An observational radiative constraint on hydrologic cycle intensification

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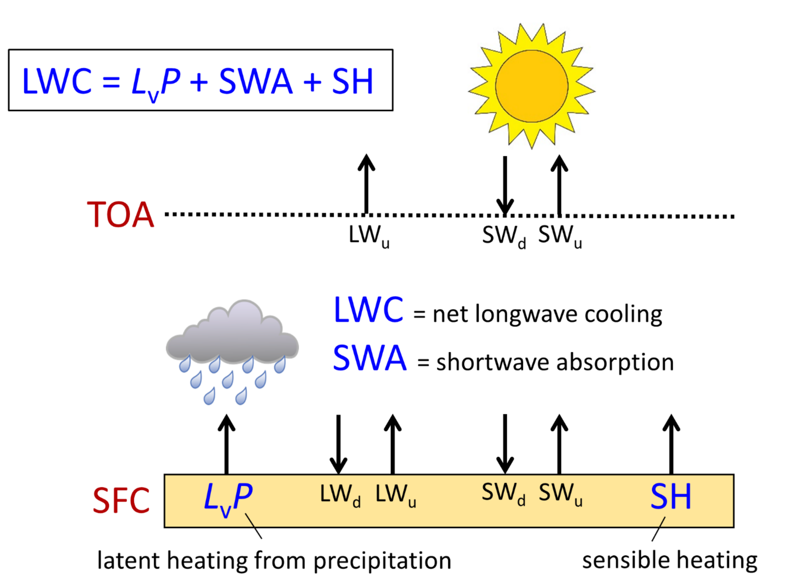
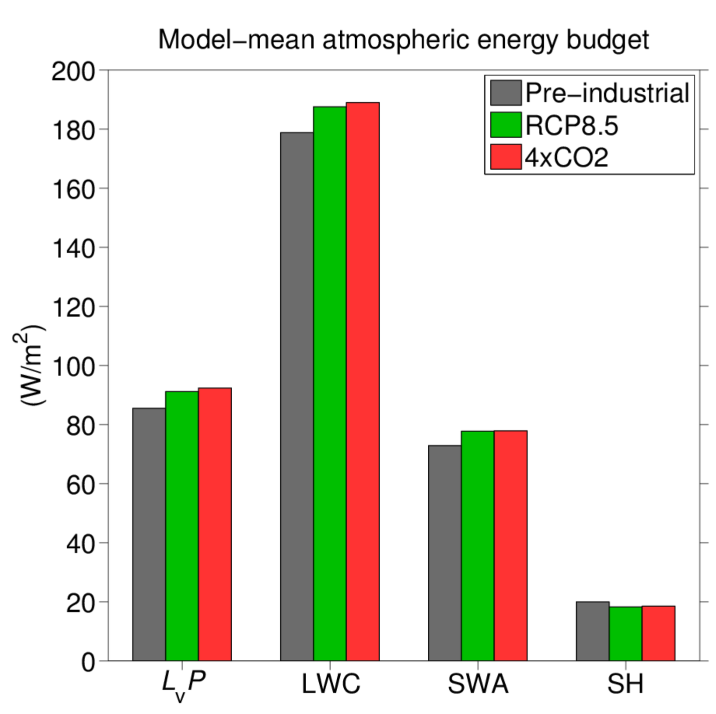
Summary

Intensification of the hydrologic cycle is a key dimension of climate change, with substantial impacts on human and natural systems. A basic measure of hydrologic cycle intensification is the increase in global-mean precipitation per unit surface warming, which varies by a factor of three in current-generation climate models (about 1–3 %/K). Part of the uncertainty may originate from atmosphere–radiation interactions. As the climate warms, increases in shortwave absorption from atmospheric moistening will suppress the precipitation increase. This occurs through a reduction of the latent heating increase required to maintain a balanced atmospheric energy budget. Using an ensemble of climate models participating in CMIP5, we show that such models tend to underestimate the sensitivity of solar absorption to variations in atmospheric water vapor, leading to an underestimation in the shortwave absorption increase and an overestimation in the precipitation increase. This sensitivity also varies considerably among models due to differences in radiative transfer parameterizations, explaining a substantial portion of model spread in the precipitation response. Consequently, attaining accurate shortwave absorption responses through improvements to the radiative transfer schemes could reduce the estimated ensemble-mean increase in global precipitation per degree warming for the end of the twenty-first century by about 20%, and would reduce the spread in this quantity as well.

