Tropical cyclone spin-up revisited

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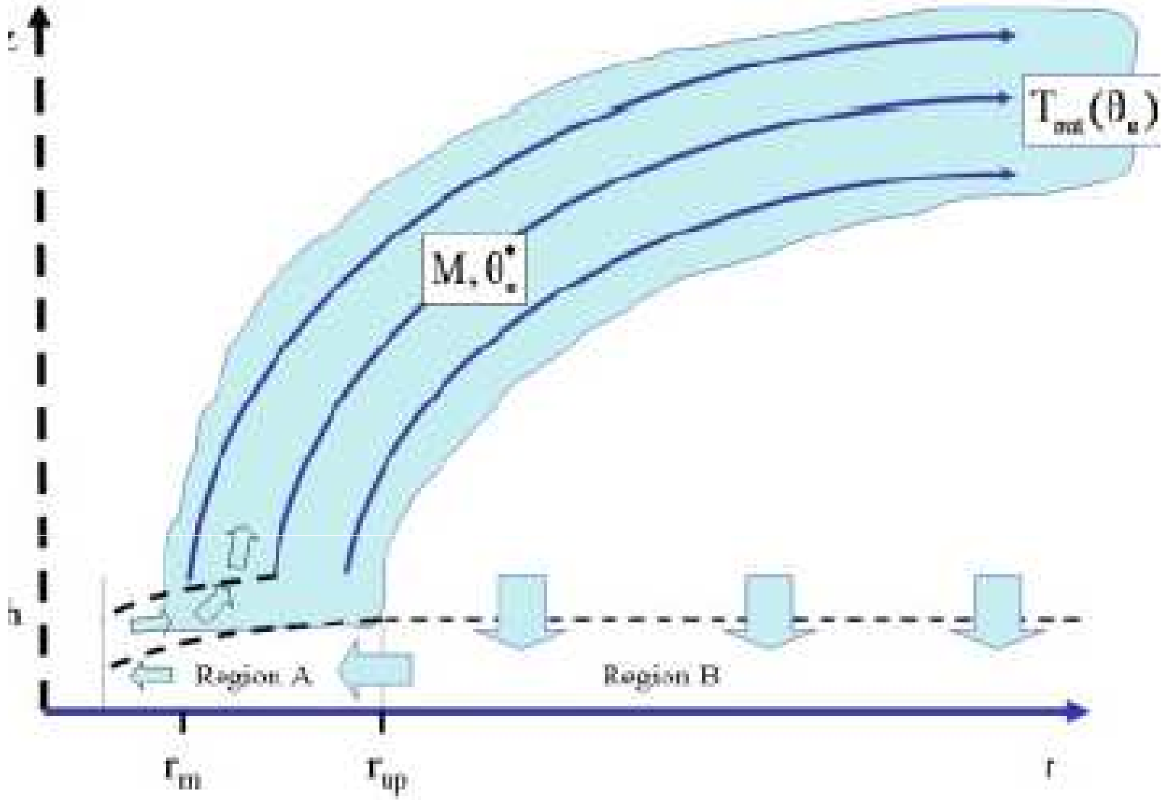
Introduction

- Investigating tropical cyclone amplification in a three dimensional model
- Problem posed as axisymmetric – flow becomes asymmetric
- 'vortical hot towers' (VHTs) – deep convective vortex structures
- What are the relative roles of convergence in the boundary layer to convergence above in the spin-up of the mean tangential winds, both in the inner core and in the region of gales?
- A revised model for the behavior of the boundary layer in the inner-core region, proposed by Smith *et al.* (2008)

