Understanding Atypical Mid-Level Wind Speed Maxima in Hurricane Eyewalls

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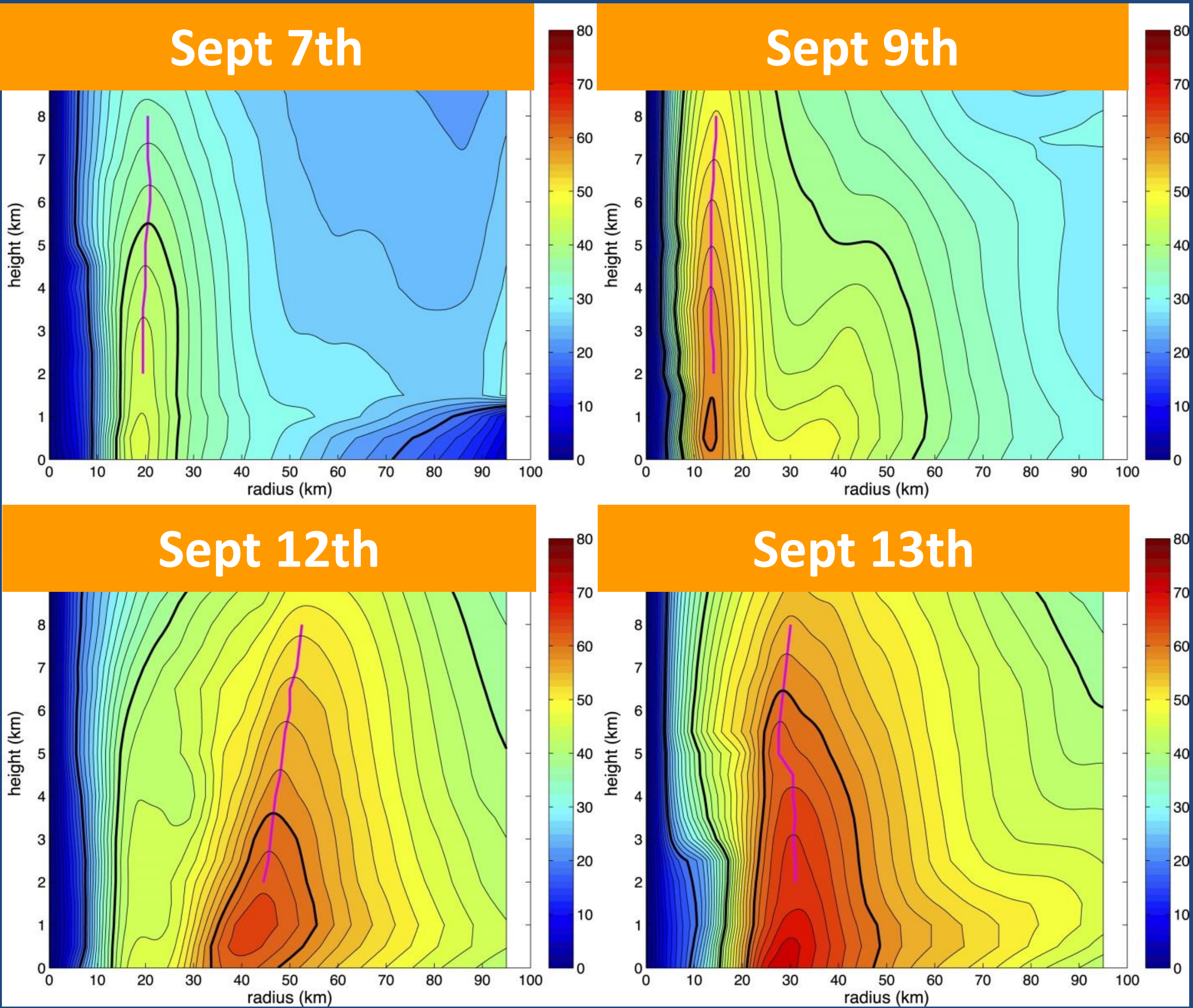
Source: NASA/ISS

Motivation

- Eyewall winds are typically maximized at the top of the boundary layer (~500-1000 m), and decrease monotonically upwards.
- In Patricia (2015), there is an atypical profile, with an additional maximum at mid-levels (4-5 km).
- Here, we show that this structure is likely a consequence of systematic unbalanced flow.

Typical Radius-Height Wind Structure

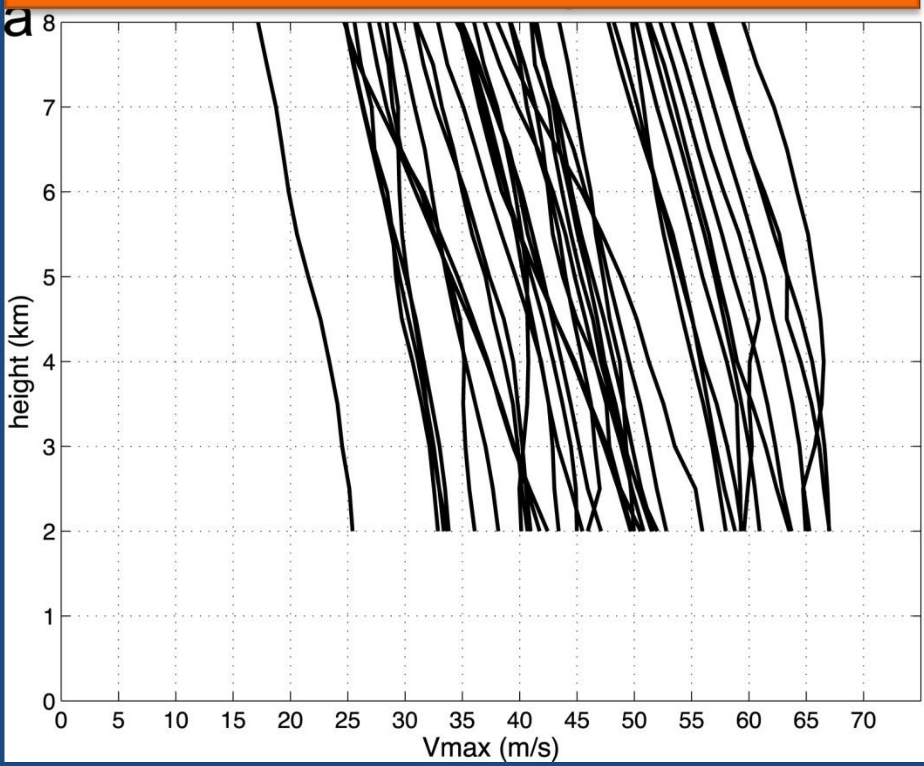
Hurricane Ivan (2005)



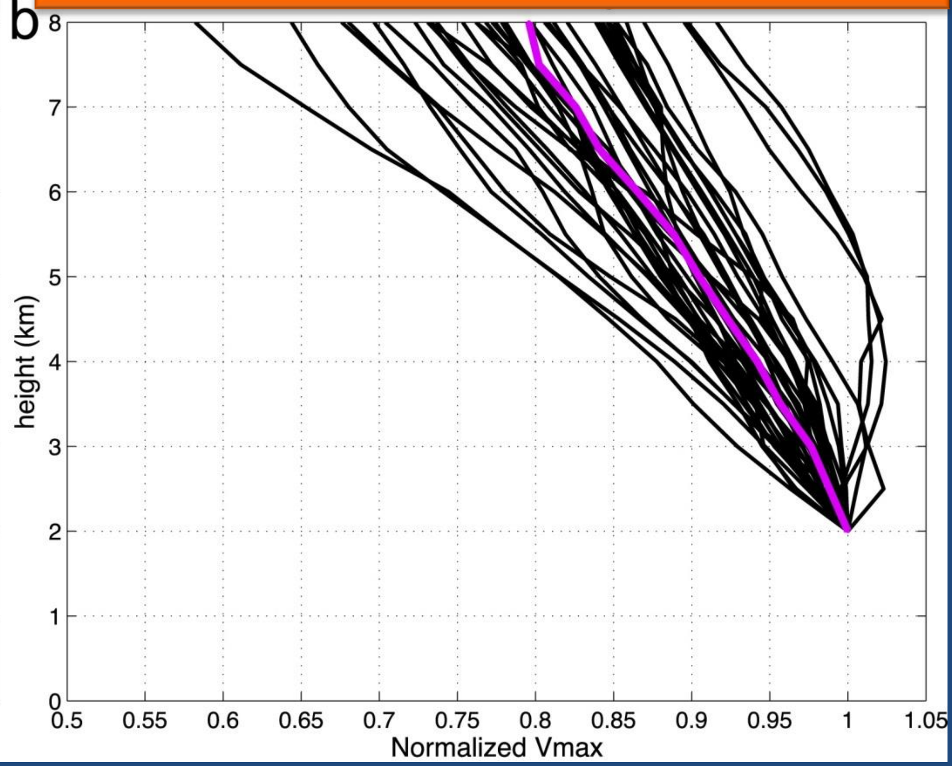
Stern et al. (2014)

Vertical Profiles of Tangential Wind

Az. Mean Vmax vs. Height



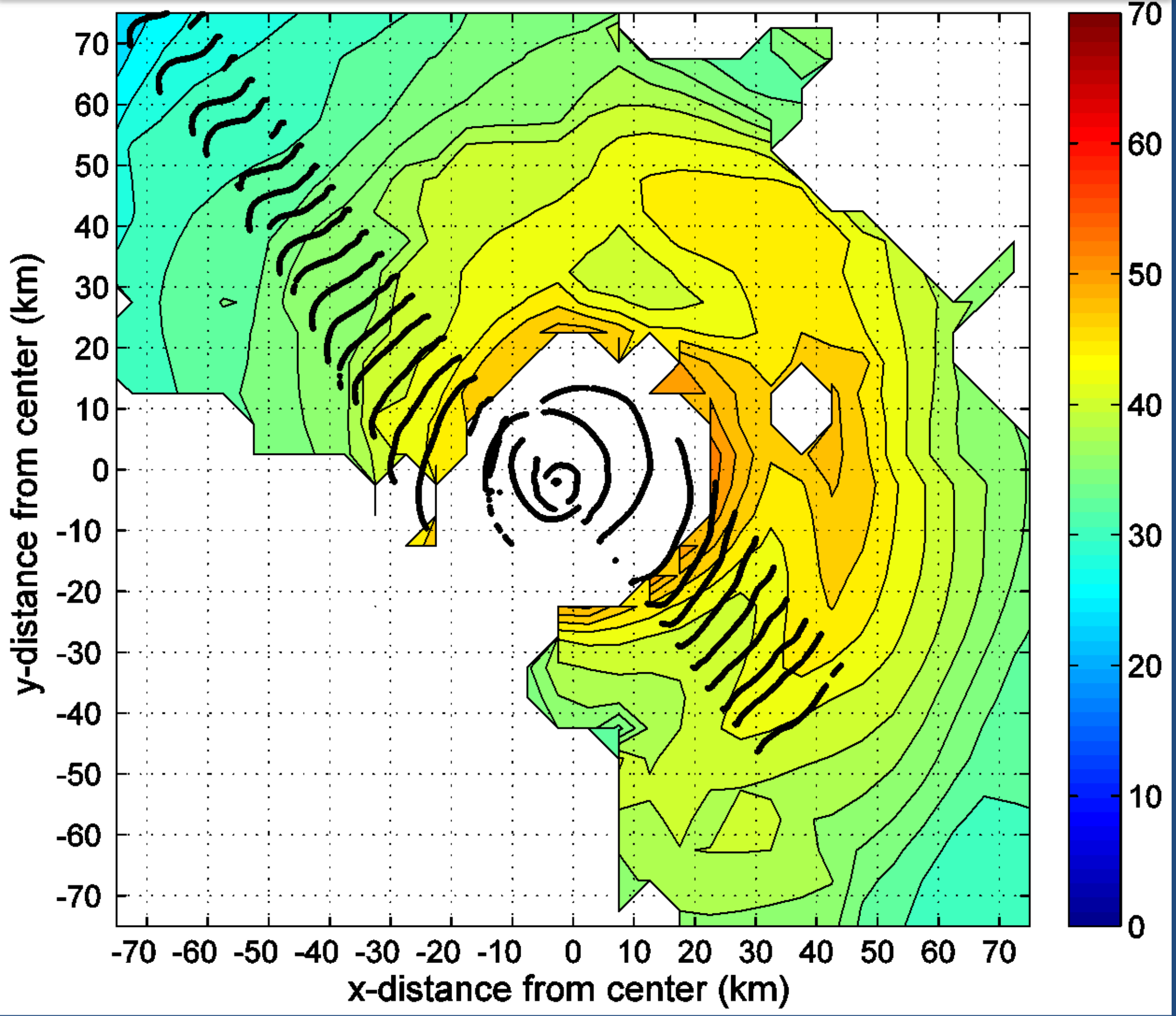
Normalized Vmax vs. Height



Stern et al. (2014)

