

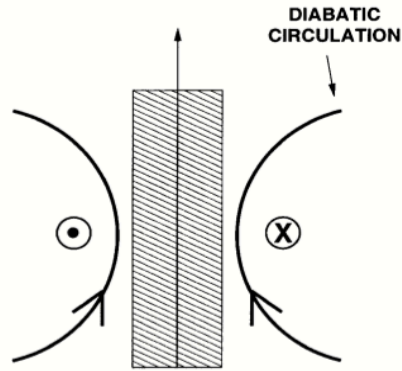


# **Dynamic and thermodynamic structures before and during rapid intensification of tropical cyclones under vertical wind shear**

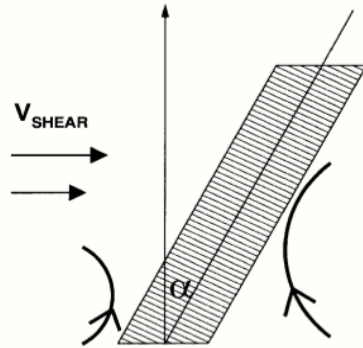
Dandan Tao and Fuqing Zhang



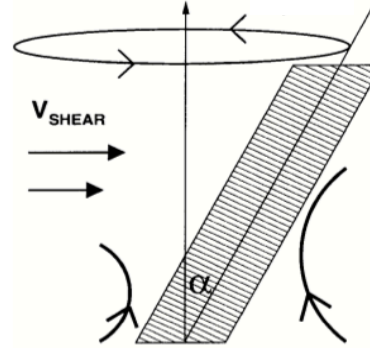
# Precession and Alignment



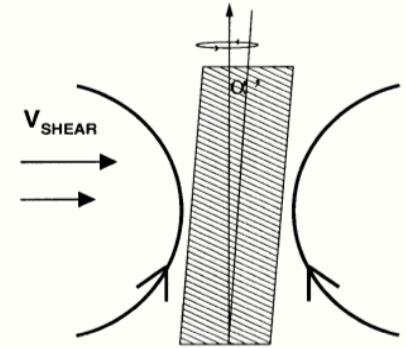
**Straight Vortex Column**



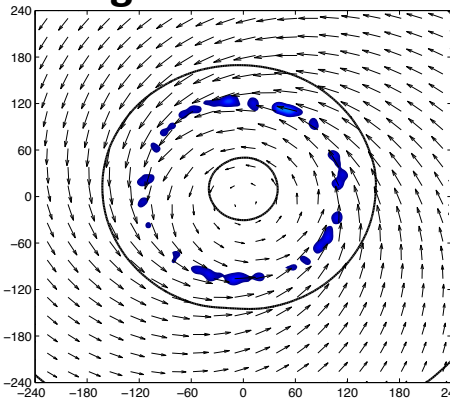
