Paper review

mainly refer to

Vertical Vortex Development in Hurricane Michael (2018) during Rapid Intensification

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Outline

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Introduction(1/2)

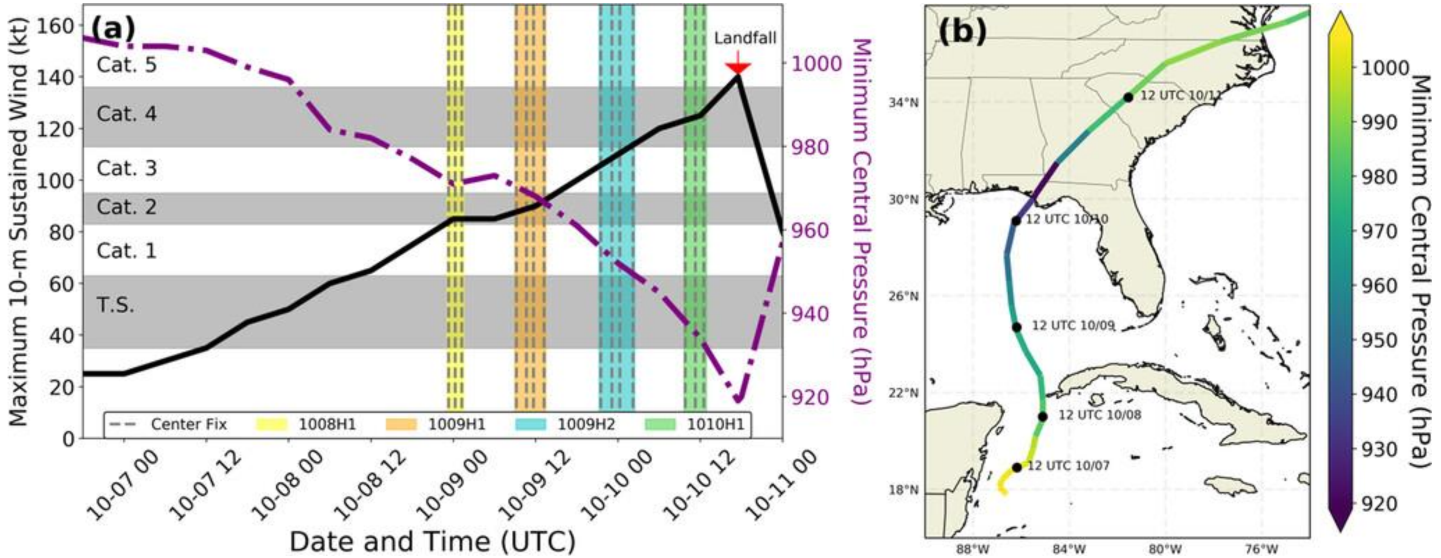
- The NHC defines rapid intensification (RI) as an increase in the maximum sustained winds of a tropical cyclone (TC) of at least 30 kt (1 kt ≈ 0.51 m s^{-1}) in a 24-h period (Kaplan and DeMaria 2003; Kaplan et al. 2010).
- Hendricks et al. (2010) quantified the impact of environmental factors on TC intensity change and concluded that RI is mostly controlled by internal dynamical processes in similarly favorable environments.
- Convection within the RMW has been shown in theoretical work to favor RI as well (Vigh and Schubert 2009).
- The transition in intensification from discrete CBs to a more axisymmetric secondary circulation is also hinted in the composite study of aircraft observations.
- Simulation of RI in Hurricane Wilma (2005) suggested the importance of the formation and location of the upper-level warm core strengthened through subsidence from deep asymmetric CBs (Chen and Zhang 2013).

Introduction(2/2)

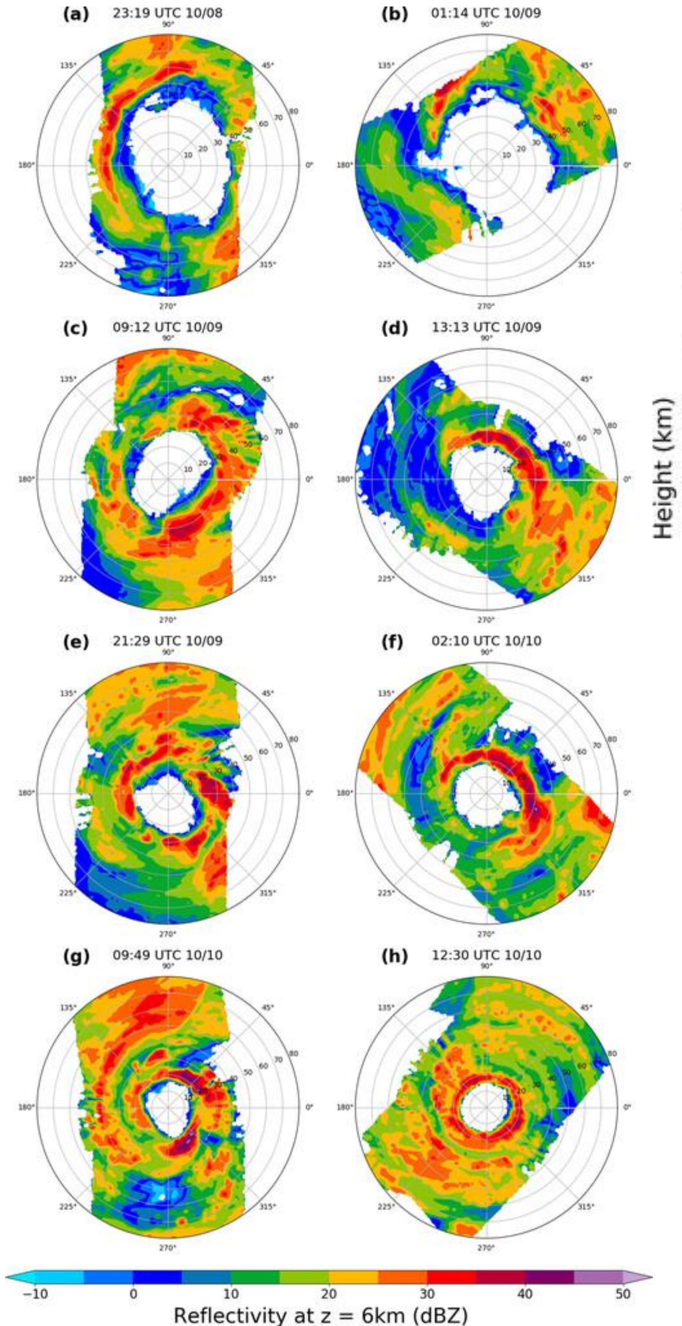
- In general warming at higher altitude in the atmosphere can be more efficient at lowering surface pressure through hydrostatic arguments (Hirschberg and Fritsch 1993).
- Stern and Nolan (2009) used TDR data and theory to evaluate the role of vertical structure of the tangential wind field in intensification of a TC, but questions remained about decay of the tangential wind field in the upper levels where past observations had been more sparse.
- A combination of a 14-dB increase in sensitivity (Aircraft Operations Center 2016) of the TDR flying aboard the NOAA P3 Hurricane Hunter Aircraft during the 2018 Atlantic hurricane season and the excellent aircraft data coverage during Hurricane Michael allow herein for detailed observation of the upper levels during RI.
- This study is focused on investigating the axisymmetric dynamical aspects of vertical growth of the vorticity tower of Hurricane Michael and inferred connections of upper-level processes to RI of the near-surface wind field.