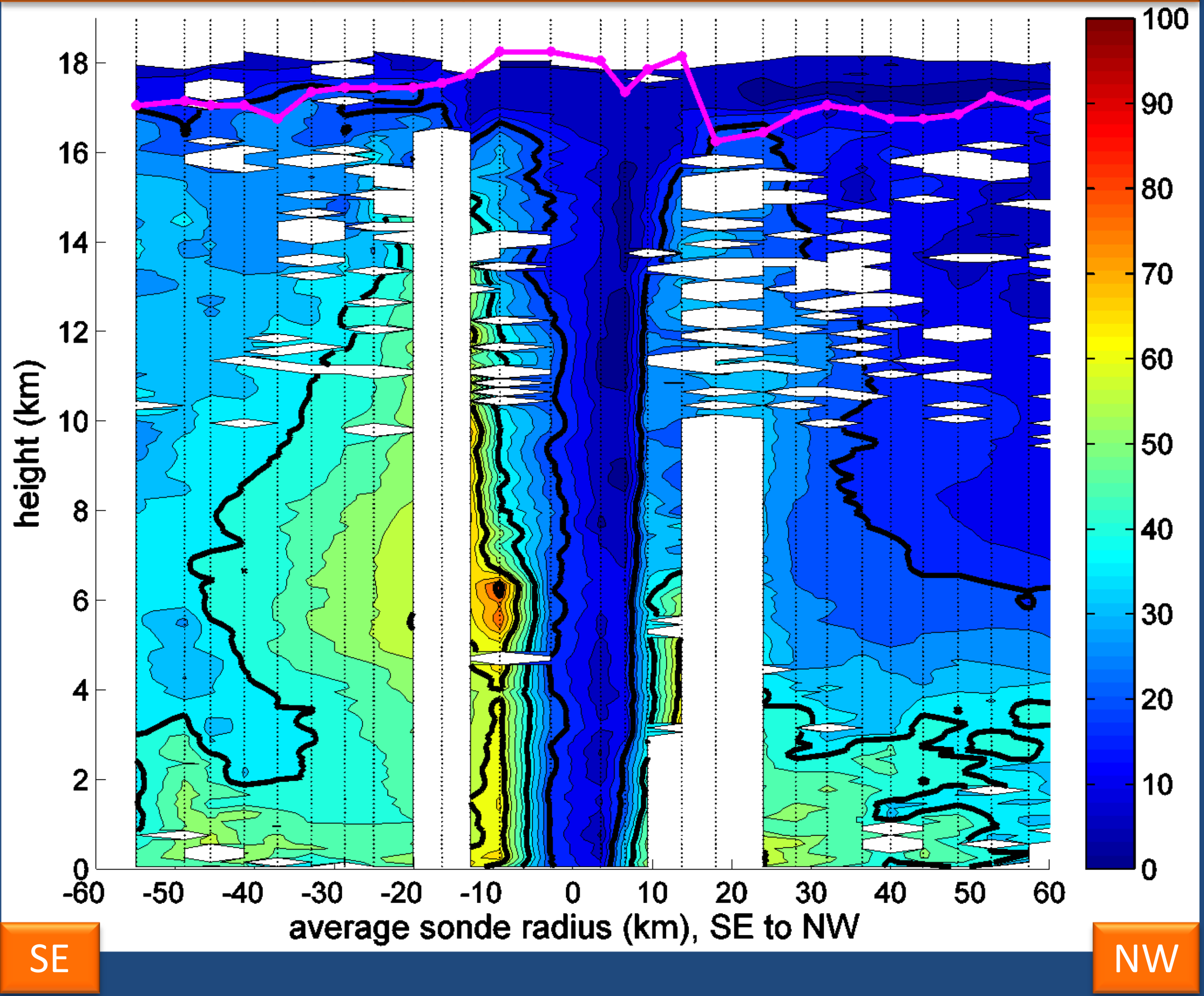
Wind Speed at z=2 km and Dropsonde Trajectories

Hurricane Patricia (10/23/15)



Wind Speed from TCI Dropsondes

Patricia (10/23/15), ~2000 UTC

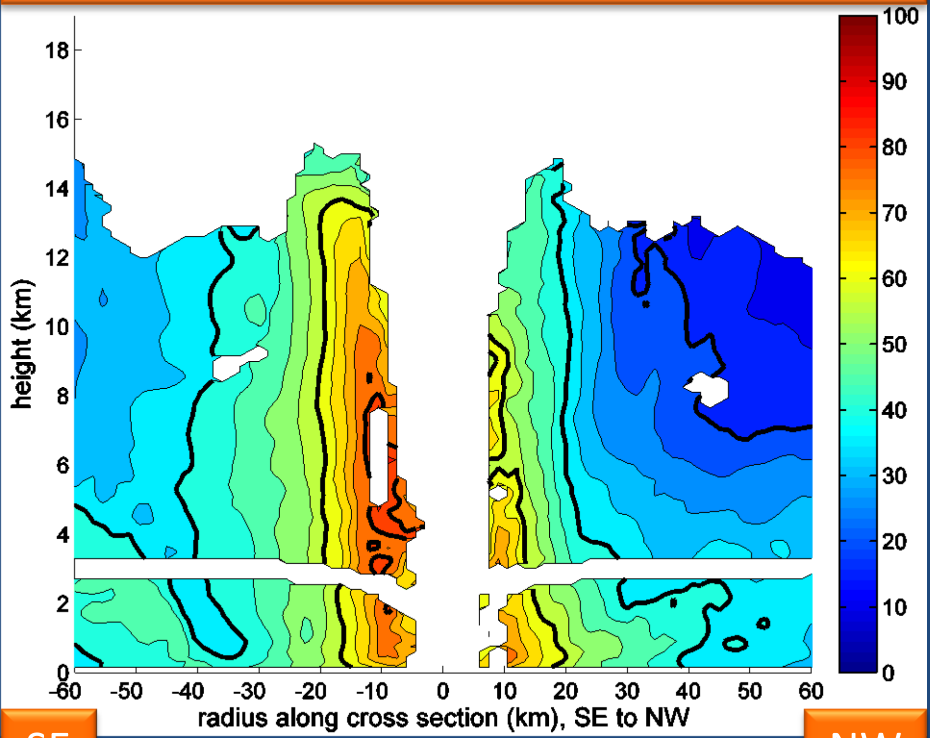


Tropopause

Radius of Dropsonde

Wind Speed from P3 Doppler Analyses

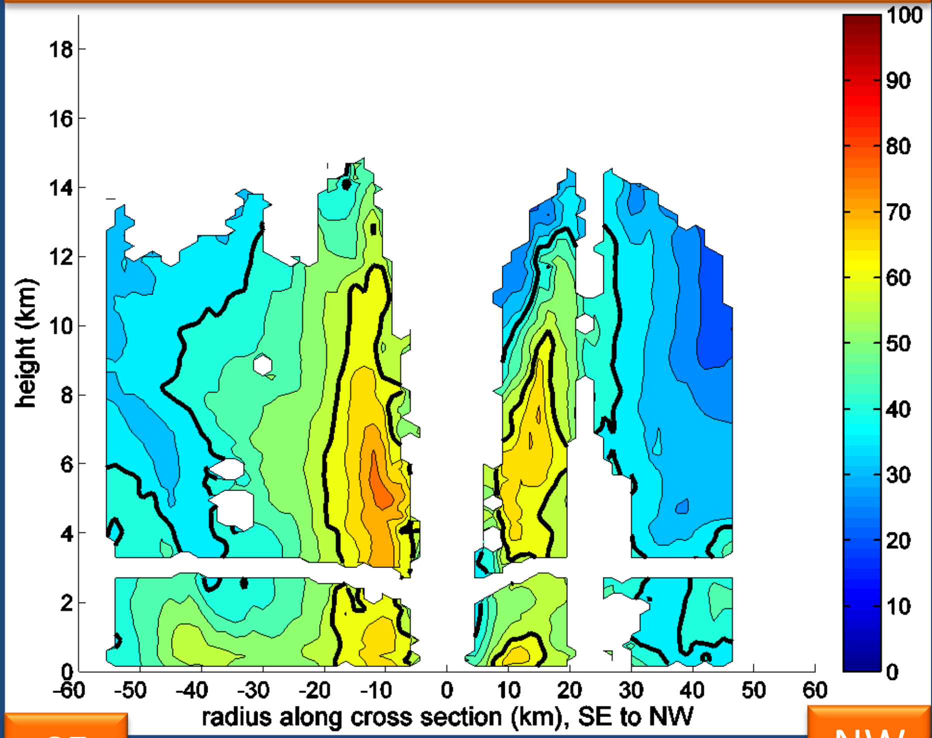
SE to NW Leg (~1730 UTC)



SE

NW

SE to NW Leg (~2030 UTC)

