How well do dynamical seasonal forecasts capture soil-moisture atmosphere coupling?

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Motivation and coupling metrics

Previous studies have highlighted "hotspots" where seasonal predictions can benefit from realistic soil moisture initialization since they combine intense land–atmosphere coupling processes with strong soil moisture persistence (see review by Seneviratne et al. 2010). The North American Great Plains and the region between the Danube basin and the Mediterranean are often identified as belonging to these hotspots.

In this study we evaluate land-atmosphere coupling strength in C3S models and the skill of soil moisture forecasts, and soil moisture initial conditions in land-atmosphere coupling hotspots of the northern hemisphere.

We use two diagnostic metrics to assess the strength of land-atmosphere coupling:

- A 1-legged metric for the terrestrial leg of coupling:

$$I_{SM-E} = \sigma(E)\rho(SM, E)$$

- 2-legged metric for the terrestrial and atmospheric legs:

$$I_{SM-X} = \sigma(X)\rho(SM, E)\rho(E, X),$$

where X is either 2m-temperature of precipitation (following Lorenz et al., 2015).

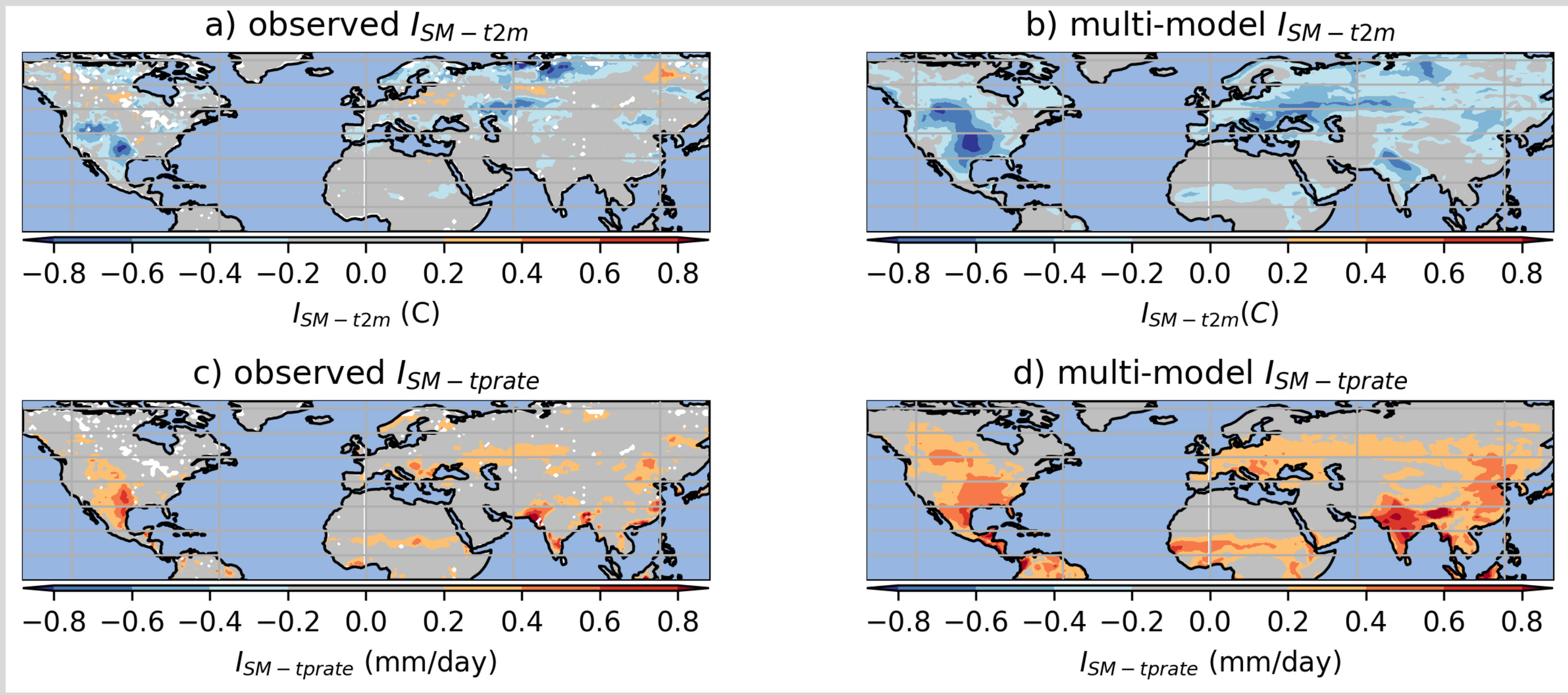

Figure 1: Metrics of soil moisture-atmosphere coupling strength for summer (JJA) in observations (a, c) and C3S models (initialized 1st May; b, d) show highlight hotspots but also indicate that the C3S hindcasts overestimate coupling strength.

