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Proceeding Paper

An Integrated Modeling Framework to Estimate Time Series of Evapotranspiration at Regional Scales Using MODIS Data and a Two-Source Energy Balance Model †

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Abstract: Satellite remote sensing has become an important tool for monitoring and evaluating the impacts of drought. In this study, a modeling framework aimed at estimating the time series of evapotranspiration (ET), a key variable for drought monitoring, at a regional scale is presented. A two-source energy balance (TSEB) model was used concurrently with Terra/Aqua MODIS data and the ERA5 atmospheric reanalysis dataset. The modeling framework is based on the SEN-ET scheme to calculate the surface energy balance of the soil-canopy-atmosphere continuum and estimate ET at 1 km spatial resolution. The model was applied for the whole Iberian Peninsula, and it was evaluated with a pistachio orchard flux tower data in Lleida (NE Iberian Peninsula). Preliminary daily ET evaluation results showed a RMSE, MBE and R^2 of around 0.64 $W{\cdot}m^{-2}$, −0.1 $W{\cdot}m^{-2}$ and 0.39, respectively, for 101 days in 2022. Ongoing evaluation is being carried out on two forested watersheds as well as mountain meadows and semi-arid vegetation flux towers.

Keywords: remote sensing; drought; evapotranspiration; two-source energy balance; water resource management; MODIS

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1. Introduction

Drought is a devastating, recurring, and globally natural hazard that causes extreme damage to natural ecosystems, agriculture, economy, society, and health [1]. Drought is characterized as a creeping phenomenon, gradually emerging over time. This gradual manifestation makes drought prediction onsets and ends difficult and challenging [2]. However, drought impacts are apparent in vegetation greenness and crop water requirements over time [3].

Evapotranspiration (ET) is a key variable of the hydrologic cycle that leads to water loss from the processes of transpiration and evaporation through plant canopy and soil, respectively [4]. ET plays a critical role in climate system as a nexus of the water, energy, and carbon cycles and sequentially affects plant growth and yield [5,6]. Accurate evaluation of ET is critical for estimating crop water requirements, planning irrigation, enhancing efficient use of water resources, and monitoring and predicting drought [7,8]. Mediterranean areas, characterized by water-limited crop production, face accelerant climate change impacts associated with increasing extreme temperatures and decreasing precipitation [9]. Iberian Peninsula is among the most vulnerable areas of southern Europe due to its Mediterranean climate and agricultural predominance [10]. Thus, ET estimates can be an indicator for monitoring agricultural drought and assessing water use efficiency in these areas. Quantitative ET methods can be classified into ground observations and model-based estimation. Calculating ET with ground observation methods on regional scales is difficult due to spatial heterogeneity [11]. Thermal-based surface energy balance models are widely used to estimate ET through reflected and emitted energy from the Sun to the land surface [12]. The surface energy balance models can be categorized as single-source and dual-source models. The single-source models assume the land surface as a single system, but the dual-source models differentiate soil and vegetation energy fluxes separately [13]. Two-source energy balance (TSEB) model is a dual-source model that shows better performance on vegetation-soil-mixed surfaces [11,12].

Remote sensing data has revolutionized water resource management studies as they address the limitations of ground observations by providing parameters at different spatiotemporal resolutions. Remote sensing data has been widely used as input data to estimate ET through surface energy balance models by proving numerous key parameters such as the land surface temperature, surface albedo, emissivity, and vegetation indices. This, integration of remote sensing data and thermal-based surface energy models enhances our ability to understand and manage water resources effectively.

The Moderate Resolution Imaging Spectroradiometer (MODIS) on-board of Terra and Aqua satellites is a critical instrument used in Earth observation and global-change research that provides essential environmental parameters, including land surface temperature, ocean color, vegetation cover, and atmospheric conditions. With a freely available long-term dataset spanning more than a 22-year for researchers and scientists worldwide, MODIS plays a crucial role in monitoring climate change, ecosystem dynamics, and natural disasters. MODIS cloud contamination and other gaps can lead to missing data and reducing data quality. However, MODIS quality-assessment (QA) data with gap-filling algorithms can be applied to maximize the high-quality data effects and reduce and replace poor-quality and missing data.

