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Global observation-based diagnosis of soil moisture control on land surface flux partition

Belen Gallego-Elvira (1), Christopher M. Taylor (1,2), Phil P. Harris (1,2), Darren Ghent (2,3), Karen L. Veal (2,3), and Sonja S. Folwell (1)

(1) Centre for Ecology and Hydrology, Crowmarsh Gifford, Wallingford, United Kingdom (belgal@nerc.ac.uk), (2) National Centre for Earth Observation, UK, (3) Department of Geography, University of Leicester, Leicester, UK

Soil moisture plays a central role in the partition of available energy at the land surface between sensible and latent heat flux to the atmosphere. As soils dry out, evapotranspiration becomes water-limited ("stressed"), and both land surface temperature (LST) and sensible heat flux rise as a result. This change in surface behaviour during dry spells directly affects critical processes in both the land and the atmosphere. Soil water deficits are often a precursor in heat waves, and they control where feedbacks on precipitation become significant. State-of-the-art global climate model (GCM) simulations for the Coupled Model Intercomparison Project Phase 5 (CMIP5) disagree on where and how strongly the surface energy budget is limited by soil moisture. Evaluation of GCM simulations at global scale is still a major challenge owing to the scarcity and uncertainty of observational datasets of land surface fluxes and soil moisture at the appropriate scale.

Earth observation offers the potential to test how well GCM land schemes simulate hydrological controls on surface fluxes. In particular, satellite observations of LST provide indirect information about the surface energy partition at 1km resolution globally. Here, we present a potentially powerful methodology to evaluate soil moisture stress on surface fluxes within GCMs. Our diagnostic, Relative Warming Rate (RWR), is a measure of how rapidly the land warms relative to the overlying atmosphere during dry spells lasting at least 10 days. Under clear skies, this is a proxy for the change in sensible heat flux as soil dries out. We derived RWR from MODIS Terra and Aqua LST observations, meteorological re-analyses and satellite rainfall datasets.

Globally we found that on average, the land warmed up during dry spells for 97% of the observed surface between 60S and 60N. For 73% of the area, the land warmed faster than the atmosphere (positive RWR), indicating water stressed conditions and increases in sensible heat flux. Higher RWRs were observed for shorter vegetation and bare soil compared to tall, deep-rooted vegetation due to differences in both aerodynamic and hydrological properties. The variation of RWR with antecedent rainfall provides information on which evaporation regime a particular region lies in climatologically. Different drying stages for a given antecedent rainfall can thus be observed depending on land cover type. For instance, our results suggest that forests in a continental climate remain unstressed during a 10 day dry spell provided the previous month saw at least 95 mm of rain. Conversely, RWR values indicate that under similar conditions regions of grass/crop cover are water-stressed.