**Tilt**



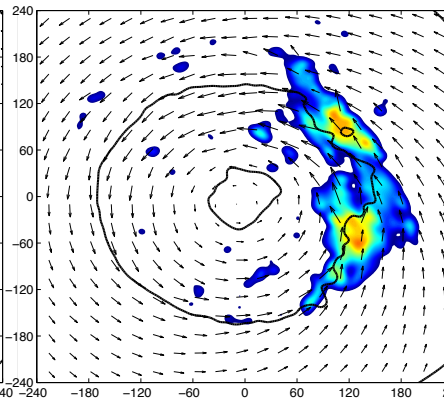
**Precession**



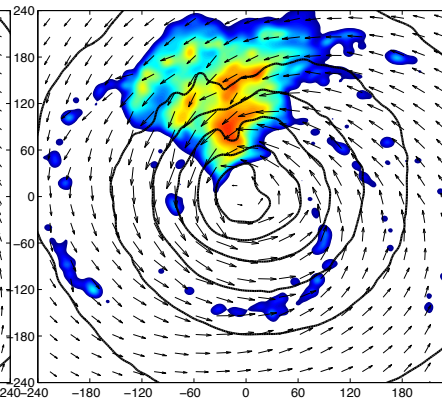
**Alignment**



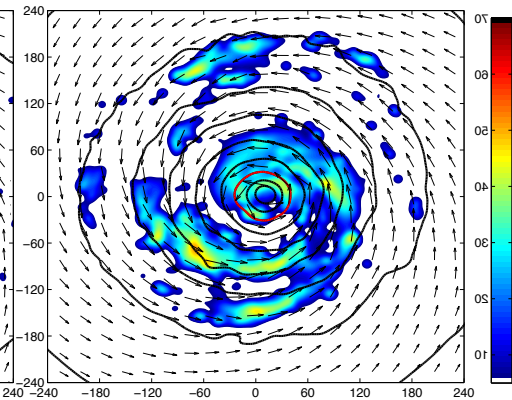
**8 h**



**24 h**



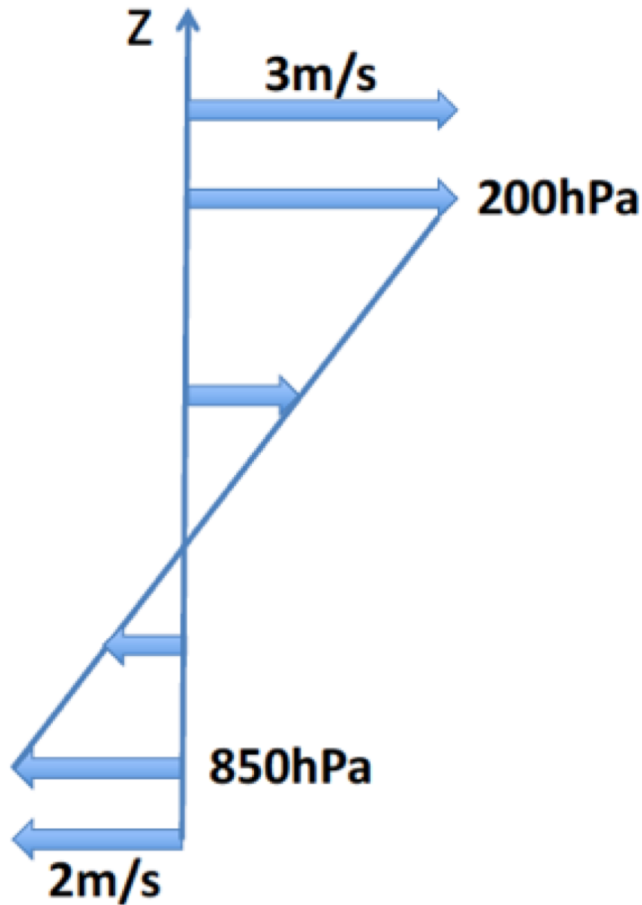
**85 h**



**106 h**



## Shear profile



## Vortex profile

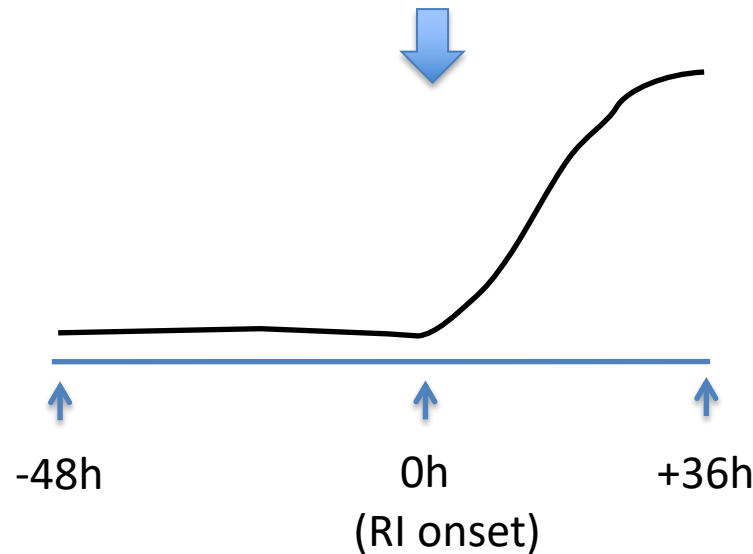
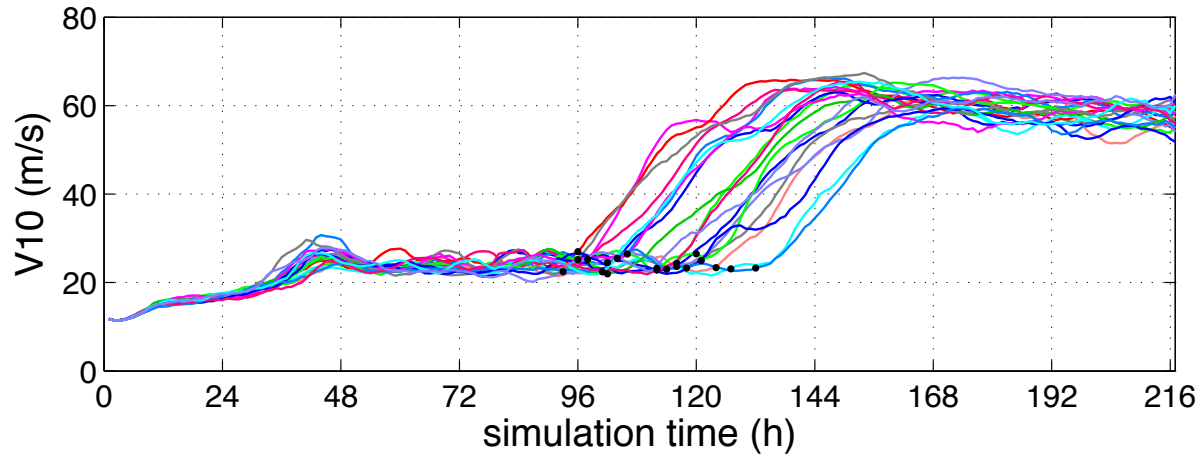
- Rankine Vortex
- Surface maximum
- $V_{\max} = 15 \text{ m/s}$  at  $R_{\max} = 135 \text{ km}$

