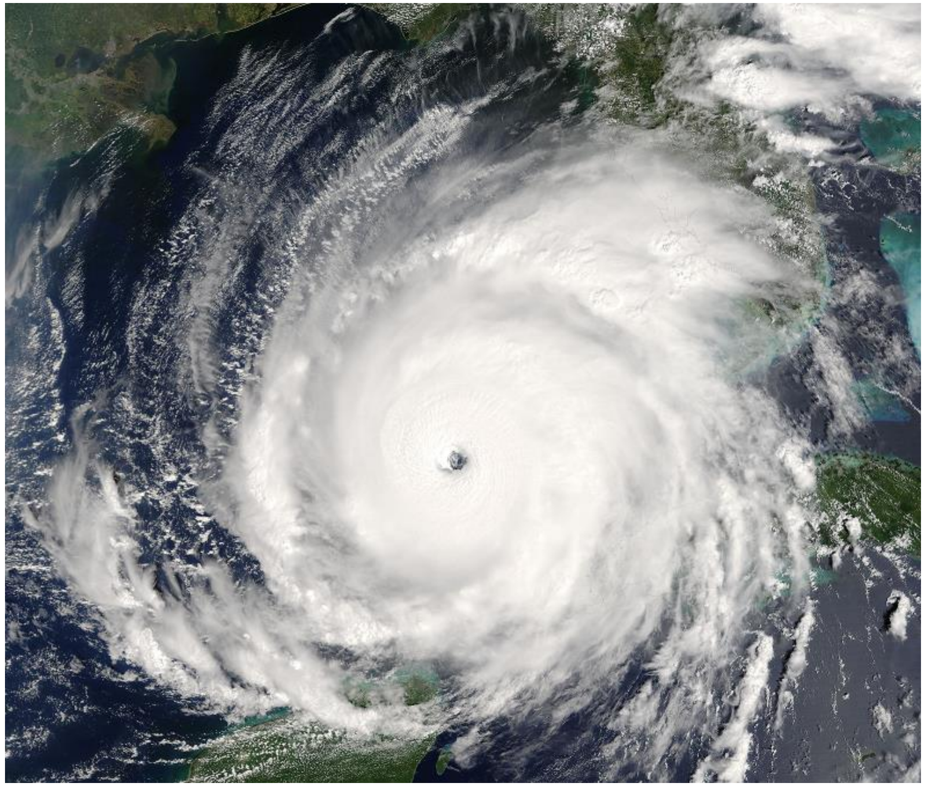
Modeling of Hurricane Stratiform Rainband Heating Structure in Axisymmetric Framework

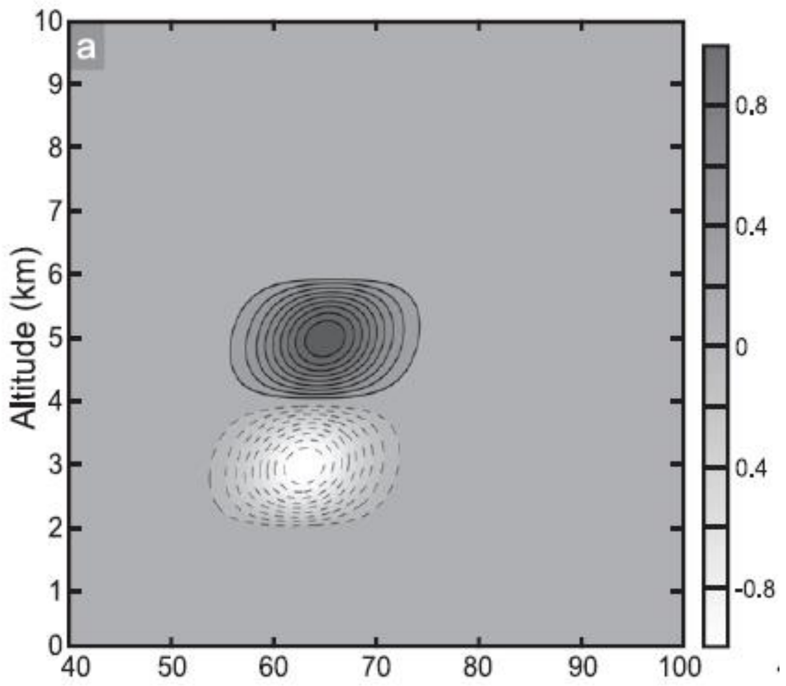
Chris Yu and Anthony Didlake



Hurricane Rita 2005

Motivation

- The stratiform sector within the stationary rainband complex has a large spatial coverage
  → Influencing the vortex-scale wind field and storm evolution
- Didlake and Houze (2012)
  → Enhances and broadens the storm tangential wind
  → Contributing to structural and intensity changes
- Moon and Nolan (2010) examined the dynamic response of the hurricane wind field to idealized heating patterns of a stratiform rainband



Moon and Nolan (2010)

We are very interested to see how hurricane vortex responds to a more realistic heating structure in stratiform sector

