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Procedia Environmental Sciences 19 (2013) 303 – 310

Procedia Environmental Sciences

Four Decades of Progress in Monitoring and Modeling of Processes in the Soil-Plant-Atmosphere System: Applications and Challenges

EVASPA (EVapotranspiration Assessment from SPAce) tool: An overview

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Abstract

Evapotranspiration (ET) is a fundamental variable of the hydrological cycle and its estimation is required for irrigation management, water resources planning and environmental studies. Remote sensing provides spatially distributed cost-effective information for ET maps production at regional scale. We have developed EVASPA tool for mapping ET from remote sensing data at spatial and temporal scales relevant to hydrological or agronomical studies.

EVASPA includes several algorithms for estimating evapotranspiration and various equations for estimating the required input information (net radiation, ground heat flux, evaporative fraction…), which provides a way to assess uncertainties in the derivation of ET. The tool integrates data from various remote sensing sensors and it can be easily adapted to new sensors. To test the tool, evapotranspiration maps have been produced for the Crau-Camargue pilot site (south-eastern France), where several energy balance stations deployed in contrasted areas provide ground measurements. An overall description of the tool and first results of performance assessment (comparison to ground data) are presented here.

Keywords: Evapotranspiration mapping; remote sensing; Landsat; MODIS; Crau-Camargue.

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doi:10.1016/j.proenv.2013.06.035

1. Introduction

Evapotranspiration (ET) is a fundamental variable of the hydrological cycle which plays a major role on surface water and energy balances. ET estimation is required for irrigation management, water resources planning and environmental studies. At the local scale ET can be accurately determined from detailed ground observations (eddy covariance towers, lysimeters) but for the production of ET maps at regional scale, spatially distributed cost-effective information is required. This information can be provided by remote sensing sensors. Since the end of the 90's pre-operational algorithms, such as S-SEBI ([1]) or SEBAL ([2], [3]) have been proposed, that make it possible to derive ET maps from remote sensing data (see also reviews by [4] and [5]). Although several ET mapping methods exist, ET products that meet the requirements for routine applications are still very scarce [6]. Some remote sensing derived ET products have been proposed recently, such as MOD16 (from MODIS, Moderate Resolution Imaging Spectroradiometer, on board of TERRA and AQUA [7]), WACMOS ET (from AATSR and MERIS sensors on board of ENVISAT, together with information from MSG and MODIS, [6]) or ET MSG (from SEVIRI sensor [8]). MOD16 is provided globally but only every 8days and ET MSG maps are available each 30 minutes but have ~3km spatial resolution. WACMOS products provide ET daily data globally with 25 km spatial resolution and with 1 km resolution for MSG disc. Further validation and uncertainties assessment are required before these products are ready available for practical applications.

EVASPA (EVapotranspiration Assessment from SPAce) is a tool developed at INRA, in collaboration with CESBIO, to produce ET maps at relevant spatial and time scales for hydrological or agronomical purposes. The tool includes several ET estimation methods (S-SEBI, the triangle approach and aerodynamic methods) and various equations for estimating the required input information (albedo, net radiation, ground heat flux…). Highlighted features of this tool are: (i) the possibility of integrating data from various remote sensing sensors, (ii) to be easily adapted to new sensors, (iii) to provide an estimation of uncertainties (thanks to the combination of the various ET estimates) and (iv) to produce continuous daily ET maps even for days without available remote sensing images (by means of interpolation methods). Overall, EVASPA offers adaptability to input data availability and versatility for studies with different ET information needs. Besides, a graphical user interface (GUI) has been implemented in order to make it more accessible to potential users (Fig. 1). This proceeding aims to give an overview of the first operational version of the EVASPA tool as well as to present some first results of performance assessment (comparison to ground data).

