Remote Sensing for Environmental Monitoring and Change Detection (Proceedings of Symposium HS3007 at IUGG2007, Perugia, July 2007). IAHS Publ. 316, 2007.

Towards a continuous monitoring of evapotranspiration based on MSG data

FRANÇOISE GELLENS-MEULENBERGHS, ALIRIO ARBOLEDA & NICOLAS GHILAIN
Royal Meteorological Institute of Belgium, Avenue Circulaire, 3, B-1180 Brussels, Belgium
f.meulenberghs@oma.be

Abstract In the framework of the EUMETSAT's Land Surface Analysis–Satellite Application Facility (LSA–SAF), a method was developed to estimate evapotranspiration (ET) over Europe. The methodology follows a Soil Vegetation Atmosphere Transfer (SVAT) approach. LSA–SAF provides main forcings deduced from Meteosat Second Generation (MSG): visible and infrared surface radiative fluxes and daily surface albedo. The temporal sampling allowed by MSG is particularly interesting to work out correct ET temporal means taking cloud cover into account. The methodology involves the ECOCLIMAP database, well suited for the tile approach. Successive versions of the model are building with an increasing complexity. Today, half-hourly ET maps over Europe are produced in near-real time by the LSA–SAF Host Institute. Examples are given as illustrations. Comparisons are mainly done with ground flux measurements. Future planned developments are outlined.

Key words Europe; evapotranspiration; Land Surface Analysis; long-term monitoring; Meteosat Second Generation; Satellite Application Facility; Soil Vegetation Atmosphere Transfer; surface energy balance; surface fluxes

INTRODUCTION

The evapotranspiration (ET) includes both the contributions of the evaporation of the soil and the transpiration of the vegetation. It is an important term of the hydrological cycle. The associated energy flux is called the latent heat flux. The ET process is thus dealing with both the water cycle and the energy budget. It results from many interactions over a broad range of spatial and temporal scales. Accurate estimates are still challenging and research is still ongoing to explore the different facets of this complex process. Ground flux stations have hopefully been developed during the last decade. However, they are restricted to a selection of particular places and ecosystems. Remote sensing technology is expected to contribute to the understanding of the terrestrial biosphere–atmosphere interactions at a larger spatial scale by providing an integral monitoring tool. Geostationary satellites have been especially designed to follow quickly evolving phenomena depending on cloud cover conditions and the diurnal cycle.

EUMETSAT has recently established the Satellite Application Facility (SAF) concept (see http://www.eumetsat.int/Home/Main/What_We_Do/SAFs/index.htm). Within the framework of the Land Surface Analysis–SAF (LSA–SAF, http://landsaf.meteo.pt/), a method has been developed to estimate the evapotranspiration (ET) from Meteosat Second Generation (MSG) over Europe (Gellens-Meulenberghs *et al.*, 2006). The objective is to provide users with quasi-real time results and to store long-term archives to allow both a quick monitoring and long-term studies directed towards possible change detection.

In practice the model is built with an increasing complexity corresponding to successive versions. In this paper we present the state of development of the model at the end of the Initial Operation Phase (IOP). At first, the main features of the methodology and input data used are outlined. Some results are then presented as illustration and emphasis is put on the importance of the validation. Perspectives for further work are then sketched out.

METHODOLOGY

The methodology follows a Soil Vegetation Atmosphere Transfer (SVAT) approach based on the ECMWF Tessel SVAT scheme (Viterbo & Beljaars, 1995; van den Hurk *et al.*, 2000). It is adapted for remote sensing to accept as main input forcings derived from the MSG-SEVIRI sensor.

The developed ET model first considers sub-grid (or sub-pixel) homogeneous entities called "tiles" and then the aggregation of the results obtained for the different tiles to obtain ET averaged values at pixel level. The different possible tile types (grassland, crops, forests, bare soil, etc.) and the respective coverage fraction ζ_i are deduced from a land cover database for each MSG pixel.