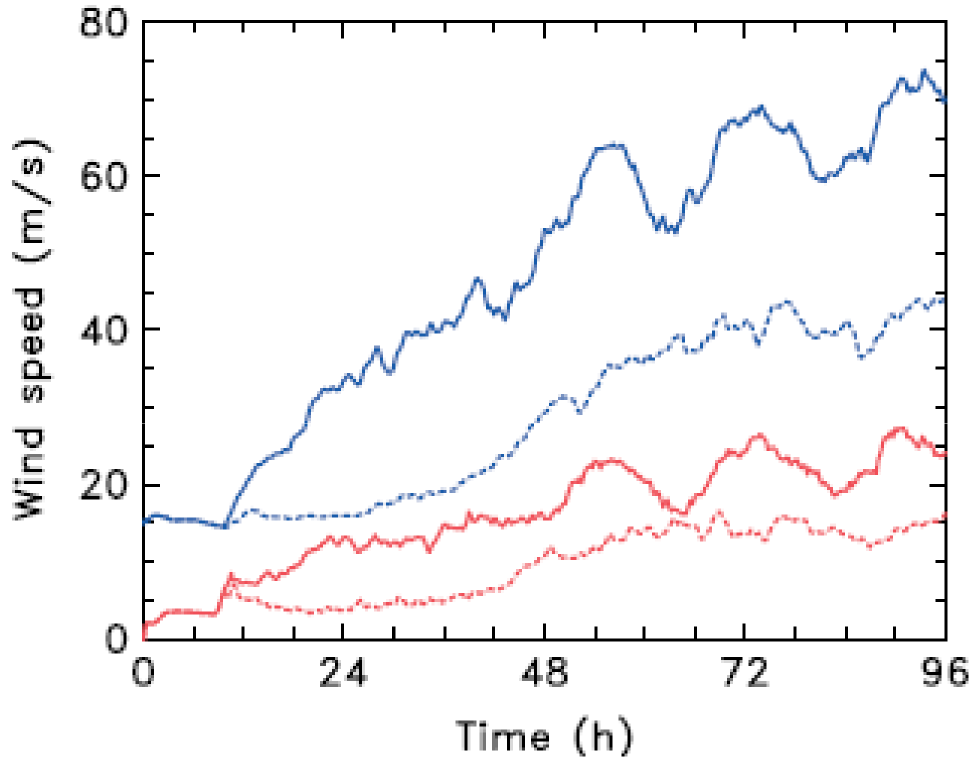


Conceptual model of the hurricane inner-core region
proposed by Smith *et al.* (2008)