Memory of dry/wet spring conditions in summer anomalies

Comparing summers preceded by a dry spring with those preceded by a wet in two coupling "hotspots", one can see persistence of spring soil moisture anomalies into the summer months, but also a notable impact on the atmosphere form the coupling. Summers preceded by dry conditions are associated with reduced evaporation, warmer 2m-temperature, and elevated z500 contours compared to those preceded by wetter springs.

The multi-model mean composite for the same years indicates that the soil-moisture anomalies seen in the observations are not present in the models, and the pattern of atmospheric variables are also missing. For North America, the soil-moisture pattern looks more realistic, but the temperature anomalies extend too far to the east do to unrealistically large coupling there.

Soil-moisture anomalies on 1st May are in general agreement on the sign of the anomaly each year, but the magnitude is overall too small. However, persistence of soil-moisture anomalies in SE Europe is too low.

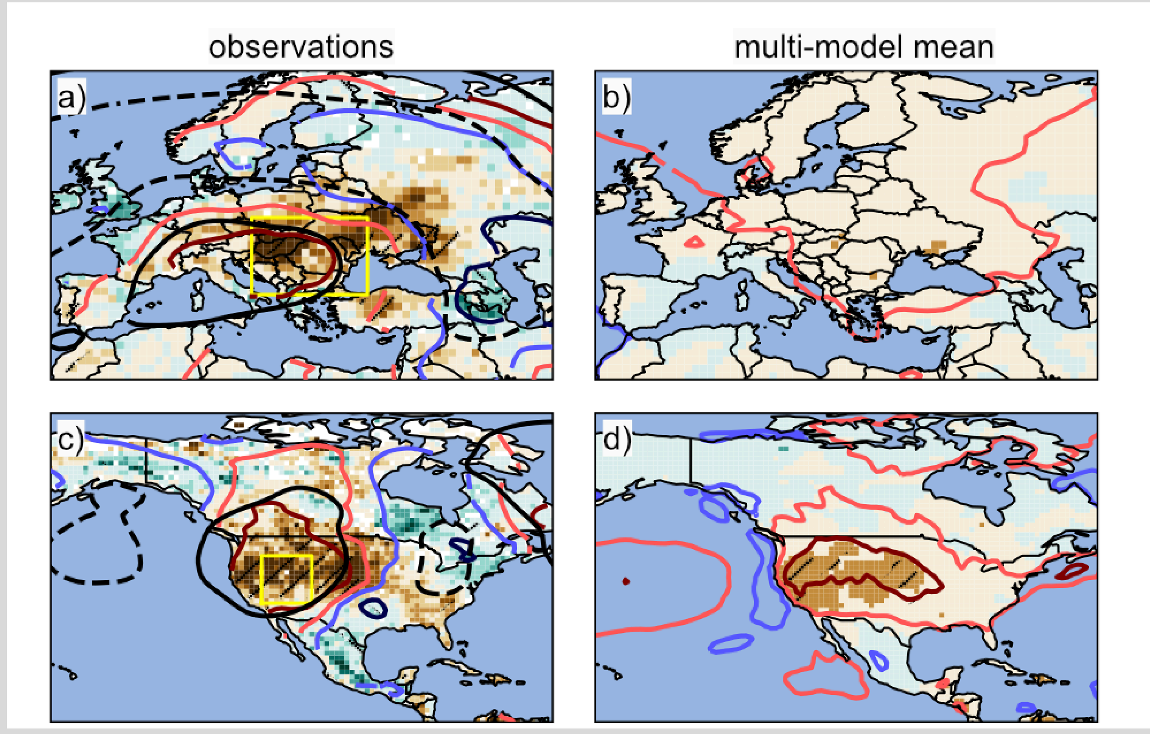

Figure 2: difference in JJA soil moisture (brown-green contours), evaporation (hatches), temperature (red and blue contours at 0.2 (light) and 0.7 (dark)) and z500 (black contour) for years preceded by dry vs those preceded by wet spring for observations and C3S hindcasts.

