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# Uso de la evapotranspiración derivada de Observación de la Tierra para mejorar la detección temprana de sequías en pastizales semiáridos

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## RESUMEN

La sequía es un fenómeno recurrente en los pastizales de Borena, Etiopía, con impactos severos sobre la producción ganadera y las comunidades agro-pastoriles. Los datos de Observación de la Tierra (EO) ofrecen un gran potencial para mejorar la detección de sequías mediante información espacio-temporal oportuna; sin embargo, muchos indicadores tradicionales se centran únicamente en la sequía meteorológica o no son adecuados para ecosistemas semiáridos. La evapotranspiración real (ET) es un indicador clave, ya que integra condiciones atmosféricas (i.e. sequía meteorológica), disponibilidad de agua (i.e. sequía hidrológica) y el estado fisiológico de la vegetación (i.e. sequía agrícola/ecológica). Este estudio evalúa estimaciones de ET obtenidas con el modelo de balance de energía de tres fuentes (3SEB), forzado con datos globales de Copernicus (Sentinel-3 y ERA5), para caracterizar la respuesta de la vegetación a la sequía en ecosistemas semiáridos. El modelo se validó en tres sitios de eddy-covariance (EC), dos dehesas en España y una sábana en Sudáfrica que presentan condiciones similares a las que encontramos en Etiopía. Además, se generaron mapas de ET para Borena (2019–2022) y se compararon con el índice de vegetación de diferencia normalizada (NDVI), comúnmente usado en indicadores de sequía para caracterizar la respuesta de la vegetación. Los resultados preliminares muestran buena concordancia con las mediciones EC (RMSE ~1 mm/día) y una respuesta más rápida de la ET frente al NDVI, lo que resalta su potencial para la detección temprana del estrés hídrico. El trabajo futuro se centrará en comparar indicadores basados en ET con índices tradicionales de sequía mediante un análisis espacio-temporal, así como con mediciones de servicios ecosistémicos.




**Palabras clave:** *Evapotranspiración, Copernicus, Sequías, Pastizales, Infrarrojo térmico*

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# Uso de la evapotranspiración derivada de Observación de la Tierra para mejorar la detección temprana de sequías en pastizales semiáridos

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**Resumen:** La sequía es un fenómeno recurrente en los pastizales de Borena, Etiopía, con impactos severos sobre la producción ganadera y las comunidades agro-pastoriles. Los datos de Observación de la Tierra (EO) ofrecen un gran potencial para mejorar la detección de sequías mediante información espacio-temporal oportuna; sin embargo, muchos indicadores tradicionales se centran únicamente en la sequía meteorológica o no son adecuados para ecosistemas semiáridos. La evapotranspiración real (ET) es un indicador clave, ya que integra condiciones atmosféricas (i.e. sequía meteorológica), disponibilidad de agua (i.e. sequía hidrológica) y el estado fisiológico de la vegetación (i.e. sequía agrícola/ecológica). Este estudio evalúa estimaciones de ET obtenidas con el modelo de balance de energía de tres fuentes (3SEB), forzado con datos globales de Copernicus (Sentinel-3 y ERA5), para caracterizar la respuesta de la vegetación a la sequía en ecosistemas semiáridos. El modelo se validó en tres sitios de *eddy-covariance* (EC), dos dehesas en España y una sábana en Sudáfrica que presentan condiciones similares (i.e., clima, estructura, fenología) a las que encontramos en Borena. Además, se generaron mapas de ET para Borena (2019–2022) y se compararon con el índice de vegetación de diferencia normalizada (NDVI), comúnmente usado en indicadores de sequía para caracterizar la respuesta de la vegetación. Los resultados de ET preliminares muestran buena concordancia con las mediciones EC (RMSE ~1 mm/día) y una respuesta más rápida frente al NDVI, lo que resalta su potencial para la detección temprana del estrés hídrico. El trabajo futuro se centrará en comparar indicadores basados en ET con índices tradicionales de sequía mediante un análisis espacio-temporal, así como con mediciones de servicios ecosistémicos.