Model

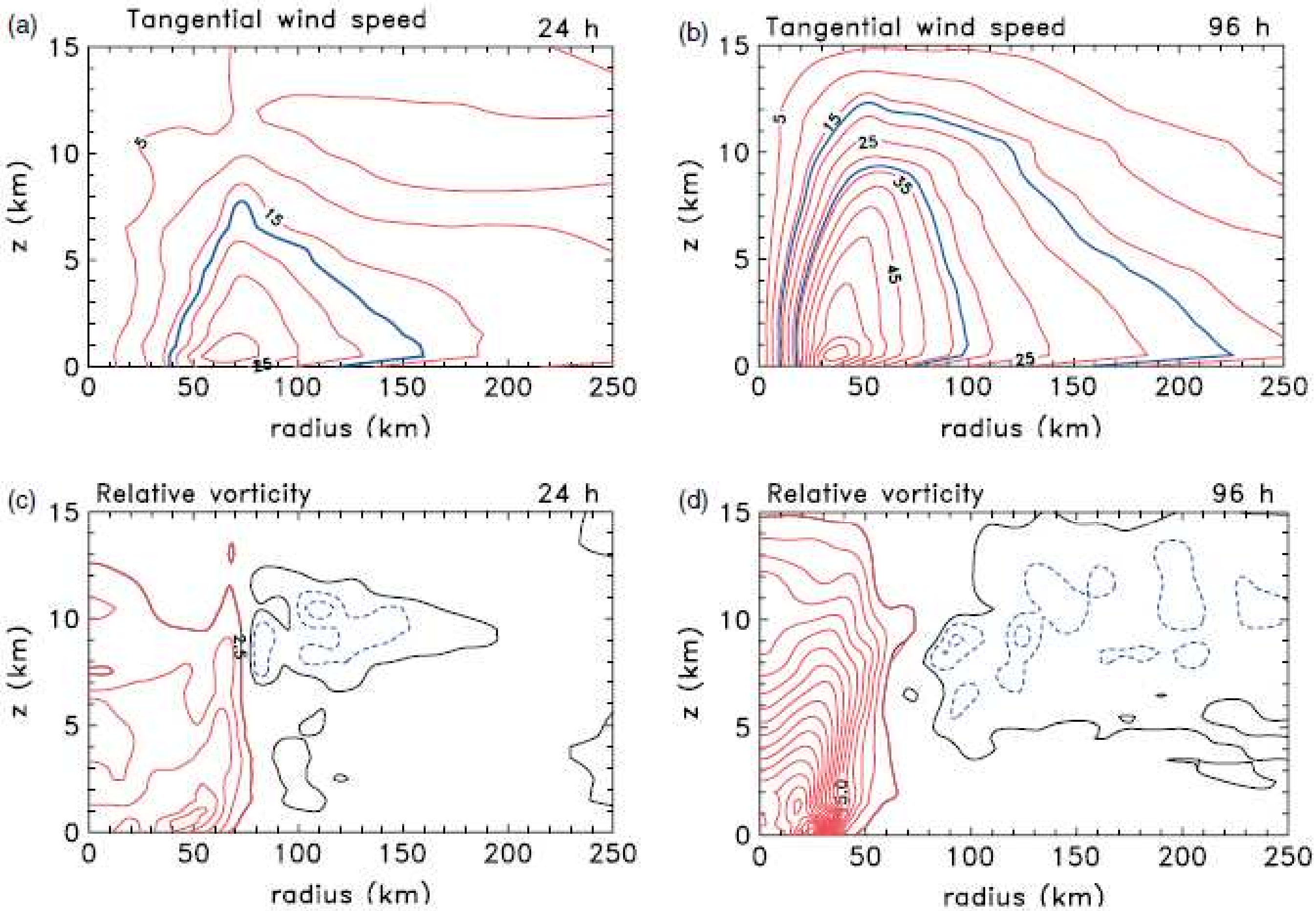
- MM5 model configured with three domains: a coarse mesh of 45 km resolution and two 2-way nested domains (15 and 5 km)
- 24 σ –levels in vertical, f-plane centered at 20°N
- bulk-aerodynamic boundary layer sheme
- Explicit moisture sheme / warm rain sheme – Experiment 1 / 2
- No cumulus parametrization
- Sea surface temperature 27°C
- The initial vortex:
  - axisymmetric
  - max tangential wind speed 15 m/s at the surface, radius of 135 km
  - Wind decreases sinusoidally with height, vanishing at 50 mb
- Temperature field – initialized to be in gradient wind balance with the wind field