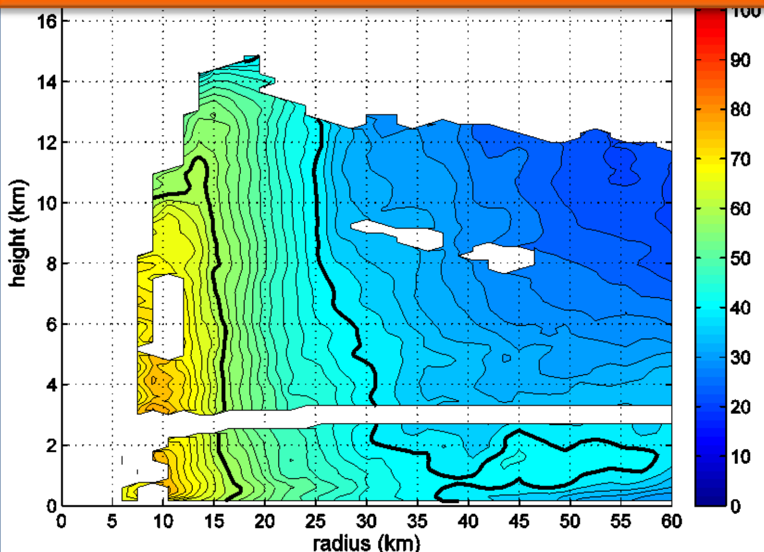


SE

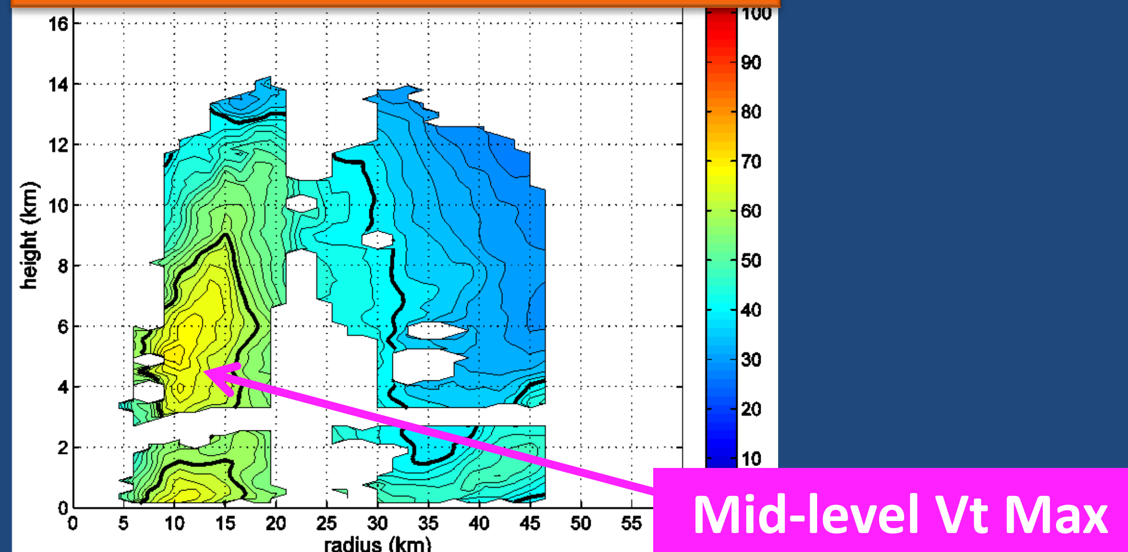
NW

Azimuthal Mean Vt and Vr from P3 Doppler Analyses

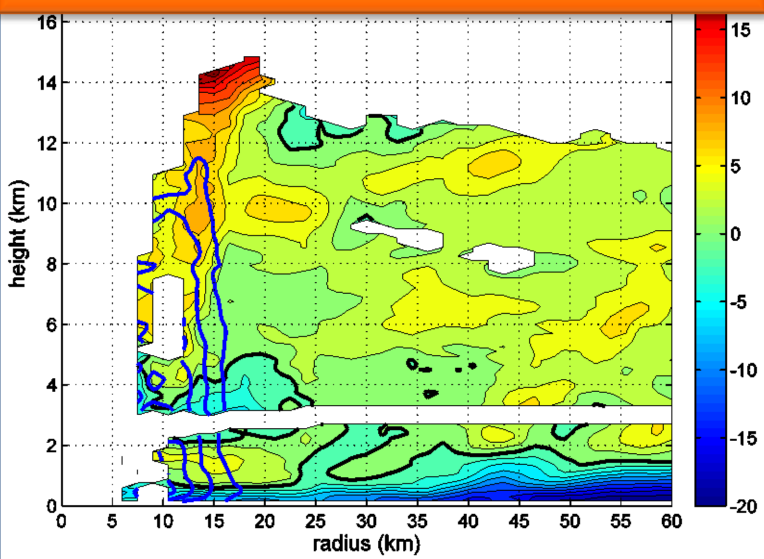
Vt (1730Z), max = 78 m/s



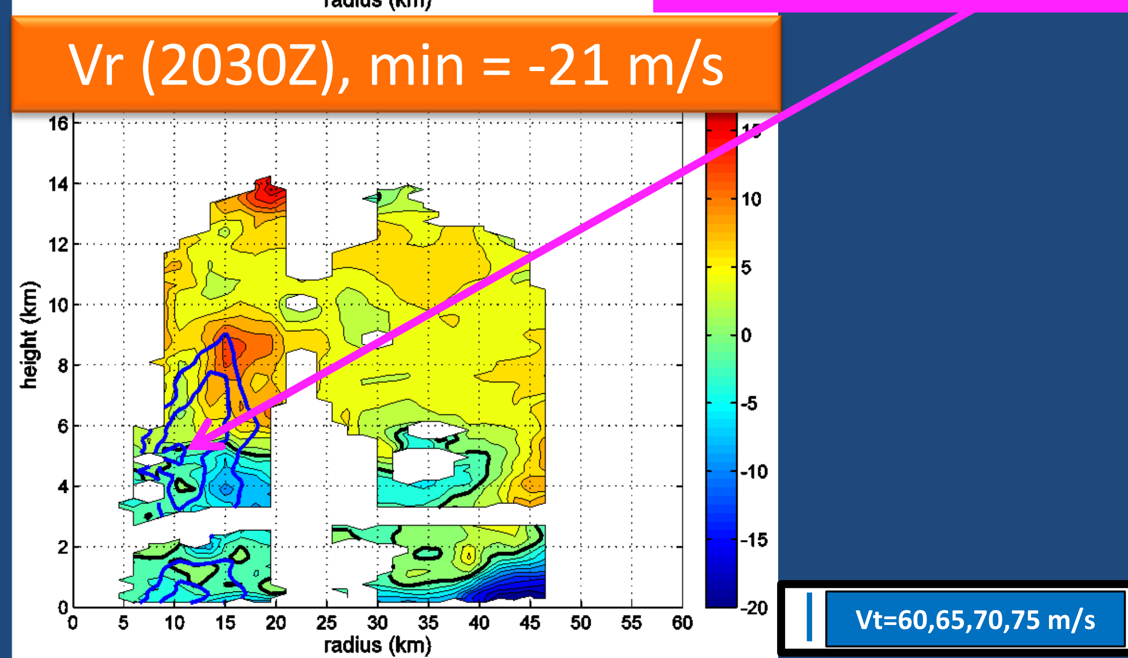
Vt (2030Z), max = 71 m/s



Vr (1730Z), min = -22 m/s

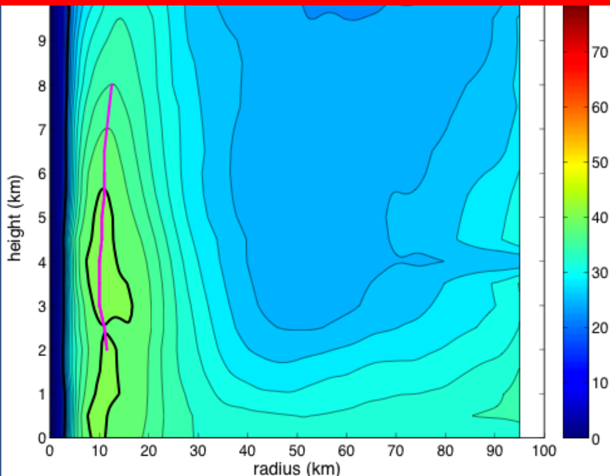


Vr (2030Z), min = -21 m/s

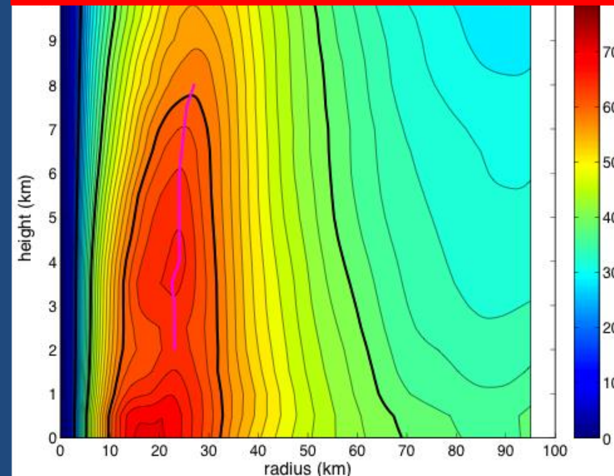


