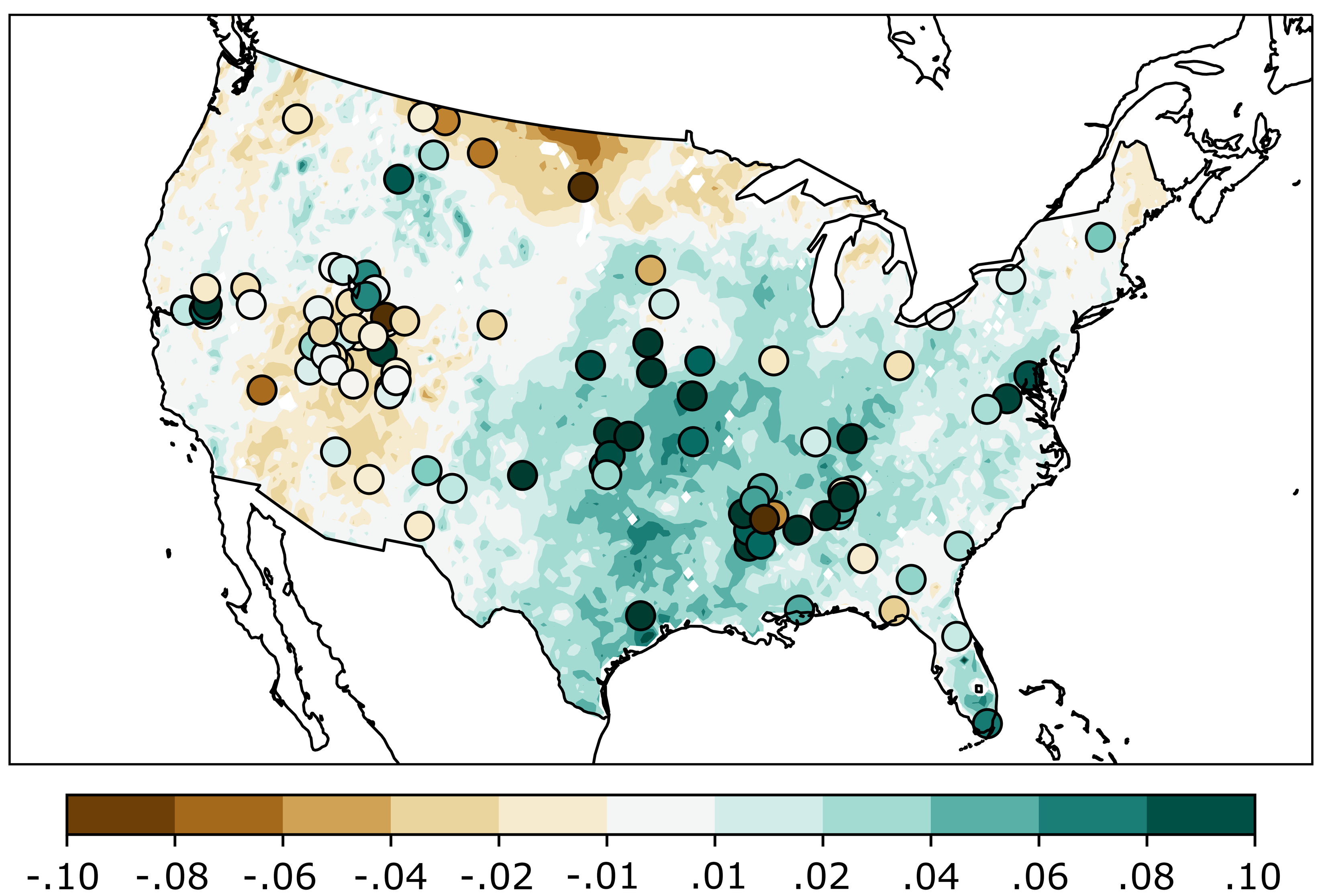
Past and Future Soil Moisture Trends are Controlled by Precipitation

