A Multi-scale Analysis on the Genesis of Hurricane Karl (2010) and Tropical Storm Matthew (2010).

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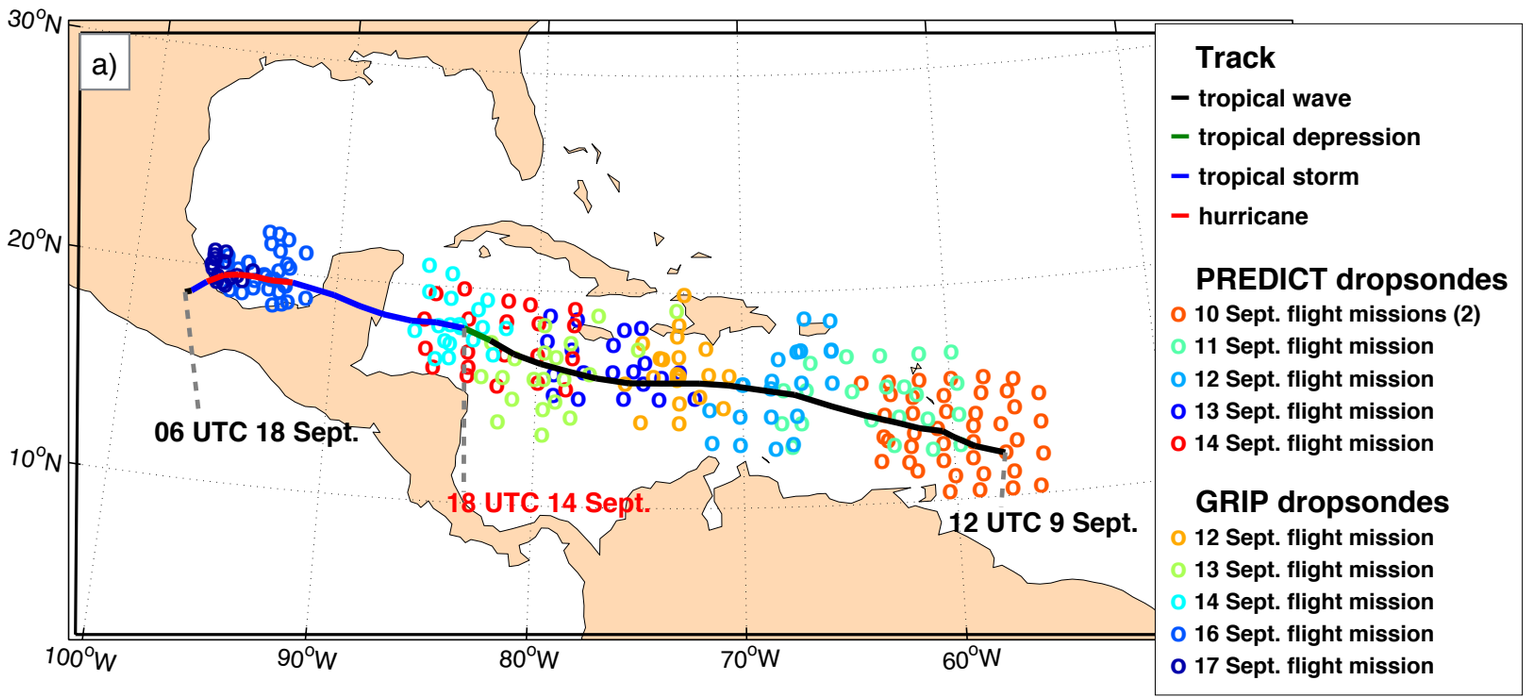
Howard University Program for Atmospheric Sciences

