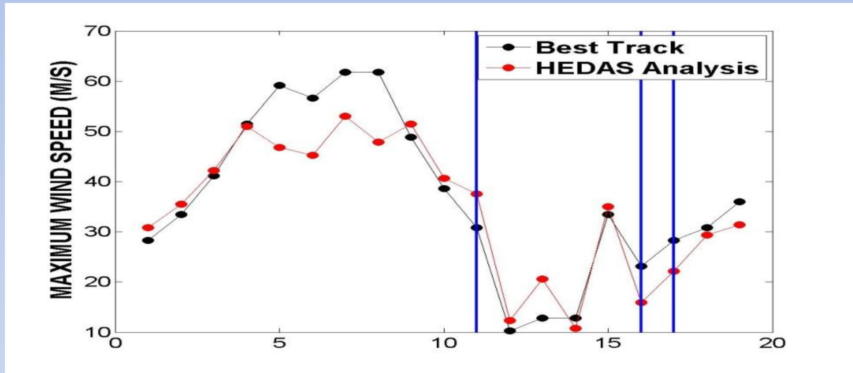
Balanced Model Response to Tangential Wind Perturbations

HRD Data Assimilation Meeting May 26, 2011

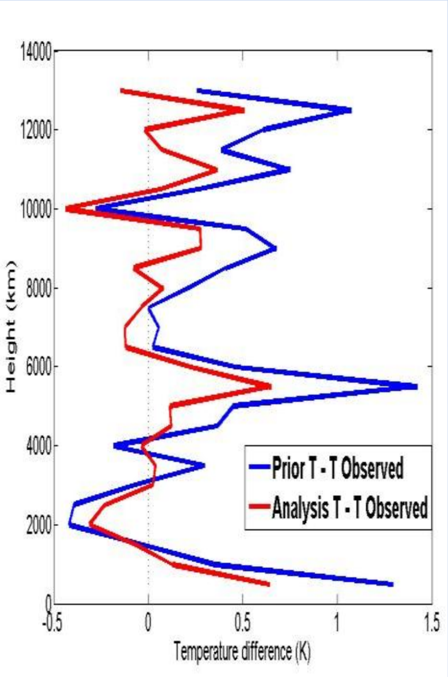
Kathryn Sellwood

Problems encountered during Vortex-scale data assimilation efforts

D.A. does not produce observed initial intensity

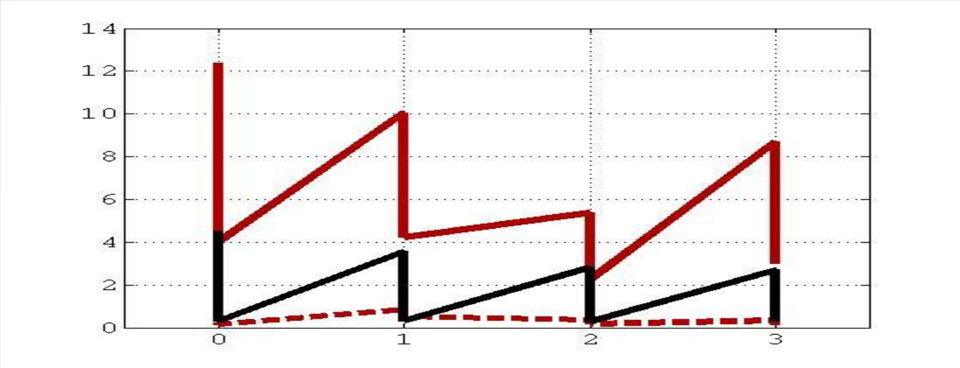


Temperature field does not adjust as expected



Model loses observational information quickly

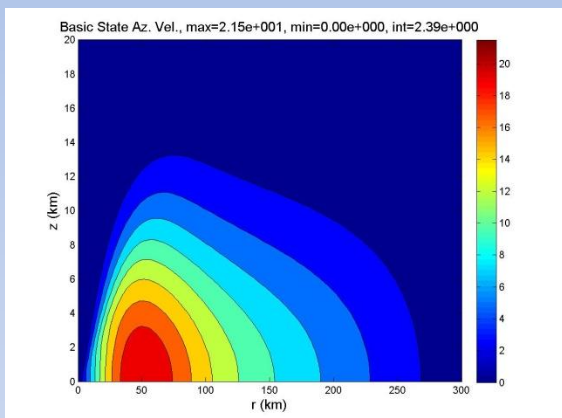
RMS model wind error during assimilation

