Tropical Cyclone Spin-up within a Wave Critical Layer

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Outline

- Introduction
- Diagnosis of a numerical model simulation
- PREDICT GV dropsonde data
- Conclusions

Genesis: a two-stage process

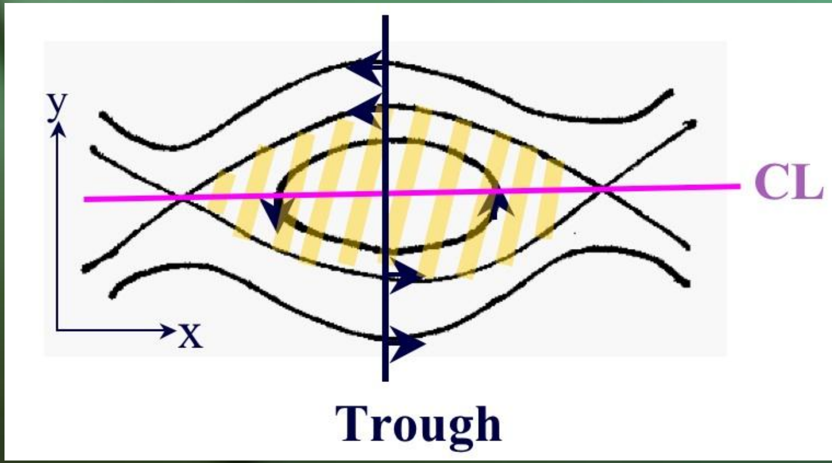
- The problem of tropical cyclogenesis can be regarded as a two-stage process (Karyampudi and Pierce 2002)
  - Stage 1: preconditioning of the synoptic and meso-α scale environment
  - Stage 2: construction and organization of a TC proto-vortex at the meso-β scale.

These two stages distinguish processes at different spatial scales that may overlap somewhat in time.

Marsupial Framework: Hypotheses

Dunkerton, Montgomery and Wang (2009):

- H1: The wave critical layer in the lower troposphere provides a favorable environment for vorticity aggregation
- H2: The wave critical layer has a region of approximately closed circulation, where air is repeatedly moistened by convection and protected from dry air intrusion to some extent.
- H3: The parent wave is maintained and possibly enhanced by diabatically amplified mesoscale vortices within the wave critical layer.



The wave pouch provides a locally favorable (meso-alpha) environment for the construction and development of the meso-beta proto-vortex.

Top-down vs. Bottom-up

Theories on how a surface vortex develops generally fall into two categories

- top-down development: a mid-level vortex (that presumably forms within the stratiform region of an MCS) somehow engenders a surface circulation by "building downward" (Bister and Emanuel 1997; Ritchie and Holland 1997; Simpson et al. 1997)
- bottom-up development: cyclonic relative vorticity anomalies are generated at low altitudes (~ 1 km) through condensational heating in relatively downdraft-free convection (Hendricks et al. 2004; Montgomery et al. 2006)

Questions:

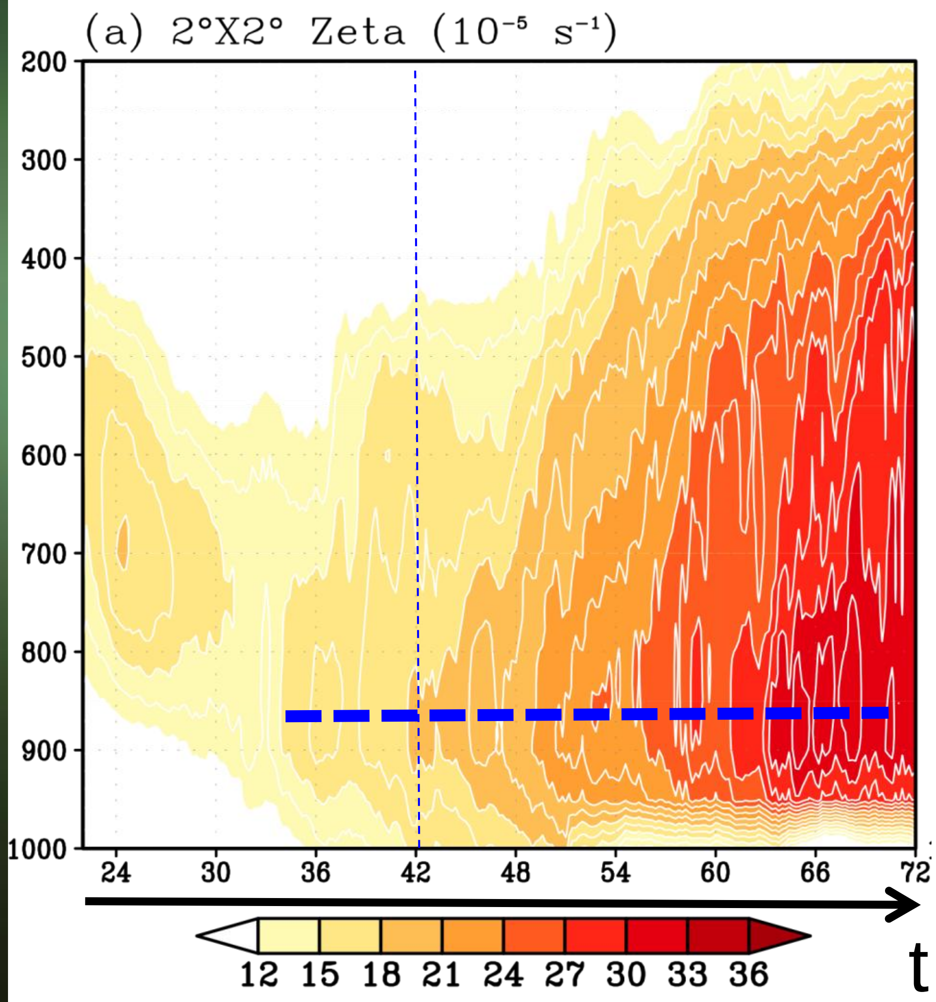
- *How does the circulation evolve at the meso-alpha (~ wave pouch) and meso-beta scales (proto-vortex) during TC formation?*

- *What thermodynamical conditions make the pouch center a preferred location for genesis?*

Numerical Simulation

- Advanced Research Core of Weather Research and Forecasting model (WRF-ARW)
- Felix (2007) (Wang et al. 2010a,b)
  - Resolution: 81-27-9-3 km
  - Initialized and driven by ECMWF analysis data
- Initialized 69 hours prior to the NHC genesis time

Vorticity Evolution: Felix (2007)



Vorticity Budget Equation

The flux form of the vorticity equation in isobaric coordinates can be written as