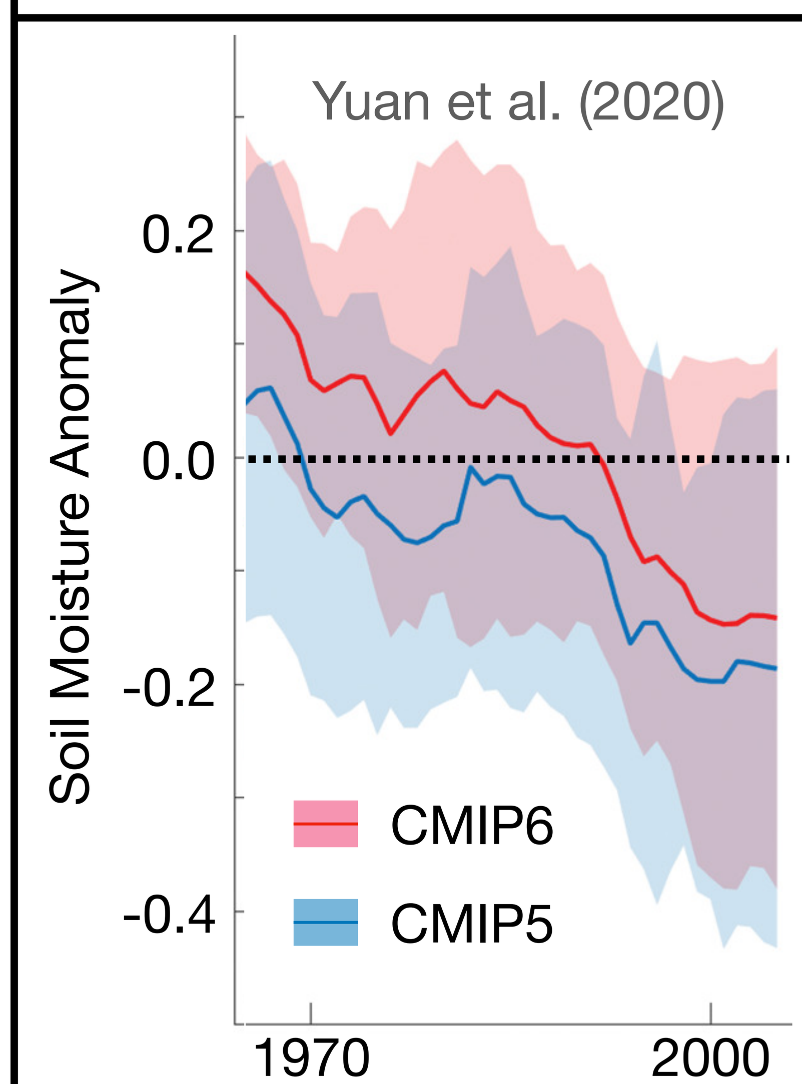
Lucas R. Vargas Zeppetello[1], Aleyda Trevino[2], Peter Huybers[3]

[1]U.C. Berkeley
[2]San Francisco State University
[3]Harvard University

We found that soil moisture observations from the International Soil Moisture Network and the European Space Agency agree on the magnitude and spatial pattern of the decadal trend over the Continental U.S. from 2011-2020 (see below; $r = 0.45$, $p < 0.05$). A simple two-layer model of the coupled surface energy and moisture budgets also reproduces the spatial pattern of the trends when forced by observed solar radiation and precipitation time series (top center). When the model is forced only by precipitation, the fidelity to observed trends over the U.S. and Europe remains (bottom center). Internal precipitation variability is responsible for these observed trends.



CCI and ISMN Surface Soil Moisture Trends [m³/m³/decade]