Outline

- Observational Data
- Modeling tools

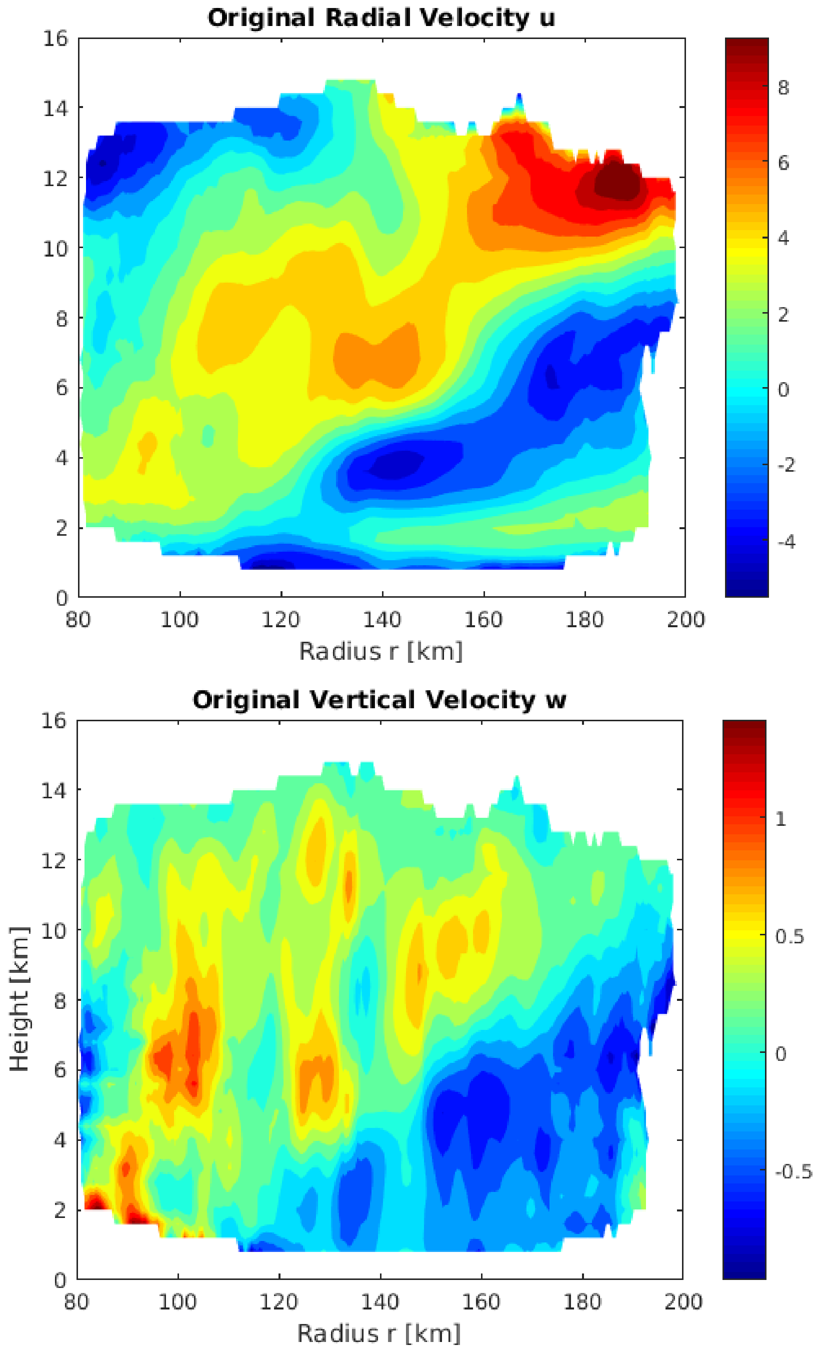
  - Prognostic Model

  - Diagnostic Model
- Reconstructing heating structure
- Implication on the angular momentum budget
- Concluding Remark

Observational Data

- Using airborne Doppler radar data, Didlake and Houze (2012) found that mid-level inflows separated into three inflow bursts in Hurricane Rita

- **<u>What is the heating and cooling structure responsible for the observed secondary circulation pattern?</u>**



Modeling Tools

Prognostic Model	Diagnostic Model
Weather **R**esearch and **F**orecasting (**WRF)** ▪ **A**dvanced **R**esearch **W**RF (**ARW**): Version 3.9.1 ▪ Regional, global or idealized ▪ Microphysics and boundary layer parameterizations are turned **OFF** ▪ Artificial heat source is added	**Sawyer-Eliassen Equation** ▪ Based on 1. Linear Theory 2. Axis-symmetric assumption, 3. Gradient wind and Thermal wind balance. ▪ Capture secondary circulation due to axis-symmetric heating

$$\frac{\partial}{\partial r}\left(A\frac{\partial r\psi}{r\partial r}\right)+\frac{\partial}{\partial r}\left(B\frac{\partial\psi}{\partial z}\right)$$

$$+\frac{\partial}{\partial z}\left(B\frac{\partial\psi}{\partial r}\right)+\frac{\partial}{\partial z}\left(C\frac{\partial r\psi}{r\partial r}\right)$$

$$=\left(\frac{\partial Q}{\partial r}+\frac{\partial M}{\partial z}\right)$$

A is static stability,

B is baroclinicity, and

C is inertial stability

Vortex Response to axis-symmetric heating

- WRF-ARW:

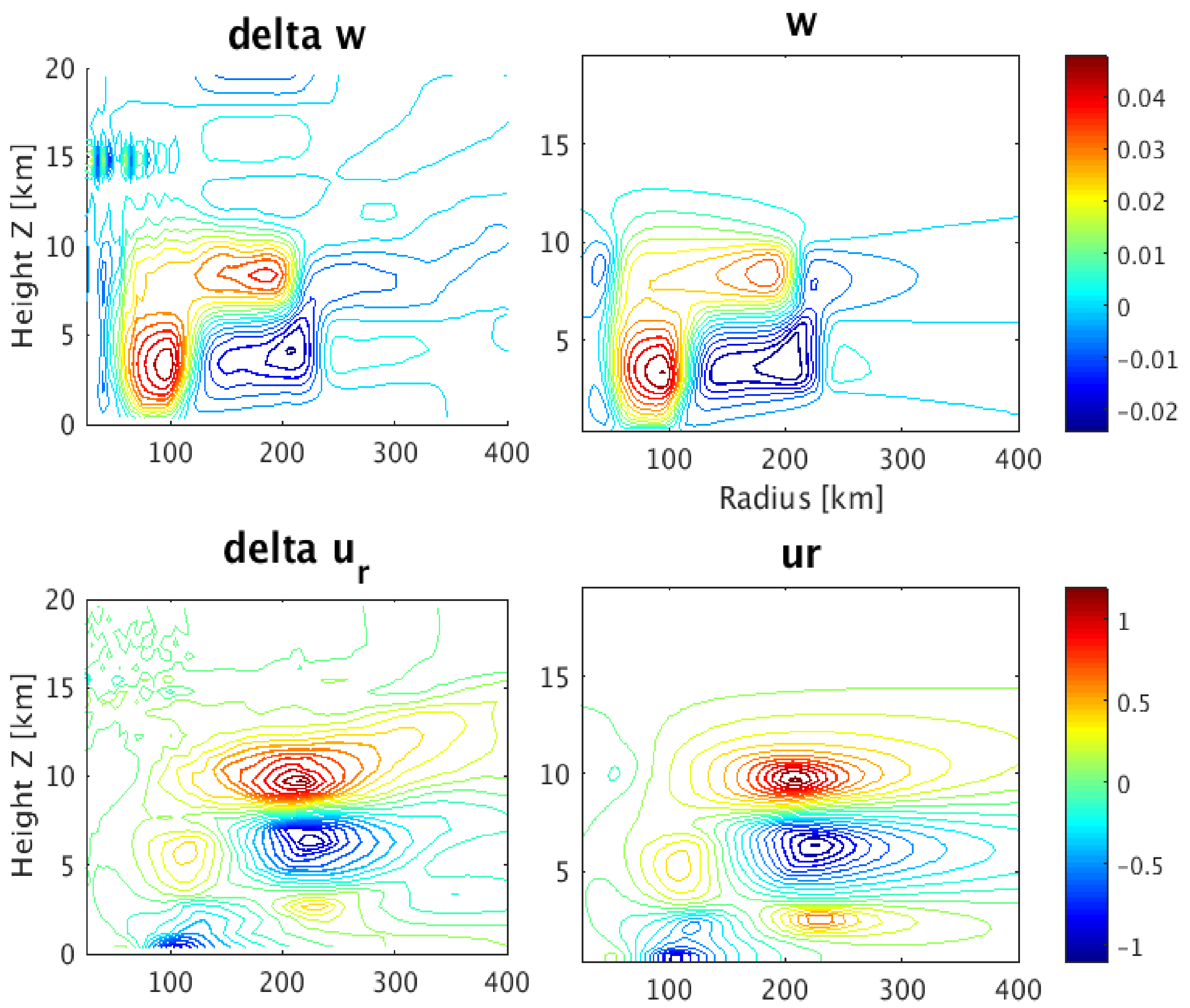
  Two experiments are conducted:

  1. CTRL: No heat source

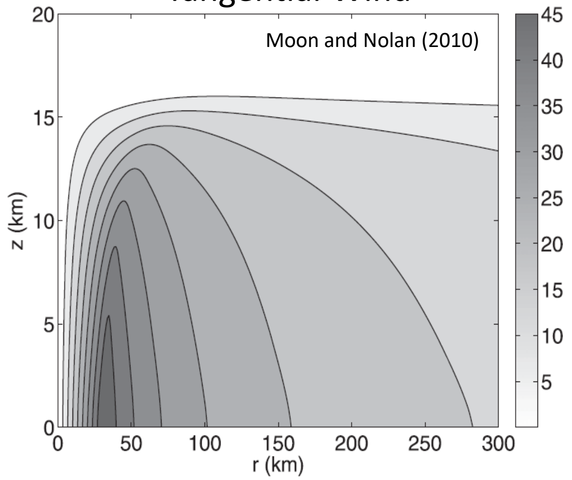
  2. CTRL+heat: heating added

- Calculate the difference in the vortex circulations (e.g. [CTRL+heat]-CTRL)

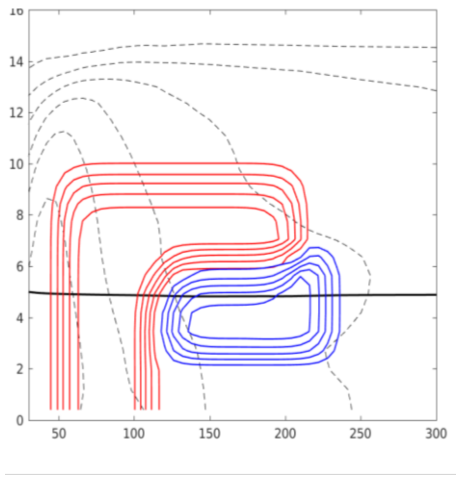
WRF-ARW **Eliassen Model**



Tangential Wind



Heating Profile



Reconstructing Heating Structure

- Heating structure can be reconstructed under axis-symmetric framework using Sawyer-Eliassen equation

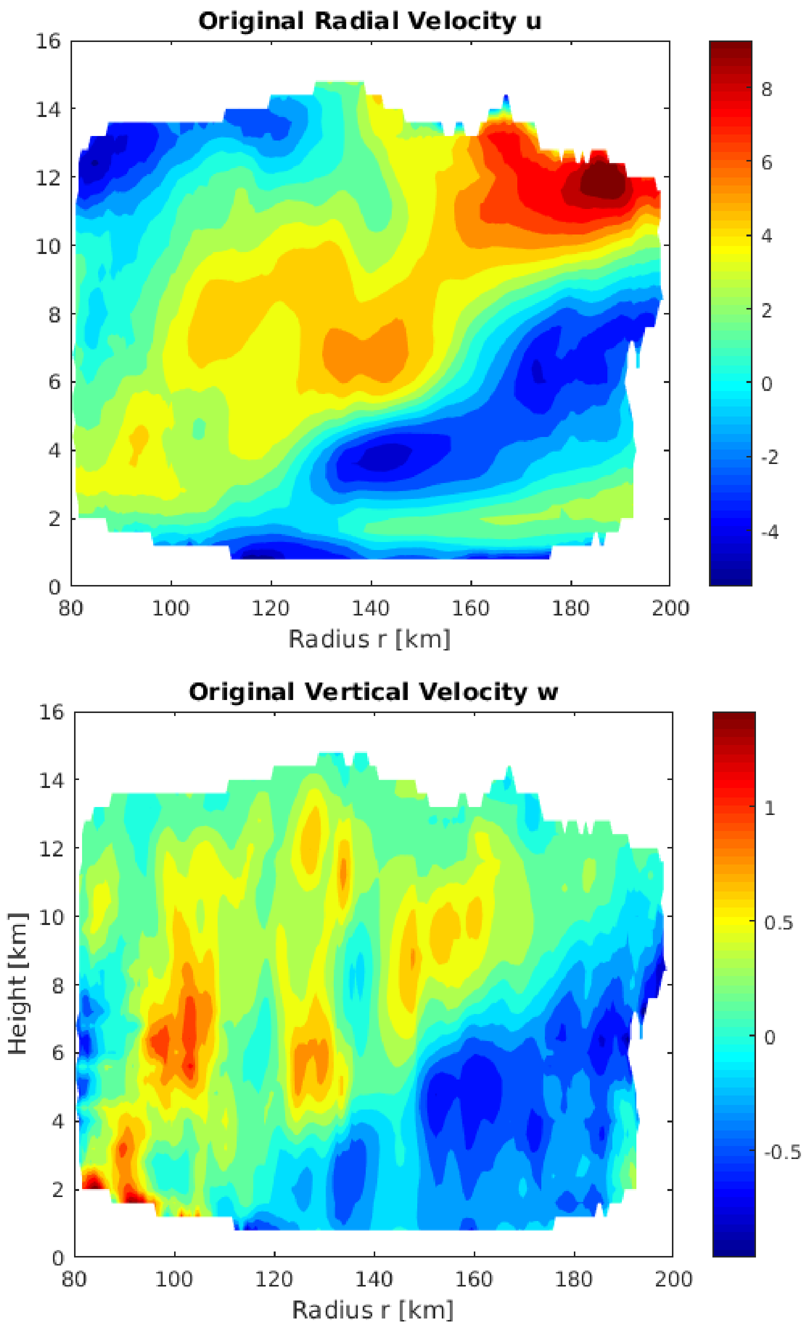
$$\nabla_g^2 \psi = \left(\frac{\partial Q}{\partial r} - \frac{\partial M}{\partial z}\right)$$

