8D.6 MECHANISMS FOR THE GENERATION OF MESOSCALE VORTICITY FEATURES WITHIN TROPICAL CYCLONE RAINBANDS

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1. INTRODUCTION

There has been considerable observational and modelling work recently focusing on the role of mesovortices in mesoscale convective systems. Results have shown that these vortices can strengthen inflow jets and initiate convection including tropical cyclogenesis (Ritchie and Holland 1997). May and Holland (1999) demonstrated that midlevel jets in tropical cyclone rainbands could be developed by potential vorticity production through the vertical gradient of heating in the stratiform regions. They found that the rate of PV production was comparable to the intensification rate of the cyclone, which emphasised the potential positive role rainbands may have on the intensification of tropical cyclones.

2. NUMERICAL MODEL

The hydrostatic numerical model used in this study is the triply-nested movable mesh high resolution tropical cyclone model TCM3 (Wang 1999). The innermost mesh has a grid resolution of 5 km, 20 σ levels and the model physics include an explicit treatment of cloud microphysics, which include warm rain and mixed ice phase processes.

3. MECHANISMS OF VORTEX DEVELOPMENT

Outside the radius of maximum winds, the mid-low levels generally exhibit weak cyclonic vorticity due to the opposing contributions from the shear and curvature terms. Examination of the absolute vorticity fields for a beta plane simulation (Fig. 1) show a region of anticyclonic vorticity occurring in the rainbands at the 600-800 hPa level. The regions of anticyclonic vorticity are a consistent feature within the simulated rainband, both in space and time.

The initial source of this vorticity is the tilting of system generated horizontal vorticity into the vertical. The shearing of the tangential wind with height in the stratiform region due to the buoyancy gradients created by the mesoscale updraft and downdraft and the underlying physical processes of condensation, melting and evaporation, generate the horizontal vortex lines. As an updraft associated with a convective cell moves downwind through the stratiform section of the rainband, these vortex lines are tilted upward resulting in a cyclonic-anticyclonic vorticity couplet radially across the band.

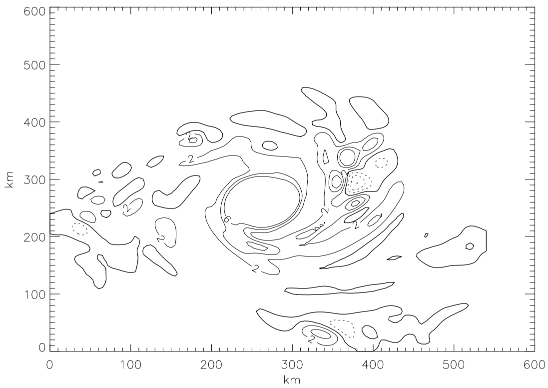

Fig. 1 Plan view of the absolute vorticity (10^{-4} s^{-1}) at 600 hPa. Contour interval is 2, negative values are dashed and the zero line is bold.

Once the mesoscale anticyclone has been developed it is maintained by stretching as it is advected cyclonically downwind. The anticyclonic mesovortex is strained into a filament as it approaches the centre of the storm and is eventually wrapped into the core of the storm. Although the mesoscale anticyclone is inertially unstable by normal standards, the size and coherence of the vortex over its lifetime of about 2.75 hours suggests that it is balanced. This supports the findings of Davis and Weisman (1994), who demonstrated that the longevity of anticyclonic mesovortices is not ultimately dependent on the measure of inertial instability and that they may be as equally balanced as cyclonic mesovortices.

4. MIDLEVEL JET AND PV DYNAMICS

The midlevel jet does not appear in the rainbands until the band has matured to a more stratiform structure. The jet is a descending rear-to-front jet in the sense that it flows downwind through the stratiform precipitation region, decreasing with height as it approaches the convective section of the band. The

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broad region of heating and positive buoyancy above the freezing level works in conjunction with the cooling below to accelerate the rear-to-front flow at the midlevels. The radial position of the jet lies in between the counter-rotating mesovortices, which enhance the strength of the concentrated tangential velocity.

