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Operational evapotranspiration estimates from SEVIRI in support of sustainable water management

George P. Petropoulos[a,*], Gareth Ireland[a], Salim Lamine[a,b], Hywel M. Griffiths[a], Nicolas Ghilain[c], Vasileios Anagnostopoulos[d], Matthew R. North[a], Prashant K. Srivastava[e,f], Hro Georgopoulou[g]

[a] Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, SY23 2DB Wales, United Kingdom
[b] Department of Ecology and Environment, University of Sciences and Technology Houari Boumediene, BP 32, El Alia, Bab Ezzouar, Algiers, Algeria
[c] Royal Meteorological Institute, Brussels, Belgium
[d] Distributed and Knowledge Management Systems Lab, National Technical University of Athens, Greece
[e] NASA Goddard Space Flight Center, Greenbelt, MD, USA
[f] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[g] InfoCosmos Ltd., Pindou 71, 13341, Athens, Greece

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ABSTRACT

This study aimed at evaluating the accuracy of the evapotranspiration (ET) operational estimates from the Meteosat Second Generation (MSG) Spinning Enhanced Visible Infra-Red Imager (SEVIRI) at a range of selected ecosystems in Europe. For this purpose *in-situ* eddy covariance measurements were used, acquired from 7 selected experimental sites belonging to the CarboEurope ground observational network over 2 full years of observations (2010–2011). Appraisal of ET accuracy was also investigated with respect to land cover, season and each site(s) degree of heterogeneity, the latter being expressed by the fractional vegetation cover (FVC) operational product of SEVIRI.

Results indicated a close agreement between the operational product's ET estimates and the tower based *in-situ* ET measurements for all days of comparison, showing a satisfactory correlation (r of 0.709) with accuracies often comparable to previous analogous studies. For all land cover types, the grassland and cropland sites exhibited the closest agreement (r from 0.705 to 0.759). In terms of seasons the strongest correlations were observed during the summer and autumn (r of 0.714 & 0.685 respectively), and with FVC the highest correlation of 0.735 was observed for the class FVC 0.75-1 when compared against the observed values for the complete monitoring period. Our findings support the potential value of the SEVIRI ET product for regional to mesoscale studies and corroborate its credibility for usage in many practical applications. The latter is of particular importance for water limiting environments, such as those found in the Mediterranean basin, as accurate information on ET rates can provide tremendous support in sustainable water resource management as well as policy and decision making in those areas.

1. Introduction

The combined impacts of climate change, population increase and migration to urban areas are likely to cause significant water resource crises in the coming decades (Jones, 2014). The temporal and spatial scales of these crises mean that mitigation of, and adaptation to them, require reliable data on which management decisions can be made (Wagner et al., 2015). However, these data are lacking for a number of important hydrological processes, especially in regions such as Africa (Legesse et al., 2003) South America (Smolders et al., 2004) and Asia (Remesan and Holman, 2015; Srinivasan et al., 2015). One such process which is of key importance in many practical applications is evapotranspiration (ET) (Srivastava et al., 2013c; Ireland et al., 2015). This critical process is the way in which water is transferred as vapour from the terrestrial and marine environments into the atmosphere and is principally influenced by meteorological factors and soil moisture availability (Srivastava et al., 2013a; Sepulcre-Canto et al., 2014). As such, it is central to the hydrological cycle as well as to hugely significant biogeochemical cycles (particularly carbon), and is the main pathway of the energy system by which solar energy is transferred

* Corresponding author.
E-mail address: petropoulos.george@gmail.com (G.P. Petropoulos).

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through latent heat (LE). As a result, its importance as a control on regional climate characteristics (Jung et al., 2010; Srivastava et al., 2015c), agriculture and regional water resources cannot be understated (Buytaert et al., 2006; Srivastava et al., 2013b, 2015b).

There is a long history of ground surface-based instrumental retrieval of ET using a number of techniques, including evaporation pans, atmometers and lysimeters (for a review see Petropoulos et al., 2013). Such techniques are limited by the fact that they are often used in single sites and are also unable to provide spatiotemporal estimates of ET at regional or continental scales. In recent years, several ground based monitoring networks have been established (e.g. Fluxnet) in order to integrate data collected at single sites around the world (Wang and Dickinson, 2012). However, the retrievals of regional estimates of ET remain limited by the cost of instrumentation implementation and the fact that such measurements are time-consuming and labour intensive.

The advent of Earth Observation (EO) technology has led to the development of a number of modelling techniques proposed to obtain spatiotemporal estimates of ET (Sun et al., 2011; Gellens-Meulenberghs et al., 2012; Marshall et al., 2013; Cruz-Blanco et al., 2014; Ghilain et al., 2014). Some studies of ET have also been performed on European ecosystems using mesoscale model derived weather variables (Verstraeten et al., 2005; Srivastava et al., 2014, 2015d) as well as satellites such as MODIS (Srivastava et al., 2015a), SEVIRI (Petropoulos et al., 2015a), and AVHRR (Taconet et al., 1986). In contrast to conventional ground surface-based methods, these methods can provide maps of ET at varying spatial and temporal resolutions and at relatively low or often no cost. Yet, before such EO-derived maps are used, it is essential to undertake validation studies for a number of reasons (Jia et al., 2010; Petropoulos et al., 2013), including: (i) to determine the suitability and credibility of an EO algorithm or operational product before it is used for practical applications; (ii) to allow for the identification, quantification and understanding of the sources of errors in algorithm formulation and (iii) to direct efforts to re-evaluate and improve ET retrieval parameters and algorithm structure. These reasons allow environmental managers, regulatory agencies and disaster management agencies to use the product with greater confidence and also, crucially, allow for climate change projections to be evaluated (Mueller et al., 2011; Kalivas et al., 2013).