- ∇_g^2 is the generalized Laplace operator for Sawyer Eliassen model

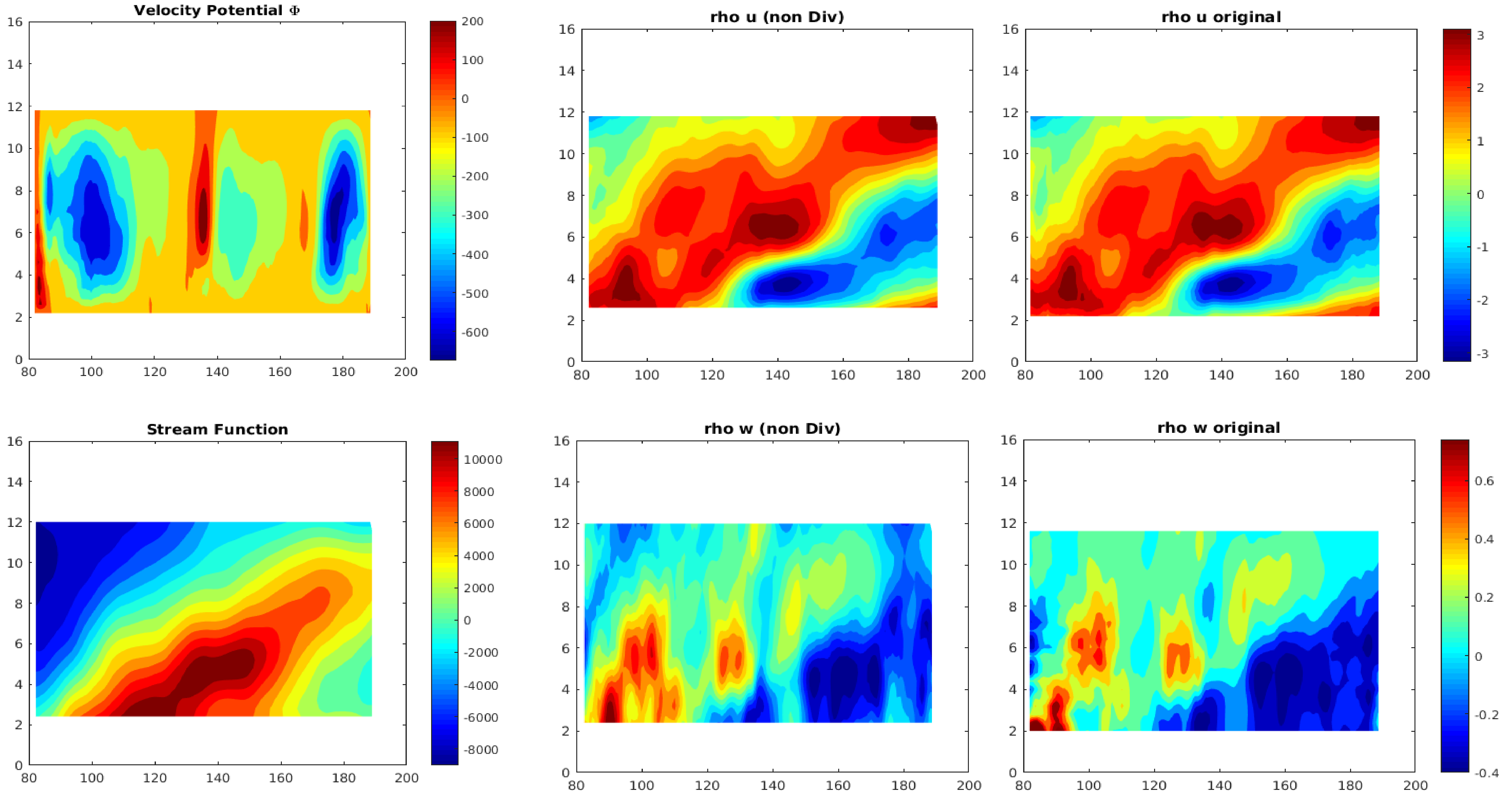
Procedure:

- Extract non-divergent part of the observed circulation and compute streamfunction
- Use Sawyer Eliassen model to differential heating gradient $\frac{dQ}{dr}$
- Radially Integrate to obtain Q

From Didlake and Houze (2012)



Non Divergent Component **Full Component**



Integrate to get Q

- Substiting stream function ψ into the Eliassen Model

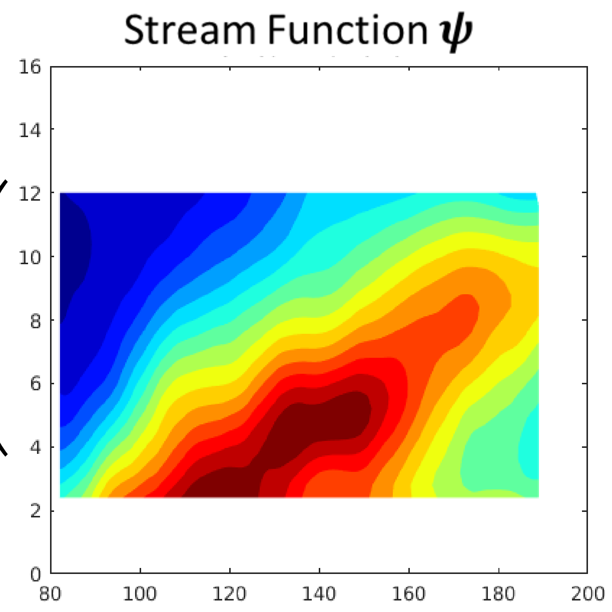
- Further assumptions:

  1. Neglect the momentum forcing term

  2. Assuming $Q = 0$ at the outer boundary

- Integrate $\frac{\partial Q}{\partial r}$ radial inward

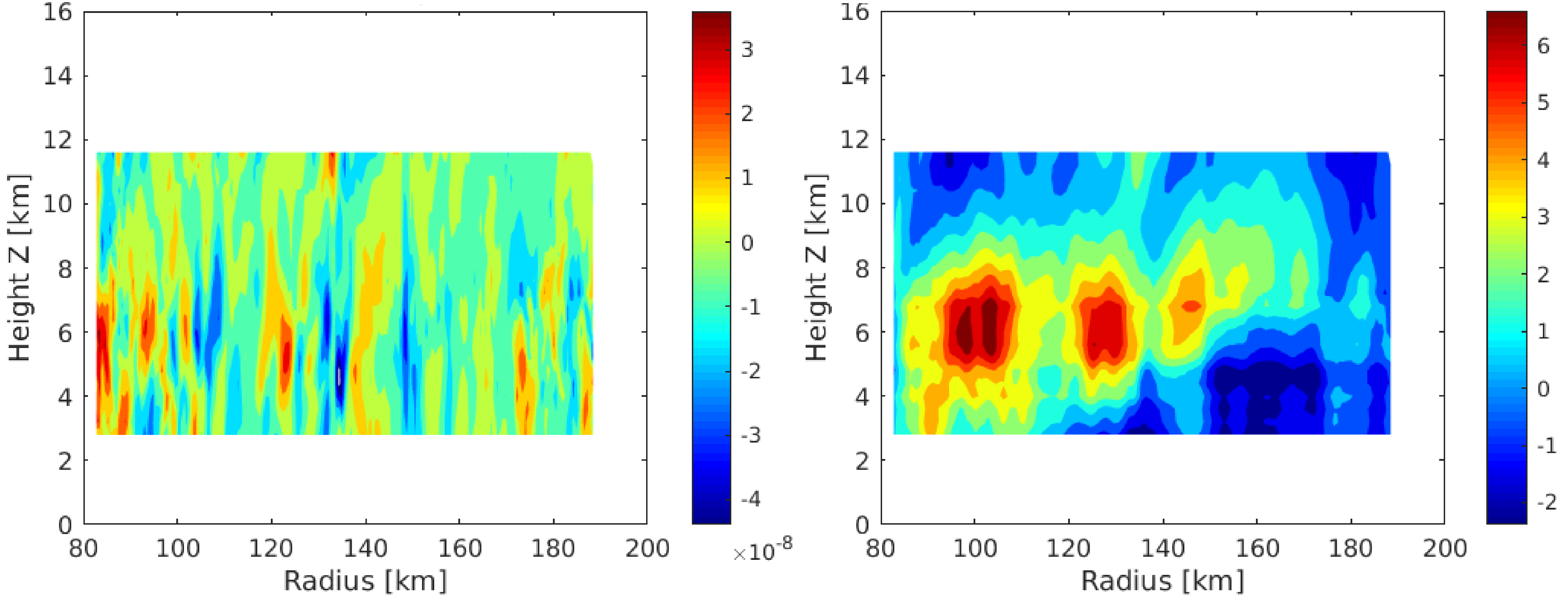
$\nabla_g^2 \Bigg($



$\Bigg)$

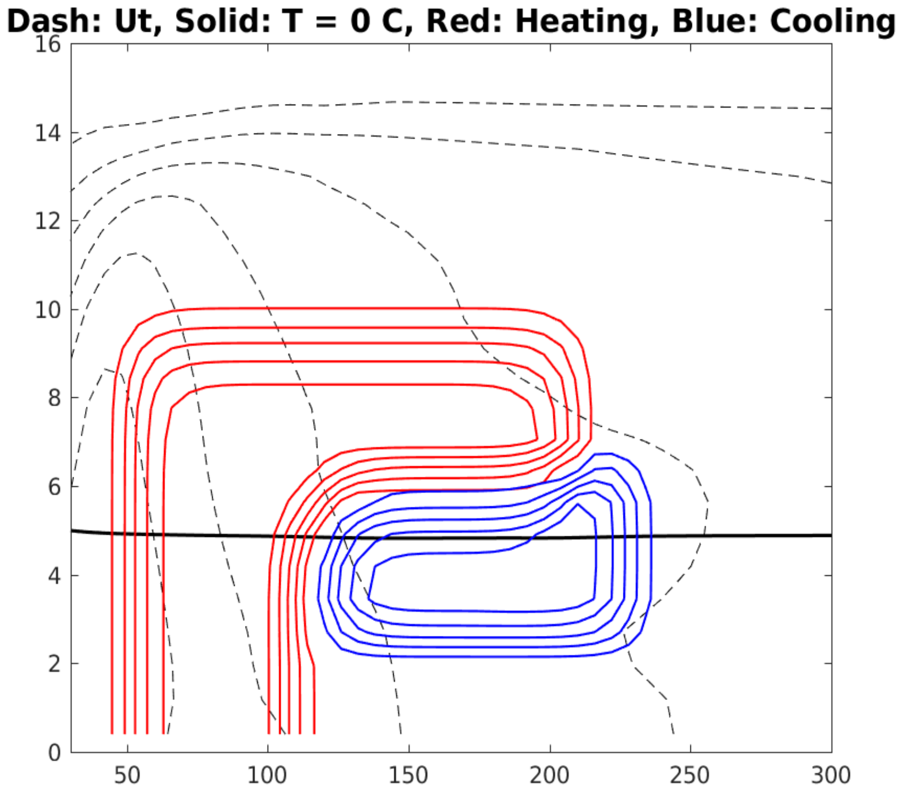
$$= \left(\frac{\partial Q}{\partial r} - \frac{\partial(\xi M)}{\partial z} \right)$$

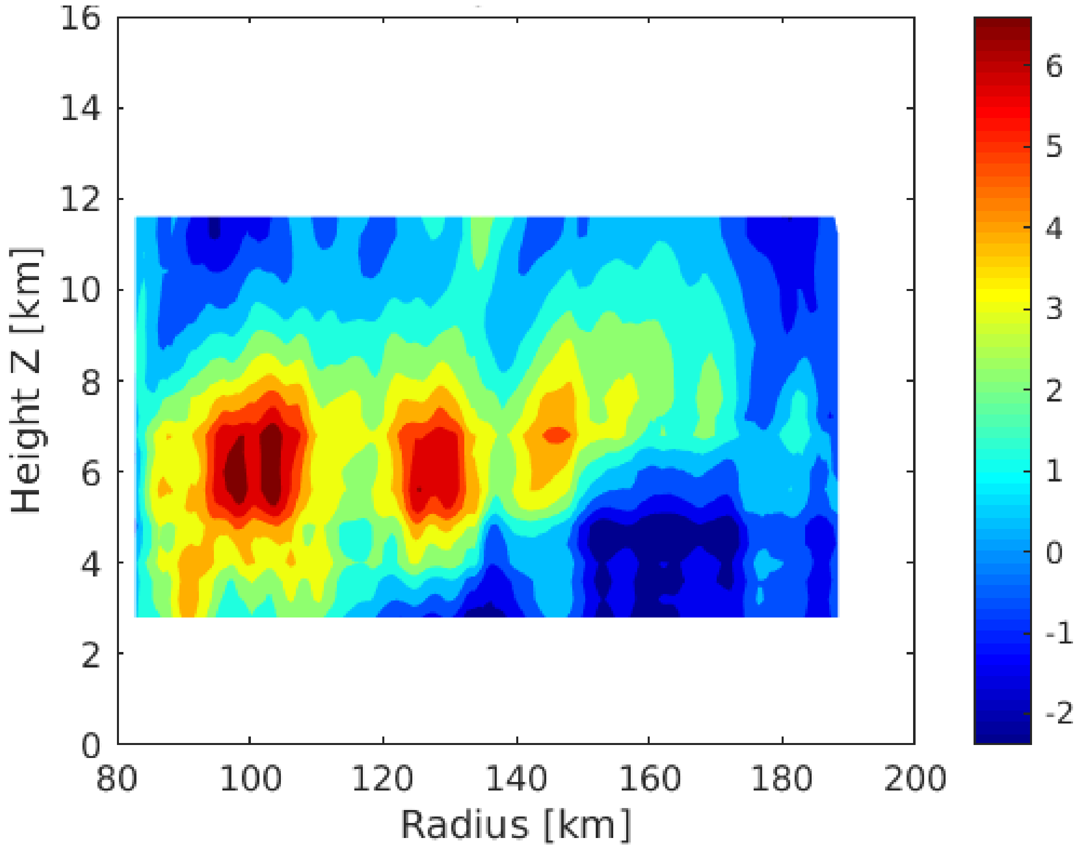
Differential Heating $\frac{dQ}{dr}$ | Real Heating $q\ [W]$



Modifying the WRF heat source

- We modify the WRF heat source based on results from Eliassen Model.