Rapid intensification and maturity



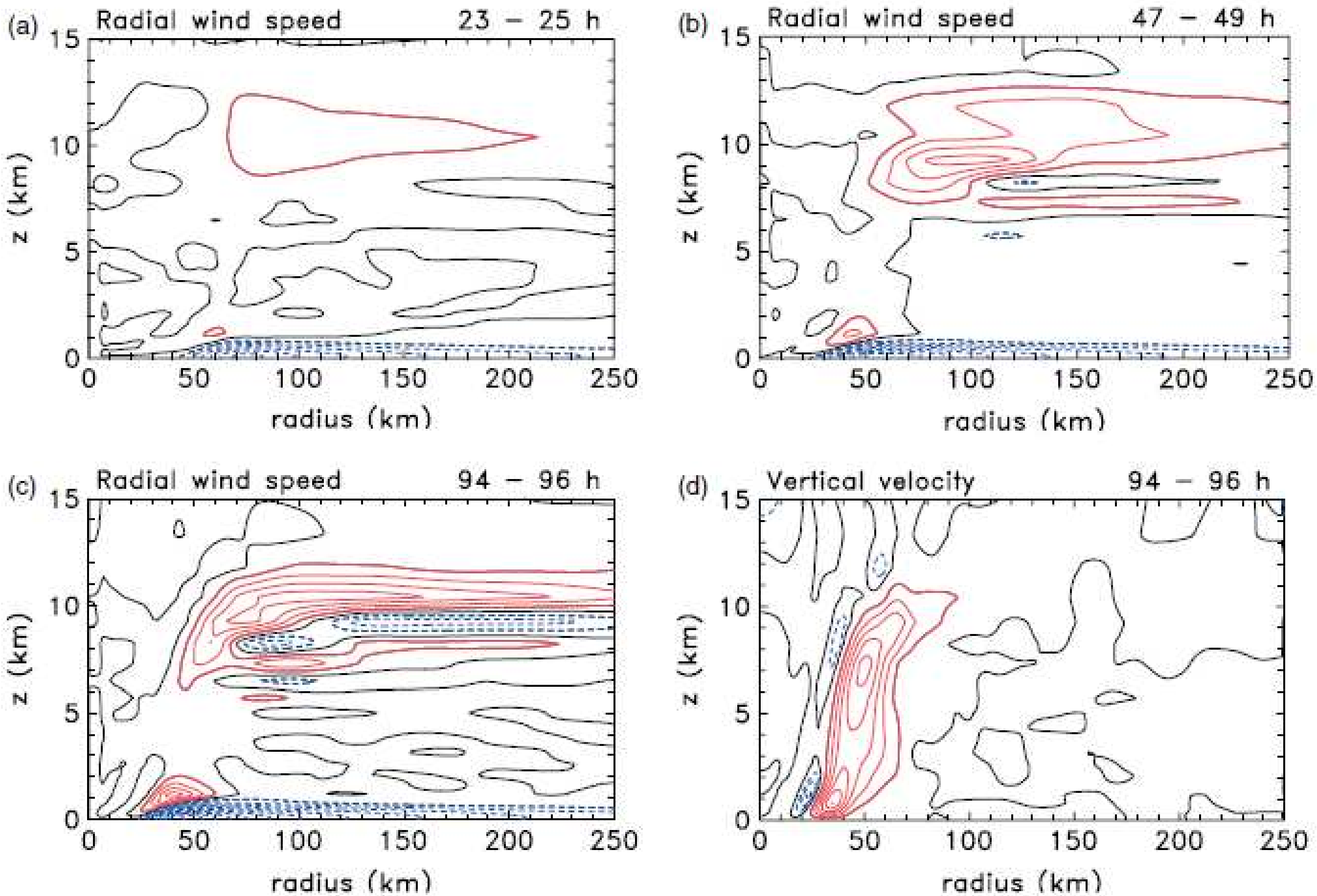
Vortex development in control and warm-rain experiments. Time series of azimuthal-mean maximum tangential wind component (blue) and minimum radial wind component (sign reversed, red) in Experiment 1 (solid) and Experiment 2 (dashed)

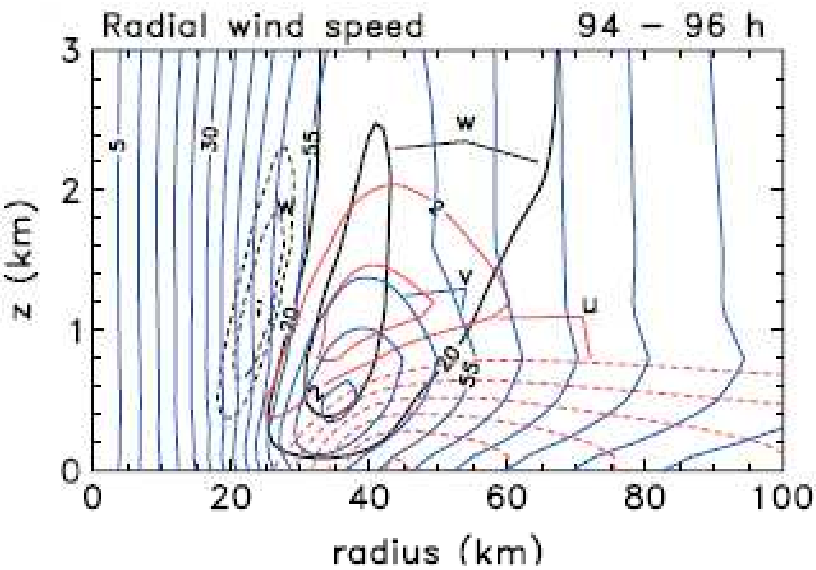
Azimuthally averaged aspects



Azimuthal-mean tangential wind speed and vertical component of relative vorticity in Experiment 1 at 24 and 96 hours