Data and method

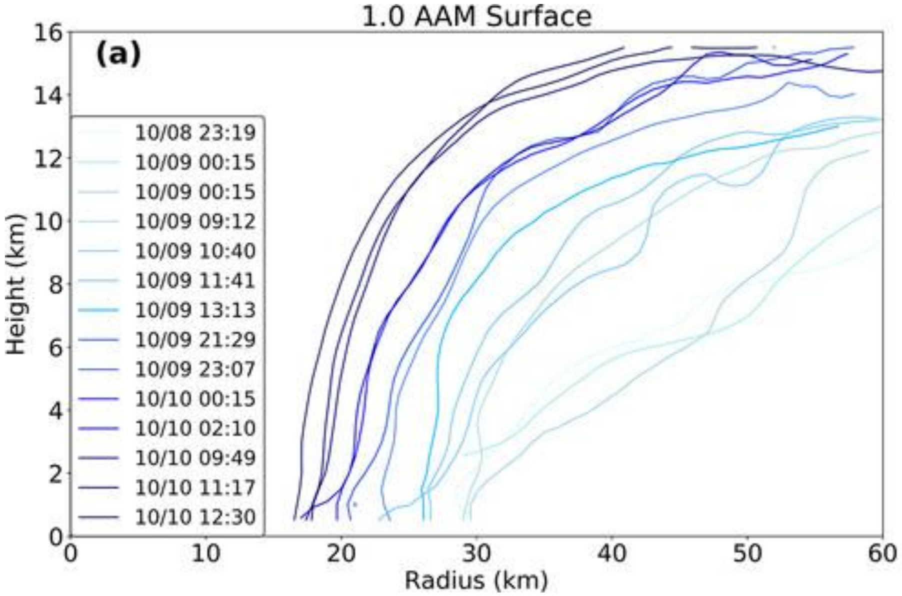
- Airborne radar data
  - Four P3 missions (14 passes)
- Radar quality control (QC)
  - SOLO II radar editing software
    - removal of noise, ground clutter, second trip echoes, and other nonmeteorological data
  - "random forest" machine-learning model
- Dual-Doppler analyses
  - Spline Analysis at Mesoscale Utilizing Radar and Aircraft Instrumentation (SAMURAI)
- Thermodynamic retrieval
- Azimuthal mean calculation



Inner-core changes throughout RI

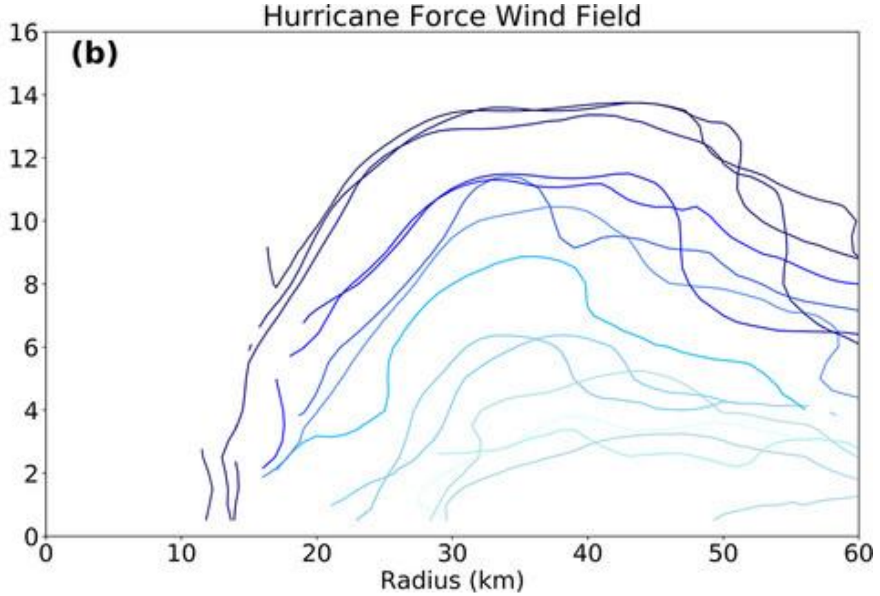


absolute angular momentum (AAM)