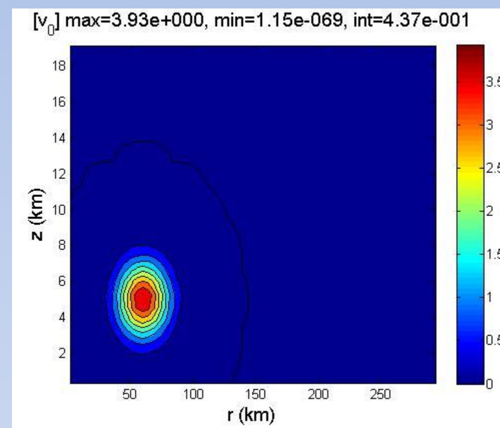


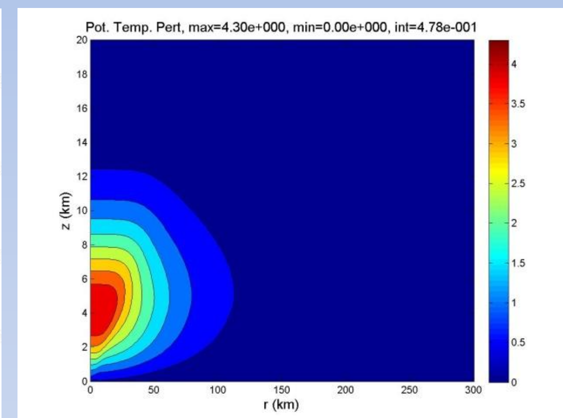
Possible Causes of Model Imbalance

- Few temperature observations relative to number of wind observations
- Temperature observations are confined to one vertical level or column
- Covariance matrix is not properly prescribed
- Adjustment timescale is longer than the D.A. cycles
- Non- uniform distribution of observations
- Observed variables differ too greatly from model values
- Disagreement between actual physical processes and observed structures and model representation

What is the symmetric response to a 4 m/s perturbation to the azimuthal wind field in a balanced vortex?







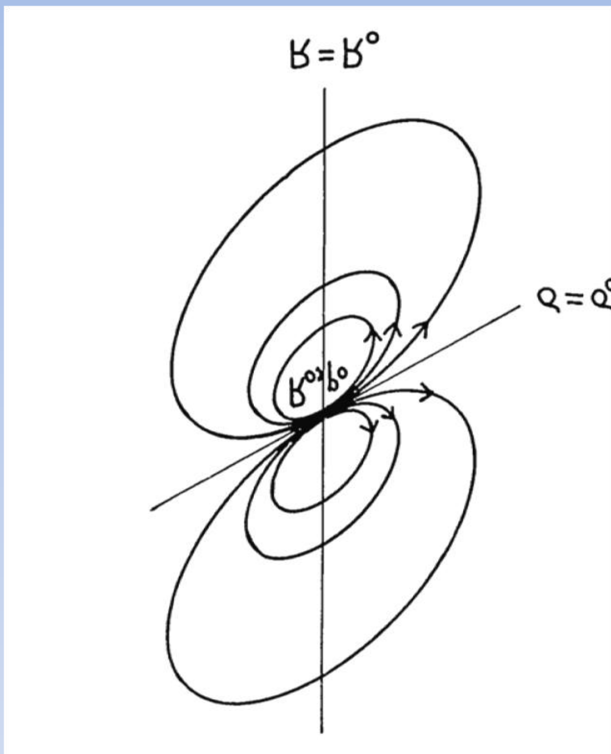
MODEL VORTEX:

