SATELLITE VERSUS STATIONS: EVALUATION OF THE MOD16A2 EVAPOTRANSPIRATION PRODUCT IN MATO GROSSO, BRAZIL

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ABSTRACT: Evapotranspiration (ET) holds a crucial role in water resource management and agricultural planning. ET is pivotal in the hydrological cycle, representing the energy required to transport soil moisture to the atmosphere as water vapour. Given the ever-changing patterns of precipitation and temperature, it is imperative to obtain accurate and timely ET estimates for effective irrigation and farming practices. Remote sensing-based ET products, like MOD16A2, have gained prominence for their ability to provide spatially explicit and continuous estimates, offering insights into precision agriculture and efficient resource allocation while minimising the need for on-site data collection. While MOD16A2 is globally used, the majority of calibration and validation data originates from North American sites. Notably, the accuracy of MOD16A2 ET estimates in Brazilian agricultural regions, particularly Mato Grosso, remains largely unexplored. This research assesses MOD16A2 against the United Nations Food and Agricultural Organisations (FAO) Penman-Monteith (PM) method, a standard ET model, using ground-based weather data from the Instituto Nacional de Meteorologia (INMET) Brazil. This study aims to evaluate MOD16A2's accuracy in capturing ET variations in Brazil, providing insights into its applicability in this context.

1. INTRODUCTION

Water scarcity and its implications for agriculture, ecosystems and overall regional hydrology have become increasingly pressing challenges in the face of global climate change. Accurate assessment of evapotranspiration (ET), a critical component of the terrestrial water balance, is pivotal for understanding and managing water resources since it describes the mechanism and energy needed to transport the liquid water stored in the soil-watershed-canopy system to the atmosphere, converted into water vapour. Mato Grosso, Brazil, renowned for its significant agricultural activities, presents a unique environment where ET plays a crucial role in water resource management. Spatial and temporal changes in precipitation and temperature patterns will have an impact on the viability of the farm land and therefore necessitate irrigation to ensure that the supply of water is sufficient. Accurate ET estimates are crucial as it provides direct insight into crop water use and assists management practices such as scheduling of field-scale irrigation and tillage.

The MOD16A2 Evapotranspiration product, developed by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), has gained recognition as a valuable tool for quantifying ET at a global scale. However, its applicability and accuracy in specific regional contexts, such as Mato Grosso, Brazil, remain an area of inquiry and assessment. This paper endeavours to address this knowledge gap by evaluating MOD16A2 ET product over the agriculture areas in the Mato Grosso region. A comparative analysis with ET estimates derived from the United Nations Food and Agricultural Organisation (FAO) Penman-Monteith (PM) method was conducted.

Through this comparative analysis, we aim to elucidate the strengths and limitations of the MOD16A2 ET product. This deeper understanding into the temporal and spatial variability of ET in Mato Grosso can shed light on the intricate dynamics that govern water availability in that region. This knowledge holds the potential to guide stakeholders in crafting more effective strategies for addressing the region's water challenges, optimising agricultural practices, and ultimately, contributing to the sustainable management of water resources in Mato Grosso.

2. LITERATURE REVIEW

Currently, various methods have been developed to quantify ET. This includes lysimeters, energy balance methods (e.g. eddy covariance technique), weather-based methods (e.g. FAO Penman-Monteith method) and satellite-based thermal methods (e.g. MOD16A2 ET product) (Kalma et al., 2008). Lysimeters, while accurate for measuring localised ET at a small scale, is often costly and their data require adequate treatment and instrumental problems may happen (Allen et al., 2011). Additionally, lysimeters can be intrusive where it disrupts the soil and vegetation in the immediate vicinity. On the other hand, the FAO Penman Monteith method is not only a non-intrusive approach, it also provides a continuous temporal record of ET, capturing seasonal and inter-annual variations. Lysimeters often yield point measurements and are limited in their temporal coverage. In this study, the ET estimated from the FAO Penman-Monteith method will be used as the ground data to compare the MOD16A2 ET product.