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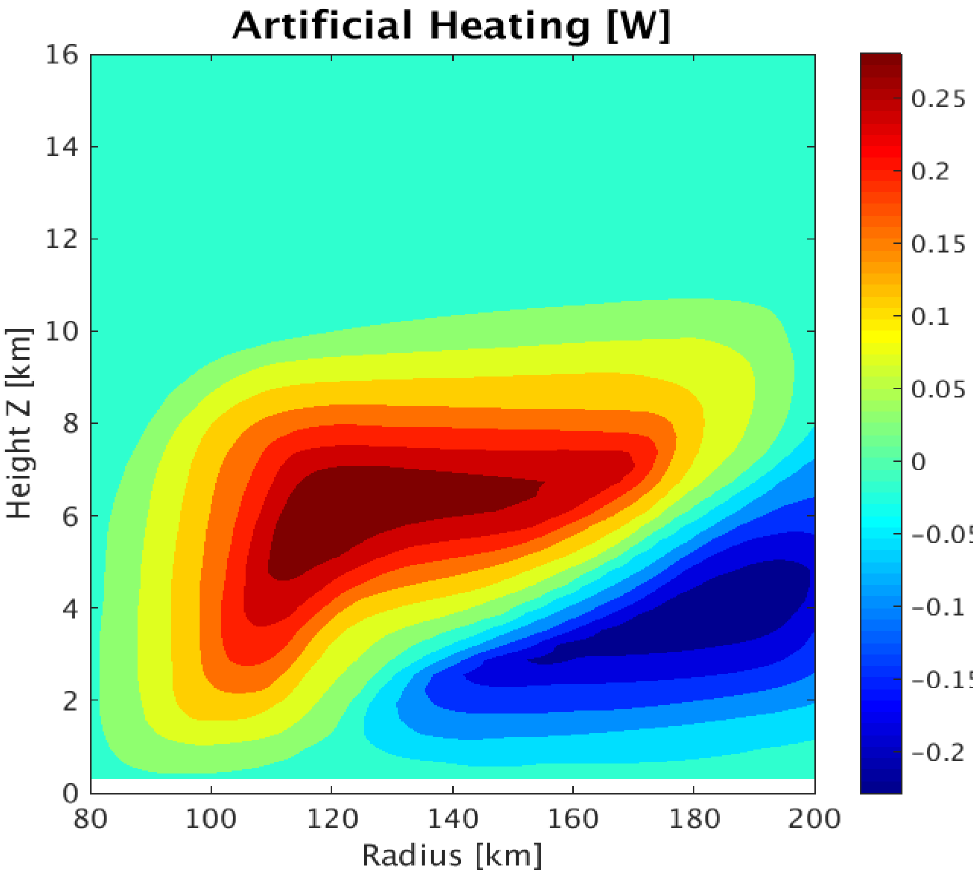
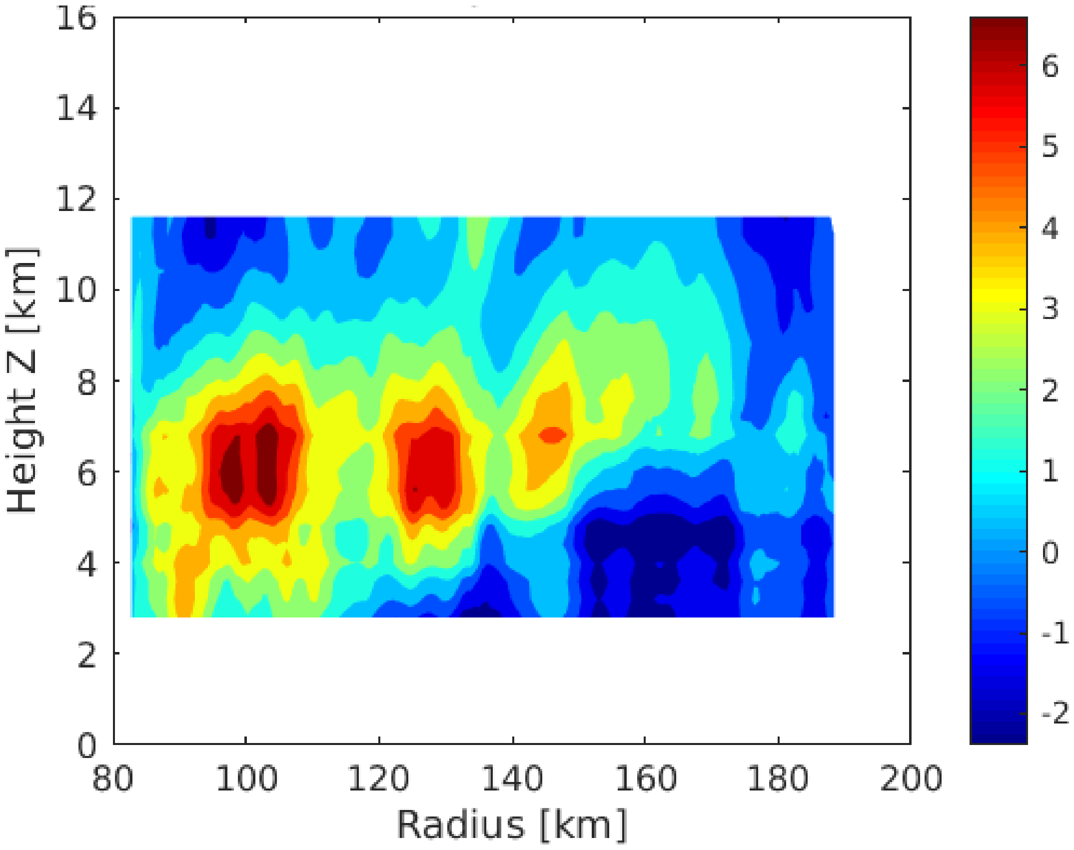
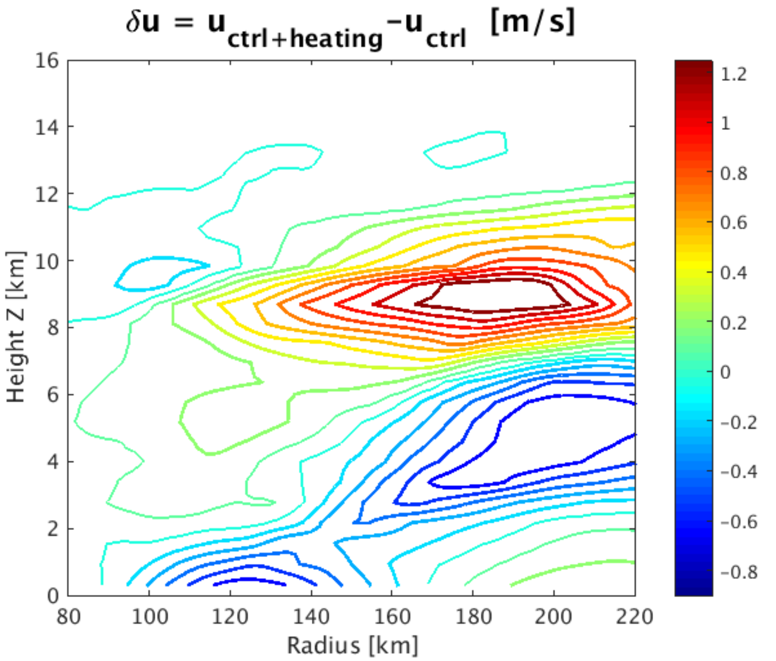