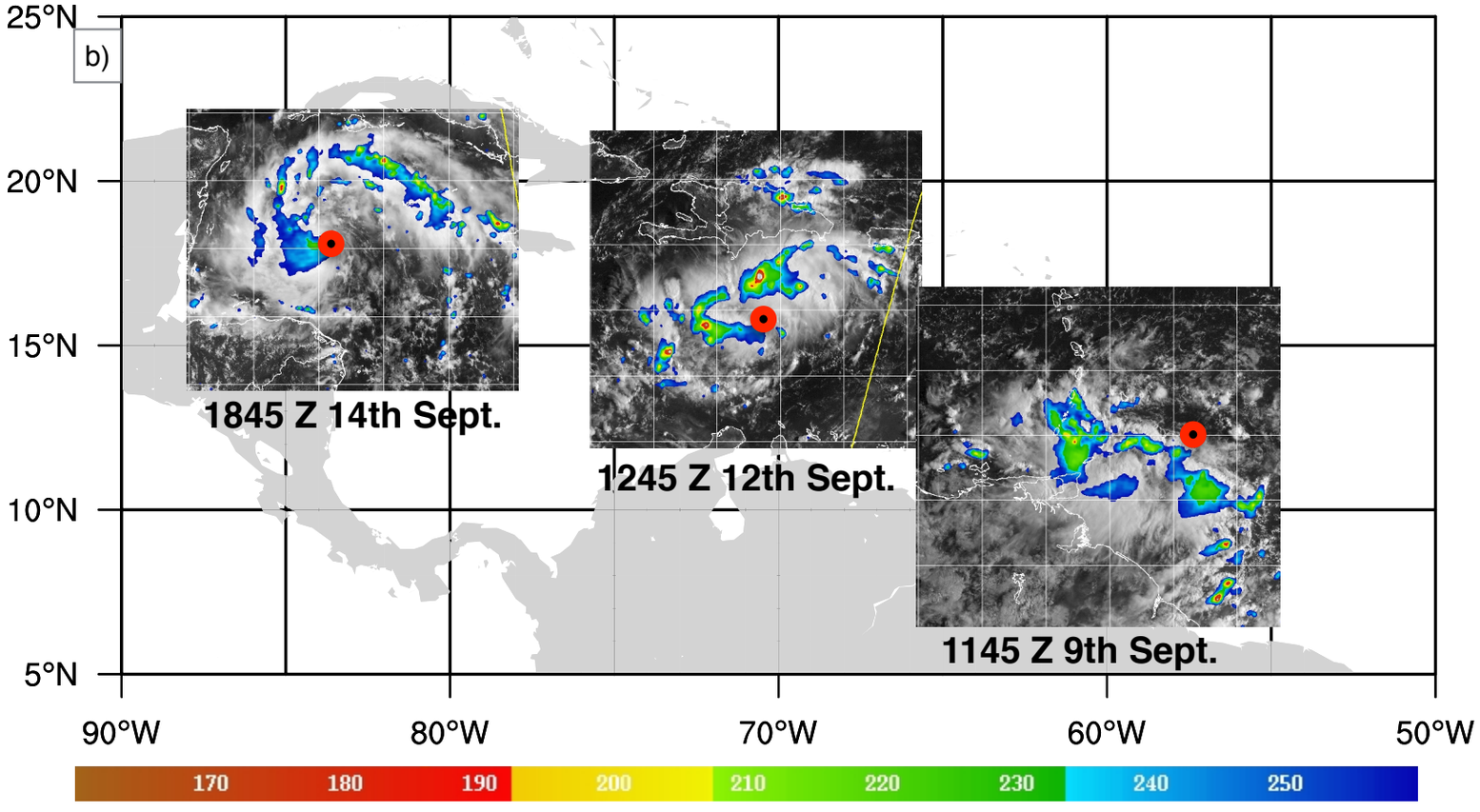
Spring 2015 Group Meeting

Friday 1st May 2015

Hurricane Karl

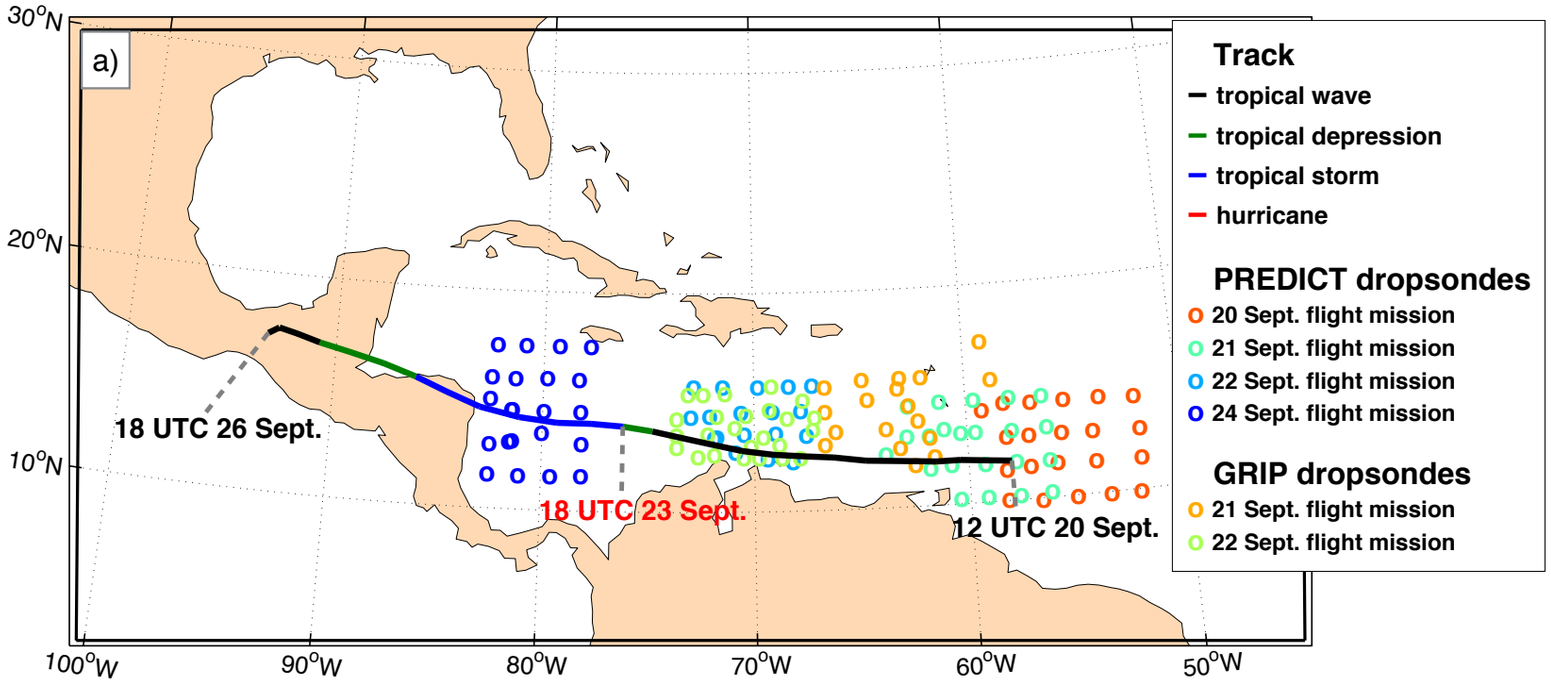


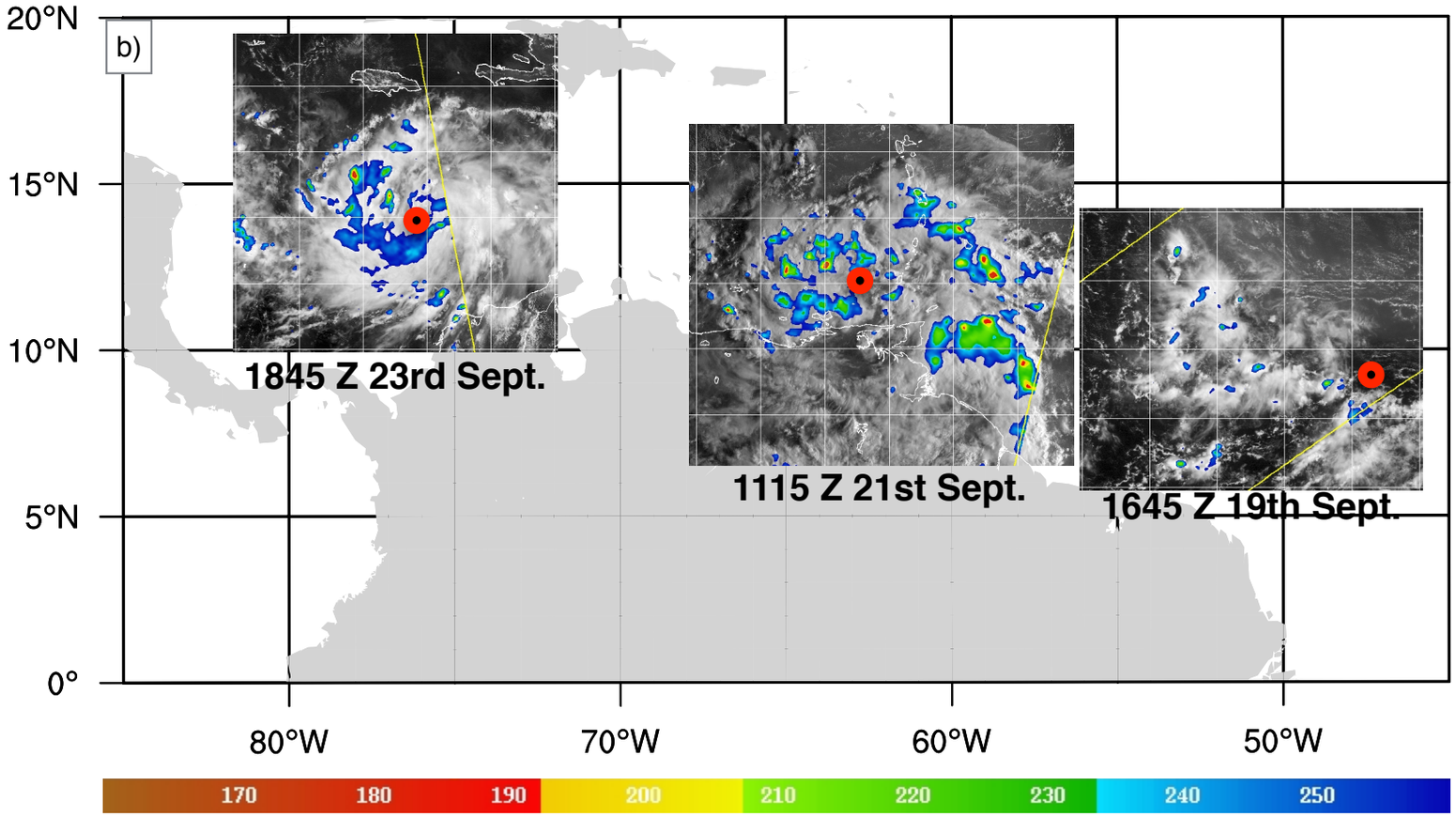
- Formed at 18.1 N, 83.6 W on September 14th at 18Z.
- Karl was a category 3 hurricane.



- Minimum central pressure of 956 hPa.
- Maximum sustained winds of 110 knots.

Tropical Storm Matthew

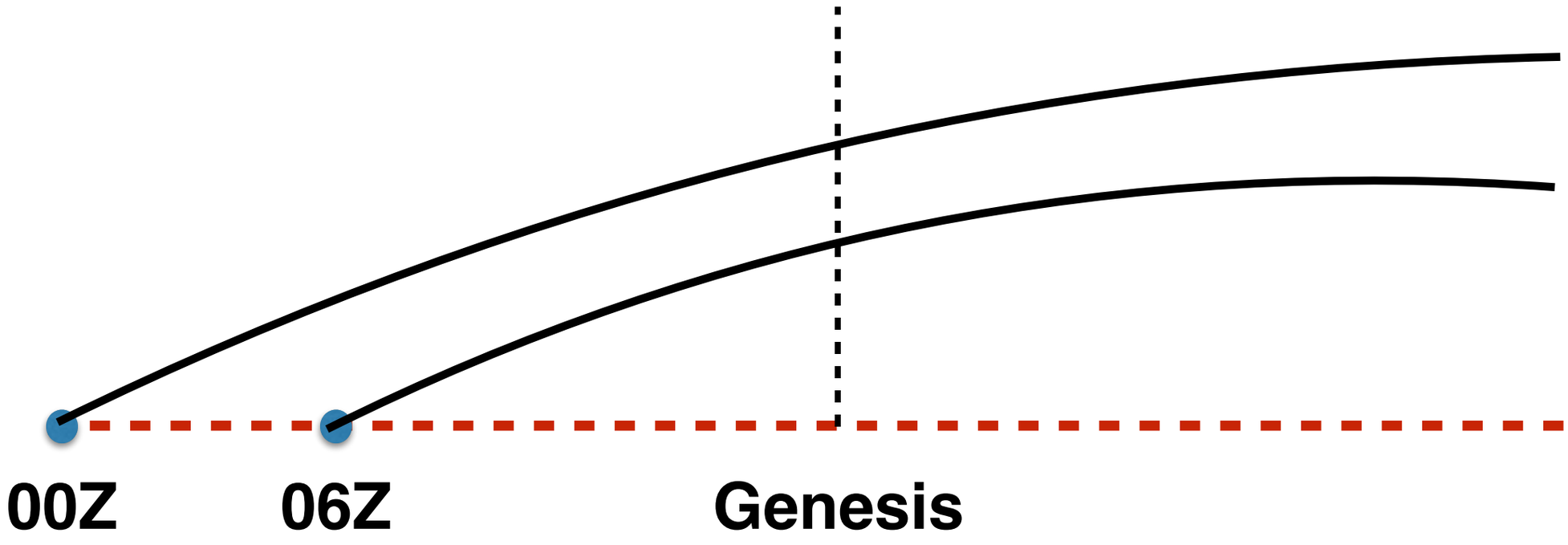




- Formed at 13.9 N, 76.2 W on September 23rd at 18Z.
- Matthew was a Tropical Storm (TS).
- Minimum central pressure of 998 hPa.
- Maximum sustained winds of 50 knots.

Experimental Design

- Experiments were initialized from GFS/GDAS analysis and cycled every 6 hours.
  - Karl initialized on Sept 8th 00Z and cycled through Sept 15th 00Z with deterministic forecasts until Sept 18th 06Z.
  - Mathew initialized on Sept 19th 00Z and cycled through Sept 24th 00Z with deterministic forecasts until Sept 26th 18Z.



Model Setup

- Three domains with two-way nesting at 13.5-km, 4.5-km and 1.5-km grid spacing.
- 35 vertical levels together with a model top of 50 hPa.
- Explicit cumulus parameterization.
- Assimilation performed on 13.5-km domain.

