Vorticity Budgets in Tropical Cyclones Using the ELDORA Radar and Dropsondes*

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Radar and Dropsonde Analysis

We have developed a model-independent three-dimensional variational scheme (3D-VAR) to analyze airborne Doppler radar data along with dropsonde observations (López and Raymond 2011). The 3D-VAR scheme employs an efficient two-step process: (1) Radar observations within each grid box are analyzed locally to obtain estimates of particle velocity and the associated error covariance matrix. (2) A global variational scheme then uses these data to compute a global wind field. The global penalty function incorporates all radar error covariance information as well as dropsonde observations, imposes a strong mass continuity constraint, and contains horizontal and vertical smoothing terms. In each grid box a local Cartesian reference frame is used in which the error covariance matrix is diagonal, simplifying the incorporation of radar data into the 3D-VAR analysis. No hand editing of radar data was done in this analysis.

Vorticity Analysis

We present three examples of our analysis encompassing the development of typhoon Nuri (2008) in the western Pacific. We make a complete evaluation of the flux form of the vorticity equation, resulting in the vorticity tendency as a residual. This vorticity tendency is then integrated over the system to obtain a circulation tendency as a function of height. This circulation tendency reflects the true development of the system, which supports the reliability of our analysis scheme.

- The absolute vertical vorticity and storm-relative winds are shown in the first row below.

- The second row shows the circulations, circulation tendencies, and the vertical mass flux as a function of height.

Vorticity Equation

The tendency for the vertical component of absolute vorticity is

$$\frac{\partial \zeta_z}{\partial t} = -\boldsymbol{\nabla}_h \cdot \boldsymbol{Z}$$

where the horizontal flux of vertical vorticity is

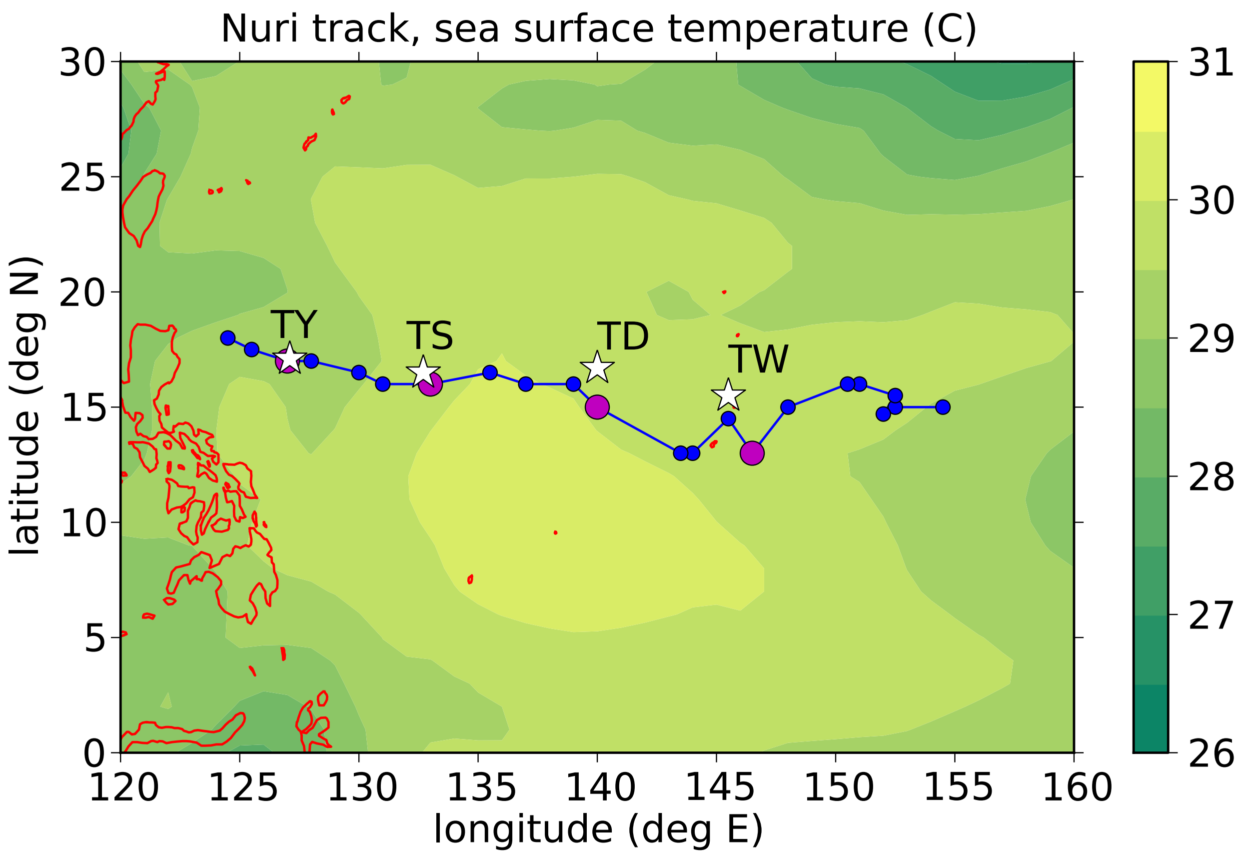
$$\boldsymbol{Z} = \boldsymbol{v}_h \zeta_z - \boldsymbol{\zeta}_h v_z + \widehat{\boldsymbol{k}} \times \boldsymbol{F} = conv + tilt + frict.$$