This Atypical Wind Structure is Not Unique to Patricia

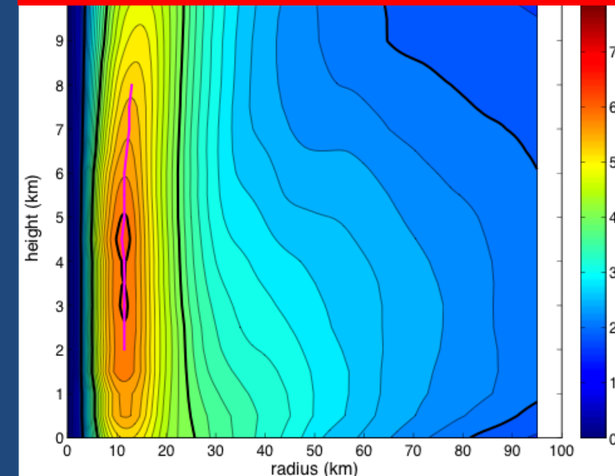
Dennis 07/10/2005



Rita 09/21/2005

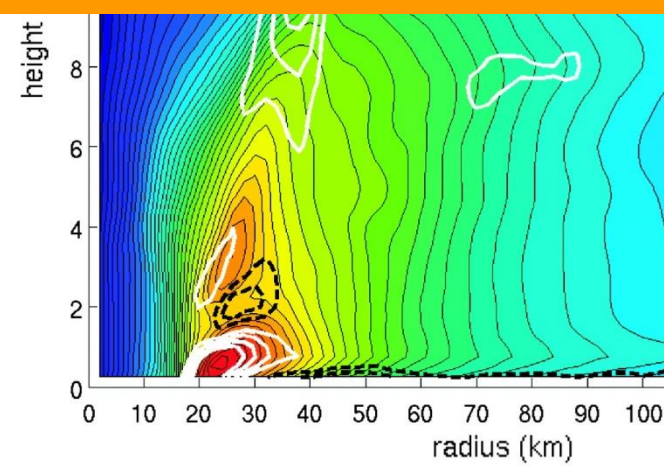


Felix 09/03/2007

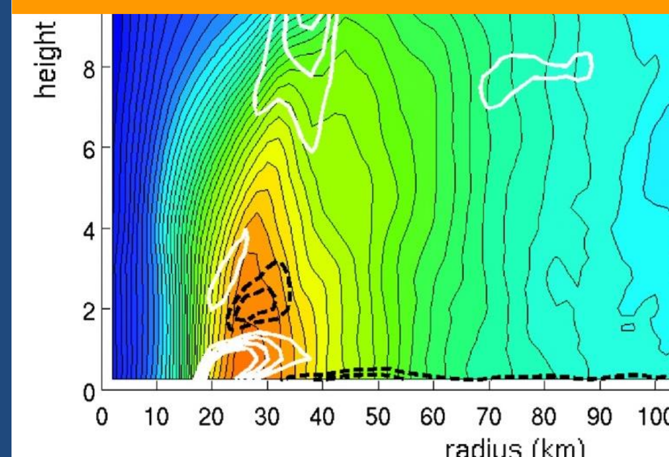


Idealized WRF Simulation

Tangential Wind



Gradient Wind



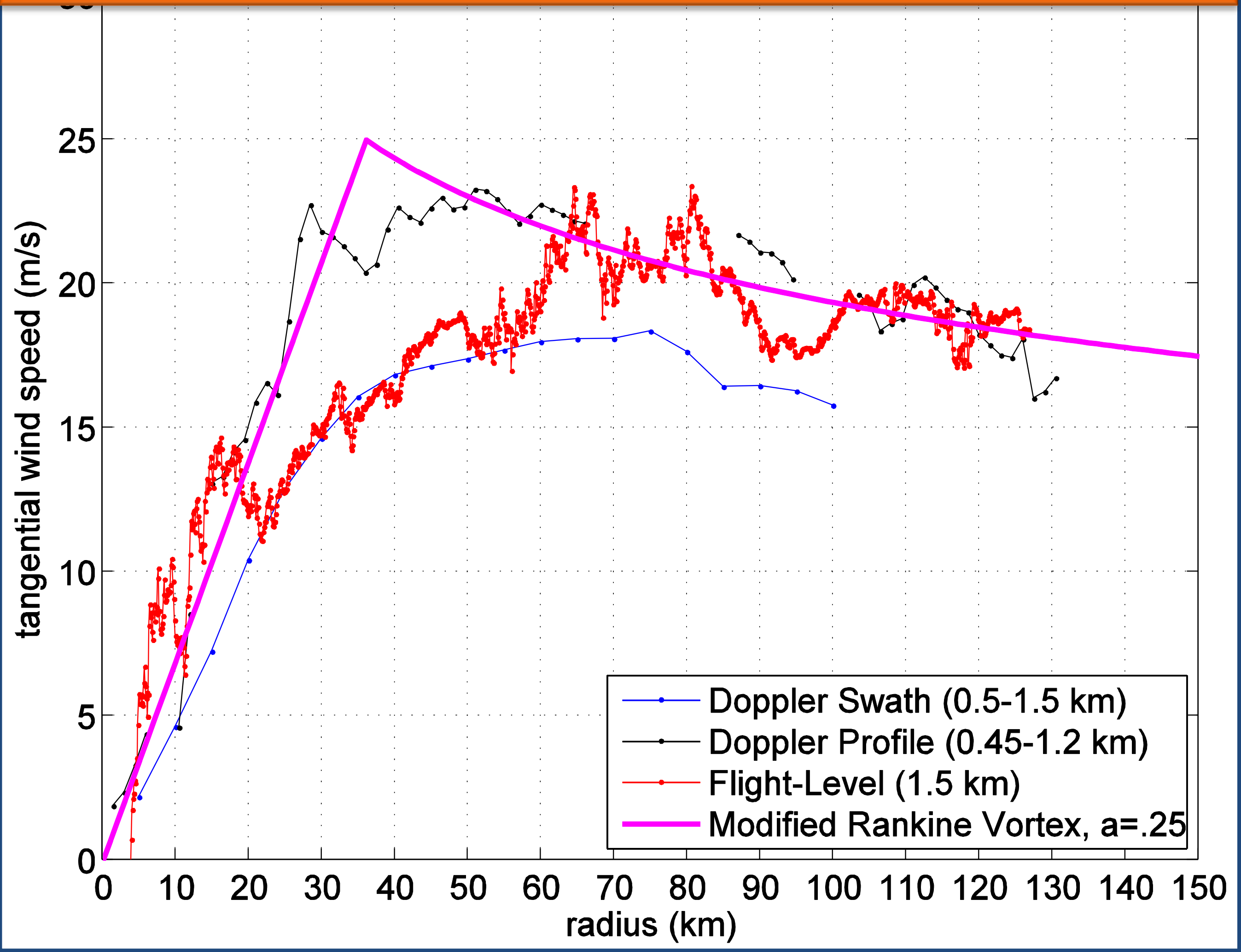
Supergradient Flow

Subgradient Flow

Stern et al. (2014)