## 20 ensemble members

- Moisture Perturbation  $\pm 0.5 \text{ g/kg}$  under 950 hPa



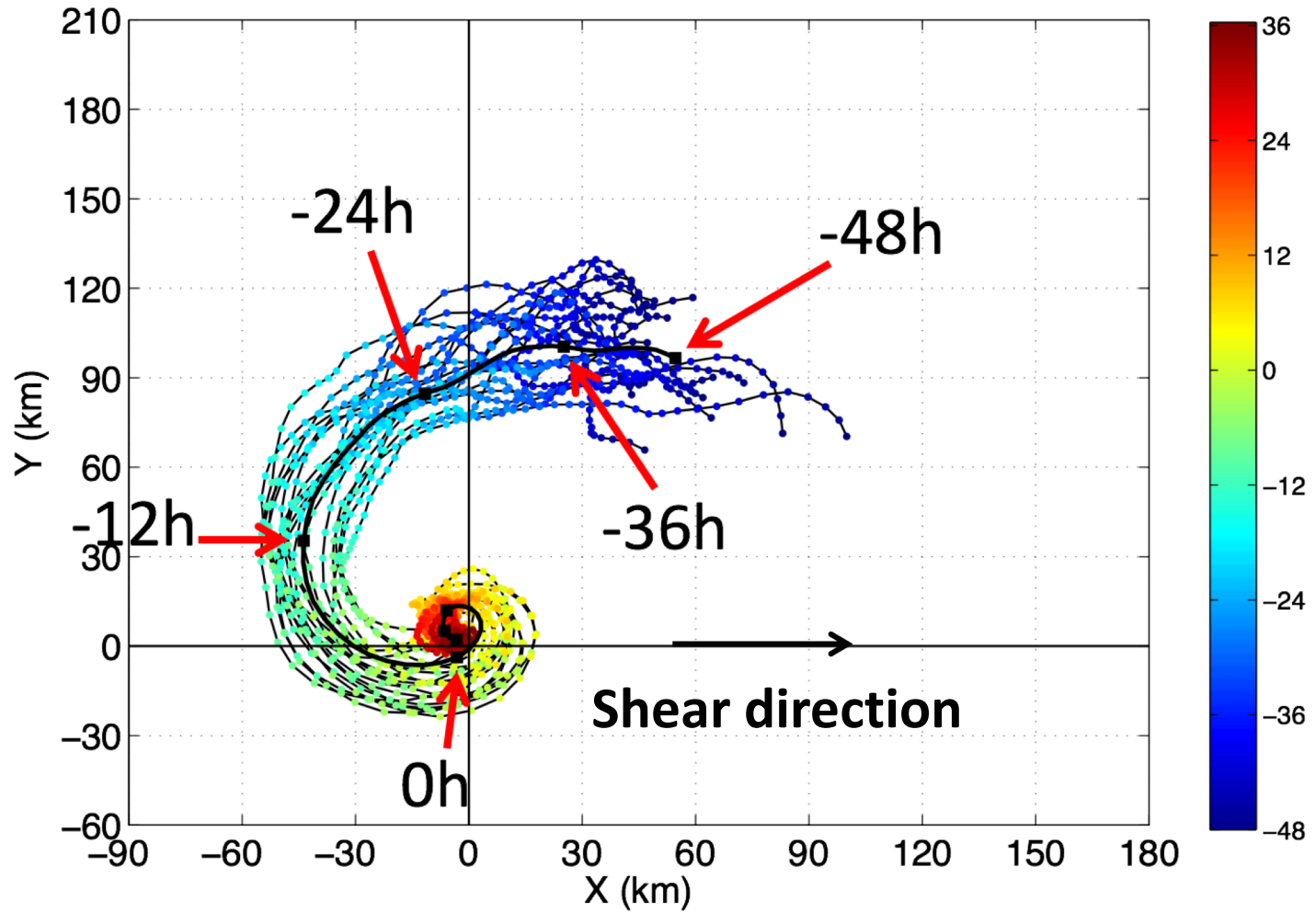
# Maximum 10-m total wind evolution



- RI onset time: start time that maximizes the 24-h intensity change.