The wind is $\boldsymbol{v} = (\boldsymbol{v}_h, v_z)$ and the absolute vorticity is $\boldsymbol{\zeta} = (\boldsymbol{\zeta}_h, \zeta_z) = \boldsymbol{\nabla} \times \boldsymbol{v} + 2f\widehat{\boldsymbol{k}}$. The frictional force $\boldsymbol{F}$ is obtained from a simple boundary layer model. The absolute circulation is

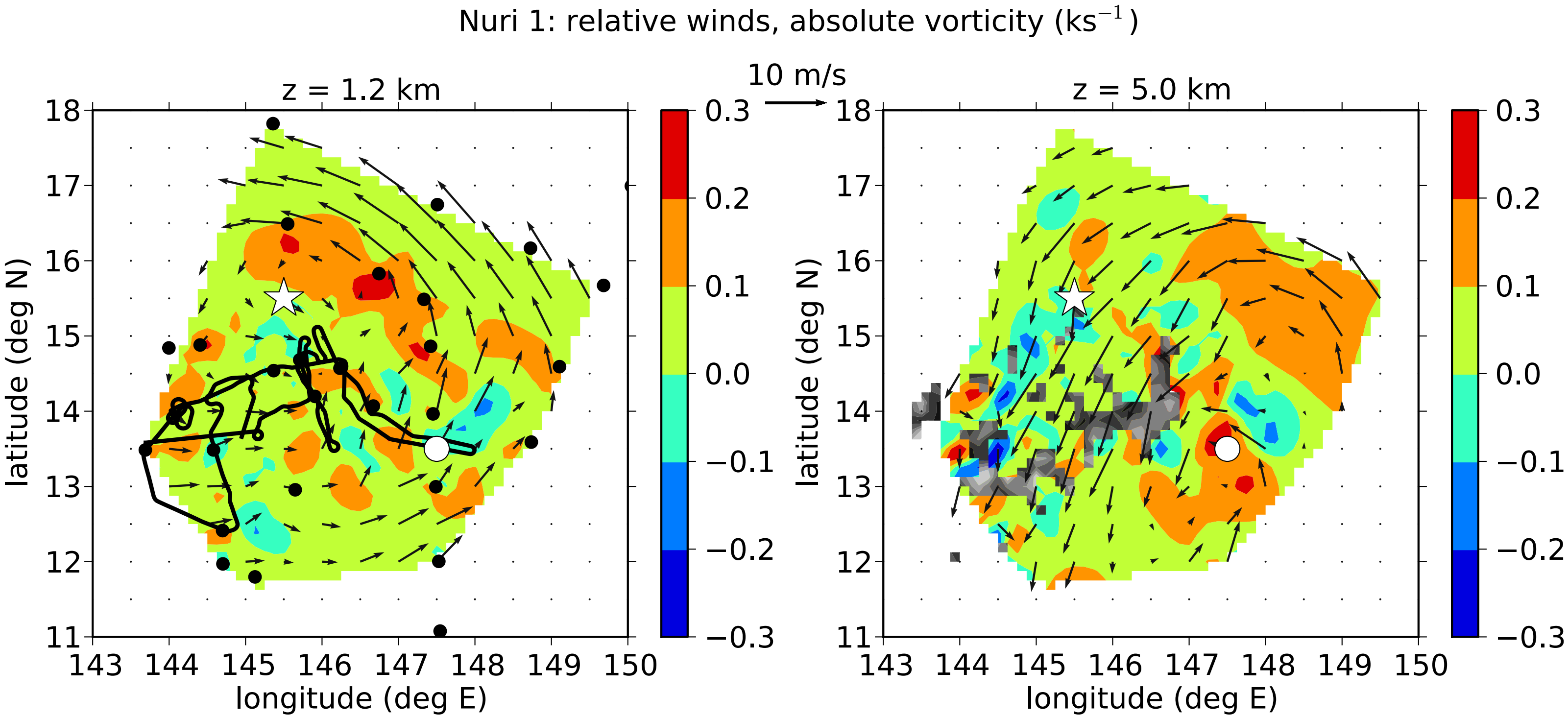
$$\Gamma = \int \zeta_z dA.$$

All components of $\boldsymbol{Z}$ can be computed from the 3D-VAR analysis, resulting in time tendencies of ζ_z and Γ.

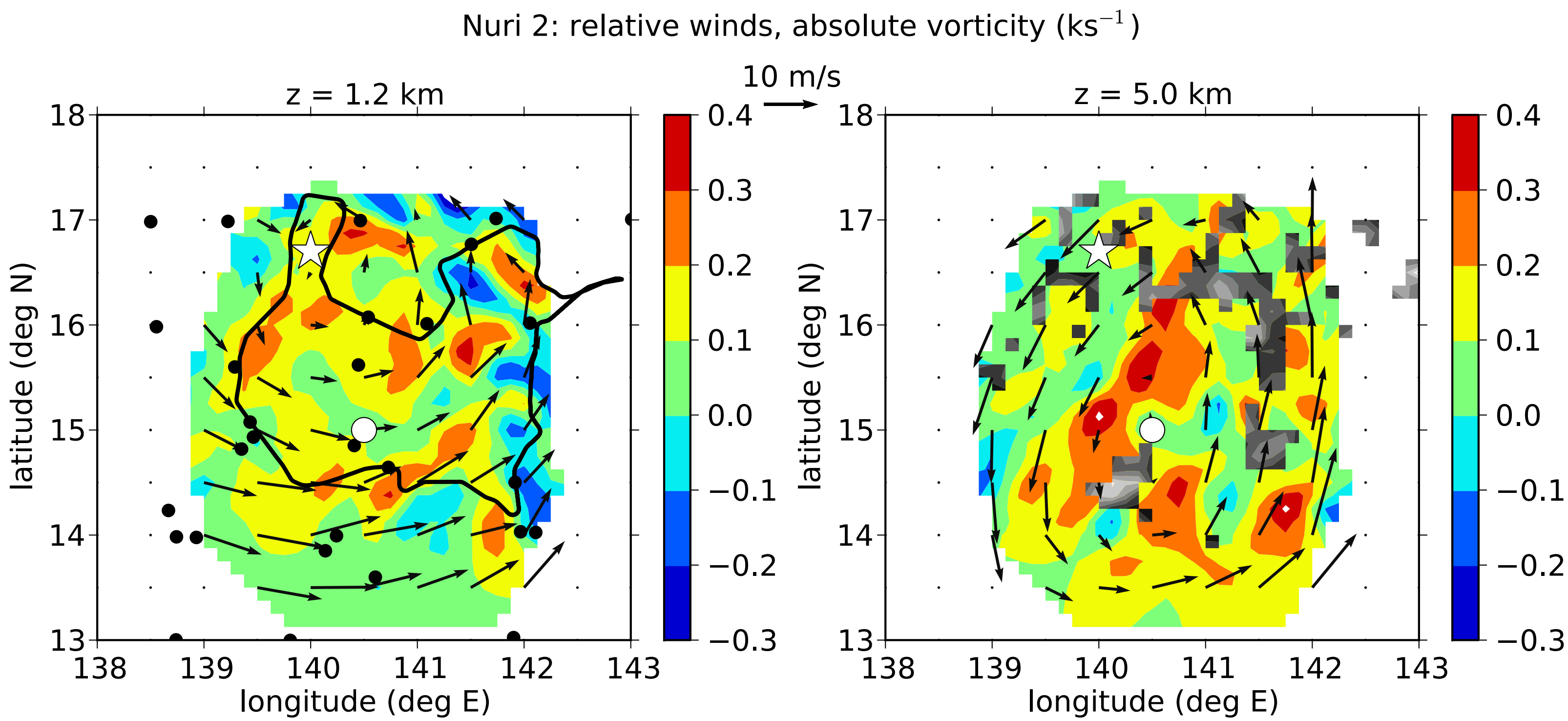
Track of Developing Typhoon Nuri (2008) (Raymond and López 2011)