At tile level i, the surface energy budget is expressed by:

$$Rn_i - H_i - LE_i - G_i = 0 \tag{1}$$

where H_i, LE_i, and G_i are the sensible, latent, and ground heat flux, respectively and Rn_i is the net radiation at the surface.

$$Rn_i = (1 - \alpha)S\downarrow + \varepsilon(L\downarrow - \sigma T^4_{sk,i}) \tag{2}$$

In this expression α is the albedo, $S\downarrow$ is the downwelling short wave surface flux, ε is the emissivity, $L\downarrow$ is the downwelling surface longwave flux, σ is the Stefan-Boltzmann constant and $T_{sk,i}$ is the skin temperature.

The sensible and latent heat fluxes are respectively computed as:

$$H_i = \frac{\rho_a}{r_{a\,i}}\left[c_p(T_{sk,i} - T_a) - gz_a\right] \tag{3}$$

and

$$LE_i = \frac{L_v \rho_a}{(r_{a\,i} + r_{c\,i})}\left[q_{sat}(T_{sk,i}) - q_a(T_a)\right] \tag{4}$$

with ρ_a the air density, $r_{a\,i}$ the aerodynamic resistance, c_p the heat capacity at constant pressure, T_a the air temperature at the height z_a, g is the acceleration due to gravity, $r_{c\,i}$ is the canopy or stomatal resistance, q_a is the air specific humidity and q_{sat} is the value of the surface specific humidity at saturation. The canopy resistance is computed following the Jarvis (1976) approach.

The method of Chehbouni *et al.* (1996) is adopted here to derive G_i from the Leaf Area Index (LAI_i) at the tile level. The averaged H and LE fluxes at pixel level are given by:

$$H = \sum \zeta_i H_i \tag{5}$$

and

$$LE = \sum \zeta_i LE_i \tag{6}$$

In the above expressions, all fluxes are expressed in W m^{-2}. The evapotranspiration flux E (kg m^{-2} s^{-1}) at pixel level is then simply given by:

$$E = LE / L_V \tag{7}$$

with L_V the latent heat of vaporisation ($L_V \sim 2.5\ 10^6$ J kg^{-1}).

INPUT DATA

The LSA–SAF provides input fields to the ET-model with MSG-SEVIRI spatial resolution (3 × 3 km at sub-satellite point), based on both visible and thermal channels. The input variables used are the half-hourly short- and longwave downward radiative fluxes ($S\downarrow$ and $L\downarrow$, respectively) and the daily surface albedo (α). Other meteorological forcings (air temperature and humidity, wind speed, …) are taken from the analyses and forecasts of the ECMWF model. In this version of the model, the soil moisture (SM) needed to compute the stomatal resistance ($r_{c\ i}$) in equation (4) is also provided by ECMWF. The ECOCLIMAP database (Masson *et al.*, 2003) is designed for the tile approach in SVAT models and gives the monthly mean evolution of the surface properties. It is used to provide both the fraction of vegetation cover (ζ_i) and different parameters like the leaf area index (LAI_i) necessary to compute $r_{c\ i}$ for each tile.

RESULTS

Presently, half-hourly ET maps over Europe are produced for demonstration in near-real time, at the Portuguese Meteorological Institute (Host of the LSA–SAF). An example of European ET (mm/h) map produced in the LSA–SAF system is shown in Fig. 1 for 30 November 2006 at 10:00 UCT. In order to display more details, a focus is made on the Iberian Peninsula in Fig. 2. A sequence of hourly ET maps from 10:00 UCT to 15:00 UCT is presented. Several characteristics of the results can be easily noticed: (a) the sequence of images shows a clear diurnal cycle; (b) effects of clouds on ET results are observed over the Landes Forest in southwest France and in southeast Spain; and (c) for clear-sky regions, variations of ET from one pixel to another are observed: these variations are caused by differences in meteorological conditions and land cover types. Some spurious features can also be noticed at some places of the land–sea borders. They are mainly related to the pre-processing of model input data that should be improved in the future.