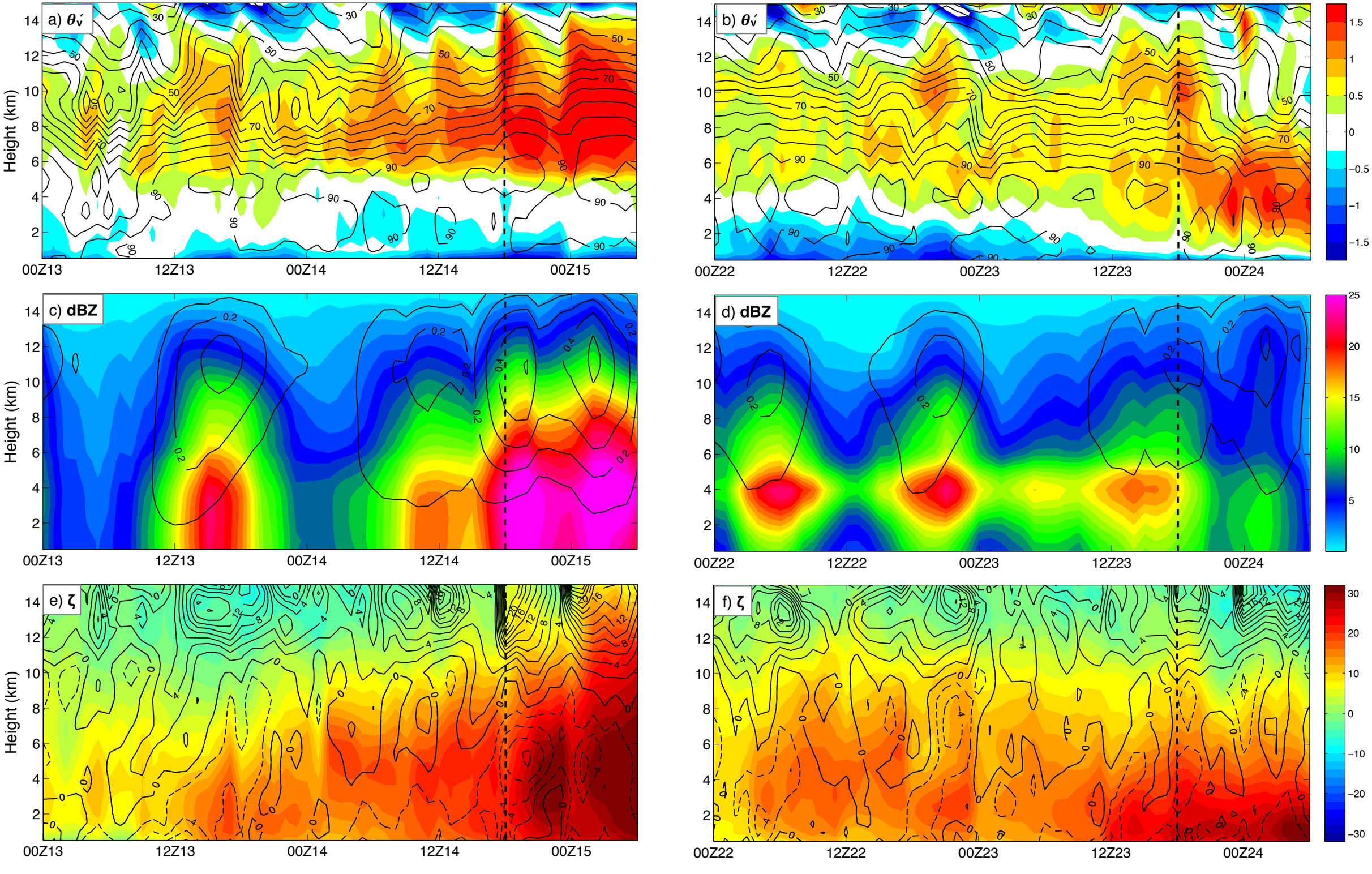
Data Assimilation System

- 60 ensemble members
- Localization of 900 km in the horizontal & 15 levels in the vertical
- Relaxation coefficient of 0.8
- Two way coupling between EnKF and 4DVar
  - 4DVar uses ensemble mean first guess and ensemble perturbations
  - EnKF update the ensemble members
  - Hybrid 4DVar analysis replaces the EnKF analysis
- 80% of the increment comes from the ensemble perturbations during the hybrid minimization.

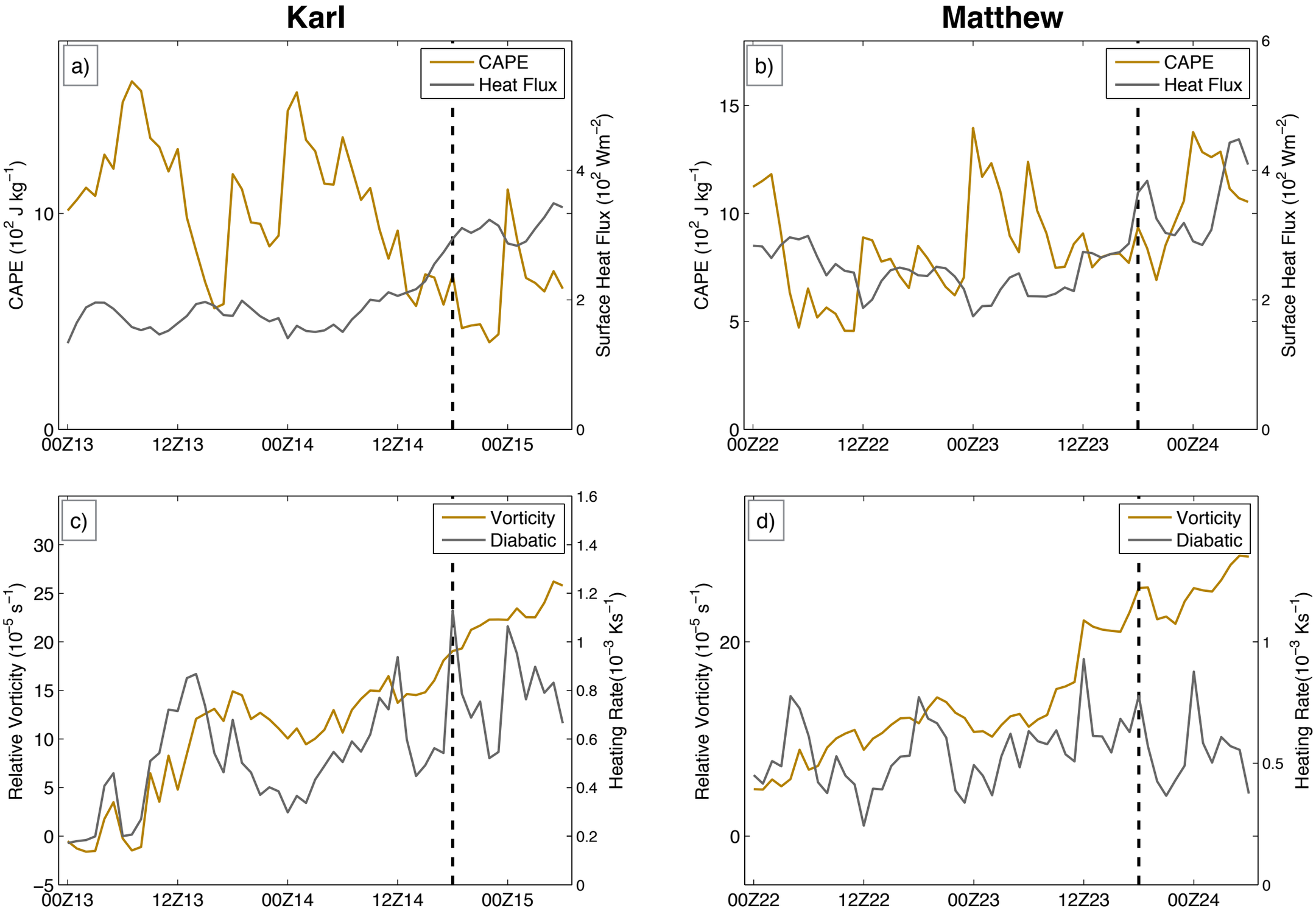
Inner-core (90 km) Vertical Profiles

Karl

Matthew



Surface Heat Flux, CAPE, Vorticity and Diabatic Heating



Vorticity Budget

Vorticity tendency equation:

$$\left.\frac{\partial \zeta}{\partial t}\right|_{SR} = -(V_h - C)\cdot\nabla_h(\zeta + f) - w\frac{\partial \zeta}{\partial z} - (\zeta + f)\nabla_h\cdot(V_h - C) - \left(\frac{\partial w}{\partial x}\frac{\partial v}{\partial z} - \frac{\partial w}{\partial y}\frac{\partial u}{\partial z}\right) + \frac{1}{\rho^2}\left(\frac{\partial \rho}{\partial x}\frac{\partial p}{\partial y} - \frac{\partial \rho}{\partial y}\frac{\partial p}{\partial x}\right) + \frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y}$$

Flux form of the vorticity tendency equation:

$$\left.\frac{\partial \zeta}{\partial t}\right|_{SR} = -\nabla_h\cdot\left\{w\left[\left(\partial k\times V_h\right)/\partial z\right]\right\} - \nabla_h\cdot\left[(V_h - C)(\zeta + f)\right] + \frac{1}{\rho^2}\left(\frac{\partial \rho}{\partial x}\frac{\partial p}{\partial y} - \frac{\partial \rho}{\partial y}\frac{\partial p}{\partial x}\right) + \frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y}$$