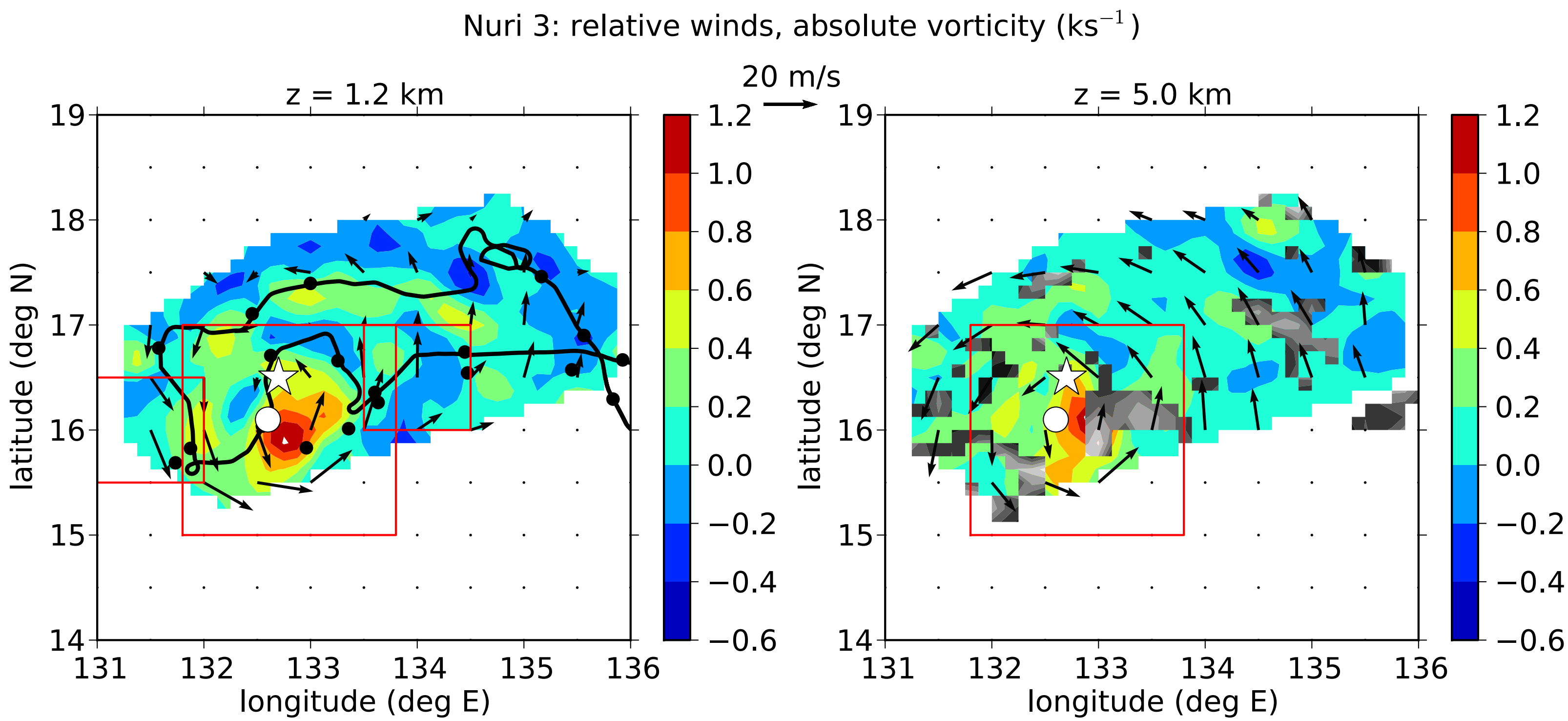
Nuri 1 (16 Sept 2008: tropical wave) vorticity, wind, reflectivity, dropsonde locations, and flight track



