

IMPROVEMENT OF A SURFACE ENERGY BALANCE MODEL BY THE USE OF MSG-SEVIRI DERIVED VEGETATION PARAMETERS

Nicolas Ghilain, Alirio Arboleda and Françoise Gellens-Meulenberghs

Royal Meteorological Institute
Avenue circulaire, 3
B-1180 Bruxelles, Belgium

Abstract

In the framework of the EUMETSAT Land Surface Analysis (LSA) - Satellite Application Facility (SAF), models have been developed to retrieve from the MSG SEVIRI imager, surface variables like albedo, short- and long-wave radiation fluxes and vegetation parameters (Leaf Area Index, LAI, and Fraction of Vegetation Cover, FVC). An energy balance model is also being elaborated to produce actual evapotranspiration (ET) estimates as one of the end products of the LSA-SAF. The model is a simplified Soil-Vegetation-Atmosphere (SVAT) scheme adopting the tile approach, i.e. a sub-pixel computation of surface fluxes. The atmospheric forcings are 30 minutes full spatial resolution MSG derived surface radiative fluxes complemented by the ECMWF screen-level meteorological variables (air temperature and humidity, wind speed, ...). Important factors that strongly influence ET estimates are the time-dependent vegetation characteristics. In SVAT schemes, the influence of vegetation on energy partition is parameterized using key phenological factors, such as FVC and LAI. While some models use fixed vegetation characteristics during the whole year, others take advantage of a finer temporal sampling of vegetation evolution up to a couple of days. This contribution will first present the chosen way to use remote sensed daily vegetation parameters derived from SEVIRI in the LSA-SAF ET model. Secondly, we will show how the partitioning of surface heat fluxes is improved when using a finer characterization of vegetation both spatially and temporally. At last, we will present the impact of remotely sensed vegetation parameters uncertainty on the LSA-SAF ET model outputs.

INTRODUCTION

Evapotranspiration is a key process of the global water cycle. Evapotranspiration over land is the water vapour released into the atmosphere by turbulence at the surface interface. Sources of evapotranspiration over land are wet soils, water bodies, and the transpiration of vegetation, which contributes to a large extend to the process. Many attempts have been done to use remote sensing to monitor and quantify with the best accuracy evapotranspiration, making use of simple empirical methods to fully detailed physical parameterization and of different kind of satellites, either polar or geosynchronous (Courault et al., 2005; Verstraeten et al., 2008, for reviews). In all classes of algorithms, the evolution of the vegetation characteristics plays a crucial role, since plants are the main medium for exchange of water between the soil and the atmosphere. Examples of impacts of vegetation changes on water cycle and more generally on regional climate can be found in the literature. The reader can refer for example to Irizarry-Ortiz et al. (2003), where vegetation changes are used to explain area reduction of the Sahara desert during the mid-Holocene period. However, in such algorithms, the vegetation characteristics parameterized can still now be kept constant during the whole year. In others, the parameterization accounts for monthly variations and in some for day-to-day variations. In this contribution the impact of using daily MSG products for sampling vegetation characteristics instead of a monthly parameterization is investigated, especially for North Africa where a large panel of climates and vegetation types exist.

THE ENERGY BALANCE MODEL AND THE LSA-SAF

In the context of the Land Surface Analysis SAF of EUMETSAT, abbreviated by LSA-SAF, different products related to land surface and exchanges between surface and atmosphere are delivered based on the MSG-SEVIRI images. One general class of products includes the four radiation components at the surface, namely the downward short and long wave radiation, the land surface temperature and the surface albedo. A second class includes different biophysical variables that can be grouped into three sub-classes: products related to water, vegetation and fire. One of the water related products is delivering land evapotranspiration. In this contribution, the algorithm that produces LSA-SAF evapotranspiration maps is the host of the new development presented.

Gellens-Meulenberghs et al. (2008) gives in this issue a detailed description of the algorithm (also presented in Gellens-Meulenberghs et al., 2007). The physical model used follows the formulation of van den Hurk et al. (2000). The evapotranspiration process is parameterized to take into account influences from atmospheric conditions, i.e. wind speed, air temperature, air humidity, and radiation components, as well from surface characteristics, i.e. vegetation related parameters and soil water availability. In the context of remote sensing and near-real time operational services, the model is used in conjunction with remotely sensed LSA-SAF radiation components, a semi-static vegetation database issued from remote sensing, i.e. ECOCLIMAP (Masson et al., 2003), and atmospheric forcings, including soil water availability, from a GCM, i.e. ECMWF short-term forecasts. In this configuration, the algorithm is called MET, standing for Meteosat based EvapoTranspiration.

