Acceleration of high winds in idealised simulations of extratropical cyclones

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In intense, Shapiro–Keyser-type cyclones, regions of high winds develop in association with the bent-back front. These regions of high winds can be associated with cold conveyor belts or sting jets. Sting jets occur at the tip of the bent-back front, in association with a distinctive hooked cloud head. As they descend, the jets accelerate horizontally by as much as 20 ms^{-1} ($\approx$ 44 mph) during a descent of approximately 5 km.

But where does this acceleration come from? The co-location of the sting jet with the cloud-head led Browning (2004) to hypothesize that this acceleration is caused by evaporative cooling or by the presence of conditional symmetric instability. However, sting jet simulations with latent heating turned off still produce a wind speed maxima in the frontal fracture region (Baker et al. 2012; T. Baker and P. Knippertz 2012, personal communication). So is moisture necessary for the production of sting jets? And why should negatively buoyant air accelerate horizontally? To investigate these questions, idealised, baroclinic wave studies using the Weather Research and Forecasting (WRF) model were performed. The model is run without surface friction and latent heating on a horizontal grid of 20 km. Except for weak numerical diffusion, the simulations are adiabatic.

The resulting simulations reproduce rapidly-developing, Shapiro–Keyser-type cyclones with a strong warm front, T-bone structure and frontal fracture. Regions of strong winds, resembling cold conveyor belts and sting jets, develop in association with the bent-back front. The momentum equations are split into their constituent terms representing different forces, and the numerical values of these terms are evaluated at each time step in the model simulation. Contributions of these different forces determine both the horizontal and vertical accelerations within the cyclone. The diagnosis of the direction, magnitude and relative size of these forces is used to understand the development of high winds associated with the bent-back front. Are the high winds advected down from the upper-level jet? What role does the increasing pressure gradient to the southwest of the low pressure centre play in the formation of these high winds?

References

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