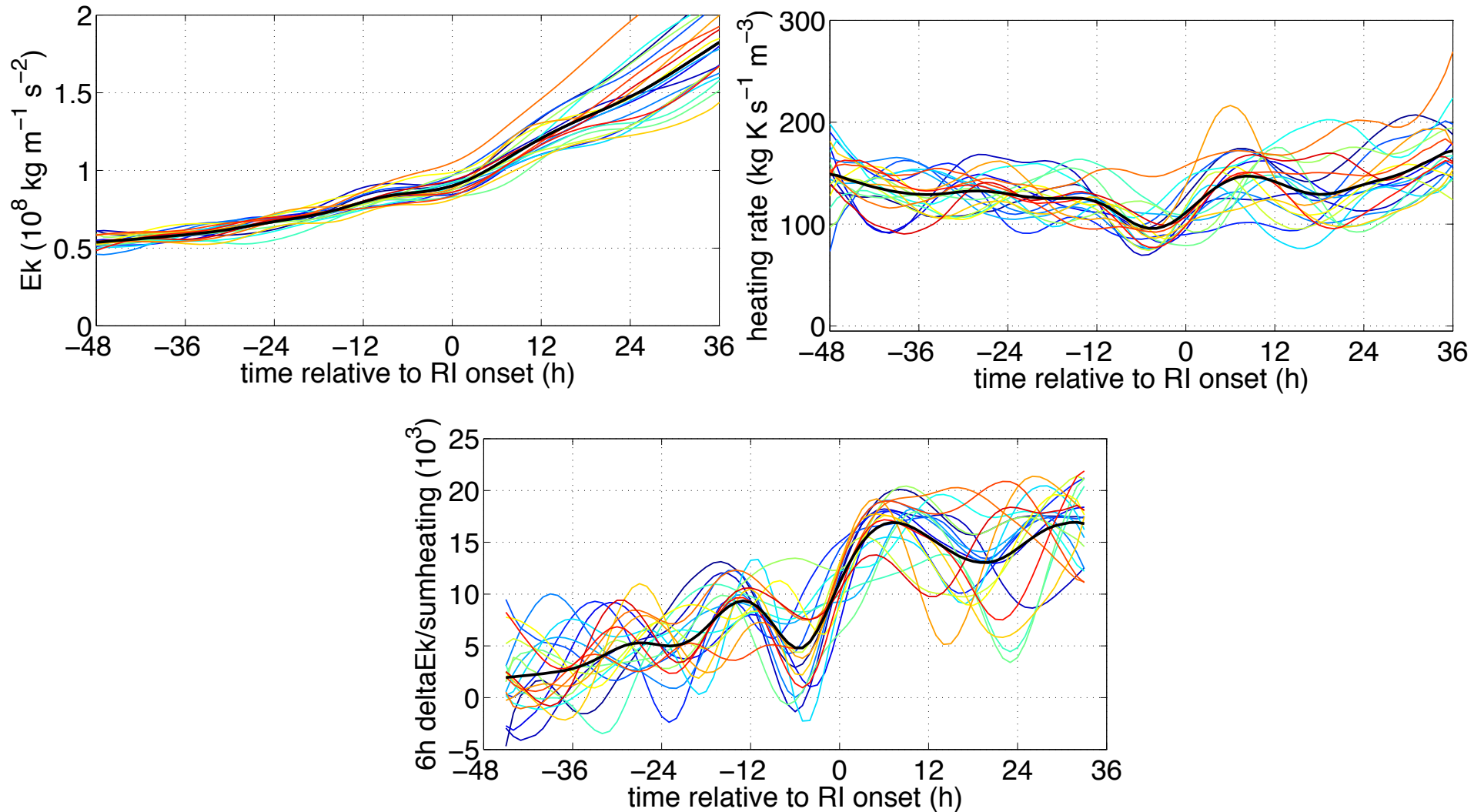


# 450-850-hPa tilt evolution (RI onset relative time)



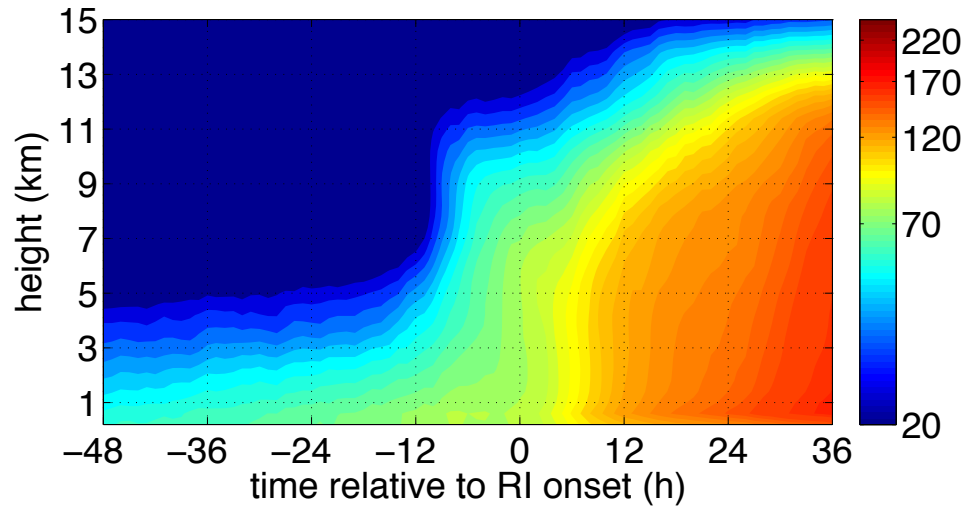


**Left: Total kinetic energy below 9.8km within 200km**  
**Right: Accumulated diabatic heating rate within 200km radius**  
**Bottom: Ratio of 6-h Ek change over 6-h heating summation**

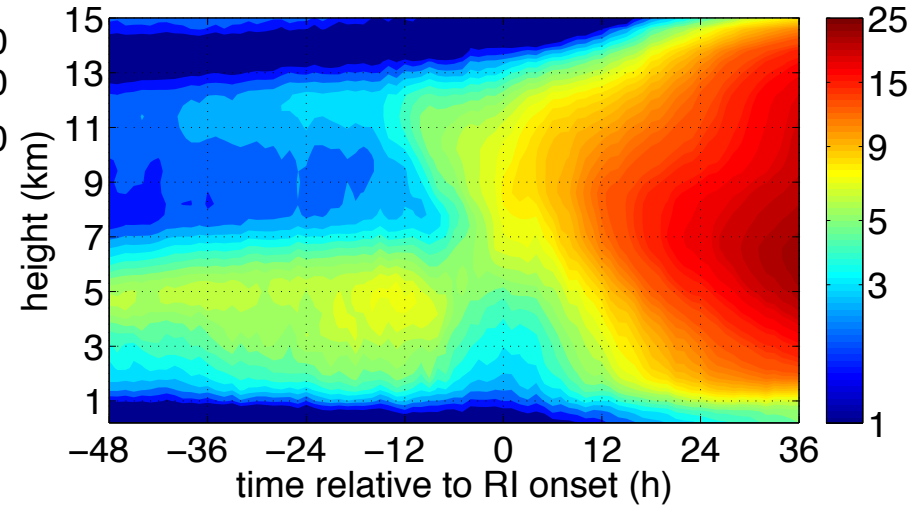




## Mean vorticity within R=50km



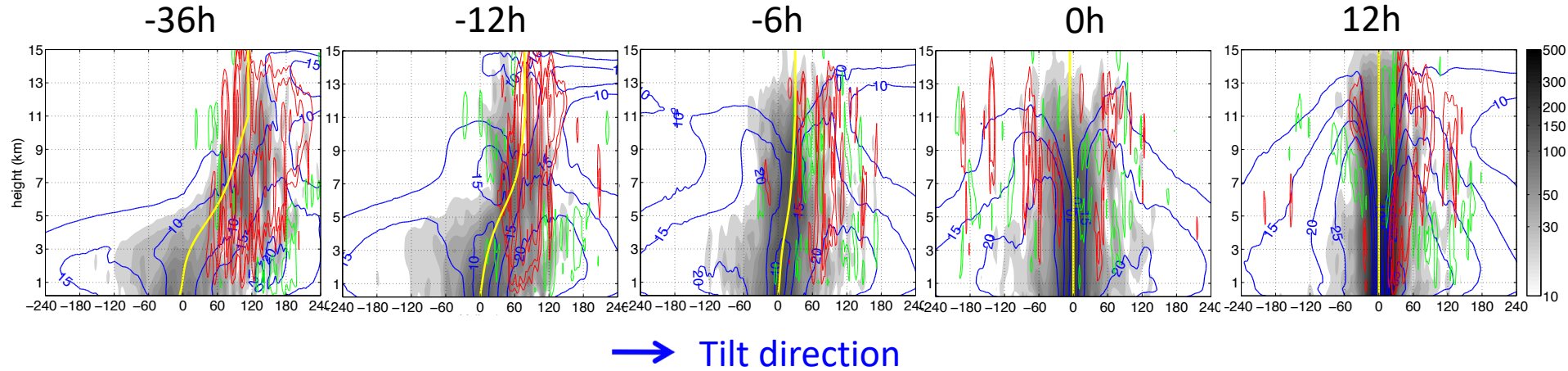
## $\theta'$ (K) above surface center



- The sudden increase in the mid- to upper-level inner-core vorticity before RI
- Two warming area before RI
- Upper-level warming dominates after RI onset



