7C.5 THE DEVELOPMENT OF ASYMMETRIC VERTICAL MOTION IN IDEALISED TROPICAL CYCLONES UNDER THE INFLUENCE OF VERTICAL SHEAR

Sarah C. Jones* and Elizabeth A. Ritchie
Meteorologisches Institut, Universität München, München, Germany
University of New Mexico, Albuquerque, New Mexico

1. INTRODUCTION

Numerical modelling studies have shown that asymmetries in vertical motion develop when a tropical cyclone is influenced by environmental vertical shear. In unsaturated flow the orientation of the vertical motion asymmetry is related to the vertical tilt of the tropical cyclone vortex (Jones 1995, 2000; Frank and Ritchie 1999). The asymmetry is wavenumber one, with ascent 'downtilt right' (i.e. to the right of an observer facing in the direction of the vertical tilt) and descent 'downtilt left'. The asymmetric vertical circulation aids in the maintenance of balance by creating a cold anomaly on the downtilt side of the vortex and a warm anomaly on the uptilt side. The ascent maximum 'downtilt right' occurs as the cyclonic circulation of the tropical cyclone vortex ascends up the distorted isentropes.

When the inner-core of a tropical cyclone becomes saturated, the orientation of the asymmetric vertical motion changes (Frank and Ritchie 1999, 2001). The ascent in the inner-core is enhanced 'downshear left' and reduced 'downshear right'. Frank and Ritchie attribute the change in the orientation of the vertical motion asymmetry to the destruction of the cold anomaly due to latent heat release in slightly unstable saturated air. In the calculations of Frank and Ritchie (1999) the inclusion of moist processes leads to the tropical cyclone vortex having little or no vertical tilt. In this paper we investigate the role of latent heat release in saturated flow on the evolution of tropical-cyclone-like vortices in environmental vertical shear.

2. IDEALISED REPRESENTATION OF LATENT HEAT RELEASE IN SATURATED FLOW.

We can consider the vertical motion in the eyewall of a tropical cyclone in vertical shear to consist of the axially-symmetric ascent of the secondary circulation plus the wavenumber-one ascent-descent pattern associated with the vertical shear. When the inner-core of the tropical cyclone is unsaturated, the wavenumber-one vertical motion will be that seen in dry calculations. Once the inner-core is saturated this wavenumber-one component will be modified due to latent-heat release. We can investigate the modification of the wavenumber-one vertical circulation by adding an idealised representation of latent heat release in saturated flow to the dry calculations. Thus we do not have the complexities of surface fluxes and convection present in the calculations of Frank and Ritchie (1999, 2001), and therefore do not have a symmetric secondary circulation. However, we are making the dry calculations of Jones (1995, 2000) more representative of a real tropical cyclone.

In saturated flow the static stability is reduced in the presence of vertical motion (Durran and Klemp 1982). This reduction in static stability can be represented by adding a heating term to the right hand side of the thermodynamic equation to give

$$\frac{D\theta}{Dt} = wq \qquad (1)$$

where θ is the potential temperature, t is time, w is the vertical velocity and q is a constant. The reduced static stability in the presence of vertical motion is then given by

$$N_m^2 = N^2 - \frac{g}{\theta_0} q \qquad (2)$$

where $N^2 = g/\theta_0 \, \partial\theta/\partial z$ is the dry static stability, z is the height, g = 9.81 $m s^{-2}$ and θ_0 = 300 K.

The asymmetric vertical motion associated with vertical shear has considerably smaller amplitude than the eyewall ascent and acts to increase or decrease the ascent in the eyewall. This will lead to increased latent heat release in regions of increased saturated ascent and decreased latent heat release in regions of reduced saturated ascent. In our calculation we do not have a symmetric secondary circulation and so we apply (1) to both ascending and descending motion to give heating in regions of ascent and cooling in regions of descent.

The calculations described in this paper use the model configuration of Jones (1995). The initially-barotropic vortex has maximum tangential wind of 20 $m s^{-1}$ at a radius of 100 km. The environmental flow is westerly with zero flow at the surface and a uniform vertical shear of $4 x 10^{-4} s^{-1}$ The environmental dry static stability, N^2, is $1.5 x 10^{-4} s^{-2}$. Two calculations are compared, one without heating (q = 0), the other with heating (q = $4.1284 x 10^{-3} K m^{-1}$) so that N_m^2 = $1.5 x 10^{-5} s^{-2}$.

