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Gap-filling terrestrial water storage in severe Amazon droughts

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Abstract: The Amazon has the largest tropical rainforest on earth. It spans over 6.8 million km^2 in the South America and serves as a vital habitat for diverse flora and fauna. The Amazon plays a crucial role in global carbon and water cycle, ecosystem functioning and climate regulation. However, the Amazon has experienced four major large-scale droughts in the past two decades – occurring in 2005, 2010, 2015 and 2023 – which have significantly impacted its ecological integrity. These extreme droughts have led to reduced tree photosynthesis, slower growth rate, diminished canopy greenness, and increased tree mortality. Beyond ecological consequences, the droughts have also posed serious social challenges, affecting public health, traditional livelihoods and regional stability.

During these drought events, the Amazon exhibited notably low terrestrial water storage (TWS), a key indicator of regional water availability. TWS data derived from GRACE/GRACE-FO satellite missions are widely used to monitor hydrological changes. However, these datasets contain temporal gaps, particularly during critical dry-season periods. Accurate gap-filling of GRACE/GRACE-FO TWS data is therefore essential for capturing below-normal water storage during severe droughts and for improving our understanding of drought dynamics in the Amazon.

In this study, we propose a new approach for gap-filling terrestrial water storage (TWS) during droughts, i.e., missing values way below the normal TWS range. This approach is based on exploring the relationship between changes in TWS and hydro-meteorological variables using various machine learning methods. We examine several key hydro-meteorological variables, individually and combinations of some/all of them. The machine learning models applied include multivariate linear regression, gradient boosting, support vector regression, multi-layer perception and temporal convolutional networks.

We compare the proposed approach with the traditional TWS gap-filling approach. For both approaches, models are trained using data from non-drought months and tested on four major drought events, during which TWS values are substantially lower than the range of training data. Our results show that our proposed approach outperforms the traditional method. A more detailed analysis of the most recent drought reveals strong spatial agreement between our estimated TWS and the observed TWS from the start to the end of the drought. This study demonstrates that the proposed approach is not only effective in filling gaps in low water storage during droughts, but also holds promise for predicting terrestrial water storage (TWS) months in advance—provided accurate weather forecasts are available. Moreover, the approach can be generalized to other tropical regions around the world.

Keywords: *Droughts, GRACE/GRACE-FO Terrestrial water storage, Amazon*