

# Vorticity Budget a in Developing Tropical Cyclone<sup>1</sup>

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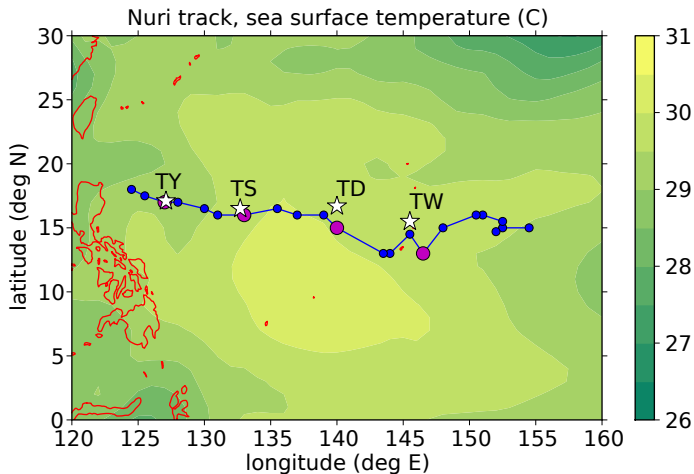
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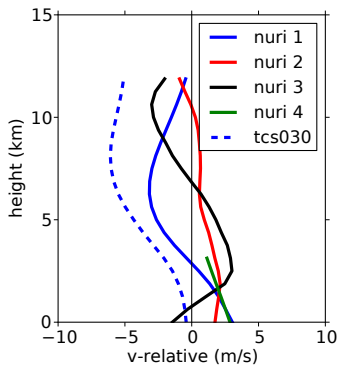
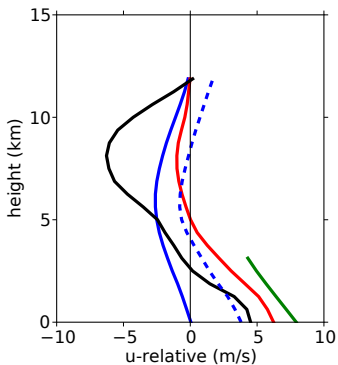
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<sup>1</sup>Work supported by Office of Naval Research and National Science Foundation.

# Track of developing typhoon Nuri (2008)

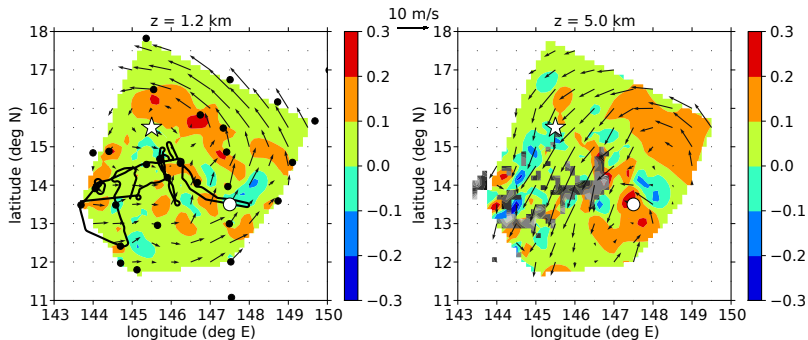


# Wind profiles



# Vorticity and system-relative winds – Nuri 1

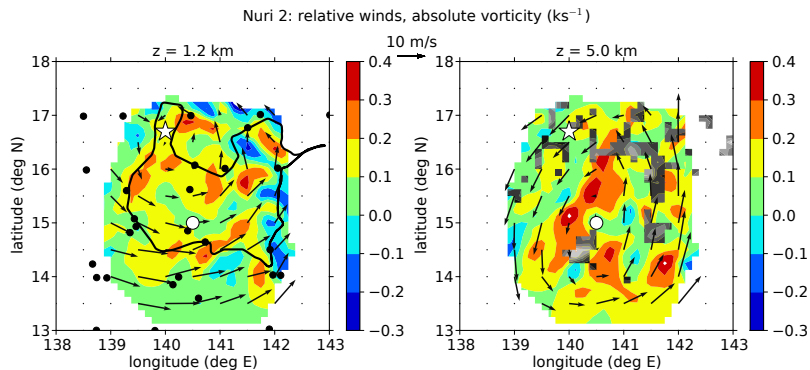
Nuri 1: relative winds, absolute vorticity ( $\text{ks}^{-1}$ )