* *Corresponding author address:* Sarah C. Jones, Meteorologisches Institut, Theresienstr. 37, 80333 München, GERMANY.
e-mail: sarah@meteo.physik.uni-muenchen.de

3. RESULTS

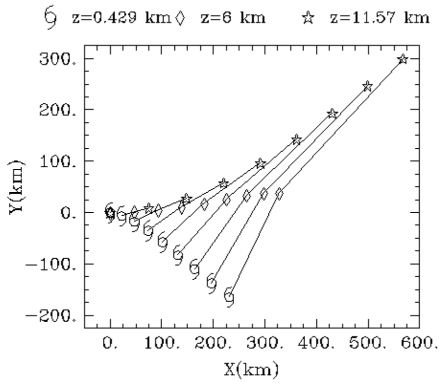

Figure 1: Track and vertical tilt of vortex at 6 hourly intervals over 48 h without heating. The symbols show the location of minimum geo-potential at 3 model levels. The vortex centre is initially located at (0, 0).

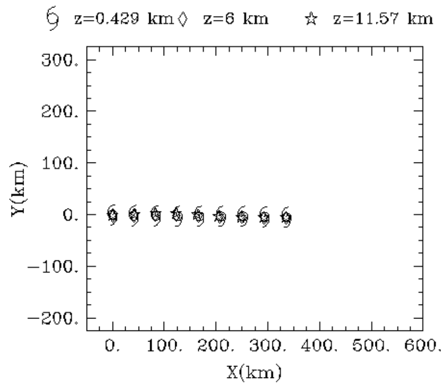

Figure 2: As Fig. 1 but with heating

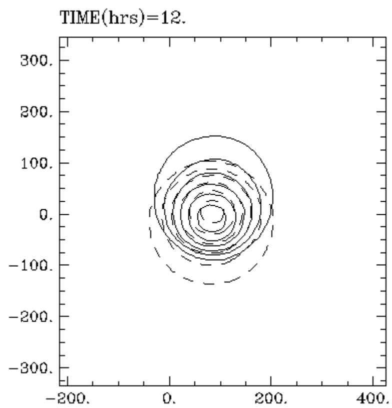

Figure 3: Horizontal cross-section of density-weighted potential vorticity at the highest (solid lines) and lowest (dashed lines) model levels at 12 h for the calculation with heating. Contour interval is 0.5 x 10^{-6} $m^{-1}s^{-1}K$.

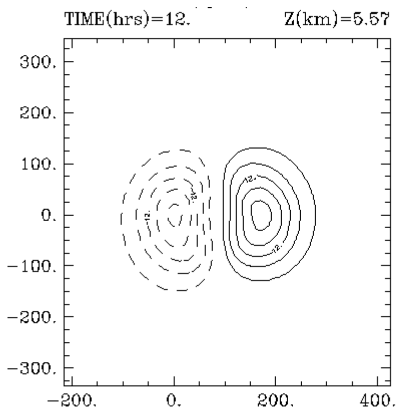

Figure 4: Horizontal cross-section of vertical velocity at z = 5.57 km at 12 h for the calculation with heating. Contour interval is 4 cm s^{-1}.

Figure 1 shows the track and vortex tilt for the calculation with no heating. The vortex develops a substantial vertical tilt with a strong downshear component. After 48 h the horizontal separation of the surface and upper-level centres is about 500 km. When the heating term is included in this calculation the vertical tilt of the vortex remains small (Fig. 2). This can be understood in terms of the reduced stability in regions with vertical motion leading to a larger Rossby penetration depth in these regions. Jones (1995) showed that for larger penetration depth the vertical tilt is smaller. In these calculations the heating is applied everywhere in the domain. In future calculations the heating will be restricted to the inner-core of the tropical-cyclone vortex.

Although the upper- and lower-level geopotential centres are almost co-located in the calculation with heating, the vortex does still have some vertical tilt, as can be seen in Fig. 3. The outer regions of the potential vorticity anomalies are displaced in the horizontal, so that 100 km away from the location of maximum potential vorticity the vortex has a south-north tilt. The vertical circulation exhibits the behaviour seen for dry calculations with ascent 'downtilt right' and descent 'downtilt left' (Fig. 4). This is consistent with the fact that the moist stability is still positive in this case. Future calculations will consider neutral and unstable moist stability.

Acknowledgement. We would like to thank Richard Patra for his assistance with the model runs. We gratefully acknowledge support from the US Office of Naval Research.

REFERENCES

Durran, D. R. and J. B. Klemp, 1982: On the effects of moisture on the Brunt-Väisälä frequency. *J. Atmos. Sci.,* **39,** 2152-2158.

Frank, W. M. and E. A. Ritchie, 1999: Effects of environmental flow on tropical cyclone structure. *Mon. Wea. Rev.,* **127,** 2044-2061.

Frank, W. M. and E. A. Ritchie, 2001: Effects of vertical wind shear on the intensity and structure of numerically simulated hurricanes. *Mon. Wea. Rev.,* **129,** 2249-2269.

Jones, S. C., 1995: The evolution of vortices in vertical shear. I: Initially barotropic vortices. *Quart. J. Roy. Meteor. Soc.,* **121**, 821-851.

Jones, S. C., 2000: The evolution of vortices in vertical shear. III: baroclinic vortices. *Quart. J. Roy. Meteor. Soc.,* **126**, 3161-3186.