Getting deeper inside the model, we can observe that vegetation characteristics play a recurrent role in a complex way. Fraction of vegetation cover, FVC, is used to partition the surface between evaporation and a transpiration component. Leaf area index, LAI, characterizing the vertical abundance of vegetation, is used to parameterize resistances to transpiration at the canopy level, the soil heat flux and the roughness length for momentum and heat used for the computation of the air surface stability.

In the operational version of MET, the vegetation parameters, like LAI and FVC, are provided by the ECOCLIMAP database. Besides the land cover map and the classification in 215 ecosystems, this database includes monthly varying vegetation parameters for each determined ecosystem. During the validation activities of MET, the ability of the algorithm using ECOCLIMAP to reproduce the seasonal variations of evapotranspiration has been proven (Gellens-Meulenberghs et al., 2008). However, in some cases, for fast changes of vegetation characteristics, the method is not well adapted. Different disadvantages of ECOCLIMAP for our purpose are the poor sampling in time, one month, and in space, average estimate for each ecosystem, for example sahelian savannah, extending from East to West of Africa, and also the fact that no inter-annual variations are allowed. Improvement is therefore needed to better characterize the vegetation state and capture its dynamics.

USING LSA-SAF VEGETATION PARAMETERS: METHODOLOGY AND RESULTS

LSA-SAF provides products related to vegetation, called here VEGA, among which we find LAI and FVC (Garcia-Haro et al., 2005a; Garcia-Haro et al., 2005b). These products are considered as good candidates to be used into MET algorithm. These products are generated every day at MSG-SEVIRI spatial resolution. Besides the estimates of LAI and FVC, and contrarily to ECOCLIMAP, the retrieval error is also provided. Although MET algorithm is working at the same spatial resolution, the use of LSA-SAF VEGA is not straightforward. The reason finds its roots in the way of computing evapotranspiration by MET. Evapotranspiration is evaluated at tile level and then averaged at pixels scale. At tile level, that can be either ecosystem or plant functional type, the evapotranspiration process is modelled using specific parameters related to vegetation. Following this way, we must get some sub-pixel estimates of LAI and FVC for MET. A simple original method to get estimation of sub-pixel values is presented here, making use of ECOCLIMAP land cover and information from LSA-SAF VEGA products.

We define a pixel as homogeneous if the land cover map assigns a percentage of more than 90% for an ecosystem within the area delimited by a MSG pixel. At first, we assume that in a small region composed of a fixed number of pixels there is no spatial variability of vegetation parameters for an ecosystem. At second, we consider a mixed pixel included in this region and composed of different

ecosystems. Using the hypothesis, we can assign to each ecosystem of the mixed pixel the vegetation characteristics derived from the closest corresponding homogeneous pixels.

Using this methodology, we compare for North Africa both algorithms: MET with ECOCLIMAP and MET with LSA-SAF VEGA. To ease the comparison with LAI, we scale the evapotranspiration by solar radiation to remove effects from clouds. A particular case in a region defined by the red delimiter in Figure 1 is shown in Figure 2 for the 14th of April 2007. From these images, we can observe similarities between both images, with a visible gradient from North to South. However, large differences are also observed in the finer structure. A visual comparison with LAI map provided by LSA-SAF in Figure 1 shows a good spatial correlation with MET with LSA-SAF VEGA.

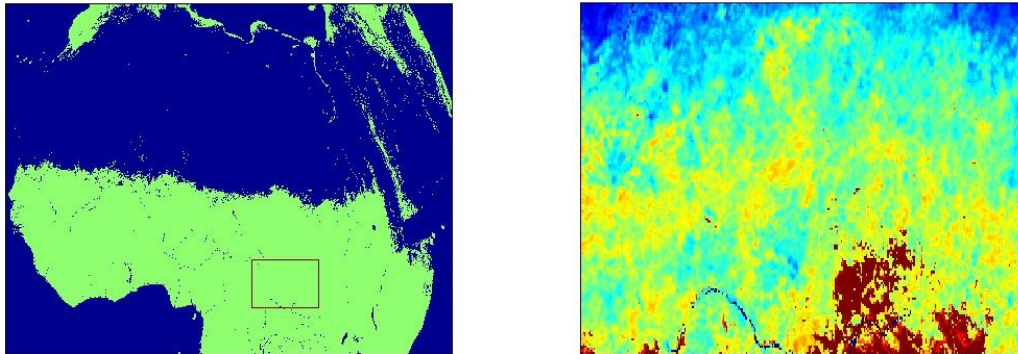


Figure 1 North Africa displayed in the MSG projection (left). The region selected to compare both methods is delimited in red. At right, leaf area index as given by LSA-SAF LAI for the region selected.