To correctly monitor the ET evolution averaged over different time steps (daily, monthly means, etc.), continuous and accurate ET estimates are needed to follow both the diurnal cycle and fluctuations induced by clouds. Validation of the results is among the most important activities. Comparisons are done with ground flux measurements (from National Meteorological Services and Fluxnet network) and with outputs from

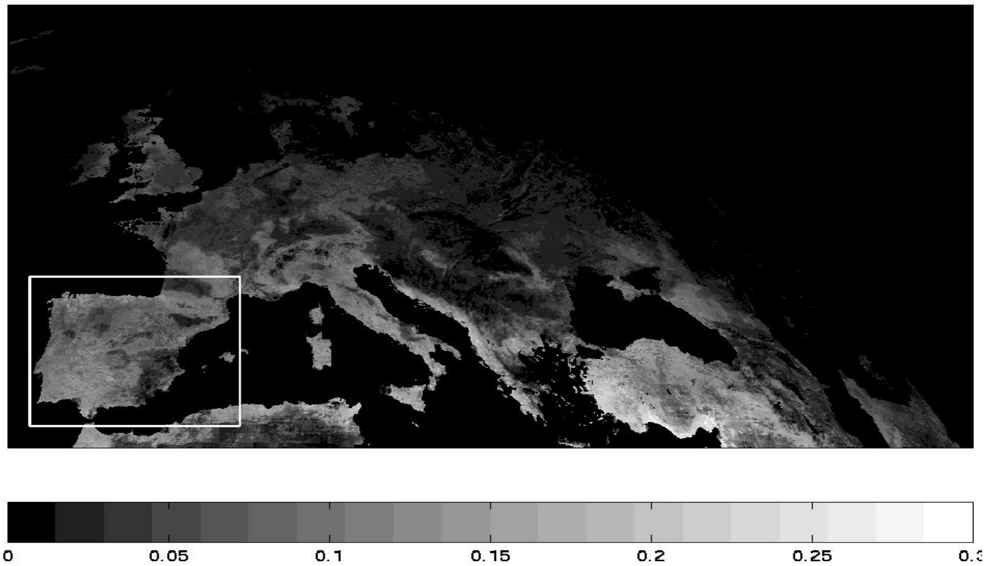

Fig. 1 Example of ET (mm/h) map over Europe produced at the host institute of LSA–SAF. This map corresponds to the conditions of 30 November 2006 at 10:00 UCT.

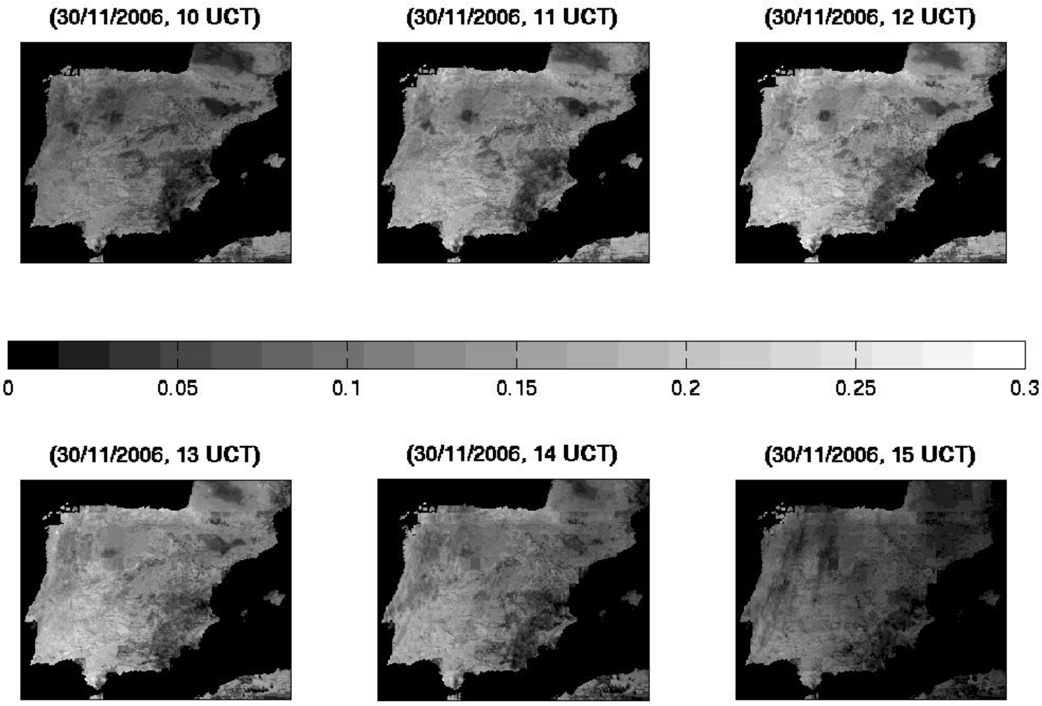

Fig. 2 Time sequence of hourly ET (mm/h) maps over the Iberian Peninsula for the 30 November 2006, from 10:00 to 15:00 UCT.