The development of the jet can also be explained by PV dynamics. A warm potential vorticity anomaly above the freezing level and a cold anomaly below generate cyclonic vorticity in the midlevels (Raymond and Jiang 1990). The PV budget results show that the production of PV from diabatic and frictional forces in the stratiform region of rainbands creates a PV dipole. Cyclonic PV is generated at the midlevels along the band, decreasing with height downwind and there is an anticyclonic anomaly produced near the surface. The production of cyclonic PV accelerates the tangential winds in the band, leading to the development of the midlevel jet.

5. VORTEX ROSSBY WAVE VERIFICATION

Fourier decomposition of the absolute vorticity field shows two counterpropagating waves associated with the outer rainband (Fig. 2). These waves satisfy the vortex Rossby wave theory proposed by MacDonald (1968), Guinn and Schubert (1993) and Montgomery and Kallenbach (1997). The wave located on the inner side of the band is composed of low azimuthal wavenumbers and propagates outwards, although the radial group velocity and hence the energy transfer is inwards. The period of this wave is 4.6 hours, which resembles the lifetime of the band of about 4 hours. The outer wave is collocated with the mesoscale anticyclone and has a period of 2.2 hours which closely agrees with the lifetime of the anticyclone. This inward travelling wave is predominately made up of wavenumbers 4, 6 and 8 and is of the mixed Rossby-gravity mode, with the gravity wave contributions growing as the band decays.

6. CONCLUSIONS

It has been demonstrated in this study that internal rainband processes can support the development of anticyclonic mesovortices on the outer sides of bands. The coherent structure and longevity of this feature has been shown to result from the strong diabatic forcing of the stratiform regions of rainbands. These features have been observed in squall-line-type convective systems (e.g. Smull and Houze 1985) which rainbands emulate. Thus it is reasonable to expect the existence of these structures in nature given the presence of the mechanisms responsible for their generation and maintenance.

The diabatic forcing of the stratiform regions is also responsible for the generation of PV that develops the midlevel jet. The jet provides a mechanism to transport vorticity from the upwind end of the band to the inner, lower levels of the storm where it could then act as a

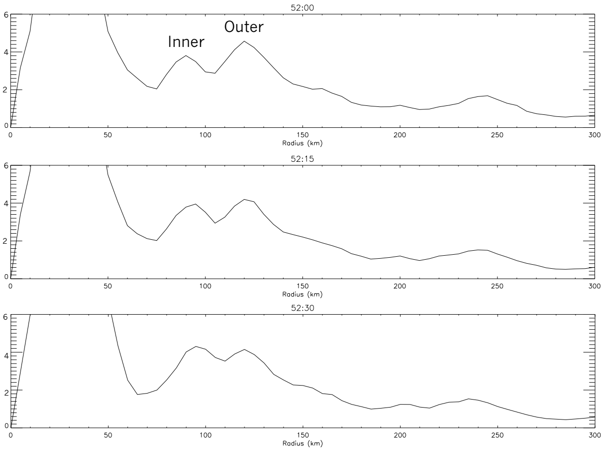

Fig. 2 Magnitude of the perturbation absolute vorticity (10^{-4} s^{-1}). Calculated as the sum of the absolute value of the Fourier amplitudes. The inner and outer waves associated with the rainband are labeled.

source of vorticity for the intensification of the cyclone.

The generation of PV within the rainband perturbs the basic state PV and creates a gradient that allows vortex Rossby waves to propagate. The outer wave associated with the rainband never travels inside of the 100 km radius and thus does not directly effect the inner core of the storm. However, idealized modeling studies have shown how such waves can contribute to the intensification of the vortex through axisymmetrisation and also play a role in the eyewall replacement cycle through induced subsidence near the radius of maximum winds (Möller and Montgomery 2000).

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