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Separating climate change signals into thermodynamic, lapse-rate and circulation effects: Theory and application to the European summer climate

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Climate models robustly project a strong overall summer warming across Europe showing a characteristic north-south gradient with enhanced warming and drying in southern Europe. However, the processes that are responsible for this pattern are not fully understood.

We here employ an extended surrogate or pseudo-warming approach to disentangle the contribution of different mechanisms to this response pattern. The basic idea of the surrogate technique is to use a regional climate model and apply a large-scale warming to the lateral boundary conditions of a present-day reference simulation, while maintaining the relative humidity (and thus implicitly increasing the specific moisture content). In comparison to previous studies, our approach includes two important extensions: First, different vertical warming profiles are applied in order to separate the effects of a mean warming from lapse-rate effects. Second, a twin-design is used, in which the temperature change signal is not only added to present-day conditions, but also subtracted from a scenario experiment. We use the regional climate model COSMO-CLM with a grid spacing of approximately 50 km (EURO-CORDEX EUR-44 setup) using transient simulations (1950-2100) with the RCP8.5 emissions scenario.

We demonstrate that the aforementioned extensions provide an elegant way to separate the full climate change signal into contributions from large-scale thermodynamics (LST), lapse-rate (LR) and large-scale circulation (LSC). In our framework the LSC effect also includes effects due to changes in land-sea contrast and the spatial variations of the SST warming pattern. We find that the LST effect yields a large-scale warming across Europe without any distinct latitudinal gradient. The LR effect, which is quantified for the first time in our study, leads to a stronger warming and some drying in Southern Europe. It explains about 50% of the warming amplification over the Iberian Peninsula, thus demonstrating the important role of lapse-rate changes. The LSC effect as inherited from the driving GCM is shown to further amplify the north-south temperature change gradient. In terms of mean summer precipitation, the LST effect leads to a significant overall increase in precipitation all across Europe, which is compensated and regionally reversed by the LR and LSC effects in particular in southern Europe.