Symmetric Tropical Storm vortex
Vortex described in RZ mean coordinates
Maximum Tangential wind of 21.5 m/s
Radius of Maximum wind at 50.4 km
Hydrostatic and Gradient wind balance

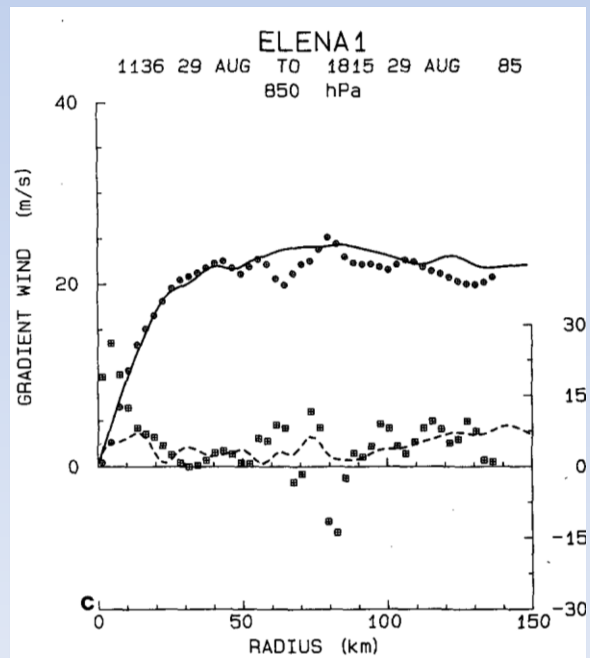
PERTURBATION:

4 m/s maximum Tangential wind perturbation
Gaussian distribution in the RZ plane
Centered at R = 60km Z = 5km
20km horizontal, 2 km vertical extent

Eliassen (1951) A point source of momentum produces secondary circulations:
• momentum redistributed



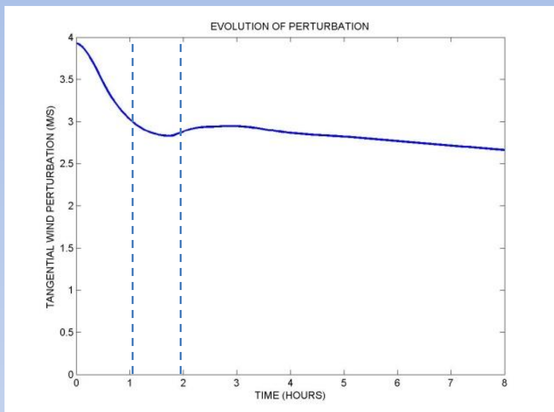
Willoughby(1979): Scale analysis shows that gradient and hydrostatic balance are a good approximation in the hurricane environment
Willoughby (1990) :Mean values of observed and gradient wind show that gradient wind is a good approximation to the mean swirling wind
Shapiro and Willoughby(1982): Response to momentum source is independent of horizontal scale
–> Eliassen model is valid for hurricane like vortices



Hurricane, warm core vortex:
•Sinking motion enhances warm core
•Mass reduced in eye region
•Central pressure falls
•Primary circulation is enhanced

Evolution of Initial Perturbation:

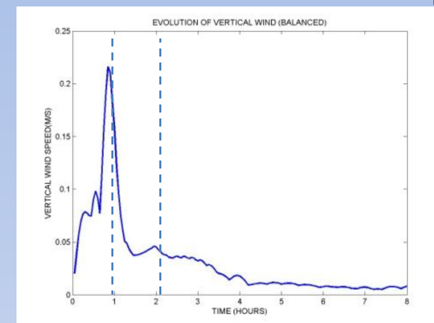
Maximum Tangential Wind Perturbation



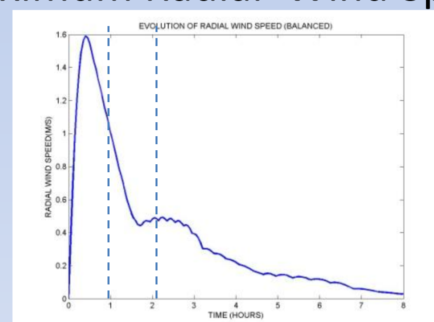
- V decreases rapidly to a minimum at
  ~ 1 hour
- Secondary Circulations reach a maximum at
  ~ 1 hour
- V   and Theta are nearly constant by hour 2
- U and W approach 0 by hour 2
- Some indication of longer response time at
  greater radii

Evolution of Balanced Response:

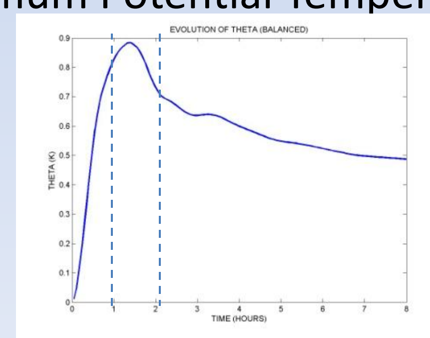
Maximum Vertical Wind Speed



Maximum Radial Wind Speed

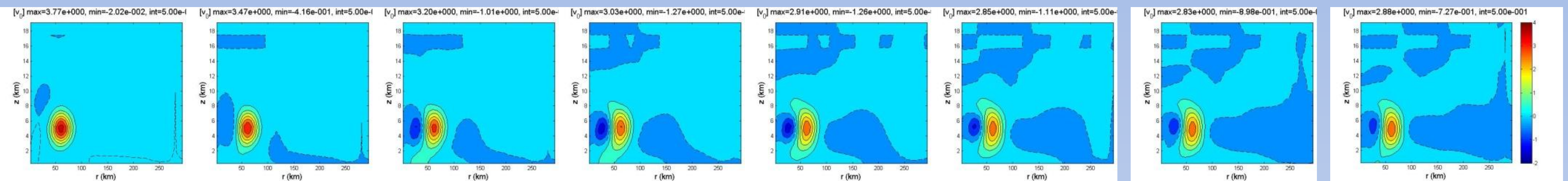


Maximum Potential Temperature

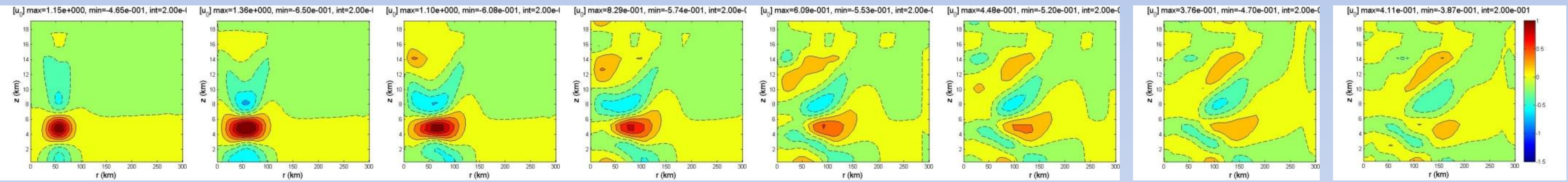


EVOLUTION OF PERTURBATION AND CIRCULATION

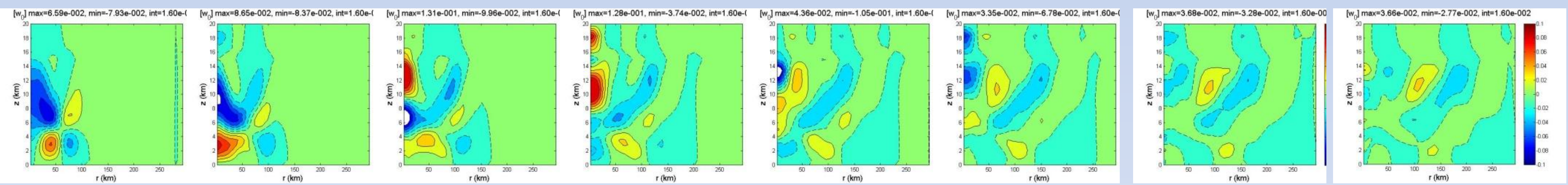
TANGENTIAL WIND SPEED PERTURBATION



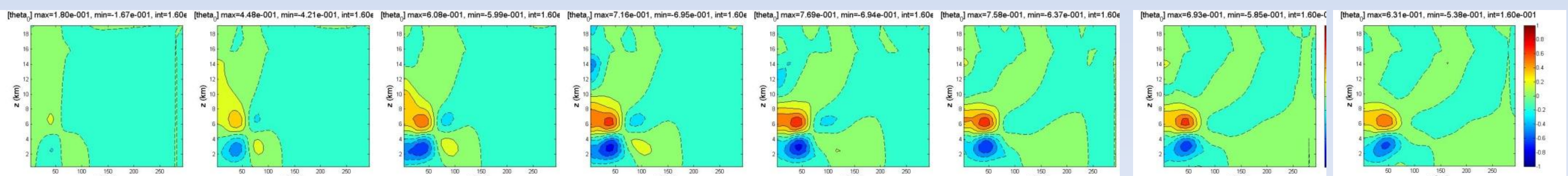
RADIAL WIND SPEED



VERTICAL WIND SPEED



TEMPERATURE PERTURBATION

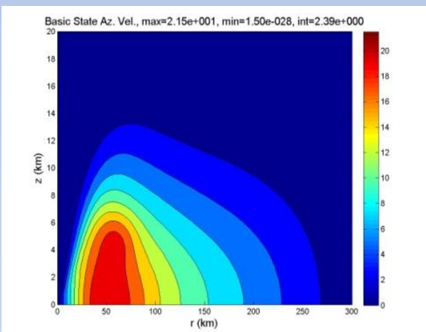


T = 15min T = 30min T = 45min T = 60min T = 75min T = 90min T = 105min T = 120min

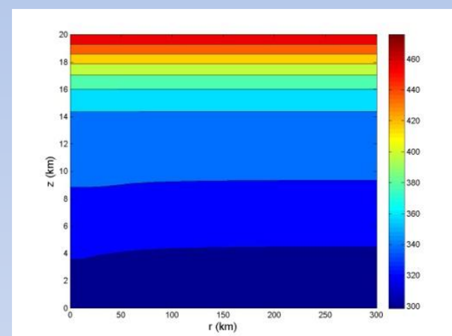
What is the temperature field that is initially in balance with this perturbation?

Vortex with 4m/s perturbation added to basic state

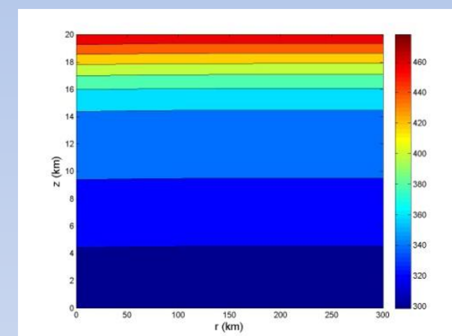
Vt



Theta

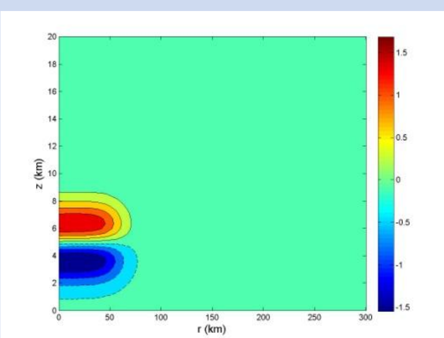


Theta (un-perturbed)



