The Dynamic Response of RAINEX-Observed Vortices to RAINEX-Inspired Rainbands

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I. Motivation

- The big question is: What do rainbands do to hurricanes?

- We know that they:

  Are closely coupled to vertical motion and vorticity

  Are associated with deviations of the "mean" wind field, particularly in the boundary layer, less so at higher altitudes (?)

- We suspect that they:

  Are associated with forced overturning circulations imposed on the larger secondary circulation - as now seen from data

  Play some role in intensity change

II. Working Hypothesis and Method

•We presume that an important impact of bands on the vortex is the vertical motions, circulations, and waves generated by latent heat release

•Motions feed back to the symmetric vortex in two ways:

--> Through direct, quasi-balanced circulations generated by heating

--> Through eddy fluxes caused by quasi-balanced asymmetries and radiating waves (V-R and gravity)

•We will try to:

--> Simulate these processes in an idealized model: 3DVPAS

--> Correlate simulated circulations with the observed

--> Estimate the dynamic effect of the waves on the symmetric vortex

What is 3DVPAS?

(Three-Dimensional Vortex Perturbation Analysis and Simulation)

•3DPVAS is a collection of codes, written entirely in Matlab, that allow for the analysis and simulation of free and forced perturbations to axisymmetric, baroclinic, balanced vortices.

•The dynamics are:

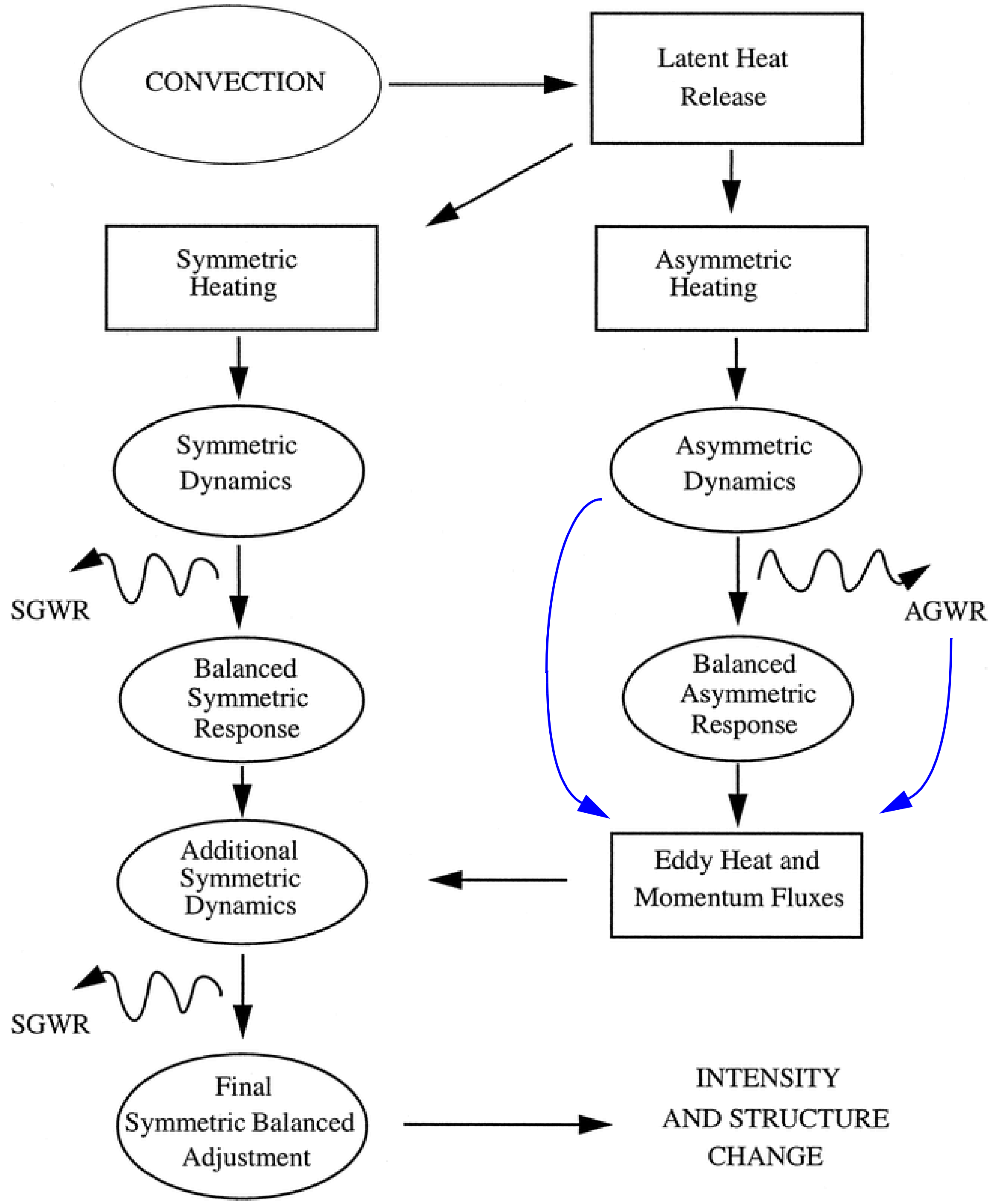
* Linear

* Nonhydrostatic

* Asymmetric, Symmetric, with some coupling between them

* Unbalanced...if that is what the forcing wants!

Nolan and Grasso
(JAS, 2003)



III. The Analysis:

1) Use RAINEX wind fields to generate basic-state vortex

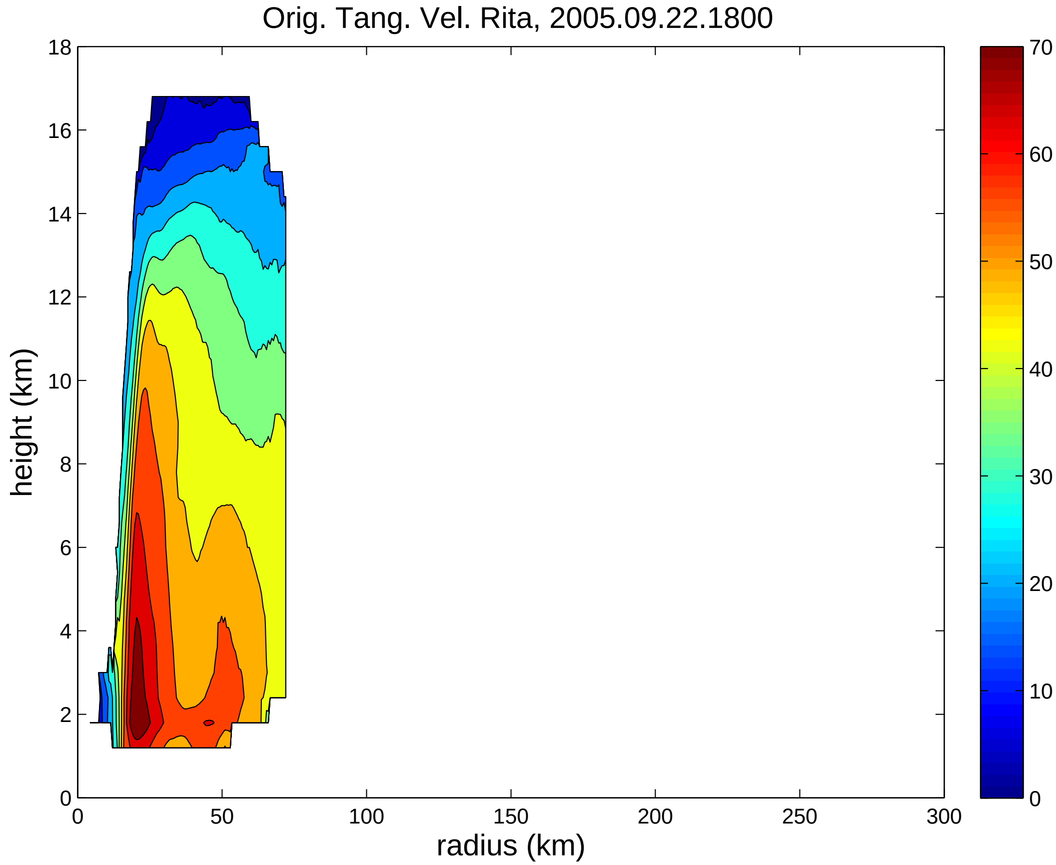
2) Design heating patterns which represent observed bands, rotating with the flow

3) Force the vortex with these heat sources, compute response and feedbacks

(1) Read radar winds into 3DVPAS

•Not so easy!

•We start with the azimuthally-averaged wind field of Hurricane Rita:



•Problem: We need the wind field to fill up the analysis domain.