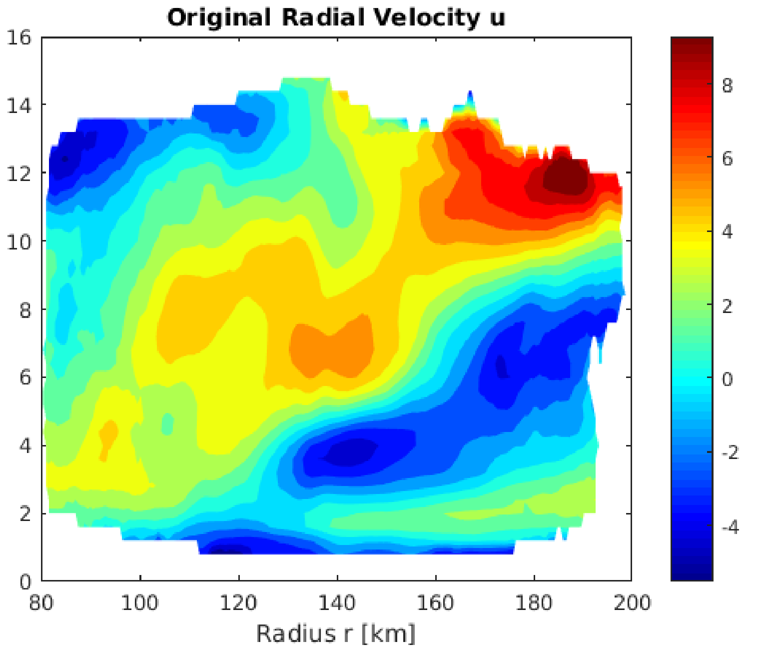


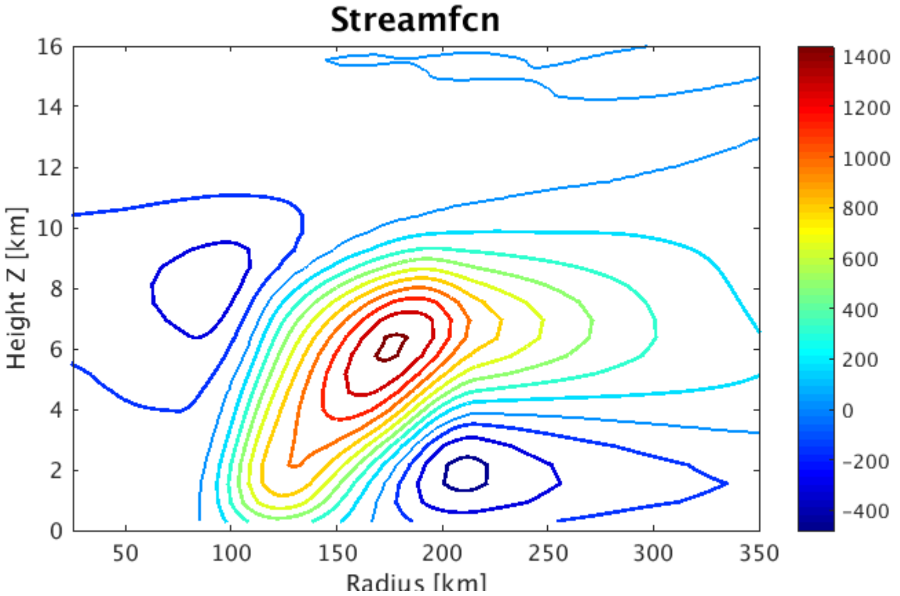
WRF simulated secondary circulation using the artificial heat source:

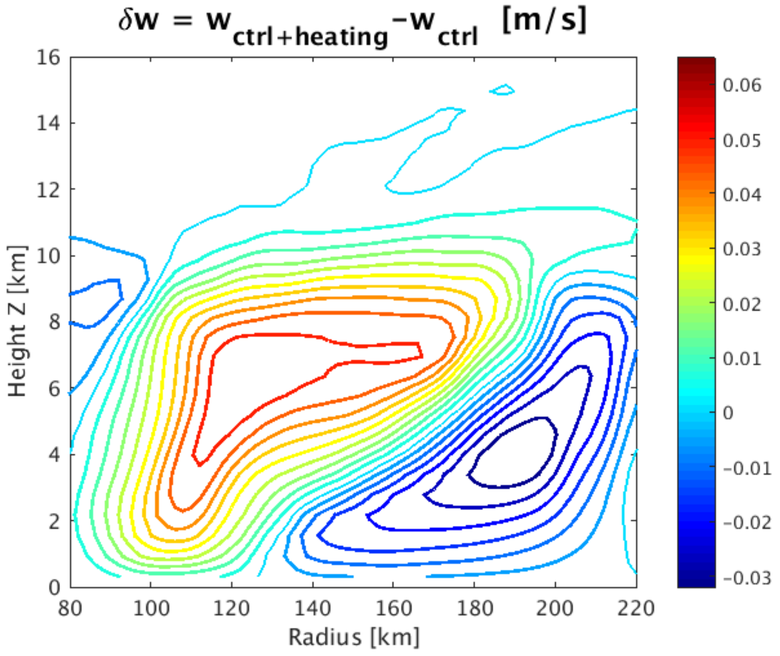
$$\delta(u, w) = (u, w)_{CTRL+heat} - (u, w)_{CTRL}$$

