shown in Fig. 11 for Lahas and Condom. Clearly, during sparse vegetated period, the modelled total albedo is consistent with the SEVIRI total albedo. In particular, the impact of precipitation events on the observations, as simulated by Eq. (5), is noticeable. During dense vegetated periods, a discrepancy can be observed between these two albedo records due to the influence of the vegetation. The errors RMSE for VIS albedo in Lahas and Condom are 0.006 and 0.008, respectively for the whole year. Also, it can be noticed from Fig. 11, the clear impact of rainfall on the soil albedo in the following hours, which is even more conspicuous for sparse or in the lack of vegetation.

5. Discussion

5.1. Discrepancies between SEVIRI and MODIS albedo products

Although a kernel-driven approach is used for both SEVIRI and MODIS, the geometric kernel is different. Pokrovsky, Pokrovsky, and Roujean (2003) found that the impact of the choice of the kernel was...
not too important for assessing the surface albedo, which was further confirmed by Carrer, Roujean, and Meurey (2010a) when comparing SEVIRI and MODIS albedo fields at landscape scale. Generally, the semi-linearity of this category of BRDF models seems to underestimate the impact of mutual shading that is prevalent in winter, especially for SEVIRI although the phenomenon could be dampened by the diffuse illumination. MODIS looks at a ground target under grazing solar zenith angle with a more or less fixed proportion of shadow in the field of view. In contrast, SEVIRI can capture the variations in proportion of shadow during the whole daily course of the sun, which provides a plausible explanation for the positive bias of MODIS albedo in winter (Fig. 6). Moreover, MODIS albedo signal appears somewhat noisy, which can be explained by the angular sampling, with day-to-day change in observation geometry, at a low sun elevation. Possibly the BRDF is constructed from a limited set of observations and fails to mimic the true BRDF over long time periods. Thus, there seems to exist a mismatch between the appropriateness of the BRDF and the measured reflectance, thereby placing a limit to the temporal scaling method during the winter season. Atmospheric effects may also affect the quality of MODIS products. Cloud shadow and utmost aerosol pathway may act as residual perturbing effects on the surface reflectance. Some authors (Jin et al., 2003b; Roesch et al., 2004; Liu et al., 2009) pointed out the negative biases observed with MODIS, which seems to increase with solar zenith angle.

5.4. Role of soil composition

Being treated as pure extinction feature of light trapping by any medium, the modelling by an exponential formula seems to find here some justification. The influence of the texture is expected to be significant in theory since the composition in pebbles, stones and relative proportion of sand and clay will shape the dependence of wetness on soil albedo. In this respect, it connects to the degree of porosity while it remains that apparent soil colour changes lightly when soils darken. Despite a panorama of different textures between stations, we were not able to show the influence of the locally observed soil texture on the relationship between soil moisture and reflectance at the satellite moderate resolution. Even it is not certain that an extensive collection of ground-based measurements would support a transposition to satellite applications due to the complexity of soil landscape in general. Another key issue that cannot be ignored is the chemistry composition of the water, which encompasses air particle deposition and soil organic matter composition. Knowing how dissolved organic material plays on the deviation from an absorption spectrum of pure water is certainly a matter of concern and the role of microbial activity is also probably worth to know. Considering all these sources of uncertainties, it is likely that there exists a physical frontier in terms of appropriate information suchlike meteorological purpose. The mixing of different soils at the scale of a satellite pixel justifies the effort for performing directly a calibration at a resolution to be consistent with foremost studies suchlike meteorological purpose.

5.5. Sources of uncertainty

Another concern is the mismatch between the time of ground measurement and satellite overpass. However, the drainage time constant and also drying rate is generally about at least a few hours, even a day. Thus, this source of uncertainty is believed to be low. For instance, on a certain day of September 2012 having extremely hot temperatures a physical, the MODIS product after having abundantly sprayed water on the soil. It confirmed a slow evolution of SSM nevertheless, which seems to support the fact that exact concomitance between SSM and albedo is

\[ \text{Ano}(i) = \frac{m(i) - \bar{m}(F)}{\text{Stdev}(m(F))} \]

where \( m \) refers to the studied variable (either soil albedo or SSM), \( i \) denotes the i-th day, \( s \) is the (day − 15, day + 15) window frame used to calculate the measured \( m(F) \) and the standard deviation \( \text{Stdev}(m(F)) \). After mitigating the seasonal effect, soil albedo and moisture are achieving a better correlation. For instance, the Pearson’s correlation coefficients for LHS and CDM are −0.49 and −0.61 in VIS domain, while −0.05 and −0.57 in NIR domain, respectively (Fig. 12).
not completely necessary to perform a calibration or for the sake of comparison.