Star: PBL circulation center

Circle: 5 km circulation center

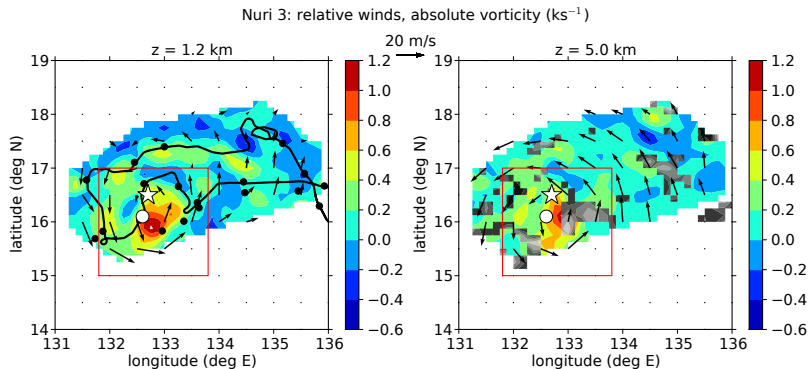
# Vorticity and system-relative winds – Nuri 2



Star: PBL circulation center

Circle: 5 km circulation center

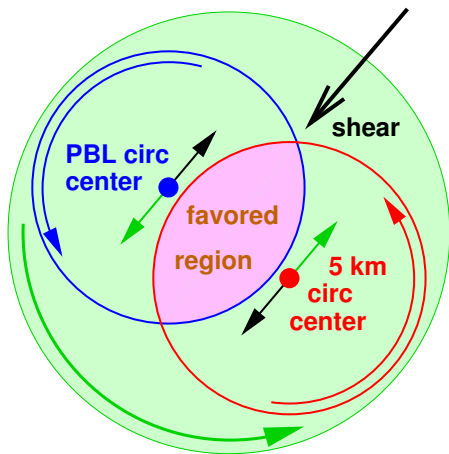
# Vorticity and system-relative winds – Nuri 3



Star: PBL circulation center

Circle: 5 km circulation center

# Overlapping closed circulations



## Hypothesis (similar to Dunkerton et al. 2009):

- ▶ Development occurs in regions protected from the intrusion of dry environmental air by closed circulations.
- ▶ Overlapping closed circulations over a deep layer in the system-relative reference frame provide this protection resulting in moister conditions.
- ▶ Moister environment generates higher precipitation rate and hence stronger convergence and spinup.



# Vorticity budget

- ▶ Flux form of vorticity equation:

$$\text{vorticity tendency} = \text{convergence} + \text{tilting} + \text{friction}$$

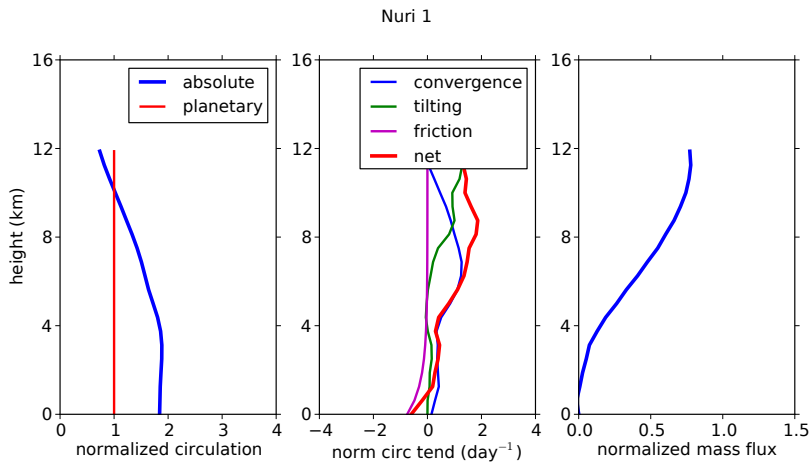
- ▶ Vorticity balance (ignore tilting):

$$\text{convergence} + \text{friction} \approx 0$$

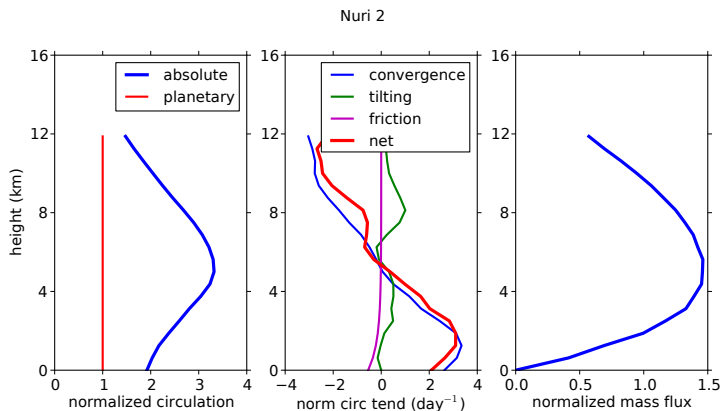
- ▶ Vorticity balance is a gradient-wind-like generalization of Ekman balance.

