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Cloud-radiative heating shapes idealized extratropical cyclones by changing atmospheric stability

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"All models are wrong. Some are wrong in a useful manner." (adapted by the authors from George Box) In this presentation, we utilize an error in the surface flux formulation of the ICON-NWP numerical weather prediction model to elucidate how cloud-radiative heating affects the intensity of idealized extratropical cyclones.

We present idealized baroclinic life cycle simulations with two versions of the global atmosphere model ICON-NWP. Both versions simulate the same cyclone when run without radiative heating, but disagree when cloud-radiative heating is allowed to affect atmospheric temperature and the cyclone evolution. In version 2.1, taking into account cloud-radiative heating leads to a weaker cyclone, while in version 2.6 a stronger cyclone results. The simulations use a new modeling technique for which only cloud-radiative heating interacts with the cyclone and clear-sky radiative heating is omitted. The technique circumvents changes in the mean state due to clear-sky radiative heating that has complicated the interpretation of previous work.

A defining difference between the two model versions is the amount of simulated low-level clouds. Compared to version 2.6, version 2.1 simulates twice as many low-level clouds and a twice as strong cooling of the planetary boundary layer by cloud-radiative heating. While the increase in low-level clouds is tied to an error in the surface flux formulation in version 2.1 that was corrected in version 2.6, the error provides an opportunity to probe the impact of cloud-radiative heating in the boundary layer (below 2 km) versus the free-troposphere (above 2 km). Sensitivity studies show that negative cloud-radiative heating in the boundary layer from the tops of low-level clouds weakens the cyclone by making the atmosphere more stable. At the same time, they show that negative cloud-radiative heating near the tropopause from the tops of high-level clouds strengthens the cyclone by decreasing atmospheric stability. The changes in stability are particularly evident in regions of upward motion.

Overall, our results indicate that the vertical distribution of clouds and their radiative heating are an important factor for the dynamics of extratropical cyclones and that model differences in the simulation of low-level clouds can translate to model differences in cyclone intensity.