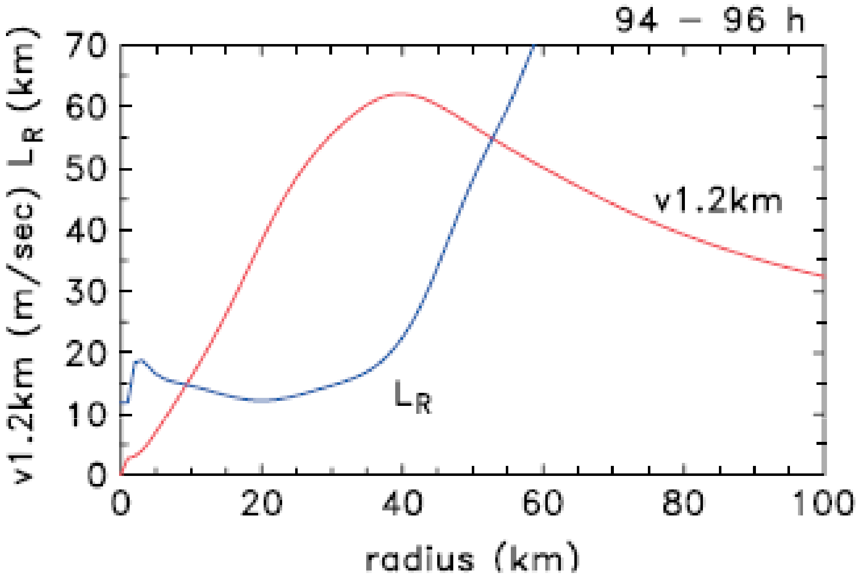
Time-averaged fields





Radial (u), tangential (v) and vertical velocity (w) in the inner core region

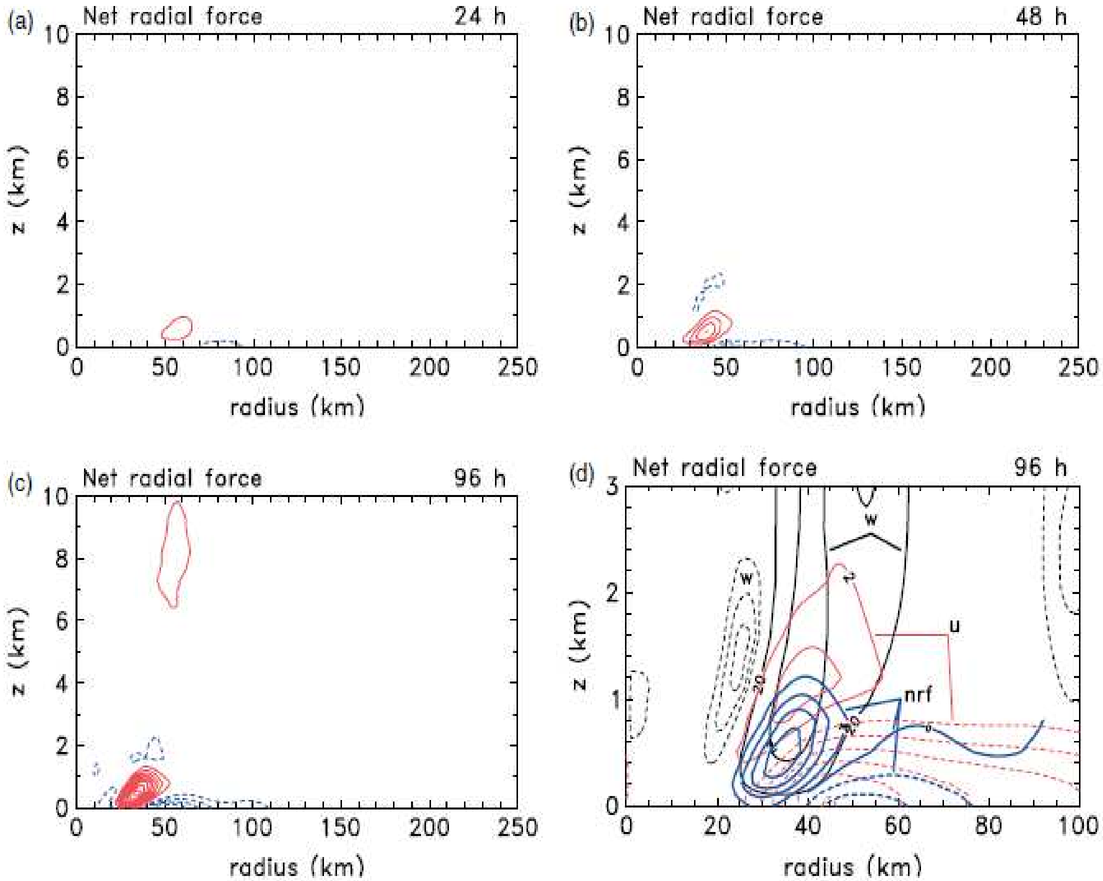
- V_{max} near the top of the boundary layer and within the region of strongest ascent
- Little above V_{max} large radial component (>8 m/s)
- W_{max} at 800m, declines with height – result of termination of the inflow
- Narrow region of subsidence in the eye