Integrate over area to convert vorticity tendency equation to a circulation tendency equation. Normalize by the planetary circulation.

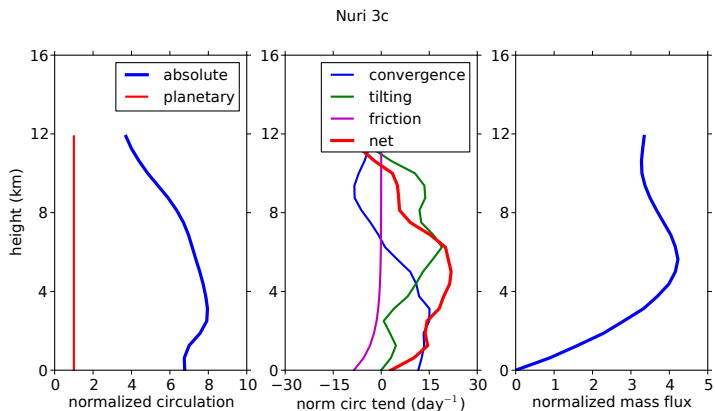
# Nuri 1 (tropical wave)



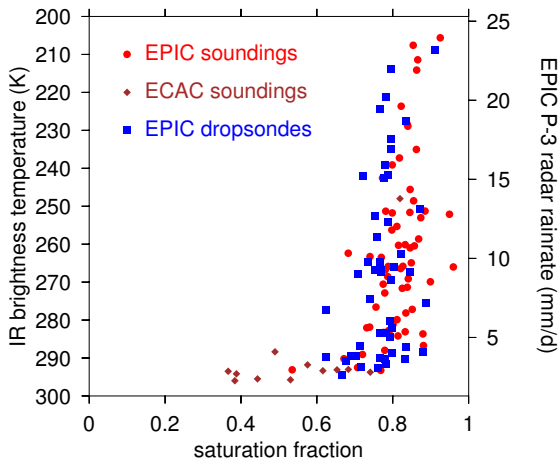
# Nuri 2 (tropical depression)



# Nuri 3 central region (tropical storm)



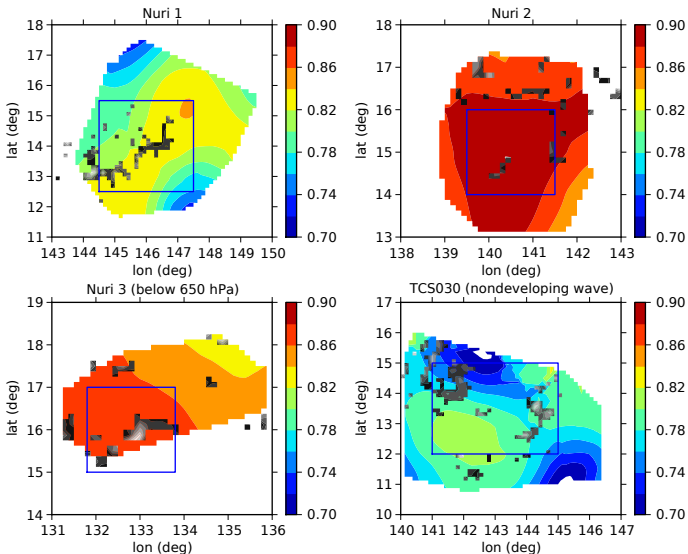
# Humidity and saturation fraction



saturation fraction = precipitable water/saturated precipitable water

# Saturation fraction in Nuri

Saturation fraction and strong reflectivity



# Conclusions

- ▶ At tropical wave and depression stages, Nuri was far from vorticity balance. Hence the hypothesis of convective forcing by Ekman pumping is problematic at this stage of Nuri. **So, what controls convection???**
- ▶ Spinup occurred in Nuri during periods of strong, low-level convergence (convective burst). This convergence is likely related to the existence of strong, deep convection in protected regions with high relative humidity.
- ▶ Overlapping, system-relative closed circulations at the surface and 5 km in Nuri provided a column protected from intrusions of environmental air, thus promoting high humidity. TCS030 lacked these circulations.