HDSS Analysis of Moist Entropy Production in Hurricane Core

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Experiment Design

- *Perform analysis of TCI HDSS observations for Patricia, Marty and Joaquin to verify 3 hypotheses regarding relationship between outflow and storm core characteristics*
- Use numerical simulation to clarify how observed structures relate to internal storm processes

TCI Cross-Section Analysis Methodology

- **No thinning of dropsonde data was done**
- **If any position, temperature, moisture or wind data were missing, all data for that point were excluded.**
- **Mapped to height / along-track and pressure / along-track grid using interpolated best-track position.**
- **Very light (i.e. 1-2 passes) with narrow-window boxcar smoother to eliminate high-frequency noise.**

TCI Cross-Section Analysis Methodology

- Use cross-sections that run through eye (some slight adjustments if eye is missed in flight track)
- Radial wind derived from along track wind, positive radially outward from center
- Divergence is radial derivative of radial wind
- Ice equivalent potential temperature:

$$\theta_{ei} \simeq \theta e^{\frac{l_{iv} r_v}{c_p T_d}}$$

- Computation of potential vorticity, using vorticity approximated by radial derivative of cross-track wind

Working Hypothesis 1

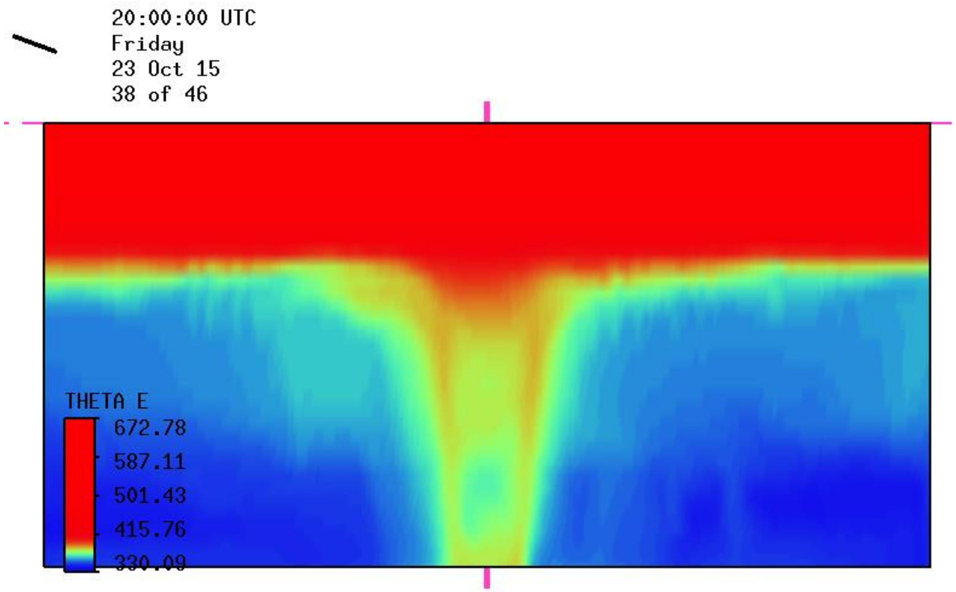
- Outflow occurs along a q surface corresponding to the q_e produced in the eye and brought up the eye-wall
- The high values of q_e generated in the eye are possible through isothermal (relative to SST) decompressional heating and moistening.
- Therefore, for a given SST, the lower the surface pressure, the higher the q_e possible and so the higher (larger q) the outflow channel.
- Since all TCs reach the freezing level, the highest outflow will be given by the ice-equivalent potential temperature:

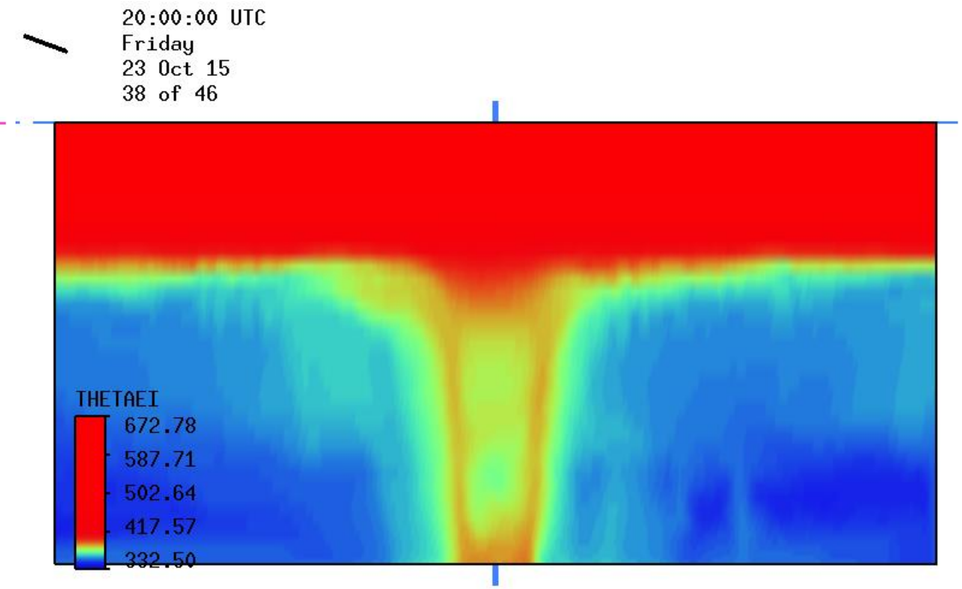
$$q_{ei} = q e^{\frac{l_{iv} r_v}{c_p T_{LCL}}}$$

Numerical simulation of Patricia

$$q_e = qe^{\frac{l_{lv} r_v}{c_p T_{LCL}}}$$

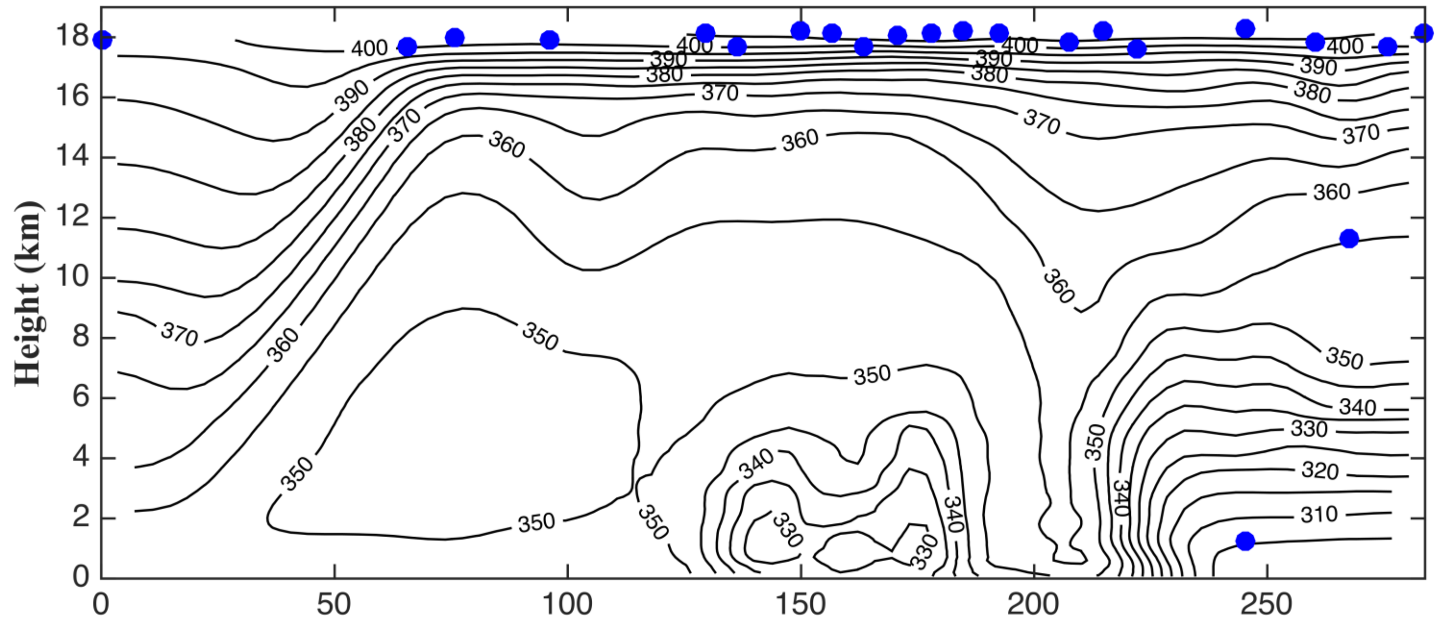
$$q_{ei} = qe^{\frac{l_{iv} r_v}{c_p T_{LCL}}}$$



