The impact of initial soil moisture and soil temperature anomalies on local hydroclimate in Tropical South America

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“Modeled Hydrometeorological Responses to Extreme Soil Conditions in Tropical South America: Methodology and Physical Mechanisms”

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CESM2 Experimental Design on the impact of extreme soil conditions

Control Simulation: Continuous run during 1980-2018, at *f09* resolution
Sensitivity Experiments: 10-member ensemble of 1-month runs, initialized with extreme soil moisture or extreme soil temperature

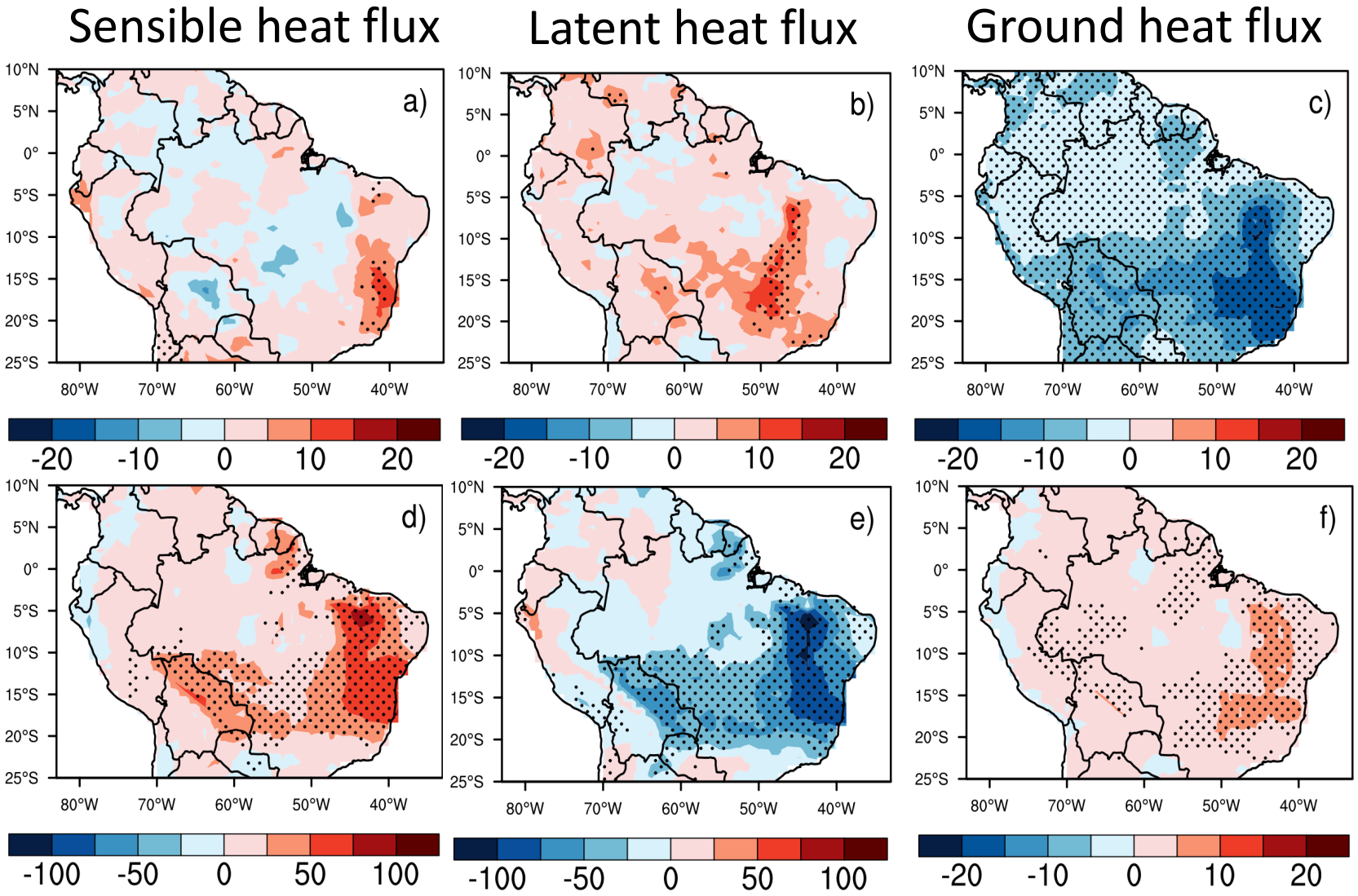
Sensitivity Experiments		Initial Soil Temperature in the target area	Initial Soil Moisture in the target area
Impact of Initial Soil Temperature (Tsoi)	"Hot"	99th percentile	Same as control
	"Cool"	1st percentile	Same as control
Impact of Initial Soil Moisture (Soilliq)	"Wet"	Same as control	99th percentile
	"Dry"	Same as control	1st percentile

Model Output Differences (ten day average)

between runs initialized with soil extremes (November as an example)

