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TIME SERIES ANALYSIS OF EVAPOTRANSPIRATION FOR ASSESSING DROUGH IMPACT ON WHEAT YIELD

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ABSTRACT

Drought is a devastating natural hazard which causes reductions in crop yields. This study aims to analyze the relationship between wheat yield and evapotranspiration (ET) dynamics across the last two decades in the Iberian Peninsula. A two-source energy balance (TSEB) model with Terra/Aqua MODIS data and the ERA5 atmospheric reanalysis dataset were used to calculate daily ET at 1 km spatial resolution. The Breaks for Additive Seasonal and Trend (BFAST) method was applied to detect drought events. The ET time series was decomposed into seasonal, trend, and remainder components using BFAST to identify changes in trend and seasonal components in the 22-year daily ET time series. Breakpoints were identified in the ET time series corresponding to the years of yield decline. Results showed ET anomalies can serve as an indicator for recognizing droughts. This research suggests the utility of time series analysis of ET for early drought detection, a practical approach for mitigating the impact of climatic change on crop yields.

Index Terms— Agricultural drought, evapotranspiration, BFAST, time series analysis, MODIS

1. INTRODUCTION

Drought, a widespread natural disaster occurring across multiple time scales with far-reaching impacts, leads to yield reduction [1]. Droughts are caused by the interaction between precipitation and evapotranspiration (ET) [2]. ET plays a critical role in the water and energy cycles, leading to water loss from the combined processes of transpiration and evaporation through plant canopy and soil, respectively [3]. Agricultural drought occurs when the amount of water available for plants is less than the essential threshold during the growing season [4].

Quantifying and monitoring ET, as a measure of crop water requirements, plays a crucial role in predicting crop yield and planning irrigation schedules within irrigated agricultural areas. Moreover, anomaly detection in ET trends provides a valuable signal for assessing the impact of water shortage on crops, recognizing, and monitoring the onset and severity of agricultural drought [5].

ET can be locally estimated using ground observations and regionally estimated by surface energy balance models, such as the two-source energy balance (TSEB) model that assumes the land surface as a dual-source system [6], [7].

Recently, with emerging remote sensing data, various long-term change detection methods have been presented to recognize temporal changes. One of them, the Breaks for Additive Season and Trend (BFAST) method could identify long-term trends and detect seasonal, gradual, and abrupt changes.

The Iberian Peninsula (IP) is among the most vulnerable areas of southern Europe due to its heterogeneous atmospheric influences [8], Mediterranean climate, and agricultural predominance. The Mediterranean climate is characterized by water-limited crop production. Recently, Mediterranean areas have suffered an increase in the frequency of concurrent droughts and heatwaves since the 1950s, resulting in crop yield reductions [9].

This study aims (1) to decompose the 22-year daily ET time series, modeled with Terra/Aqua MODIS data and the TSEB model, into trend, seasonal, and remainder components using BFAST to detect changes (breaks) and (2) to analyze both ET and wheat yield change dynamics as an indicator for recognizing agricultural drought.

2. MATERIALS AND METHODS

2.1. Study area

Four agricultural study areas within the Iberian Peninsula were located, which is characterized by a Mediterranean climate and different agricultural practices, including rainfed and irrigated crops (Figure 1). Since the last two decades, several droughts were recorded in the Iberian Peninsula, influencing both rainfed and irrigated crop yields, especially wheat.

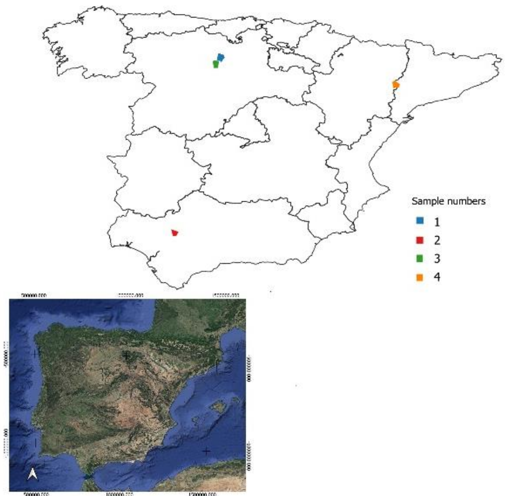

Figure 1. Selected study areas. Coordinates in UTM-30N WGS84

2.2. Data

2.2.1. Wheat yield data

The Annual Survey on Crop Areas and Yields (ESYRCE) data was used as a crop yield source in this study. The project was initiated by the Ministry of Agriculture, Food and Environment of Spain in collaboration with the Statistical Services of the Communities and data has been collected since 2000. Wheat yield was extracted from this database for four specific areas where wheat was planted for at least five years.