The present study aims: (1) to calculate smoothed and gap-filled MODIS biophysical products as input for ET estimation (2) to estimate daily time series of remote sensing-based ET using an integrated modeling framework at regional scales with Terra/Aqua MODIS images, the ERA5 atmospheric reanalysis dataset and the TSEB model; and (3) to evaluate the model performance over heterogeneous surfaces in the Mediterranean region.

2. Materials and Methods

2.1. Study Area

The Iberian Peninsula, located in southwestern Europe, is recognized as a climate change "hotspot" within the Mediterranean region and it was selected for the model application. As an ongoing model evaluation, the pistachio orchard flux tower (NE Iberian Peninsula) was selected to evaluate the performance of the TSEB model (Figure 1).

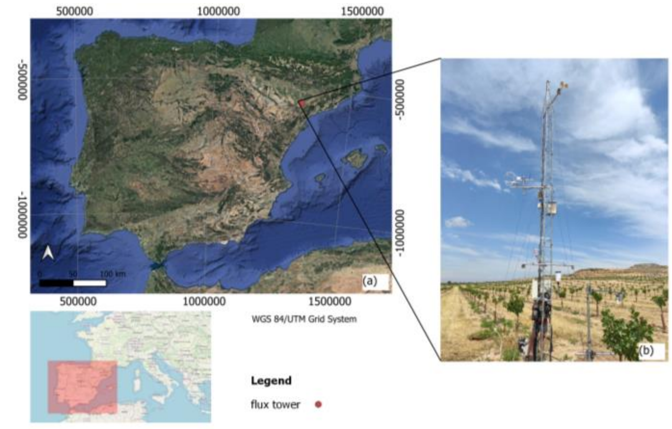

Figure 1. (**a**) Study area with the location of the eddy covariance tower, (**b**) general view of the pistachio orchard flux tower. Coordinates in UTM-30N WGS84.

2.2. Brief Overview of the ET Modeling Framework

The model framework based on the SEN-ET was used with some modifications for the study areas to estimate ET at regional scales (model description can be found at https://www.esa-sen4et.org/). The processing flow for estimating energy heat flux using MODIS data and the TSEB model modifications are shown in Figure 2.