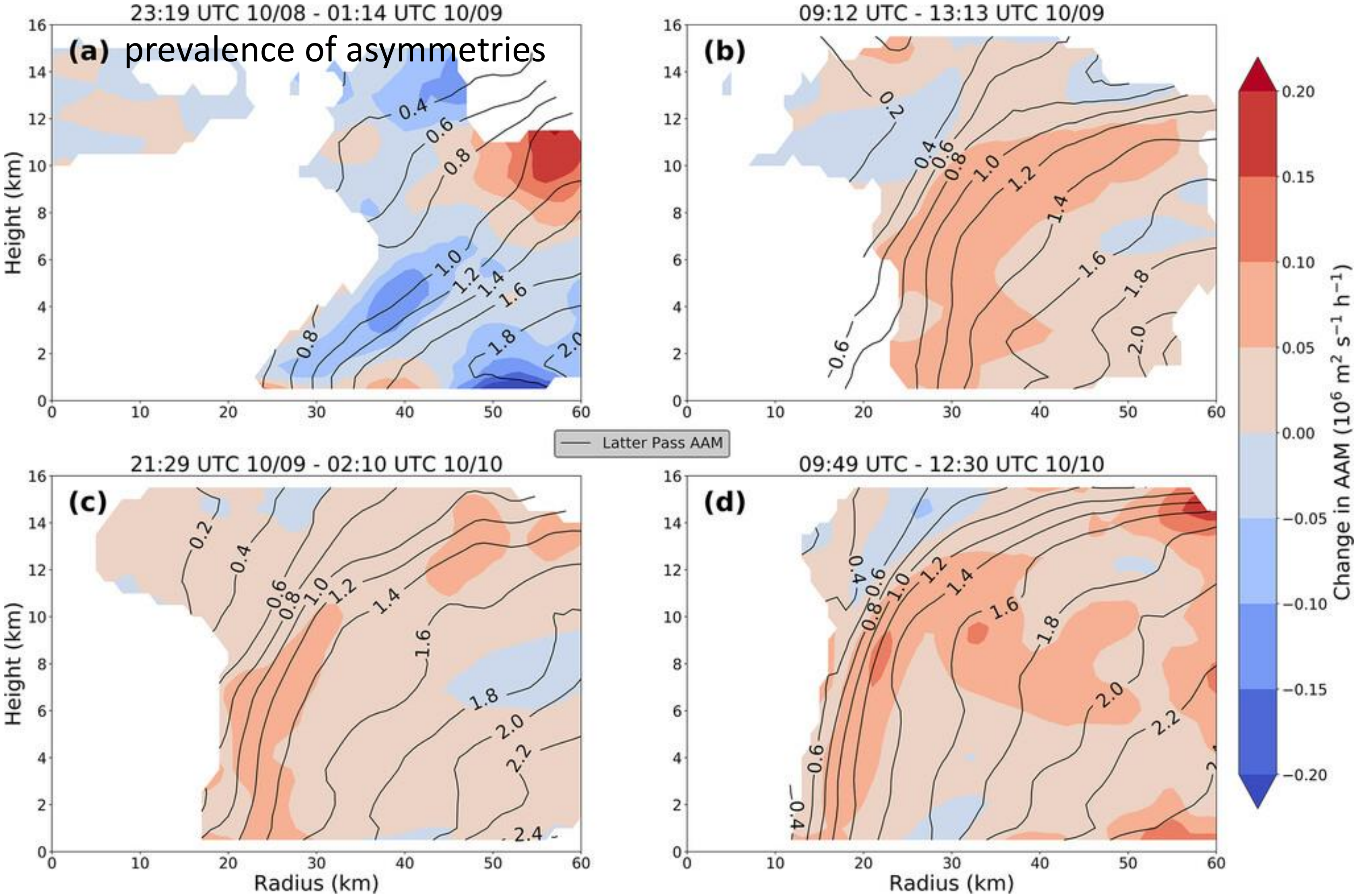


$$\mathrm{AAM} = r v_t + \frac{1}{2} f r^2$$

hurricane-force 33 m s^{-1} wind



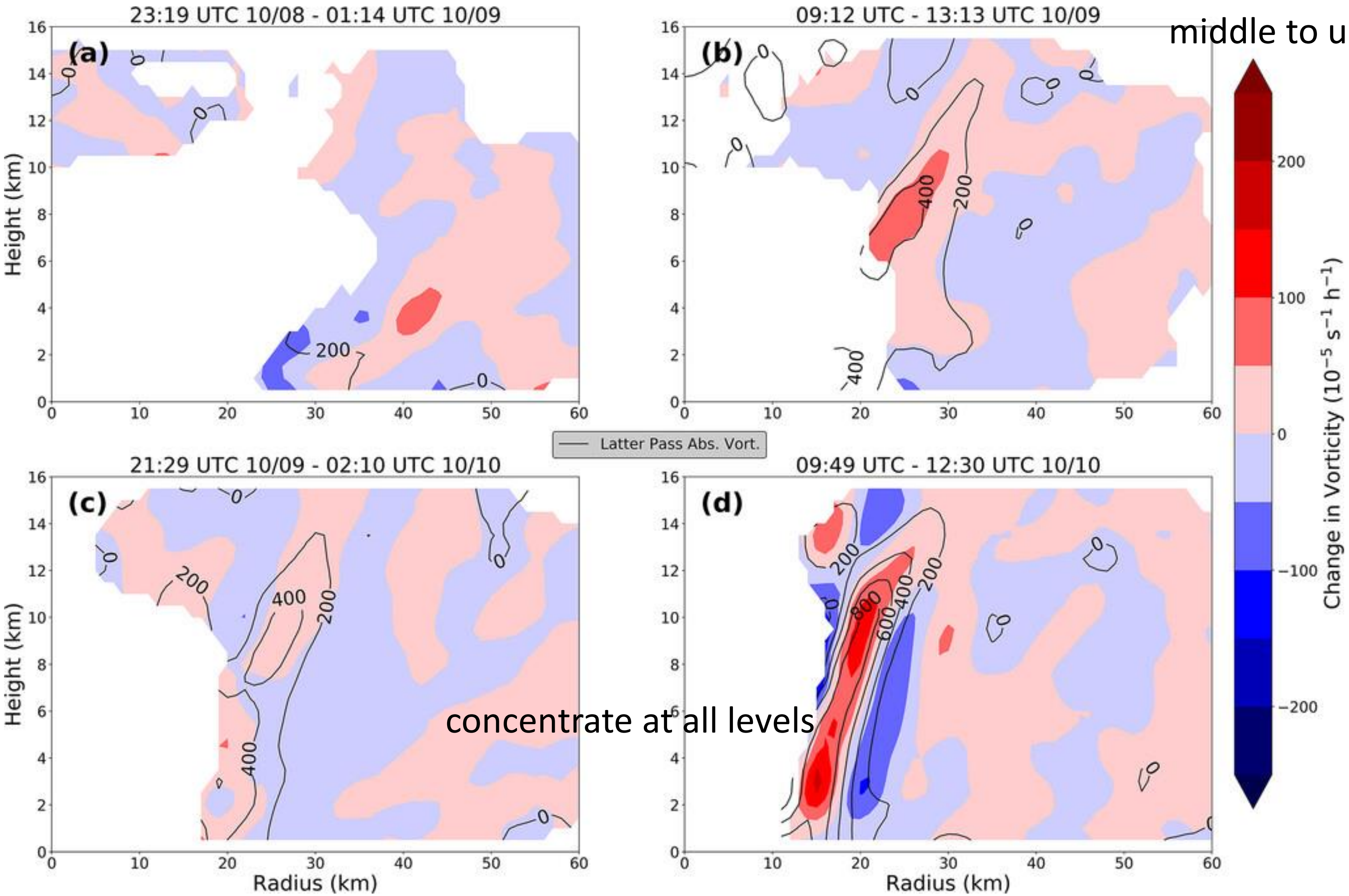
Changes in angular momentum