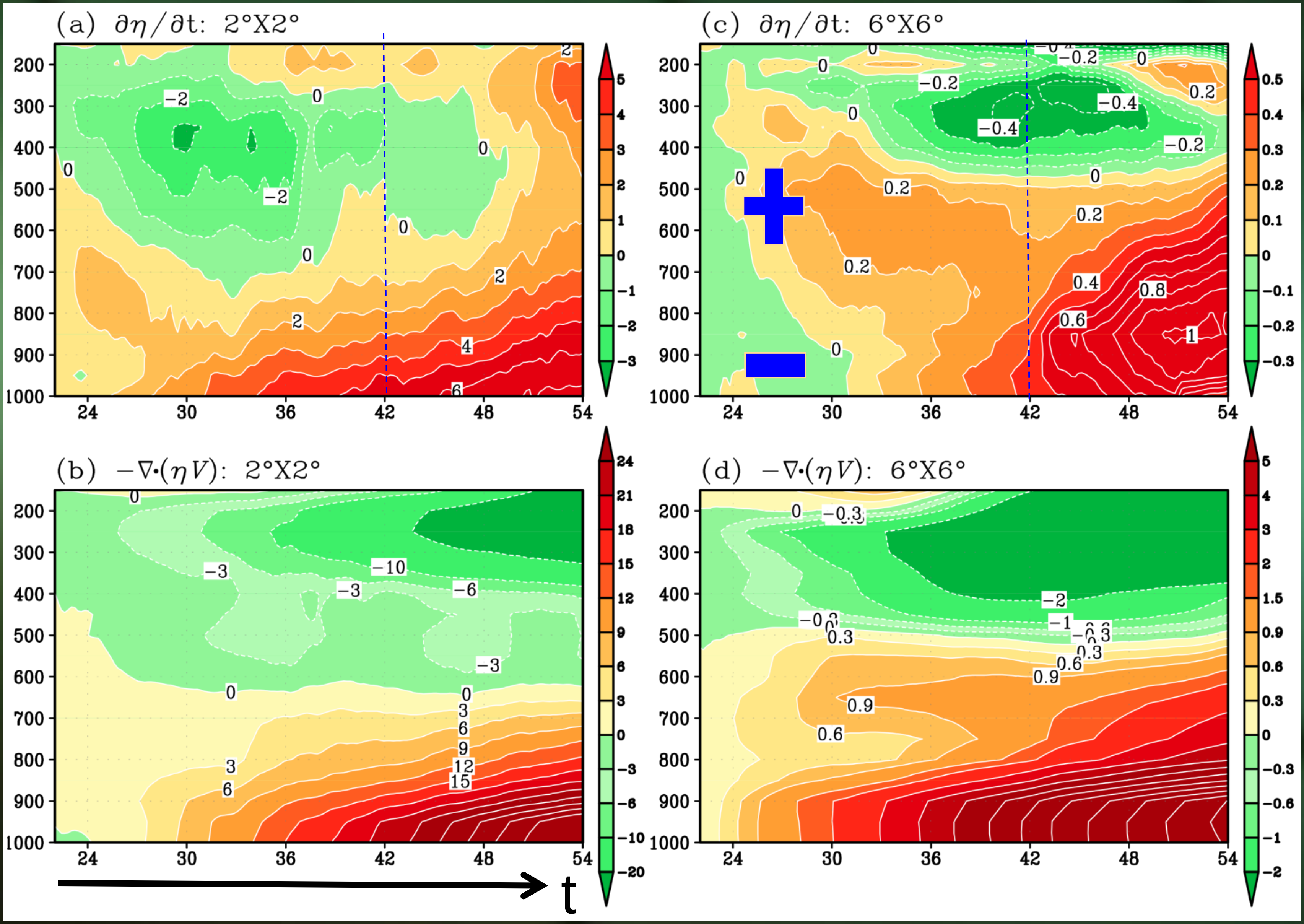
$$\frac{\partial \eta}{\partial t} = -\nabla \cdot (\eta \vec{V}') - \nabla \cdot (-\omega \vec{k} \times \frac{d\vec{V}}{dp}) + \nabla \cdot \vec{R}$$

RHS1: the divergence of advective vorticity flux, including the horizontal advection and vertical stretching terms
RHS2: : the divergence of non-advective vorticity flux, including the vertical advection and tilting terms
RHS3: the residual term, including frictional and turbulent forces

The time-integrated vorticity equation:

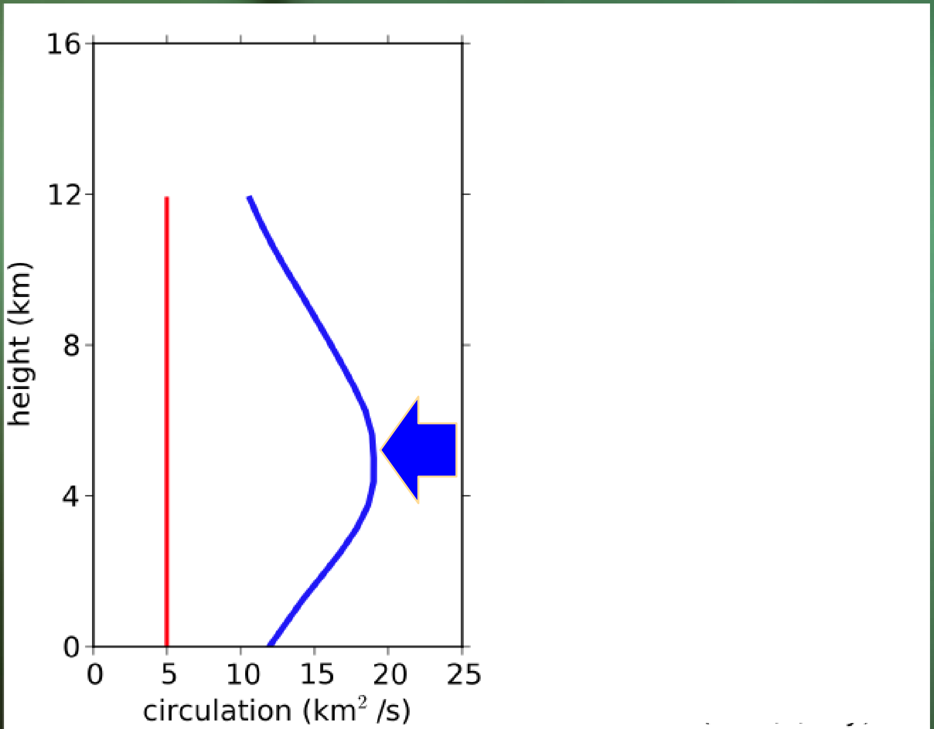
$$\int \frac{\partial \eta}{\partial t} dt = -\int \nabla \cdot (\eta \vec{V}') dt - \int \nabla \cdot (-\omega \vec{k} \times \frac{d\vec{V}}{dp}) dt + \int \nabla \cdot \vec{R} dt$$

Felix: Integrated Vorticity Budget

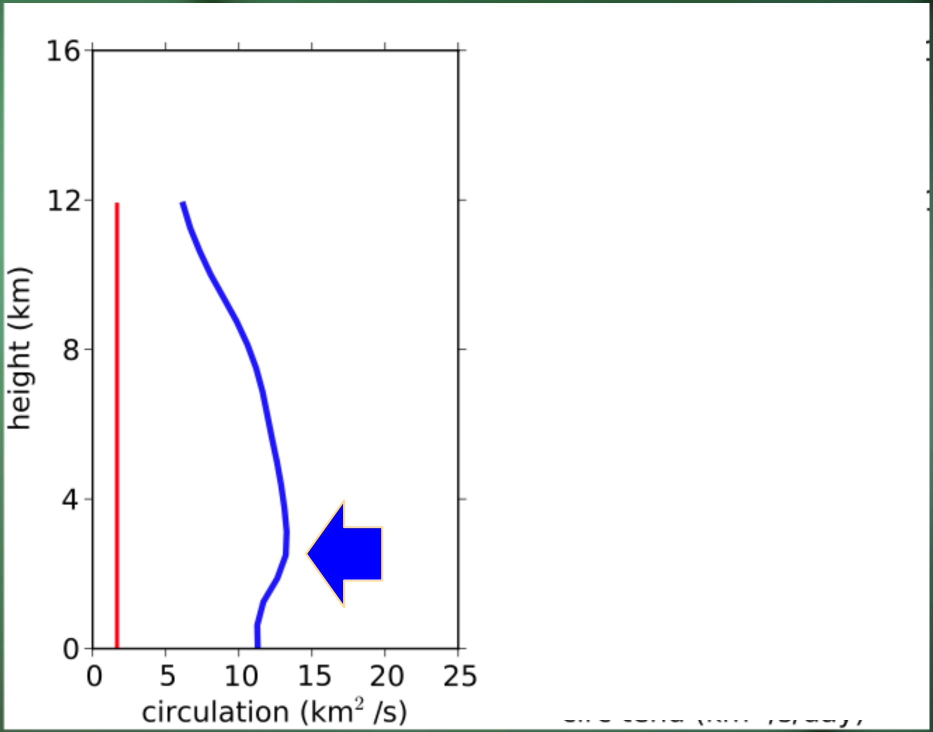


Nuri

Nuri (3 lat X 5 lon)