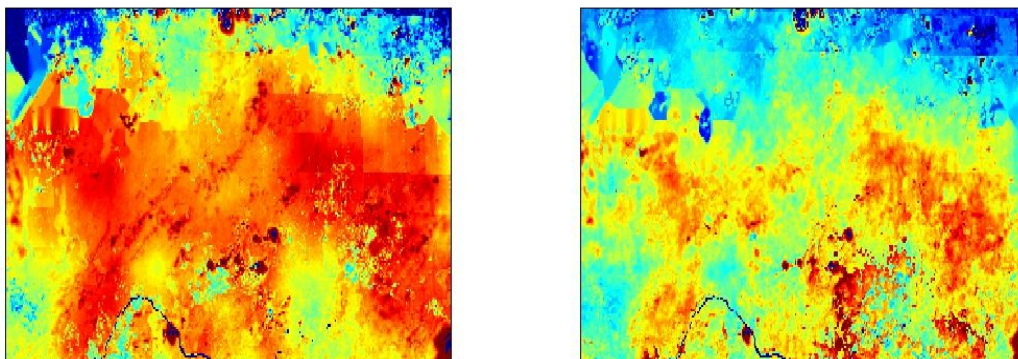


Figure 2 Evapotranspiration scaled by solar radiation as produced by MET algorithm with ECOCLIMAP (left) and with LSA-SAF VEGA and the sub-pixel method (right). The domain is represented in Figure 1.

UNCERTAINTY PROPAGATION FROM VEGETATION PARAMETERS TO EVAPOTRANSPIRATION

Another interesting aspect for using LSA-SAF VEGA instead of ECOCLIMAP database in MET is dealing with associated uncertainties. This section is devoted to assess uncertainties from both ECOCLIMAP and LSA-SAF VEGA with the simple sub-pixel methodology estimates and compare their relative impacts on the resulting evapotranspiration. The two first sub-section deal with the assessment of the uncertainty related to both sources of vegetation parameters, and, in the last sub-section, these uncertainties are propagated into the MET algorithm.

Uncertainty of ECOCLIMAP vegetation parameters

As already mentioned, ECOCLIMAP provides a database of vegetation parameters. However, no information about uncertainty is given. An estimation of the uncertainty on ECOCLIMAP estimates is derived hereafter, based on the maps acquired from LSA-SAF VEGA. In ECOCLIMAP, the uncertainty related to one parameter of a particular ecosystem is considered to be the combination of the spatial and temporal variability, $u_{intra-var}$, in addition to a mean retrieval error, $u_{retrieval}$. In practice, ECOCLIMAP gives an estimate $LAI_{eco,i}$ for a given ecosystem i . It applies for one month and for every pixel covered by this ecosystem. Taking all images of LSA-SAF VEGA for the considered month and selecting only the homogeneous pixels covered by ecosystem i , we calculate the variability of LAI, here measured as the standard deviation, for this month and this ecosystem. We then calculate the mean retrieval uncertainty of LSA-SAF VEGA for the month and the ecosystem, where the retrieval uncertainty is interpreted as the standard deviation of the error distribution. The total uncertainty is therefore the combination of the mean retrieval uncertainty and intra-variability, as stated by equation 1.

$$U_{tot,ECO} = \sqrt{u_{intra-var}^2 + u_{retrieval}^2} \quad (1)$$

We then repeat the operation for each month and each ecosystem. In Figure 3, at left, LAI from ECOCLIMAP for different months and vegetation classes are compared to the monthly mean LAI from LSA-SAF. The error bars represent the uncertainty computed by equation 1 for each estimate. A first observation of the graph is that the squares representing the monthly mean of each vegetation class are positioned near the 1:1 regression line between ECOCLIMAP LAI and LSA-SAF LAI. It implies that no systematic difference between both is detected. At second, however, the extension of the error bars shows that to the single value of LAI provided by ECOCLIMAP for one ecosystem by month corresponds actually a quite large uncertainty distribution, if we use LSA-SAF LAI images. Moreover, it is shown, in Figure 3 at right, that the relative width of the distribution increases with decreasing LAI.