2.2.2. ET data

Daily remote sensing-based ET was calculated by a two-source energy balance (TSEB) model based on the SEN-ET (model description can be found at https://www.esa-sen4et.org/) with some modifications for the study area.

Terra/Aqua MODIS data and the ERA5 atmospheric reanalysis dataset was used to apply the model for the whole Iberian Peninsula.

The model was evaluated with pistachio orchard flux tower data in Lleida (NE Iberian Peninsula). Preliminary daily ET evaluation results showed an RMSE, MBE, and R^2 of around 1.49 $mm\cdot day^{-1}$, -0.1.2 $mm\cdot day^{-1,}$ and 0.55, respectively for Terra imagery, and an RMSE, MBE, and R^2 of about 1.08 $mm\cdot day^{-1}$, -0.81 $mm\cdot day^{-1}$ and 0.56, respectively for Aqua dataset, within 265 days in 2022. More information about the model parametrization, calibration and evaluation can be found at [10].

2.2.3. BFAST

BFAST can be applied to both seasonal and non-seasonal satellite image time series such as hydrology, climatology, and econometrics [11]. BFAST is an iterative algorithm that decomposes time series into trend, seasonal, and remainder components for detecting and characterizing the time and number of changes within time series. BFAST also characteristic changes with magnitude and direction.

The parameter h in the BFAST algorithm affects the trend change detections as it determines the minimum time between breakpoints. The minimum segment size is also influenced by the h parameter, and its optimal values vary spatially. A minimal 2.6 years between breakpoints for semi-arid landscapes was recommended [12].

In this study, the 22-year daily ET time series were analyzed using BFAST. A harmonic seasonal model was applied for detecting changes in ET time series. A seasonal–trend decomposition procedure based on Loess (STL) was used to iteratively fit a piecewise linear trend and a seasonal model. The h parameter was adapted to 0.09, which means a minimum of two years was considered between change detections within the time series, indicating that if more than one breakpoint detects within two years, only the more remarkable one is considered.

3. RESULTS

3.1. Wheat yield time series

The cultivated areas and the amount of wheat yield (kg/m^2) in each selected study area are shown in Table 1 and Figure 2, respectively. In this study, only years in which wheat was planted were considered.

Wheat yield in rainfed areas (sample numbers 1 and 2) fluctuated over the 22-year period. By contrast, the wheat yield trend in sample number 3 (an irrigated area) showed a more stable trend. In addition, the crop yield trend in sample number 4 showed a considerable increase, with a peak in 2015, although it decreased remarkably from this time onward.

Table 1. Cultivated areas in each selected study area

Sample number	Area (ha^2)	agricultural practices
1	8.1	rainfed
2	0.56	rainfed
3	3.4	irrigated
4	0.29	irrigated

