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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. 2013; 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. To understand where the horizontal acceleration of these winds come from, the terms on the right-hand side of the horizontal momentum equation are evaluated near the surface in the model. In and downstream of the region of strongest winds, the winds in the region of the descending sting jet air are accelerated by the downward advection of high-momentum air. This downward advection is the dominant term in this area and explains the local acceleration of the wind speed. This acceleration is offset by the horizontal pressure-gradient force, which decelerates the flow. Ahead of the wind maximum, horizontal advection of high-momentum air advects the wind maximum eastward.

References

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