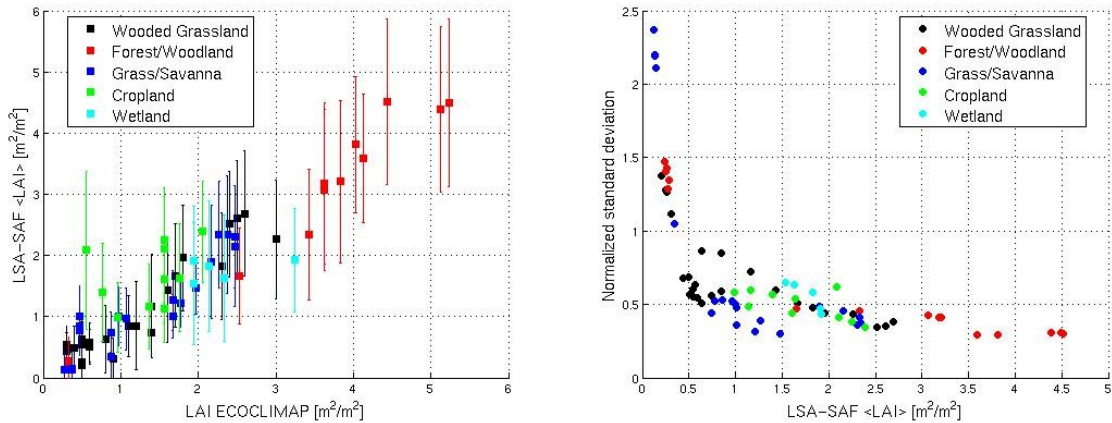


Figure 3 At left, comparison between LAI given by ECOCLIMAP for different vegetation classes and months between April and August 2007 and the mean LAI given by LSA-SAF. Errorbars represent the combination of intra-variability and mean retrieval error. These uncertainties are also represented at right in function of the mean LSA-SAF LAI.

Uncertainty of sub-pixel estimation

Computation of the uncertainty of the sub-pixel estimation of vegetation parameters using LSA-SAF VEGA is also needed. In this case, besides the retrieval uncertainty of the LSA-SAF VEGA products for the homogeneous pixels, we have to quantify the uncertainty related to the hypothesis made in the proposed method to obtain sub-pixel estimates. In other words, we have to quantify the uncertainty in function of the distance between the mixed pixel and the homogeneous pixel. In practice, we select all homogeneous pixels associated with one specified ecosystem. Then, for a sample chosen randomly within this population, we compute the difference between the sample and the rest of the homogeneous pixels in function of the distance. This procedure provides, for each range of distance, a density distribution of the error. Empirical functions of distances are built using isolines of the cumulative distributions obtained. An example for a frequent ecosystem in North Africa, ecosystem 34 of ECOCLIMAP, “sahelian woodland”, is given in Figure 4, where the relative uncertainty of LAI is

represented in function of distance by the isolines-percentiles 25%, 50%, 75%, 90% 95% and 99%. The sample used to build this histogram is composed of all LAI corresponding to homogeneous pixels of the ecosystem 34 in 28 LSA-SAF LAI images equally distributed between the month of April and August. We observe that for this ecosystem, isolines are increasing very rapidly for the range of distance between 1 and 10 pixels, and after, increase linearly at a slower rate. This behaviour is observed for almost all ecosystems in North Africa.

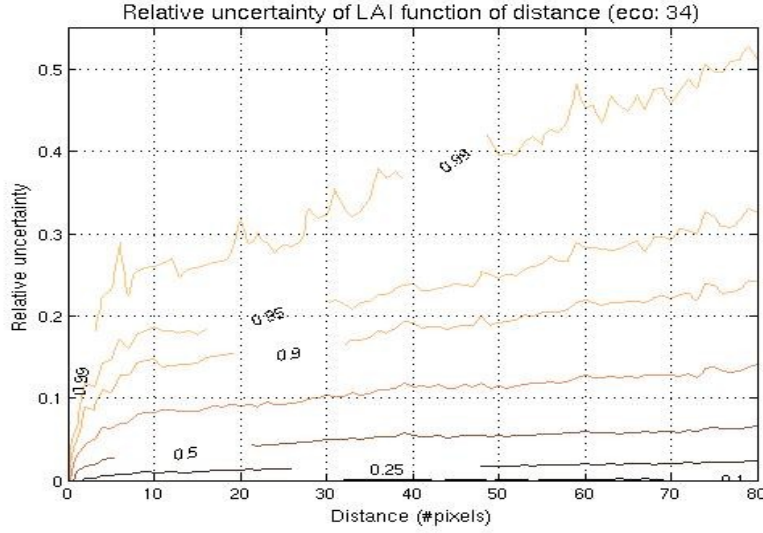


Figure 4 Ecosystem 34, “Sahelian Woodland”: percentiles of the cumulative distributions of relative uncertainty of LAI for each range of distance, in number of pixels.