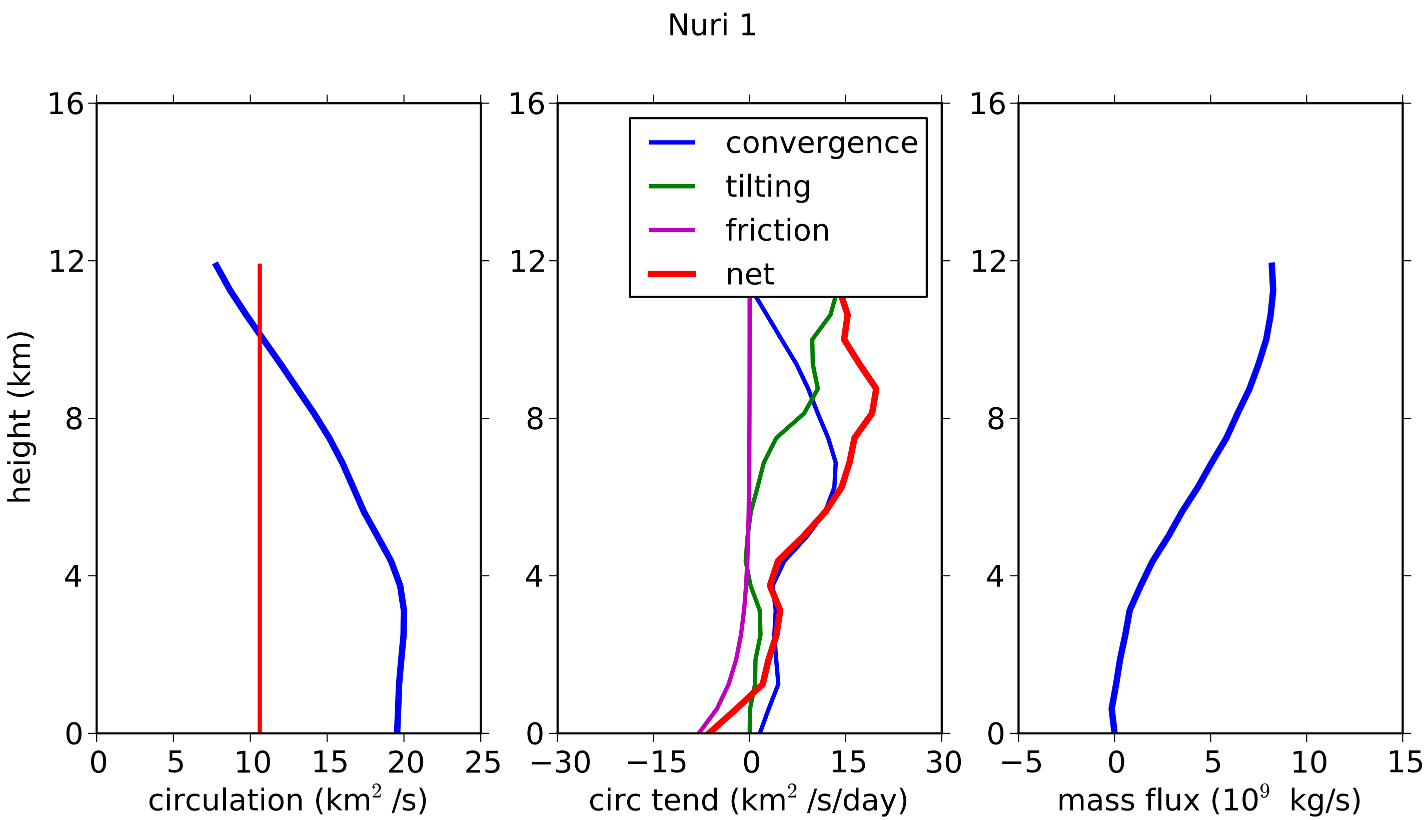
Nuri 2 (17 Sept 2008: tropical depression) vorticity, wind, reflectivity, dropsonde locations, and flight track



