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Collective impacts of soil moisture and orography on deep convective thunderstorms

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Thunderstorm activity in many land regions peaks in summer, when surface heat fluxes and the atmospheric moisture content reach an annual maximum. Studies using satellite and ground-based observations have shown that the timing and vigor of summer thunderstorms are influenced by the presence of triggering mechanisms such as soil-moisture heterogeneity or orography. In the current process-based study we aim to dissect the combined impact of soil-moisture and orography on moist convection by using convection-resolving climate simulations with idealized landsurface and orographic conditions.

First we systematically investigate the sensitivity of moist convection in absence of orography to a mesoscale soil-moisture anomaly, i.e. a region with drier or moister soil. Consistent with previous studies, a high sensitivity of total rain to soil-moisture anomalies over flat terrain is found. The total rain in the presence of a dry soil-moisture anomaly increases linearly if the soil-moisture anomaly is dried: an anomaly that is 50 % dryer than the reference case with a homogeneous soil-moisture distribution produces up to 40 % more rain. The amplitude of this negative response to the dry soil-moisture anomaly cannot be reproduced by either drying or moistening the soil in the whole domain, even when using unrealistic soil-moisture values. A moist soil anomaly showed little impact on total rain.

The triggering effects of the soil-moisture anomalies can be reproduced by an isolated mountain of 250 m height. In order to test to what extent the impact of the soil-moisture anomaly and the mountain are additive, the soil-moisture perturbation method is applied to soil-moisture over the isolated mountain. A 250 m high mountain with drier (moister) soil than its surrounding is found to enhance (suppress) rain amounts. However, the sensitivity of rain amount to the soil-moisture anomaly decreases with the mountain height: A 500 m high mountain is already sufficient to eliminate the sensitivity to the soil-moisture anomaly, moist or dry alike.

These sensitivity regimes as a function of mountain height are discussed in terms of the dynamic interaction between the background flow and local mesoscale circulations induced by soil-moisture heterogeneity and the mountain.