Tory and Montgomery 2008; Fang and Zhang 2010

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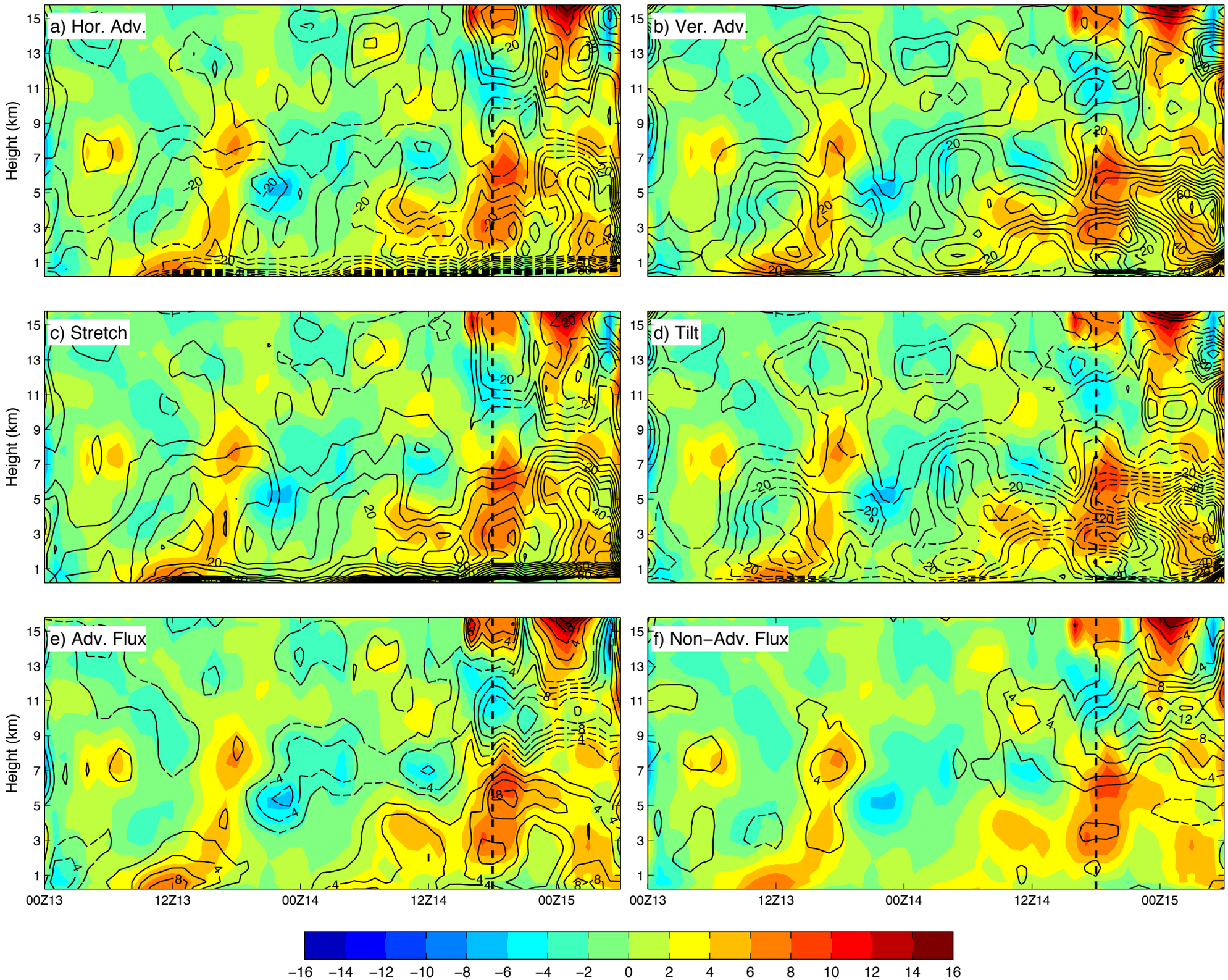
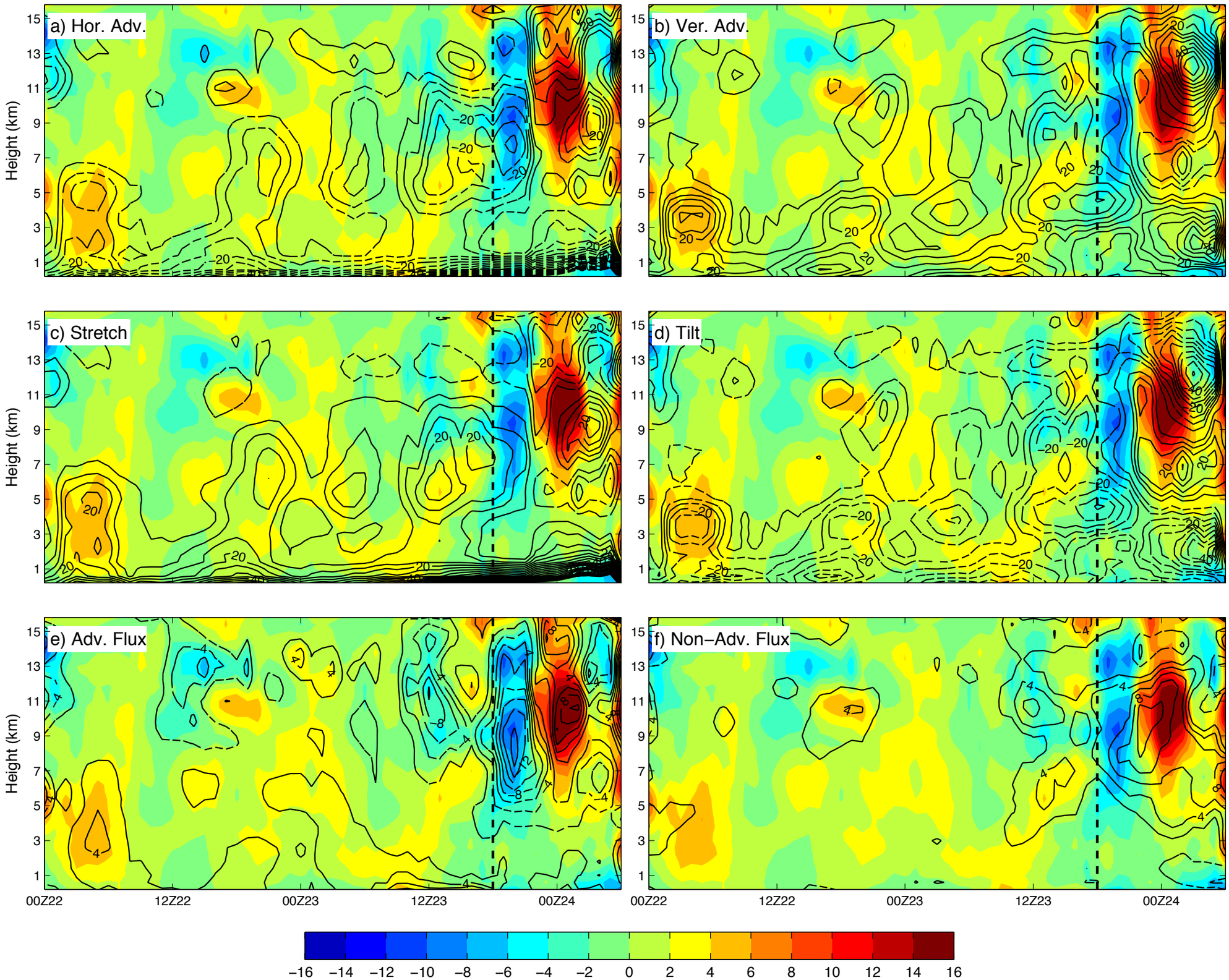
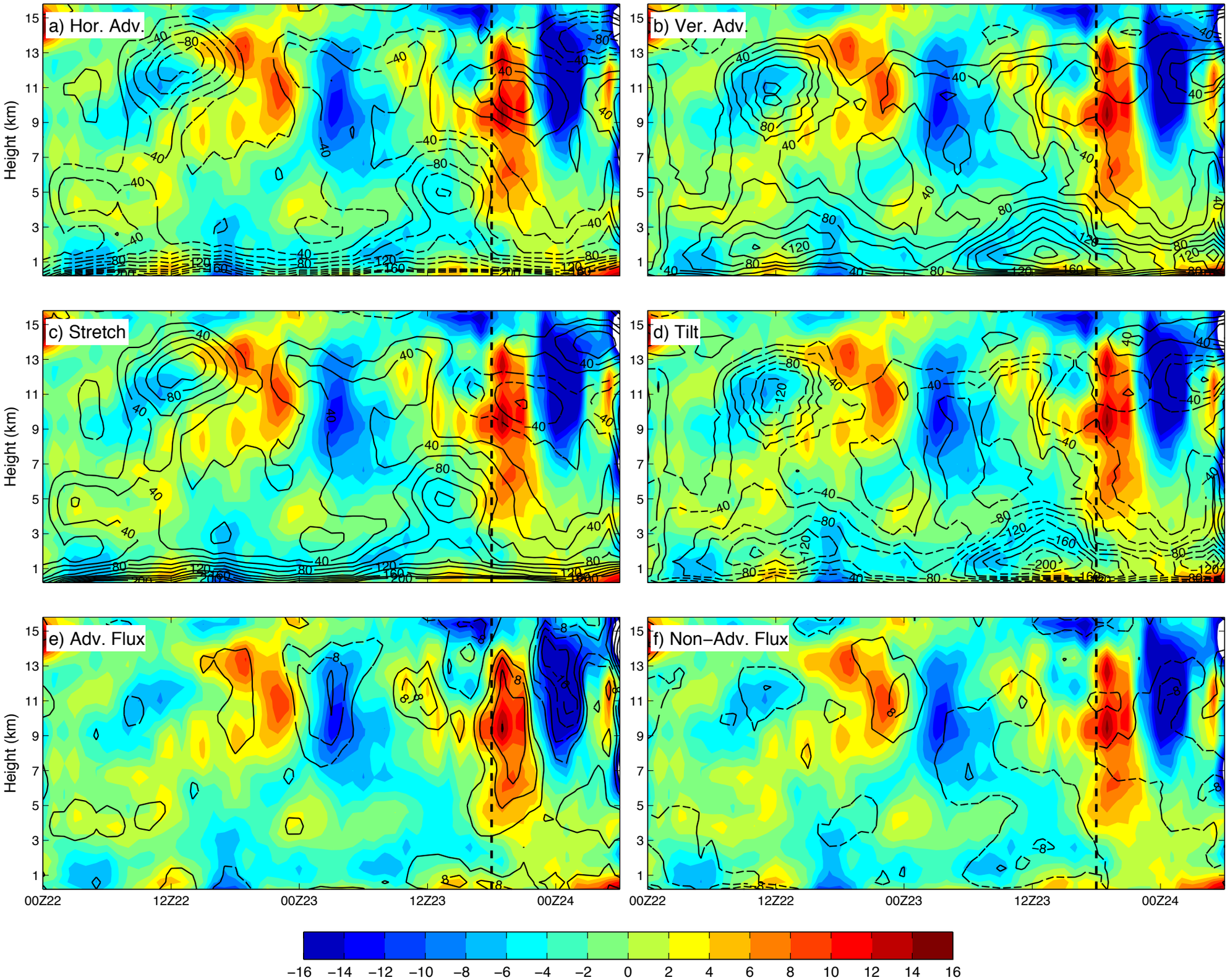
Hurricane Karl Vorticity Budget