The soil albedo is expected to vary substantially at short-term since a water-saturated soil may show halved albedo compared to dry soil. Since the consistence between satellite-based surface products is mandatory, the method exploits the rule of energy conservation. It permits a dynamic separation of soil and vegetation components in having LAI and FAPAR as required input. This method is prototyped using a suite of LSA-SAF and MODIS products. For LSA-SAF LAI, FAPAR and albedo products, BRDF is used as a common input variable, which ensures better coherency among albedo and vegetation biophysical parameters. However, it is found that the generated soil albedo can be negative, indicating that the energy conservation law is not always complied with. In the case of MODIS, another reason seems to be that FAPAR product is an instantaneous product for satellite overpass while transmittance is derived for nadir view.

Last but not least is the limitation of the method in the presence of growing vegetation. Nevertheless, what seems important to modellers is to have a well-behaved determination of the soil moisture beforehand in winter and overall during springtime.

Fig. 10. Comparison between observed SEVIRI albedo (orange for VIS, red for NIR) and soil moisture for the two SMOSMANIA stations of Lahas (LHS) and Condom (CDM).
6. Conclusions

In this study, we quantified the impact of soil moisture on the surface albedo measured from space in the optical domain in agricultural areas presenting a significant amount of bare soil surfaces. An attempt was made to verify a pre-existing parameterization of the soil albedo using MODIS and METEOSAT (SEVIRI) data. First of all, a method was implemented for retrieving the soil albedo with a sufficient degree of confidence. The accumulation of MODIS observations from year to year served to derive a global static map of soil albedo – and also of vegetation albedo – in a robust manner. The geography consistency was checked owing to a comparison with the global soil background albedo map generated by the University of Swansea. Some discrepancies were shown for the VIS (NIR) soil albedo since our method gave values lower (higher) by 0.036 (0.029).

Further, the daily SEVIRI albedo was compared with ground observations of SSM in southwestern France. It was found that SEVIRI albedo was sensitive to SSM for sparse vegetation seasons in areas dominated by crops (Lahas and Condom stations). The sensitivity to SSM was higher for VIS than that for NIR, which seems to be supported by physical considerations like the result of soil–water association. This dependence can be well fitted by a three parameter exponential function. Using the relationship derived for the Lahas and Condom stations a prognostic soil albedo was generated which was compared favourably with the original SEVIRI in the lack of marked vegetation.

The present outcomes will serve to depict a dynamic soil albedo based on soil moisture variations in land surface models. The lack of soil moisture observations at the landscape scale can be a source of discrepancy in the protocol of comparison although dedicated satellites could now do that with acceptable precision. Hence, the level of

Fig. 11. Time series of VIS and NIR albedo observed by SEVIRI and reconstructed using in-situ soil moisture from the SMOSMANIA stations of Lahas (LHS) and Condom (CDM). LAI, in situ soil moisture and precipitation fields (TRMM Multi-satellite Precipitation Analysis) are also shown.
correlation between in situ soil moisture and satellite surface albedo must be judged encouraging whereas there certainly exists gain for improvement in regard to scaling.

We showed that soil albedo is prone to serve as a proxy for soil moisture estimates under certain conditions. In the future, it is likely that more refined prognostic albedo parameterizations will be developed in land surface models. They could play the role of an operator of observations and albedo observations could be integrated in land surface models using land data assimilation (e.g., Barbu, Calvet, Mahfouf, & Lafont, submitted for publication), already able to assimilate microwave observations. In this regard, optical remote sensing could form the complement of microwave remote sensing for disaggregating coarse scale pixels of soil humidity fields.

Acknowledgements

The authors wish to acknowledge, for the availability of MODIS data, the next organizations: Earth Observing System Data and Information System (EOSDIS). 2009. Earth Observing System Clearing House (ECHO) / Reverb Version 10.X [online application]. Greenbelt, MD: EOSDIS, Goddard Space Flight Center (GSFC) National Aeronautics and Space Administration (NASA). URL: https://wist.echo.nasa.gov/api/.