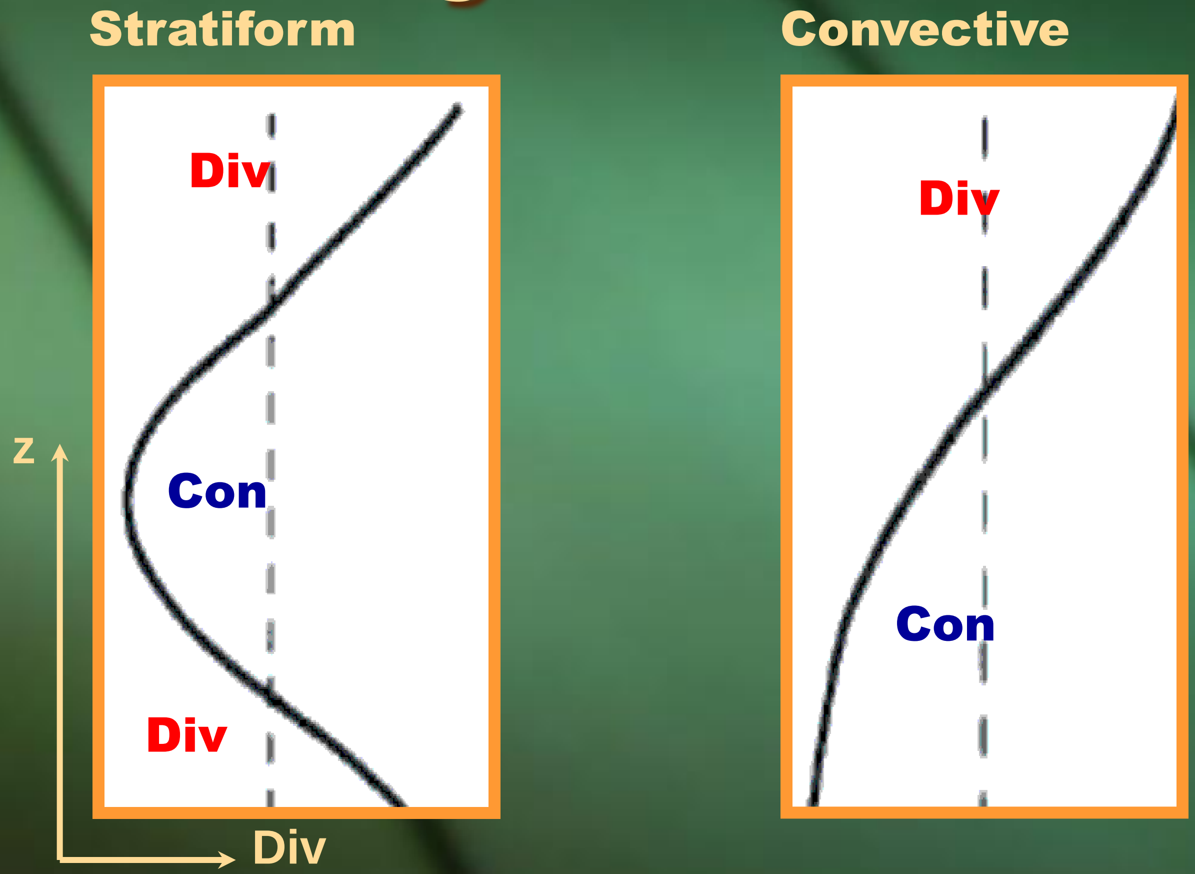
Nuri (2 Square Box)



Different vorticity profiles are due to different divergence profiles.