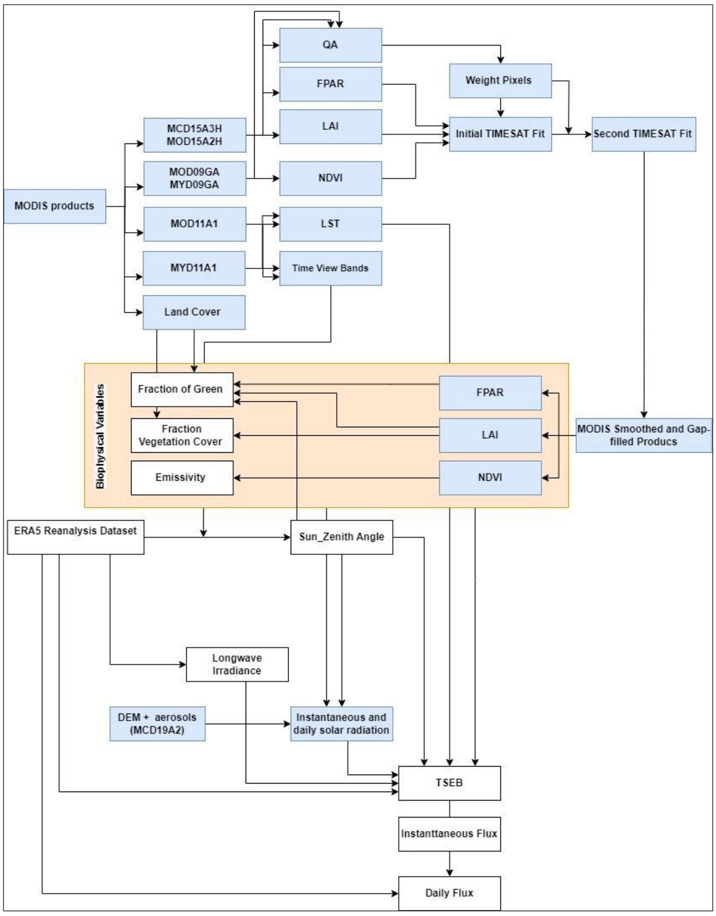

Figure 2. Processing flow diagram for surface energy fluxes estimation at instantaneous and daily scales. Blue indicates model modifications for MODIS data.

2.3. Remote Sensing and Meteorological TSEB Input Variables

Both optical and thermal data were driven from Terra/Aqua MODIS sensors. Also, meteorological data including air temperature, atmospheric vapor pressure, wind speed above the canopy, atmospheric pressure, and total column water vapor were extracted from the ERA5 reanalysis dataset. Instantaneous incoming shortwave radiation and daily were computed using a DEM [14], water vapor and aerosols from MODIS combined AOD product (MCD19A2). Sun zenith angle was computed using the acquisition time in the LST MODIS product.

2.4. Time Series of Vegetation Properties and Biophysical Data

TIMESAT was used to both temporally smooth and spatially complete biophysical variables. This process transformed noisy signals (due to clouds and other atmospheric and image acquisition artifacts) of remotely sensed vegetation indices including LAI, NDVI and FPAR into smooth seasonal curves by using MODIS QA data providing a weighting mechanism to reduce the influence of clouds and atmospheric noise on satellite data. TIMESAT has three different smoothing functions to fit the time-series data: double logistic, asymmetric Gaussian, and Savitzky–Golay filtering [15].

3. Results

Time series of LAI, NDVI, and FPAR data were analyzed by TIMESAT. High weights were assigned for higher quality retrievals and low weights for lower quality retrievals as well as the double logistic smoothing method was selected since showed a better fit to the data. After the initial fit from TIMESAT, it failed to fit a curve to the time series of LAI and FPAR products, therefore, a second run of TIMESAT was applied to LAI and FPAR time series data as Gao et al. suggested [16].

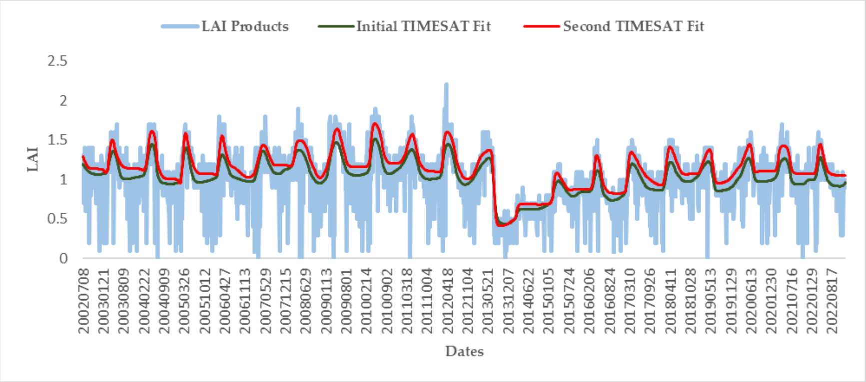

Figure 3. LAI observations from 2002 to 2022 for a sample point (Latitude: 39°35.81′ N, Longitude: 2°24.63′ E).

TSEB evaluation for 2022 yielded a RMSE, MBE, and proportion of error (PE) and R^2 of around 0.64 $W \cdot m^{-2}$, -0.1 $W \cdot m^{-2}$, 32 and 0.39, respectively, for 100 days when compared with daily ET measured by the pistachio flux tower (Figures 4 and 5).

