EUMETSAT’S LSA-SAF EVAPOTRANSPIRATION: COMPARISONS OF OPERATIONAL PRODUCT TO OBSERVATIONS AND MODELS AT HYDROLOGICAL BASINS SCALE

A. Arboleda, N. Ghilain, F. Gellens-Meulenberghs

Royal Meteorological Institute, Avenue Circulaire, 3, B-1180 Bruxelles, BELGIUM
Corresponding author, e-mail: arboleda.alirio@meteo.be

ABSTRACT

Instantaneous and daily evapotranspiration (ET) products developed in the framework of EUMETSAT’s Satellite Application Facility on Land Surface Analysis (LSA-SAF) are based on a physical approach in which data derived from Meteosat Second Generation (MSG) satellites together with land-cover information are used to constrain a physical model of energy exchange between the soil-vegetation system and the atmosphere. A first algorithm generates, in near-real time, an instantaneous evapotranspiration estimate (MET) over four regions defined in the MSG FOV (Europe, Africa and the west of South America) with MSG spatial resolution (3 km at sub satellite point) and a temporal time step of 30 minutes. Once all instantaneous ET estimates for a given day have been generated, a second algorithm integrates these values and generates a daily-integrated product (DMET). The MET product has been validated mainly over Europe given that over remaining regions (Africa and South America), reference data for validation is very scarce and the validation has been accomplished mainly by models inter-comparison and comparison to local observations over a few locations. The MET and DMET products have been declared operational in November 2010 and since then, instantaneous and daily ET products are disseminated to interested users through LSA-SAF system (*http://landsaf.meteo.pt/*) and via EUMETCAST.

INTRODUCTION

Evaluating energy fluxes at the Earth surface is of great importance in many disciplines like weather forecasting, water management, agriculture, hydrology, ecology and global climate monitoring. Evapotranspiration (ET) defined as the flux of water between the surface (soil + vegetation) and the atmosphere is one of the main components of the terrestrial water budget. It is associated with the latent heat flux (LE), a key link between the energy and water cycles. Accurate measurements of evaporation rates at large spatial scales are central to understanding land and atmosphere interactions in the context of global warming. The method implemented in the context of the LSA-SAF project, follows a physical approach in which data derived from Meteosat Second Generation (MSG) geostationary satellites together with external land-cover information are used to constrain a physical model of energy exchange between the soil-vegetation-atmosphere systems. The scope of the method is limited to evaporation from terrestrial surfaces rather than from lake or ocean surfaces. This method is one of the firsts that intent to derive ET operationally over large areas in the context of remote sensing.

The instantaneous product has been extensively validated over the European window producing very satisfactory results [1]. Over remaining regions (Africa and South America), reference data is scarce and the validation has been accomplished mainly by comparison to observations over a few locations and by models inter-comparisons [1]. In order to more finely assess, the model capabilities in dry/very dry areas prevailing in the African Continent, validation is considered a continuous activity on this region.

In this contribution we present some results of the validation of DMET product at local scale. Some examples of the product at larger scales cumulated daily and monthly with emphasis on a selected hydrological basin are also presented.

INSTANTANEOUS PRODUCT (MET)

A complete description of the method has been presented in Ghilain et all (2011), and is also available on LSA-SAT ET documentation (http://landsaf.meteo.pt/). To summarise the method, main used equations and a short description are presented below:

$$(1-\alpha)S\downarrow + \varepsilon(L\downarrow - \sigma T^{4}_{sk,i}) + H + LE_i - G_i = 0 \tag{1}$$

$$H_i = \frac{\rho_a}{r_{ai}}\left[c_p(T_{sk,i} - T_a) - gz_a\right] \tag{2}$$

$$LE_i = \frac{L_v \rho_a}{(r_{ai} + r_{ci})}\left[q_{sat}(T_{sk,i}) - q_a(T_a)\right] \tag{3}$$