$$\Delta M = (\mathrm{AAM_{Last}} - \mathrm{AAM_{First}})\,/\,(t_{\mathrm{Last}} - t_{\mathrm{First}})$$

Changes in vorticity

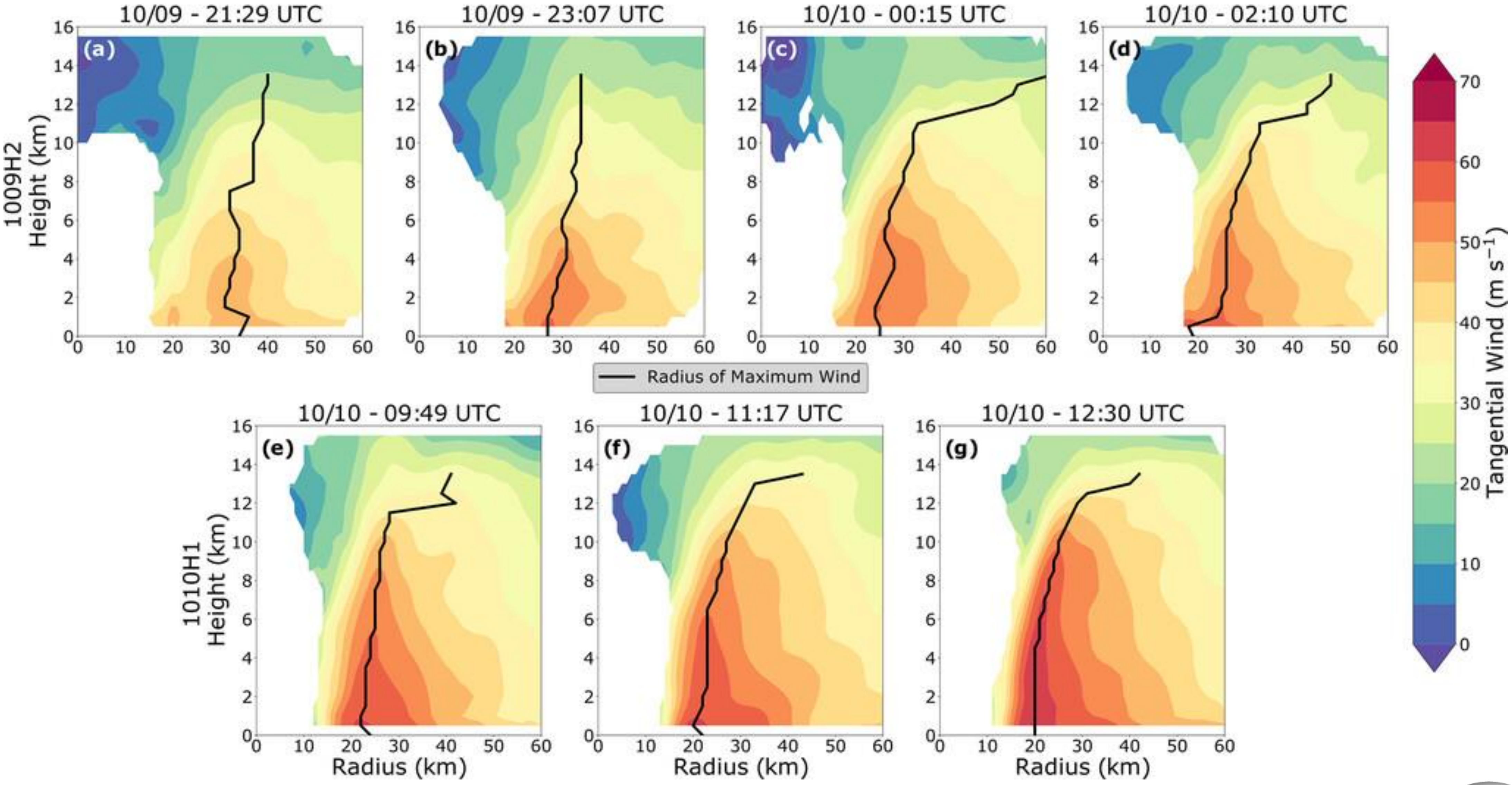
concentrate in the middle to upper levels