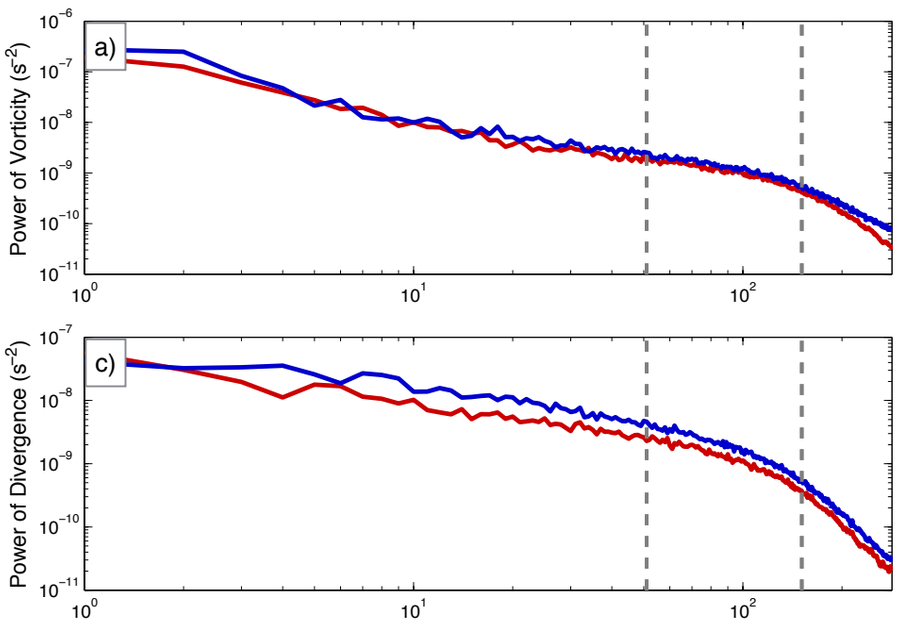
TS Matthew Vorticity Budget

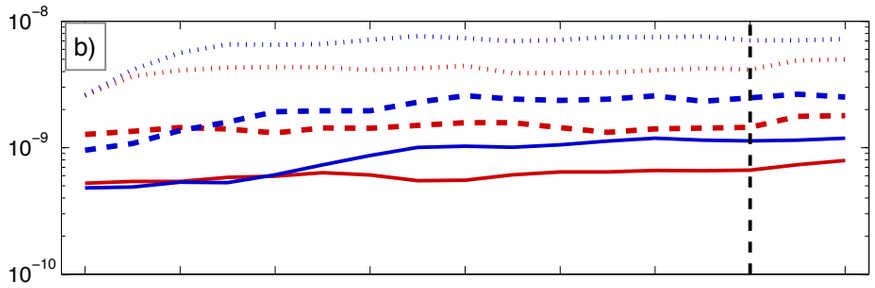


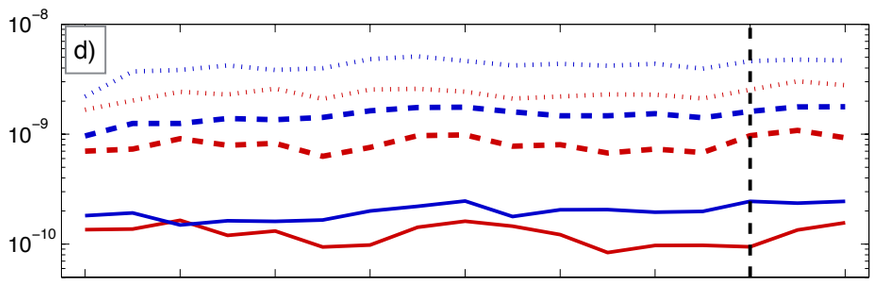
TS Matthew Vorticity Budget (90 - 300 km)

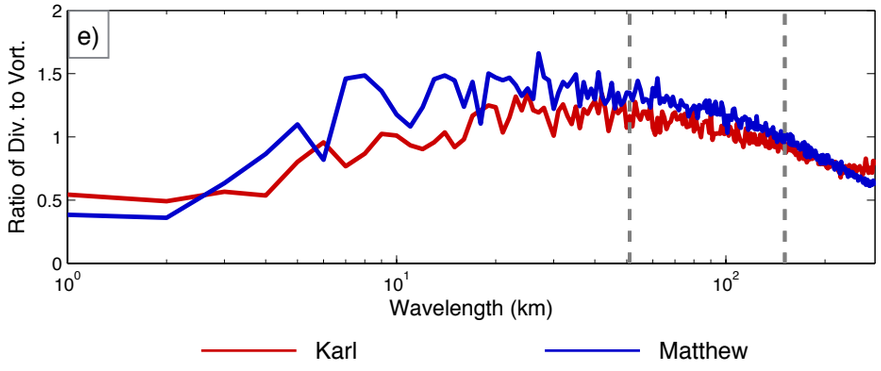


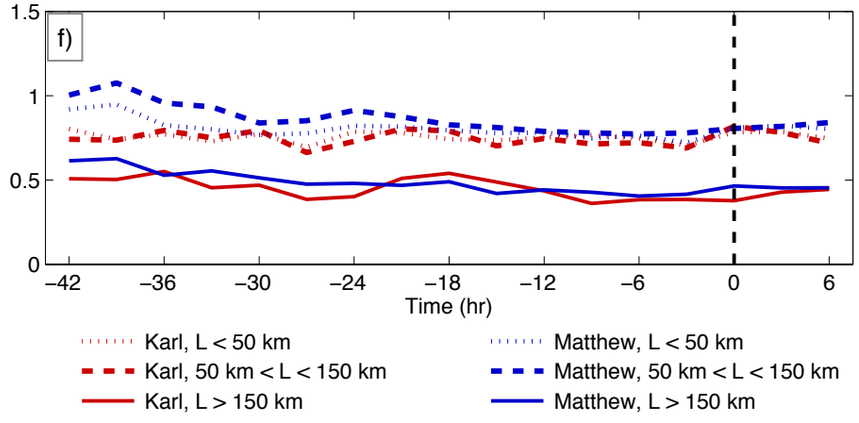
Spectral Decomposition









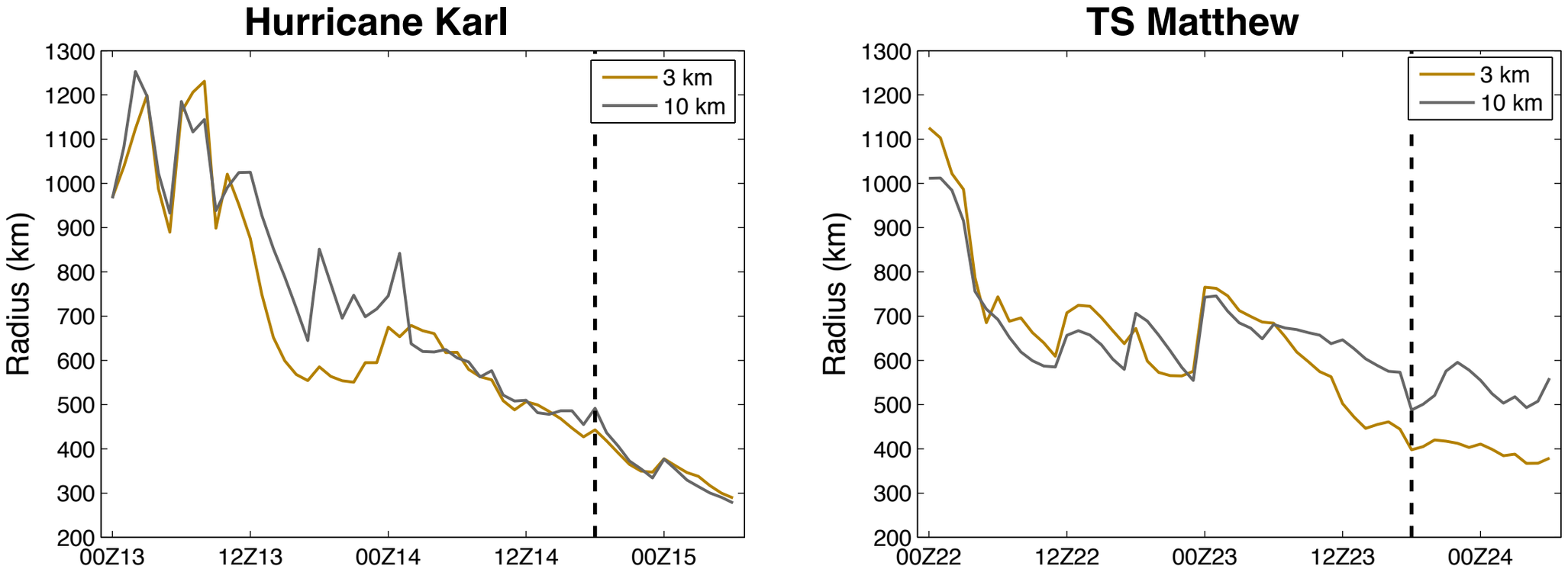


- Analysis are averaged over 12 hours centered on genesis.
- Convective scale : L < 50 km.
- Cluster scale : 50 < L < 150 km.
- System scale : L > 150 km.