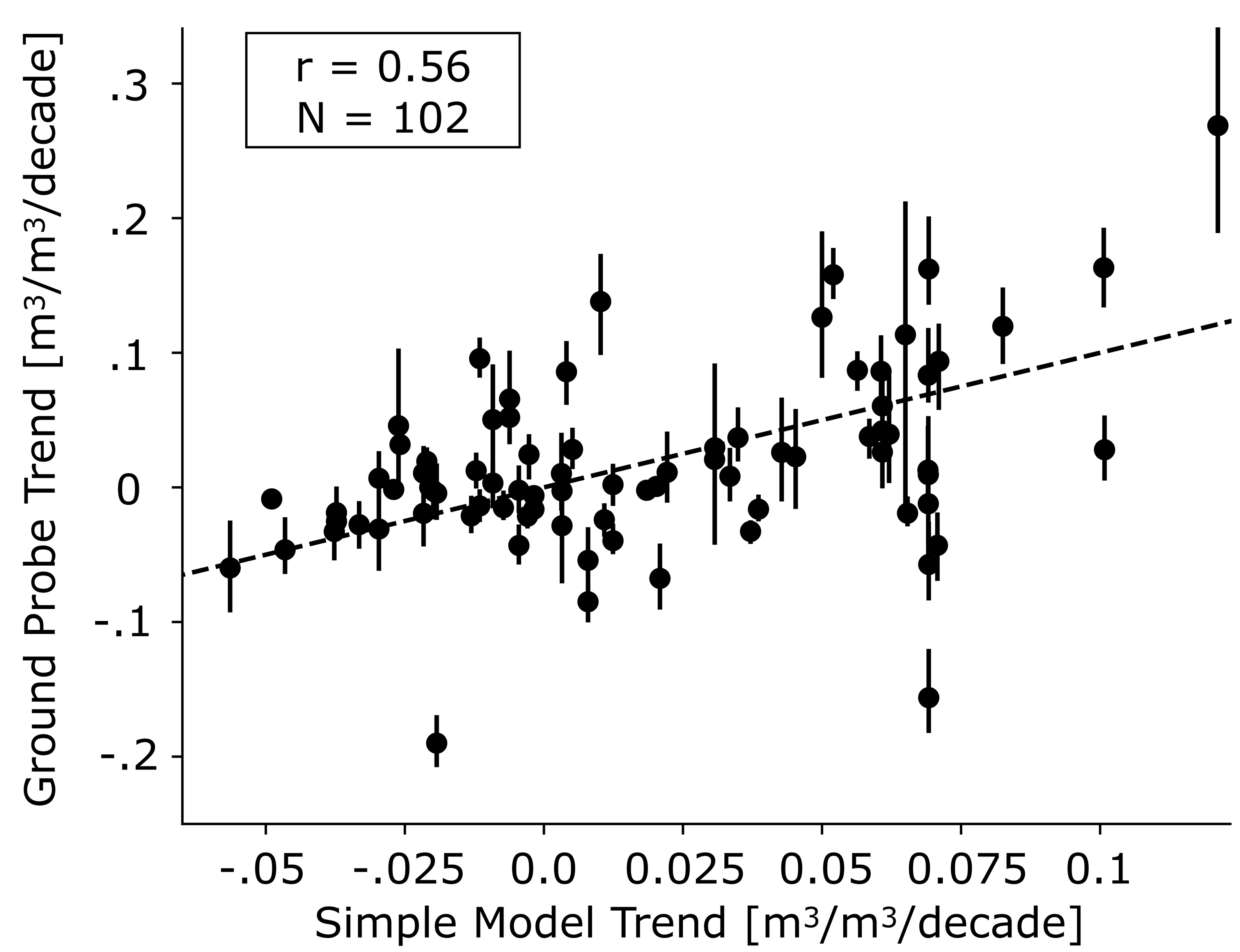


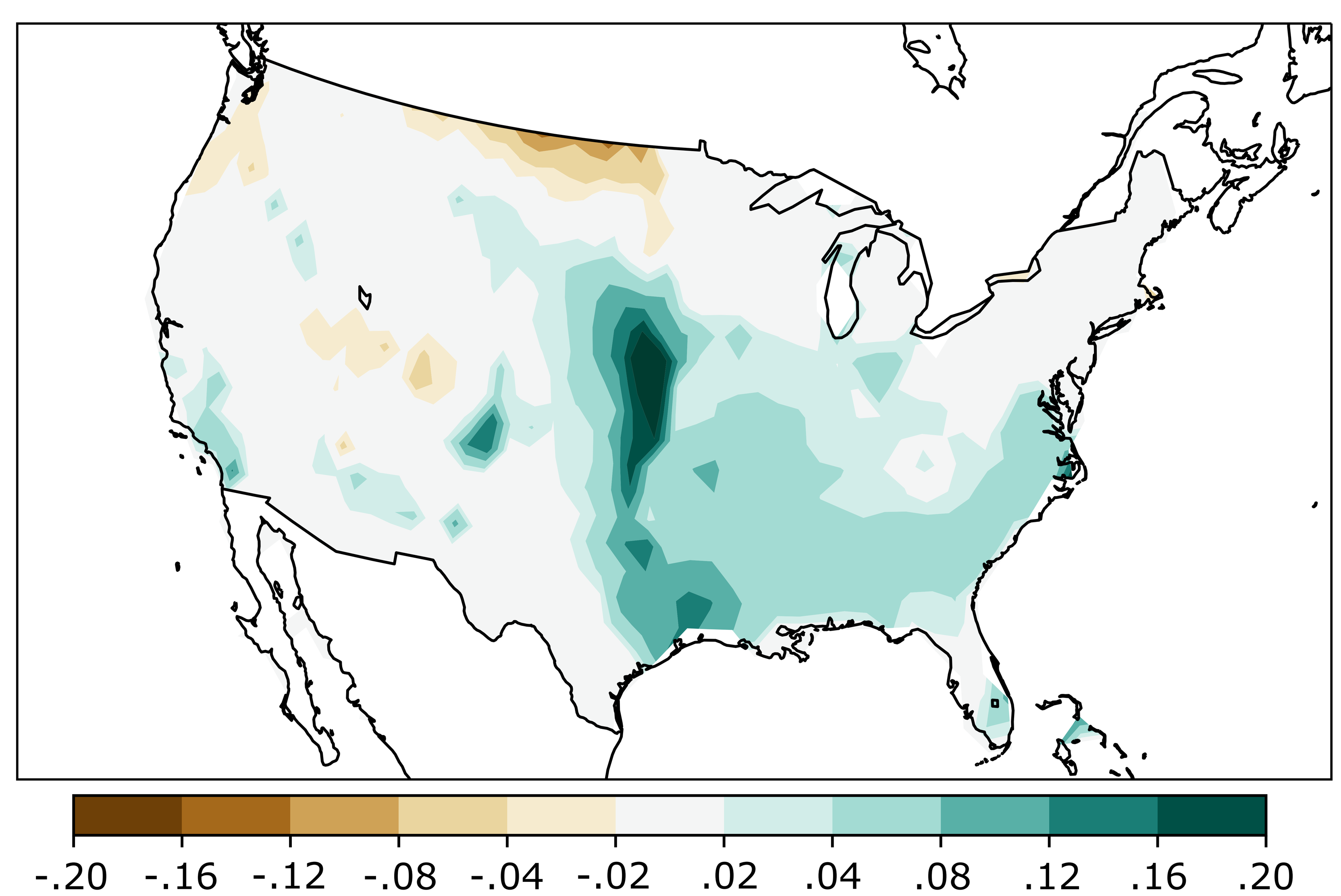
In both CMIP5 and CMIP6 models, the dominant trend across the continental U.S. is a drying of the soil surface.

This is a feature of both model generations that has no observational basis.

By understanding the processes responsible for observed trends, we hope to better constrain our projections of future surface soil moisture.

Below: Simple model trends (2011-2020) compared to co-located points where ground probes are available.





Simple Model Surface Soil Moisture Trends [m³/m³/decade]

Above: Decadal trends predicted by the simple model when forced by observed precipitation and the climatological seasonal cycle in all other forcing variables. The spatial pattern of the observed trends is reproduced; the same is true for Europe, where only satellite observations are available as a benchmark for model performance.