$$G_i = \beta_i . R_{n_i} \tag{4}$$

At surface level, the net radiation (Rn) is decomposed into 3 fluxes: sensible heat flux (H), soil heat flux (G) and latent heat flux (LE), which is the energy balance variable directly related to ET; it also establishes the link between the energy and the water cycles. α is the surface albedo, ε is the surface emissivity, σ is the Stefan-Boltzmann constant, $T_{sk,i}$ is the skin temperature, r_{ai} is the aerodynamic resistance, r_{si} the stomatal resistance, S↓ and L↓ are respectively short and long wave surface fluxes which, together with albedo, are derived from satellite observations. In the model, every image pixel is divided into homogeneous entities representing particular cover types (grass, forest, bare soil, etc.) The energy balance equation (1) is solved separately for each cover type in considered pixel. A simple relationship is used to estimate the ground heat flux G (equation 4), where the method of Chehbouni *et al*. (1996) is adopted to derive β_i from the Leaf Area Index. The global pixel value for LE, H and ET fluxes is calculated as a weighted contribution of individual tiles.

For every 30 minutes time step, the instantaneous algorithm generates one output file containing ET estimates in mm/h (figure 1a) and information about the quality of estimates (Quality flag) on pixel-by-pixel basis (figure 1b). Quality flags reflect the quality of input data and possible assumptions done to work out the results. A detailed description of output files can be found in the MSG ET ('MET') Product User Manual ('PUM') available from the LSA-SAF web site (http://landsaf.meteo.pt/).

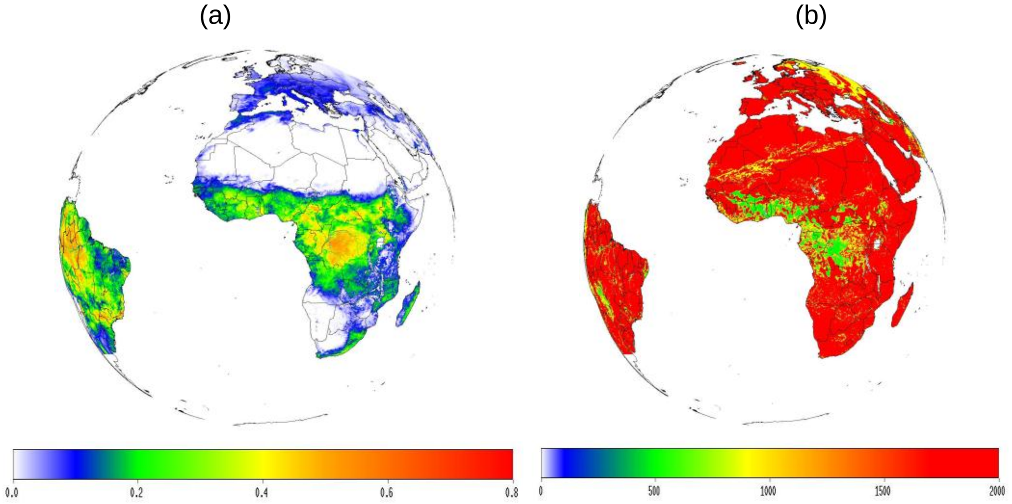

***Figure 1*, LSA-SAF instantaneous evapotranspiration product –MET- (a) and associated quality flag (b) for 2010/10/29 at 12:00 UTC over full MSG disk**

DAILY PRODUCT (DMET)

The daily evapotranspiration product is obtained by temporal integration of instantaneous values according to equation (5).

$$DMET = \sum_{t1=1}^{t2=48} MET_i \qquad (5)$$

In this equation, MET_i corresponds to instantaneous evapotranspiration for i time-step between first (theoretically at 00:30 UTC) and last slot (theoretically at 24:00 UTC) for a given day. In optimal conditions (no missing slots) 48 images are integrated for a given day. The implemented procedure accounts for missing slots and values by allowing pixels “evapotranspirate” at a rate equivalent to the average between two existing time-steps (previous and next existing values). Every output file is composed of 3 images containing DMET estimates, information about the percentage of missing values for every pixel on the image and information about the number of missing slots for a given day. The daily product is generated with a lag time of one day. In figure 2, an example of the DMET product (a) and the accompanying information on missing values (b) is presented for 10th September 2010 over the full MSG disk.