Using the isoline corresponding to the standard deviation of the distributions interpreted as the uncertainty related to the distance effect, we can combine this latter one, noted u_{dist} , and the retrieval error, $u_{retrieval}$, interpreted as the standard deviation of the error distribution, by means of relation 2.

$$U_{tot} = \sqrt{u_{dist}^2 + u_{retrieval}^2} \quad (2)$$

Uncertainty assessment for evapotranspiration

Uncertainty of input vegetation parameters has been assessed in the two previous sub-sections. We first present the comparison of the uncertainty from both sources on an example illustrated in Figure 5. In this figure, the uncertainty on LAI is represented in relative unit. For both, for the Sahelian region, we have uncertainty exceeding 100%. This situation occurs because intra-variability within the specific ecosystem is larger than the mean value. For both, uncertainty of LAI is quite similar for equatorial region, resulting from the fact that there is nearly no intra-variability within the ecosystem “African equatorial forest”. For regions extending between these two limits, we can observe that the uncertainty of LAI is reduced when using LSA-SAF VEGA parameters, and this is particularly striking over West Africa.

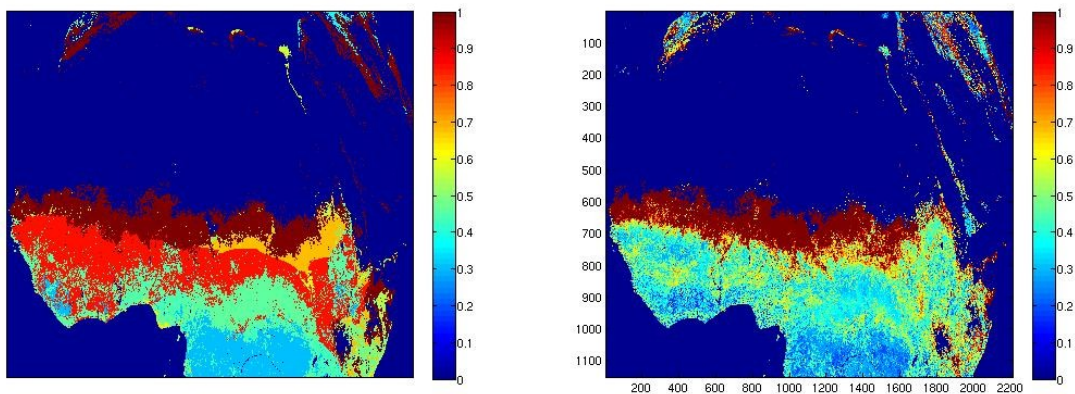


Figure 5 Global relative uncertainty on LAI for the month of April 2007 in North Africa for ECOCLIMAP (left) and LSA-SAF VEGA with the sub-pixel method (right). Both images are displayed using the MSG projection.

For our purpose, we have to evaluate the impact of these input uncertainties on the final evapotranspiration uncertainty. Taking limits of the interval of uncertainty for both vegetation parameters input, allows giving an estimation of the output uncertainty on evapotranspiration. It is illustrated in Figure 6 for a test case. In this example, we observe that the uncertainty of evapotranspiration is, as expected, also reduced in the region between equatorial forest and the southern border of Sahara desert. From this result, it is expected to get similar improvements for the other months and other regions, since North African region covers a large panel of climates, from very wet to very dry, and vegetation dynamics.