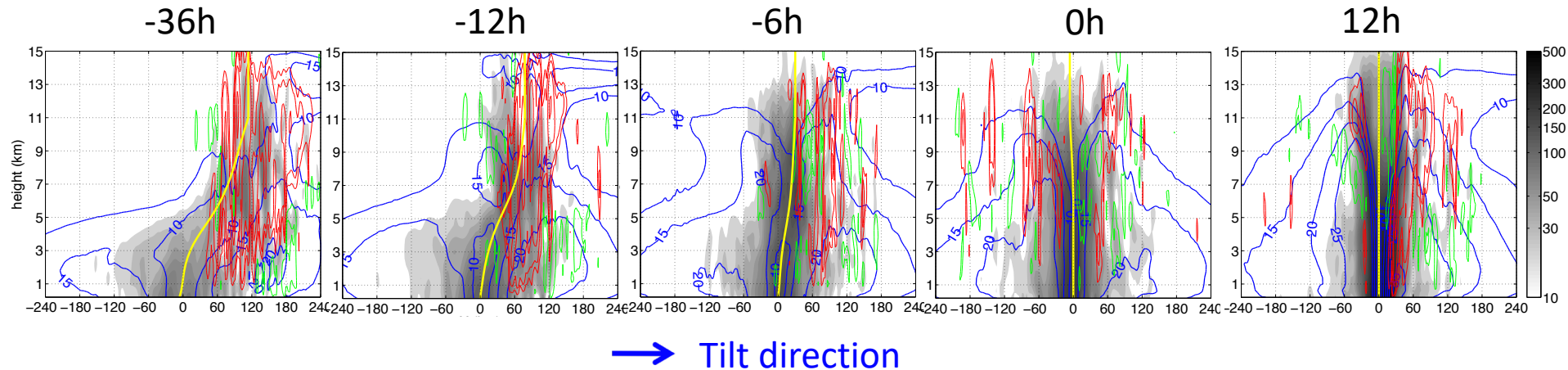
# Vorticity (shading), total horizontal wind (blue contour) W (updrafts in red, downdrafts in green)







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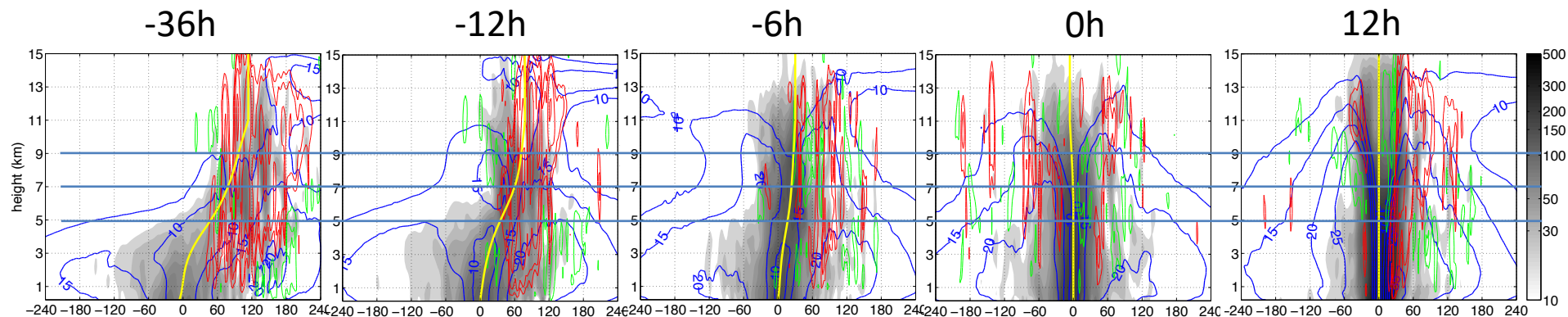


$$\frac{\partial \zeta}{\partial t} = \underbrace{-u \frac{\partial \zeta}{\partial x} - v \frac{\partial \zeta}{\partial y}}_{\text{red box}} - \underbrace{w \frac{\partial \zeta}{\partial z}}_{\text{blue box}} + \underbrace{(\zeta + f) \frac{\partial w}{\partial z}}_{\text{black box}}$$

$$\underbrace{- \frac{\partial v}{\partial z} \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \frac{\partial w}{\partial y}}_{\text{green box}} + D_{\zeta},$$



# Vorticity (shading), total horizontal wind (blue contour) W (updrafts in red, downdrafts in green)



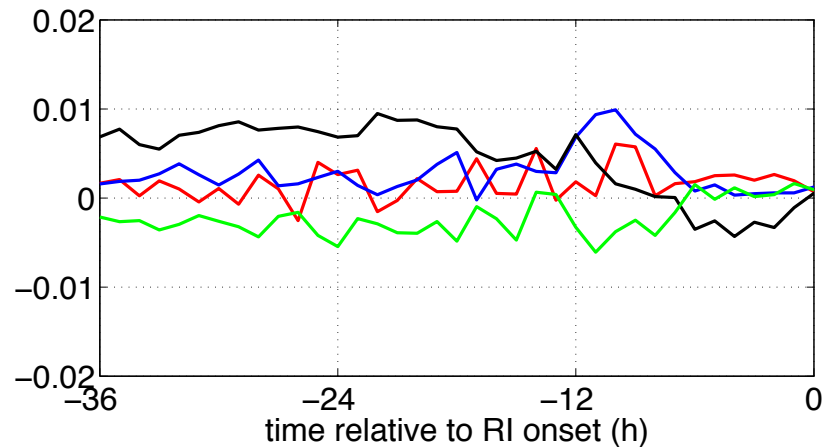
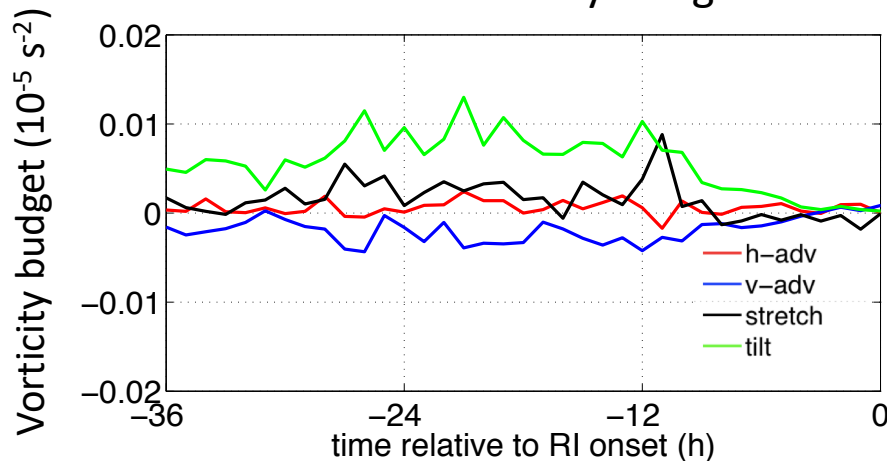
→ Tilt direction