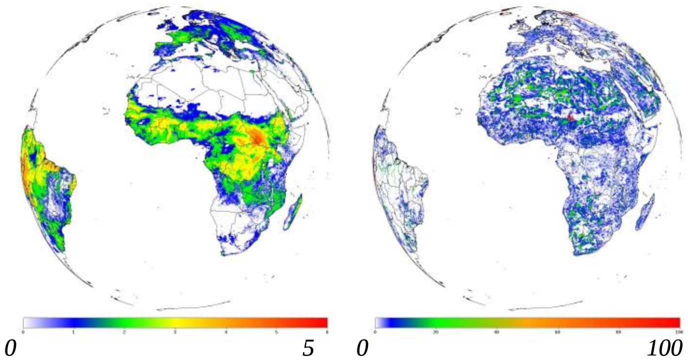

***Figure 2*, DMET (mm/d) product (a) and corresponding missing pixels (0-100%) image (b) for 10th September 2010 over full MSG disk**

Examples of cumulated ET.

Below we present some examples of monthly-cumulated ET over the Full MSG disk (figure 3) and a 12 plots image representing the daily average evapotranspiration for every moth of the year 2010 over the Nile river basin, extracted and cumulated from the north and South Africa MSG window.

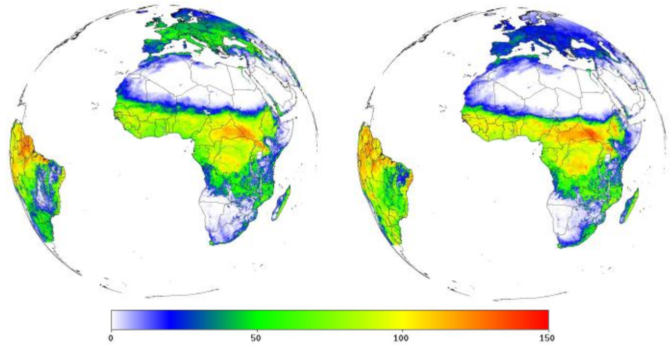

***Figure 3*, Example of monthly-cumulated ET (mm) September and October 2010 over full MSG disk**

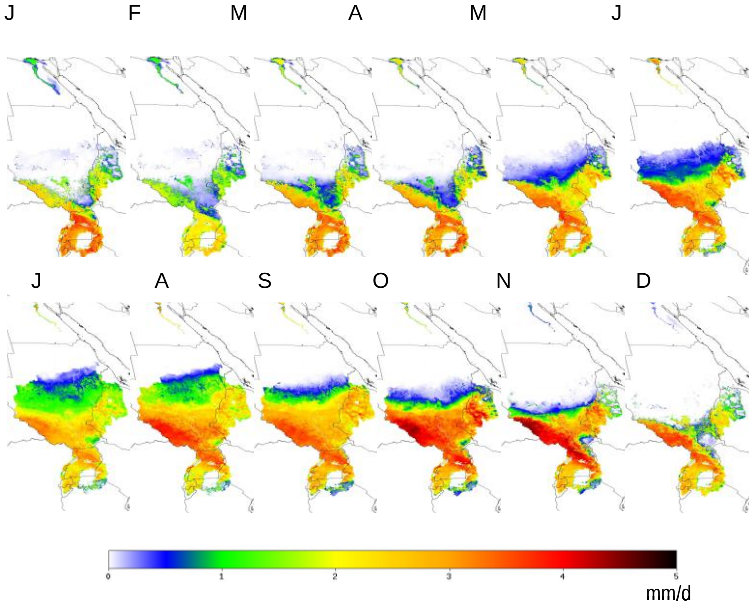

***Figure 4*, daily averaged evapotranspiration for every moth of the year 2010 over the Nile river basin**

The examples above illustrate the possibilities offered by ET products. Indeed, in many disciplines the knowledge of the evolution in time of these variables is of great importance for the management of water resources for human consumption, agricultural use, etc. the knowledge of the evolution of ET rates at basin or larger scales can be a first step to detect changes related to climate, desertification or highlight the impact of deforestation.