1. Background



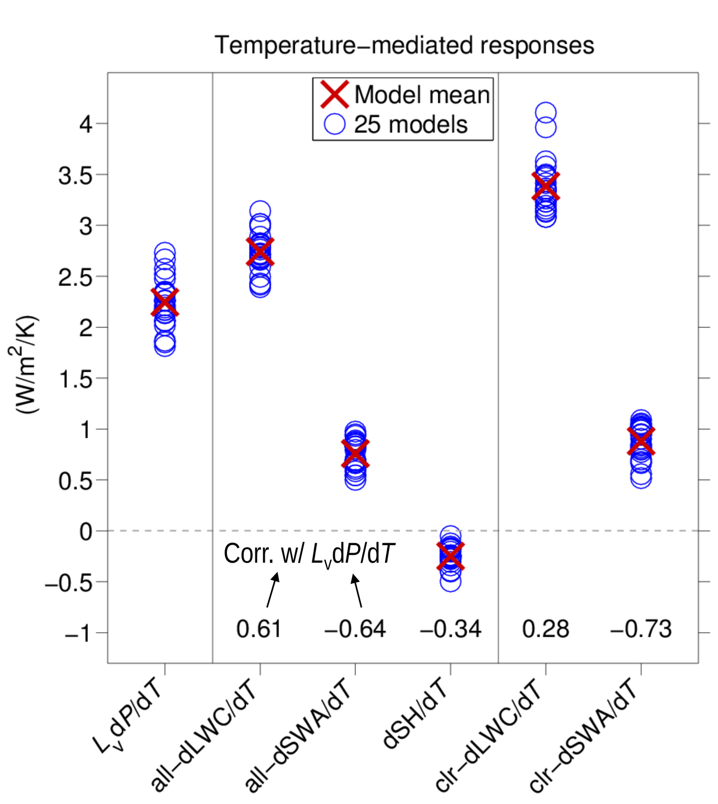
The atmospheric energy budget. The four main terms considered in the budget are displayed in blue text.

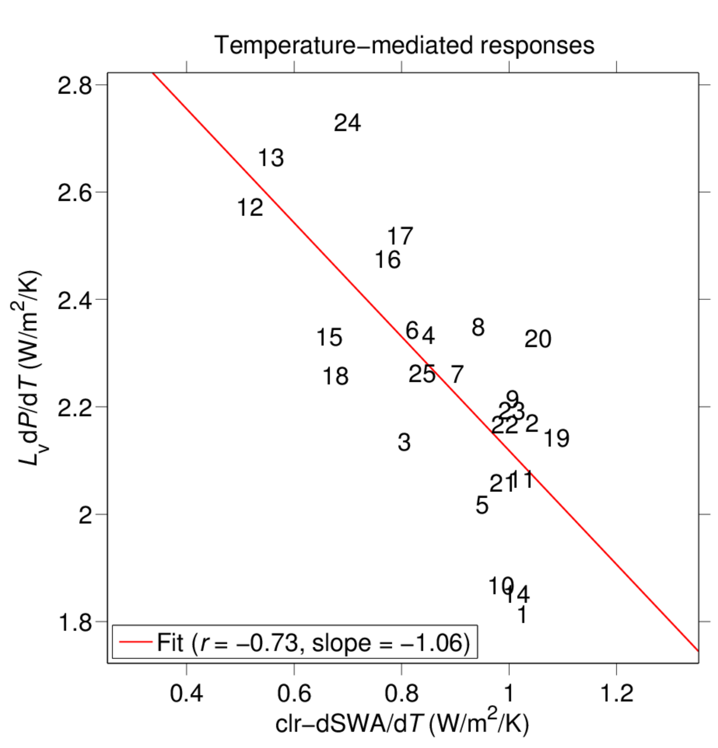


- **Spread in global-mean precipitation change is linked to model differences in the response of the atmospheric energy budget components under climate change.**