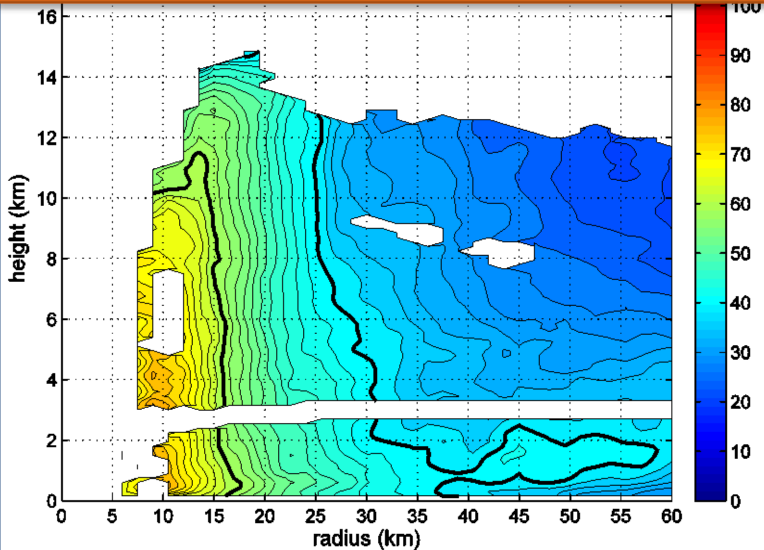
Modeling an Idealized Patricia

Tangential Wind vs. Radius, Patricia 10/21/15

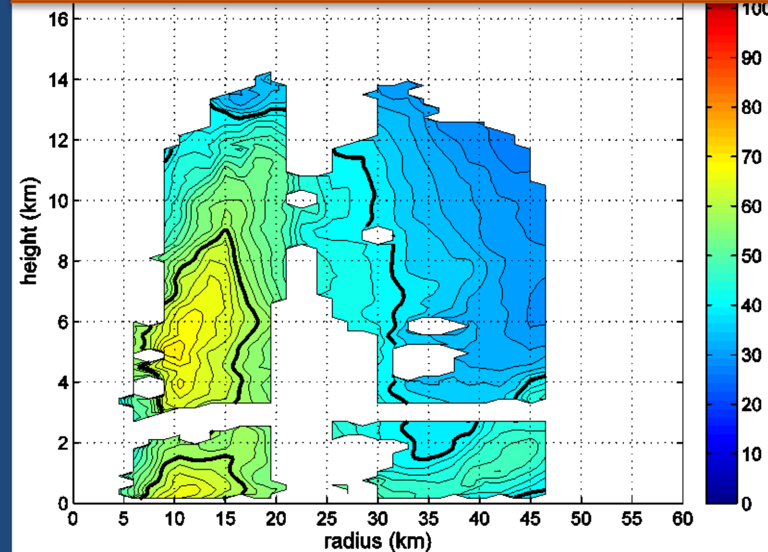


Example Axisymmetric CM1 Simulation

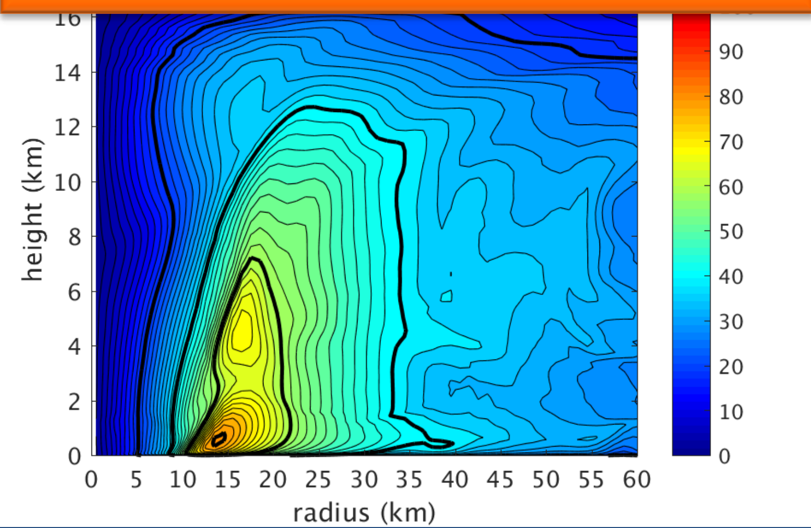
Vt (1730Z), max = 78 m/s



Vt (2030Z), max = 71 m/s

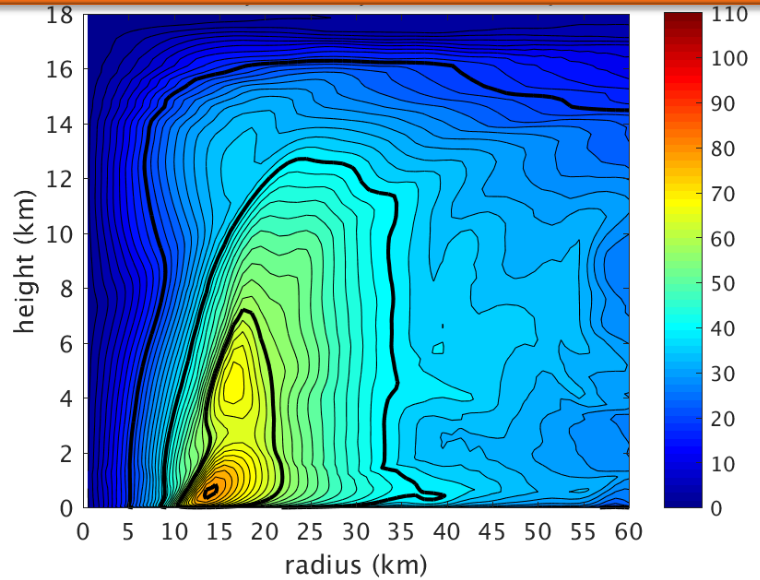


CM1 Vt (t=37h), max = 81 m/s

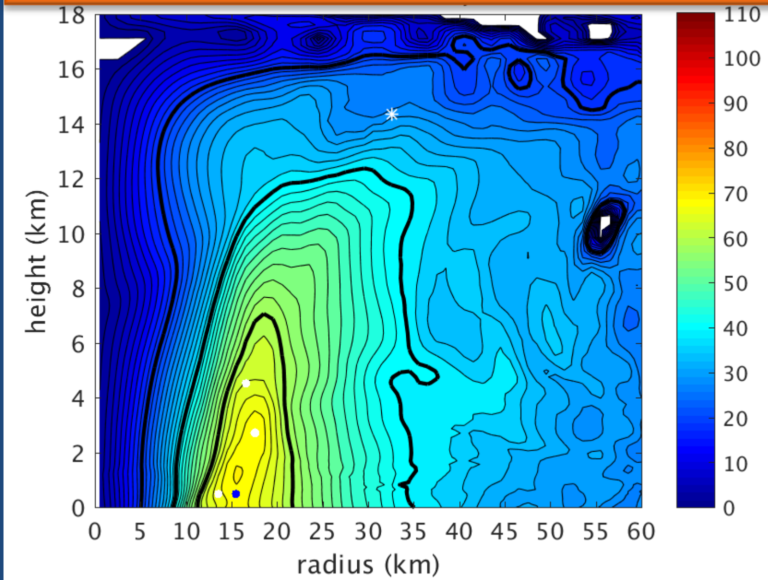


Example Axisymmetric CM1 Simulation

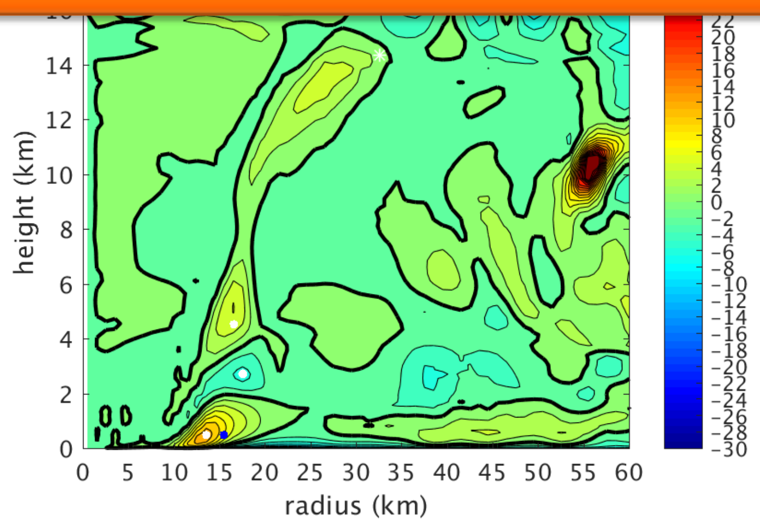
Vt, max = 81 m/s



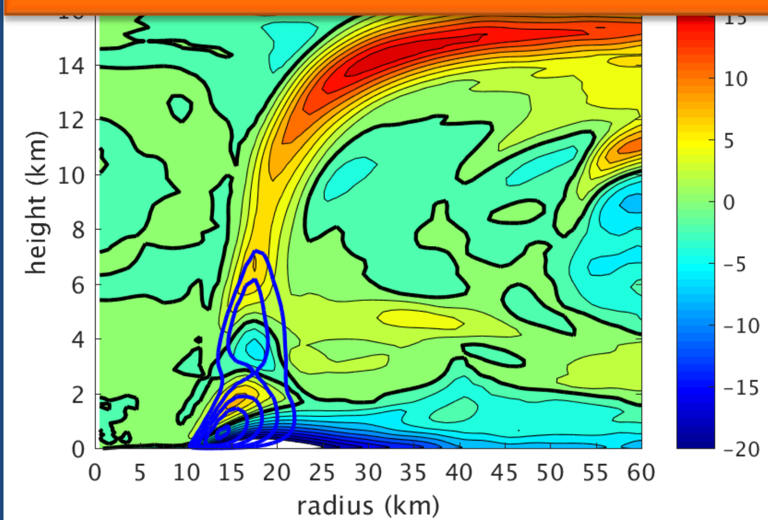
Gradient Wind (Vg)



Agradient Wind (Vt-Vg)



Radial Wind



Unbalanced Flow

Steady-state and Symmetric Radial Momentum Equation

$$u\frac{\partial u}{\partial r} + w\frac{\partial u}{\partial z} - \left(f + \frac{v}{r}\right)v = -\frac{\partial \phi}{\partial r} + DIFFUSION$$

If there is no advection or diffusion:

$$\cancel{u\frac{\partial u}{\partial r}} + \cancel{w\frac{\partial u}{\partial z}} - \left(f + \frac{v}{r}\right)v = -\frac{\partial \phi}{\partial r} + \cancel{DIFFUSION}$$

Then we get gradient wind balance

$$\left(f + \frac{v}{r}\right)v = \frac{\partial \phi}{\partial r}$$

Kepert (2001)

Unbalanced Flow

If advection and/or diffusion are non-zero, we get unbalanced flow

$$u\frac{\partial u}{\partial r} + w\frac{\partial u}{\partial z} - \left(f + \frac{v}{r}\right)v = -\frac{\partial \phi}{\partial r} + DIFFUSION$$

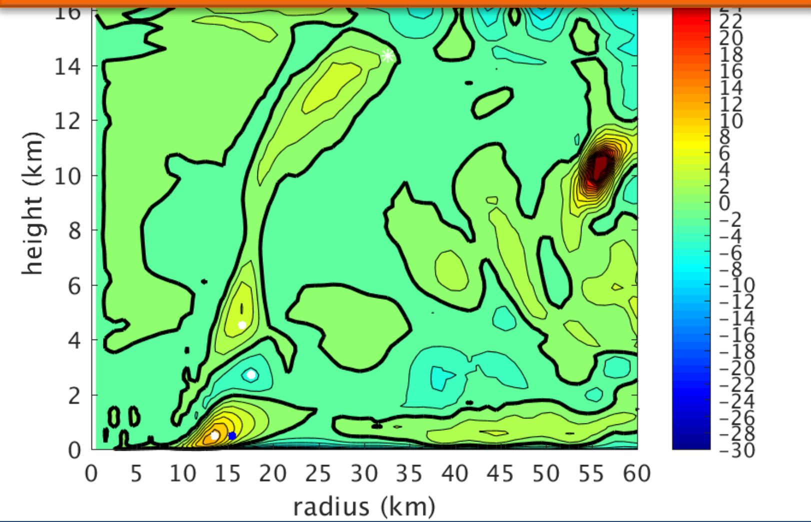
$u\frac{\partial u}{\partial r} > 0$ AND/OR $w\frac{\partial u}{\partial z} > 0$ Contribute to supergradient flow

$u\frac{\partial u}{\partial r} < 0$ AND/OR $w\frac{\partial u}{\partial z} < 0$ Contribute to subgradient flow

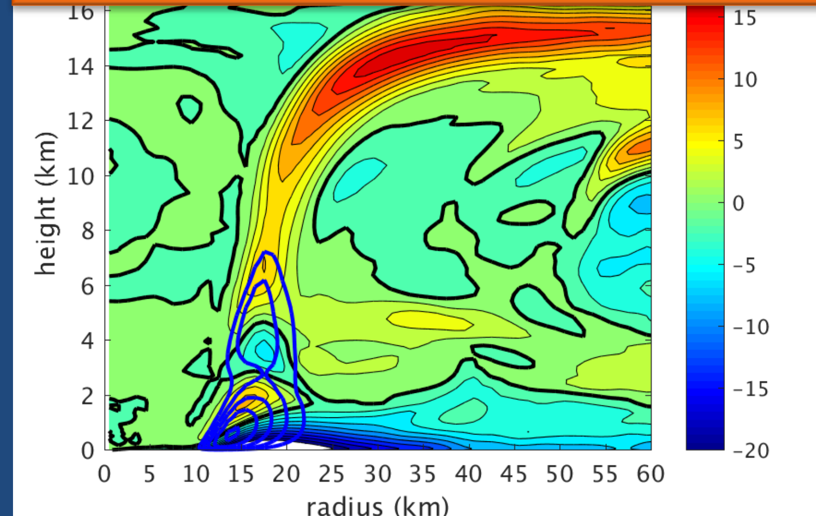
Kepert (2001)

Contributions of Radial and Vertical Advection

Agradient Wind (Vt-Vg)



Radial Wind



Inflow decreasing inwards
Ouflow increasing outwards
Vr increasing with height in an updraft

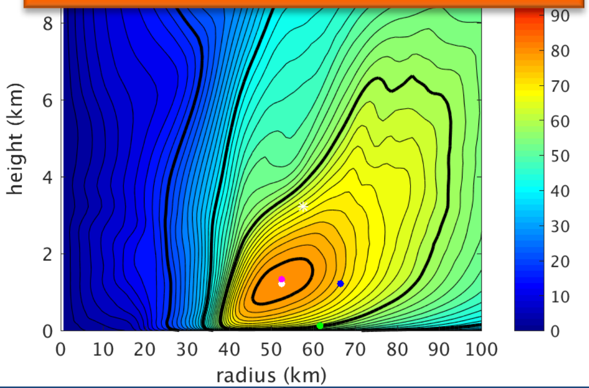
↓

Supergradient Flow

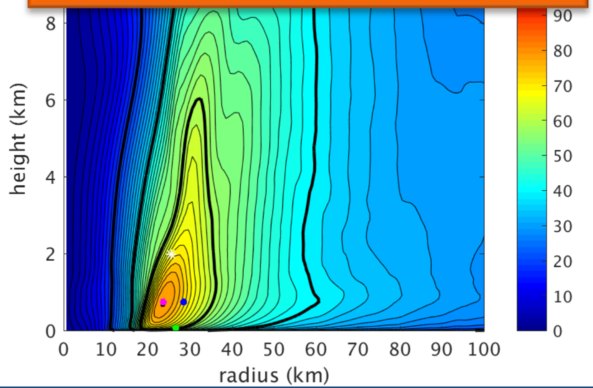
Relationship Between Vertical Structure and Size

