4A.6 IDEALISED MODELLING OF TROPICAL CYCLONES IN VERTICAL SHEAR: THE ROLE OF SATURATED ASCENT IN THE INNER CORE

Richard Patra *

Meteorological Institute, University of Munich

1. INTRODUCTION

It is well known that asymmetries in vertical motion and precipitation develop when a tropical cyclone is influenced by environmental vertical shear of the horizontal wind. Idealized studies have investigated these asymmetries in dry model calculations as well as full physics runs. In unsaturated flow the maximum ascent is to the right of an observer facing in the direction of the vertical tilt (Jones 1995, hereafter J95). When the inner-core of the tropical cyclone is saturated the ascent maximum is downshear left (Frank and Ritchie 1999). This study tries to bridge the gap between the dry and full physics cases by isolating the effects caused by latent heat release in the saturated inner-core. Therefore a dry model is modified to include an idealised representation of latent heat release.

2. IDEALISED MODELLING OF LATENT HEAT RELEASE

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 that acts to increase or decrease the ascent in the eyewall. Once the inner-core is saturated there will be increased latent heat release in regions of increased saturated ascent and decreased latent heat release in regions of reduced saturated ascent.

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 $Q = \gamma\, w$ to the right hand side of the thermodynamic equation where γ is a proportionality factor determined for each grid point individually and w the vertical velocity. The heating is confined within a radius of $150km$. The reduced static stability is then given by $N_m^2 = \frac{g}{\theta_0}\left(\frac{\partial\theta}{\partial z} - \gamma\right)$ where $g = 9.81ms^{-2}$, $\theta_0 = 300K$, θ is potential temperature and z is height.

The model configuration used in this study is described in J95. An initially barotropic vortex with maximum tangential wind of $20ms^{-1}$ at a radius of $100km$ is used. The shear is $4.0 \cdot 10^{-4}s^{-1}$. Neither surface fluxes of heat and momentum nor explicit moisture are included so there is no symmetric secondary circulation. Thus the modified latent heat release due to the asymmetric vertical circulation in vertical shear is modelled.

3. STRONG SYMMETRIC ASCENT (S)

For the results presented in this section we envisage a situation in which the tropical cyclone we are modelling contains strong symmetric ascent in the inner-core. The shear induced asymmetric component of the vertical circulation is assumed to be weaker than the symmetric component and so modifies the symmetric component but does not change its sign. Thus the inner-core remains saturated. This is represented in our model by heating in regions of ascent and cooling in regions of descent.

In the absence of heating the vortex develops a strong vertical tilt. If the moist stability is reduced in the inner-core the vortex remains upright as in the cases in J95 with reduced dry stability. The maximum ascent is still downtilt right.

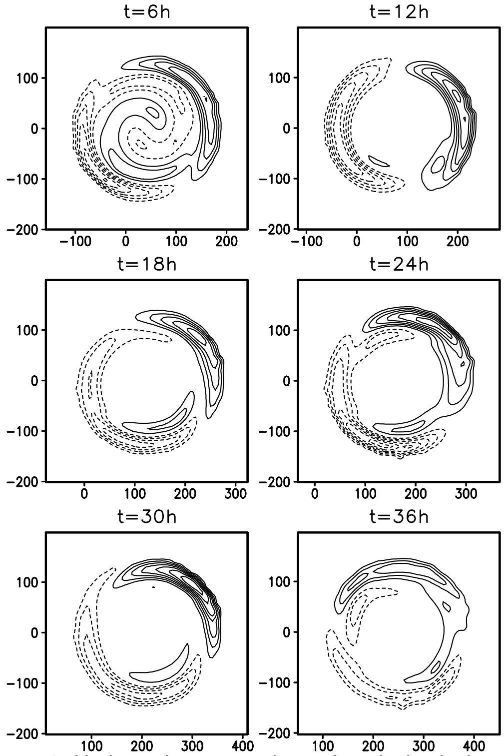

Figure 1: Horizontal cross-sections of vertical velocity at $z = 5.6km$, centered at the location of minimum surface perturbation geopotential. Contour interval is $0.1ms^{-1}$, negative contours are dashed.

If the inner-core is moist neutral ($\gamma := \frac{\partial\theta}{\partial z}$) the vertical circulation is markedly different. A strong vertical circulation develops at a radius of $100 - 150km$ (Fig. 1). The maximum of ascent is located downshear and shifts cyclonically towards downshear left by $18h$. When averaged over the entire model run, most of the ascent occurs in the downshear left quadrant. This is consistent with observations of full physics runs which show the same behaviour after eyewall saturation (Frank and Ritchie 1999). Interpretation of the vertical circulation as a mechanism to maintain a thermally balanced state (J95) is no longer possible in this situation and another explanation for the forcing of the vertical circulation has to be found. The vertical circulation appears to be related to the development of fila-

* Corresponding author address: Richard Patra, Meteorological Institute, University of Munich, Theresienstr. 37, 80333 Munich, Germany; e–mail: richard@meteo.physik.uni-muenchen.de

ments of potential vorticity that enable the potential vorticity of the inner-core to remain upright.