- Convective scale contribution is greater than the cluster and system scales.
- The square root of the ratio of Divergence to Vorticity shows the system scale is relatively balanced.

Rossby Radius of Deformation

$$L_R = \frac{NH}{(f+\zeta)^{\frac{1}{2}}\left(f+2VR^{-1}\right)^{\frac{1}{2}}} = \frac{NH}{I}$$



- Energy produced by convective heating within the lower to middle troposphere is confined to the system scale vortex.

Schubert et al. 1980; Schubert and Hack 1982; Ooyama 1982; Frank 1983; Fang and Zhang 2011

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Hurricane Karl Secondary Transverse Circulation

24-hr forecast
00 UTC 14 Sept.

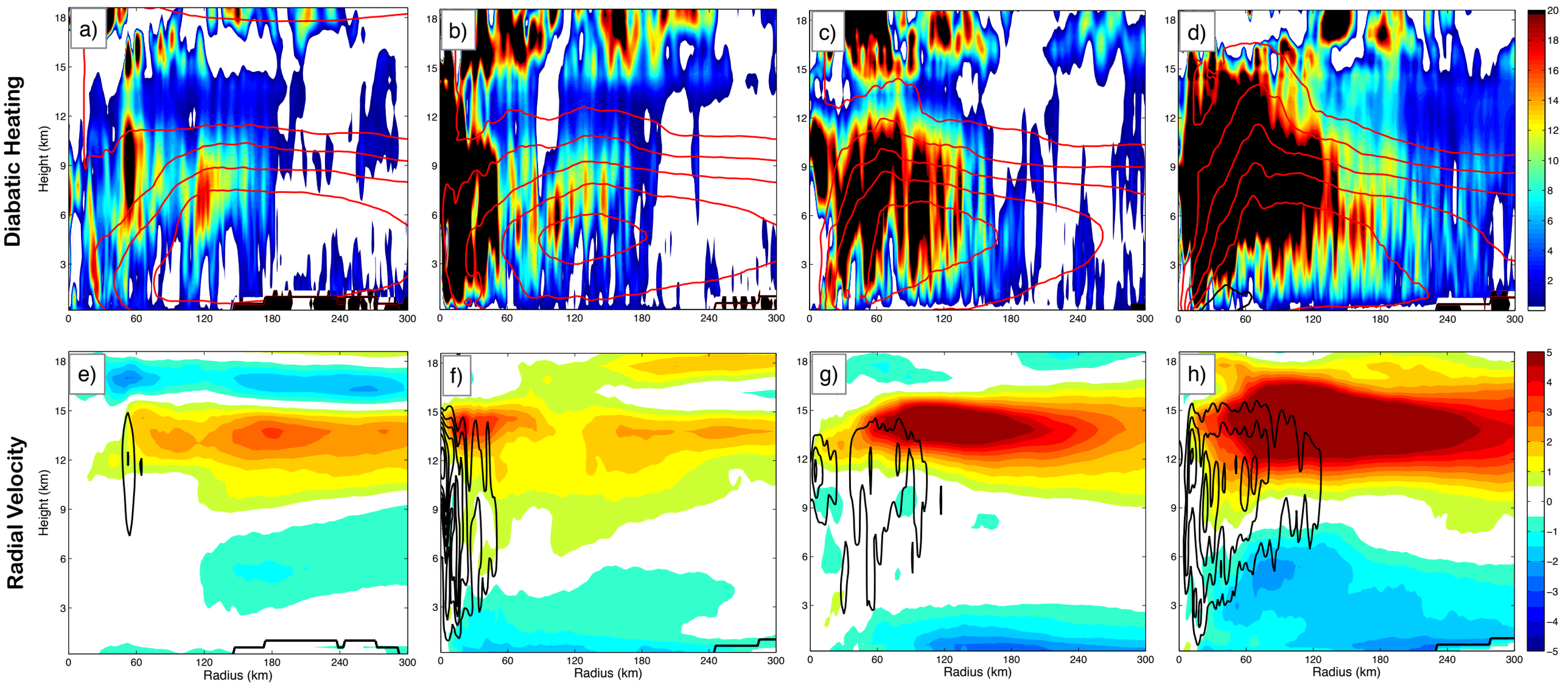
30-hr forecast
06 UTC 14 Sept.

36-hr forecast
12 UTC 14 Sept.

42-hr forecast
18 UTC 14 Sept.

Diabatic Heating

Radial Velocity



- Heating and momentum forcing resulted in system scale convergent inflow in the lower troposphere.

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TS Matthew Secondary Transverse Circulation

24-hr forecast
00 UTC 23 Sept.

30-hr forecast
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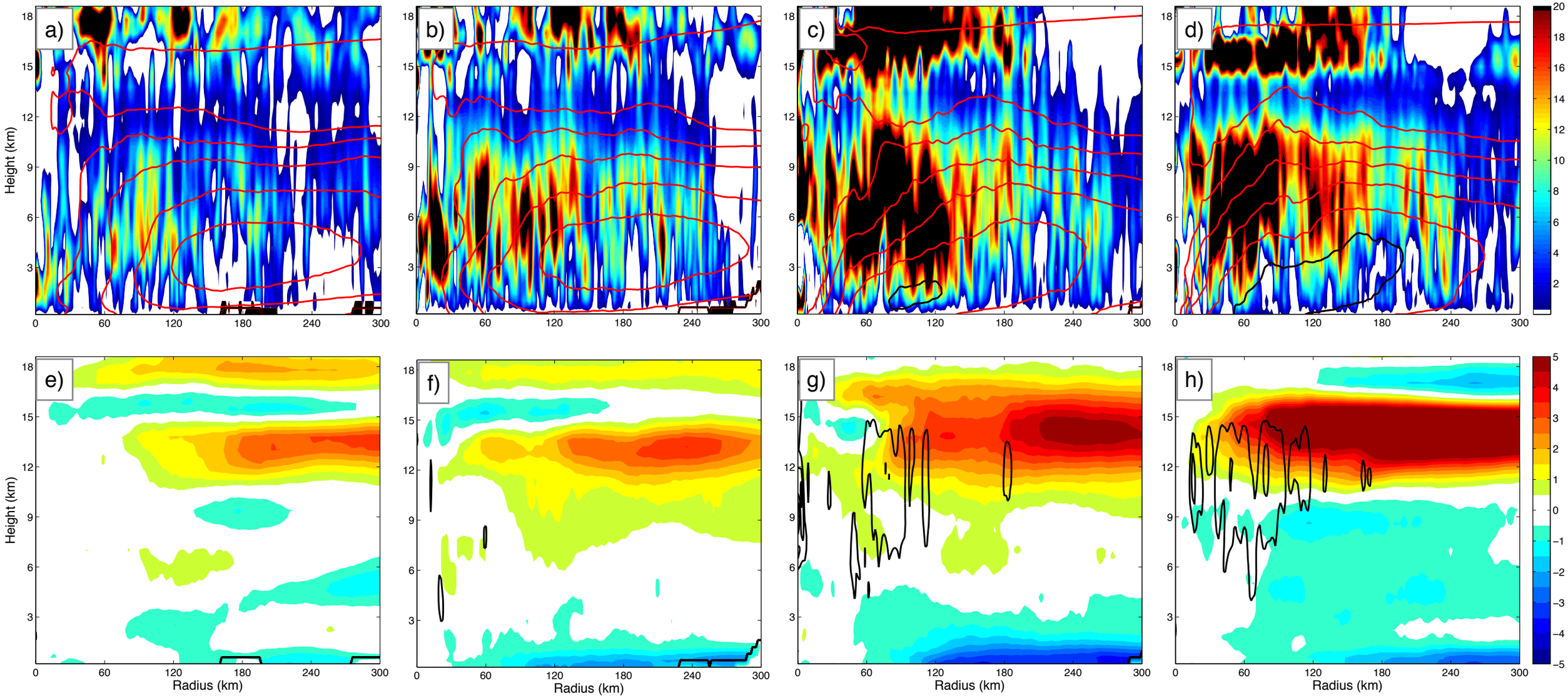
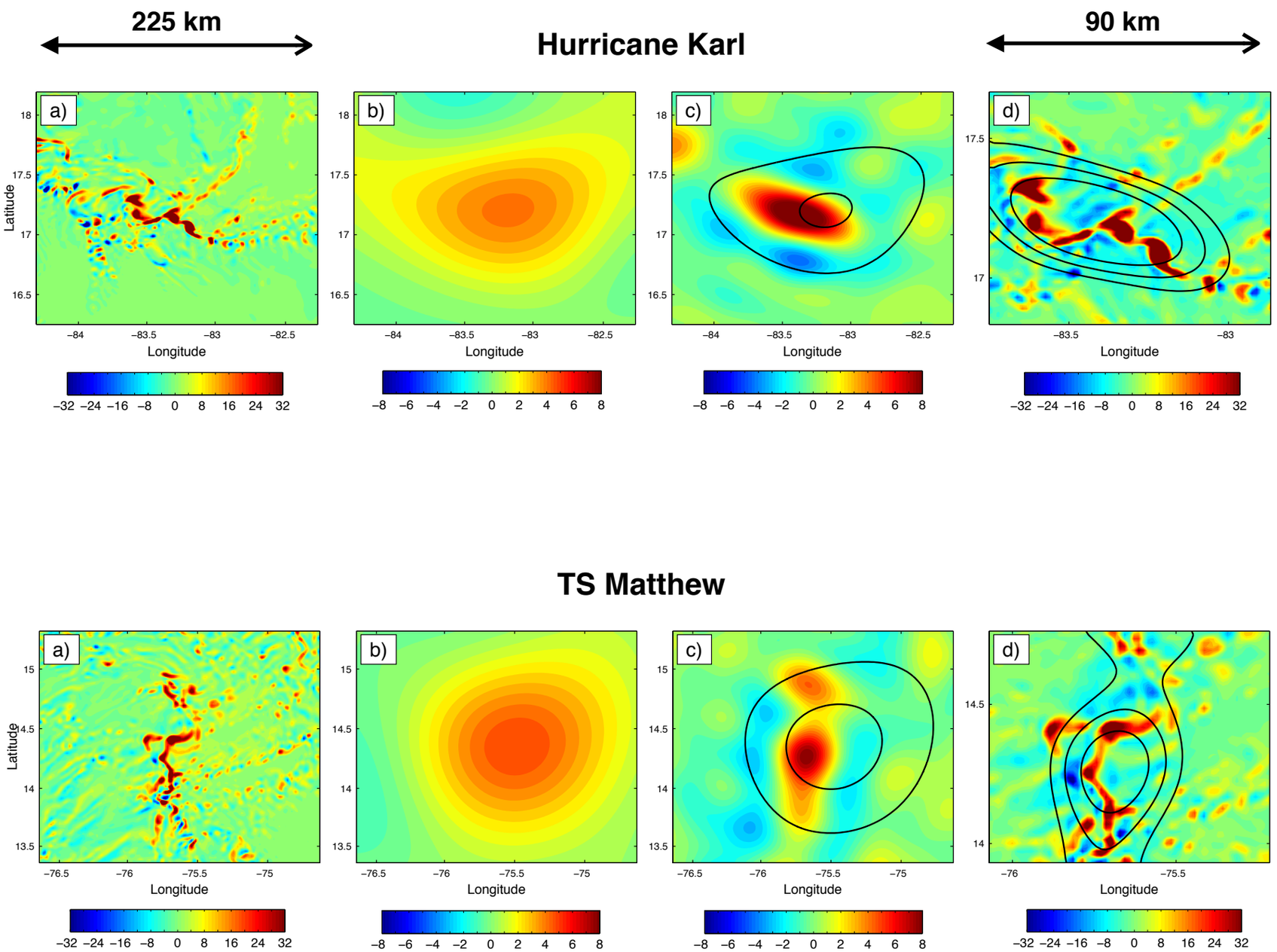
Diabatic Heating