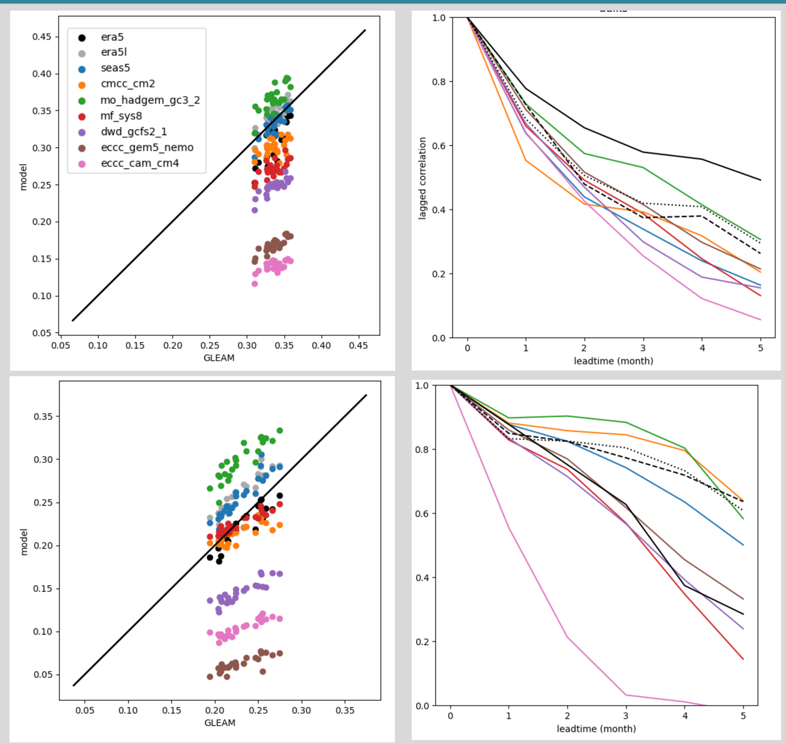

Figure 3: Scatter plot of 1 May soil moisture obs vs models (left) and lagged correlation (right) in the yellow boxes (Fig 2).

Why do C3S models overestimate soil-moisture atmosphere coupling?

Biases in the multi-model mean for the various coupling metrics correspond to areas where there are large biases in temperature and precipitation. In Central USA and Eastern Europe, the models with the largest biases in T2m and precipitation tend to have the largest overestimates in coupling strength as soil moisture dries too rapidly in these areas and models (unrealistically) transition from Energy limited to soil-moisture limited regimes. These biases in the central US are well known in GCMs used for CMIP type activities (e.g. Lin et al., 2017) and also appear within the first few hours of weather forecasts (Weverberg et al. 2018).

These are tied to a feedback loop: Too much SW↓→ high temp and high evaporation → too little moisture recycling → too little cloud → too much SW↓. A similar feedback seems to be happening in Eastern Europe.

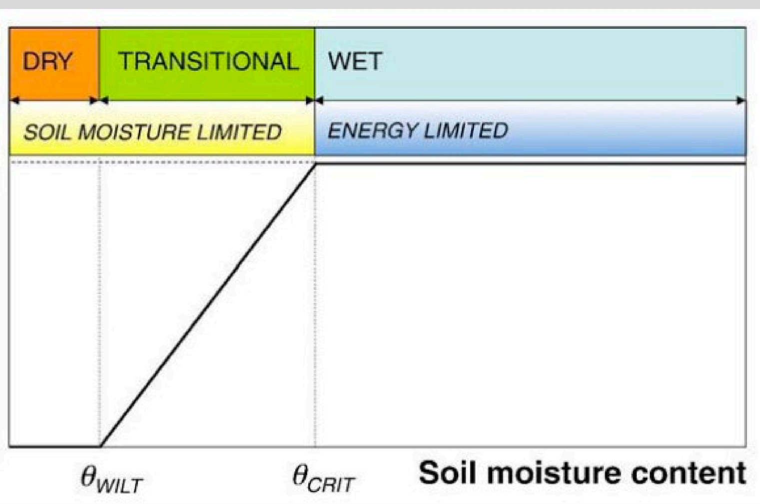

Fig 4: Soil-moisture evaporation coupling regimes from Seneviratne et al. 2010

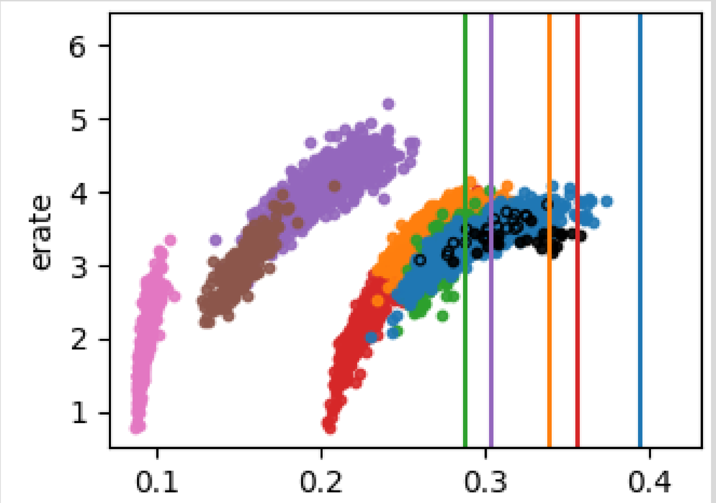

Fig 5: Scatter plot of August evaporation vs soil moisture for C3S models (colors) and observations (black). Lines show θ_{crit} from the models.