The authors feel also indebted to IPMA (Portugal) for the distribution of SEVIRI products from Land SAF. Siliang Liu received his Ph.D. grant from Météo-France.

References


Carrer, D., Roujean, J. L., Hauettecouer, O., & Elias, T. (2010). Daily estimates of aerosol optical thickness over land surface based on a directional and temporal analysis...


A. A parameterization of SEVIRI and MODIS daily surface albedo with soil moisture: Calibration and validation over southwestern France
Annexe B

Processing of the input directional reflectance and BRDF products
Fig. B-1 Time Series of MODIS TERRA Daily Composited albedo (Circle and Square) vs. 8 Day albedo (black line), LAI, Solar and View Geometry, Reflectance in 2007.
Fig. B-2 Time Series of MODIS TERRA Directional Spectral Reflectance (B1-RED and B2-NIR) and NDVI (2007) without screening the influences of cloud, snow, etc.
Fig. B-3 Time Series of MODIS TERRA Directional Reflectance (B1-RED and B2-NIR) and NDVI (2007) with screening the influences of cloud, snow, high&medium aerosol, etc.
Fig. B-4 Time Series of MODIS TERRA Directional Reflectance (B1-RED and B2-NIR) and NDVI (2007) with screening the influences of cloud, snow, etc. The effect of aerosol is highlighted in the color of olive. (triangle-TERRA, circle-AQUA)
Fig. B-5 Time Series of MODIS TERRA+AQUA (MCD) (B1-RED, B2-NIR) BRDF coefficients with marking the QA of snow and magnitude algorithm usage.
Fig. B-6 Time Series of MODIS TERRA Directional Reflectance Comparison: Original MOD09GA vs. Reconstructed Reflectance using 8d BRDF coefficients (black color). The associated QAs are marked to show the influences of cloud, snow, aerosol, etc.
B. PROCESSING OF THE INPUT DIRECTIONAL REFLECTANCE AND BRDF PRODUCTS
Annexe C

Parameterization of LAI and SM in ISBA Land Surface Model

Brief Introduction of ISBA Surface Model Driven with Offline Forcing

This brief documentation aims to provide basic information on how the processes relative to biomass, moisture are described in ISBA (Noilhan, J. and S. Planton, 1989 Noilhan and Planton (1989)).

ISBA model is running offline with 11 outside forcings, namely TA(Atmospheric temperature), QA(Atmospheric humidity), PS(Atmospheric pressure), RAIN(Rain precipitation), SNOW(Snow Precipitation), WIND(Wind Speed), DIR(Wind Direction), LW(Long-wave radiation), DIR_SW(Direct short-wave radiation), SCA_SW(diffuse short-wave radiation), CO2(flux of CO2).

The land surface processes are driven by these forcings and initialized by start status. The following sections describe Growth model for Leaf Biomass, Carbon Assimilation of A-gs option, Soil Moisture Stress Parameterization and Soil Water Balance.

Growth Model for Leaf Biomass

The leaf area index (LAI) is derived from the leaf biomass \(B\), related to the net assimilation of the canopy \(A_n\) expressed in units of \(kgCO_2m^{-2}s^{-1}\) growth is described as the accumulation of carbon obtained from assimilation of atmospheric \(CO_2\), and senescence as the result of a deficit of photosynthesis. In ISBA-A-gs, the leaf biomass \(B\) is obtained from the differential equations:

\[
\frac{dB}{dt} = \frac{M_C}{P_CM_{CO_2}}A_n - Bd(t) \tag{C.1}
\]

where \(P_C\) is proportion of carbon in the dry plant biomass, and \(M_C\) and \(M_{CO_2}\) are the molecular weights for the carbon and \(CO_2\), respectively.
The mortality increment term of equation C.12 represents an exponential extinction of \( B \) characterized by a time-dependent effective life expectancy (expressed in units of days):

\[
\tau(t) = \tau_M \frac{A_{n, fm(t)}}{A_{n, max}},
\]

where \( \tau_M \) is the maximum effective life expectancy of the active biomass, \( A_{n, fm(t)} \) is the maximum leaf net assimilation reached on the day before time \( t \) and \( A_{n, max} \) is the optimum leaf net assimilation.