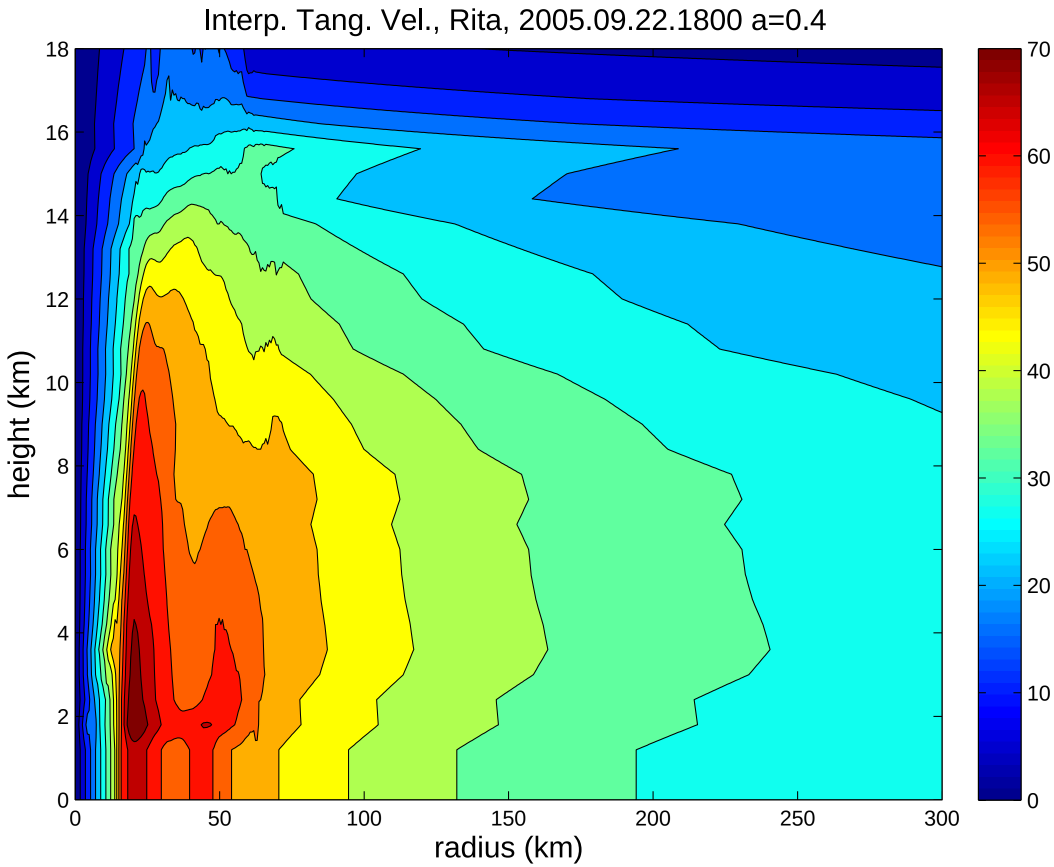
•Solution:

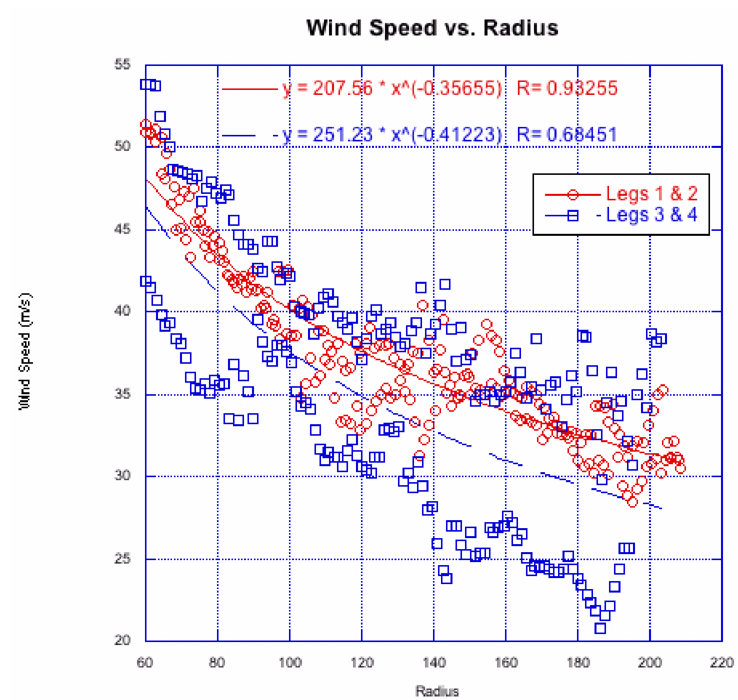
* Fill missing eye data with solid-body rotation

* Extend outward with decay rate similar to observed: $V \sim r^{-a}$, $a = 0.4$

* Extend to “surface” with constant wind

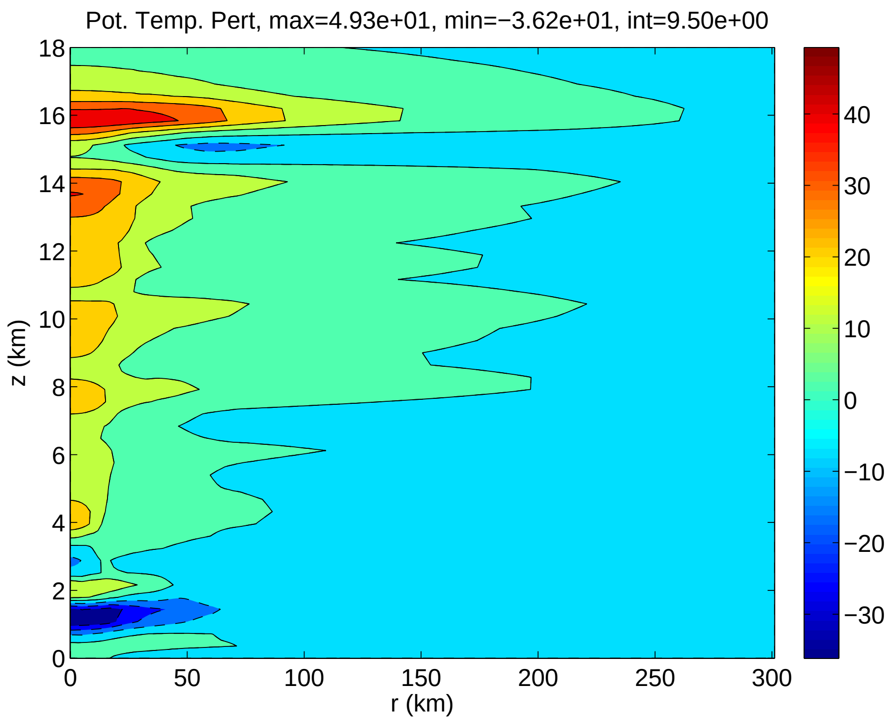
* Extrapolate upper-level decay rate to top

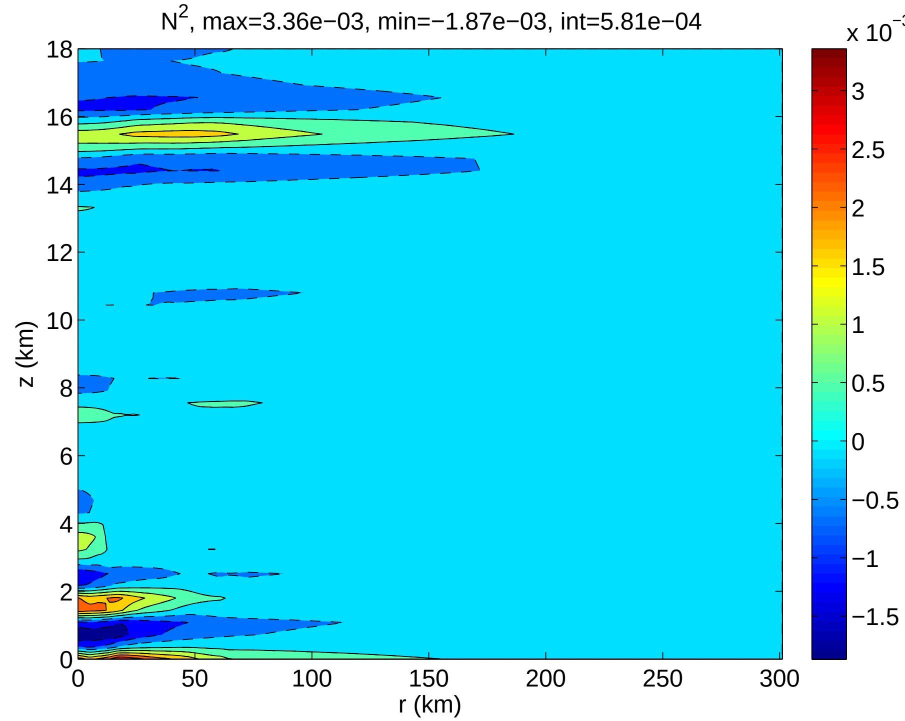




•Balance:

* Find $\bar{p}(r,z)$ and $\bar{\theta}(r,z)$ that hold $\bar{v}(r,z)$ in hydrostatic and gradient wind balance