3. STUDY AREA AND METEOROLOGICAL DATA

The state of Mato Grosso is located in the central-western region of Brazil between the coordinates of 06°00′ S, 19°45′ S and 50°06′ W, 62°45′ W. This study used the following climatic variables from 2022: solar radiation (MJ m^{-2} day^{-1}), relative humidity (%), maximum air temperature (°C), minimum air temperature (°C) and mean wind speed at 2m (m s^{-1}). Data from 4 automatic weather stations were obtained from the Instituto Nacional de Meterologia (INMET) that is distributed throughout Mato Grosso, Brazil as seen in Figure. 1. Climatic variables were downloaded from the INMET website (https://bdmep.inmet.gov.br/). These 4 automatic weather stations were chosen because they are located within agricultural fields in Mato Grosso. Complete meteorological data was available from March to December 2022 for Stations A923, A931 and A933. Meteorological data was only available from July to December 2022 for Station A943.

Station	Latitude	Longitude
A908	-14.0164	-52.2117
A923	-15.8	-54.3811
A931	-14.9278	-53.8836
A933	-17.15	-54.5017

Figure. 1 Location of INMET Meteorological Stations in Mato Grosso

4. METHODOLOGY

4.1 FAO Penman-Monteith Method

The Penman-Monteith method (Penman & Keen, 1948) is a widely used standard method for modelling evapotranspiration used by the United Nations Food and Agriculture Organisation (FAO). It approximates net evapotranspiration from meteorological data, as a replacement for direct measurement of evapotranspiration.

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2\,(e_S - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \qquad (1)$$

where ET_o is the reference evapotranspiration (mm day^{-1}), Rn is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2m height (°C), u_2 is the wind speed at 2m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), e_s-e_a is the saturation vapour pressure deficit (kPa), Δ represents the slope vapour pressure curve (kPa °C^{-1}) and γ is the psychrometric constant (kPa °C^{-1}).

As illustrated in the methodological flowchart in Figure. 2, climatic variables at the selected INMET meteorological stations were used as inputs in the FAO Penman-Monteith equation to estimate evapotranspiration. As the temporal resolution was daily, the sum of every 8 days of evapotranspiration was calculated to produce $ET_{(PM\_FAO\_56)}$.

4.2 MOD16A2 Data Acquisition

The Terra Moderate Resolution Imaging Spectroradiometer (MODIS) MOD16A2 Version 6.1 Evapotranspiration product is an 8-day composite dataset. It provides a spatial resolution of 500m. The MOD16 ET Algorithm is the basis of the MOD16A2 operational product. In this algorithm, terrestrial ET is calculated using a modified Penman-Monteith equation which uses MODIS land cover, albedo, Leaf Area Index (LAI), and Enhanced Vegetation Index (EVI) and daily meteorological data from NASA's Global Modeling and Assimilation Office (GMAO) reanalysis datasets as inputs for regional and global ET mapping and monitoring (Mu et al., 2011).

The MOD16A2 ET product was obtained from Google Earth Engine. The pixels from MOD16A2 ET that coincided with each meteorological station location were used to conduct the comparison. The MOD16A2 ET product includes a quality assurance (QA) band which is designed to help users understand the data. Data with high QA is used in this study. The methodological flowchart is shown in Figure. 2.