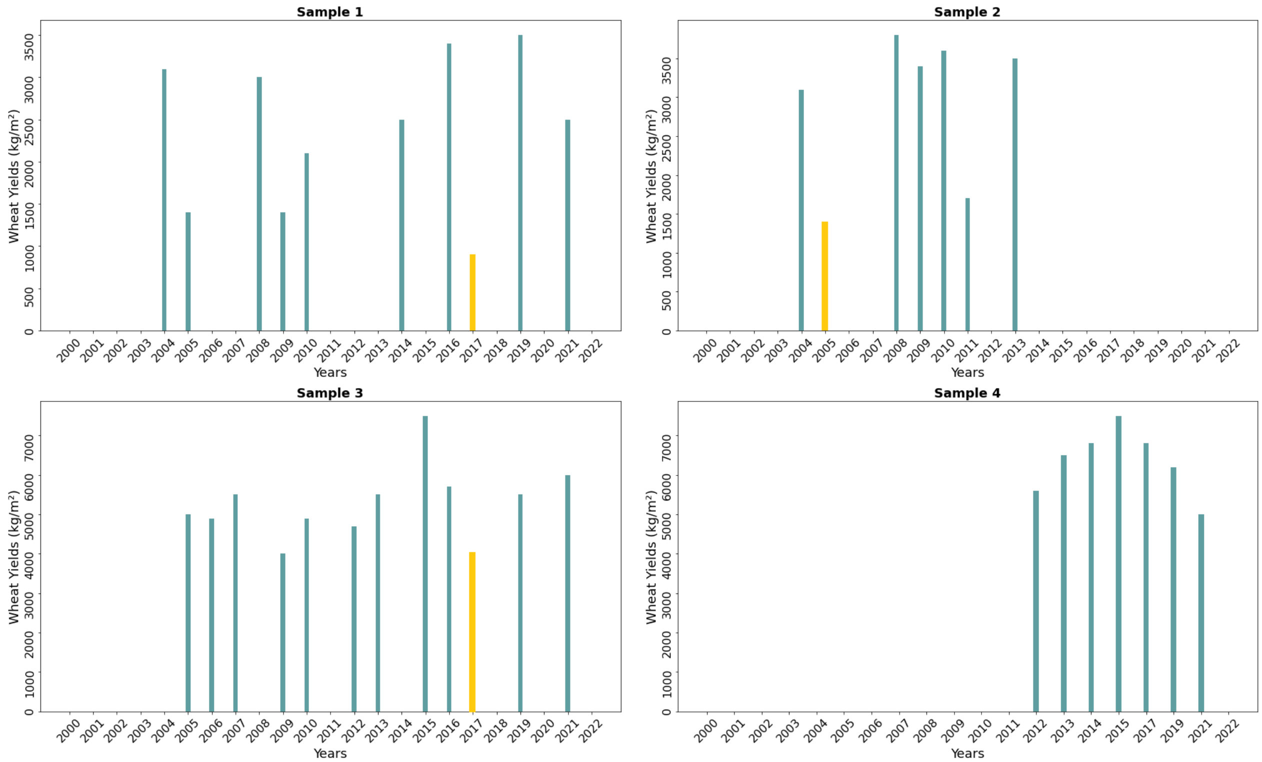

Figure 2. Wheat yield (kg/m^2) for each selected study area (orange color showed the most significant changes)

3.2. Timing of changes in ET dynamics

Figures 3 and 4 showed the detected timing of changes occurring in trend and seasonal ET time series in each selected study area. BFAST detected both gradual and abrupt breakpoints in the Terra and Aqua images.

4. DISCUSSION

Seasonal and trend components of long-term time series of ET data usually consist of both gradual and abrupt changes. Gradual changes normally reflect changes in other factors such as irrigation methods and land degradation. However, abrupt changes are normally caused by disturbances such as fire, insect attack, or drought [13].

Generally, both Terra and Aqua presented similar outcomes in BFAST analysis.

Regarding sample number 1, in both terra and aqua, BFAST detected changes in the years 2009 and 2017 in the trend and seasonal components and the largest break was in 2017 with a magnitude of 1.02 and 1.09 in Terra and Aqua, respectively, which aligned with the years of yield reductions (highlighted with orange color in figure 2). However, no changes were detected in 2005 with a significant reduction in the wheat crop.

In sample number 2, the largest breakpoint was detected in Terra dataset in 2005 which aligned with the yield data (highlighted with orange color in figure 2). By contrast, in aqua, 2009 was selected.

In the case of sample number 3, the wheat yield showed significant fluctuations over the studied period. Additionally, BFAST identified various gradual and abrupt changes in the trend and seasonal components of ET time series. Changes in the years of 2009 and 2017 were identified by BFAST in both Terra and Aqua. The largest change was detected in the year 2017 with a magnitude of -0.8 and -0.95 in Terra and Aqua, respectively, coinciding with a year of reduced yield (highlighted with orange color in figure 2).

In sample 4, A breakpoint was identified in the Terra trend component in 2012, which corresponded with the yield data. Despite considerable wheat yield reductions in 2021, no changes were identified by BFAST.