COMPARISONS TO GROUND OBSERVATIONS

Detailed information about validation approaches and obtained results has been presented in the product validation report and in Ghilain et. all 2011 The validation of the ET products has been achieved by comparing the algorithm output (instantaneous and cumulated) to evapotranspiration derived from measurements made at selected locations and by comparing the algorithm output to the output from other models. Some results of the comparisons between model estimates and observation are presented below. It is expected daily evapotranspiration product (DMET) to have accuracy equivalent to the accuracy of instantaneous product. To verify this hypothesis, the output of the DMET algorithm has been compared to daily-cumulated ET values at the same locations used for the instantaneous product validation. Furthermore, by using the same validation stations, the coherence of both products can be assessed and the conclusions from instantaneous product can be extrapolated to daily product. In order to achieve meaningful comparisons of the daily product, it is necessary that measurements as well as model simulations exist for the full diurnal cycle in the analyzed period. This is one of main difficulties given that observations contain many gaps and, very often, wrong values during night or specific periods of the year. It happens also that model simulations are missing due to non-generation of an input variable or problems during the product generation. For the current comparisons, daily ET is used for the comparison only if at least 75 percent of observations and simulations exist for a given day.

In figures below, we present results of the comparisons at four locations in Europe, characterized by different land covers: the first site (Cabauw, NL) is representative of grassland in well watered conditions, the second site (Tojal, PT) is also representative of grassland but located in more dry climatic conditions; the thirst site (Wetzstein, GER) is representative of evergreen needle forest; and the fourth site (Vielsalm, BE) is representative of mixed forest. The goodness of fit between model simulation and observations has been evaluated by means of classical statistical indicators (RMS, Cor, Nash index, Bias) and for visual interpretation, 4 types of plots have been generated for every site: a) on the left panel, a density scatter plot of 30 minutes simulated vs observed values with statistical indicators b) ten days sliding averages c) Scatter plots of daily simulations vs. observations with superposed statistics and d) a Taylor diagram (Taylor, K.E) to summarise the statistics of the comparison.

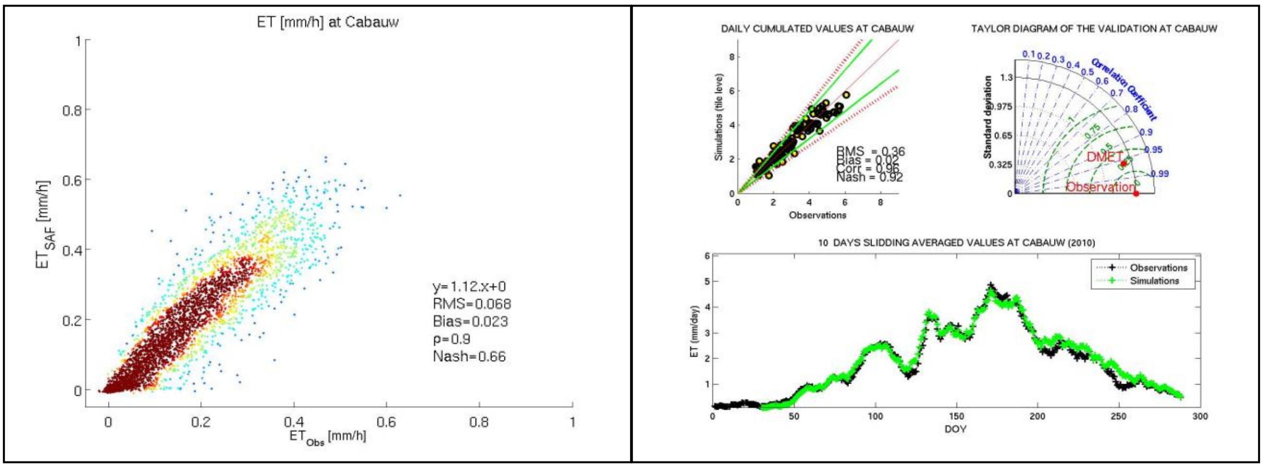

Figure 5, **Comparisons of instantaneous (left panel) and daily ET at Cabauw site for 2010**