Tangential wind and estimated Rossby length at a height of 1.2 km

- Shubert *et al.* (2007) – region of subsidence in the eye when average L_R in it less than 0.6 times eye radius (R_{max})
- L_R =(f/I)*1000 km; I - inertial stability parameter
- Average L_R =14 km; 0.6 R_{max} = 24 km – consistent with theory

Net radial force

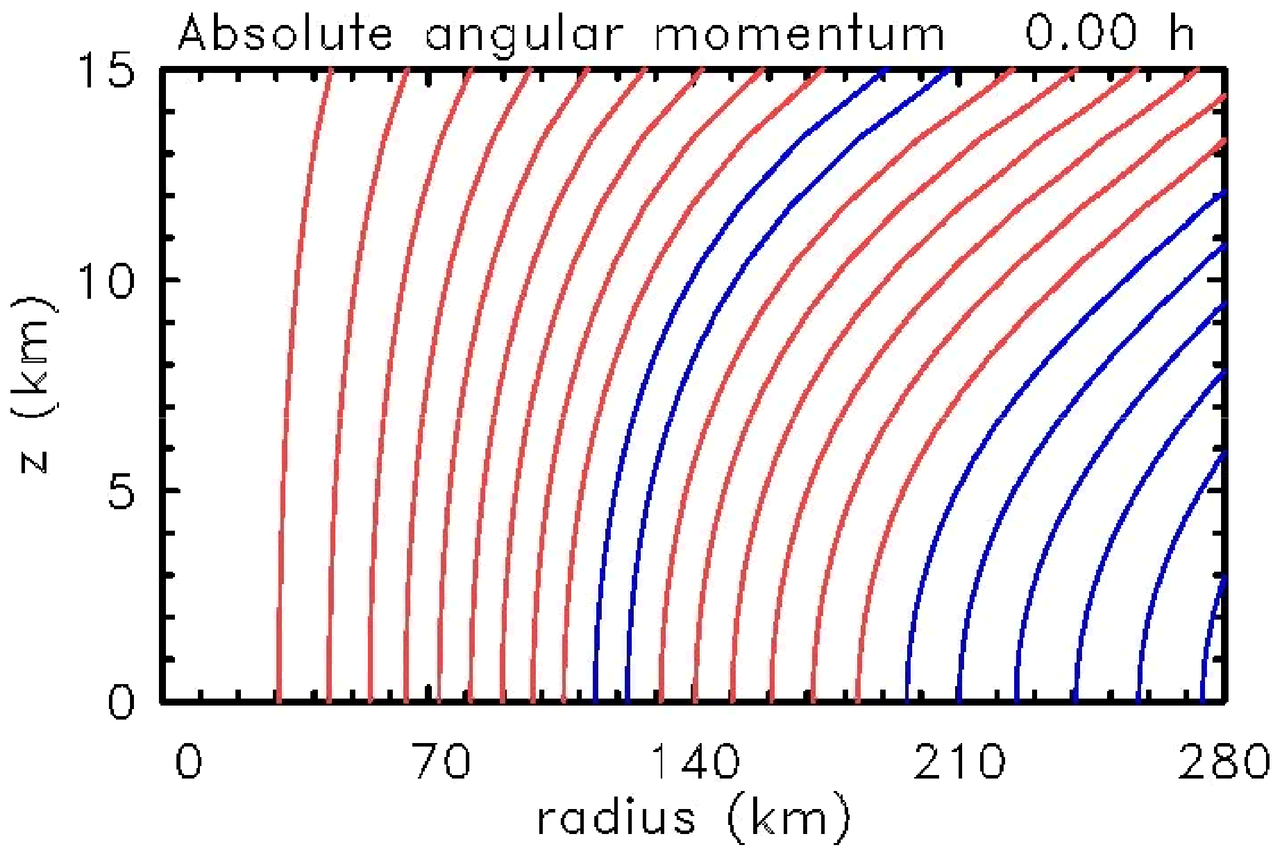