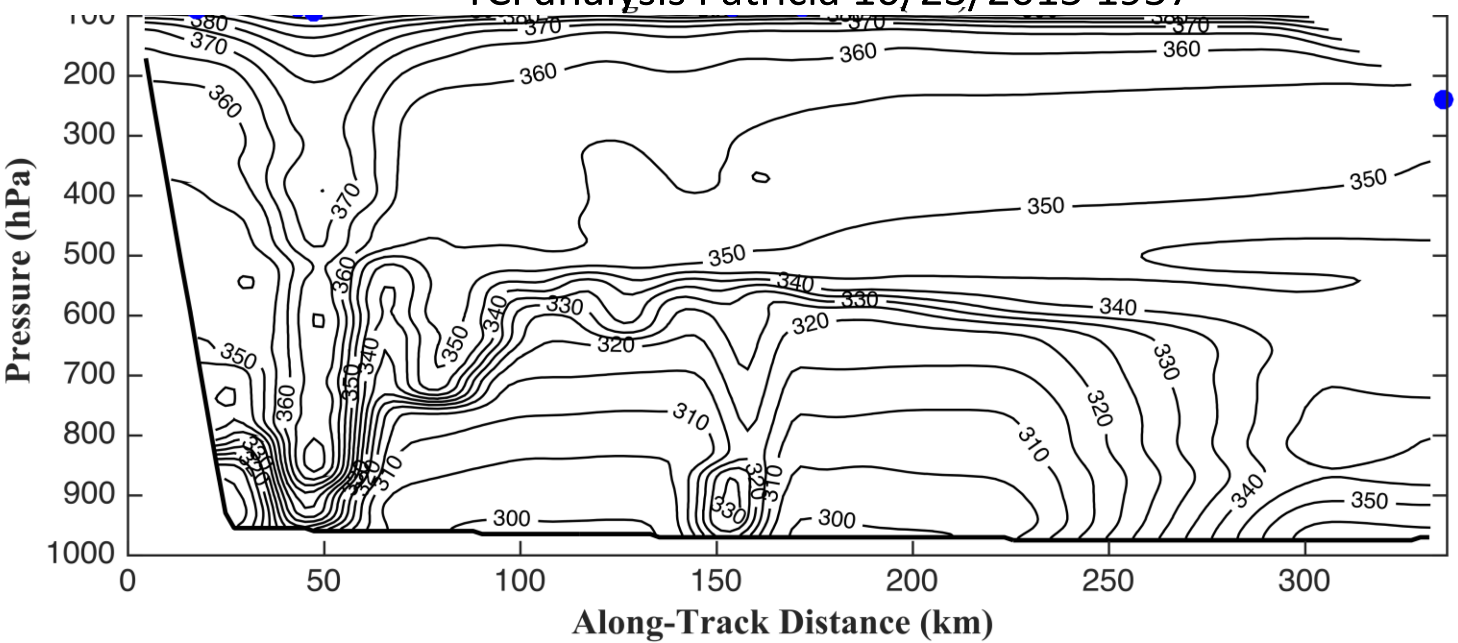


TCI analysis Patricia 10/22/2015 1801

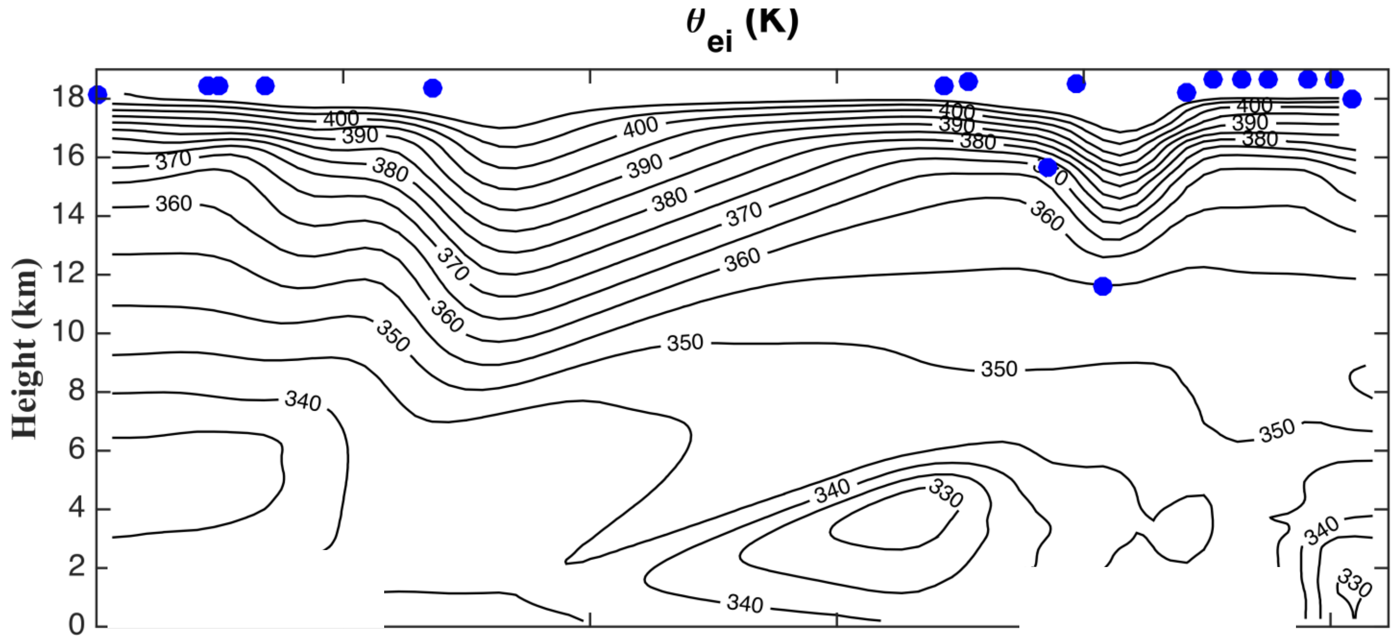
θ_{ei} (K)