Numerical Weather Prediction (NWP) models. Since the ground stations measure surface fluxes over specific vegetation types or more complex biomes, the measured fluxes are in general not representative of the whole MSG pixels in which they are located. Therefore they cannot be directly compared to ET estimates based on MSG.

Table 1 Characteristics of the ground flux stations.

Station	Country	Biome	Measurement system
Humain	Belgium	Grass	Profile method[1]
Monte Bondone	Italy	Grassland	Eddy covariance[2]
Loobos	The Netherlands	Pine Forest	Eddy covariance[2]
Puéchabon	France	Mediterranean Forest	Eddy covariance[2]

[1]Gellens-Meulenberghs (2005); [2]Baldocchi *et al.* (2001); Aubinet *et al.* (2000, 2003).

Instead, we have chosen to compare flux measurements to the tiled components of the computed ET corresponding to the specific biome under study. Table 1 sums up the characteristics of some stations selected for these comparisons.

In Fig. 3, we show some examples of validation of ET estimates over a limited period of time and for different biomes spread out in Europe. On the same figure, we also represent the 3-hourly ECMWF ET estimates with 0.5° spatial resolution. We can see from Fig. 3 that the agreement between LSA–SAF ET results and the ground flux measurements is quite good for each considered station.

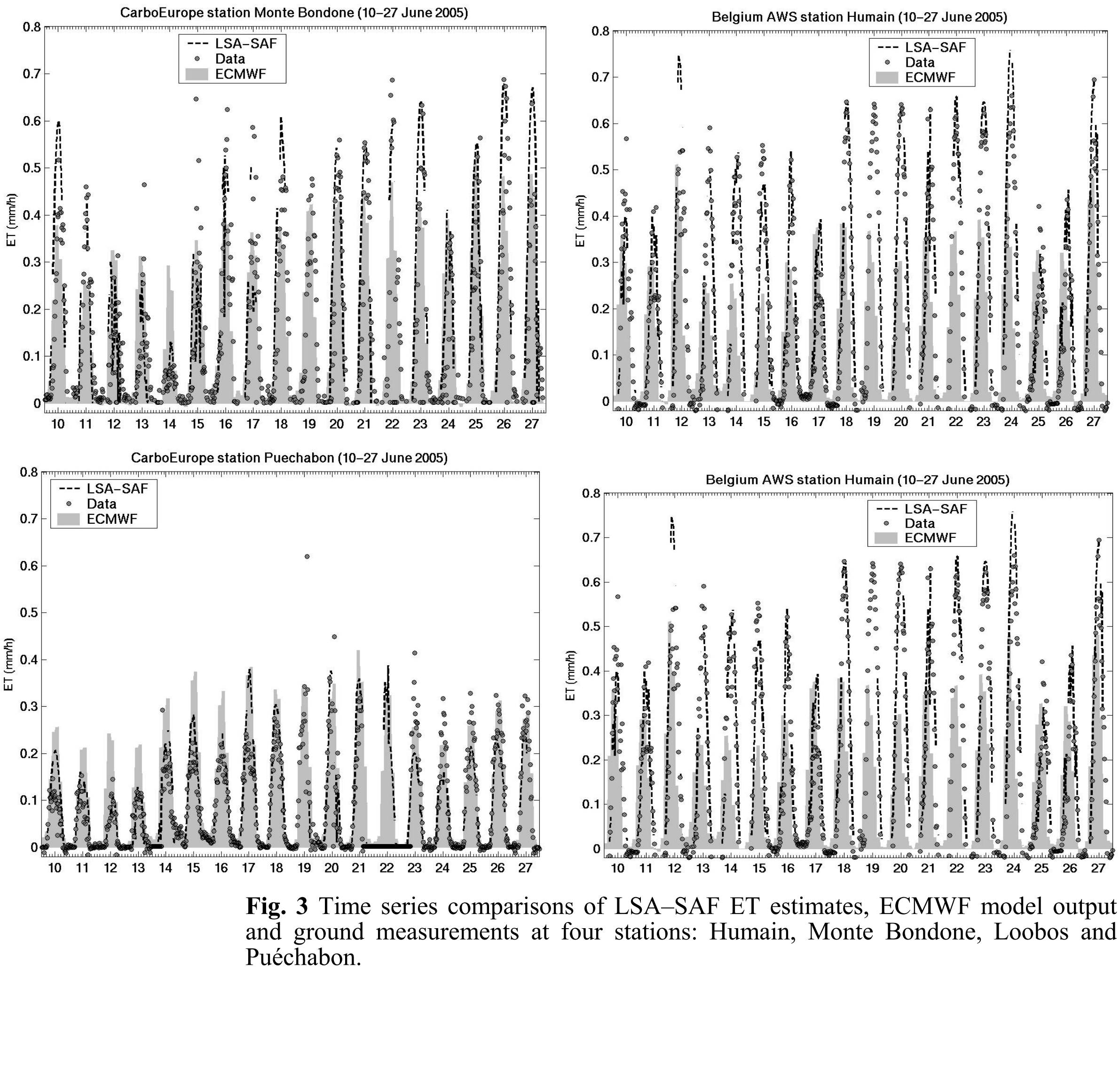

Fig. 3 Time series comparisons of LSA–SAF ET estimates, ECMWF model output and ground measurements at four stations: Humain, Monte Bondone, Loobos and Puéchabon.

FUTURE WORK

The validation effort will be pursued during the next years. The purpose is both to increase the confidence in the results quality and to highlight possible modelling weakness needing further improvements. As in the past, priority will be given to comparisons with ground flux measurements, but also to other data sources including output of numerical weather prediction models. Furthermore, the model application area is planned to be extended to the MSG full disk, i.e. mainly to Africa. The study of arid and semiarid regions will be of special concern.

At the moment of writing this text, the research has been directed towards a better description of surface properties. The objective is to integrate additional LSA–SAF results as input into the ET model. In particular, vegetation parameters (fraction of vegetation cover and leaf area index) provided by the LSA–SAF with the MSG-SEVIRI spatial resolution at a daily time step could be combined with ECOCLIMAP information to provide a better description of the biosphere.