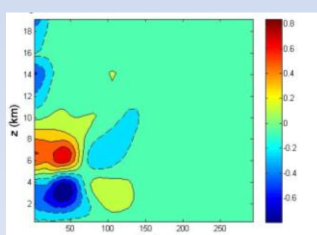
Theta difference (K)

Max = 2.52 Min = -5.3



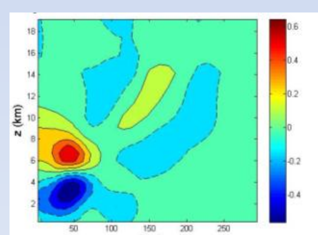
Temperature perturbation (K) in the un-Balanced vortex

Max = .84 Min = -.8



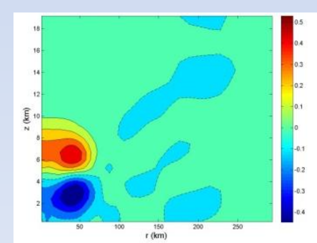
t = 1hour

Max = .64 Min = .56



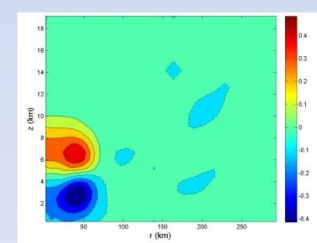
t= 2 hours

Max = .53 Min =.45



t = 4 hours

Max = .49 Min = .41

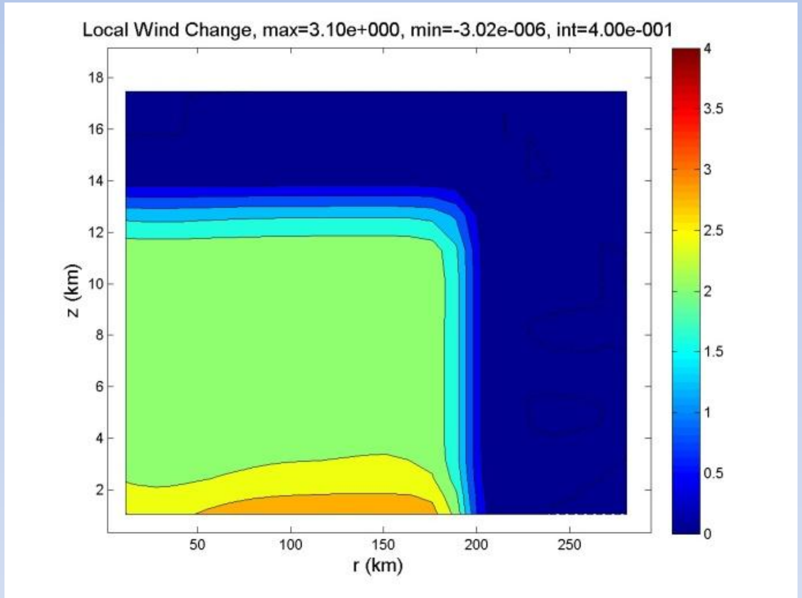


t = 6 hours

Local Response to the same 4 m/s perturbation at all locations

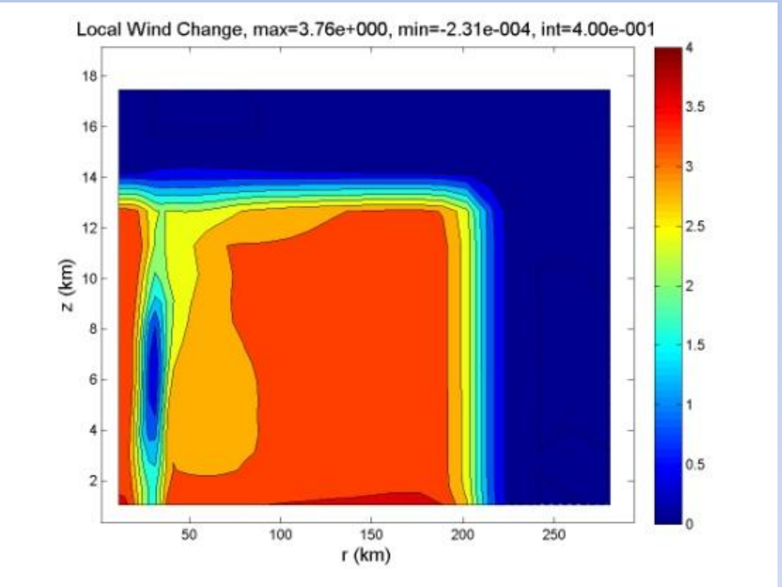
Local Wind Change at t = 4 hours

Tropical Storm



Tropical Storm Vortex:
77.5% maximum retention
Maximum near surface
Uniform elsewhere

Hurricane cat 3



Hurricane Vortex :
94% maximum retention
Maximum at outer radii
Minimum near RMW

Conclusions

- Momentum perturbations to a balanced vortex induce secondary circulations that work to restore balance and symmetry
- Momentum is redistributed upward and outward from the perturbation location
- Maximum tangential velocity is less than initially prescribed by the perturbed value