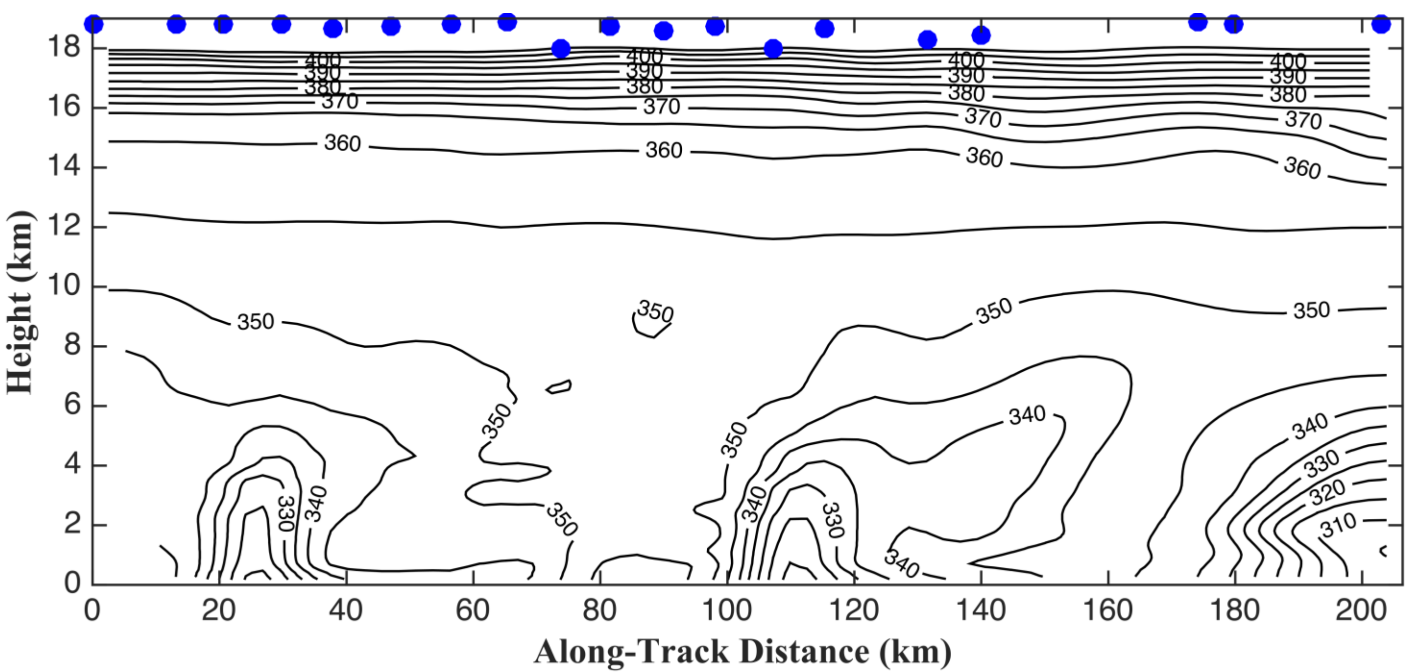
TCI analysis Patricia 10/23/2015 1957

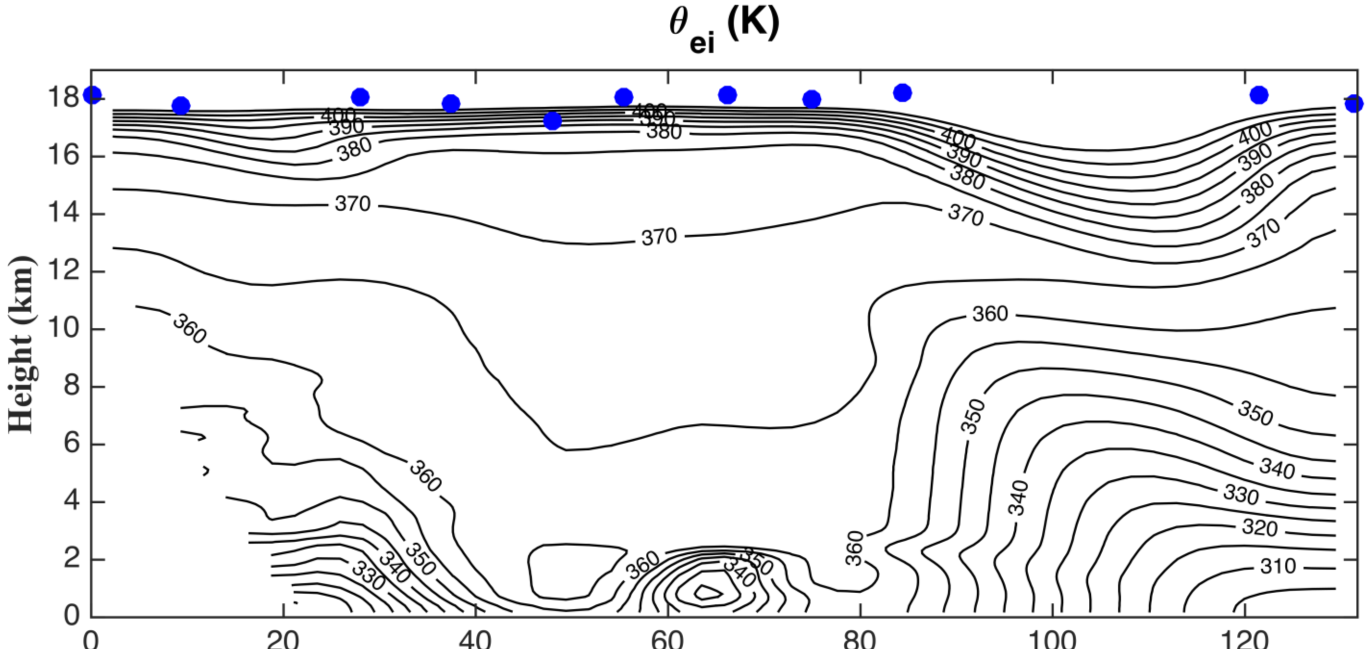


TCI analysis Marty 9/28/15 1901

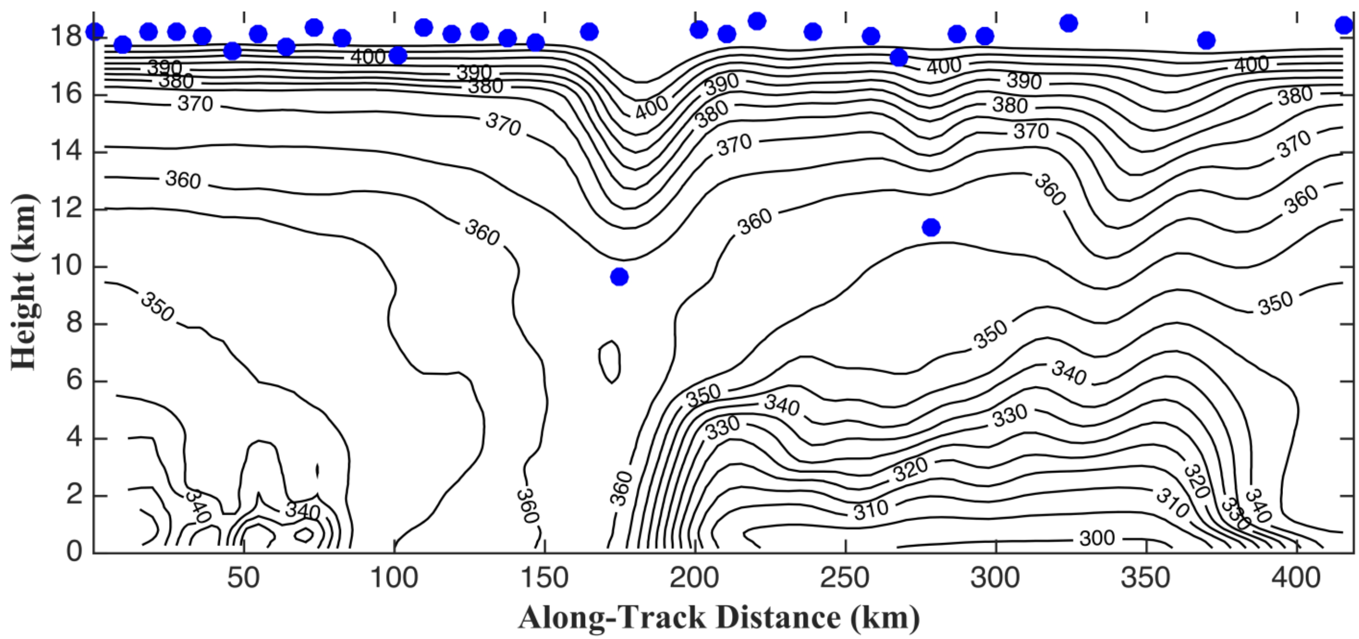


TCI analysis Marty 9/28/15 1959





TCI analysis Joaquin 10/2/1015 1739



TCI analysis Joaquin 10/4/1015 1747

Working Hypothesis 2

- Environmental outflow resistance (EOR) is the lesser of:
  1. inertial resistance to radial acceleration driven by the accumulation of mass placed at the outflow level by the upward motion in the eye wall
  2. static stability, or resistance to forced subsidence
- Work performed against EOR, q reduces the energy available from the Carnot Engine to grow the circulation to the MPI (Rappin et al, 2011)
- The inertial resistance is the inertial stability of flow (I), equal to:

$$I^2 = \left(V + f\right)^2 - \left|D_{ij}\right|^2$$

where V is relative vorticity, f is coriolis and D_{ij} is the deformation tensor.