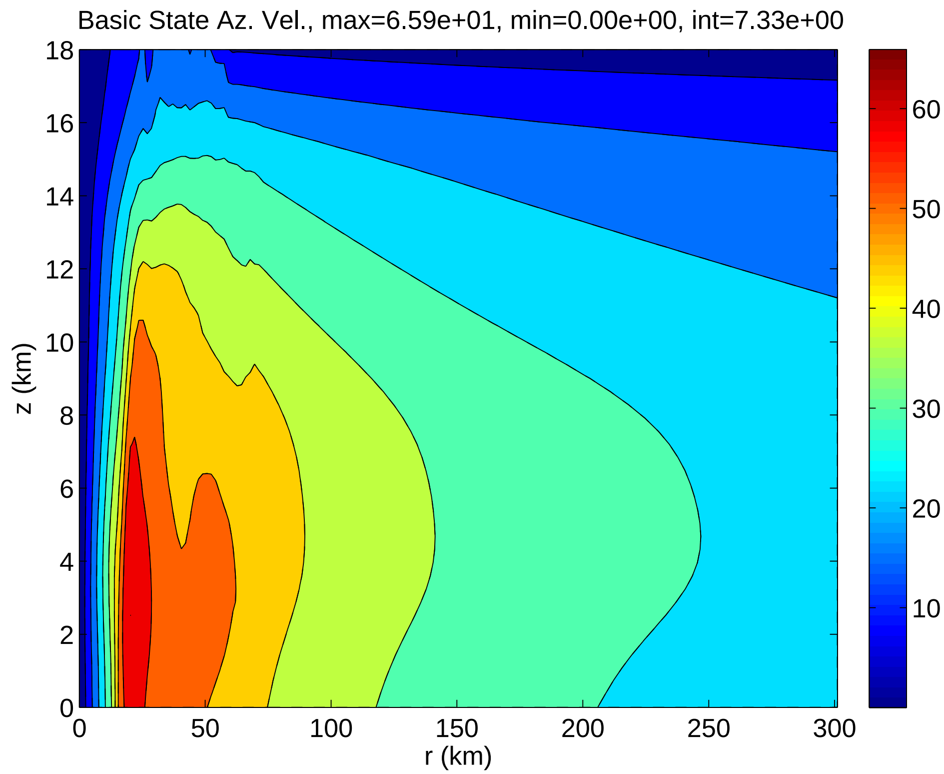


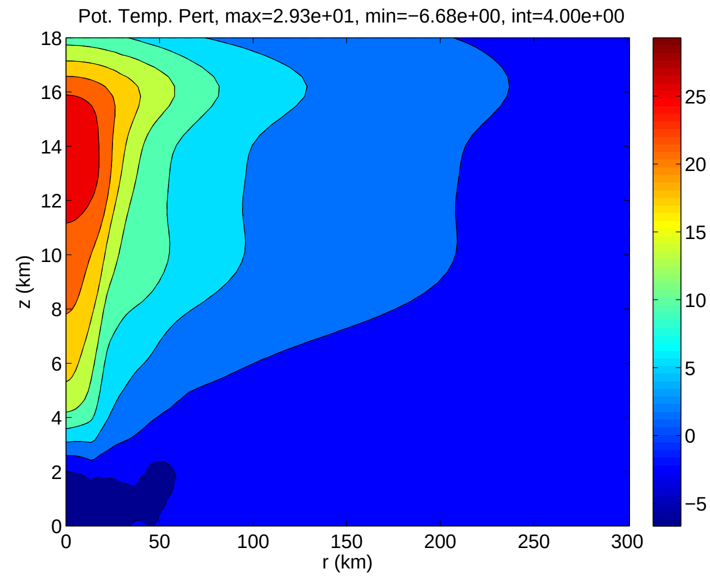


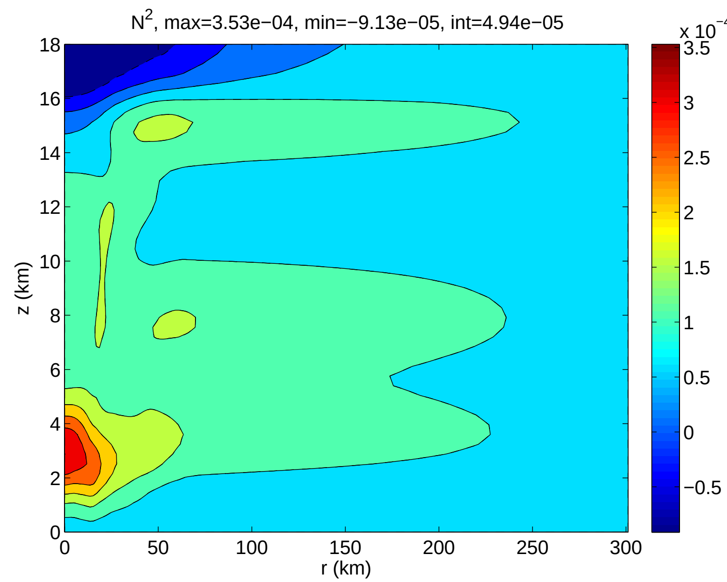
•Problems: Noise in $\bar{v}(r,z)$ makes large $\frac{\partial v}{\partial z}$ anomalies which makes large $\bar{\theta}$ anomalies which leads to negative $\overline{N^2}$ in some places

•Solution:

* Vertical smoothing of wind field



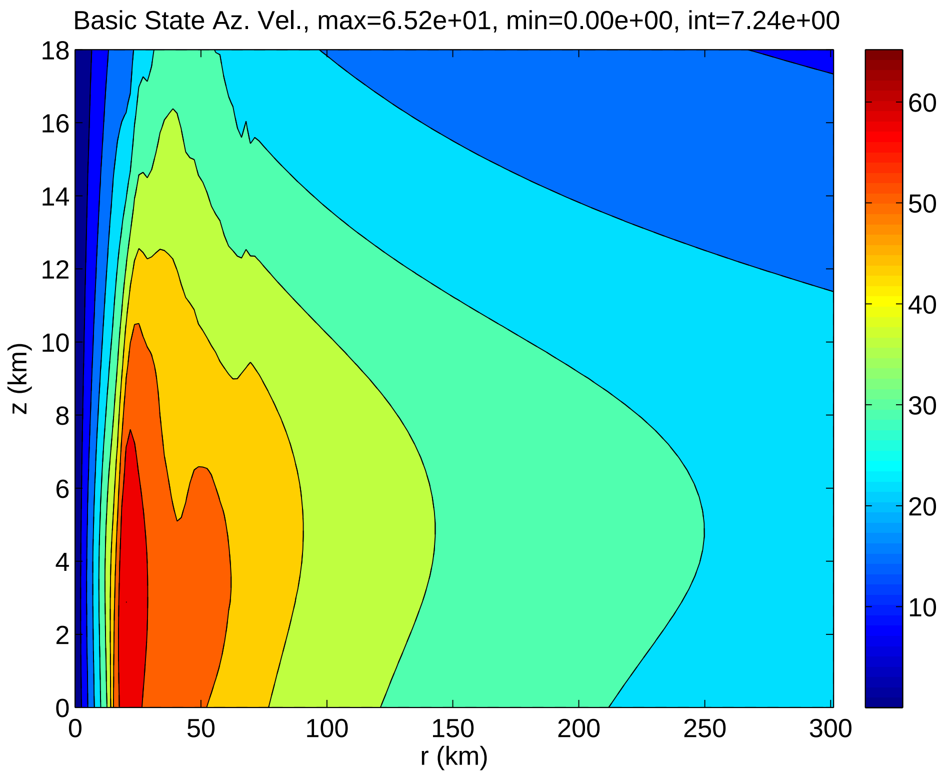


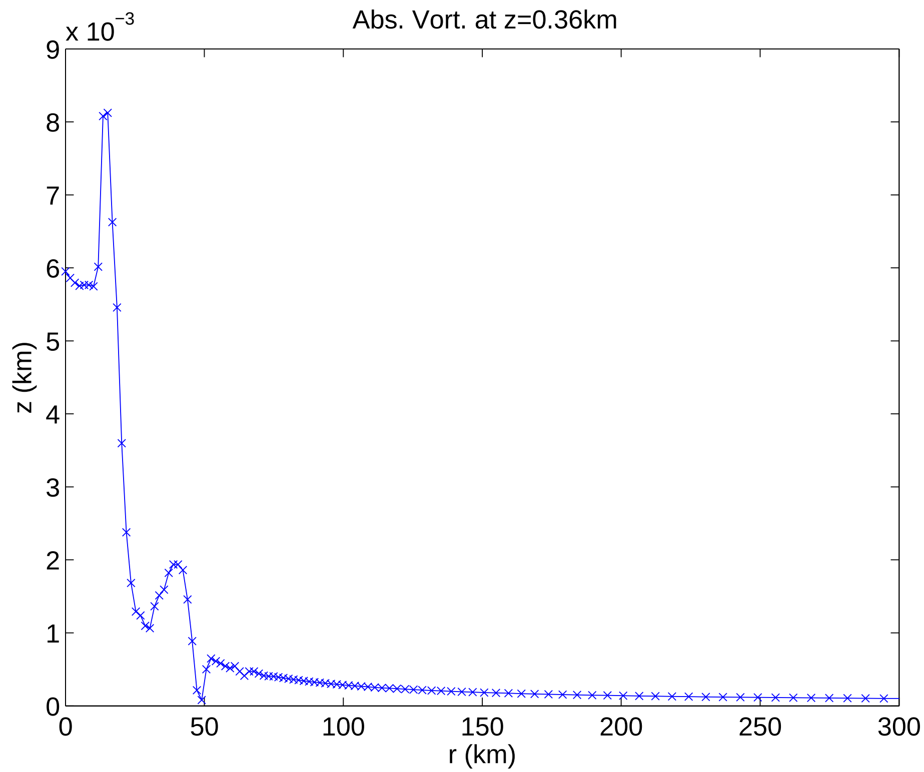


•Problem: Very large $\frac{\partial v}{\partial z}$ in upper levels still leads to negative $\overline{N^2}$

• Solution:

* Reduce upper level decay rate enough to stabilize $\overline{N^2}$

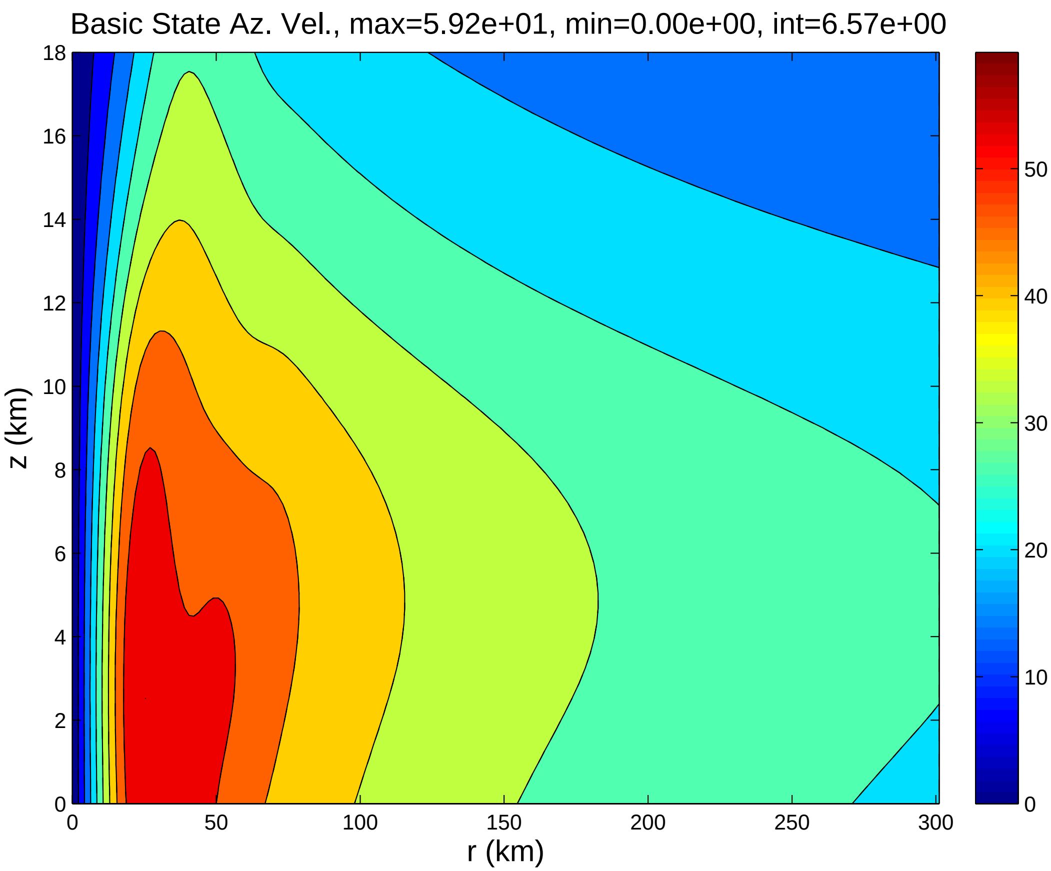


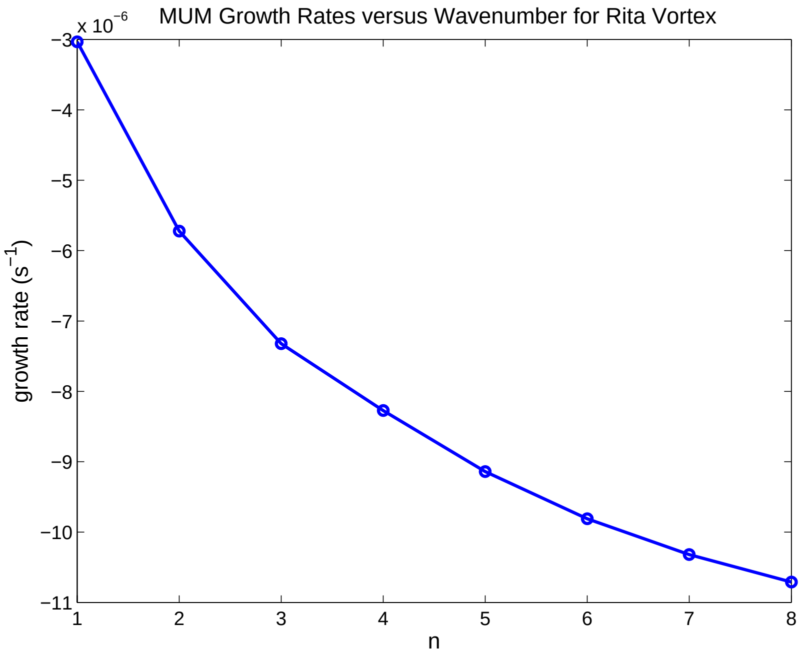


• One final problem: Vorticity peak on inner eyewall supports unstable modes

•Solution:

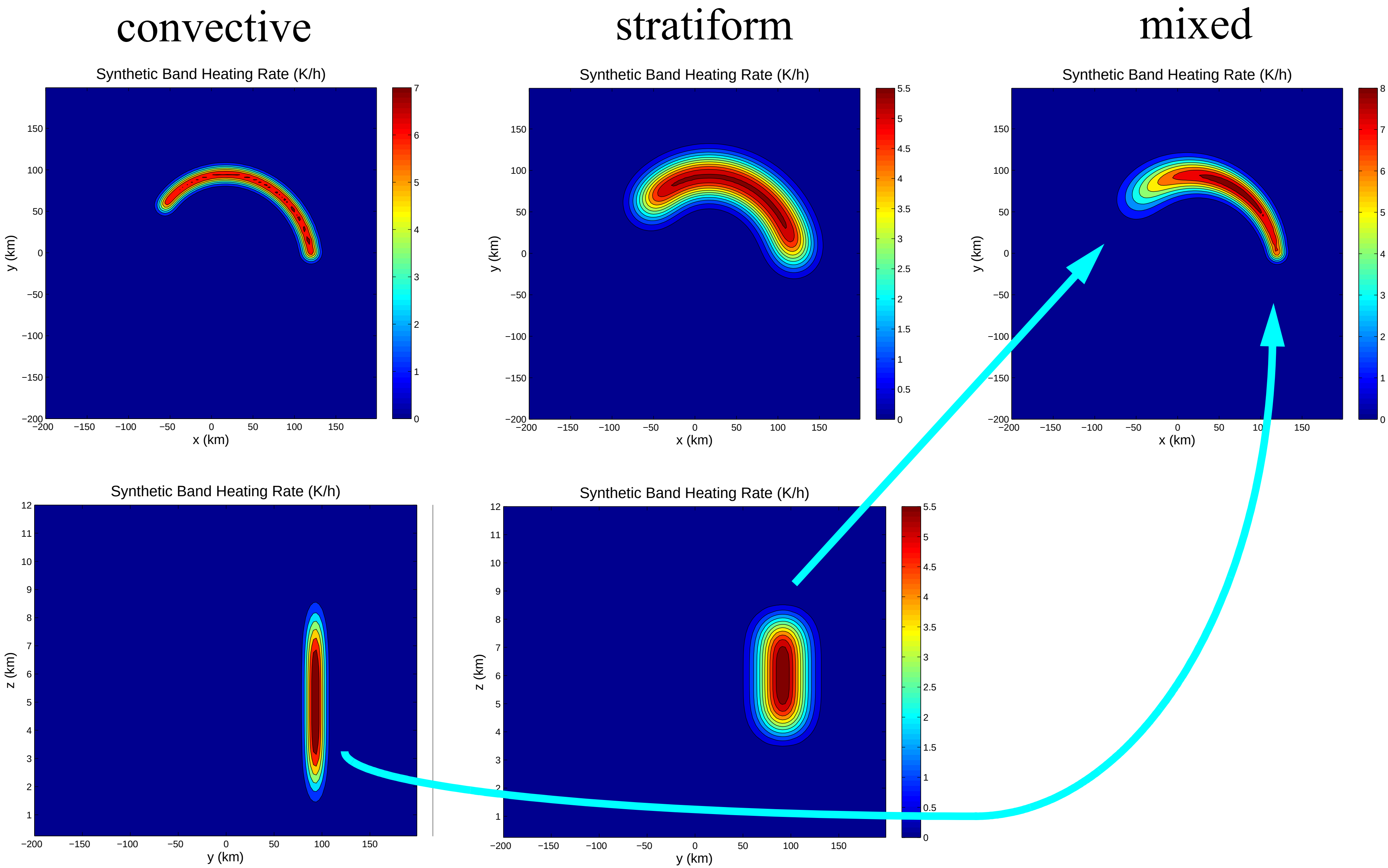
* Horizontal (radial) smoothing of wind field





This is the basic-state wind field for our calculations.