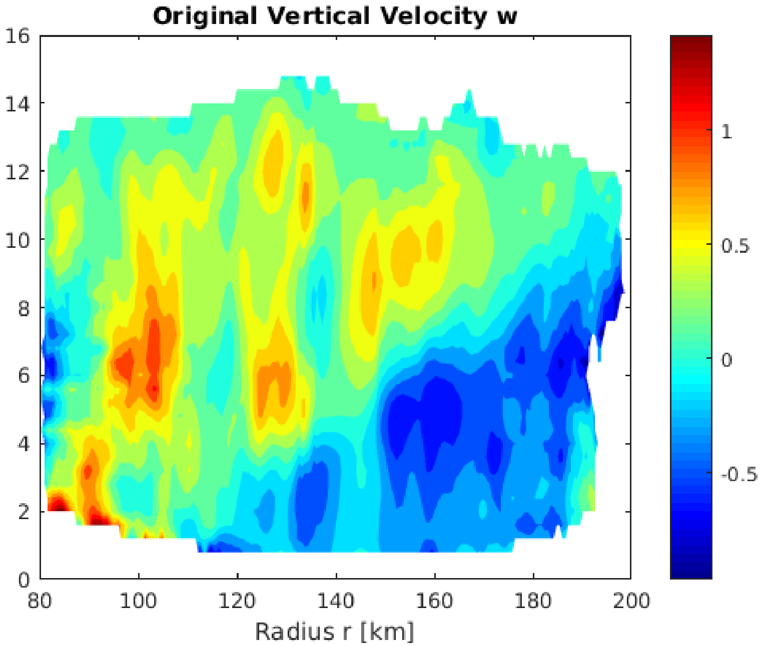


From Didlake and Houze (2012)









On expansion of tangential wind field

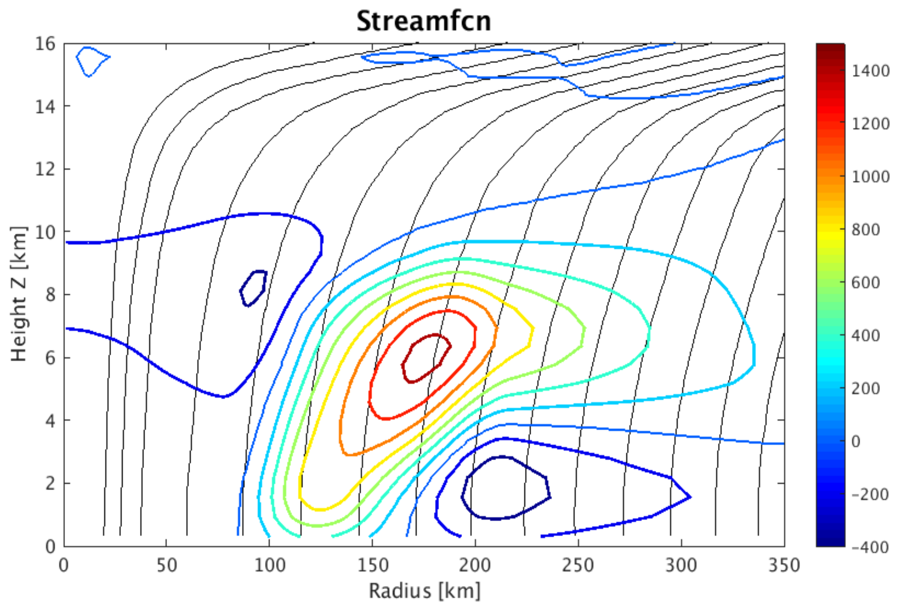
Streamfunction contour not parallel with absolute angular momentum surface

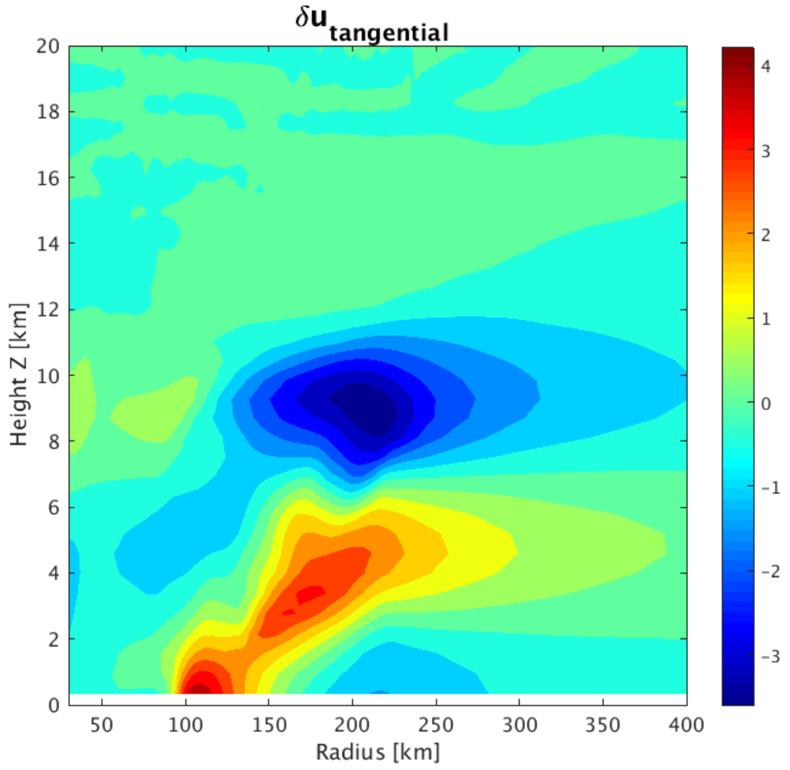
→Non-zero momentum advection due to secondary circulation.

→Absolute angular momentum is conserved

$$\frac{dM}{dt} = \frac{\partial M}{\partial t} + \boldsymbol{u} \cdot \nabla M = 0$$

→ So if $\boldsymbol{u} \cdot \nabla M \neq 0$, we have $\frac{\partial M}{\partial t} \neq 0$





Concluding Remarks:

- Using Eliassen Model, realistic heating structure can be reconstructed using airborne doppler radar collected in hurricane Rita
- With the improved heating profiles, we can simulate the mid-level inflow and realistic secondary circulation as observed in the hurricane stratiform rainband
- Expansion of tangential wind field is also observed, consistent with Didlake and Houze (2012)

Comment

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Questions