- And static stability is defined by the Brunt-Vasallai frequency defined:

$$N^2 = \frac{g}{q}\frac{\partial q}{\partial z}$$

Working Hypothesis 2

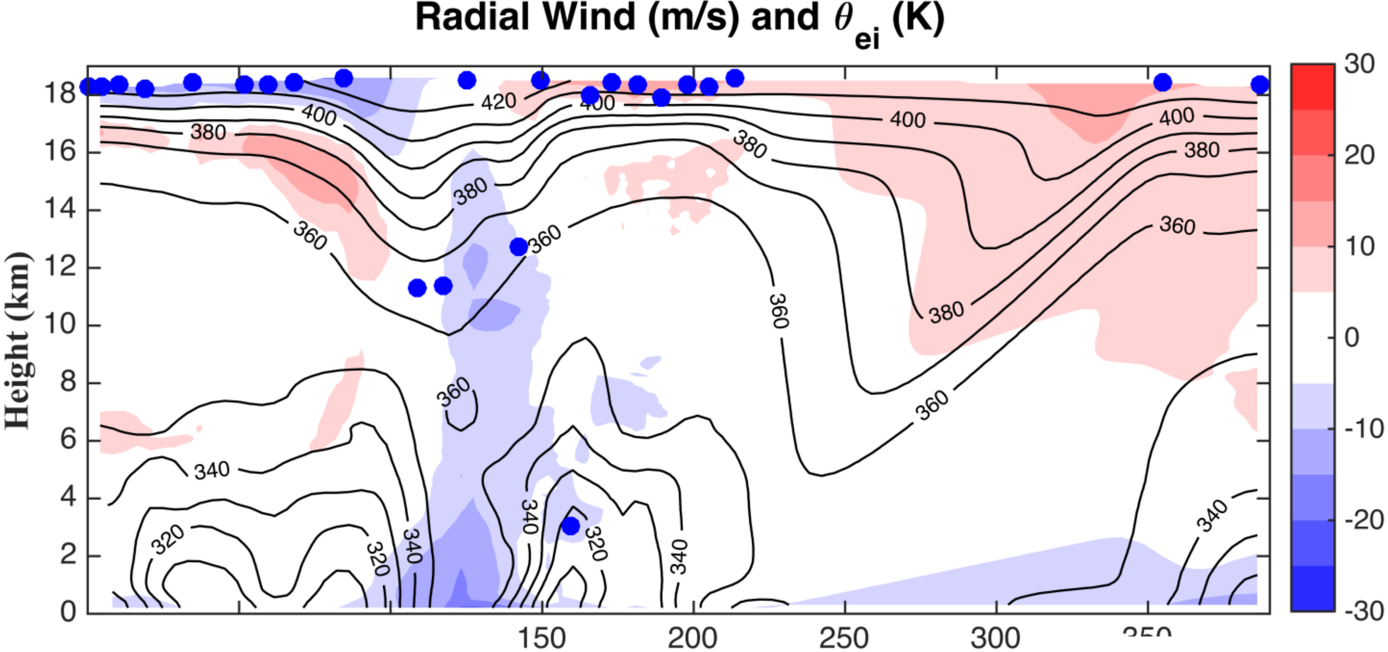
- Typically $I^2 < N^2$, and so inertial resistance determines EOR
- However, as outflow thins moving away from TC, the overall PV is conserved, producing interplay between I and N:

$$PV = \frac{(V + f)}{r}\frac{\partial q}{\partial z}$$

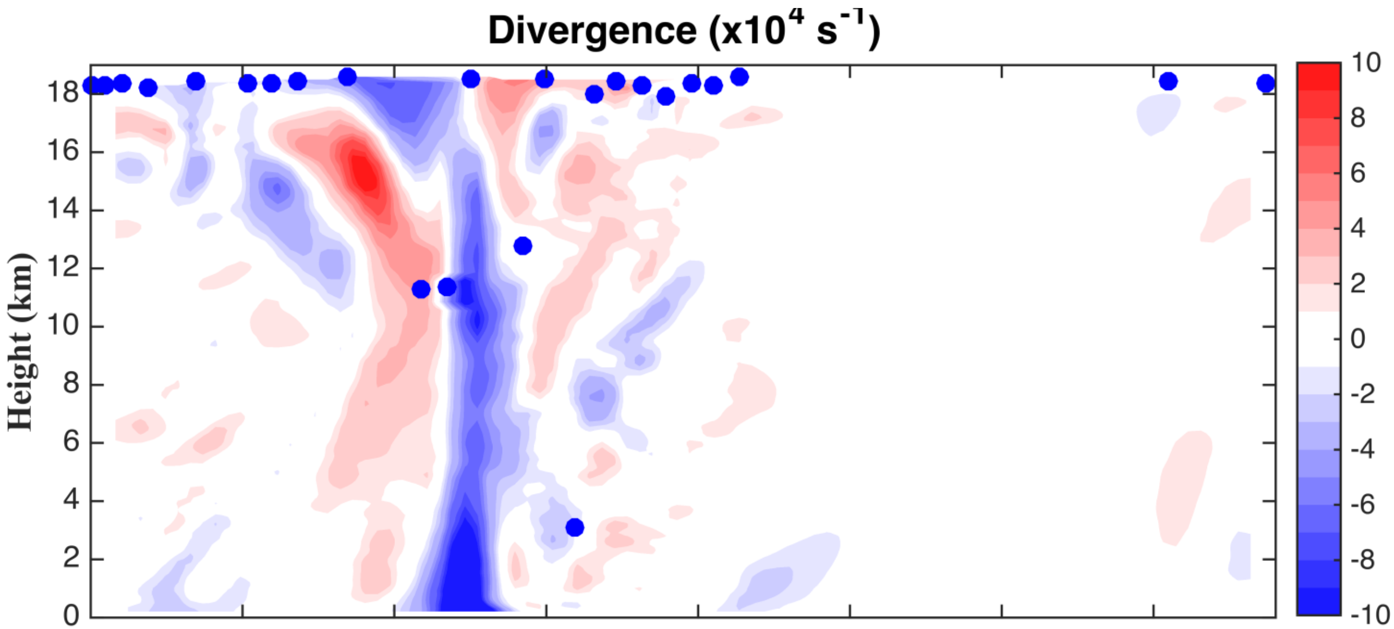
- In the end outflow resistance will be dependent on PV which takes into account both inertial stability and static stability
- The lower the PV the less the EOR

Working Hypothesis 2

- Hence, optimal storm intensity growth should produce outflow into isentropic layers with the lowest PV
- For a given SST, eyewall q_{ei} will vary, depending on how low that the surface pressure becomes.
- Therefore, this implies that the outflow resistance is modulated by the surface pressure.
- Logically, the surface pressure minimum achieved by a storm may be tied to the outflow channels of least resistance available



TCI analysis Patricia 10/22/2015 1857



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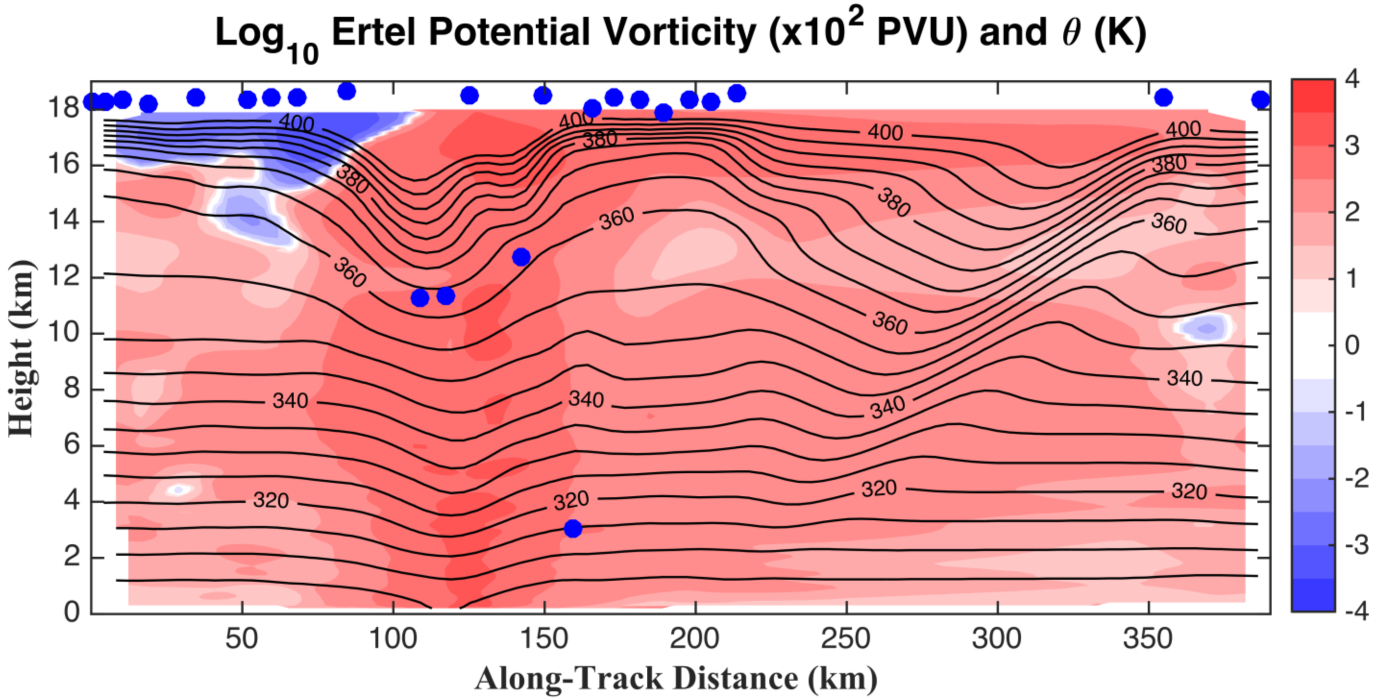