**Palabras clave:** Evapotranspiración, Copernicus, Sequías, Pastizales, Infrarrojo térmico

## ***Earth Observation-based evapotranspiration to improve the early detection of agricultural droughts in semi-arid rangeland ecosystems***

**Abstract:** Drought is a recurring phenomenon in the Borena rangelands in Ethiopia, having endured severe drought events in recent years, acutely impacting livestock production and the livelihoods of its agro-pastoralist communities. Earth Observation (EO) data has a large potential to improve drought detection, allowing to support rapid decision-making with timely spatio-

temporal information. However, many traditional EO-based indicators are either focused purely on meteorological drought or are poorly suited for semi-arid rangelands. Actual evapotranspiration (ET) is a key indicator for droughts since it integrates factors related to atmospheric conditions, water availability and plant physiological status. This work aims to evaluate ET estimates from the three-source energy balance (3SEB) model, forced with global Copernicus-based inputs (i.e., Sentinel-3 and ERA5), to better quantify vegetation's response to drought. The approach was evaluated over three eddy-covariance (EC) sites located in savanna-like regions in Spain and South Africa, representing similar conditions to Borena. ET maps were then generated over the entire Borena region (2019-2022), and a monthly time series was compared to the Normalized Difference Vegetation Index (NDVI), typically used within drought indicators to quantify vegetation's response to water deficit. Preliminary results show that 3SEB estimates were well within range of EC measurements across the three sites (ET RMSE ~ 1mm/day). Monthly ET estimates also showed a faster response than NDVI, indicating the potential to detect water stress in vegetation more rapidly than conventional spectral indices. Future work will focus on comparing ET-based indicators with traditional drought indices through spatio-temporal analysis, as well as with measures of ecosystem services.

**Keywords:** Evapotranspiration, Copernicus, Droughts, Rangelands, Thermal Infrared

## 1. INTRODUCTION

Semi-arid ecosystems play a pivotal role in regulating global water, carbon, and energy cycles (Ahlström et al., 2015). However, these ecosystems are highly vulnerable to droughts, severely affecting their functioning and their provision of ecosystem services, such as livestock production. Traditional drought indicators commonly rely on meteorological data, such as the Standardised Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010) but these do not directly account for changes in the physiological state of vegetation and fail to quantify the different dimensions of droughts (i.e. agro-ecological droughts) and their impacts on ecosystem services (Han et al. 2025)

In recent years, EO has emerged as a valuable tool to improve drought monitoring, providing timely, spatially explicit information. In this context, the development of composite drought indices (CDI) (Cammalleri et al., 2021) integrating multiple EO-based datasets has gained traction, comprehensively assessing the various dimensions of drought within a single indicator.

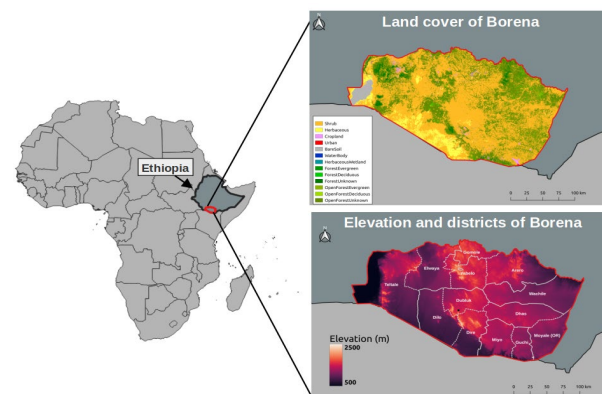
Most CDIs depict vegetation response to drought through spectral indices, such as NDVI. However, these indices may not adequately characterize vegetation's response in semi-arid ecosystems due to their high spatial heterogeneity, sparse vegetation cover, and strong influence of non-photosynthetic vegetation. In this regard, EO-based ET estimates, based on thermal infrared imagery, have the potential to better capture the physiological response of vegetation through its link with stomatal conductance and root-zone water availability (Joiner et al., 2018).

The main objective of this work, which presents ongoing activities related to the ESA-funded [SEMHy-ARID](#) project, is to evaluate ET estimates from the three-source energy balance (3SEB) model forced with global Copernicus-based inputs to better capture the various dimensions of droughts in semi-arid rangelands, with special attention to the Borena region in Southern Ethiopia.

## 2. MATERIAL AND METHODS

### 2.1. Study sites

The Borena rangelands, found in the southern Ethiopia within the Oromia Regional State (Fig. 1), are dominated by traditional pastoral land use. The climate is classified as hot semi-arid (Köppen classification: BSh) with mean annual rainfall ranging from 300 to 700 mm and a bimodal precipitation pattern comprising two rainy seasons: the main (March–May) and secondary (September–November) rainy seasons.



