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Understanding Precipitation Band Formation in Extratropical Cyclones

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Mesoscale structures within extratropical cyclones can produce heavy, often unanticipated precipitation. Even within high-resolution numerical-weather-prediction models, the formation, movement, and dissipation of multiple precipitation bands sometimes differs dramatically between model output and observed radar data, leading to errors in the forecasting of where and when the heaviest precipitation occurs on the mesoscale. One of the goals of the field and research program Diabatic Influences on Mesoscale Structures in Extratropical Storms (DIAMET) is to analyse mesoscale precipitation bands to characterize their structure and evolution in specific cases. This study, a part of DIAMET, aims to understand why these precipitation bands form and the conditions under which single bands turn into multiple bands. Our approach is to diagnose the conditions for the formation of banded precipitation within simulations of idealised extratropical cyclones.

In the control simulation, which is moist and with convection but no other parameterisations, the developing cyclone resembles the Shapiro–Keyser cyclone model. A broad warm-frontal band of lower-tropospheric ascent first develops, then a second band of ascent appears, forced by frontogenesis at the surface warm front. These two bands of ascent increase their separation over time, but not sufficiently to become separate precipitation bands.

In a simulation with surface friction increased to a value appropriate for land, the dominant front becomes the cold front and the cyclone resembles the Norwegian cyclone model. A greater horizontal distance between the surface and broad warm-frontal bands of ascent occurs, so that distinct precipitation bands form, with a more intense surface-forced band. When latent heating and cooling are added, the broad warm-frontal band is narrower and more intense and, in the mature stage of the cyclone, spawns further bands behind it. Surface fluxes serve to maintain bands formed by other processes for longer and, with the addition of radiation, produce additional bands in the cold air.

In all simulations, all precipitation bands eventually merge into a single band as the cyclone occludes. However, in simulations representative of friction over land, the occlusion happens more slowly, allowing more of the bands generated by other processes to develop.

These sensitivity simulations demonstrate that cyclones subject to greater surface friction, latent heating, surface sensible heat fluxes, and radiation are more likely to produce multiple-banded structures. These results provide support for the observed tendency for more multiple-banded structures over land and during the warm season over the UK.