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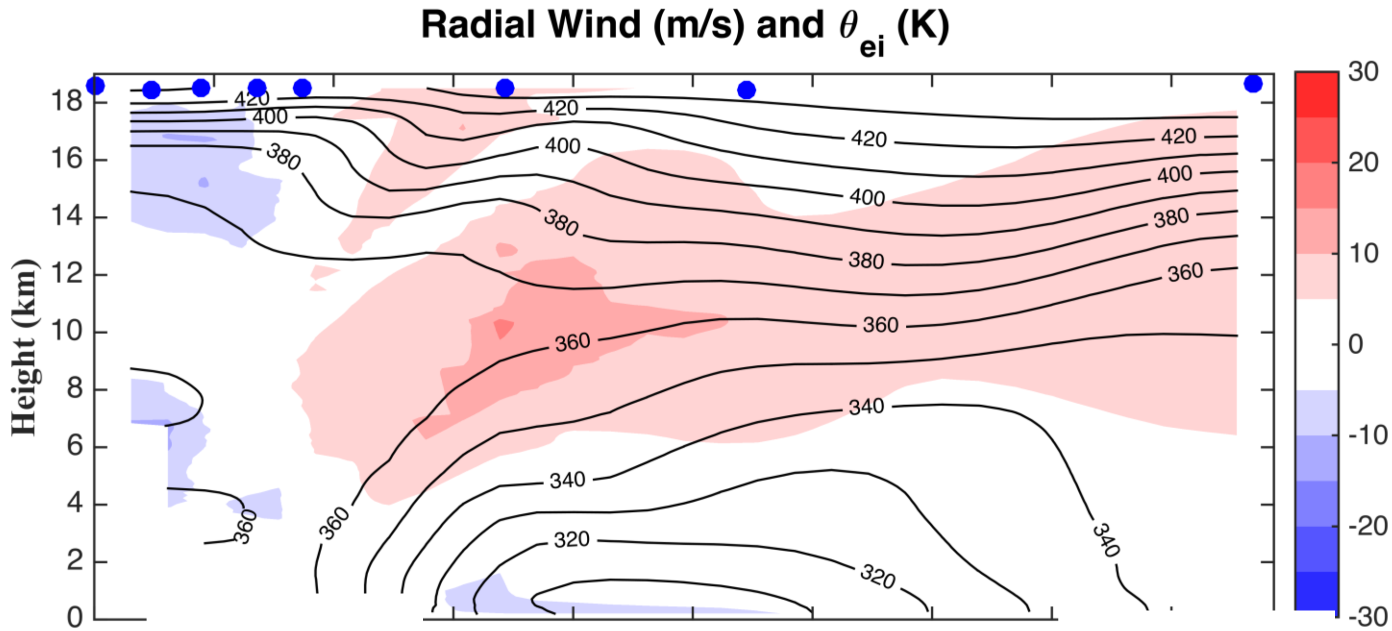
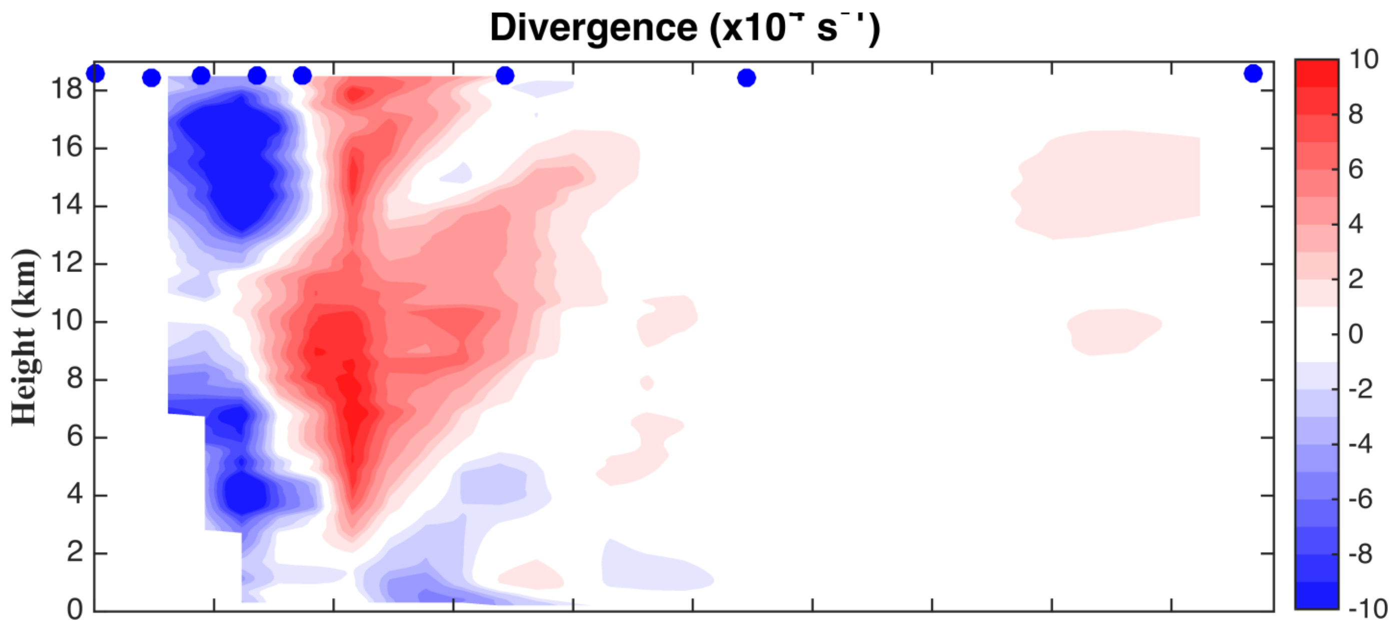