Radial Velocity

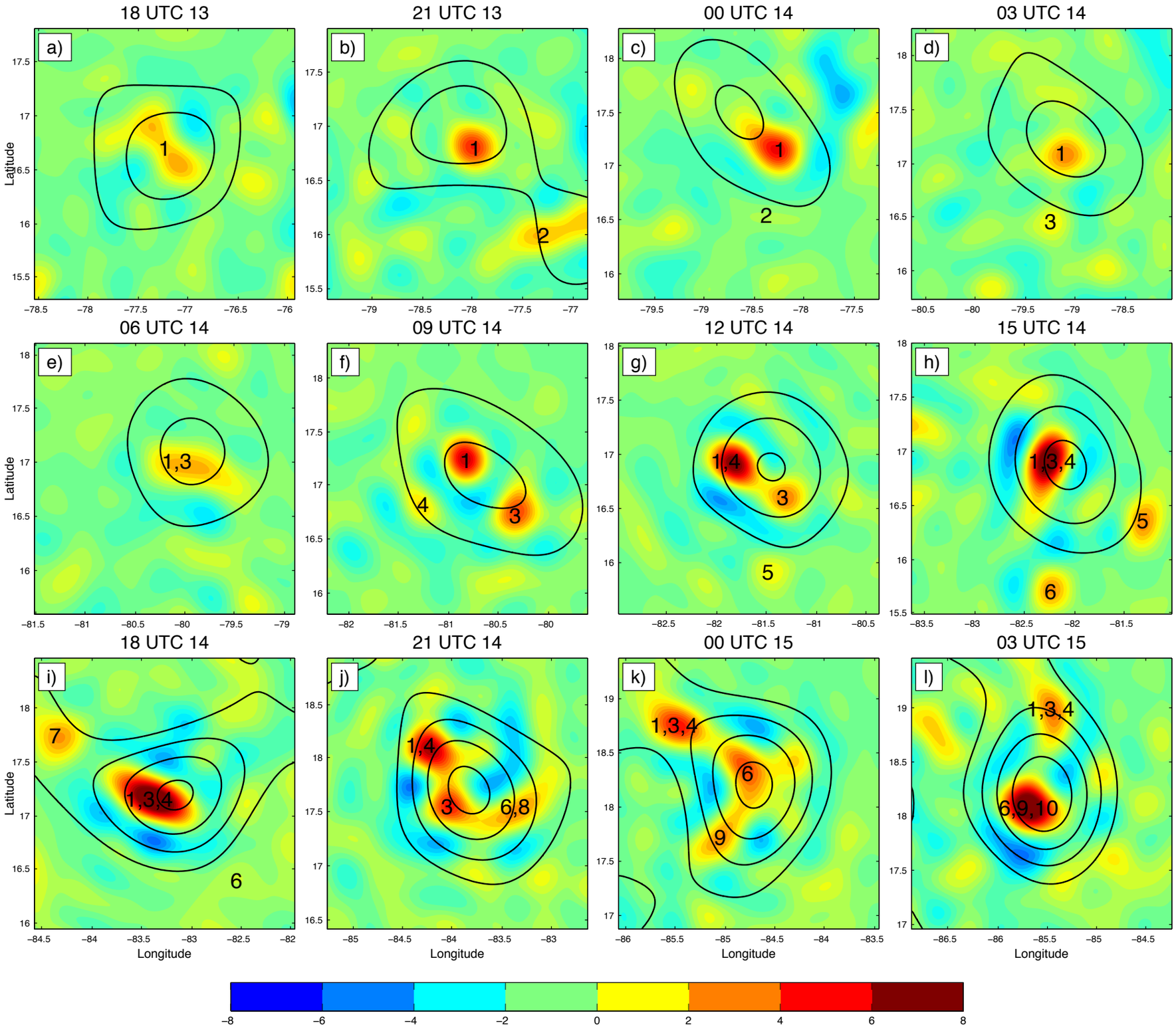
- Heating and momentum forcing resulted in system scale convergent inflow in the lower troposphere.

Multi-Scale Features of a Developing Vortex at 200 meters



- Vorticity anomalies converge towards the center.
- Large number of CVAs within the cluster scale vorticity anomaly.
- Convective and cluster scale vortices are greater in magnitude than the system scale vortex.

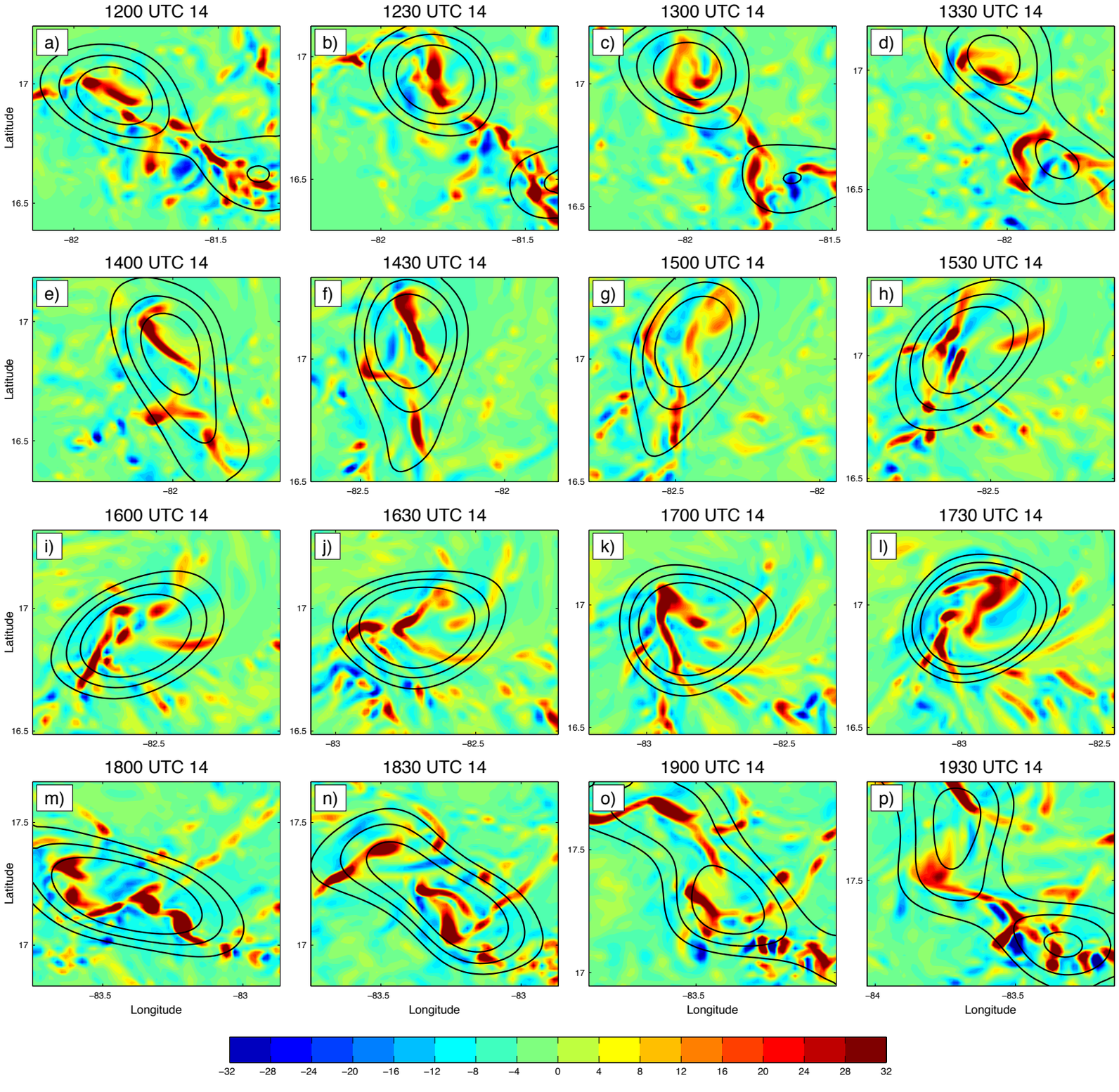
Hurricane Karl Cluster Scale Vortex Evolution



- Cluster scale vorticity mergers intensifies the system scale vortex.