2. EVASPA algorithms and input data requirements

2.1. ET mapping algorithm

Algorithms of EVASPA are based on the S-SEBI method [1] and the triangle approach [9]. Additional algorithms based on the aerodynamic equations for computing turbulent fluxes will be implemented soon. Both, S-SEBI and the triangle methods, are based on the determination of the evaporative fraction from the computation of the distance between pixel surface temperature to extreme temperature for wet and dry areas. The evaporative fraction represents the ratio between evapotranspiration and available energy (net radiation minus ground heat flux), so that an estimation of available energy (from albedo, surface temperature, vegetation density and incident radiation) makes it possible to derive ET. S-SEBI is a simplified method which consists of determining an albedo dependent maximum (respectively minimum) temperature for dry (respectively wet) conditions.

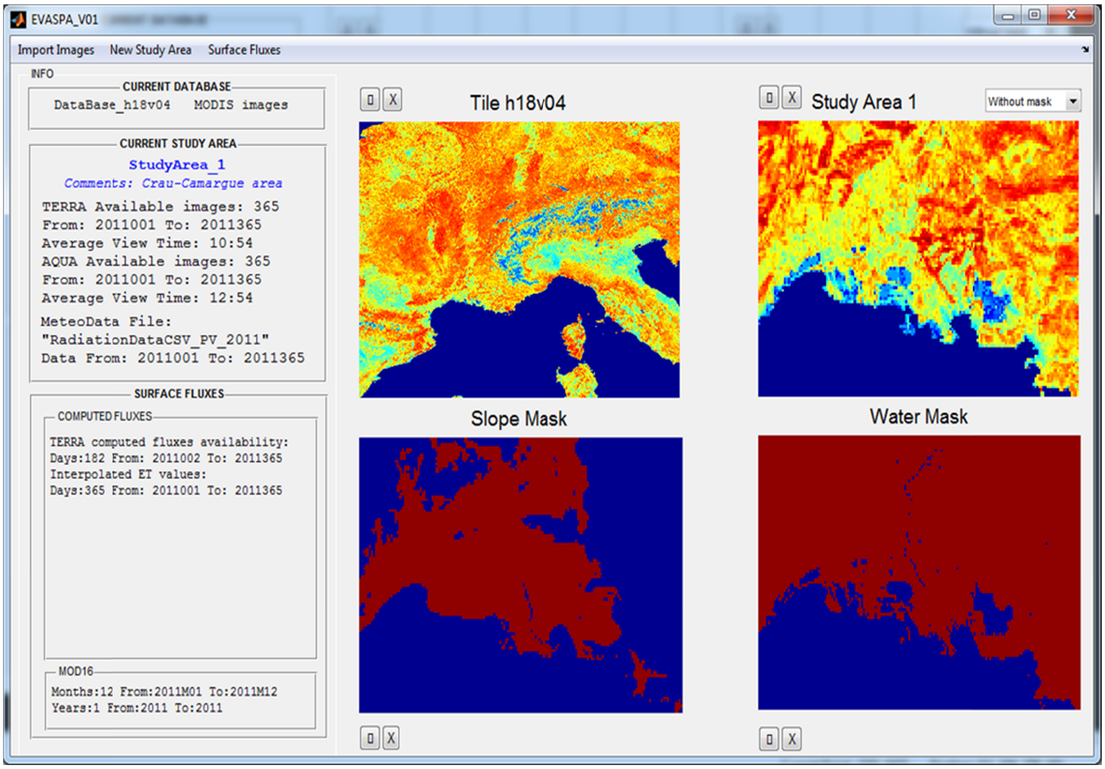

Fig. 1. Main Window of EVASPA.v01 interface

The triangle method is based on the physically meaningful relationship between the evaporative fraction (EF) and the combination of the remotely sensed surface temperature (T_s) and NDVI (Normalized Difference Vegetation Index) or f_{cover} (Fraction Cover). The scatter plot T_s vs. NDVI (or f_{cover}) has a triangle shape whose boundaries are interpreted as limiting surface fluxes, the upper limit being the dry edge and the lower limit being the wet edge. Both methods are valid when minimum and maximum evapotranspiration can be observed within the boundaries of the study area, and an important assumption is that these different cases are not primarily caused by differences in atmospheric conditions but by variations in water availability [10]. These methods provide an instantaneous estimate of EF at the satellite view time, which needs to be extrapolated to determine daily