**Figure 1.** Land cover classification and topographic map of the Borena region from Copernicus CGLOPS-1 land cover data and digital elevation model (DEM) from USGS's Shuttle Radar Topography Mission (SRTM)

Furthermore, three eddy-covariance (EC) flux sites across Spain and South Africa were used to evaluate EO-based ET products over semi-arid rangeland ecosystems comparable to the Borena region. Flux data from 2019-2023 were acquired over two EC sites in Spain (FLUXNET codes ES-LMa and ES-Abr) located in savanna-like ecosystems, composed of dispersed trees (roughly 20% cover) over a heterogeneous herbaceous understory. EC data were also collected in the Skukuza EC tower located in the Kruger National Park (FLUXNET code ZA-Kru) between 2019 and 2023 (with significant

data gaps). This site represents a typical African savanna with about 30% tree cover.

## 2.2. Three-source energy balance model

ET was estimated using 3SEB model (Burchard-Levine et al., 2022) as it is especially suited for savanna ecosystems. It is based on the widely used two-source energy balance (TSEB, Norman et al., 1995) but adds a vegetation source to its modelling framework. Surface energy balance models estimate ET as the residual of the surface energy balance, where latent heat flux (LE) is retrieved as the residual of net radiation ( $R_n$ ), sensible heat flux (H) and soil heat flux (G), assuming negligible contributions from advection, canopy heat storage and other minor energy terms. Indeed, 3SEB decomposes the surface energy balance into three sources: overstory vegetation (i.e. trees), understory vegetation (i.e. grass) and soil. This better represents savanna ecosystems by directly accounting for the phenological and structural differences of the two vegetation strata (i.e. trees vs grasses). The main inputs to 3SEB are the radiometric land surface temperature (LST), the primary boundary condition for H; leaf area index (LAI), used to estimate radiation transmission through canopies; and weather forcing, such as air temperature, wind speed, and irradiance. For more details, refer to Burchard-Levine et al. (2022).

## 2.3. EO datasets and processing

Sentinel-3 (S3) data were acquired from the Copernicus Data Space Ecosystem for both the SLSTR Level-2 LST product (1 km) and the Level-2 SYN product (300 m) between 2019 and 2023. The S3-SYN product combines shortwave optical bands from the OLCI and SLSTR instruments onboard the S3 platform. The surface reflectance, together with observation and illumination conditions, were then used to estimate vegetation biophysical traits (e.g., LAI and pigments) by inverting the radiative transfer models PROSPECT-D and 4SAIL (Nieto, 2026) through a global hybrid approach described in Guzinski et al. (2025). LST was acquired from the Level-2 S3-SLSTR LST product and was then sharpened to 300 m spatial resolution using S3-SYN bands and a data mining approach, similar to the method developed for the Copernicus Land Monitoring Service Evapotranspiration product (Guzinski et al. 2025). Meteorological scalars were processed from ERA-5 using `meteo_utils` (Nieto et al., 2026).

## 2.4. 3SEB model evaluation

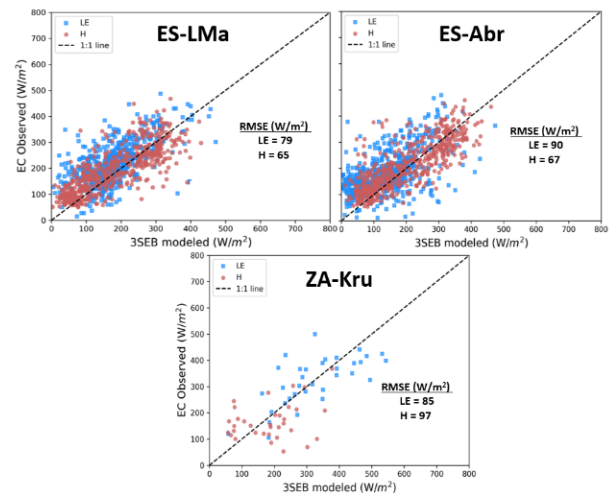
The 3SEB model was evaluated against EC-based H and LE over three sites (section 2.1). Due to the well-known energy balance closure issue, fluxes were corrected by the mean of three common methods: allocating all residuals to LE, allocating all residuals to H and maintaining the Bowen ratio.