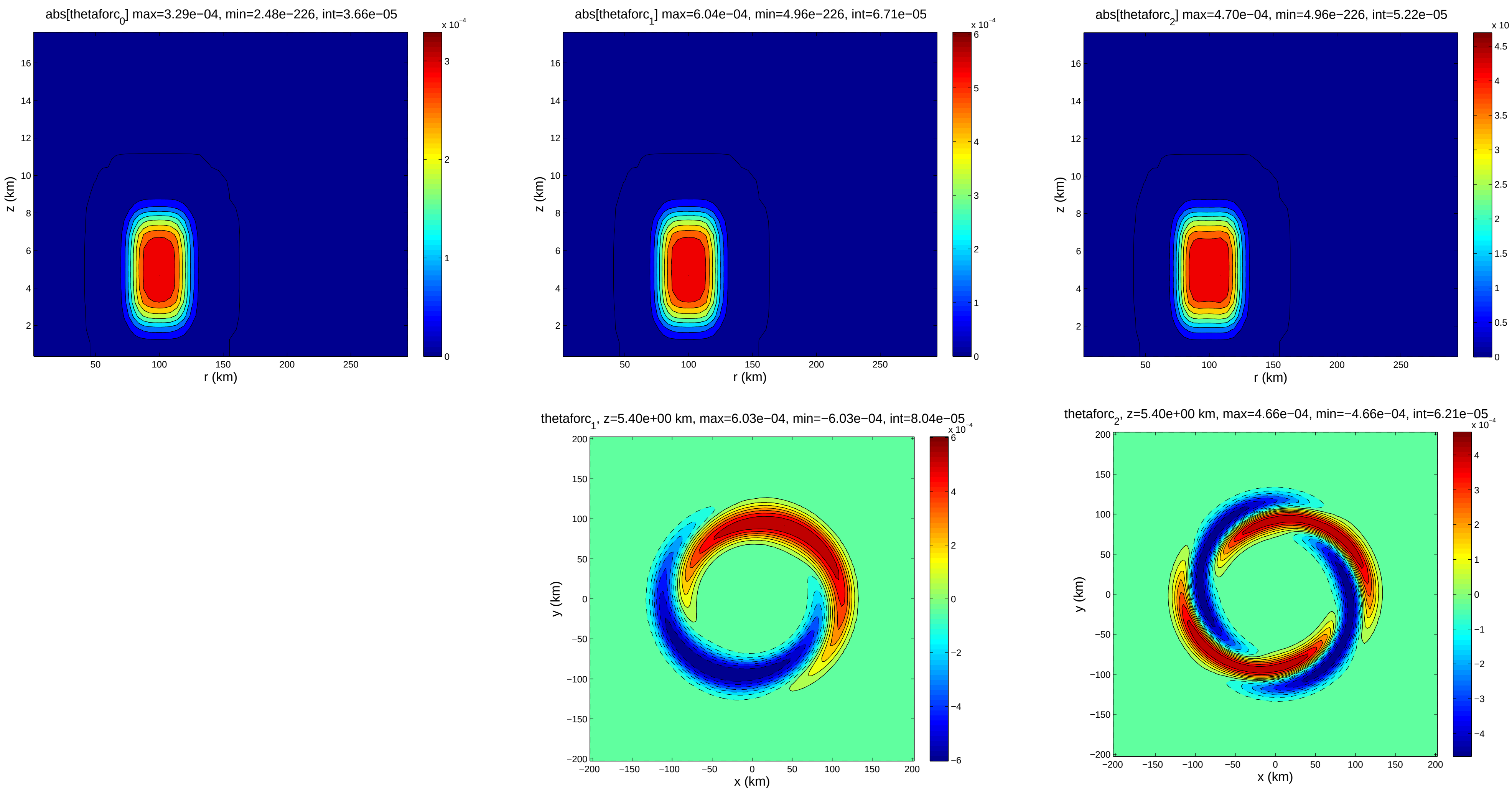
(2) Design spiral band heating patterns



(3) Compute and Analyze Response

Start with the first synthetic band, convective structure.

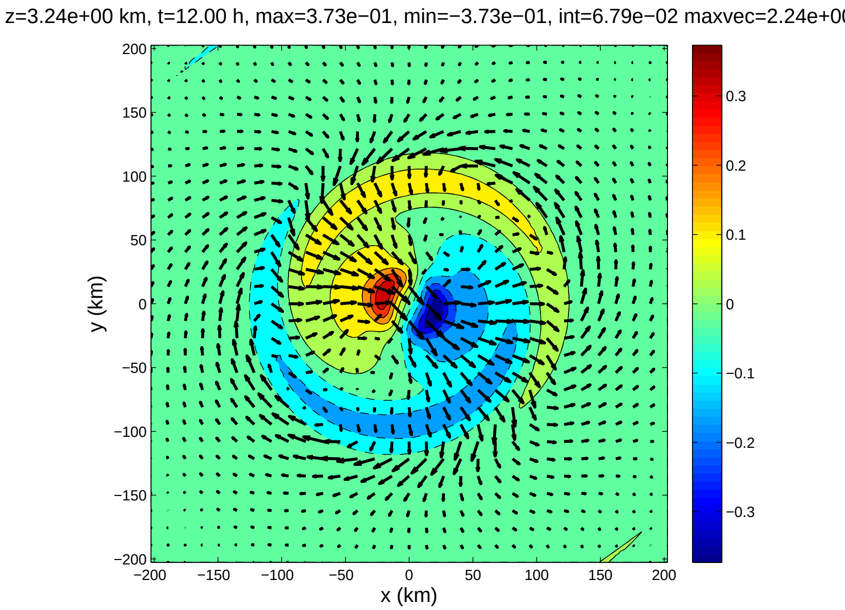
The heat source can be projected onto each azimuthal wavenumber:

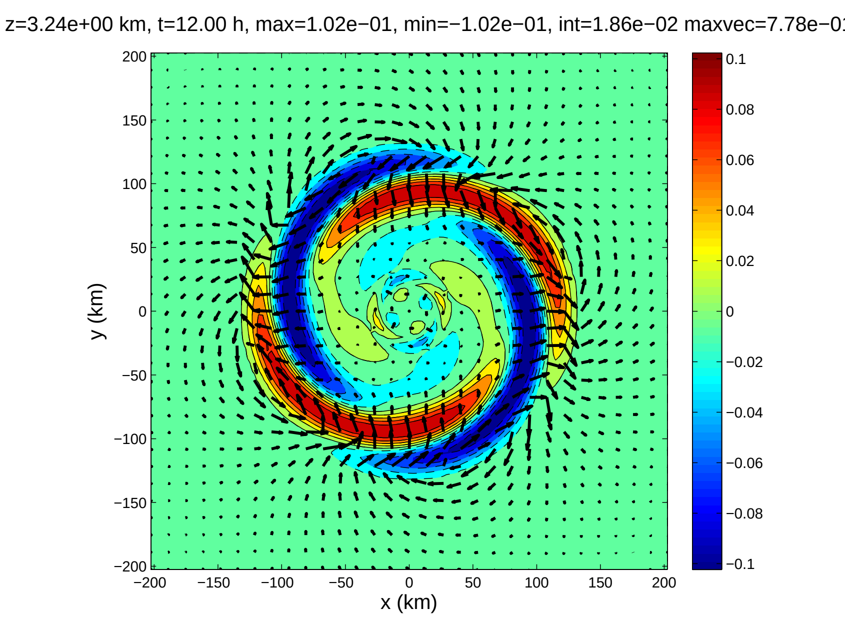


• We presume that the bands are moving with the mean circulation;
Except where noted, this is set to 75% of the local surface wind speed.

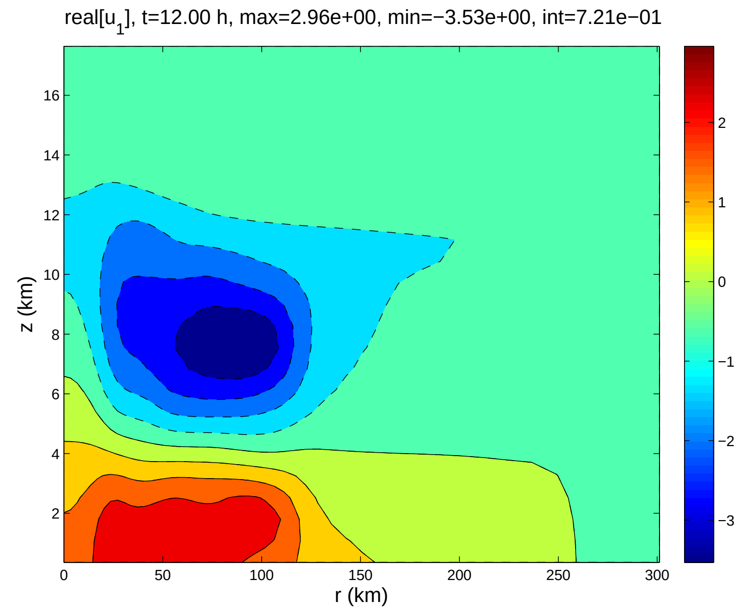
•The asymmetric heat sources force an asymmetric response:

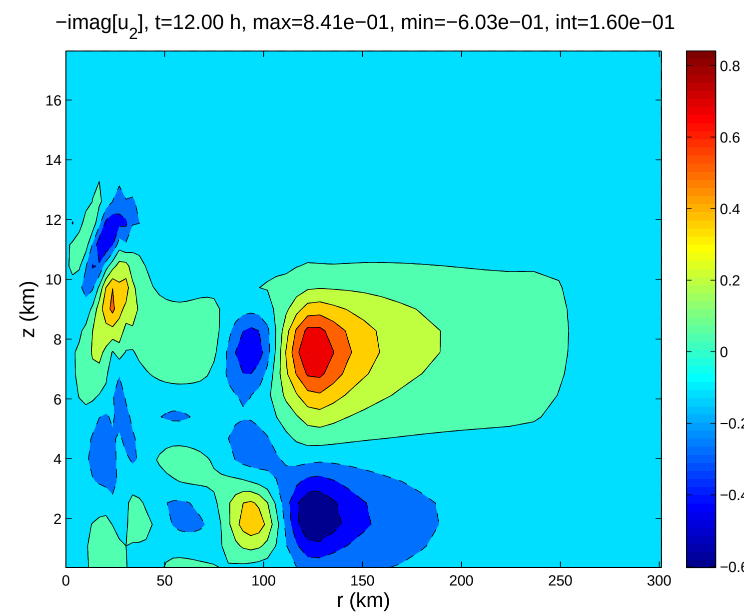
w and [u,v] vectors

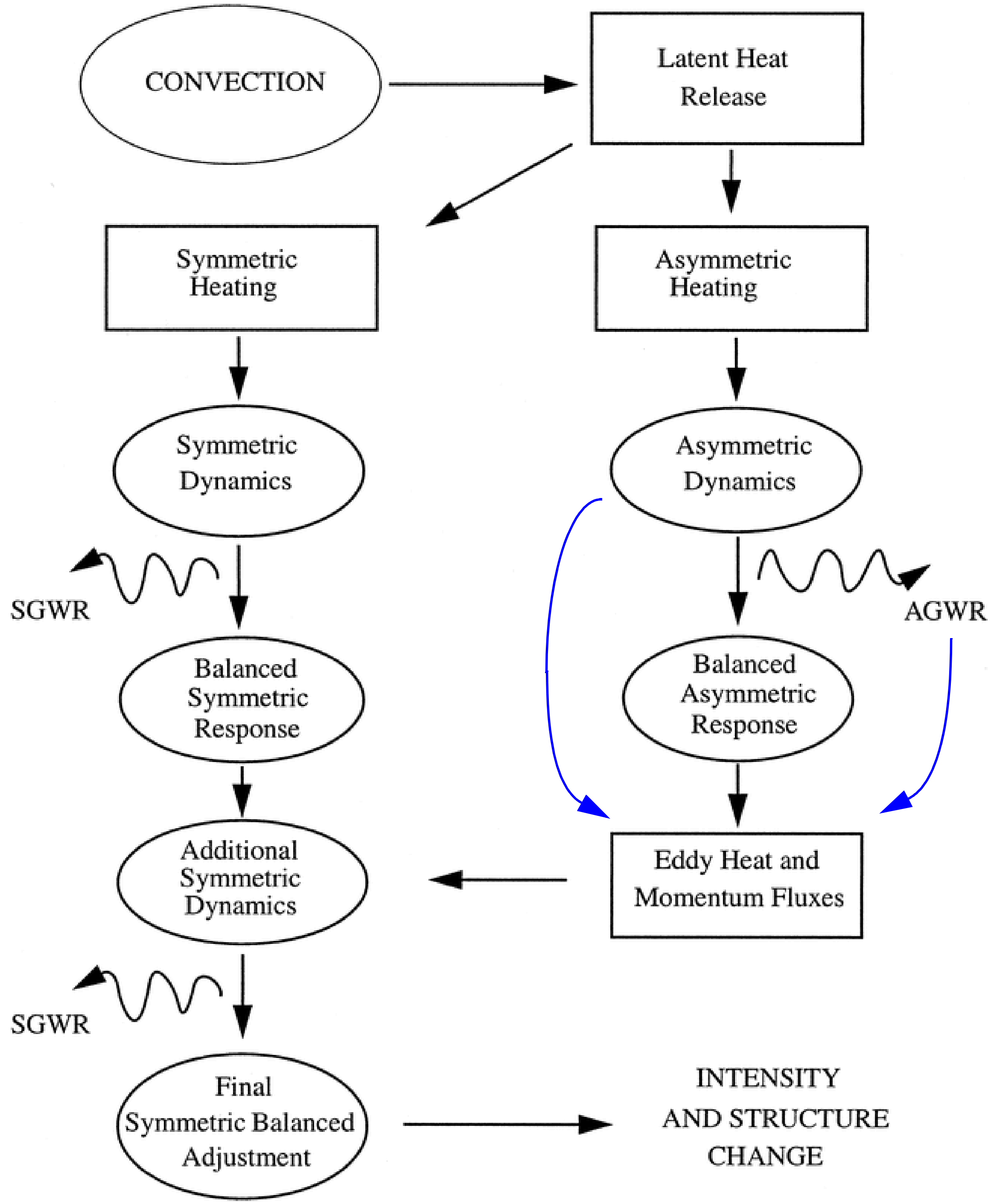




(r,z) slice of radial wind

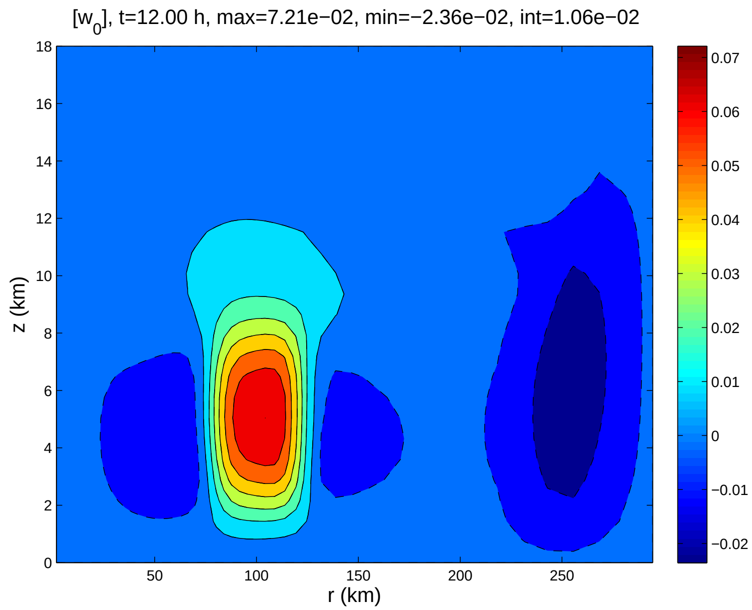


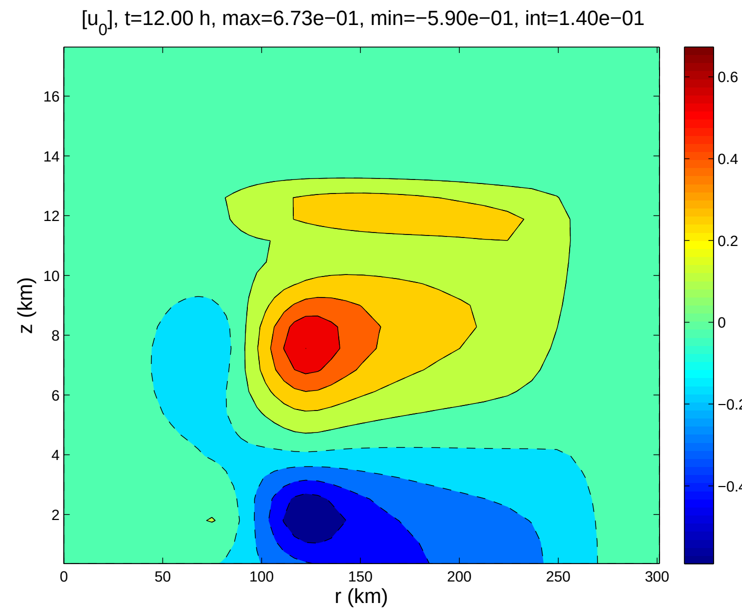


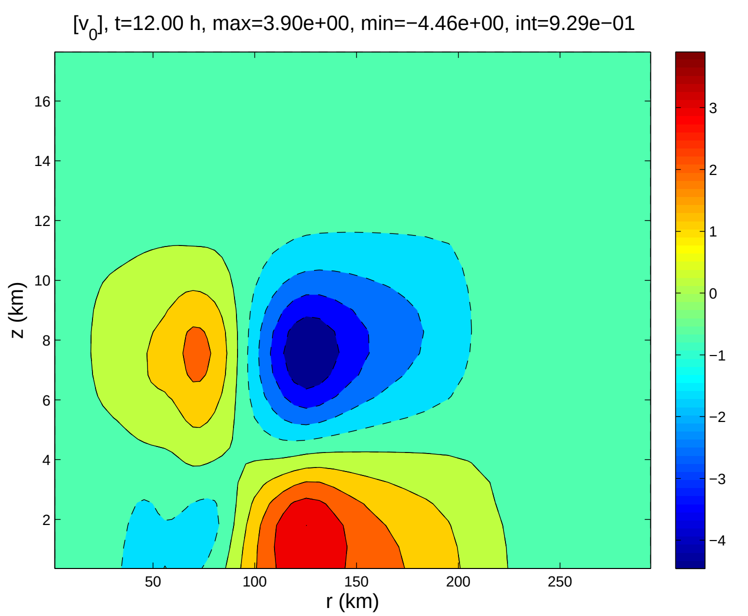


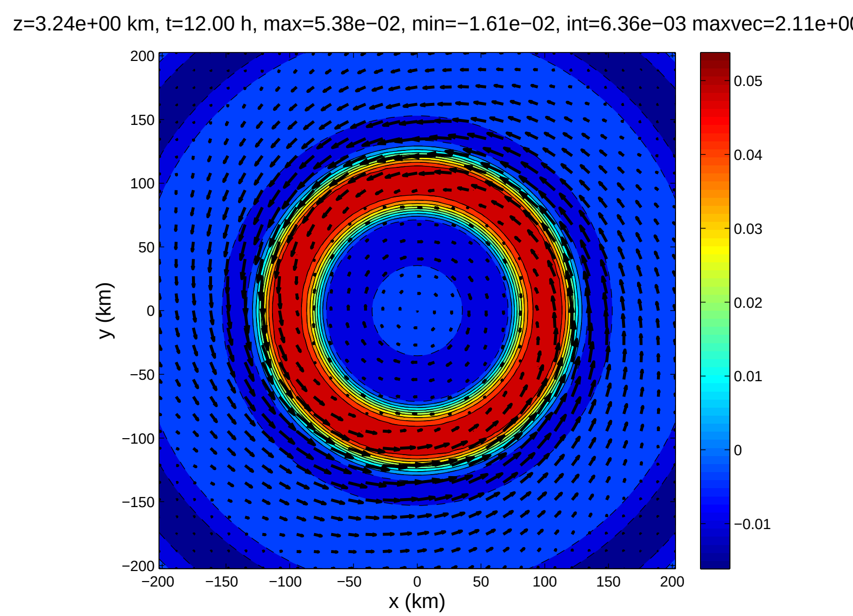
Nolan and Grasso (JAS, 2003)

- The symmetric response (intensity change) is dominated by the symmetric forcing:

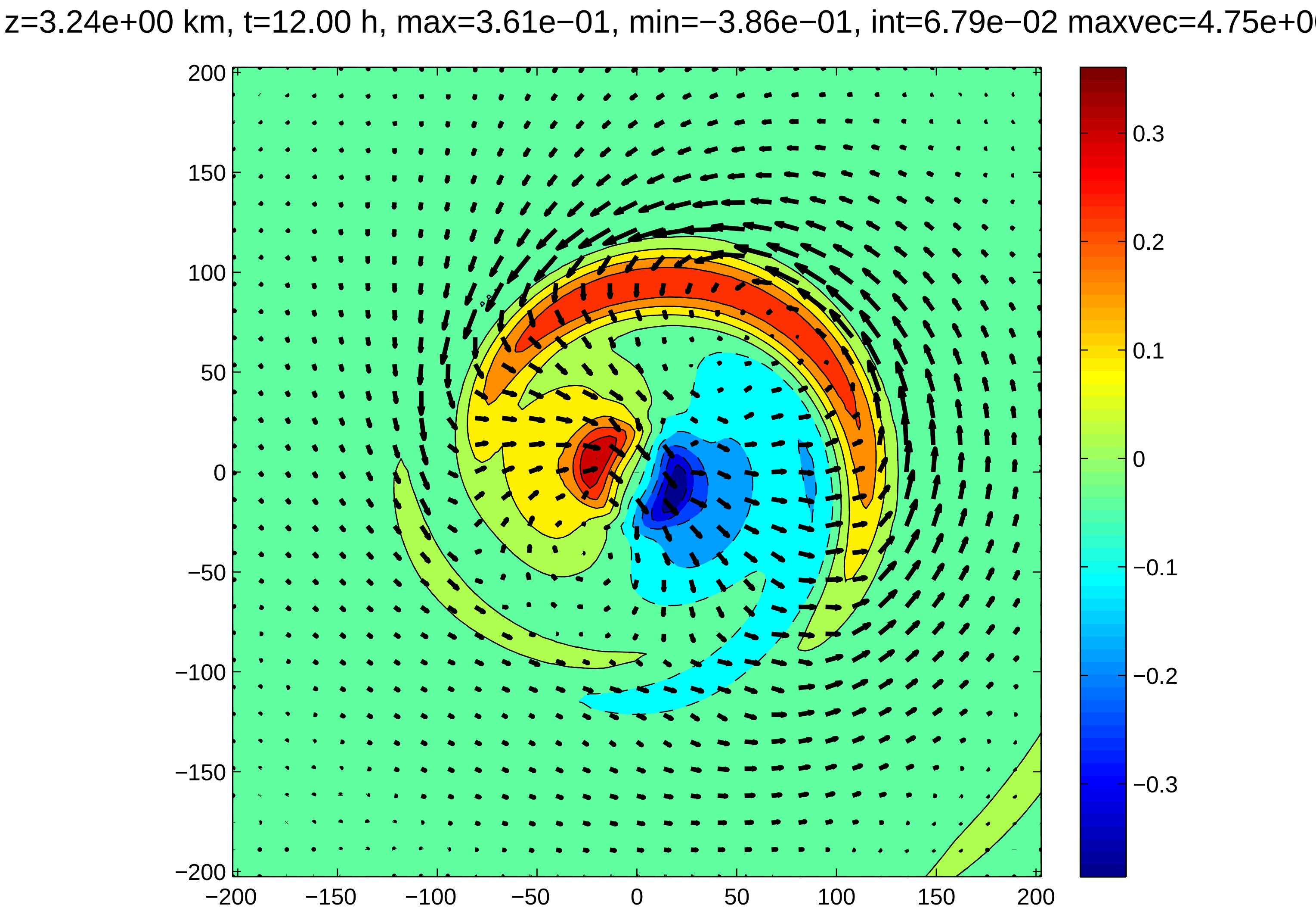








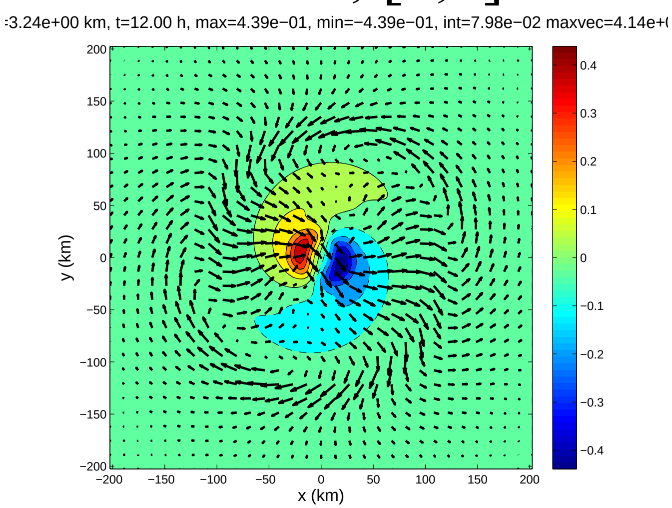
Though it is still interesting to add it all together (sum of n = 0, 1, and 2):



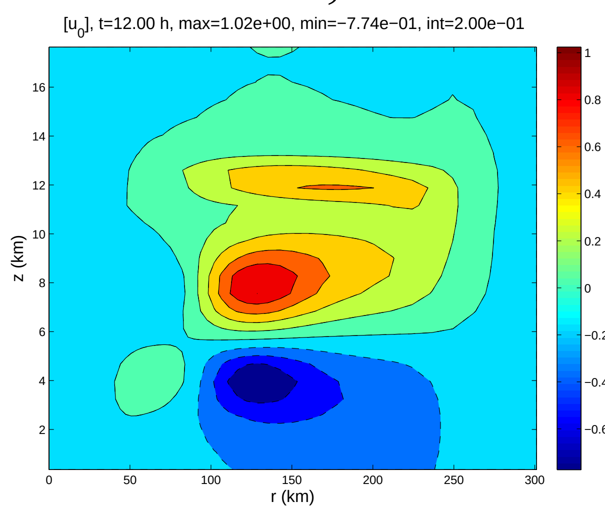
- With the framework in place, we can explore the different impacts of different band structures:

pure stratiform band

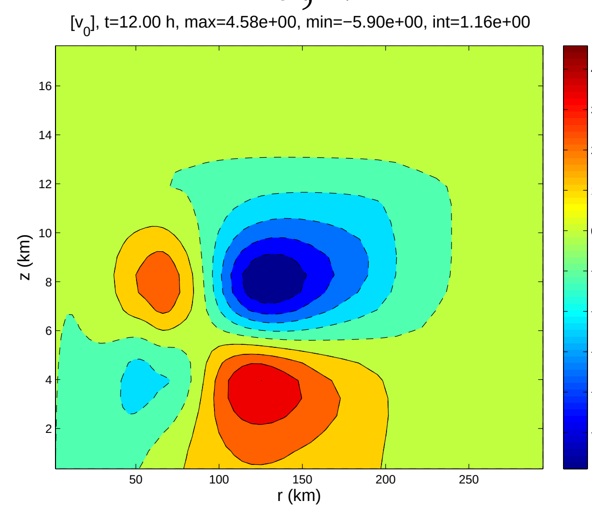
n = 1 w, [u,v]