evapotranspiration. At the moment, EF is assumed to be constant during the day. For sites with water stress conditions, the shape of EF diurnal variation is expected to be rather flat but in absence water stress a concave up shape should be used to describe EF diurnal variation [11]. The latter will be accounted for in EVASPA. Figure 2 shows the flow diagram of the algorithm for mapping ET from MODIS. The flow diagrams for other sensors like Landsat or ASTER are analogous but the ET computing inputs (NDVI, albedo, etc.) are produced differently as indicated in section 2.2.

The tool also includes an interpolation algorithm designed to compute daily ET for days without images acquisition (or with bad quality images), so that continuous monitoring of ET can be provided. This algorithm is based on the day to day interpolation of the ET/R_s ratio, R_s being the solar radiation (see [11] and [12]). At the moment it is used only for MODIS data, since temporal availability of high resolution data is very limited.

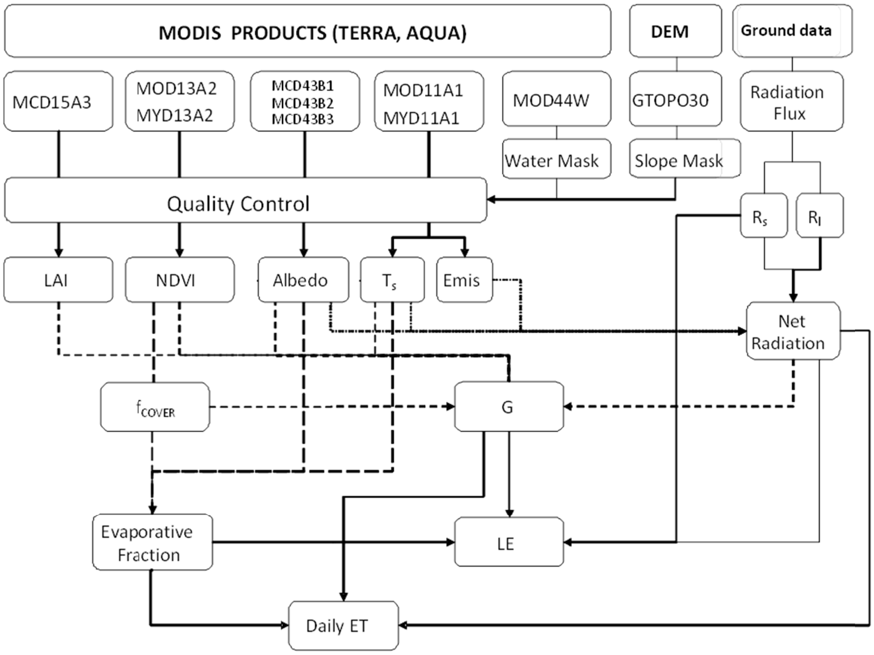

Fig. 2. Algorithm for mapping ET from MODIS data. LAI: Leaf Area Index, NDVI: Normalized Difference Vegetation Index, Ts: surface temperature, Emis: Emissivity, f_{cover}: Fraction Cover, G: Ground Heat Flux, LE: Latent Heat Flux, DEM: Digital Elevation Model, R_s and R_l: Incoming short- and long-wave radiation respectively.

2.1. EVASPA inputs

2.1.1. Low resolution

To produce ET maps at the kilometric scale, EVASPA use MODIS (TERRA and/or AQUA) freely available products as main inputs (Fig. 2) and the freely available digital elevation model (DEM) GOTOPO30 (http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/gtopo30.html). The only required ground data are the incoming short- and long-wave radiation. EVASPA processes raw data downloaded from the NASA server in HDF format and provides outputs in several formats including standard binary files.