TCI analysis Joaquin 10/02/2015 1833



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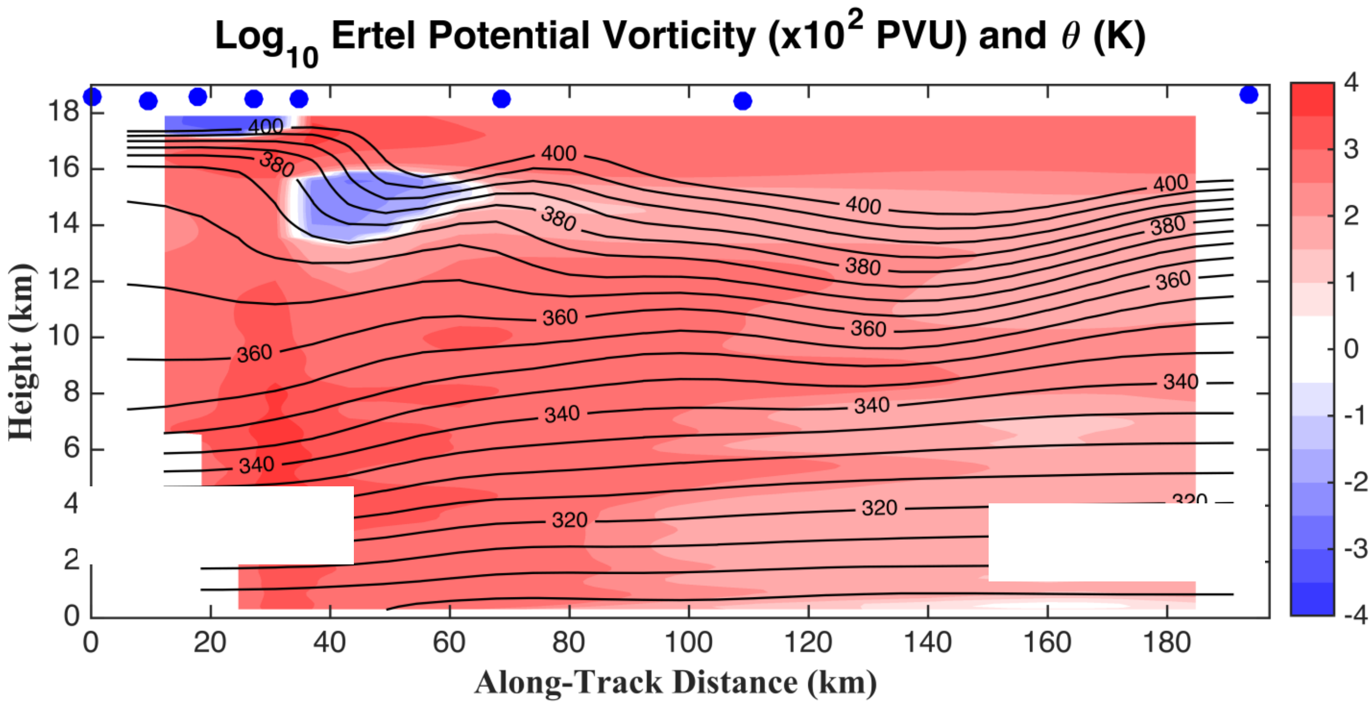
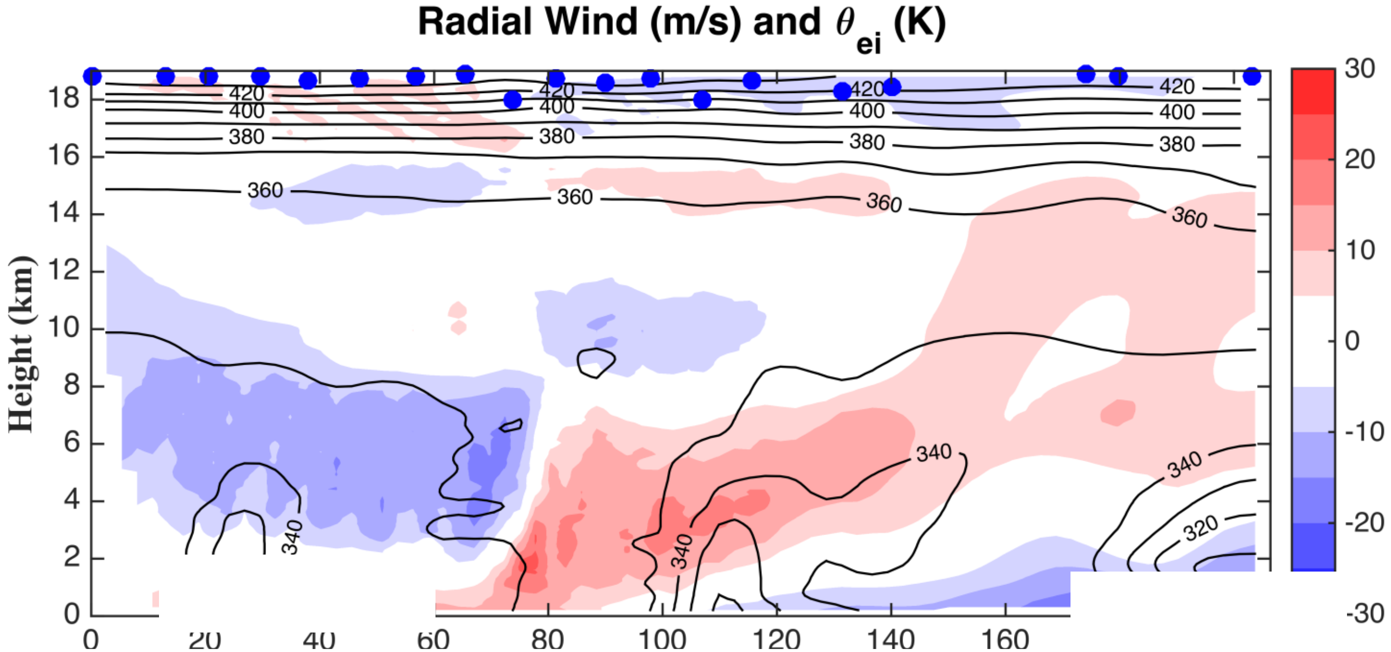
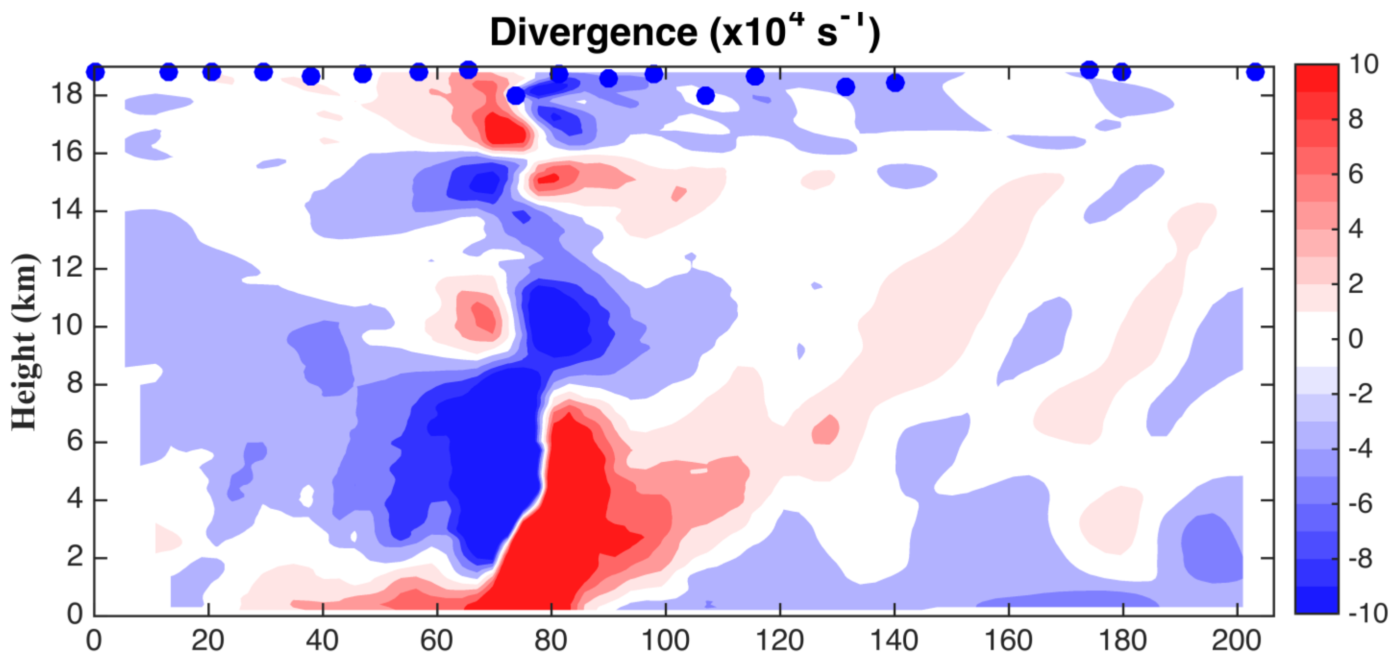