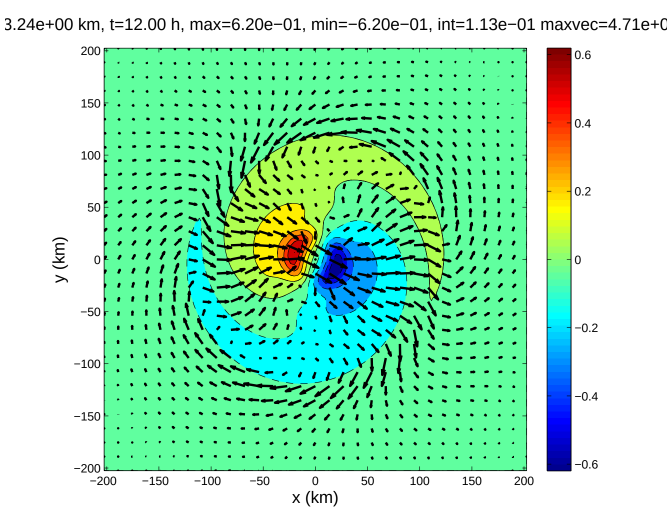
n = 0, u

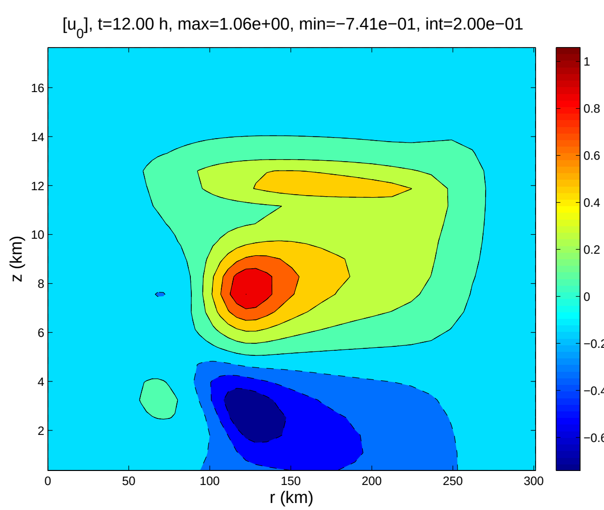


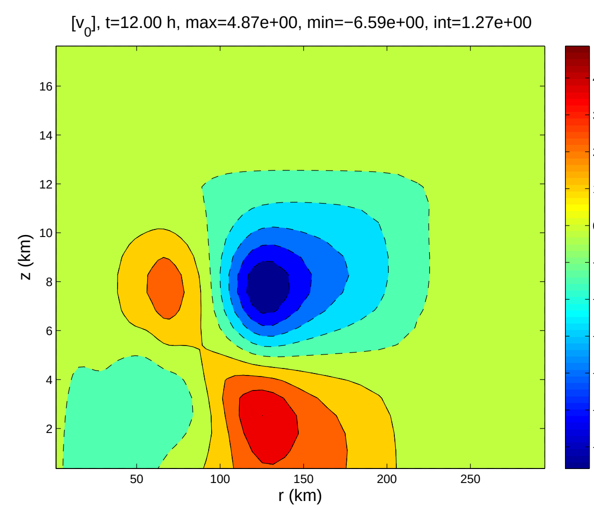
n = 0, v



mixed convective to stratiform

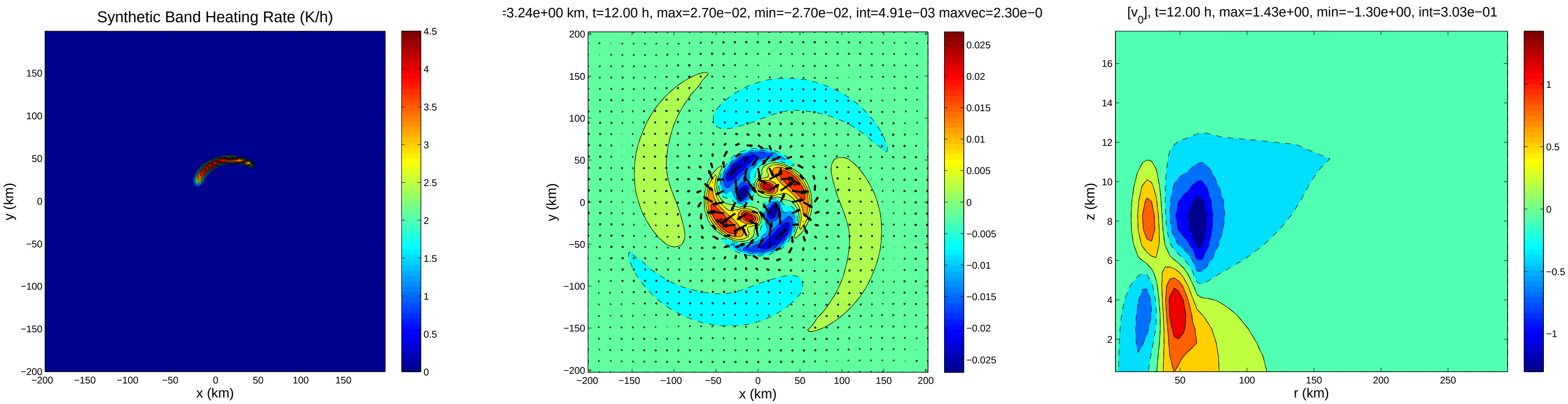




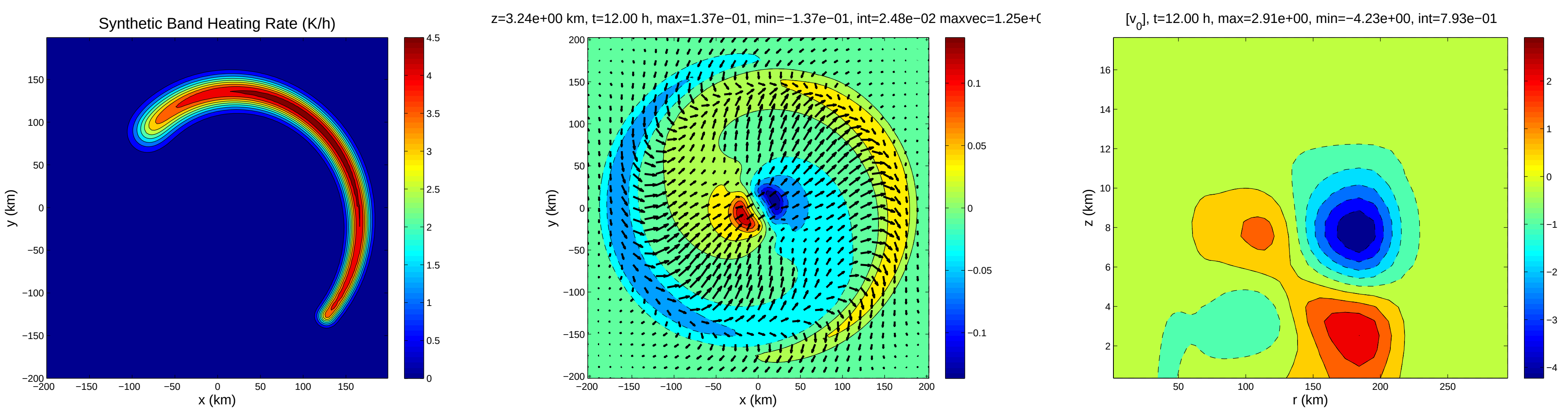


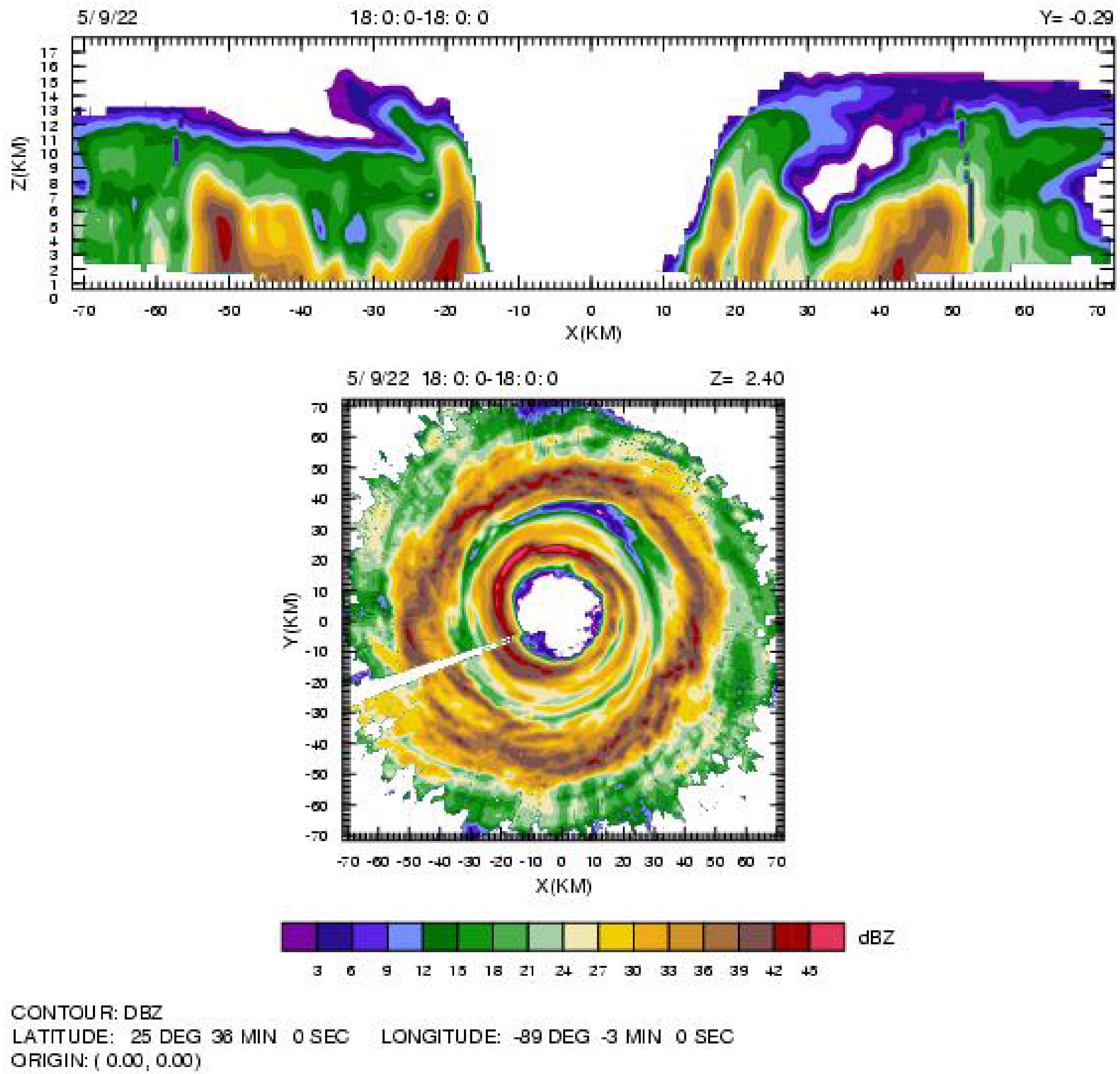
... and different band types as well.

•Inner core band, mixed convective structure:



•"Principal Band," mixed convective structure, *not rotating*:




5/ 9/22
18: 0: 0-18: 0: 0
Y= -0.29
Z(KM)
X(KM)
5/ 9/22 18: 0: 0-18: 0: 0
Z= 2.40
Y(KM)
X(KM)
dBZ
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45
CONTOUR: DBZ
LATITUDE: 25 DEG 36 MIN 0 SEC LONGITUDE: -89 DEG -3 MIN 0 SEC
ORIGIN: (0.00, 0.00)

Discussion and Future Work

* Improvements to assimilation of radar observed wind fields

* Assimilation of radial and vertical winds

* More thorough study of the response to varying types of bands

* More realistic band heating structure - either by more careful construction - or by assimilation of reflectivity data (?)

* Maybe the reverse? Inference (or inversion) of diabatic heating rates from observed vertical winds and/or band structures