The value of LAI is obtained from leaf biomass \( B \) through:

\[
LAI = \frac{B}{\alpha_B}
\]

where, \( \alpha_B \) is the specific leaf area index.

**Carbon Assimilation of A-gs option**

A-gs is an interactive leaf area index option employed in ISBA. It calculates carbon assimilation using the method of Jacobs et al. Jacobs et al. (1996).

The photosynthesis rate in light-saturating conditions is expressed as:

\[
A_m = A_{m, max} \left[ 1 - \exp \left\{ -g^*_{m} \times (C_i - \Gamma) / A_{m, max} \right\} \right],
\]

The \( g^*_{m} \) parameter (the unstressed mesophyll conductance) is corrected for leaf temperature using a Q10-type function, together with the maximum photosynthesis \( A_{m, max} \) and the compensation point \( \Gamma \). Typical values of \( A_{m, max} \) and \( \Gamma \) at a temperature of 25\(^\circ\)C for \( C_3 \) and \( C_4 \) plants, are given in Table ??.

<table>
<thead>
<tr>
<th>Parameter(X)</th>
<th>\begin{tabular}[c]{c} X(@25) \end{tabular}</th>
<th>Q10</th>
<th>( T_1 )</th>
<th>( T_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_3 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \varepsilon_0, \text{mg} J^{-1} )</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Gamma, \text{ppm} )</td>
<td>45</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( g^*_{m, \text{ums}^{-1}} )</td>
<td>see table 2</td>
<td>2.0</td>
<td>5</td>
<td>36</td>
</tr>
<tr>
<td>( A_{m, max, \text{mgm}^{-2} s^{-1}} )</td>
<td>2.2</td>
<td>2.0</td>
<td>8</td>
<td>38</td>
</tr>
<tr>
<td>( C_4 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \varepsilon_0, \text{mg} J^{-1} )</td>
<td>0.014</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Gamma, \text{ppm} )</td>
<td>2.8</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( g^*_{m, \text{ums}^{-1}} )</td>
<td>see table 2</td>
<td>2.0</td>
<td>13</td>
<td>36</td>
</tr>
<tr>
<td>( A_{m, max, \text{mgm}^{-2} s^{-1}} )</td>
<td>1.7</td>
<td>2.0</td>
<td>13</td>
<td>38</td>
</tr>
</tbody>
</table>
To avoid lengthy iterations, the internal \( \text{CO}_2 \) concentration \( C_i \) is obtained by combining the air \( \text{CO}_2 \) concentration \( C_s \) and \( \Gamma \) through the following closure equation:

\[
C_i = fC_s + (1 - f)\Gamma,
\]

where the coupling factor \( f \) is sensitive to air humidity and depends on the cuticular conductance \( g_c \) and on \( g_m^* \), \( f_0^* \) is the value of \( f \) for \( D_s = 0 \).

The net assimilation \( A_n \) is limited by a light deficit according to a saturation equation applied to the photosynthetically active radiation \( I_a \):

\[
f = f_0^*(1 - D_s/D_{\text{max}}^*) + (g_c/[g_c + g_m^*])(D_s/D_{\text{max}}^*),
\]

where leaf respiration is given by \( R_d = A_m/9 \), and the light conversion efficiency by \( \varepsilon = \varepsilon_0(C_i - \Gamma)/(C_i + 2\Gamma) \), where \( \varepsilon_0 \) is the maximum quantum use efficiency.

\[
A_n = (A_m + R_d)(1 - \exp(-\varepsilon I_a/(A_m + R_d)) - R_d),
\]

Finally,

\[
g_s = (g_c + 1.6(A_n - A_{\text{min}}(D_s/D_{\text{max}}^* A_m + R_d)) + R_d(1 - \frac{A_n + R_d}{A_m + R_d})/(C_s - C_i)
\]

where \( A_{\text{min}} \) represents the residual photosynthesis rate associated with cuticular transfers when the stomata are closed because of a high saturation deficit:

\[
A_{\text{min}} = (g_m^* \times g_c(C_s - \Gamma)/(g_m^* + g_c).
\]

From the above equations, the water use efficiency can be expressed simply, in the case of a zero value of \( g_c \):

\[
WUE = \frac{C_s - \Gamma}{1.6\rho_a[f_0^*/D_{\text{max}}^* + (1-f_0^*)/D_r]}.
\]

where \( \rho_a \) is air density.