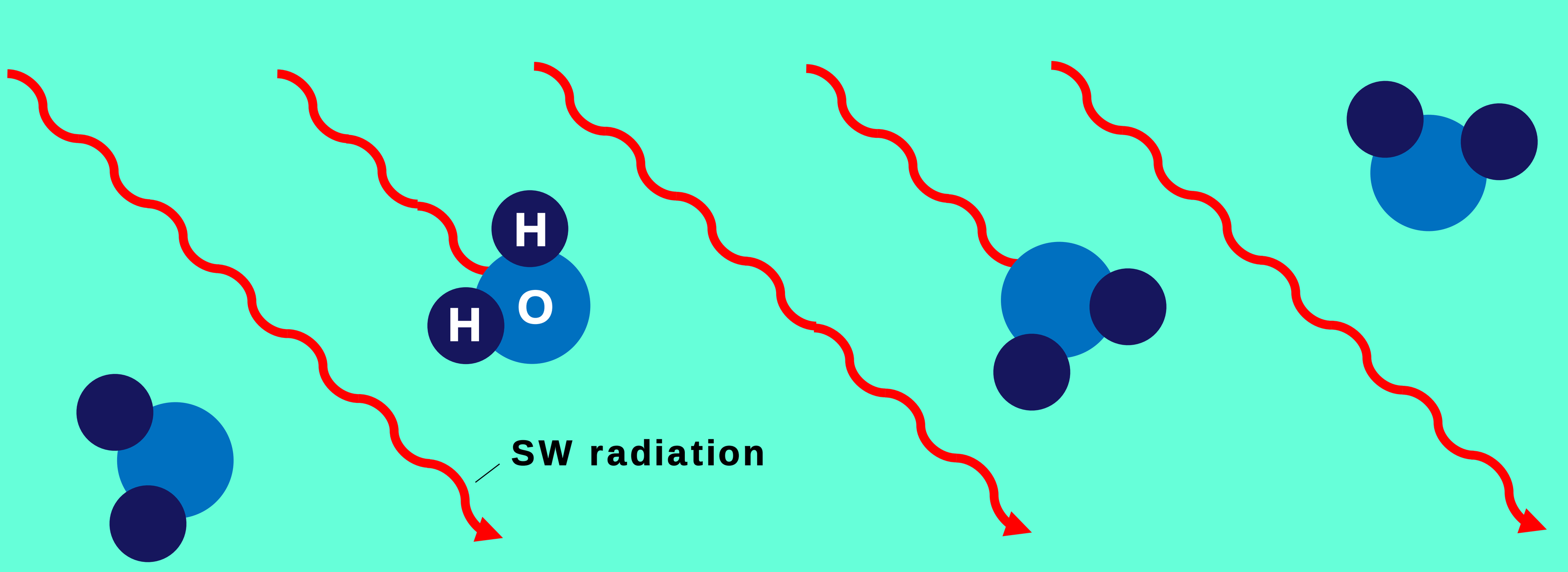
2. Understanding model spread in the temperature-mediated L_vP response ($L_v dP/dT$)

The Gregory method is applied to separate temperature-mediated responses and rapid adjustments under 4xCO$_2$

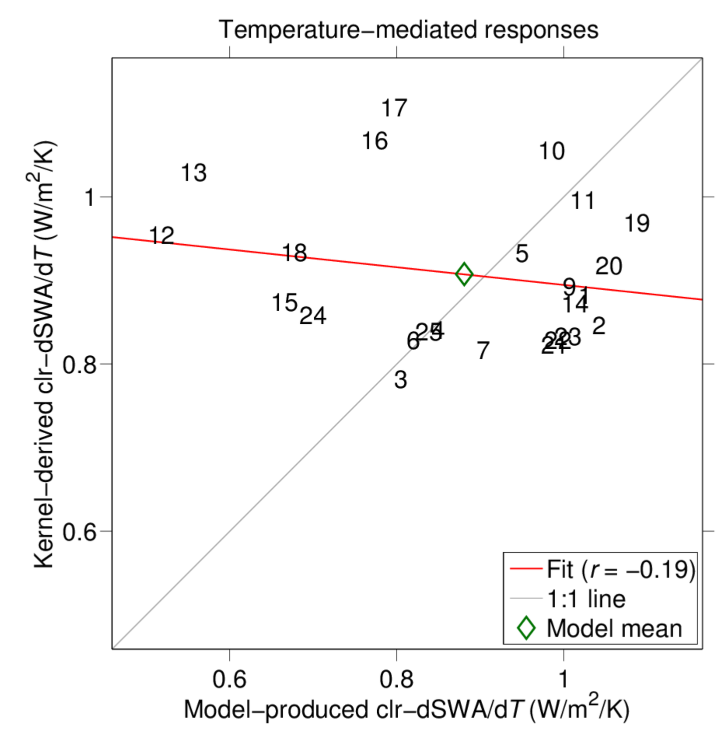




- **Spread is strongly related to model differences in the clear-sky temperature-mediated SWA response.**

