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Lagrangian analysis of the role of cloud processes for the dynamics of extratropical cyclones in the global weather prediction model IFS

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Phase changes of water and the associated latent heating and cooling can have a significant impact on the synoptic- and mesoscale dynamics of extratropical cylcones by altering the stability profile, generating potential vorticity (PV) anomalies, and redistributing moisture. This work employs a Lagrangian approach to investigate the role of specific diabatic processes for the cyclone dynamics and evolution. A detailed case study of a strong North Atlantic winter cyclone is presented, based on a simulation with the global IFS model of the ECMWF. An extended model version provides instantaneous diabatic heating rates for each microphysical process parameterized in the IFS. Lagrangian diagnostics based on trajectories are applied in order to quantify the contribution of individual cloud processes to dynamical features and to identify parts of the flow that are strongly affected by specific processes. Air parcels that experience strong diabatic modification by selected cloud processes accumulated along their flow form coherent airstreams. They are objectively identified using threshold criteria and a clustering technique. In this work, a focus is on below-cloud processes, namely snow sublimation and rain evaporation. It is shown that their role is not only to diabatically cool and modify the PV of airstreams but also to provide a significant moistening. Several coherent airstreams affected by below-cloud processes are identified in different parts of the cyclone. They include a coherent flow relevant for the evolution of the cold front, a low-level flow ahead of the warm front towards the cyclone centre, and an airstream that rises as part of the warm conveyor belt and impacts the upper levels. A key inference from this detailed Lagrangian analysis is that below-cloud processes affect the structure and dynamics of extratropical cyclones not only in the lower, but also in the upper troposphere. As a consequence, uncertainties in the parameterization of these processes can project on uncertainties in the prediction of the large-scale upper-tropospheric flow.