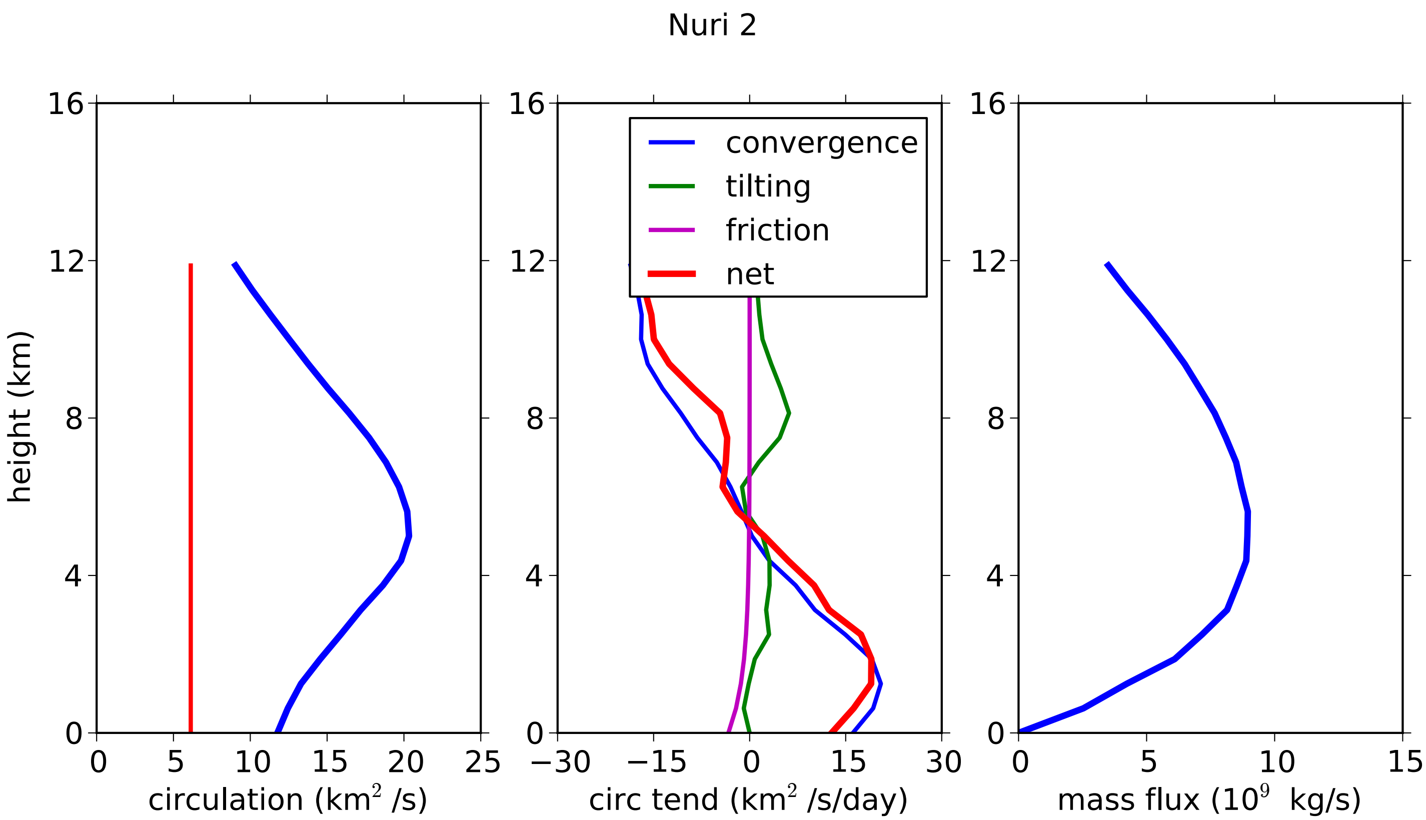
Nuri 3 (18 Sept 2008: tropical storm) vorticity, wind, reflectivity, dropsonde locations, and flight track