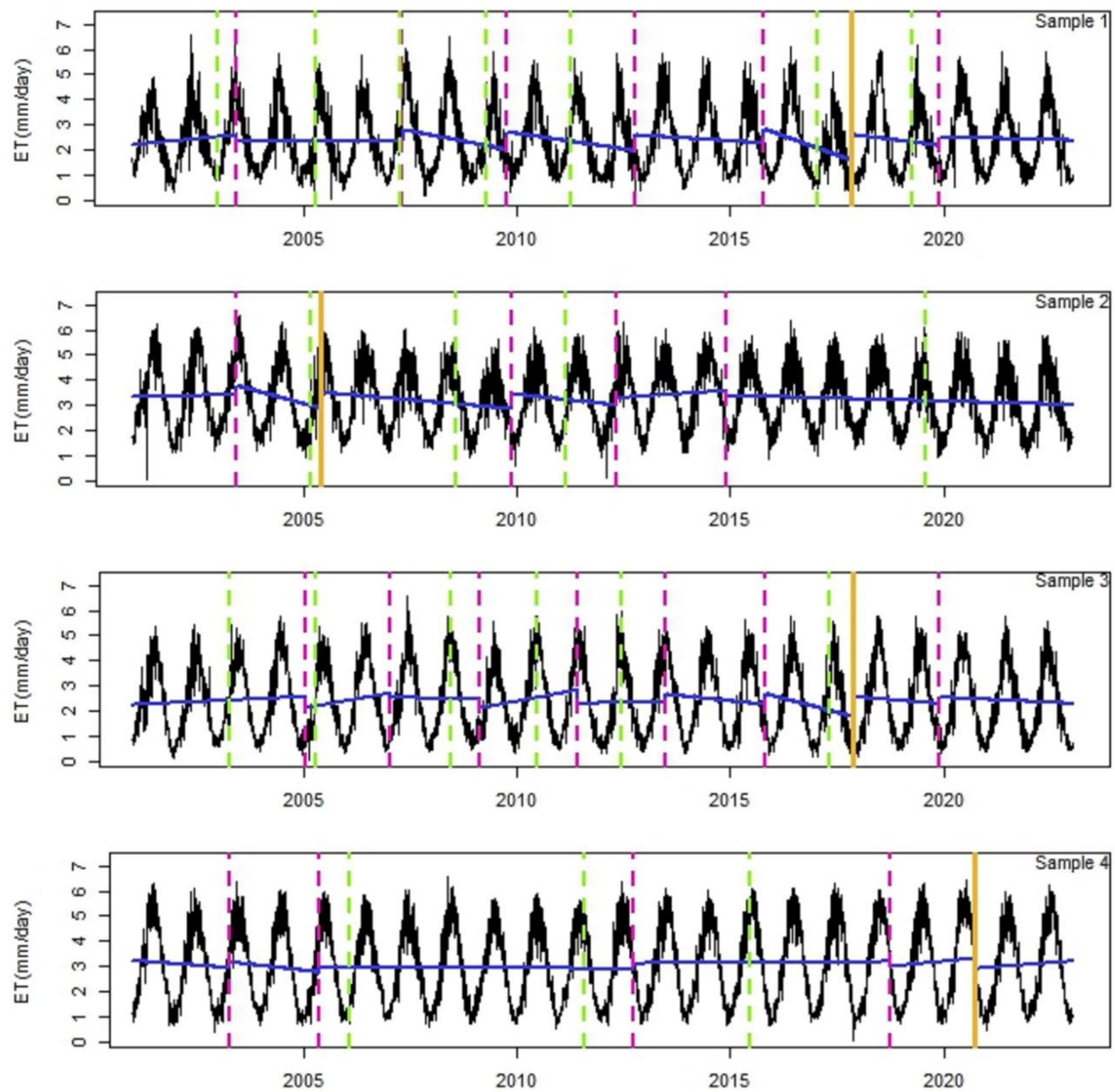

Figure 3. BFAST detected changes in trend (blue) and seasonal (black) components of the daily ET time series using Terra MODIS data. The dash lines represent the dates of detected breakpoints in trend (purple) and seasonal (green) components, together with the most significant changes (orange line)