Tsoi test (upper row): responses to initial soil temperature anomalies

Soilliq test (lower row): responses to initial soil moisture anomalies

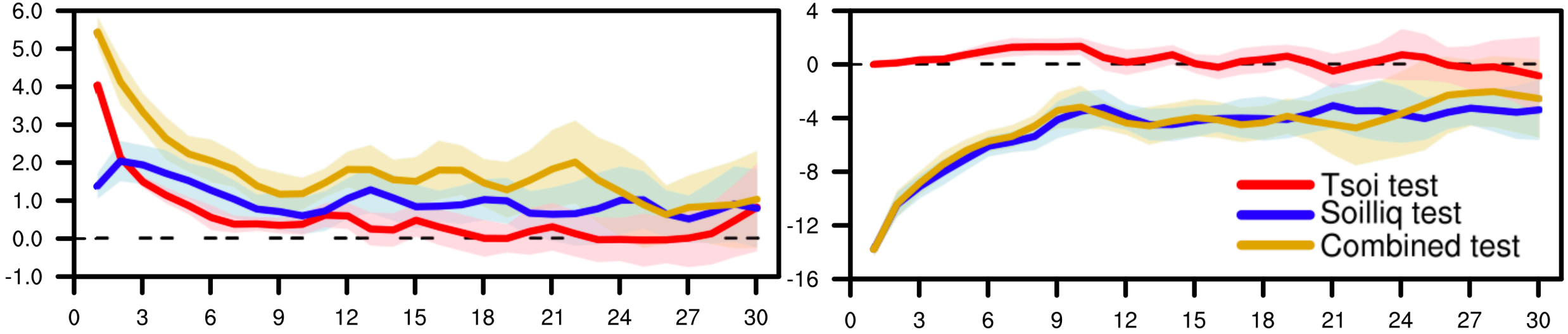


Model Output Differences

between runs initialized with soil extremes (November as an example)

a) Soil temperature

b) Soil moisture



Daily time series of top-10cm soil temperature (in °C, left) and soil water (in mm, right), ensemble mean and spatial average over Southeastern Amazon (65°W-50°W, 17°S-10°S).

- **The initial Soilliq anomalies have a stronger and longer lasting impact than the initial Tsoil anomalies.**
- **Combined effects are dominated by the impact of initial soil moisture anomalies**

Back-of-the-envelope calculations (I)

Heat corresponding to the imposed anomalies of initial soil temperature or initial soil moisture [for soil depth Δz]:

- A volumetric soil moisture anomaly of +0.1 (m^3/m^3) (realistic range between wet and dry conditions), the latent heat needed to eliminate this anomaly through evapotranspiration is

$$H = \Delta\theta * \Delta z * \rho_w * L_v = 0.1 * \Delta z * 1.0 * 10^3 * 2.45 * 10^6$$
$$= \Delta z * 2.45 * 10^8 (\, J/m^2)$$

- Assuming a common soil heat capacity of 2.8×10^6 ($J/m^3/°C$), the estimated H corresponds to a soil temperature anomaly of ΔT (evaporative cooling of the surface)

$$\Delta T = \frac{H}{C_s * \Delta z} = \frac{\Delta z * 2.45 * 10^8}{\Delta z * 2.8 * 10^6} = 88\ (°C)$$

Back-of-the-envelope calculations (II)

Heat corresponding to the imposed anomalies of initial soil temperature or initial soil moisture [for soil depth Δz]:

- Assuming a common soil heat capacity of 2.8x10^6 (J/m^3/°C) and a soil temperature anomaly of $+\ 5℃$ (within the realistic range of variability), the associated heat is

$$H = C_s * \Delta z * \Delta T = \Delta z * 2.8 * 10^6 * 5 = \Delta z * 1.4 * 10^7 (\ J/m^2)$$

- This is equivalent to the amount of latent heat needed to reduce soil moisture by $\Delta\theta$ through evaporation:

$$\Delta\theta = \frac{H}{\Delta z * \rho_w * L_v} = \frac{\Delta z * 1.4 * 10^7}{\Delta z * 1.0 * 10^3 * 2.45 * 10^6} = 0.0057 (\mathrm{m^3/m^3})$$

(corresponding to 1-2% change of soil saturation, hardly noticeable in the context of extreme drought events)

Summary

- **The local impact of initial soil temperature anomalies is negligible (in tropical low lands)**

- **The local impact of initial soil moisture anomalies is strong**
  - Soil moisture anomalies incurs a large magnitude of local soil temperature response, which may have strong non-local impact (depending on the region).
  - Soil moisture initialization should be considered for LS4P.

Summary

- **The local impact of initial soil temperature anomalies is negligible (in tropical low lands)**
  - The heat can be dissipated rapidly through surface fluxes (when no soil freezing/thawing is involved)
  - Non-local impact (through planetary waves or other large scale circulation changes) may feed back to indirectly impact local climate, which would be highly region dependent. (Tibet Plateau, North America, South America?)

- **The local impact of initial soil moisture anomalies is strong**
  - Strong non-local impact is also expected due to the large magnitude of local temperature response.
  - Soil moisture initialization should be considered for LS4P.