The influence of soil moisture stress on \( g_m, f_0 \) and \( D_{\text{max}} \) is described by Calvet and Noilhan (2000) and Calvet et al. (2004). The leaf to canopy conversion of net assimilation \( A_{\text{nl}} \) and conductance \( g_{sl} \) can be depicted as:

\[
A_{\text{nl}} = \text{LAI} \int_0^1 A_n dz/h
\]

\[
g_{sl} = \text{LAI} \int_0^1 g_s dz/h
\]

where \( h \) is canopy height and \( z \) is the distance to the ground.
Soil Moisture Stress Parameterization

**Initial version** Soil moisture effect is applied to mesophyll conductance, normalizing $g_m^*$ by the normalized soil moisture:

$$f_2 = \frac{\bar{\Theta} - \Theta_{wilt}}{\Theta_{fc} - \Theta_{wilt}}$$  (C.13)

**Improved version** It is found that the relationships between $g_m$ and $D_{max}$ for low vegetation and between $g_0$ and $f_0$ for high vegetation.

For low vegetation, C3 plants:

$$\ln(g_m^*) = 2.381 - 0.6103\ln(D_{max}^*)$$

C4 plants:

$$\ln(g_m^*) = 5.323 - 0.8923\ln(D_{max}^*)$$

For high vegetation, $D_{max}^* = -37.97\ln(g_m^*) + 150.4$

Soil Water Balance

**2-layer option** $w_g$ and $w_2$ represents surface soil moisture and deep layer soil moisture. Force-restore method applied by Deardorff (1977) to the ground soil moisture:

$$\frac{\partial w_g}{\partial t} = \frac{C_1}{\rho_w d_1}(P_g - E_g) - \frac{C_2}{\tau}(w_g - w_{geq}); 0 \leq w_g \leq W_{sat}$$  (C.14)

$$\frac{\partial w_2}{\partial t} = \frac{C_1}{\rho_w d_2}(P_g - E_g - E_{tr}) - \frac{C_3}{d_{2r}}\max[0, (w_2 - w_{fc})]; 0 \leq w_2 \leq W_{sat}$$  (C.15)

where $P_g$ is the flux of liquid water reaching the soil surface (including the melting), $E_g$ is the evaporation at the soil surface, $E_{tr}$ is the transpiration rate, $\rho_w$ is the density of liquid water, and $d_1$ is an arbitrary normalization depth of 1 centimeter. In the present formulation, all the liquid water from the flux $P_g$ goes into the reservoirs $W_g$ and $W_2$, even when snow covers fractions of the ground and vegetation. The coefficients $C_1$ and $C_2$, and the equilibrium surface volumetric moisture $w_{geq}$, have been calibrated for different soil textures and moistures (Noilhan and Planton, 1989). Noilhan and Planton (1989).

The expression of $C_1$ depends on the soil moisture content. For wet soils (i.e., $w_g \geq w_{wilt}$), this coefficient is expressed as:

$$C_1 = C_{1sat}\left(\frac{w_{sat}}{w_g} + 1\right)$$  (C.16)

For very dry soils (i.e., $w_g \geq w_{wilt}$), the vapor phase transfer needs to be considered in order to reproduce the physics of quter exchange. These transfers are parameterized as a function of the wilting point $w_{wilt}$, the soil water content $w_g$, and the surface temperature.
$T_s$, using the Gaussian expression:

$$C_1 = C_{1\text{max}} \exp\left[-\frac{(w_g - w_{\text{max}})^2}{2\sigma^2}\right] \quad (C.17)$$

where, $w_{\text{max}}$, $C_{1\text{max}}$, and $\sigma$ are respectively the abscissa of the maximum, the mode, the standard deviation of the Gaussian functions. $C_2$ and the equilibrium water content, $w_{\text{eq}}$, are given by

$$C_2 = C_{2\text{ref}} \left(\frac{w^2}{w_{\text{sat}} - w^2 + 0.01}\right) \quad (C.18)$$

$$w_{\text{eq}} = w_2 - a w_{\text{sat}} \left(\frac{w^2}{w_{\text{sat}}}\right)^p (1 - \left(\frac{w^2}{w_{\text{sat}}}\right)^8 p) \quad (C.19)$$