Initial RMW=90 km

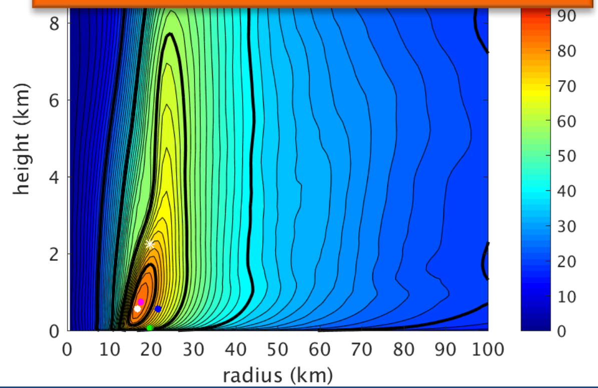
α=0.25



α=0.50

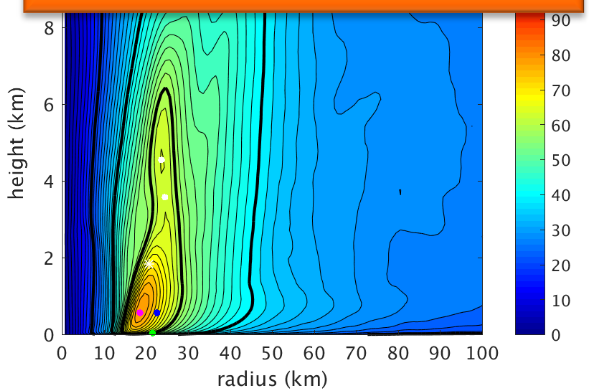


α=1.0

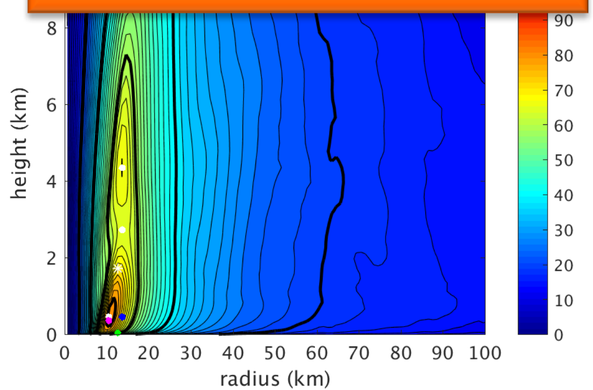


Initial RMW=36 km

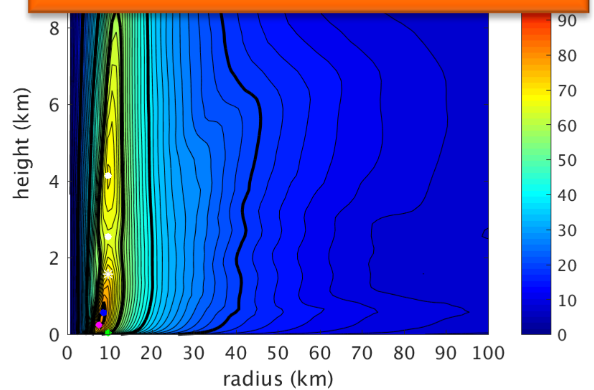
α=0.25



α=0.50

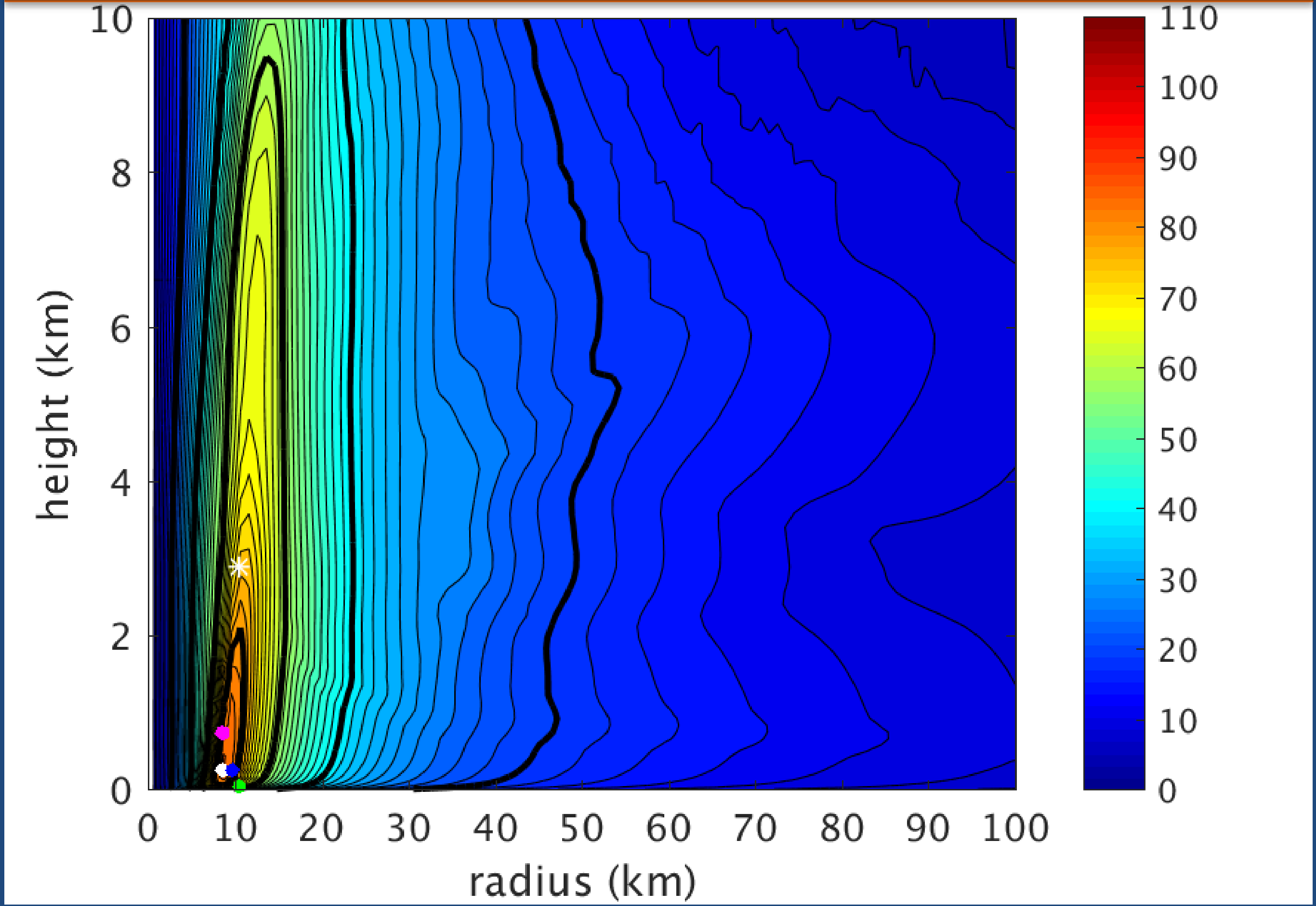


α=1.0

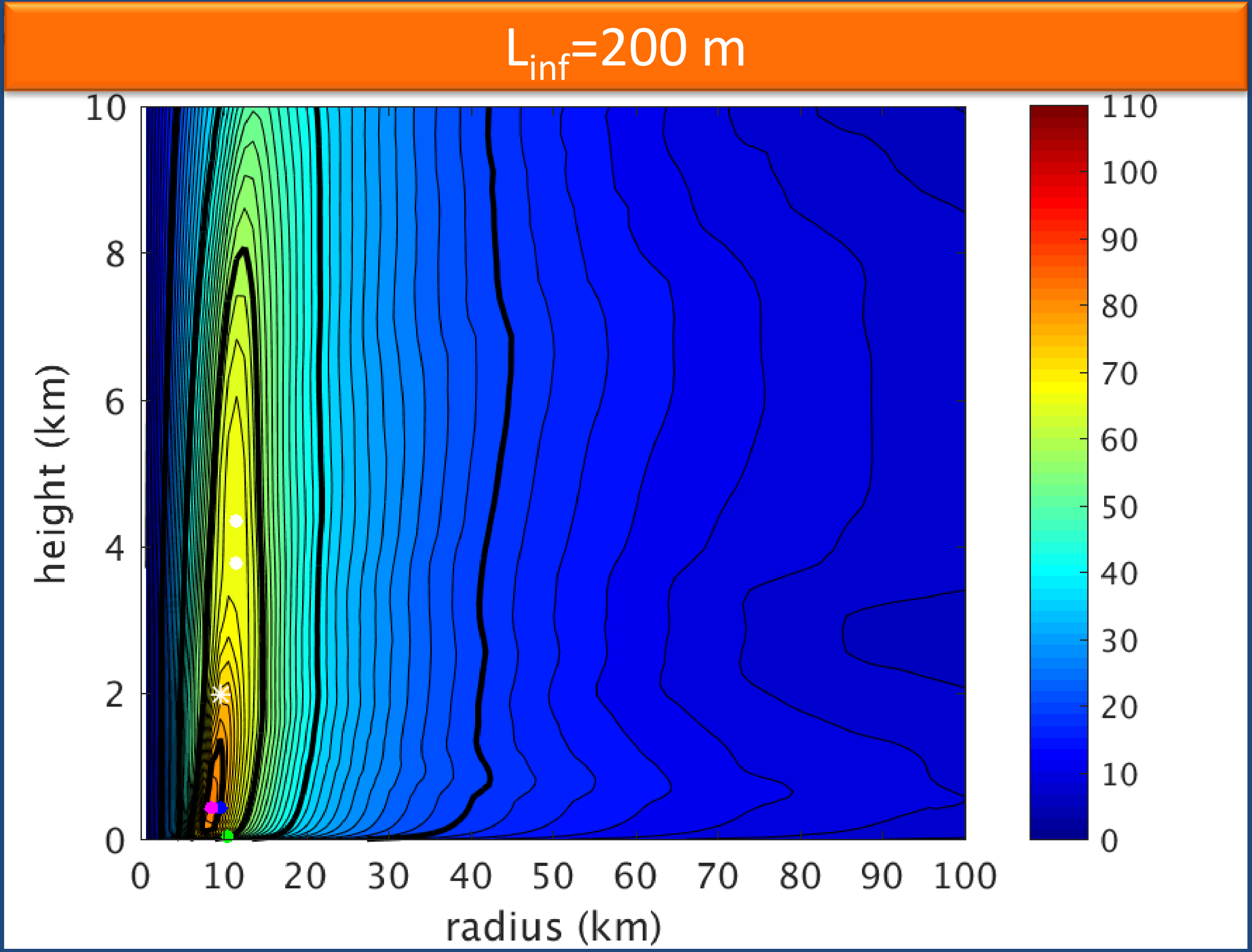


Sensitivity to Vertical Diffusion

L_{inf}=400 m

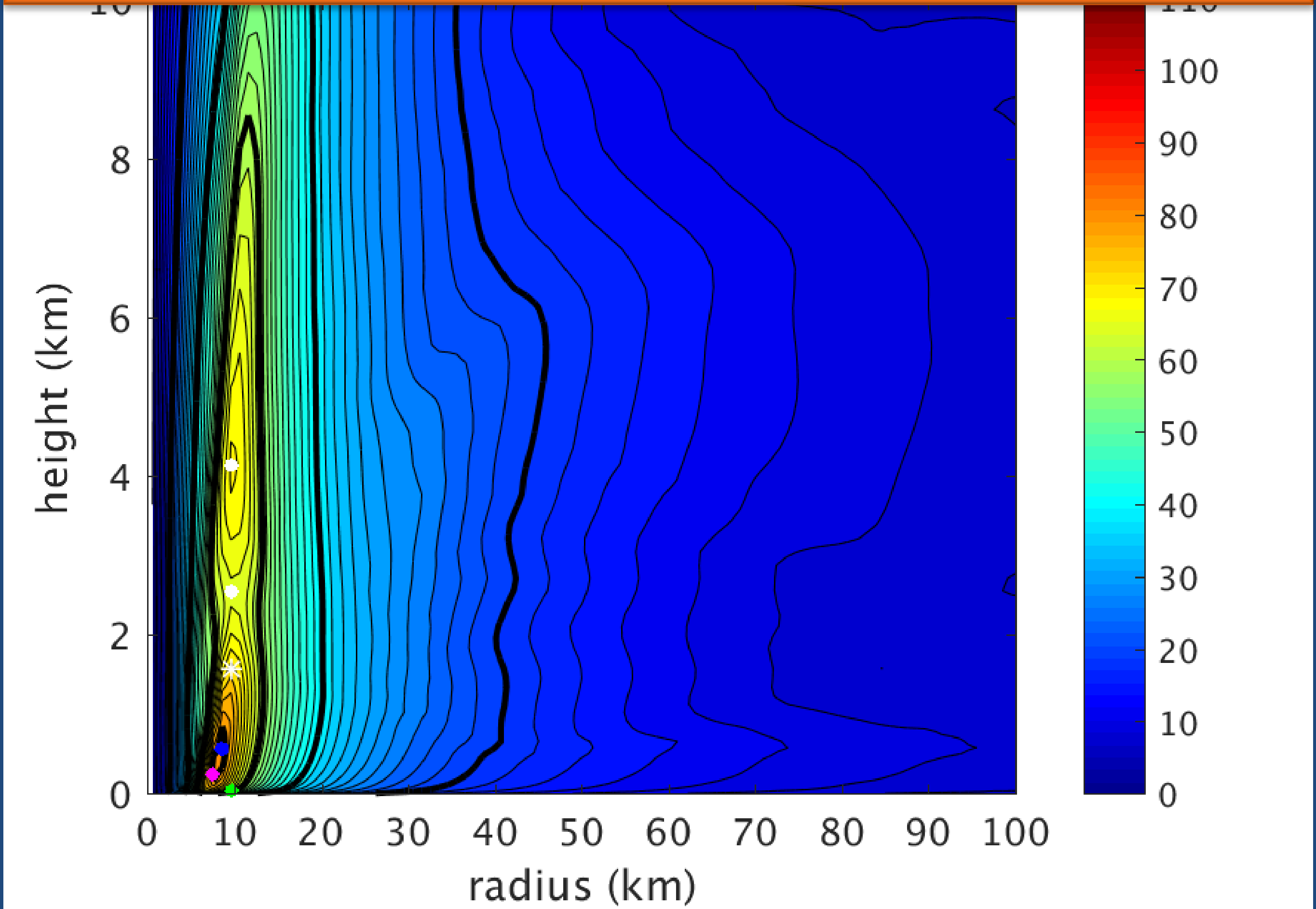


Sensitivity to Vertical Diffusion



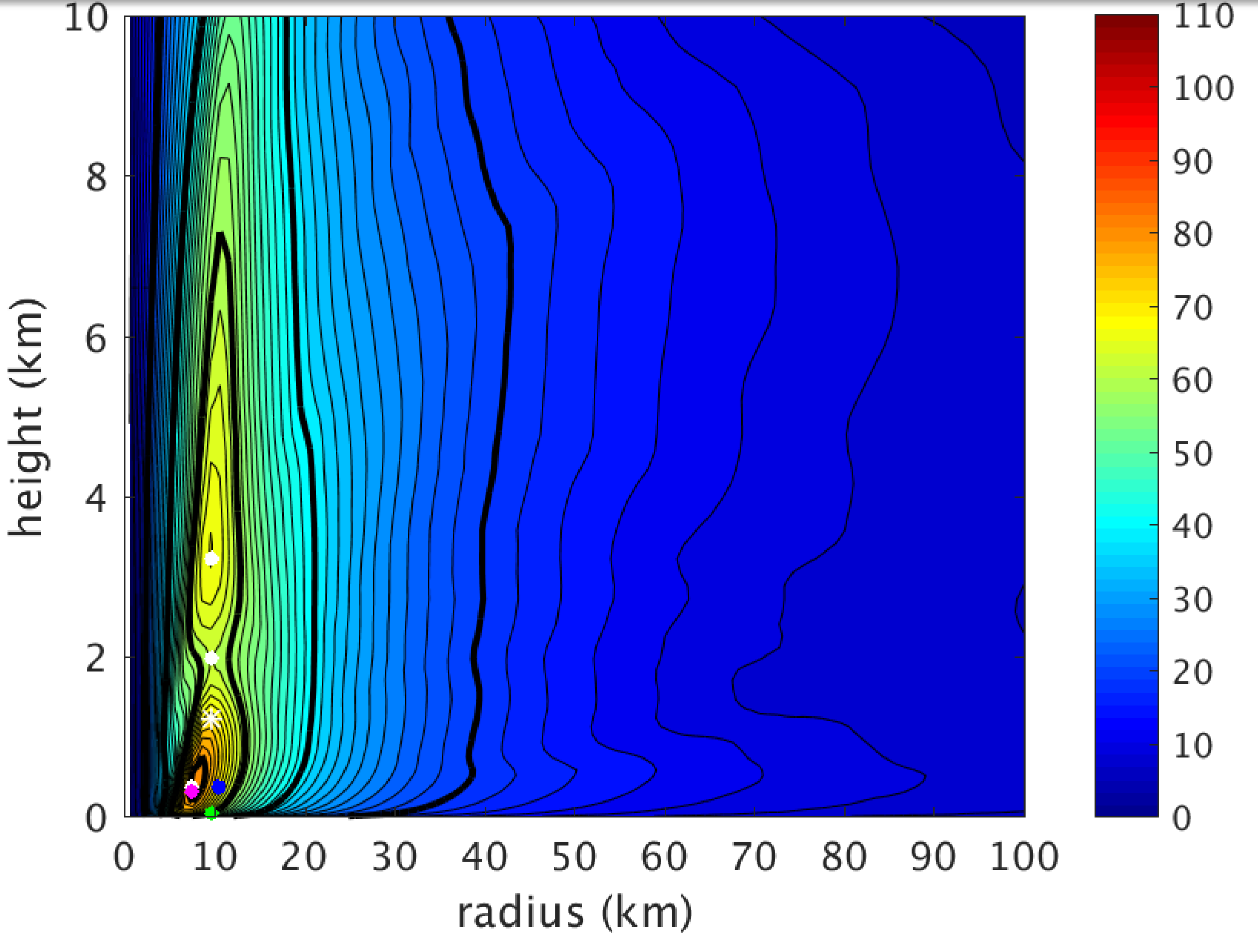
Sensitivity to Vertical Diffusion

L_{inf}=100 m