- Net radial force

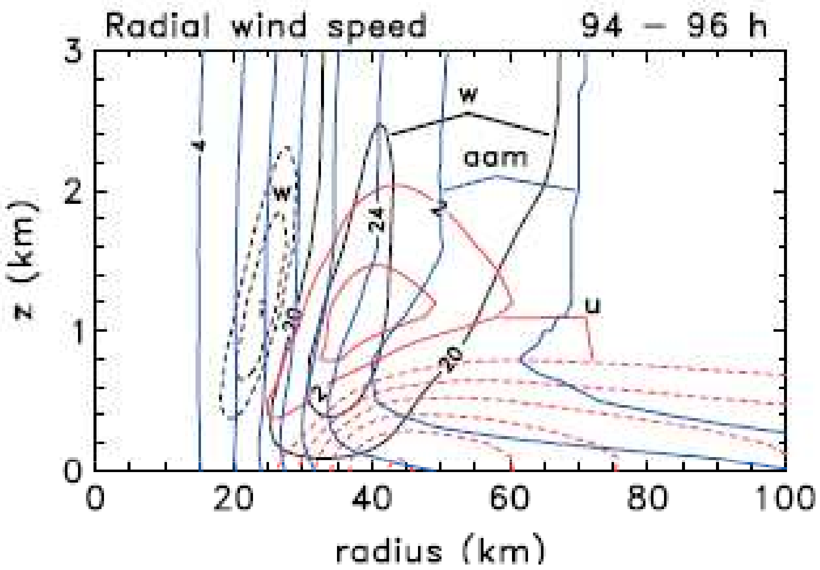
$$F = -\frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{v^2}{r} + fv$$

- F<0 subgradient
- F>0 supergradient
- F=0 gradient wind balance

- Main low level flow aproximately coincidents with the region of subgradient flow



Absolute angular momentum 0.00 h
15
10
5
0
z (km)
0
70
140
210
280
radius (km)