**3-layer option** Within this version, bulk soil layer (equivalent to $w_2$ in the previous section) is divided into a root-zone layer and base-flow layer ($d_3 - d_2$). The governing equations are written

$$\frac{\partial w_2}{\partial t} = \frac{C_1}{\rho_c d_2} (P_g - E_g - E_{\text{tr}} - \frac{C_3}{d_2^2 \tau}) \max[0, (w_2 - w_{\text{fc}})] - \frac{C_4}{\tau} (w_2 - w_3); 0 \leq W_g \leq W_{\text{sat}} \quad (C.20)$$

$$\frac{\partial w_3}{\partial t} = \frac{d_2}{(d_3 - d_2)} \frac{C_3}{d_2^2 \tau} \max[0, (w_2 - w_{\text{fc}})] + \frac{C_4}{\tau} (w_2 - w_3) - \frac{C_3}{(d_3 - d_2) \tau} \max[0, (w_3 - w_{\text{fc}})]; 0 \leq w_3 \leq W_{\text{sat}} \quad (C.21)$$

where $C_4$ represents the vertical diffusion coefficient. It is defined as:

$$C_4 = C_{4\text{ref}} \bar{\omega}_c^{C_{4b}} \quad (C.22)$$
TITLE: Implementation of a satellite-based prognostic daily surface albedo depending on soil wetness and impact study in SURFEX modelling platform over France

ABSTRACT

The objective of this thesis is to introduce a prognostic daily surface albedo and evaluate its impact for energy and hydrology in SURFEX Modeling platform over France. As a first step, the existing albedo climatology is evaluated with daily MODIS and SEVIRI albedo products over France, which shows a difference. Secondly, soil and vegetation albedo are separated through a static regression method and a dynamic physical method using multi-year MODIS albedo dataset. The soil background albedo shows a consistent comparison with the equivalent of University Swansea.

Finally, a prognostic albedo depending on soil wetness and chlorophyll is implemented in-situ soil moisture records over 12 SMOSMANIA stations and leaf chlorophyll content measurements. Gathering soil and vegetation inputs, the method for a prognostic surface albedo is verified using satellite products and in-situ measurements over the dehesa ecosystem (Majadas, Spain). The impact of a changing surface albedo on energy budget is evaluated in SURFEX modelling platform over France. A joint assimilation of leaf area index and surface soil moisture with albedo is complemented using SEKF, which shows positive effects for the case of vegetation that are not too dense.
La thèse a pour objectif de développer un albédo de surface journalier pronostique dans les modèles météorologiques et d’évaluer son impact pour le bilan d’énergie et l’hydrologie dans la plate forme de modélisation SURFEX sur le domaine France. En premier lieu, un albédo climatologique est à ce jour considéré dans SURFEX. Il est analysé dans cette étude par rapport aux albédos quotidiens de SEVIRI et MODIS dont ce dernier est obtenu à partir d’une méthode originale que l’on valide. Ensuite, une méthode est développée pour obtenir des albédos du sol et de la végétation de façon séparée à la fois statiquement, donc sur une base climatologique, puis dynamiquement en s’appuyant sur plusieurs années de données du satellite MODIS.

Une fois réglé l’albédo du sol journalier, il est recherché une calibration avec l’humidité du sol nu à l’aide des données du réseau de stations sol SMOSMANIA du sud-ouest de la France. Il est montré que l’on peut prédire l’évolution de l’albédo de surface, par comparaison avec les observations spatiales avec l’humidité seule dans la limite d’une végétation faiblement couvrante. Cet albédo simulé est complété par celui de la végétation seule à partir d’une paramétrisation simplifiée du code de transfert radiatif PROSAIL. L’approche théorique est validée avec les données du site de Majadas pour lequel on montre que l’on sait simuler le cycle d’évolution de l’albédo total avec prise en compte de la chlorophylle au niveau de la feuille. En dernier lieu, il a été réalisé une étude d’impact du nouveau albédo évolutif sur le bilan d’énergie et l’hydrologie dans SURFEX sur la France. Il est aussi mis en place une assimilation de l’albédo conjointement avec l’indice foliaire et l’humidité superficielle, ce qui a des effets positifs pour le cas des végétations qui ne sont pas trop denses.