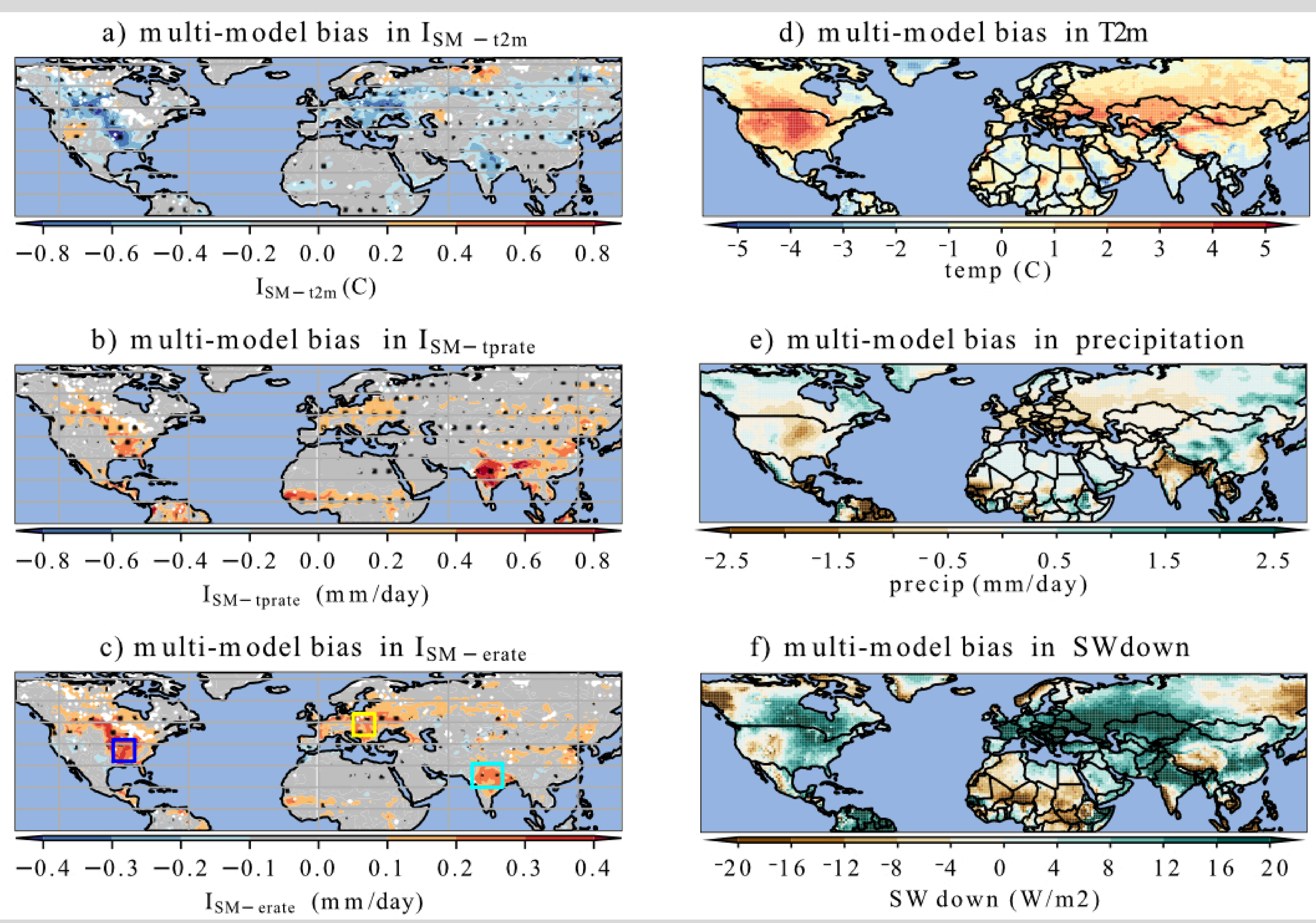

Figure 6: Multi-model mean bias in JJA soil-moisture-atmosphere coupling strength (a-c) and temperature (d) precipitation (e) and SW↓ (f) for C3S models against observations.

References

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