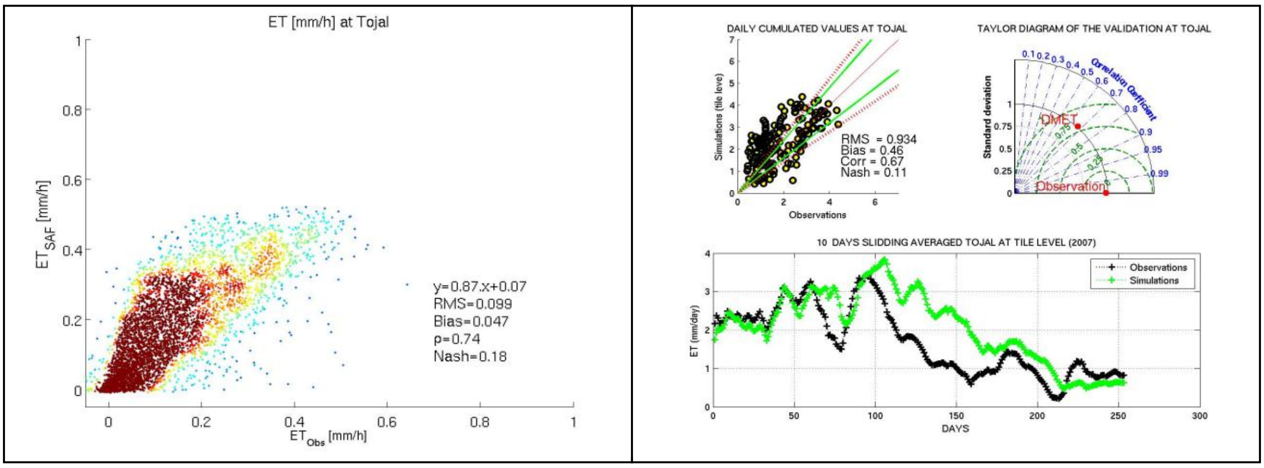

Figure 6, **Comparisons of instantaneous (left panel) and daily ET at Tojal for 2007**

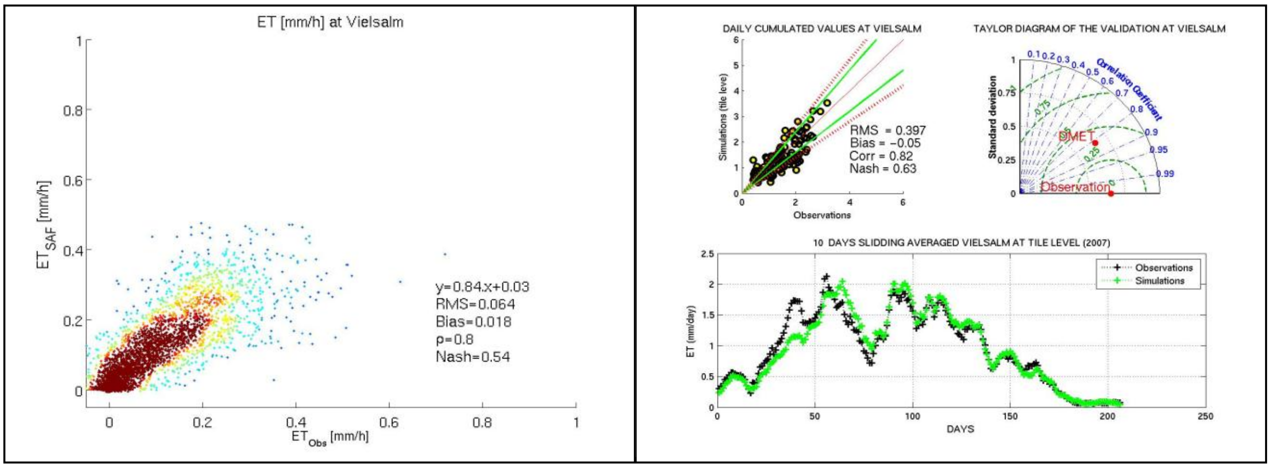

Figure 7, **Comparisons of instantaneous (left panel) and daily ET at Vielsalm for 2007**