concentrate at all levels

$$\Delta\zeta = (\zeta_{\text{Last}} - \zeta_{\text{First}}) / (t_{\text{Last}} - t_{\text{First}})$$

Axisymmetric tangential wind field



Vorticity budget equation

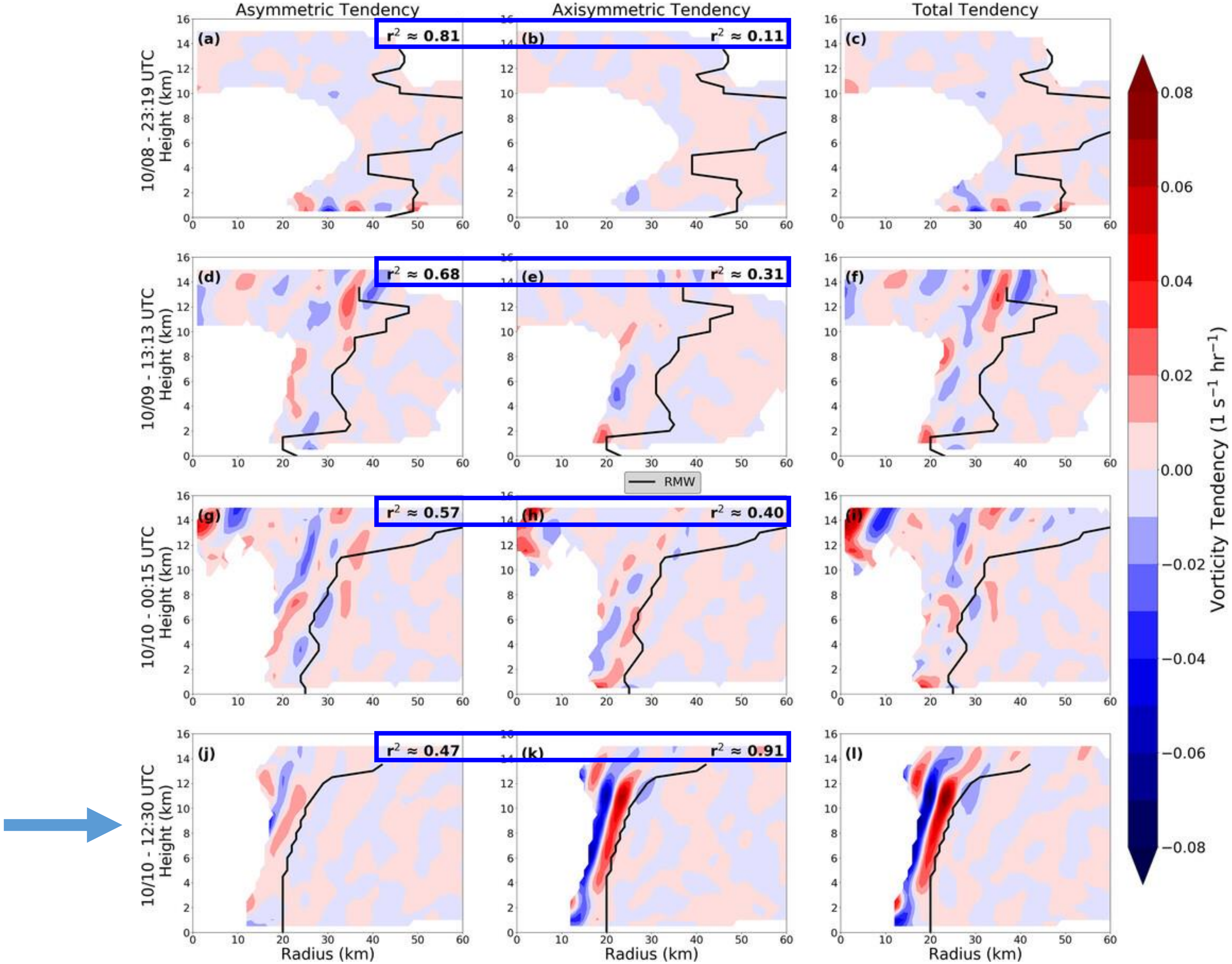
	radial advection	vertical advection	stretching	tilting of horizontal vorticity

axisymmetric
$$\frac{\partial_L}{\partial t}\bar{\zeta} = -\bar{u}\frac{\partial\bar{\zeta}}{\partial r} - \overline{w}\frac{\partial\bar{\zeta}}{\partial z} - \left(f_0 + \bar{\zeta}\right)\bar{\delta} - \frac{\partial\overline{w}}{\partial r}\frac{\partial\bar{v}}{\partial z}$$

asymmetric
$$-\left[\overline{u'\frac{\partial\zeta'}{\partial r}} + \overline{\frac{v'}{r}\frac{\partial\zeta'}{\partial\lambda}}\right] - \overline{w'\frac{\partial\zeta'}{\partial z}} - \overline{\zeta'\delta'} - \left[\overline{\frac{\partial w'}{\partial r}\frac{\partial v'}{\partial z}} + \frac{1}{r}\overline{\frac{\partial w'}{\partial\lambda}\frac{\partial u'}{\partial z}}\right]$$

