



Research Paper

Retrieval of daily gross primary production over Europe and Africa from an ensemble of SEVIRI/MSG products



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ABSTRACT

The main goal of this paper is to derive a method for a daily gross primary production (GPP) product over Europe and Africa taking the full advantage of the SEVIRI/MSG satellite products from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) sensors delivered from the Satellite Application Facility for Land Surface Analysis (LSA SAF) system. Special attention is paid to model the daily GPP response from an optimized Monteith's light use efficiency model under dry conditions by controlling water shortage limitations from the actual evapotranspiration and the potential evapotranspiration (PET). The PET was parameterized using the mean daily air temperature at 2 m (T_a) from ERA-Interim data. The GPP product (MSG GPP) was produced for 2012 and assessed by direct site-level comparison with GPP from eddy covariance data (EC GPP). MSG GPP presents relative bias errors lower than 40% for the most forest vegetation types with a high agreement ($r > 0.7$) when compared with EC GPP. For drylands, MSG GPP reproduces the seasonal variations related to water limitation in a good agreement with site level GPP estimates (RMSE = $2.11 \text{ g m}^{-2} \text{ day}^{-1}$, MBE = $-0.63 \text{ g m}^{-2} \text{ day}^{-1}$), especially for the dry season. A consistency analysis against other GPP satellite products (MOD17A2 and FLUXCOM) reveals a high consistency among products (RMSD < $1.5 \text{ g m}^{-2} \text{ day}^{-1}$) over Europe, North and South Africa. The major GPP disagreement arises over moist biomes in central Africa (RMSD > $3.0 \text{ g m}^{-2} \text{ day}^{-1}$) and over dry biomes with MSG GPP estimates lower than FLUXCOM (MBD up to $-3.0 \text{ g m}^{-2} \text{ day}^{-1}$). This newly derived product has the potential for analysing spatial patterns and temporal dynamics of GPP at the MSG spatial resolutions on a daily basis allowing to better capture the GPP dynamics and magnitude.

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¹ FLUXNET EC IP.

1. Introduction

Serious concerns associated with climate change are strongly present on the African and European continents leading, among others, to significant effects on plant distribution, growth and productivity (EEA, 2012; IPCC, 2014). Thus, a better understanding of the productivity dynamics of ecosystems across these continents is needed.

Terrestrial ecosystem models provide a powerful tool to integrate our understanding on ecosystem functioning and observations at multiple scales in response to multiple environmental factors (Tian et al., 2010; Yebra et al., 2015). There is a renewed interest in developing carbon flux models that are entirely driven by remotely sensed (RS) observations to estimate gross primary production (GPP) (Running et al., 2004; Gilabert et al., 2015; Tramontana et al., 2016). Estimates of daily GPP (MOD17) (Heinsch et al., 2006; Zhao et al., 2011; Running and Zhao, 2015) are produced operationally for the global terrestrial surface using imagery from the MODerate resolution Imaging Spectroradiometer (MODIS) sensor (Running et al., 2004). Additionally, there clearly is a motivation to extend knowledge acquired from modeling efforts with the MODIS datasets to other sensor's data, such as the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board of the Meteosat Second Generation (MSG) platform.

Most of the methodologies for the estimation of GPP from satellite data, such as the widely used MODIS GPP product (Zhao et al., 2011), rely on the well-known satellite-based Production Efficiency Models (PEMs). Most of the PEMs are based on Monteith's light use efficiency (LUE) concept (Monteith, 1972). This concept is still considered to be efficient and widely applicable for the prediction of GPP at different spatial and temporal scales (Waring and Running, 2007) and considers GPP equal to the product of the incoming photosynthetically active radiation (PAR), the fractional absorption of that flux (f_{APAR}) and the light use efficiency (ϵ). The latter can be operationally parameterized as a function of a maximum value (ϵ_{max}), which is reduced by different factors related with types of stress that affect the functionality of the plant, such as water availability and thermal stress. These factors range from 0 (total inhibition) to 1 (no inhibition). ϵ_{max} can be set as invariant across sites and biomes (Myneni et al., 1995) or be derived from biome-dependent values (Garbulsky et al., 2010). According to Schaefer et al. (2012), three areas of the PEMs still need improvements: 1) parameterization of ϵ_{max} , 2) response function under low temperatures, and 3) GPP response under dry conditions (mainly driven by water stress factors).