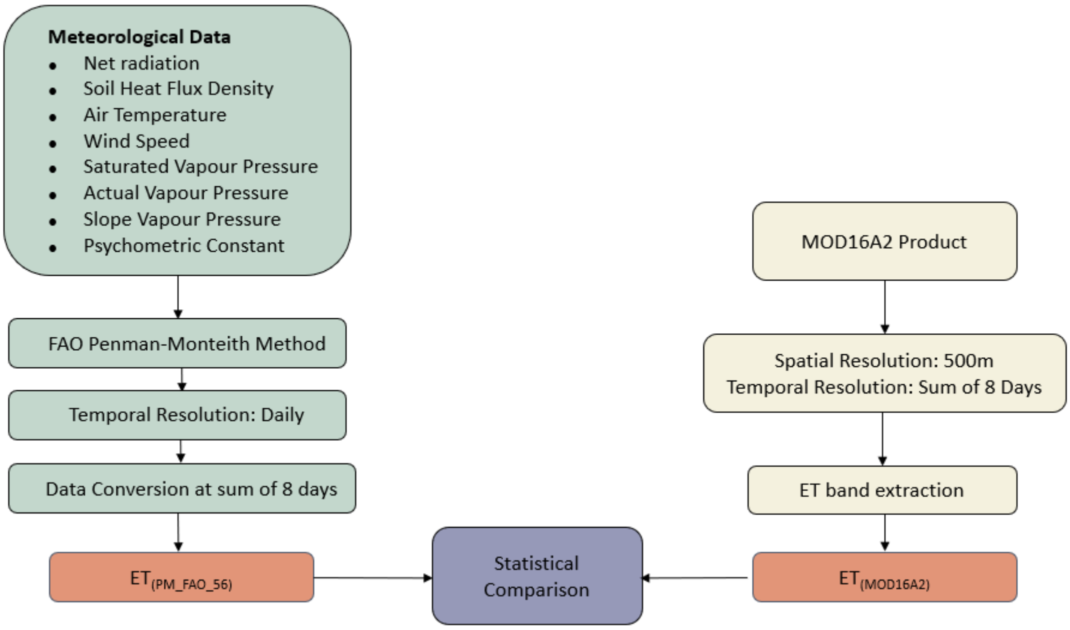

Figure. 2 Methodology Flowchart

5. RESULTS AND DISCUSSION

In general, estimates of ET from MOD16A2 showed some similarities when compared to the ET estimates generated from the FAO Penman-Monteith method across all 4 meteorological stations. The average r value is 0.768 which shows a strong correlation between the remotely-sensed ET data from MOD16A2 and the ET estimates from FAO Penman-Monteith method. There was a strong correlation at Stations A923, A933 and A943 with a r value more than 0.8. ET measured at Station A931, on the other hand, had a moderate correlation ($r = 0.47$). As illustrated in Figure. 3 and Table 1, the performance of ET (MOD16A2) over individual stations also showed some variability. In particular, Station A943 has a larger RMSE value of 31.94mm/ 8days. A study conducted over 8 sites (3 in Amazon, 3 in Cerrado, and 2 in Pantanal) across different biomes in Mato Grosso showed that the RMSE value ranges from 6.6mm/ 8days to 14.6mm/ 8 days (Biudes et al., 2022). Another study conducted in the Pampas region in Argentina observed a systematic overestimation of around 60%, with a RMSE of 27.4mm/ 8days. They reduce the systematic error by applying a linear adjustment equation. The statistical parameters improved considerably after calibration, resulting a RMSE of 4.6mm/8 days (Degano et al., 2021).

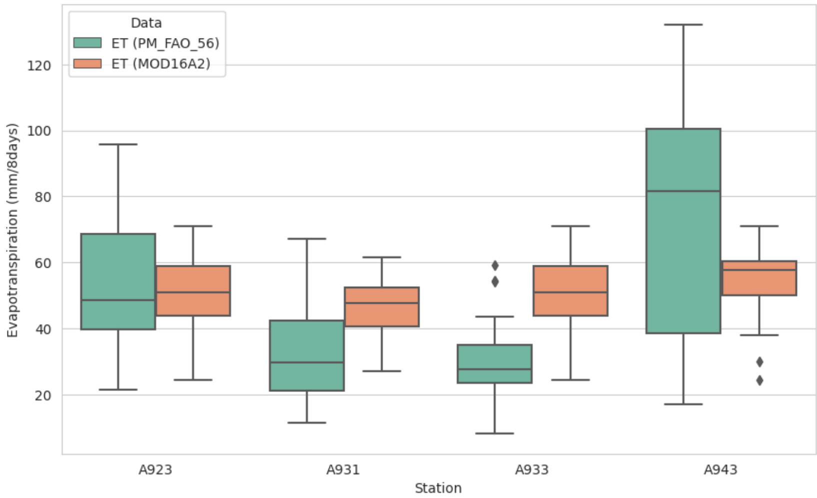

Figure. 3 Distribution of $ET_{(MOD16A2)}$ and $ET_{(PM\_FAO\_56)}$ across stations

Table 1 Statistical performance of the MOD16A2 ET product compared with ET derived from the FAO Penman Monteith Method