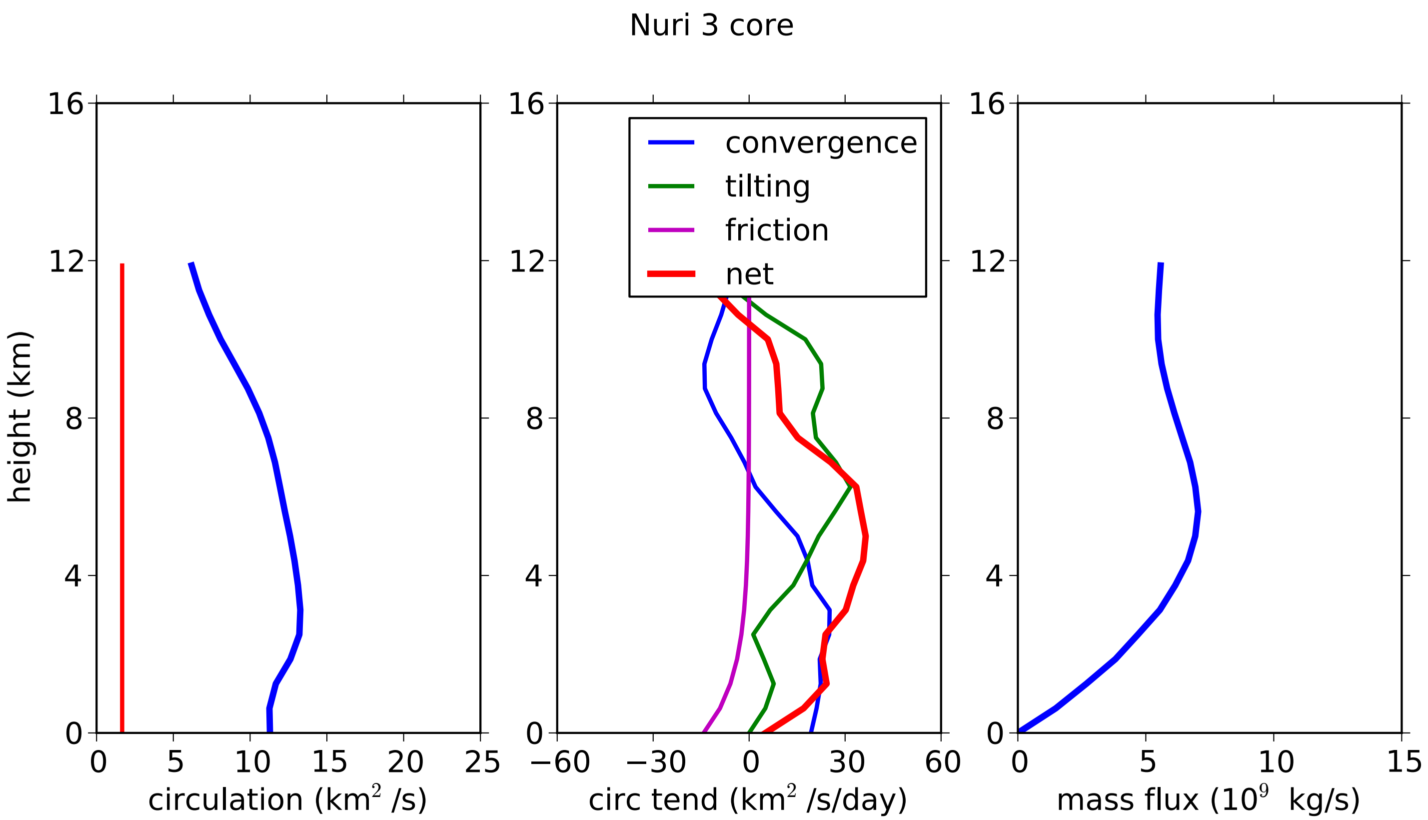
Nuri 1 circulation, circulation tendency, vertical mass flux



Nuri 2 circulation, circulation tendency, vertical mass flux



Nuri 3 core circulation, circulation tendency, vertical mass flux



Conclusions

ELDORA plus dropsondes produces a detailed picture of the vorticity evolution in tropical cylone Nuri. This picture can be used to test conjectures regarding the process of tropical cyclogenesis.

References

López Carrillo, C., and D. J. Raymond, 2011: Retrieval of three-dimensional wind fields from Doppler radar data using an efficient two-step approach. *Atmos. Meas. Tech.*, **4**, 2717-2733.

Raymond, D. J., and C. López Carrillo 2011: The vorticity budget of developing typhoon Nuri (2008). *Atmos. Chem. Phys.*, **11**, 147-163.