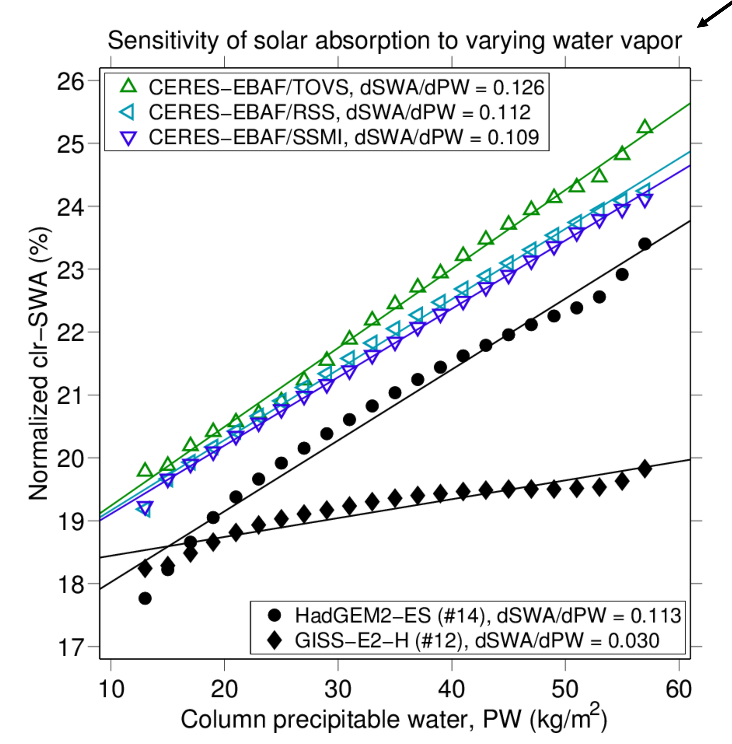


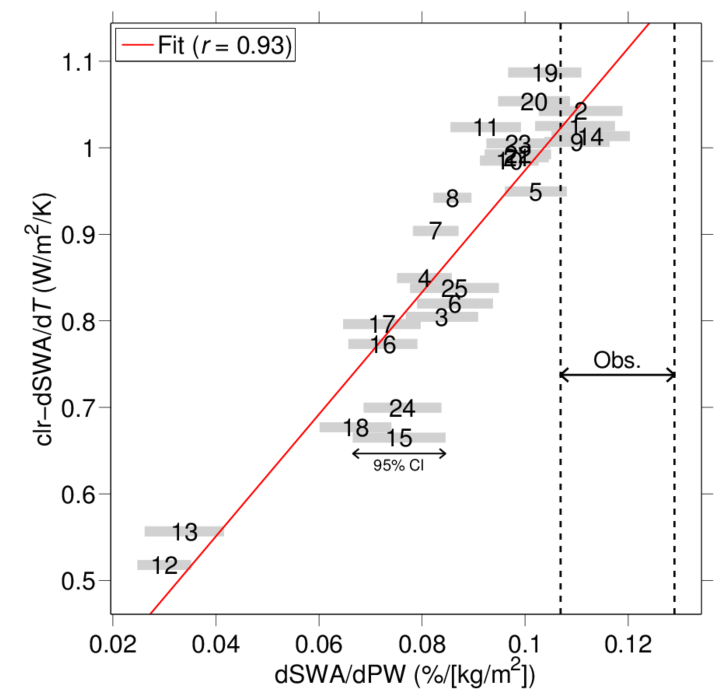
3. What causes model spread in the temperature-mediated SWA response?



- **Radiative-kernel-derived responses do not replicate the spread in model-produced responses.**
- **Thus, differences in the water vapor response per unit warming do not explain the spread.**