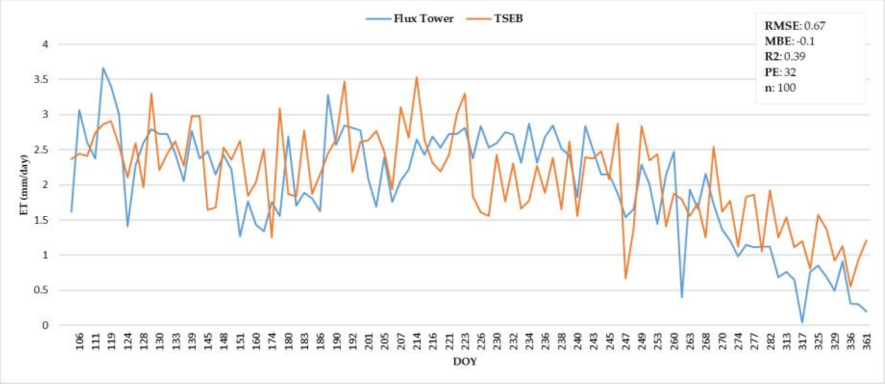

Figure 4. Comparison of daily ET from the TSEB model and the flux tower for 2022.

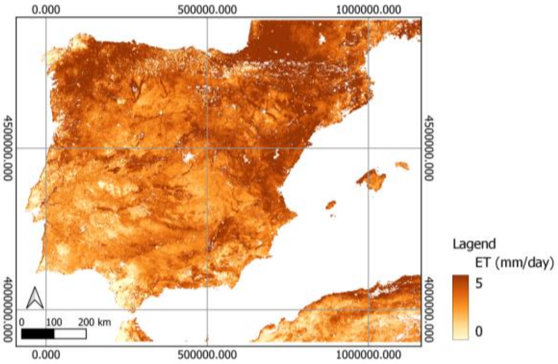

Figure 5. Daily ET estimation using the modeling framework for DOY 206-2022.

4. Discussion

In this study, TIMESAT software was applied to smooth and fill the gaps in MODIS time series data. The result showed that TIMESAT failed to fit a curve into LAI and FPAR time series products after the initial process since there were many gaps or low-quality data. Therefore, the second TIMESAT process was applied to LAI and FPAR images. Results also showed that the algorithm successfully smoothed and fitted data temporally and spatially. A two-source energy balance model based on the SEN-ET modeling framework was successfully applied using Terra MODIS data and the ERA5 atmospheric reanalysis dataset. Results showed that ET estimated by the TSEB model and remote sensing data agreed well with the flux tower observations capturing temporal dynamics of daily ET over the study period and that the modeling framework can be applied both regionally and temporally to estimate spatiotemporal ET dynamics. Currently, Aqua results from the same period are also being analyzed and evaluated.

5. Conclusions

Drought is a complex environmental phenomenon with dynamic impacts that manifest over time. Hence, to comprehensively understand its effects, it is essential to monitor it using time series data of ET. In this study, an optimized modeling framework to estimate long time series of daily ET at a regional scale in the Iberian Peninsula was presented. The modeling framework is based on the SEN-ET scheme, and synergistically uses Terra/Aqua MODIS data and the ERA5 atmospheric reanalysis dataset to estimate ET at 1 km spatial resolution. Model evaluation with the pistachio orchard flux tower data in Lleida (NE Iberian Peninsula) showed good performance of the modeling framework. The proposed modeling framework provided a pathway to construct a daily time series of remote sensing-based ET maps. Ongoing modeling framework evaluation is also being carried out on two forested watersheds as well as mountain meadows and semi-arid vegetation flux towers.

Author Contributions: Conceptualization, M.B.; methodology, M.B and J.C.; programming, M.B. and J.C.; validation, all; format analysis, all; writing, M.B. and J.C.; supervision, J.C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Terra and Aqua datasets were provided by USGS and downloaded through Google Earth Engine. Reanalysis meteorological dataset were provided by Copernicus at https://cds.climate.copernicus.eu/cdsapp#!/home.

Conflicts of Interest: The authors declare no conflict of interest.

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