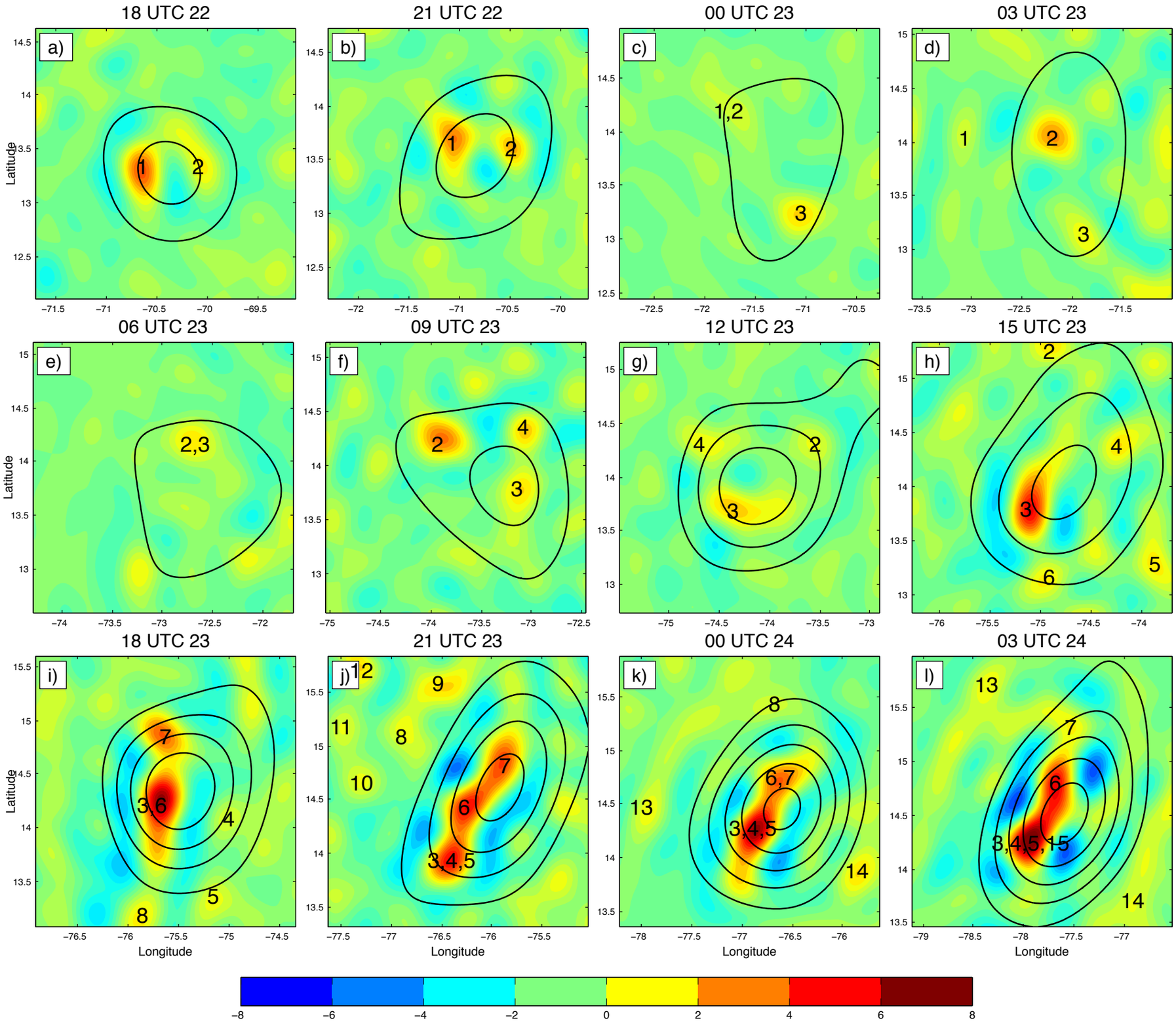
- The merging of vortices 1,3 and 4 led to the intensification of the system scale vortex during genesis.

Hurricane Karl Convective Scale Vortex Evolution



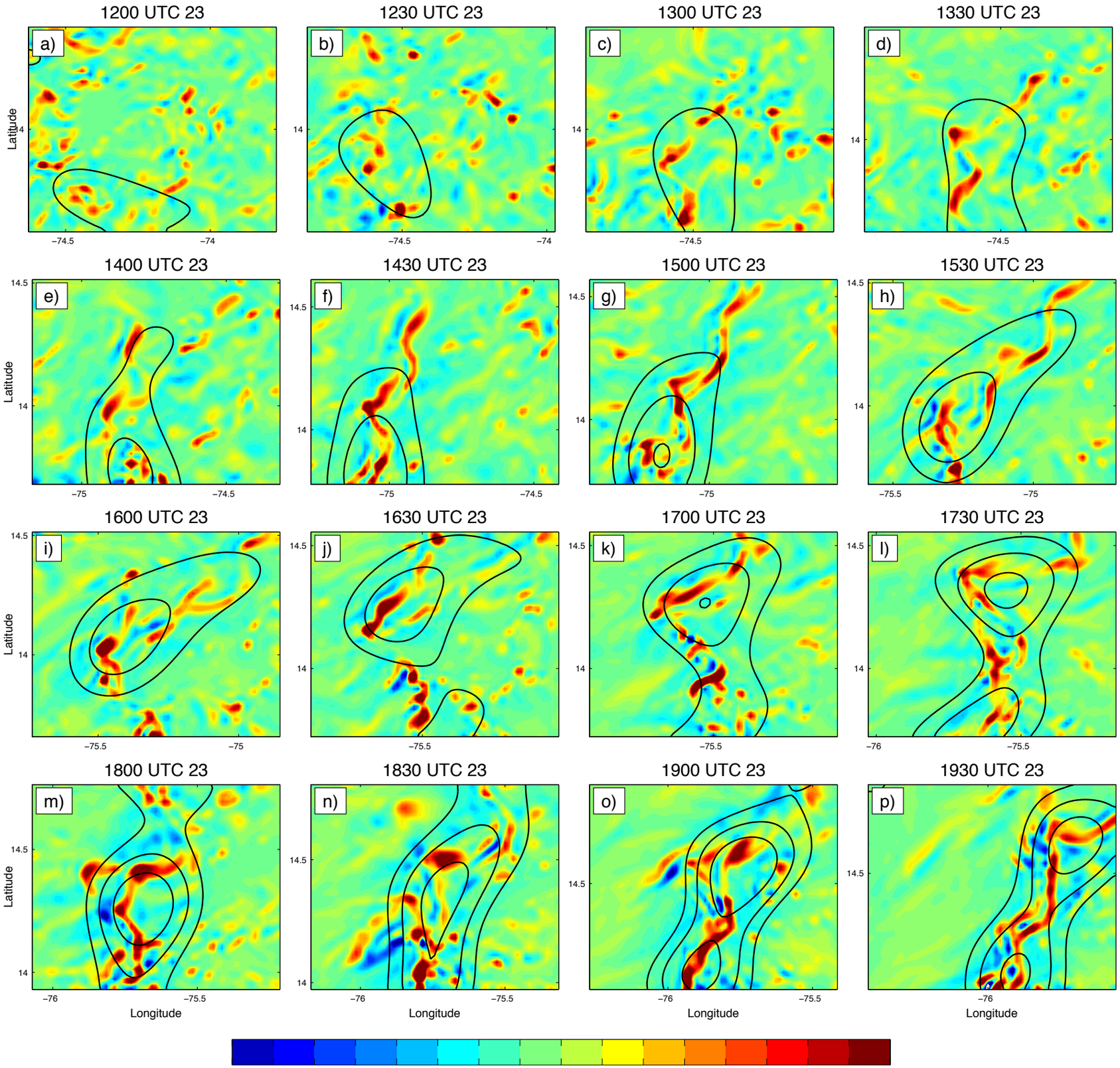
- The merger of CVAs within the cluster scale vortices 1,3 and 4 resulted in their mergers.
- Intensification of CVAs coincides with an intensification of the cluster scale vortices.

TS Matthew Cluster Scale Vortex Evolution



- Cluster scale vorticity mergers intensifies the system scale vortex.
- The merging of vortices 3,6 and 7 led to the intensification of the system scale vortex during genesis.

TS Matthew Convective Scale Vortex Evolution



The merger of CVAs within the cluster scale vortices 3,6 and 7 resulted in their mergers.

Intensification of CVAs coincides with an intensification of the cluster scale vortices.

Summary of Results

- TS Matthew shows important processes related to the top-down development theory.

- Vorticity budget shows that the low-level vortex was generated by the stretching term for both Karl and Matthew.

- Cluster-scale and Convective-scale vortex mergers are extremely important during the genesis process.

- CVAs are primarily responsible for the intensification of the low-level system scale vortex.

- Analysis imply that both systems genesis was as a result of the bottom-up process.

Future Directions

- Perform ensemble sensitivity analysis on Hurricane Karl and TS Matthew.

- Assimilate ground base radar observations to study the genesis of Hurricane Tomas (2010) and other mesoscale events affecting the Eastern Caribbean.

- Use a fully coupled atmosphere-ocean model like HWRF to study the multi-scale features of genesis.

Acknowledgments

Gregory Jenkins - Howard University

Fuqing Zhang - Pennsylvania State University

Questions and Comments