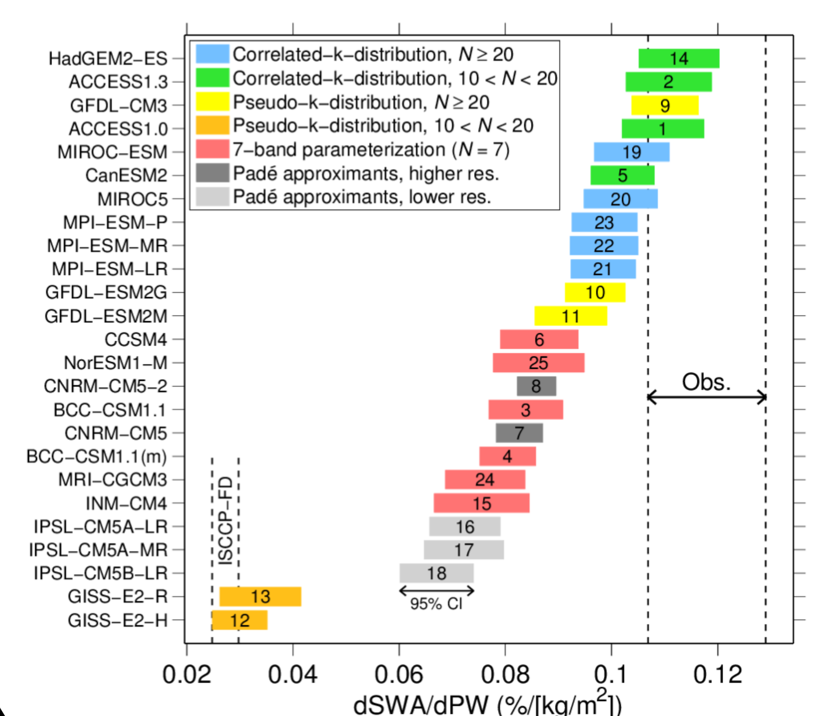
sensitivity: based on local and monthly covariations in SWA and PW over tropical oceans (piControl/present day)





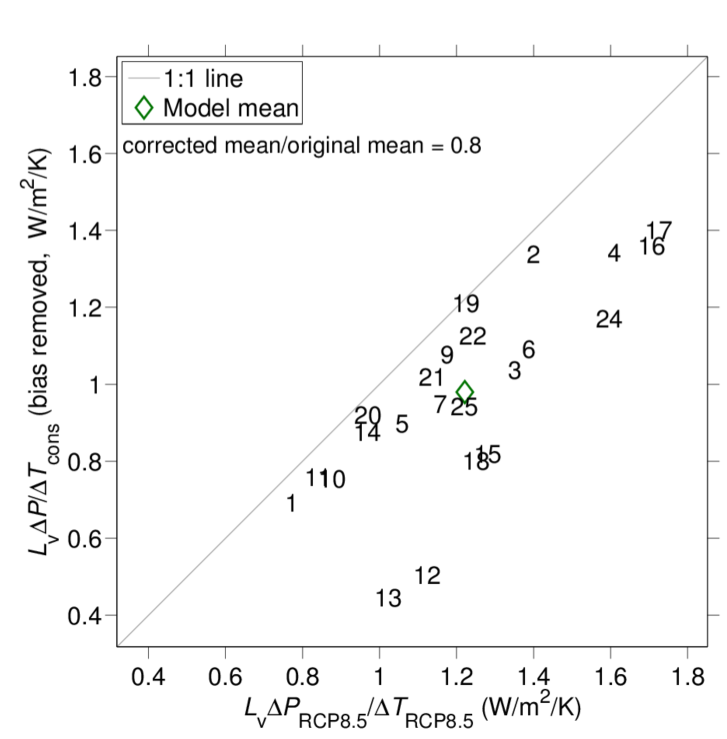
- **Spread is explained by differences in the sensitivity of SWA to a unit change in water vapor (dSWA/dPW).**
- **Models generally underestimate dSWA/dPW.**

4. Shortwave parameterization schemes



- **Differences in dSWA/dPW originate from different parameterizations of solar absorption by water vapor in a cloud-free atmosphere.**
- **More modern/advanced schemes that incorporate more computations tend to perform better.**

5. If the temperature-mediated SWA response were perfectly constrained…



$$\left.\frac{L_v \Delta P}{\Delta T}\right|_{cons} = \frac{L_v \Delta P_{RCP8.5} - \text{bias} * \Delta T_{RCP8.5}}{\Delta T_{RCP8.5}}$$

bias: the bias in temperature-mediated L_vP response resulting from a bias in SWA response

- **The ensemble-mean value of ΔP/ΔT predicted at the end of the 21st century could be reduced by 20% and model spread in the warming component of this quantity would decrease.**

For more, see: DeAngelis, A. M., X. Qu, M. D. Zelinka, and A. Hall, 2015. An observational radiative constraint on hydrologic cycle intensification. *Nature*, **528**, 249-253, doi: 10.1038/nature15770.

