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Time-variable vegetation biases in the SMAP soil moisture product and their impact on diagnosing soil moisture-vegetation coupling

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Remotely sensed soil moisture products provide unique opportunities for estimating vegetation-hydrolgy interactions, but vegetation-induced time-dependent biases in the soil moisture observations can distort these estimates. However, the nature and prevalence of such biases remain poorly understood, largely because we lack adequate tools for estimating them. To this end, we introduce Bayesian triple collocation to estimate residual vegetation-induced biases in soil moisture products. It looks for systematic vegetation-related differences between soil moisture records (remotely sensed, but also in-situ and modelled).

The SMAP soil moisture product is considered to be the most accurate global product. However, it may contain residual vegetation biases because the vegetation correction during the retrieval relies on indirect and often inaccurate vegetation information. More precisely, the vegetation optical depth (VOD) is estimated from a climatology of optical NDVI data. This may be particularly problematic over croplands, due to their complex phenology and pronounced inter-annual variability. To quantify vegetation biases in the SMAP product, we apply the Bayesian triple collocation technique, hypothesizing that the errors in the vegetation correction have a noticeable impact on the final SMAP product: both the additive bias and the sensitivity (multiplicative bias) are expected to track the VOD misspecification during the retrieval. This error structure allows us to estimate the associated bias parameters from data; we do so with respect to in-situ data (network sites and sparse in-situ sites). The procedure is applied at > 100 network and sparse in-situ sites, using the VOD from SMOS or the SMAP dual channel algorithm as reference VOD.

We find that time-dependent vegetation-associated biases in the SMAP product are widespread over croplands. This is particularly the case for the sensitivity (multiplicative bias), as seasonal changes in the sensitivity of up to 30% are widespread. This poses problems for the detection of extreme events, as droughts may not be apparent if the sensitivity happens to be small at the time.

Do these biases reduce our ability to diagnose the coupling between vegetation and soil moisture? To explore this, we compare the association R^2 between the SMOS VOD and soil moisture (anomalies), contrasting the in-situ with SMAP soil moisture. If the SMAP data were only impacted by quasi-random noise, R^2 should decrease. However, R^2 tends to increase consistently by more than 10% over croplands. The instantaneous coupling between soil moisture and VOD is hence apparently misdiagnosed, even though the shortness of the time series should be borne in mind.

In summary, our work suggests that time-dependent biases in soil moisture products could be widespread, as standard validation practices (RMSE) cannot detect them. Because they can distort estimates of vegetation-hydrology interactions and impede the detection of extreme events, they should be accounted for in observational and modelling studies.