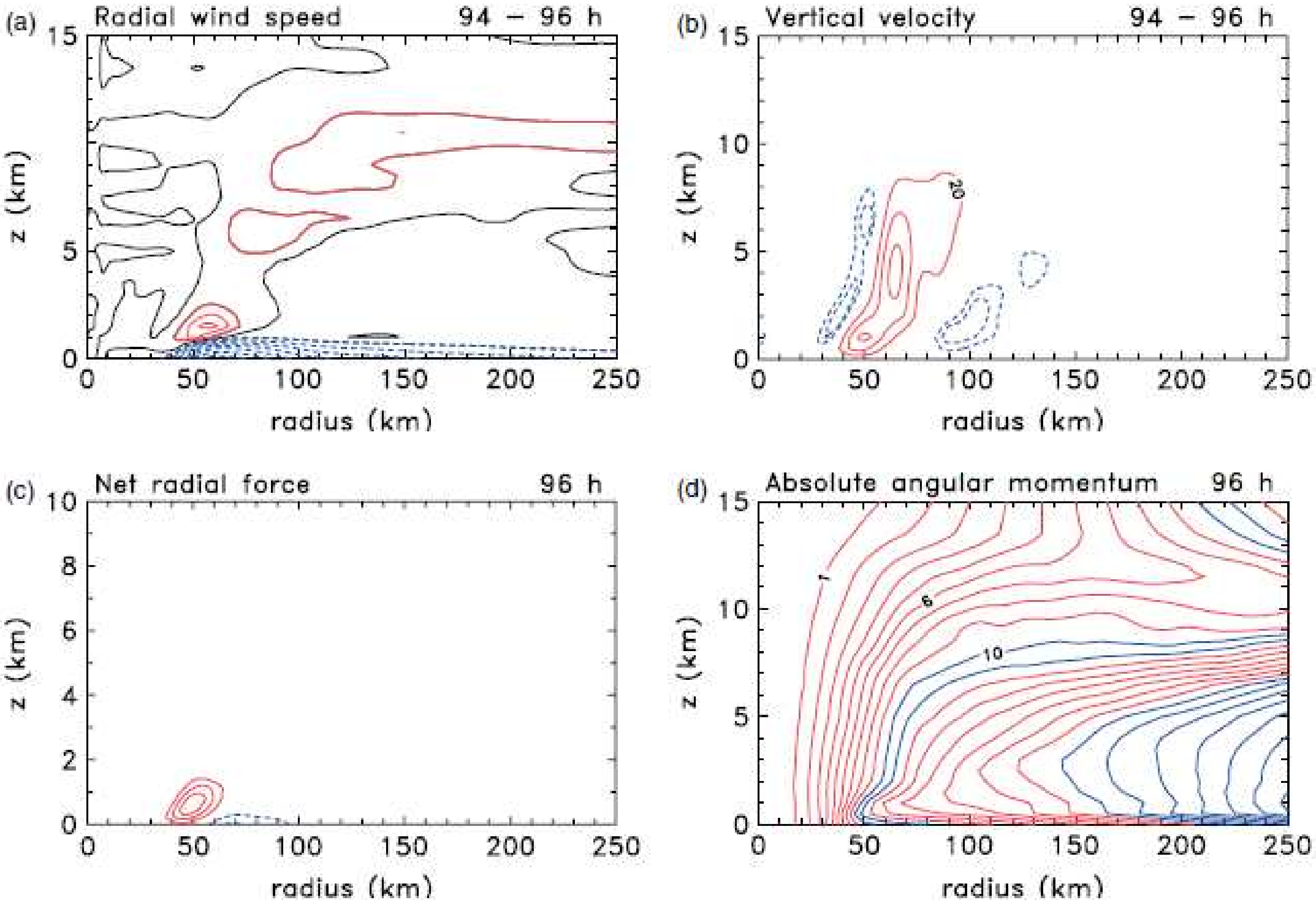


Radial velocity (u), vertical velocity (w; interval 0.6 m/s and 0.05 m/s for w<0) and absolute angular momentum (aam; interval $4x10^5 m^2/s$)

- Contours of aam:
  - Small angle to the horizontal at low levels (below 500m) – radial inflow is strong – diffusion (surface)
  - Largest inward displacement near the top of the inflow layer
  - Nearly vertical where the radial flow is weak
  - Slope upwards and outwards (same as flow) immediately above the inflow layer – material conservation of angular momentum

Intensification of the inner core – low-level proces tied strongly to the dynamics of the boundary layer

The effects of warm rain



Conclusion

- Two mechanisms for vortex intensification (both involving the radial convergence of absolute angular momentum):
    1. Mechanism associated with radial convergence above the boundary layer + conservation of absoulte angular momentum - flow achieves gradient wind balance
    2. Mechanism associated with radial convergence within the boundary layer - important in the inner core – flow not in gradient wind balance
- Supergradient winds support second mechanism – carried upwards and outwards – conceptual model proposed by Smith *et al.* (2008)
- Existence of these two mechanisms – explanation for long-standing observations of typhoons by Weatherford and Gray

- Relation between boundary layer convergence and bouyant forcing of the vortex aloft?


Thank you!