EO technology is currently at a level of maturity which allows and distribution of related products at operational scales. Such products have proven to be generally of high demand from research groups and communities interested in modelling the carbon cycle, understanding the relationships between fire regime and climate, atmospheric emissions and pollution, amongst others. One such ET product currently available is provided from the geostationary orbit Spinning Enhanced Visible Infra-Red Imager (SEVIRI) of the Meteostat Second Generation (MSG) satellite. In it ET is estimated operationally every 30′ from the SEVIRI radiometer, whereas a daily ET flux operational product is also generated with a lag time of one day at a spatial resolution of 3.1 km at the sub-satellite point. These two products are provided for the full disk divided in four sub regions (Europe, North Africa, South Africa and South America) through the LSA-SAF web site (see http://landsaf.meteo.pt/). Yet, to our knowledge, very few studies have been concerned with establishing the accuracy of the SEVIRI ET instantaneous operational product, particularly at a continental scale. Such studies have so far been focused primarily on performing either direct comparisons against corresponding *in-situ* measurements acquired concurrently (Hu et al., 2015; Petropoulos et al., 2015b), or others based on performing inter-comparison studies against other operational products or model outputs (Fensholt et al., 2011; Ghilain et al., 2011). Indeed, thus far only a few other validations of SEVIRI ET product have been published and these have focused on evaluating the product accuracy on a continental scale (Sepulcre-Canto et al., 2014). As such, there is an urgent need for more studies exploring the accuracy of ET estimates from this product.

In this context, the aim of this study has been to evaluate the accuracy of the SEVIRI ET operational product at a range of European ecosystems for 2 complete years of analysis. This is achieved through examining the agreement between these estimates and rates of ET measured at a range of CarboEurope flux tower sites with respect to (i) different land-use and land cover types commonly found in Europe; (ii) seasonality and (iii) experimental site(s) heterogeneity as expressed by the Fractional Vegetation Cover (FVC).

2. Experimental set up

2.1. Datasets

2.1.1. MSG-2 SEVIRI ET estimates

A series of operational products from SEVIRI are provided by EUMETSAT at no cost, distributed by the Satellite Application Facility (SAF) on Land Surface Analysis (LSA) (http://landsaf.meteo.pt/). For the purposes of the study, the SEVIRI instantaneous ET product (MET) was acquired for the Euro region of the Meteosat disk. The method developed by LSA-SAF allows estimation of both the instantaneous and daily total ET by the MSG SEVIRI radiometer. It follows a physically-based approach and can be described as a simplified SVAT model modified to accept EO data combined with data from other sources as forcing. The SVAT model employed is essentially a simplified version of the SVAT model TESSEL Tiled ECMWF Surface Scheme for Exchange Processes over Land; (Viterbo and Beljaars, 1995), which computes land surface processes taking both EO and atmospheric parameters as inputs. The algorithm is then adapted to accept real-time data from meteorological satellites as forcing (Gellens-Meulenberghs et al., 2007). The main forcing to the model comes from the remote sensing inputs including the daily albedo (Geiger et al., 2008a) and half-hourly short-wave (Geiger et al., 2008b) and long-wave fluxes (Ineichen et al., 2009). To provide ET with a limited amount of missing values, a gap filling procedure is also adopted in the operational algorithm. The daily ET operational product is derived by temporal integration of instantaneous ET operational product values. The integration limits correspond to the first (theoretically at 00:30 UTC) and last (theoretically at 00:00 UTC) existing slots for a given day, and the integration step is 30′. A detailed description of the SEVIRI operational ET estimation algorithm is available in Ghilain et al. (2011). The retrieval accuracy of ET is generally claimed to be 25% if ET is greater than 0.4 mm h^{-1} and 0.1 mm h^{-1} in any other case (Ghilain et al., 2011). The MET product contains instantaneous values of ET (in mm h^{-1}) plus an associated quality flag (MSG-2 ET Product ATBD, 2008).

In addition, the SEVIRI FVC product was also acquired to facilitate the analysis of site heterogeneity on ET retrieval accuracy. This product is generated daily at the full spatial resolution of the MSG/SEVIRI instrument (3 km). It is computed using three short-wave channels as inputs (VIS 0.6 μm, NIR 0.8 μm, SWIR 1.6 μm) and a parametric Bi-directional Reflectance Distribution Function (BRDF) model. In the product, FVC is delivered daily and is expressed as a percentage corrected from uncertainty derived of the view/sun angles and also the anisotropy effects from surface reflectance in the SEVIRI image. The FVC product includes routine quality check and error estimates. For each day and geographical region, the FVC product, its error estimate and the processing flag were acquired in Hierarchical Data Format (HDF5) and HDF5 file attributes. In our study, the SEVIRI FVC product was downloaded for the Euro region of the Meteosat disk for both 2010 and 2011. All SEVIRI data was obtained free of charge through the LSA-SAF web site (see http://landsaf.meteo.pt/).