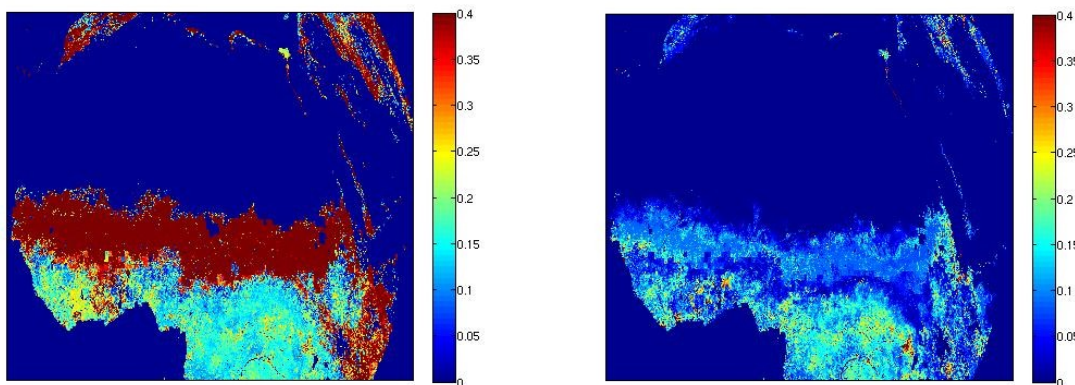


Figure 6 Relative uncertainty of evapotranspiration estimates for 14th of May 2007. At left, we use ECOCLIMAP related uncertainty and at right the uncertainty related to the treatment of LSA-SAF VEGA.

CONCLUSION AND PERSPECTIVES

Within the framework of LSA-SAF, an energy balance model has been developed to derive evapotranspiration maps over land using advantages of optical and infrared remote sensing. The code provides maps of evapotranspiration in near-real time at MSG spatial resolution and 30 minutes time step. Impact studies and research on improvements are currently on going. This contribution presents the benefits to use LSA-SAF vegetation parameters in the model instead of the semi-static ECOCLIMAP database. The use of LSA-SAF vegetation parameters is performed in combination with a land cover map within a nearest neighbour algorithm to assign sub-pixel estimates. Advantages of LSA-SAF vegetation parameters, adapted by the simple set up algorithm, are the better spatial and temporal sampling to be used in the energy balance model that leads to a finer evolution of the evapotranspiration estimates. Another advantage is seen in terms of induced uncertainties on the final evapotranspiration

maps. Assessment of the uncertainty of ECOCLIMAP fields and of LSA-SAF VEGA with the use of the simple method to get sub-pixel estimates is performed, as well as the propagation of this uncertainty into the energy balance model. It is shown that the energy balance model also benefits from the change from ECOCLIMAP to LSA-SAF VEGA, because the final uncertainty is globally reduced. The proposed method is currently investigated over all regions covered by MSG/SEVIRI and improvement is expected everywhere. Since results are promising for near-real time services related to evapotranspiration estimations from remote sensing, this method will probably be implemented in the LSA-SAF operational system to improve the quality of the evapotranspiration product.

ACKNOWLEDGMENT

The project is funded at RMI by EUMETSAT and by ESA under the PRODEX-8 program of the federal Belgian science policy.

REFERENCES

- Courault, D., Seguin, B., and Olioso, A. (2005) Review on estimation of evapotranspiration from remote sensing data: from empirical to numerical modelling approaches. *Irrigation and Drainage Systems*, **19**, pp 223-249.
- García-Haro, F.J., Sommer, S., Kemper, T. (2005a) Variable multiple endmember spectral mixture analysis (VMESMA). *International Journal of Remote Sensing*, **26**, pp 2135-2162.
- García-Haro, F.J., F. Camacho-de Coca, J. Meliá, B. Martínez (2005b) Operational derivation of vegetation products in the framework of the LSA SAF project. *Proceedings of the EUMETSAT Meteorological Satellite Conference Dubrovnik (Croatia) 19-23 Septembre*.
- Gellens-Meulenberghs, F., Arboleda, A., Ghilain, N. (2008). *Proceedings of the EUMETSAT Meteorological Satellite Conference Darmstadt (Germany) Septembre 2008*.
- Gellens-Meulenberghs, F., Arboleda, A., Ghilain, N. (2007) Towards a continuous monitoring of evapotranspiration based on MSG data. *Proceedings of the symposium on Remote Sensing for Environmental Monitoring and Change Detection. IAHS series. IUGG, Perugia, Italy, July 2007*, 7 pp.
- Irizarry-Ortiz, M.M., Wang, G. and Eltahir, E.A.B. (2003) Role of the biosphere in the mid-Holocene climate of West Africa. *Journal of Geophysical Research*, **108**, D2, pp 4042-4056.
- Masson, V., Champeaux, J. L., Chauvin, F., Meriguet, Ch. and Lacaze, R. A. (2003) Global Database of Land Surface Parameters at 1-km Resolution in Meteorological and Climate Models. *Journal of Climate*, **16**, 9, pp 1261-1282.
- Verstraeten, W.W., Veroustraete F. and Feyen J. (2008) Assessment of Evapotranspiration and Soil Moisture Content Across Different Scales of Observation. *Sensors*, **8**, pp 70-117.