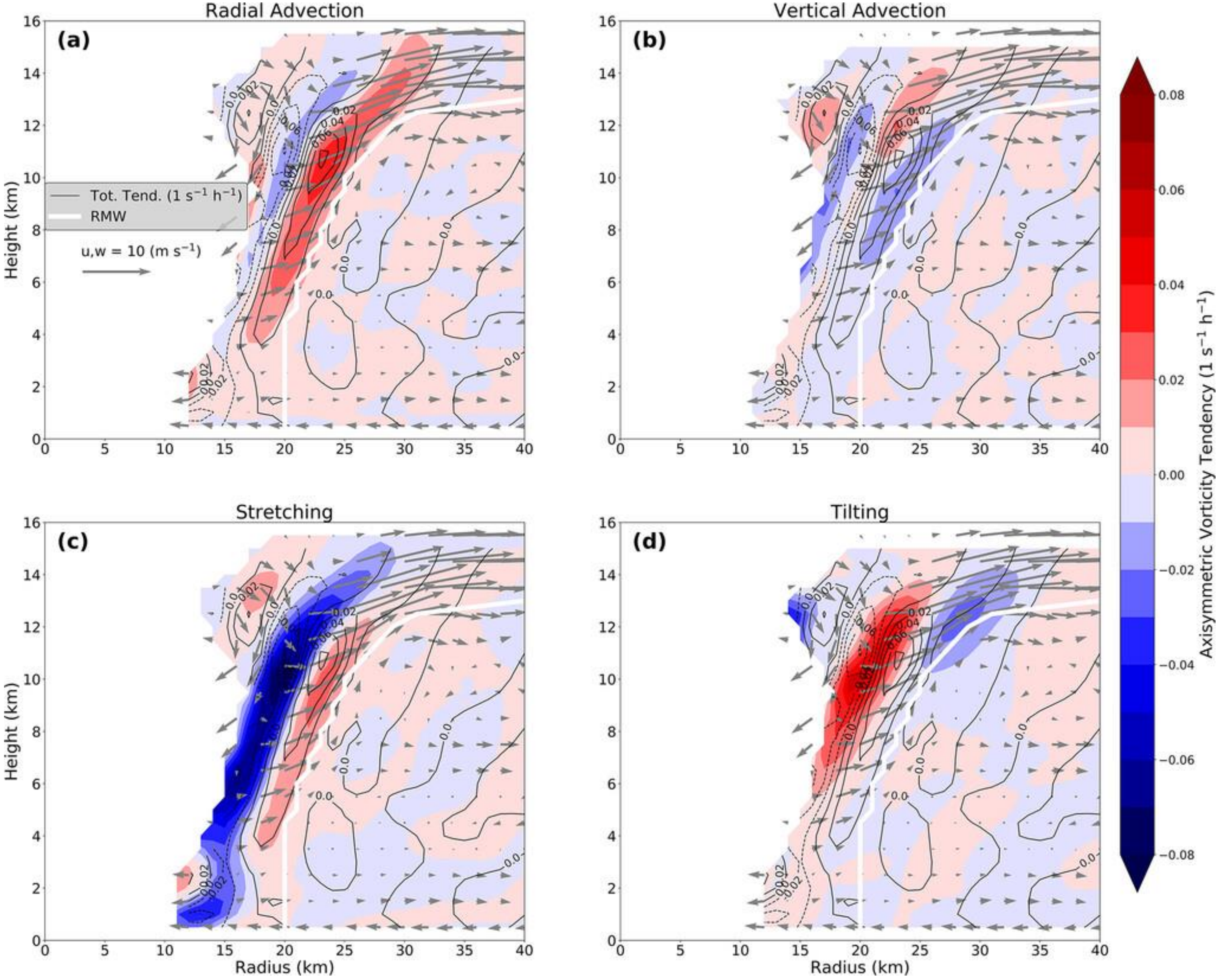
- prime terms denote eddy, or asymmetric, contributions that vary azimuthally
- an overbar indicates an azimuthal average of the quantity
- $\partial_L/\partial t$ is the local time tendency
- δ is divergence
- f_0 is the Coriolis parameter
- λ indicates the azimuthal dimension in cylindrical coordinates