## Vorticity budget terms

averaged within R=30km of 6-km and 8-km centers

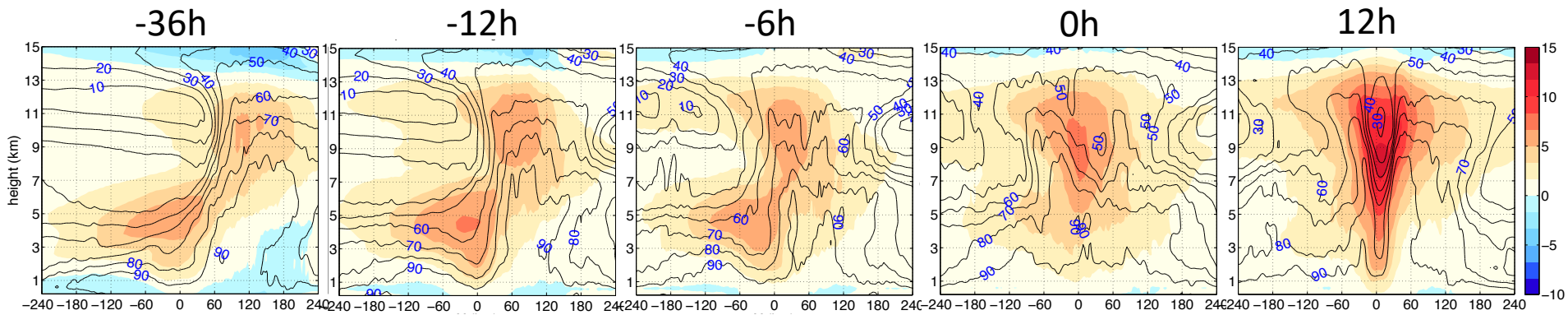
Midlevel vorticity budget

Upper-level vorticity budget



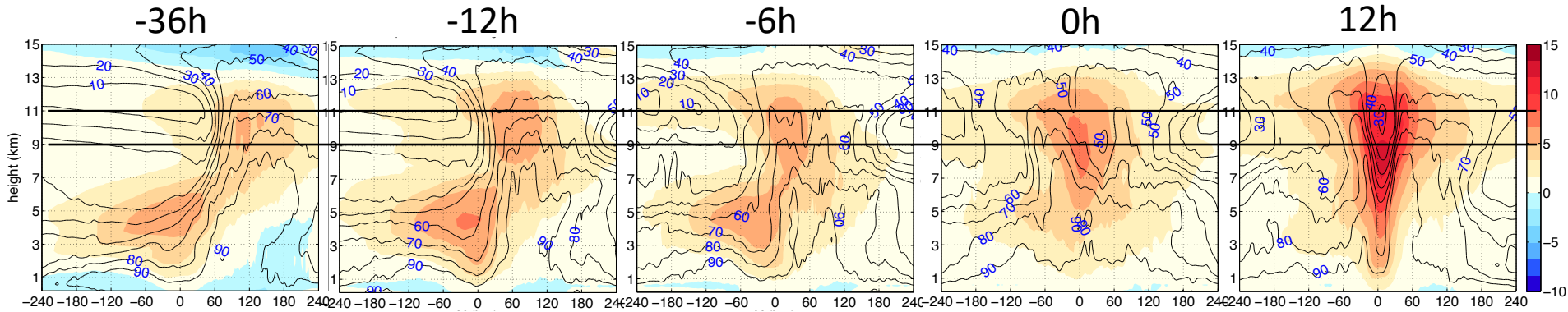


# Potential temperature anomaly (shading), RH (contours) along tilt direction

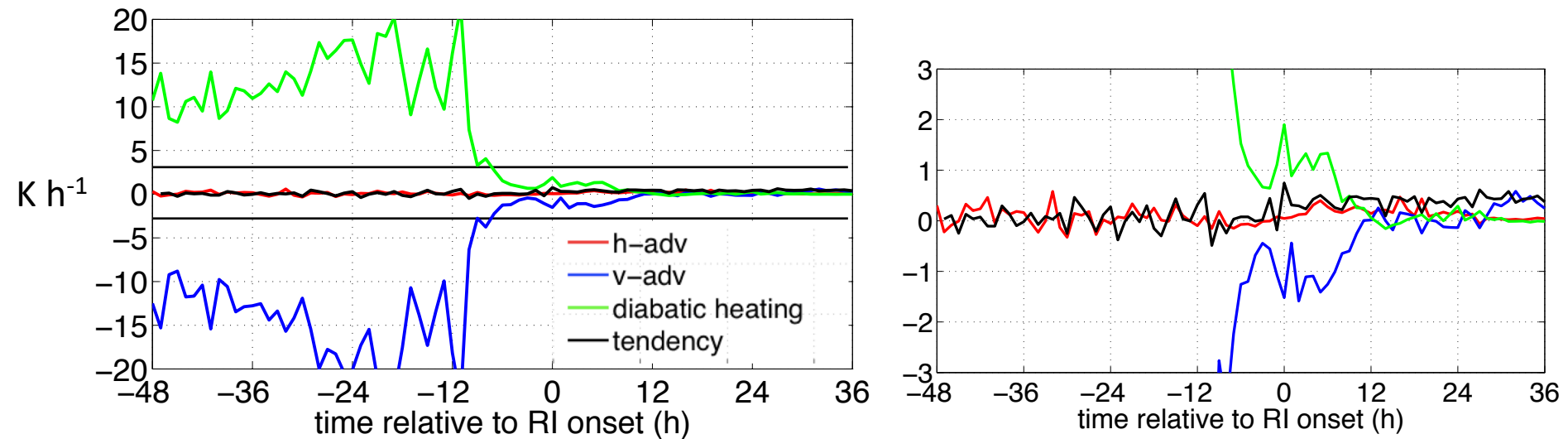




# Potential temperature anomaly (shading), RH (contours) along tilt direction

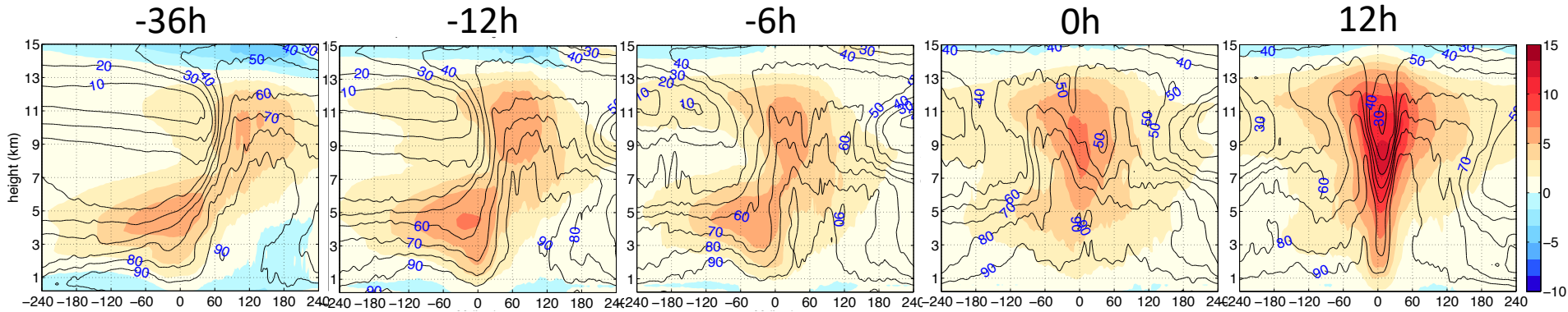