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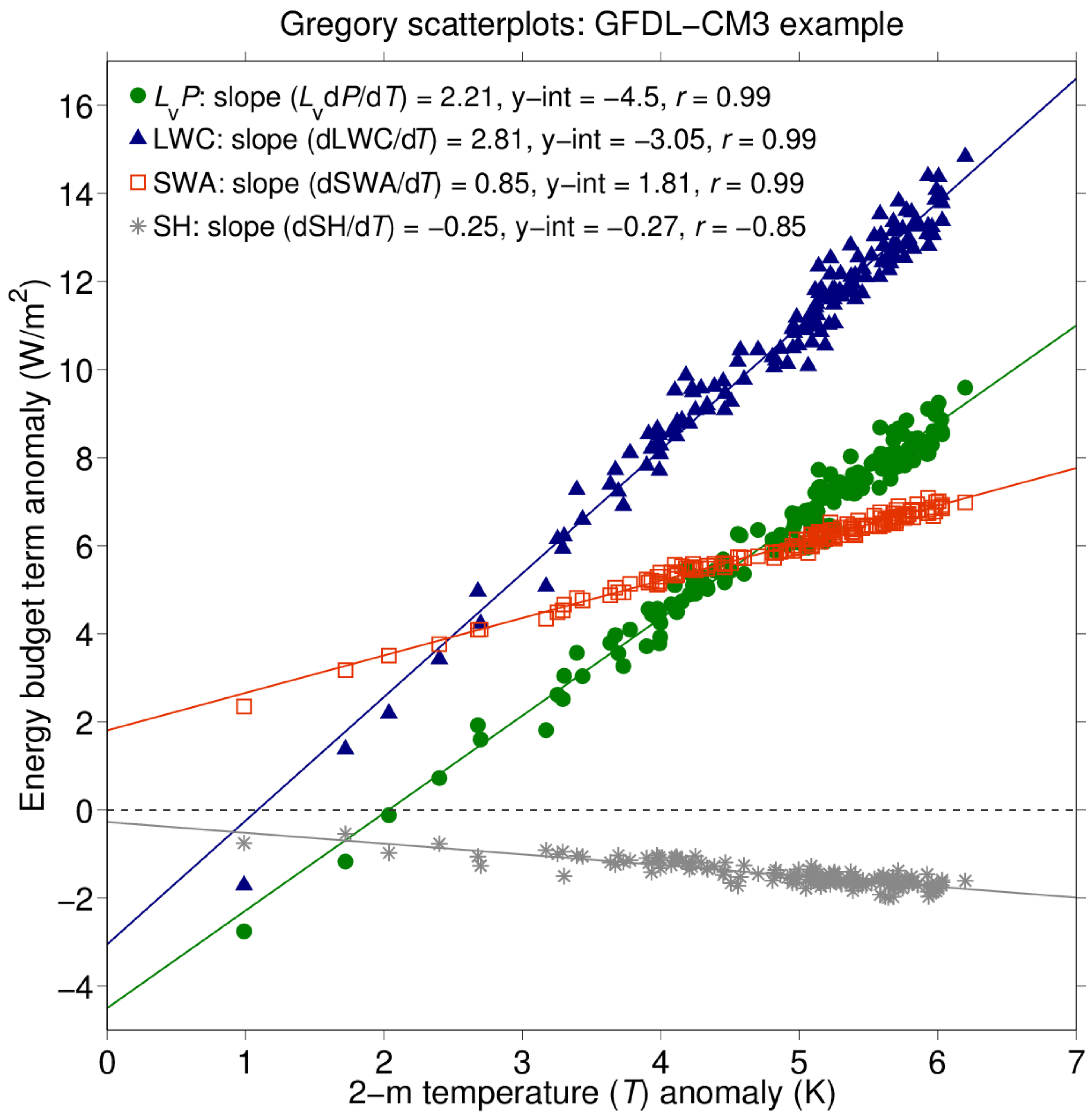
S1. Separating temperature-mediated responses and rapid adjustments



Gregory Method
Regress global-mean annual anomalies (abrupt4xCO2-piControl) in atmospheric energy budget terms against those in 2-m air temperature in simulations of instantaneous CO_2 quadrupling.
Each point represents one year of the abrupt4xCO2 simulation.
slope: temperature-mediated response (W/m^2/K)
y-intercept: rapid adjustment (W/m^2)
(more details in DeAngelis et al. 2015)

S2. Correcting late 21st century global precipitation change