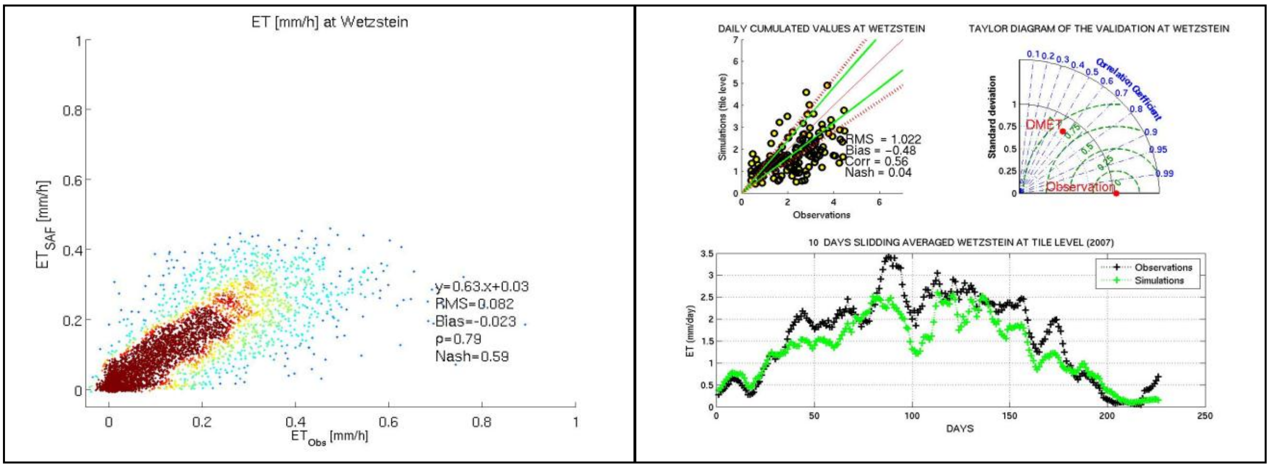

Figure 8, **Comparisons of instantaneous (left panel) and daily ET at Wetztein for 2007**

DISCUSSION

Detailed information about validation of instantaneous product has been presented in the product's validation report accessible at () and more recently in Ghilain et. all 2011. For the validation of the daily product, it is necessary that measurements as well as model simulations exist for the full diurnal cycle in the analyzed period. Available observations contain many gaps and wrong values in some period of the year what limits the number of days suitable for the analysis. For the results presented in the current contribution, daily ET is used for the comparison only if at least 75 percent of observations and simulations exist for a given day. All comparisons presented in this study have been realized on sites over Europe. For Africa and South America, the work must be continued in order to more finely assess the model performances in dry/very dry areas affected by strong soil water stress. Overall, DMET fairly matches the observed variations, with a very good agreemen For well-watered grassland site Cabauw (RMS = 0.36 and corr = 96%) followed by mixed forest Vielsalm (RMS = 0.4 and corr = 82%), grassland site Tojal (RMS = 0.9 and corr = 67%) and evergreen needle forest Wetztein (RMS = 1.0 and corr = 56%) For the grassland site Tojal, we obtain good results in spring and autumn but poor correspondence in summer, which can be attributed to bad soil moisture used as input. Main assets of the product are the applicability at large scales, the use of up-to-date products derived from Satellite remote sensing, the production on quasi-real time basis, the temporal and spatial resolution and easy data accessibility.

PLANNED SCIENCE ACTIVITIES

Two main axes will be followed to improve the general quality of MET/DMET products: The first axe concerns the improvement of the knowledge on vegetation state. For this purpose, LSA-SAF LAI and FVC products in combination with ECOCLIMAP (Masson et al., 2003) land cover database will be used. The second axe concerns the improvement of the knowledge on soil moisture status. As a first step, a full Soil-Vegetation-Atmosphere Transfer model has been developed to account for the evolution of water and temperature in the soil and to account for rain interception and snow depth evolution. In a second stage, LSA-SAF-LST will be used probably in an assimilation scheme, to improve the knowledge about the state of the surface.

REFERENCES

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