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Quantifying the role of uncertainty in microphysical processes for cloud and precipitation formation in an extratropical cyclone

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The characteristic large-scale cloud band near extratropical cyclones is associated with the so-called warm conveyor belt (WCB), which is a coherent airstream that ascends cross-isentropically from the boundary layer into the upper troposphere within two days. This transport of air into the upper troposphere can influence the large-scale flow evolution. The cross-isentropic ascent is influenced by latent heat release from the formation of liquid, mixed-phase and ice clouds. In this way, WCBs provide an environment where small-scale cloud microphysical processes are directly linked to the large-scale extratropical circulation. The parameterization of microphysical processes in numerical weather prediction models introduces uncertainties related to cloud characteristics, which can also feed back on the larger-scale flow. In particular, ice formation and the phase partitioning are often poorly represented in numerical weather prediction models.

We analyze the role of uncertainty related to the representation of microphysical processes in a two-moment microphysics scheme for the detailed WCB ascent, the cloud characteristics, as well as changes in diabatic heating contributions from the individual parameterized processes. Furthermore, the propagation of uncertainty from the microphysical processes to the larger-scale flow is investigated. Systematic sensitivity experiments for a two-way nested convection-permitting simulation with the Icosahedral Nonhydrostatic (ICON) modeling framework are performed for an extratropical cyclone case study in the North Atlantic. The experiments include systematic perturbations to environmental conditions relevant for cloud formation (concentrations of cloud condensation nuclei and ice nucleation particles as well as sea surface temperature) and microphysical parameters (capacitance of ice and snow as well as maximum supersaturation in the saturation adjustment scheme). To quantify the effect of individual microphysical process rates for WCB ascent, we aggregate heating rates from each parameterized microphysical process along online trajectories.

First results indicate that the perturbations not only substantially modify the cloud properties but also influence the WCB ascent behavior and ascent-integrated diabatic heating contributions. The perturbed parameter ensemble further shows a growth of spread of the larger-scale flow with increasing lead time. To disentangle and quantify the contributions of the five perturbed parameters, we perform a variance-based sensitivity analysis using computationally inexpensive statistical surrogate models based on Gaussian process emulation that are developed from the large, computationally expensive perturbed parameter ensemble. For example, this indicates that WCB-related surface precipitation is most strongly influenced by changes to sea surface temperature and cloud condensation nuclei concentration, while the vertical distributions of snow and ice are also substantially influenced by perturbations to their capacitance. This contribution shows how the parameter perturbations affect microphysical processes which subsequently modify characteristics of

the large-scale WCB cloud band, and illustrates how statistical emulation can be used to quantify uncertainty from parameter perturbations in a real-world case study.