2.1.2. High resolution

For high resolution sensors like Landsat and ASTER, specific equations for deriving the input variables (albedo, LAI, emissivity…) have been implemented. For example, albedo is derived from spectral reflectances using a linear combination model ([13]). Albedo, fraction cover and LAI input can also be produced using neural network algorithms ([14] and [15]). These algorithms have been implemented in the BV_NNET tool, which is a prototype software developed at INRA to estimate biophysical variables from high resolution sensors. The ground data requirements are the same as for low resolution. The inputs and outputs are standard ENVI or binary files.

3. Performance assessment of EVASPA

To test the tool, ground data from several surface energy balance stations deployed in contrasted areas of the pilot site Crau-Camargue (south-eastern France) are available. This site is a flat region characterized by highly contrasted wet and dry areas, with a high diversity of surfaces: irrigated meadows, dry grasslands (steppic area), saltmarsh scrubs, paddy fields, orchards, etc. Low resolution maps derived from MODIS can be evaluated against data from stations set in two large homogeneous sites: dry grassland and saltmarsh site which cover several squared kilometers. High resolution estimates can be evaluated at almost all sites. For heterogeneous areas like the irrigated meadows of La Crau, the assessment of the MODIS outcomes requires special attention and will be done by comparison to ET estimates derived from high resolution images, which allows accounting for the heterogeneity of coarse pixels.

The performance assessment of EVASPA simulations is being carried out at the moment. First evaluations were performed by (i) comparing net radiation estimation from ETM+ (Enhanced Thematic Mapper Plus, Landsat 7) to ground data, with errors lower than 20 Wm^{-2}: see [13]; (ii) assessing the performances of the procedure used to interpolate daily ET for days without images, with errors around 0.35 mm d^{-1}: see [12]; (iii) comparing evolution of daily ET for some ecosystems to ground station measurements.

ET maps have been produced for the Crau-Camargue pilot site. Daily ET maps at kilometric spatial resolution are produced from MODIS data and high resolution ET maps with a hectometric resolution from ETM+ when images of the study area are available. We present here the first evaluations results carried out for EVASPA ET estimations from MODIS over a large homogeneous saltmarsh scrub site located in the Rhône River Delta (known as Camargue). This site was originally set for monitoring hydrological processes and in particular shallow water table fluctuations of one of the most representative ecosystems of Camargue (particularly in the frame of research programs on wetland conservation carried out by the Tour du Valat research station). An energy balance station has been set at this study site (TDV station, 43° 29’ N; 4° 39’ E). It has provided surface energy flux data that can be used for evaluating EVASPA evapotranspiration products since 2009.

4. Results

Data series from the surface energy balance station located at TDV and EVASPA (MODIS) ET estimations were compared for the period 2009-2011. 42 versions of daily ET estimates were produced by EVASPA, as a result of the combination of all ET estimation methods and input-deriving equations, with an overall SD among versions of 0.42 mm/day. Version 7 (v7) which corresponds to the triangle method as described in [16] was one of the versions in best agreement with ground data. A first evaluation of the performance of this version is presented here; the analysis of the performance of all versions is out of the scope of this proceeding. Fig. 3 and Table 1 show how EVASPA ET derived from MODIS data was in good agreement with TDV ground measurements.

The evolution of evapotranspiration provided by EVASPA v7 closely followed the ET measurements of TDV saltmarsh scrubland (R^2=0.76). The MBE, which quantifies systematic errors, indicated that EVASPA v7 predictions slightly underestimated ET, and the RMSE, which accounts for both systematic and non-systematic errors, indicates that EVASPA can provide reasonable predictions. Underestimations are mainly related to days with low radiation and days with high and variable winds. Days with low radiation often corresponded to days without remote sensing data for which ET was interpolated. Improvements can be made to avoid substantial underestimation, by analyzing the patterns of solar radiation and by the implementation of aerodynamic methods.

