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Land-atmosphere coupling in km-scale climate modeling: effects of resolution vs. land-surface model sophistication

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Recent studies exhibit a considerable reduction of summer season precipitation frequency in the new generation of convection-permitting (CP) climate simulations. This seems to over-correct non-CP wet biases with a knock-on effect on summer temperatures via soil moisture-atmosphere feedbacks. However, it is difficult to elucidate which part of the warmth/dryness in CP simulations can be ascribed to land-atmosphere coupling and/or "atmosphere-only" processes. Another layer of uncertainty belongs to the still crude representation of land surface/sub-surface processes that become especially relevant when approaching such high resolution.

In this study we explore the modulation of land-atmosphere coupling when moving from a non-CP to a CP-scale climate modeling, considering increasingly sophisticated land surface model configurations. We perform a two-step dynamical downscaling at ~15 km (convection-parameterized) and ~ 3km (convection-permitting) resolutions with the WRF-4.2.1 regional climate model driven by ECMWF-ERA5 reanalysis. The greater alpine region and the extended summer season (May to September) of 2003 are the spatial and temporal domains of interest. A mini multi-physics ensemble is generated with four Noah-MP land-surface model configurations to examine if, and how, including crucial land processes (e.g., vertical soil water transport) modifies hot-temperature forcing mechanisms in the two resolutions. Moreover, each ensemble member is run according to three different initial soil moisture levels, defining reference, anomalously dry- and wet-initialization experiments.

Preliminary results show an improved representation of precipitation statistics (seasonal cumulative, frequency, and 99th percentile) from CP simulations, particularly over complex orography. Generally, maximum temperature reproduction benefits from the CP scale. However, localized warm biases persist over flat terrains regardless of the land surface model configuration. Finally, the two resolutions show a substantially different decay of the initial soil moisture state. At CP scale all three runs converge to similar soil moisture at the end of the integration. Conversely, non-CP runs preserve large soil moisture differences until the end of the summer season, signaling longer soil moisture memory and different soil moisture-precipitation feedback.

These factors might significantly affect the reproduction and predictability of environmental and

societal relevant hydroclimatic extremes on a wide-ranging temporal scale, from seasonal climate predictions to long-term climate projections.