In particular, the MODIS standard product parameterizes ϵ as the product of a biome-specific ϵ_{max} and the thermal and the water stress factors, which depend on minimum air temperature and vapor pressure deficit, respectively (Zhao et al., 2011; Heinsch et al., 2006). Another parameterization of the water stress based on a water stress coefficient (C_{ws}) has been applied successfully to derive daily GPP estimates in Mediterranean ecosystems (Maselli et al., 2009; Gilabert et al., 2015; Sánchez-Ruiz et al., 2017). C_{ws} accounts for the limited photosynthetic activity in case of short-term water stress from a simplified local water budget based on the ratio of actual evapotranspiration (AET) and potential evapotranspiration (PET). Commonly, evapotranspiration (ET) is normalized by the reference evapotranspiration or by PET in order to characterize water stress (Sepulcre et al., 2014). PET is driven by available energy, while AET reflects an immediate response of vegetation productivity to water-storage (Fisher et al., 2011). Different approaches have been proposed to account for the water stress by means of the AET and PET (Sepulcre et al., 2014; Idso et al., 1981).

The main goal of this paper is to provide a method for the estimation of daily GPP over Europe and Africa from the integration of an ensemble of SEVIRI/MSG products into an optimized LUE model that accounts for water shortage limitations. SEVIRI/MSG satellite products from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) sensors delivered from the Satellite Application Facility for Land Surface Analysis (LSA SAF) system are used ([\[lsa-saf.eumetsat.int\]\(http://lsa-saf.eumetsat.int\)\) for 2012. This year is selected due to the unavailability of the necessary inputs for other years. The used set of LSA-SAF products derived from SEVIRI/MSG offers convenient spatial coverage \(Europe, Africa and parts of South America\) and resolution \(Trigo et al., 2011\). Moreover, these products are produced operationally in near-real time with generation rates varying from 30 min in the case of ET to daily or 10-day in the case of several vegetation parameters, which makes them particularly suitable for the development of early warning procedures such as drought prediction. Since water availability and radiation are known as main potential climatic constraints to vegetation productivity in many areas of Europe and Africa \(Nemani et al., 2003\), special attention is paid to capture the GPP response under dry conditions by controlling the water shortage limitations. Thus, a water stress coefficient \(\$C_{ws}\$ \) based on the ratio between AET and PET, with PET parameterized using Jensen and Haise \(1963\), is proposed.](http://</p>
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The use of the MSG GPP product can benefit from different aspects. 1) The high quality of the daily down-welling radiation flux (DIDSSF) product (bias and mean absolute error below 6%) confers the MSG GPP estimates of a high reliability. The DIDSSF product is used to compute both the PAR and the C_{ws} , being the PAR the most influential variable in the GPP variance (e.g. over 60% of the variance was explained by the PAR in forests over Spain (Gilabert et al., 2015)). 2) The daily basis of the MSG GPP product aids, among others, a better characterization of vegetation state and temporal processes (e.g. sudden changes from natural hazards or management practices). 3) Clouds effect on the f_{APAR} and DIDSSF is better sampled at daily temporal scale allowing a more accurate characterization as compared to the MODIS product (Heinsch et al., 2006; Gilabert et al., 2015) and also a better understanding of the cloud coverage on the carbon uptake by vegetation.

The performance of the resulting GPP product (MSG GPP) is assessed by site-level comparisons using GPP estimates from eddy covariance (EC) towers. Moreover, the MSG GPP assessment includes consistency analyses against alternative GPP products available from independent remote sensing global data, such as MODIS GPP (MOD17A2) and global flux fields from the Max Planck Institute (MPI) (FLUXCOM) products. The paper first introduces the theoretical basis for the daily GPP retrieval together with the description of the required inputs. The next section describes the MSG GPP assessment and the data used for this purpose. It is followed by a presentation of the obtained results and a discussion section reporting on the differences, advantages and limitations of the MSG GPP retrievals. The main conclusions are presented in the final section.

2. Daily GPP retrieval

The methodology used to derive daily GPP ($\text{g m}^{-2} \text{ day}^{-1}$) was based on Monteith's LUE approach:

$$\text{GPP} = \epsilon f_{APAR} \text{PAR} \quad (1)$$

where

$$\epsilon = \epsilon_{max} C_{ws} \quad (2)$$

Parameter ϵ was parameterized as ϵ_{max} downregulated by the water stress coefficient (C_{ws}). Overall, optimized ϵ_{max} values can range between 0.55–3.5 g MJ^{-1} , as reported by several authors (Garbulsky et al., 2010; Sjöström et al., 2013; Tagesson et al., 2015). Three values were assigned to the main ecosystems types: 1.8 g MJ^{-1} for deciduous broadleaf forest (DBF), 1.5 g MJ^{-1} for evergreen needleleaf forest (ENF), and 1.2 g MJ^{-1} for remaining ecosystem types (Garbulsky et al., 2010). GPP was not computed for desert areas due to the lack of values for some inputs (e.g. DMET) and the high error provided by the f_{APAR} product in these areas.

C_{ws} was parameterized using a variant of the formulation proposed by Maselli et al. (2009):

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