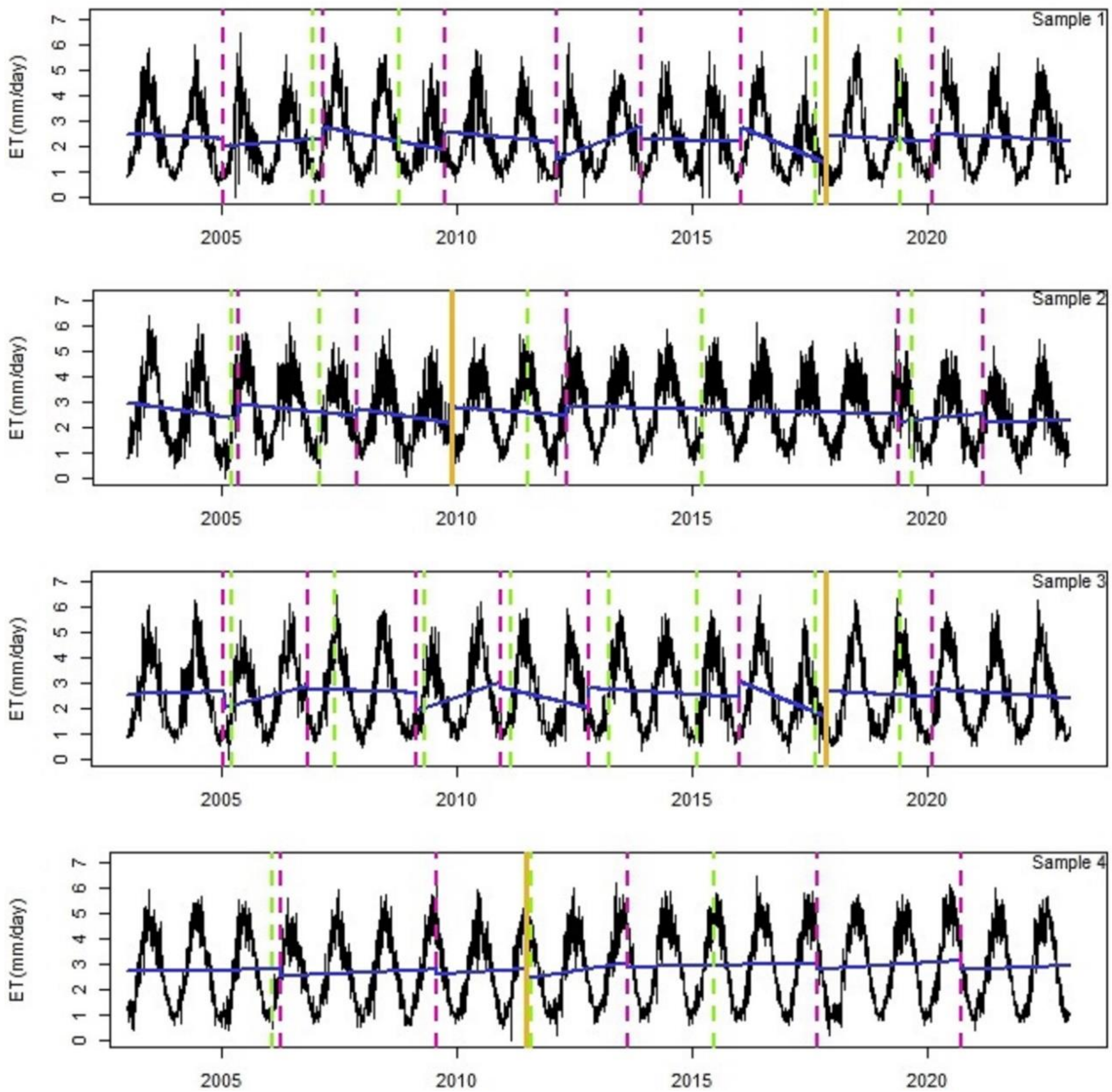

Figure 4. BFAST detected changes in trend (blue) and seasonal (black) components of the daily ET time series using Aqua MODIS data. The dash lines represent the dates of detected breakpoints in trend (purple) and seasonal (green) components, together with the most significant changes (orange line)

5. CONCLUSIONS

Quantifying and monitoring ET dynamics plays a key role in managing water resources in drought-prone agricultural areas. In this paper, the TSEB model was applied to calculate ET by Terra/Aqua MODIS data and the ERA5 atmospheric reanalysis dataset in the Iberian Peninsula. BFAST was used to detect changes in trend and seasonal components of the 22-year daily ET time series. The agreement between BFAST outcomes and wheat yield time series highlighted a significant potential of anomalous ET patterns as a reliable indicator for monitoring drought events. This research suggests the utility of time series analysis of ET for early drought detection, a practical approach for mitigating the impact of climatic change on crop yields.

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