Vorticity budget tendency

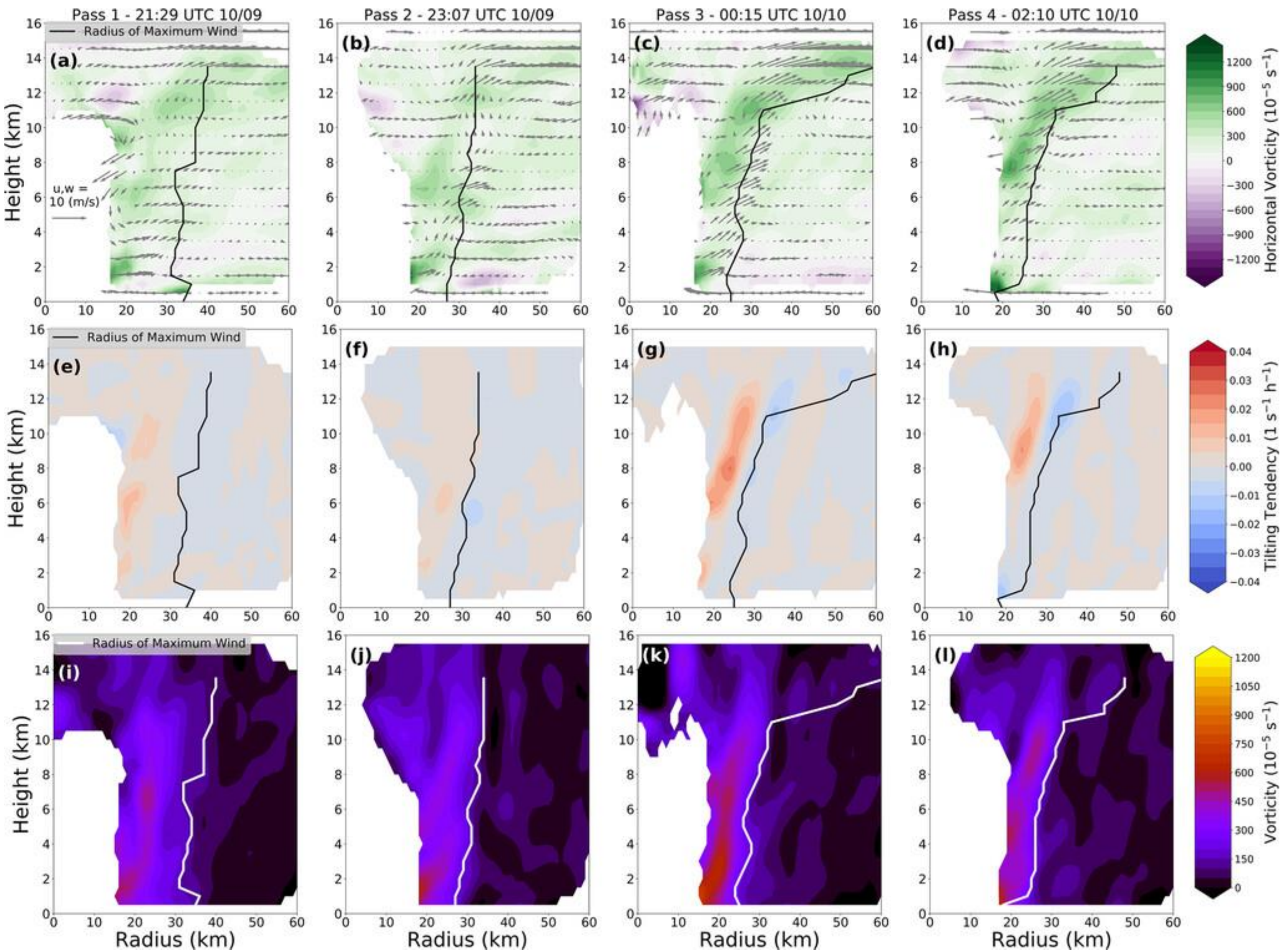


Axisymmetric vorticity budget tendency

1230 UTC 10 Oct 2018

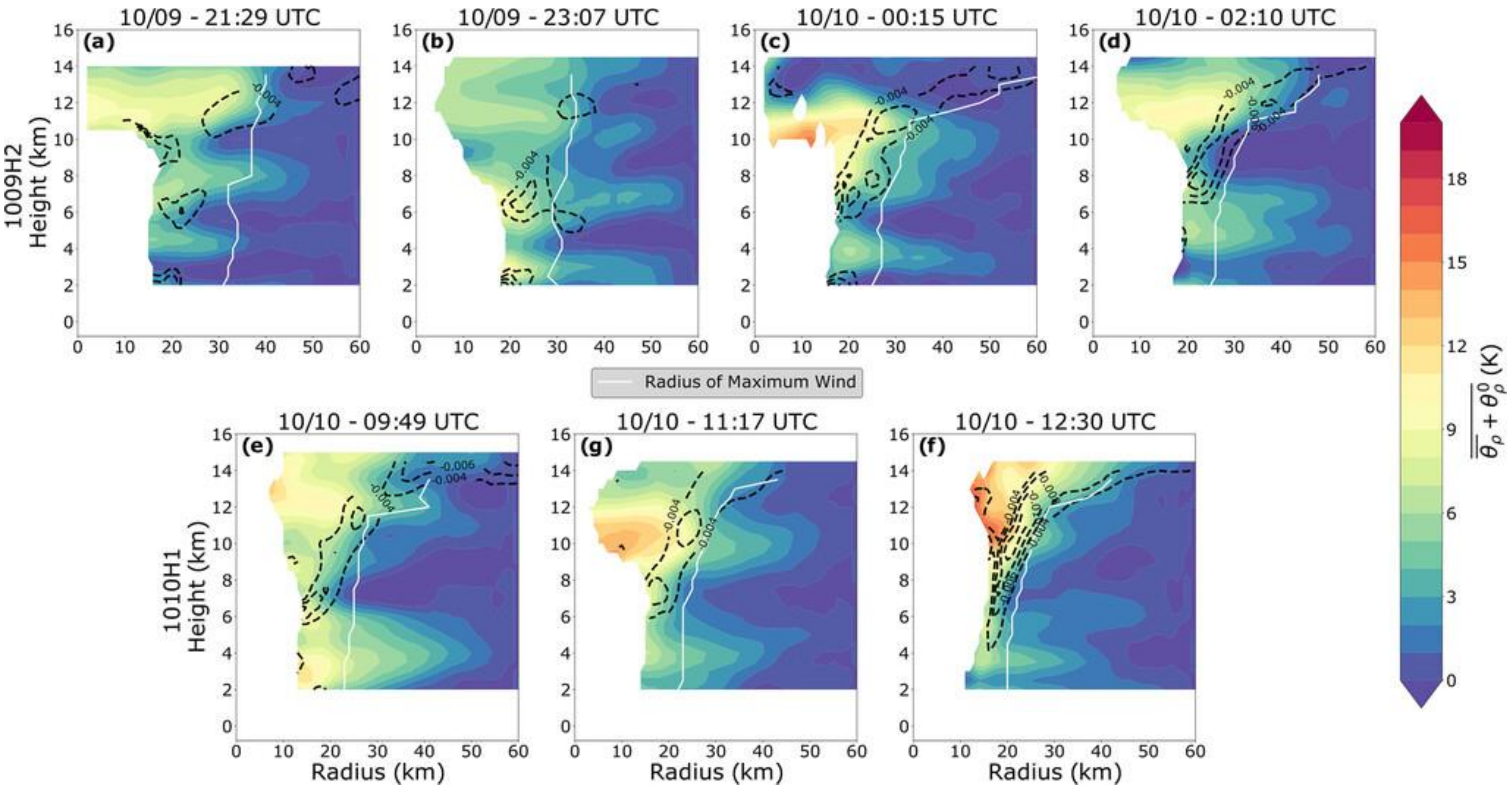


Horizontal and vertical vorticity



Thermodynamical impacts

$$\hat{f}\,\frac{\partial v}{\partial \tilde{z}} = \frac{g}{\theta_{\rho,0}}\left(\frac{\partial \theta_\rho}{\partial r}\right)_{\tilde{z}}$$



$\hat{f} = f + (2v/r)$

$\tilde{z}$: pseudo-height

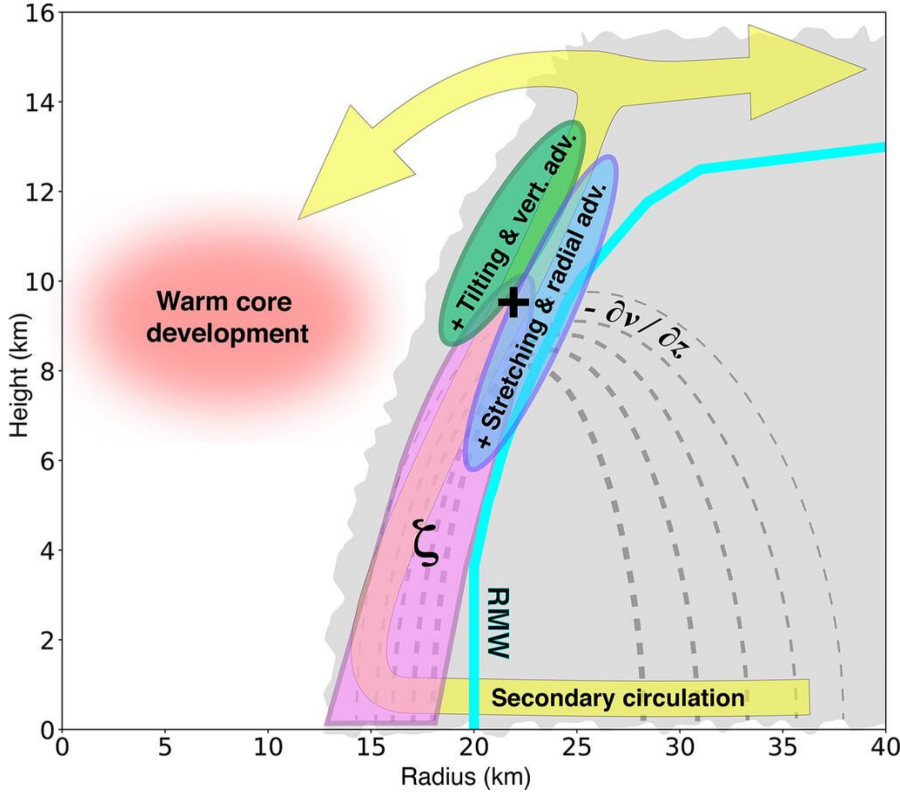
g: gravity

$\theta_{\rho,0}$: reference density potential temperature

Conclusions (1/2)

- ► Fourteen aircraft passes through the storm allowed for snapshots of the evolution in the inner core of the storm.
- ► Changes in both vertical vorticity and angular momentum exhibited increasingly positive magnitudes that concentrated in the eyewall region as the RI event progressed.
- ► Vortex intensification progressed toward axisymmetry with greater efficiency over time.
- ► Tilting alone cannot increase the overall circulation within the inner core, and the growth of the vortex tower required contributions from advection and stretching as well.
- ► Vertical advection transported vertical vorticity from the tower upward, including that reoriented by tilting, while stretching and radial advection acted to move the vorticity outward and amplify the vorticity along the inner edge of the RMW.

Schematic illustration



Conclusions (2/2)

- ►The maintenance of thermal wind balance and an increasing warm core temperature perturbation in the upper levels where heating can have an increased impact on surface pressure.
- ►The collocation of the radial gradient of density potential temperature and tilting tendency show the interconnected nature of the dynamic and thermodynamic mechanisms of intensification.
- ►Connections between tilting, diabatic heating, and eye subsidence that enhance the warm core can therefore lower surface pressure, allowing mechanisms of RI taking place in the upper levels to play a role in the intensification of the near-surface wind field.

Schematic illustration