## Potential temperature budget ( $K h^{-1}$ ) averaged within $R=16km$ of 9-km maximum warming center

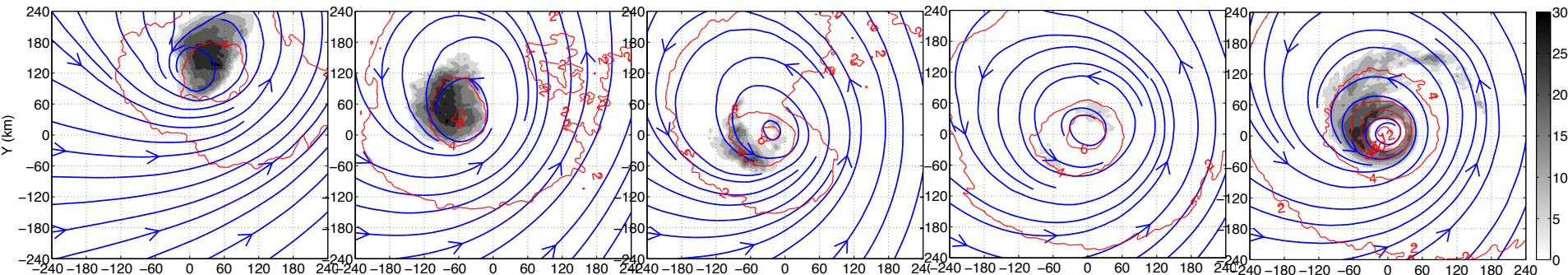




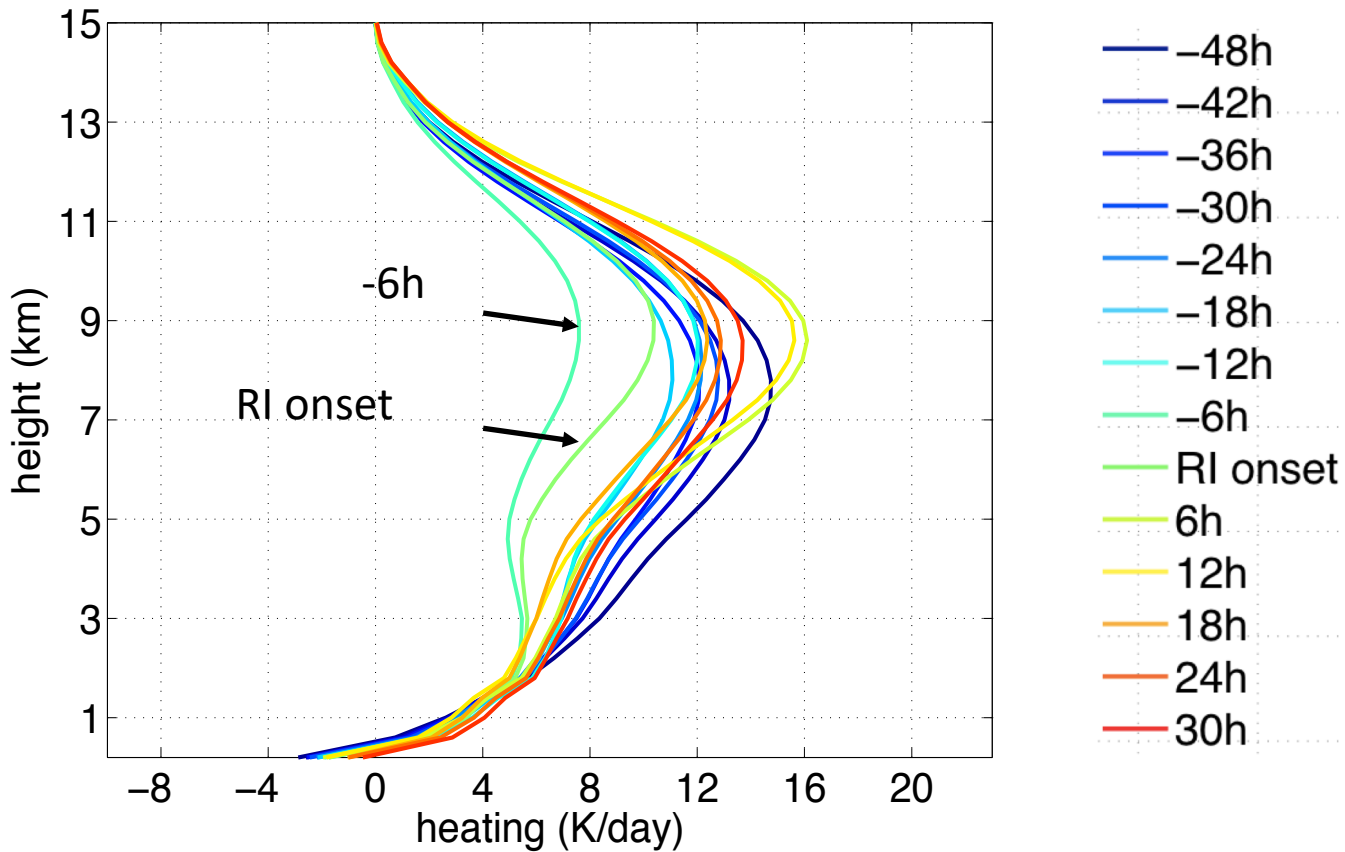
# Potential temperature anomaly (shading), RH (contours) along tilt direction



# Simulated reflectivity (gray shading), warm anomaly (red contour) and streamlines (blue contour with arrows) at 9-km height



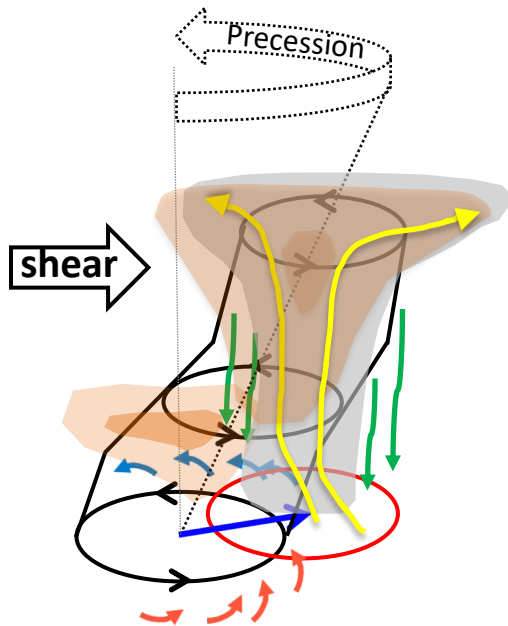