- The time scale of adjustment to perturbations

  is between 1 and 2 hours
- The balanced temperature profile for the perturbed state is significantly different from that of the original state
- Wind perturbations near the RMW are not retained well in a strong vortex

Future Work

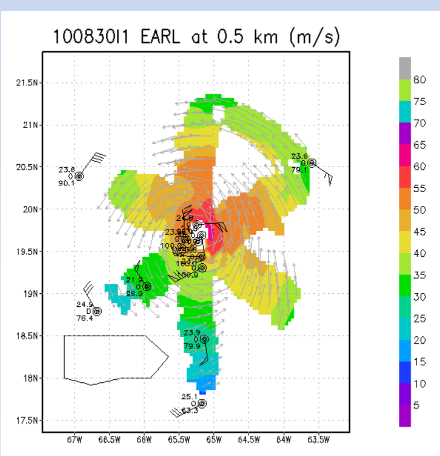
EXPERIMENT (1)

- Caluculate temperature perturbations corresponding to TDR wind observations
- Create synthetic temperature observations
- Assimilate synthetic obs in addition to current operational observations

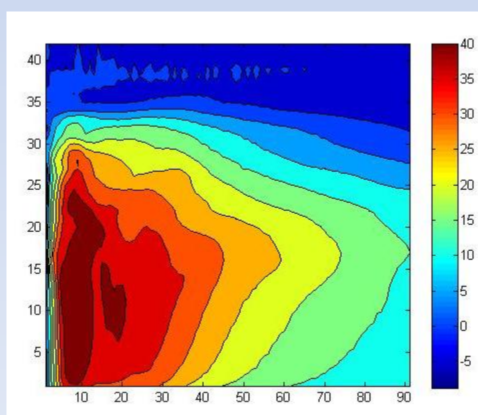
EXPERIMENT(2)

- Calculate the balanced covariances between wind and temperature perturbation and compare to model covariances
- Compare the temperature field from a HEDAS analysis with one that is in balanced with the prescribed wind field
- Dropsonde Composite to estimate observed temperature structure

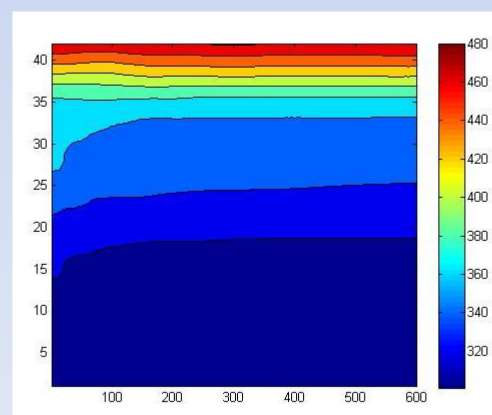
TDR Composite



HEDAS Wind analysis



Theta analysis



Balanced Theta
Actual Theta

?