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Satellite observations underestimate the impact of drought on terrestrial primary productivity

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Drought impacts on vegetation productivity and the terrestrial carbon cycle are commonly assessed using remotely sensed greenness, combined with light use efficiency models for simulating vegetation gross primary productivity (GPP). These methods combine information on incoming radiation, temperature, and vapour pressure deficit (VPD). However, current approaches do not include information on soil moisture and instead rely on VPD as a dryness proxy. Here, we quantify the partial impact of soil moisture on ecosystem productivity across a range of ecosystems, independent of the influence of VPD or any underlying modelling assumption. To do so, we combine an ensemble of artificial neural networks with eddy-covariance data, multiple soil moisture datasets and remotely sensed vegetation indices. This reveals drought impacts that reduce annual GPP by up to 40% more than estimated by standard remote sensing approaches. These drought impacts are additional to VPD effects, are not captured when solely relying on greenness changes and, when seasonally recurring, are missed by traditional, anomaly-based drought indices (e.g. Palmer Drought Severity Index, Standardised Precipitation-Evaporation Index).

We show that the most commonly used remote-sensing based vegetation productivity models have a systematic drought-related bias. To resolve this, we derive an empirical soil moisture stress function. Including its effects reduces global GPP by ∼15%, increases the variability in local annual GPP by up to factor 4 in semi-arid regions, and implies a substantially higher probability of large negative GPP extreme events.