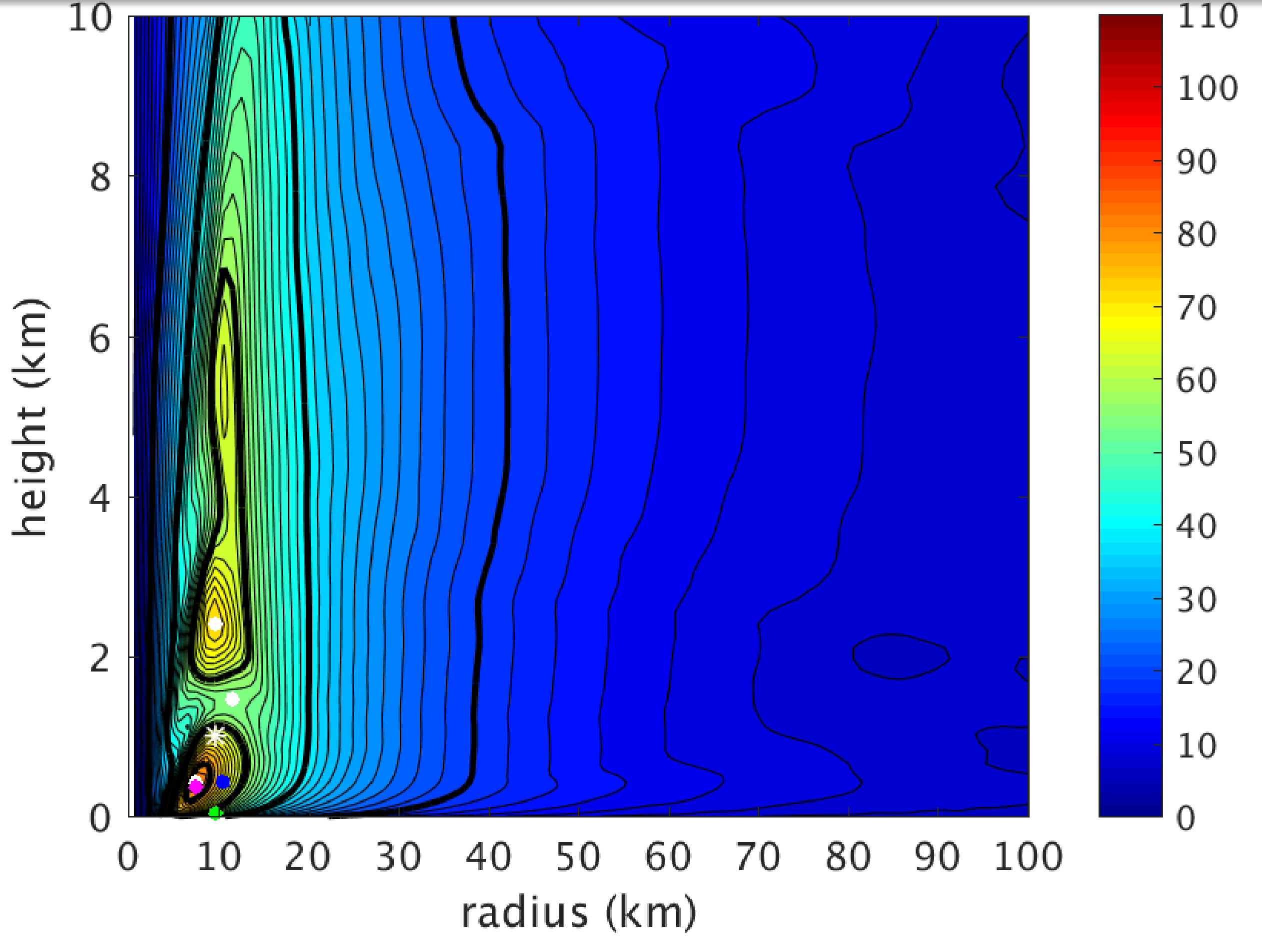
Sensitivity to Vertical Diffusion

L_{inf}=50 m



Sensitivity to Vertical Diffusion

L_{inf}=25 m



Next Steps

- Analysis of 3D idealized simulations in CM1
- Boundary layer model of Kepert forced by gradient wind fields from CM1 simulations.
- Kepert's model forced by observational analyses of gradient winds.

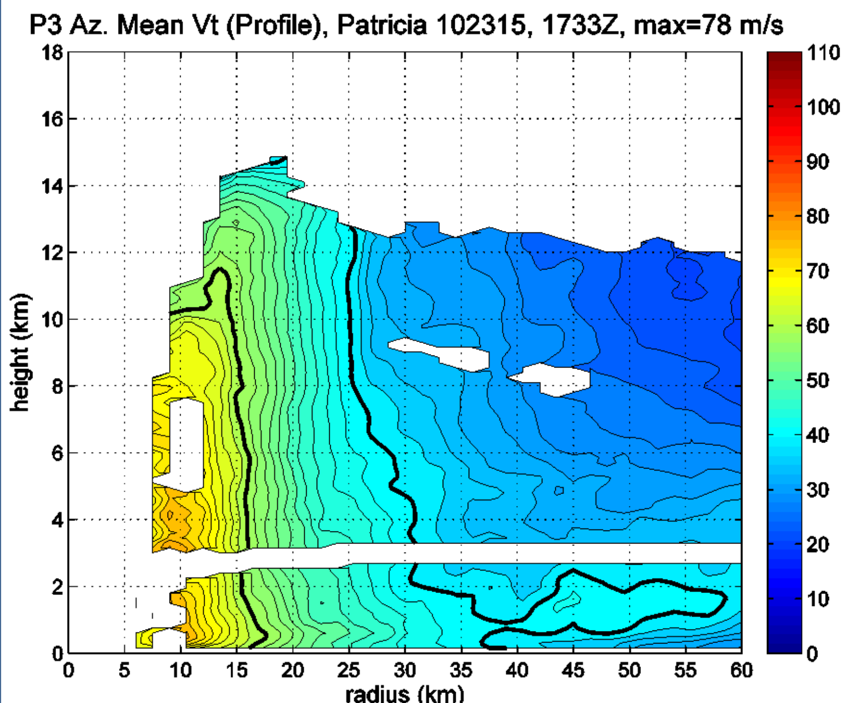
Summary and Conclusions

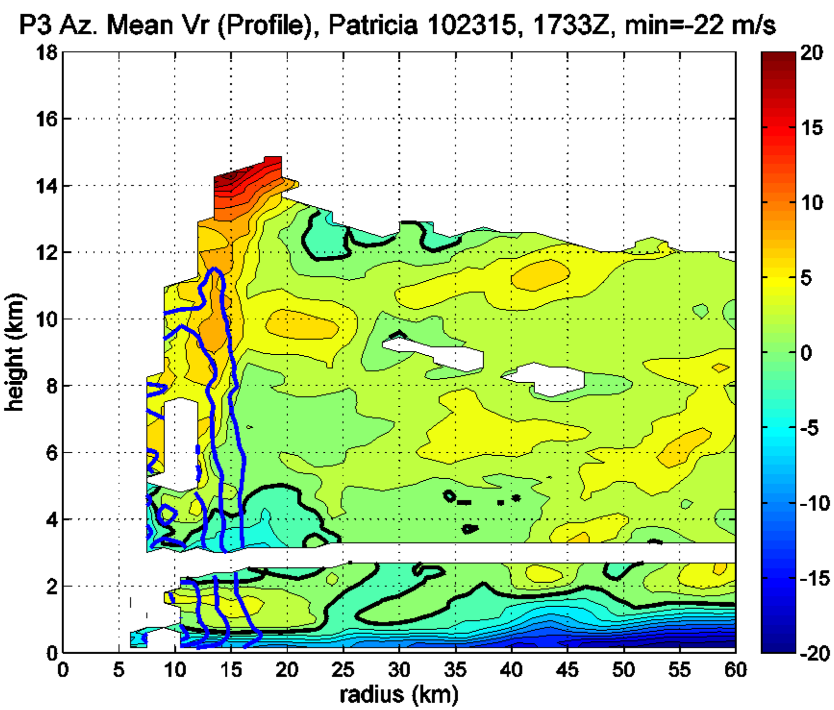
- Patricia near peak intensity had an atypical wind profile, with both a boundary layer maximum and a mid-level (4-5 km) maximum.