In the next Continuous Development and Operations Phase (CDOP) starting in March 2007, the Hydrology-SAF (H-SAF) and LSA–SAF should start a collaboration in the framework of the so-called "Inter-SAF" activities. The objective will be to assimilate a SM index derived from microwave METOP-ASCAT observations into a new version of the LSA–SAF ET-model.

CONCLUSIONS

The ET release from the surface into the atmosphere is related to both the energy budget and the hydrological cycle. It is thus of special concern for several disciplines including meteorology, hydrology and climatology, and for application sectors like water resources management, irrigation and environmental monitoring. Moreover, deriving ET by remote sensing is especially interesting in remote locations, sensitive regions or data-poor locations.

The geostationary satellites, like MSG, have a high sampling rate and are thus able to quickly follow evolving surface variables like ET hinging on both the diurnal cycle and the cloud cover. A model is currently developed in the framework of the EUMETSAT LSA–SAF to compute ET over Europe based on MSG-SEVIRI observations. The approach is based on successive adaptations of the TESSEL SVAT scheme forced with remote sensed derived input data. The present paper describes the state of development of the model forced with MSG derived radiative fluxes. Current results are generated in near-real time each 30 minutes at the LSA–SAF Host Institute and are freely accessible after registration as beta-users. Feedback from the beta-users to the development team is expected to contribute to new model enhancements. Further advances are planned during the next CDOP phase (2007–2012) and will be made by reference to validation results. Special attention will be given on the parameterization of the surface and soil properties.

The LSA–SAF ET results are expected to contribute in the future to a better knowledge of the atmosphere–biosphere exchange processes and to an enhanced understanding of our environment. As they will be generated continuously on a long-term basis, they should turn out to be a meaningful tool able to monitor the natural ET variability and future changes.

Acknowledgements We thank all data flux providers contacted, among them S. Rambal, A. Cescatti and E. Moors for the results that are illustrated in this text. This research is co-funded by EUMETSAT (in the framework of LSA–SAF) and the ESA-PRODEX Programme (Contract no. 15066/01/NL/Sfe(IC)). We acknowledge the Belgian Federal Science Policy Office for its support.

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