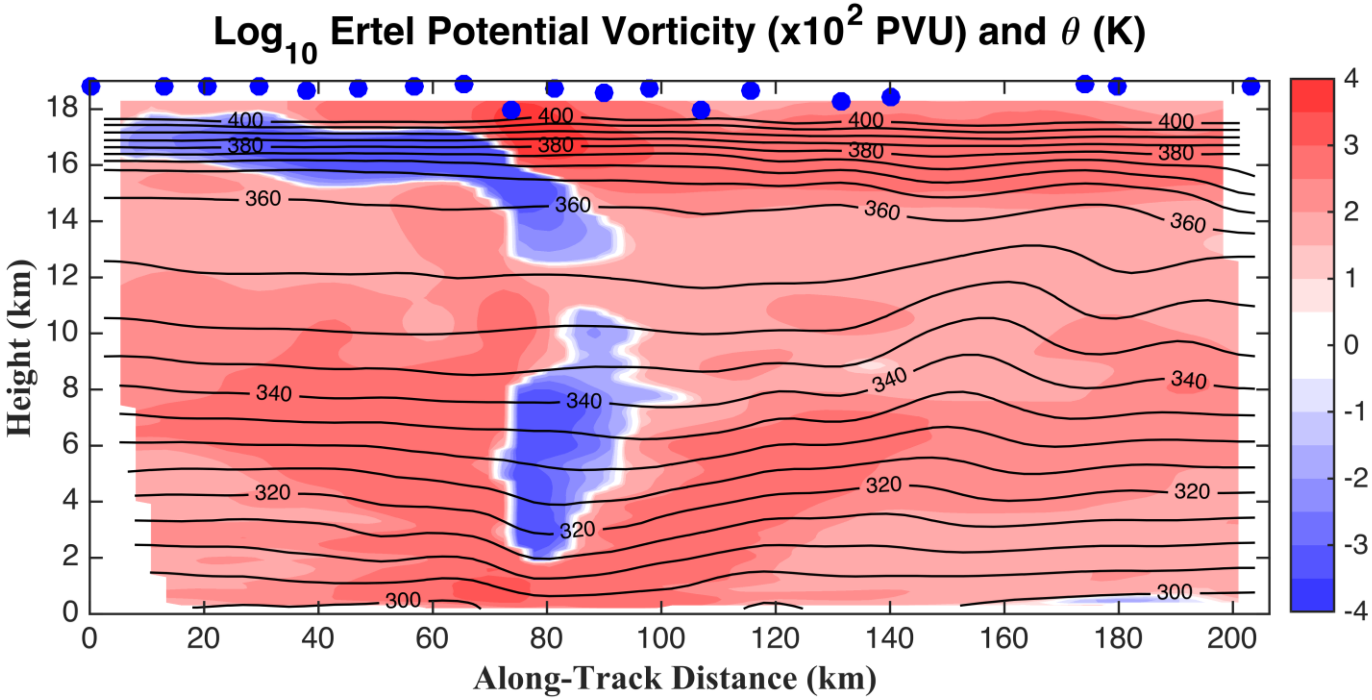
TCI analysis Joaquin 10/02/2015 1833

TCI analysis Marty 09/28/2015 1959



TCI analysis Marty 09/28/2015 1959



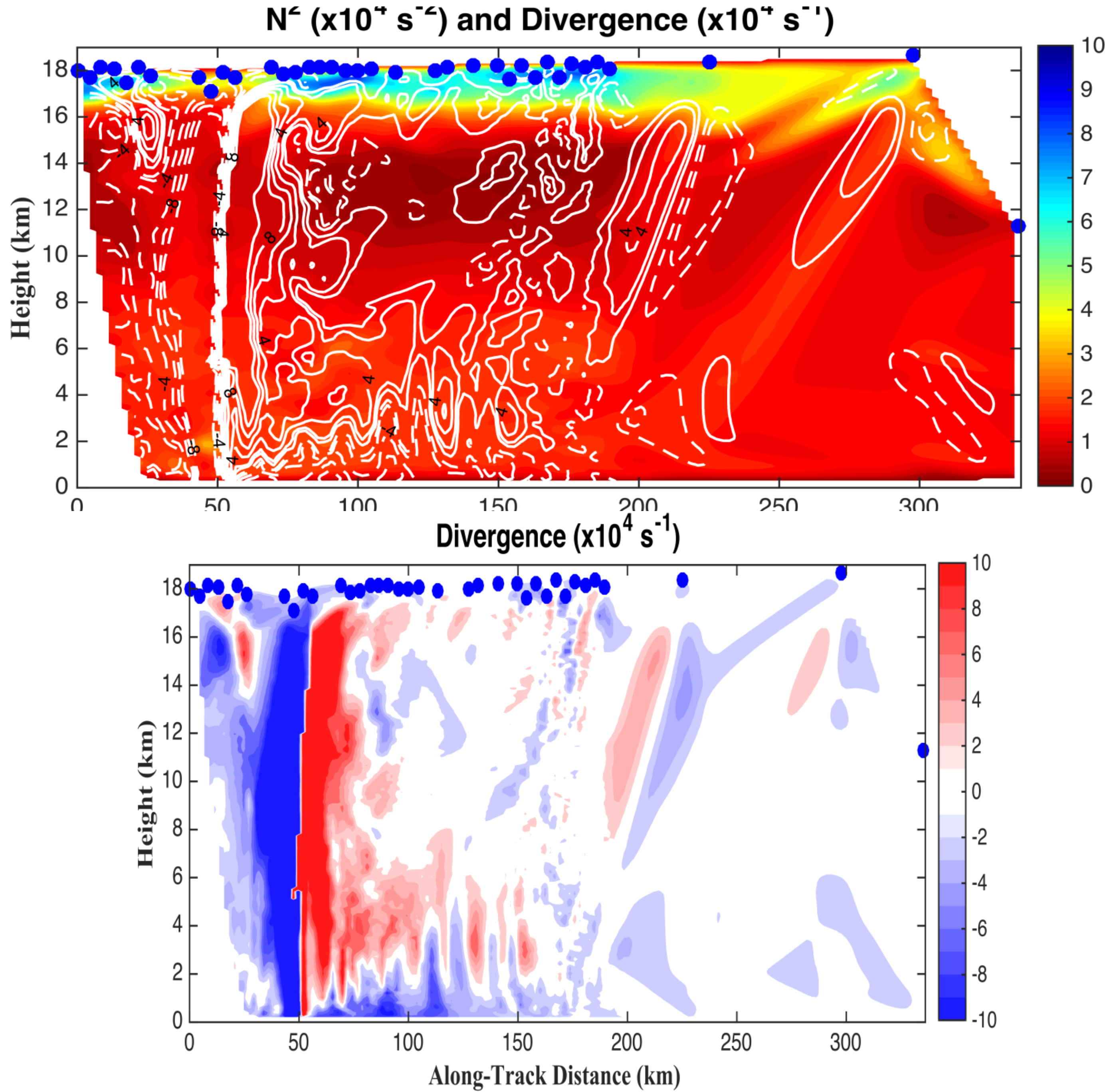


TCI analysis Marty 09/28/2015 1959

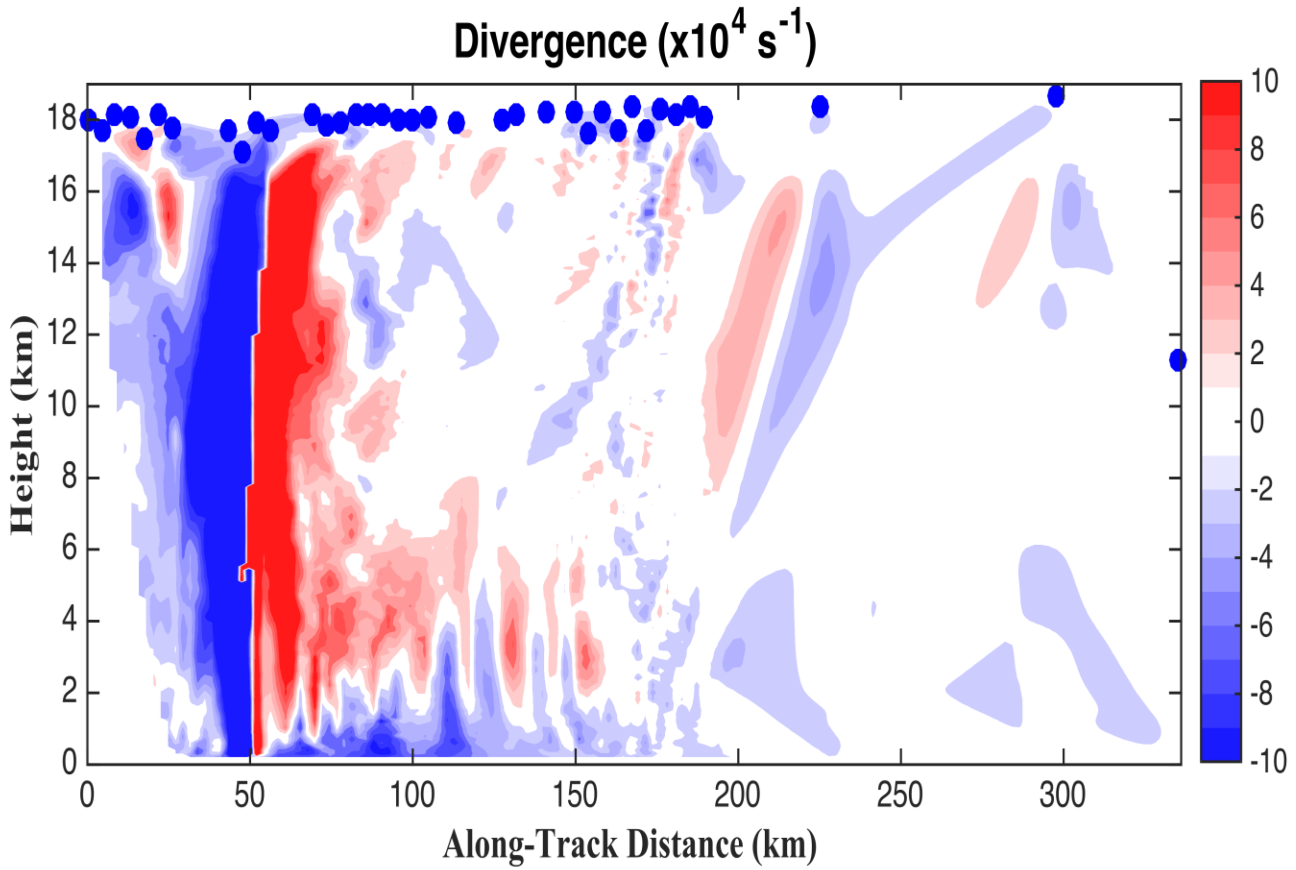
Working Hypothesis 3

- Internal gravity waves are produced by the storm core
    - azimuthal inhomogeneties in the eye wall thermal structure
    - convection in the eye wall
    - Flow over coherent PBL convective structures associated with dynamic and thermal destabilization of rapidly decompressing surface inflow in a strong helically sheared environment
- Layers of low B-V frequency can trap IGWs below, possibly enhancing wave growth

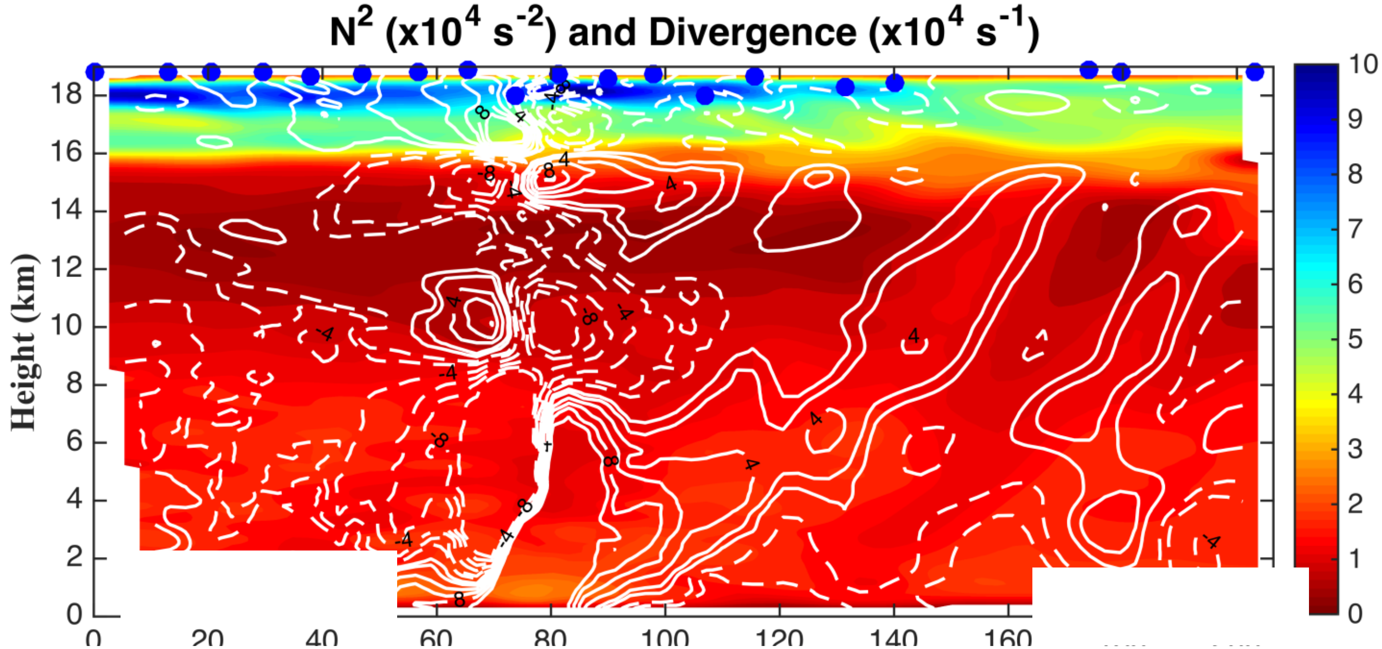