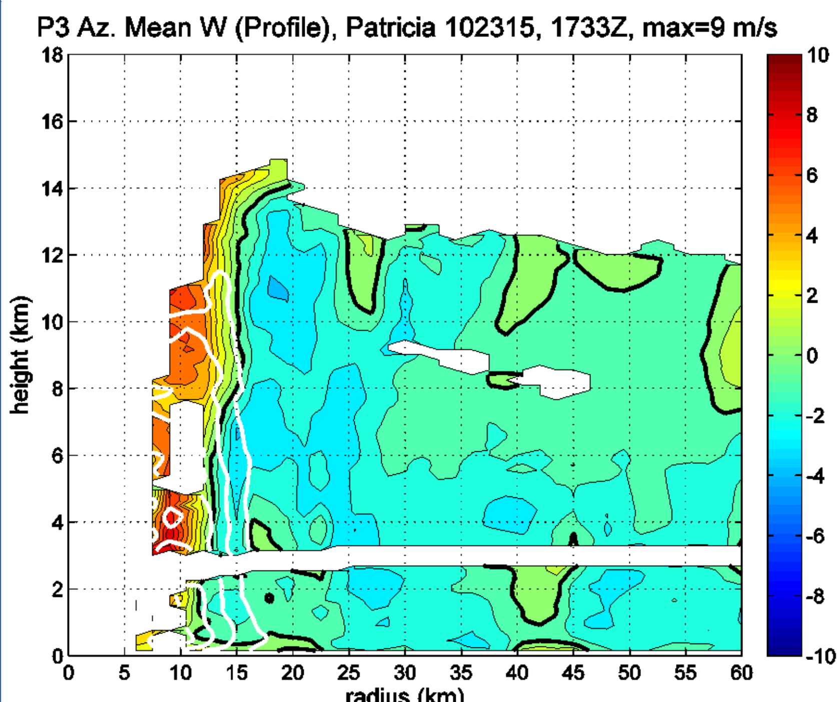
- This structure has been seen in a few other intense/small TCs.

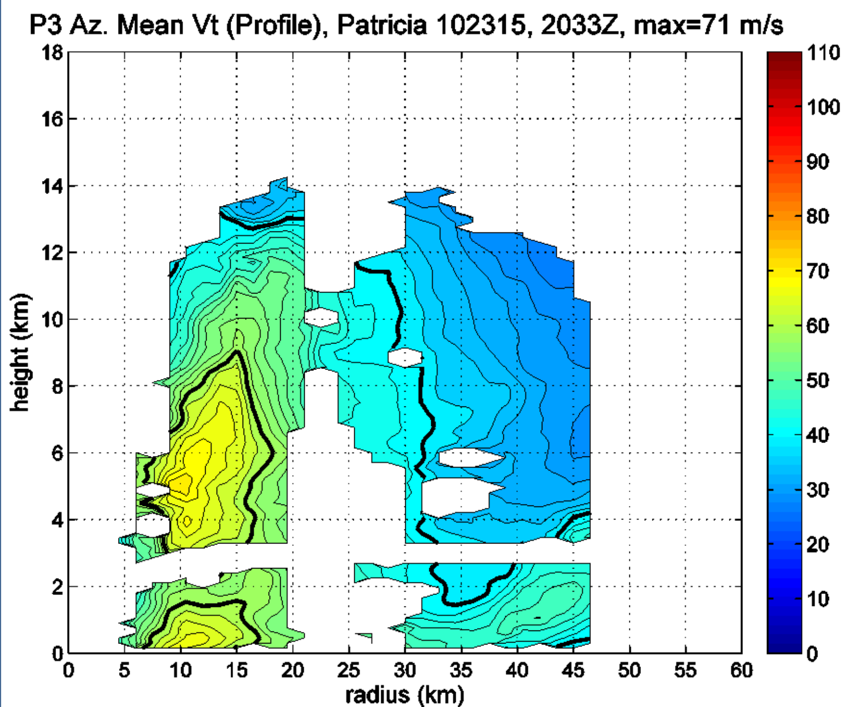
- The mid-level maximum is seen in simulations, and is a consequence of systematic unbalanced flow associated with a vertical oscillation in the radial winds.

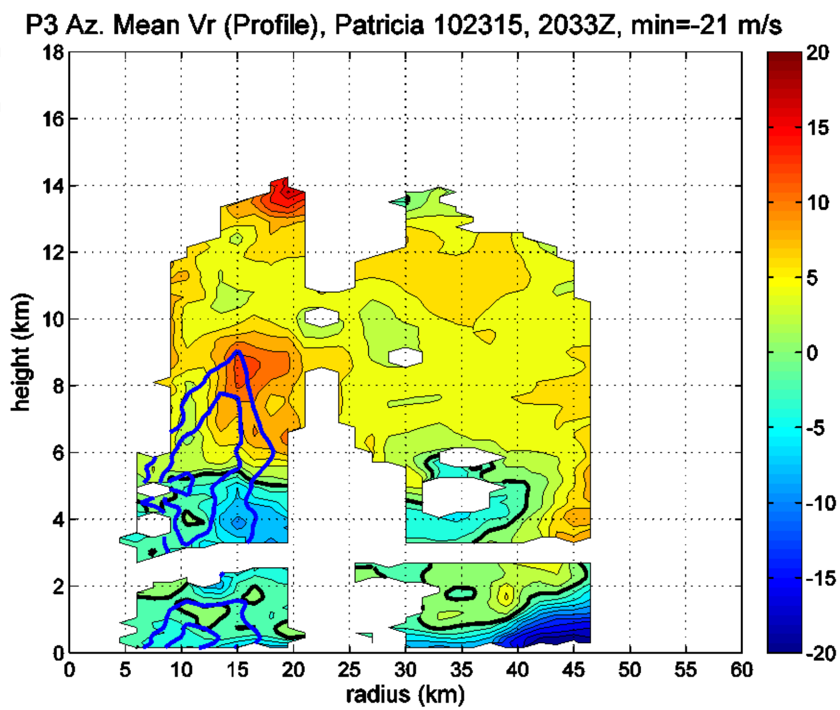
Bonus Slides!

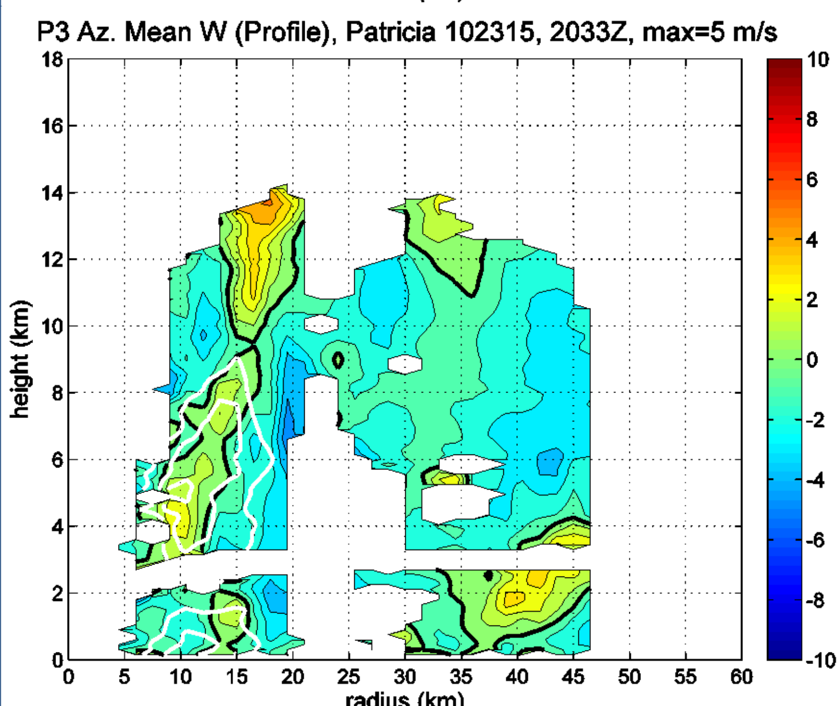

P3 Az. Mean Vt (Profile), Patricia 102315, 1733Z, max=78 m/s
height (km)
radius (km)


P3 Az. Mean Vr (Profile), Patricia 102315, 1733Z, min=-22 m/s
height (km)
radius (km)

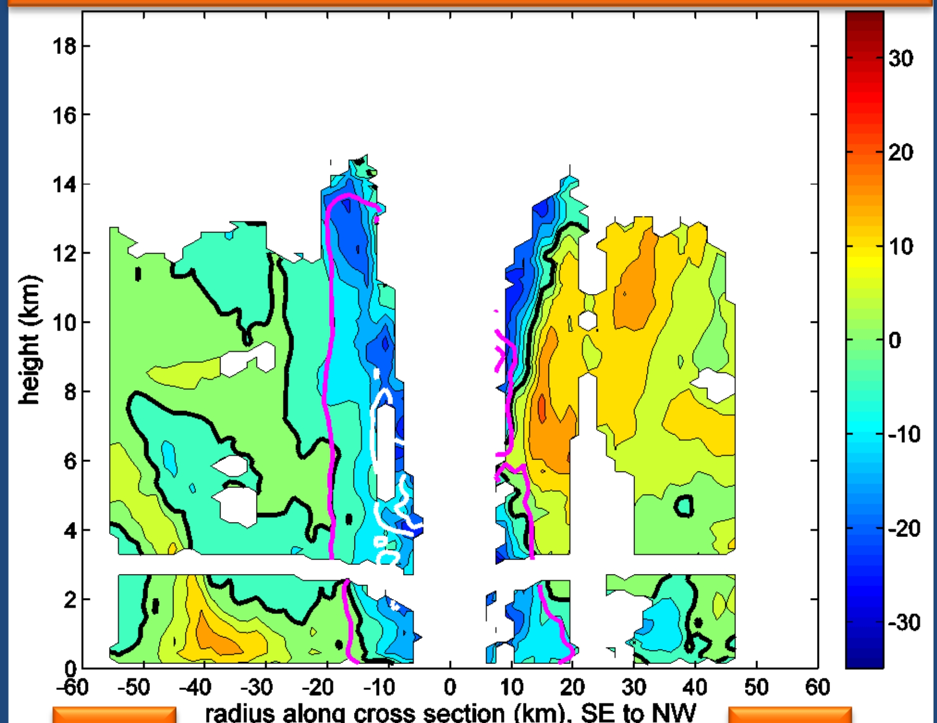

P3 Az. Mean W (Profile), Patricia 102315, 1733Z, max=9 m/s
height (km)
radius (km)


P3 Az. Mean Vt (Profile), Patricia 102315, 2033Z, max=71 m/s
height (km)
radius (km)


P3 Az. Mean Vr (Profile), Patricia 102315, 2033Z, min=-21 m/s
height (km)
radius (km)


P3 Az. Mean W (Profile), Patricia 102315, 2033Z, max=5 m/s
height (km)
radius (km)

Change in Wind Speed



SE

NW