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TESIS DOCTORAL

Retrieval and assessment of CO_2 uptake by Mediterranean ecosystems using remote sensing and meteorological data

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The knowledge of CO_2 exchange between terrestrial ecosystems and atmosphere is crucial to close the Earth's carbon budget and predict feedbacks in a likely warming climate. Gross photosynthesis (uptake of CO_2) by vegetation is responsible for the gross primary production (GPP) of the ecosystem, which normally refers to the sum of the photosynthesis by all leaves measured at the ecosystem scale.

John Monteith proposed in 1972 a simple approach that has become the paradigm for understanding GPP (Monteith, 1972). It considers GPP as proportional to the incident short wave radiation (PAR), the fractional absorption of that flux (f_{APAR}) and the radiation use conversion efficiency, also known as light-use efficiency (ε). ε has been shown to vary spatially between biomes, ecosystems, and plant species, and to vary temporally during the growing season, due to environmental and physiological limitations. It is usually modeled as the product of a maximum value ε_{max} depending on the vegetation type and another term, which can be factorized in contributions that account for the reduction in efficiency due to different types of stress. In particular, the inter-annual variations of ε in Mediterranean ecosystems are significantly influenced by the water stress

In this Thesis, a model to estimate GPP for Mediterranean ecosystems at regional scale is proposed. The three terms in Monteith's equation have been obtained following procedures optimized for the study area, peninsular Spain. The «optimized model» is driven by meteorological and satellite data (MODIS/TERRA and SEVIRI/MSG). Considering the peculiarities of the study area, i.e., the diversity of the vegetation type dynamics and its spatial heterogeneity, the algorithm has been developed to run at a daily time step (to capture the dynamics even in agro-ecosystems) and 1-km spatial resolution (to assure that the spatial resolution of the remote sensing estimates is comparable to the footprint of ground estimates). Thus, the inputs of the model have been retrieved at these temporal and spatial resolutions.

Daily PAR is around the 46% of the total flux density of solar radiation that reaches the surface during a day (Iqbal, 1983), also known as daily irradiation. Irradiation images were obtained using two different approaches: (i) by applying artificial neural networks to temperature and precipitation maps generated by ordinary kriging from *in situ* measurements (Moreno *et al.*, 2011), and (ii) from the down-welling surface short-wave radiation flux (DSSF) product derived from the SEVIRI/MSG images. A downscaling of the DSSF product was also carried out, which was based on the spatial disaggregation of the irradiance by means of a digital elevation model that also accounts for the coastline correction and a topographic correction (Moreno *et al.*, 2013). All the irradiation images were validated using ground data. The resulting images satisfactorily map the surface solar radiation at 1-km spatial resolution even in rugged terrains. The validation of both types of images shows that the mean absolute error of the daily PAR is around 1.4 MJ m^{-2} day^{-1} when using the approach (i) and between 0.5-0.9 MJ m^{-2} day^{-1}, depending on the topography, when it is derived from SEVIRI/MSG images. In the second case, the product relies only in remotely sensed data and presents thus a major advantage from an operational point of view. However, it is only available from 2011. For retrospective studies, PAR images derived from the first methodology can be used.

f_{APAR} is obtained applying to MODIS data (at 1-km spatial resolution and 8-days temporal resolution) the algorithm proposed by Roujean & Bréon (1995), which is actually used to derive the SEVIRI/MSG f_{APAR} product, delivered by the LSA SAF network (EUMETSAT) (http://landsaf.meteo.pt) at 3.1 km spatial resolution (sub-satellite point) and daily frequency over the geostationary MSG grid. Subsequently, as described in Moreno *et al.* (2014b), the f_{APAR} time series has been filtered using the local method LOESS in order to remove undesirable day-to-day variability (noise) resulting from cloud, ozone, dust, and other aerosols that generally decrease the near-infrared reflectance and increase reflectance in the visible, leading to spurious drops in the data. This methodology has been shown to capture the upper envelope of the time-series, interpolate the missing data and remove most of the noise of the original unfiltered signal.

To assign ε_{max} to the different cover types, a hybrid land-cover map for Spain from Pérez-Hoyos *et al.* (2012) was used. This multi-classification map was obtained from the synergistic combination of a number of four land-cover classifications (CORINE, GLC2000, MODIS and GlobCover) with different legends and spatial resolutions. Values of ε_{max} were obtained from literature (Garbulsky *et al.*, 2010). Regarding the reduction in efficiency as a consequence of stress, two terms corresponding to thermal and water stress were considered. In particular, water stress has been recognized to highly influence the inter-annual variation of ε in Mediterranean ecosystems. The term quantifying the thermal stress is similar to that used by Heinsch *et al.* (2003) in the MODIS GPP algorithm. Meteorological data are also used to characterize the ε inter-annual variability due to water stress. In particular, the water stress factor proposed by Maselli *et al.* (2009), C_{ws}, has been selected. It accounts for limited photosynthetic activity in case of short-term water stress. C_{ws} is obtained from a local water budget based on actual and potential evapotranspiration.

A deep insight in water stress term was carried out. What the scientific community is searching now is a procedure to account for this stress by means of remotely sensed data. In this framework, different spectral indices derived from MODIS data have been analyzed: the PRI and several broad–band spectral indices combining the near-infrared band with short-wave infrared bands. Moreno *et al.* (2012) showed that most (around 70%) of the observed concurrent seasonal variability in ε and PRI is due to the effect of illumination and viewing conditions (first order effects), part to chlorophyll and canopy structure (second order effects), and the de-epoxidation of xanthophylls only introduce third order effects (which are, at MODIS pixel scale of the same magnitude order than the sensor noise). On the other hand, Moreno *et al.* (2014a) showed that the water stress dependence of ε could not be estimated only from such broad–band spectral indices (as derived from MODIS data). However, when a typical C_{ws} profile is available from existing series of meteorological data characterizing a site, they could be useful to update C_{ws} for the actual conditions.

Once the daily GPP product is obtained, as mentioned above, its validation is rather difficult due to the lack of ground GPP data. Nevertheless, GPP estimations from several eddy covariance (EC) towers have been used. These towers belong to the European Fluxes Database Cluster (http://www.europe-fluxdata.eu). By chance these EC towers are mainly located in the semi-arid areas, which are more difficult to be modeled due to the major presence of soil background effects. Therefore, this direct validation of the GPP product serves to establish its upper uncertainty level. Moreover, an indirect validation is enclosed, by means of an inter-comparison with MODIS GPP standard product. The results have been highly satisfactory and promising. A further insight in the GPP has been also carried to explain the percentage of variance that each of the model inputs explain, which clearly states the role of the water stress in the inter-annual variation of GPP in Mediterranean Ecosystems.

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