TCI analysis Patricia 10/23/2015 1957



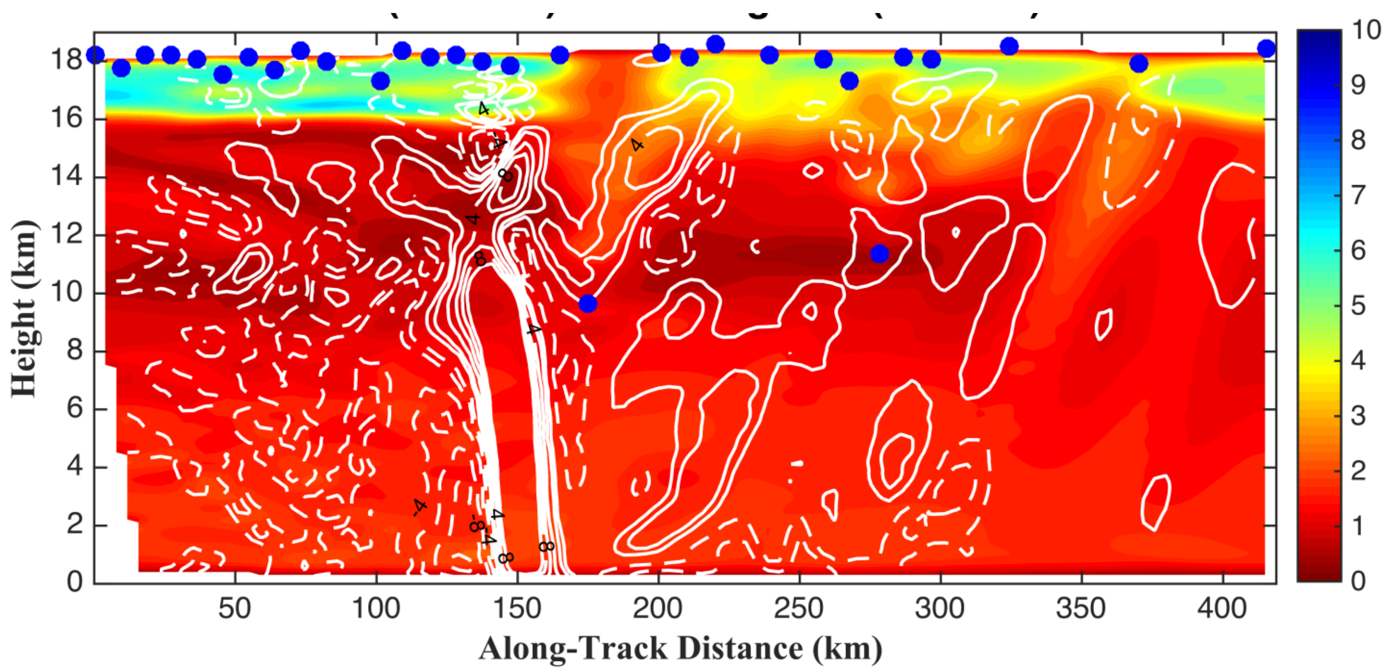
Hurricane Patricia
18 UTC 23OCT 2015



TCI analysis Marty 09/28/2015 1959



TCI analysis Joaquin 10/04/2015 1747



Conclusions

- TCI HDSS analysis confirm hypothesis 1 which states that the q of the outflow matches the q_{ei} produced in the eye, however more horizontal resolution is needed.
- TCI HDSS observations provide evidence supporting hypothesis 2 that outflow is directed toward lowest PV but inability to measure the cross track gradients of vorticity prevent a definitive measure of PV
- TCI HDSS observations provide strong evidence in support of hypothesis 3 that graviry wave propagation is attenuated by stability variations.