Station	Correlation (r)	RMSE
A923	0.87	11.77
A931	0.47	18.31
A933	0.84	21.98
A943	0.89	31.94
Average	0.768	21

RMSE: Root Mean Squared Error (mm/8days)

ET estimates from the FAO Penman Monteith Method highlight greater temporal patterns as compared to ET estimates from the MOD16A2 ET product. The performance of the MOD16A2 ET product showed little variation over the year as seen in Figure. 4. Despite being located in agricultural fields, the amplitude in ET across all 4 stations did not change much over the year. A study conducted in Caatinga which is located in the state of Pernambuco, Brazil suggests that MOD16A2 tended to overestimate ET due to the meteorological input data used in the MOD16A2 algorithm as it is derived from a 1.00°× 1.25° grid while the meteorological input data for the FAO Penman-Monteith method was acquired from automatic meteorological station on site (Miranda et al., 2017).

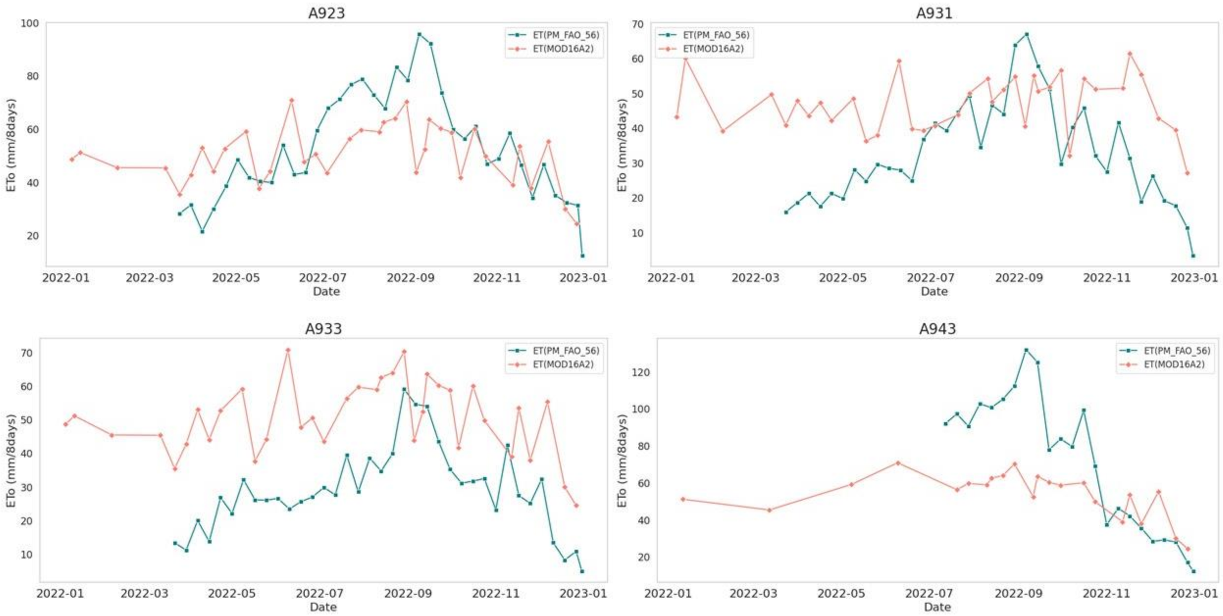

Figure. 4 Comparison between Evapotranspiration from Penman Monteith Method ($ET_{(PM\_FAO\_56)}$) and MOD16A2 ($ET_{(MOD16A2)}$)

6. CONCLUSION

In this study, we compared remotely sensed ET from MOD16A2 with ground-based ET derived from the FAO Penman-Monteith method over agricultural areas in Mato Grosso, Brazil. There is a strong correlation between ET estimates from MOD16A2 and the ET derived from the FAO Penman-Monteith method. However, it should be noted that the large RMSE value underscores the importance of further refining, seeking additional data sources, or exploring alternative operational ready ET products to ensure the accuracy of the ET estimations.

It is evident that it is necessary to evaluate the ET estimations before its applications. We suggest evaluating other remote sensing operational ready ET products such as Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) as well as the Landsat Collection 2 Provisional Actual Evapotranspiration Science Product.

7. ACKNOWLEDGEMENT

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