# Vertical diabatic heating profiles averaged within the 270-km \* 270-km horizontal box



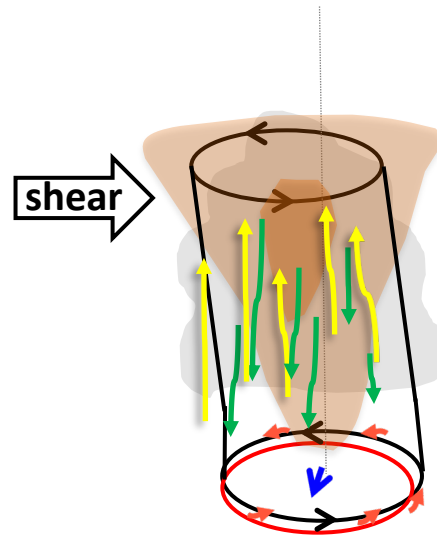


# Schematic diagram

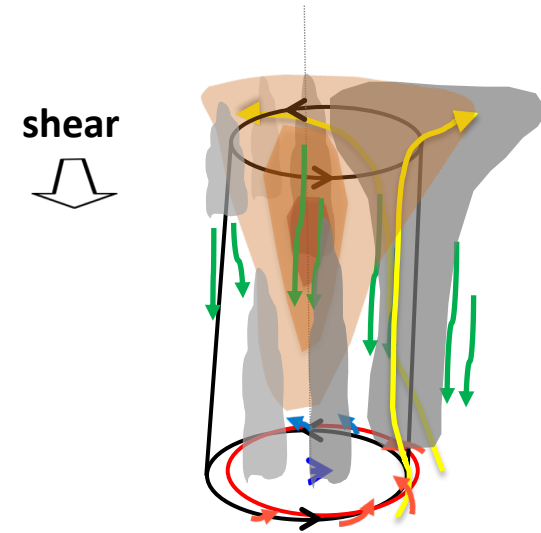
Before RI onset



Near RI onset



After RI onset



- Projection of mid/upper level vortex related positive vorticity at surface
- ➔ Tilt Vector      ➞ Boundary layer inflow      ➞ Boundary layer outflow
- ☁ Convection      ☀ Warm anomaly      ↓ Downdrafts      ↑ Updrafts