# 3. RESULTS AND DISCUSSION

## 3.1. 3SEB evaluation

The Copernicus-based 3SEB model performed similarly across the three EC sites, with the RMSE of LE and H ranging between 79-90  $W/m^2$  and 65-97  $W/m^2$ , respectively (Fig. 2). The LE in both ES-LMa and ES-Abr

were slightly underestimated (bias:  $\sim -40 W/m^2$ ) as compared to H (bias:  $\sim 15 W/m^2$ ), which was affected by a slight underestimation of  $R_n$  (data not shown). Instantaneous modelled LE were extrapolated to daily ET based on the incoming shortwave irradiance ratio approach (Guzinski et al. 2025), resulting in RMSE of roughly 1 mm/day across all sites (data not shown).



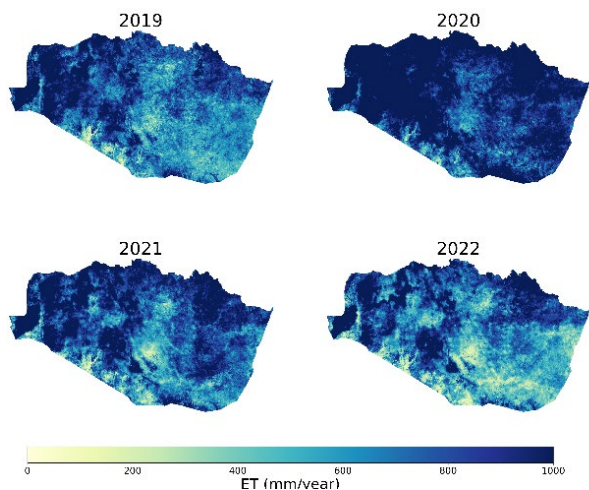
**Figure 2.** Scatter plots of modelled latent heat (LE, blue), and sensible heat (H, red) fluxes using 3SEB against eddy-covariance (EC) measurements in Majadas de Tiétar (ES-LMa), Albuera (ES-Abr) and Skukuza (ZA-Kru).

## 3.2. ET in Borena region

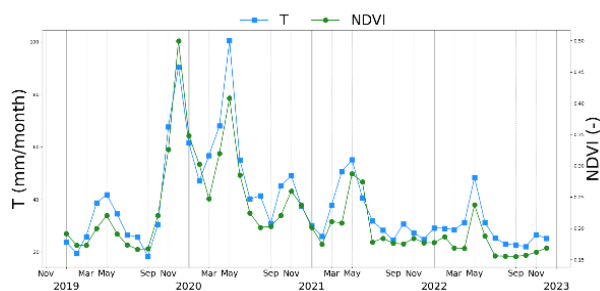
Figure 3 illustrates annual ET maps of the Borena region from 2019 to 2022. There is large spatial variability within the region, especially affected by its topography, where more elevated areas tended to have less inter-annual variability and be less affected by the drought years (2019, 2021 and 2022) compared to lowlands, which were mostly dominated by savannas and grasslands.

These drought episodes are further illustrated in Fig. 4, which presents a time series of modelled monthly mean transpiration (T) and NDVI for grasslands in the region. As shown, the T and NDVI time series exhibit similar trends, indicating the effects of rainfall deficits in nearly all rainy seasons during this period, except for late (Oct-Dec) 2019, 2020, and, to a lesser degree, spring (March-May) 2021. Although faint, the T signal seems to be more sensitive to water availability than NDVI, with a quicker increase and decrease during local peaks affected by rainfall events. These effects would likely be even more visible at shorter time steps (i.e. dekadal) compared to the monthly time step assessed here. Joiner et al. (2018) also demonstrated that ET generally had a quicker response to water deficits as compared to NDVI and other spectral indices. Indeed, ET is more closely linked to soil moisture depletion and vegetation physiological responses (i.e., reduced transpiration) than greenness indices, which could provide a more rapid early-warning detection of droughts. Further work will focus on conducting a spatiotemporal analysis comparing ET-based indices with conventional drought indices (e.g., SPEI or CDI) and evaluating them against ecosystem

service indicators, such as grassland production and food security.



**Figure 3.** Annual ET maps using Copernicus-based 3SEB of Borena region for 2019-2022



**Figure 4.** Monthly time series of 3SEB transpiration (T) (blue) and NDVI (green)

#### 4. AGRADECIMIENTOS

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