4. WEAK SYMMETRIC ASCENT (W)

Here we consider a tropical cyclone with a weak symmetric circulation so that the asymmetric vertical circulation has the same amplitude as the symmetric ascent. Thus only the region of asymmetric ascent is saturated. We model this using $\gamma := 0$ for $w < 0$. The proportionality factor is $\gamma := 0.9 \left[\frac{\partial\theta}{\partial z}\right]_{initial}$ so the inner-core is moist stable.

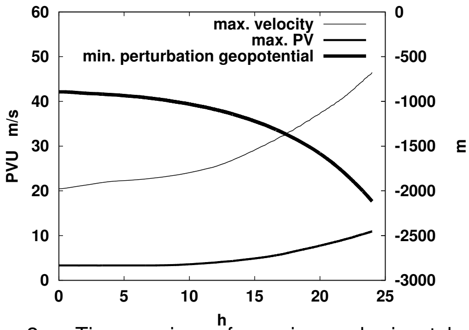

Figure 2: Time series of maximum horizontal velocity/maximum PV/minimum perturbation geopotential at lower ($z = 1.2km$) levels.

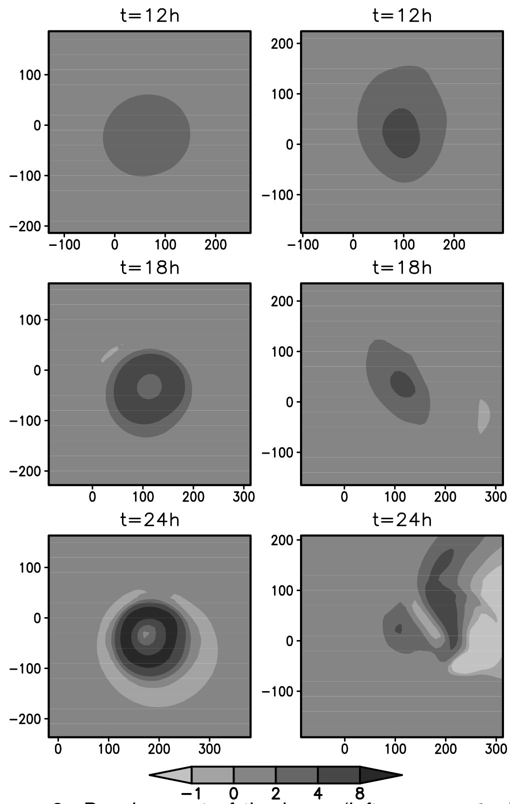

Figure 3: Development of the lower (left; $z = 1.2km$) and upper (right; $z = 10.8km$) PV anomalies (in PVU).

The vortex intensifies rapidly at lower levels from tropical storm to hurricane strength (Fig. 2). The PV increases at lower levels (Fig. 3), while at upper levels the PV anomaly decays and even becomes negative at $24h$. This filament of negative PV propagates outward. A ring of high PV develops around the vortex center at lower levels. Both the

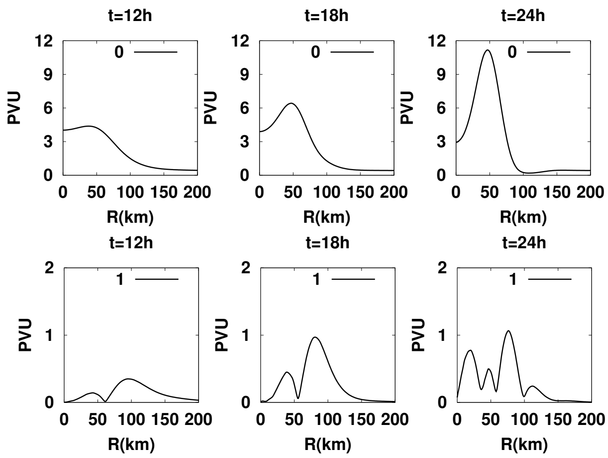

Figure 4: Azimuthal Fourier decomposition for PV at $z = 1.2km$ for wavenumbers 0 and 1.

wavenumber-0 and wavenumber-1 components of the low-level PV increase with time (Fig. 4). The wavenumber-0 maximum moves outward to $50km$ radius. Wavenumber-1 disturbances propagate inward and outward with time. The diabatic modification of PV due to the release of latent heat in the inner-core ascent and the subsequent axisymmetrisation of the PV field are responsible for the intensification. The intensification mechanism is that described by Möller and Montgomery (1999), but in this case the PV source/sink is linked to the shear induced vertical circulation and not specified externally. In the S calculations no intensification is observed because the heating on one side of the vortex and cooling on the other leads to low level PV anomalies of equal magnitude but opposite sign.

5. CONCLUSION

It was shown in this study that neutral moist static stability in the inner-core of a tropical cyclone significantly changes the behaviour of the asymmetric vertical circulation as observed in full physics calculations. If the region of saturated ascent is confined to one side of the tropical cyclone core the tropical cyclone can intensify. This result might explain why tropical depressions appear better able to withstand vertical shear than tropical storms (DeMaria 1996).

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