The TDV saltmarsh scrubland hydrological conditions mainly depend on precipitation and ET. The saltmarsh ET was observed to be closely related to the fluctuations of the water table (Fig. 3). When the water table was shallow the TDV scrubs could withdraw water and ET reached ET_o (Reference evapotranspiration FAO-56 PM [17]) values (energy-limited system), whereas in dry seasons when water table was deeper (below 0.75 m), ET was substantially lower than potential values due to water availability restrictions. MODIS ET estimations successfully followed the annual ET patters and gave reasonable overall accuracy of daily ET values. Therefore, EVASPA could be used to retrieve ET evolutions in years when ground data were not available. Note that MODIS images are available from 2000 to present.

Table 1. Mean values, standard deviation and range (max, min) of daily ET measurements (*ET ground*) and estimations (*ET EVASPA v7*) for 2009-2011. Statistical estimators for ET estimations: RMSE (Root Mean Squared Error), MBE (Mean Bias Error), R^2 (Correlation coefficient)

2009-2011	*ET ground* (mm day^{-1})	*ET EVASPA v7* (mm day^{-1})
Mean	1.94	1.81
SD	1.10	1.12
Min	-0.43	0.03
Max	5.39	5.02
RMSE		0.78
MBE		-0.12
R^2		0.76

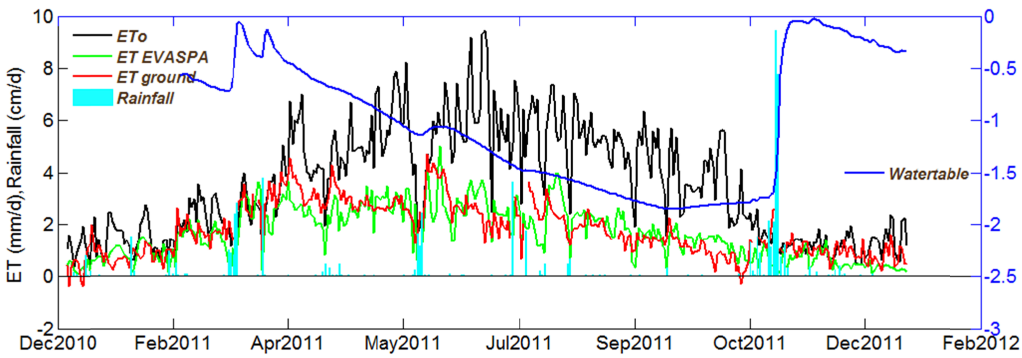

Fig. 3. Evolution of daily evapotranspiration (2011): EVASPA estimations (ET EVASPA, MODIS version 7 in green) and TDV ground measurements (ET ground in red). Also included: the reference evapotranspiration (ET_o in black, FAO-56 PM), rainfall (cyan) and water table depth (blue)

5. Concluding remarks and future work

EVASPA is a tool for mapping ET which offers broad adaptability to different remote sensing sensors and methods to derive ET. Initial evaluation of ET estimations derived from MODIS is promising. Good agreement has been found between ET estimations and ground data collected in flux stations set over large homogeneous areas. Once the performance of ET estimations has been assessed against a representative period of ground data, EVASPA can be used to derive historical ET series (from 2000). The tool is in continuous development and improvement, with the objective of providing ET maps at relevant spatial and time scales for hydrological or agronomical purposes. EVASPA performance assessment is currently being carried out for the pilot site Crau-Camargue (south France). EVASPA will be used to map evapotranspiration over other test areas in South Spain in the frame of the SIRRIMED European project, which aims at improving irrigation efficiency (http://www.sirrimed.org/), and in Tunisia and Morocco in the frame of the SICMED program which aims at a better understanding of the Mediterranean anthropo-ecosystems and their evolutions (http://www.sicmed.net/).

Acknowledgements

EVASPA tool is a prototype software developed in MATLAB within the frame of the European project SIRRIMED (Sustainable use of IRRIgation water in the MEDiterranean Region, http://www.sirrimed.org/) and with the support of CNES (Centre National d'Etudes Spatiales, France) through the TOSCA research calls and the preparation of the MISTIGRI satellite mission (MIcro Satellite for Thermal Infrared GRound surface Imaging) [18]. The authors gratefully acknowledge Foundation Ramon Areces (Madrid, Spain) for the financial support.

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