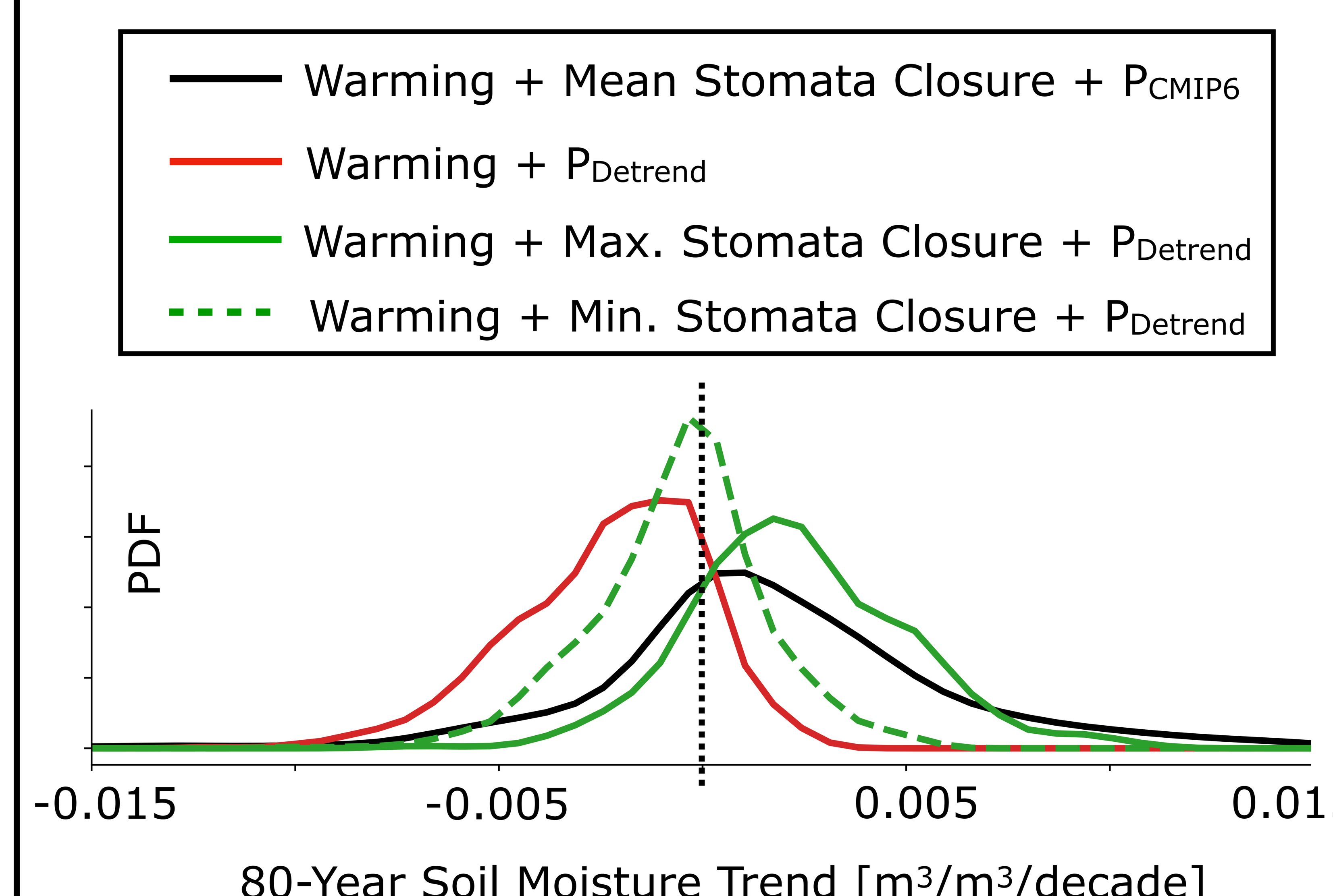
The two processes that have been put forward as likely contributors to surface soil moisture trends in climate change simulations are:

(i) Global warming's influence on global aridity, and
(ii) Changes in evaporative resistance driven by stomatal closure in response to rising CO_2.

Using the simple model, we can compare these changes to one another, given the uncertainty in climate model representations of stomatal closure in response to rising CO2 emissions (Yang et al. 2019).

Below, we show results from four experiments designed to test the relative influence of these two processes to internal variability in precipitation and potential long-term trends.

When precipitation variability is incorporated in the projections along with some representation of stomatal closure, trends in soil moisture that are distinguishable from zero are unlikely to manifest, even on 80-year timescales.



Vargas Zeppetello et al. (2024) "Disentangling contributions to past and future trends in US surface soil moisture" *Nature Water.*

Yang et al. (2019) "Hydrologic implications of vegetation response to elevated CO2 in climate projections" *Nature Climate Change.*

Yuan et al. (2020) "Historical Changes in Surface Soil Moisture over the Contiguous United States: An Assessment of CMIP6" *GRL.*