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Physical mechanisms of tropical climate feedbacks revealed by regional temperature and moisture trends

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Climate models generally maintain close-to-constant tropospheric relative humidity in a warming climate. As a result, models with more negative lapse rate feedbacks tend to have more positive water vapour feedbacks. Despite this intermodel relationship, the regional structures of the tropical lapse rate and water vapour feedbacks are very different. What determines the regional structure of these feedbacks?

Here we compare the modelled behaviour of tropical climate feedback processes with satellite observations over the period 1979-2010. We combine surface temperature data with upper-tropospheric temperature data from the Microwave Sounding Unit / Advanced Microwave Sounding Unit (MSU/AMSU) instruments as a metric of lapse rate feedback. We use data from the High-Resolution Infrared Sounder (HIRS) Channel 12 ($\sim$6.3 microns) to measure changes in upper-tropospheric relative humidity, a strong driver of the water vapour feedback. There is considerable uncertainty in the tropical-mean trend in upper-tropospheric relative humidity as derived from HIRS, since trends are small and variability is large. This makes it difficult to discern tropical-mean relative humidity trends. However, by investigating the regional structure of these trends we discover consistent signatures of processes driving lapse rate and water vapour feedbacks across climate models and observational datasets.

Upper-tropospheric warming trends are relatively constant over the Tropics because the tropical atmosphere is unable to maintain strong temperature gradients. The regional structures of upper-tropospheric warming are similar between models and observations. Therefore, the majority of the regional variation in tropical lapse rate feedback actually comes from regional variation in surface temperature changes, not tropospheric temperature changes.

The magnitude of upper-tropospheric moistening generally increases with surface warming as expected from simple moisture availability arguments, except in parts of the world with the very greatest surface warming over the period 1979-2010. We interpret this as a signature of strong warming over arid desert regions where moisture supply is limited. Upper-tropospheric moistening is also sensitive to precipitation trends. There is some disagreement among models and with observations over the sensitivity of upper-tropospheric humidity to regional changes in precipitation. These relationships could provide process-based metrics of climate models' ability to simulate the physical processes driving tropical water vapour and lapse rate feedbacks.