Raymond and Lo´pez Carrillo 2010

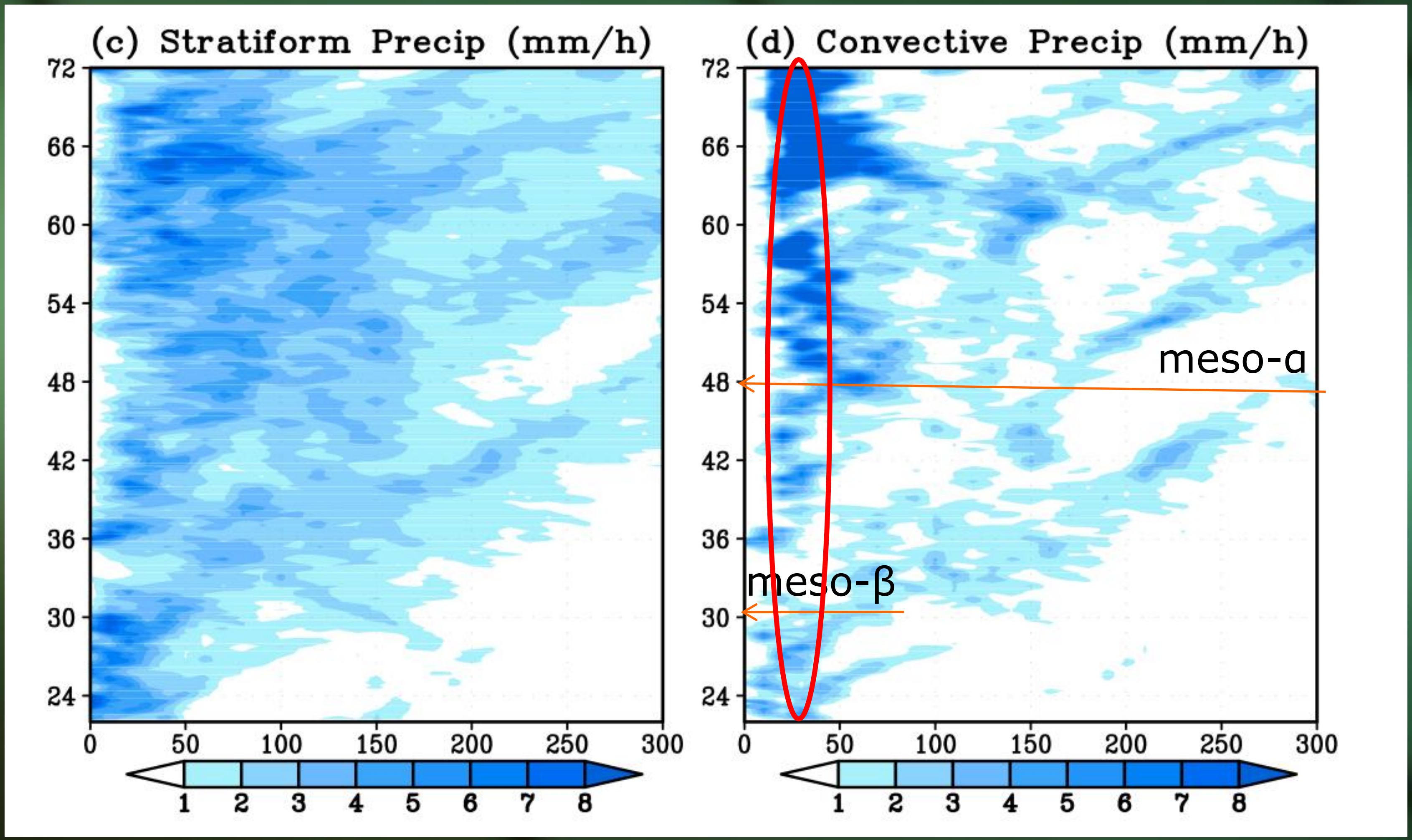
Stratiform vs. Convective Divergence Profiles



Stratiform process: favors the development of a mid-level vortex.
Convective process: favors the spin-up of the low-level circulation.

Time-Radius Plots of Stratiform vs. Deep convective Precipitation

Time (hour)



Radius (km)

Wang et al. (2010)

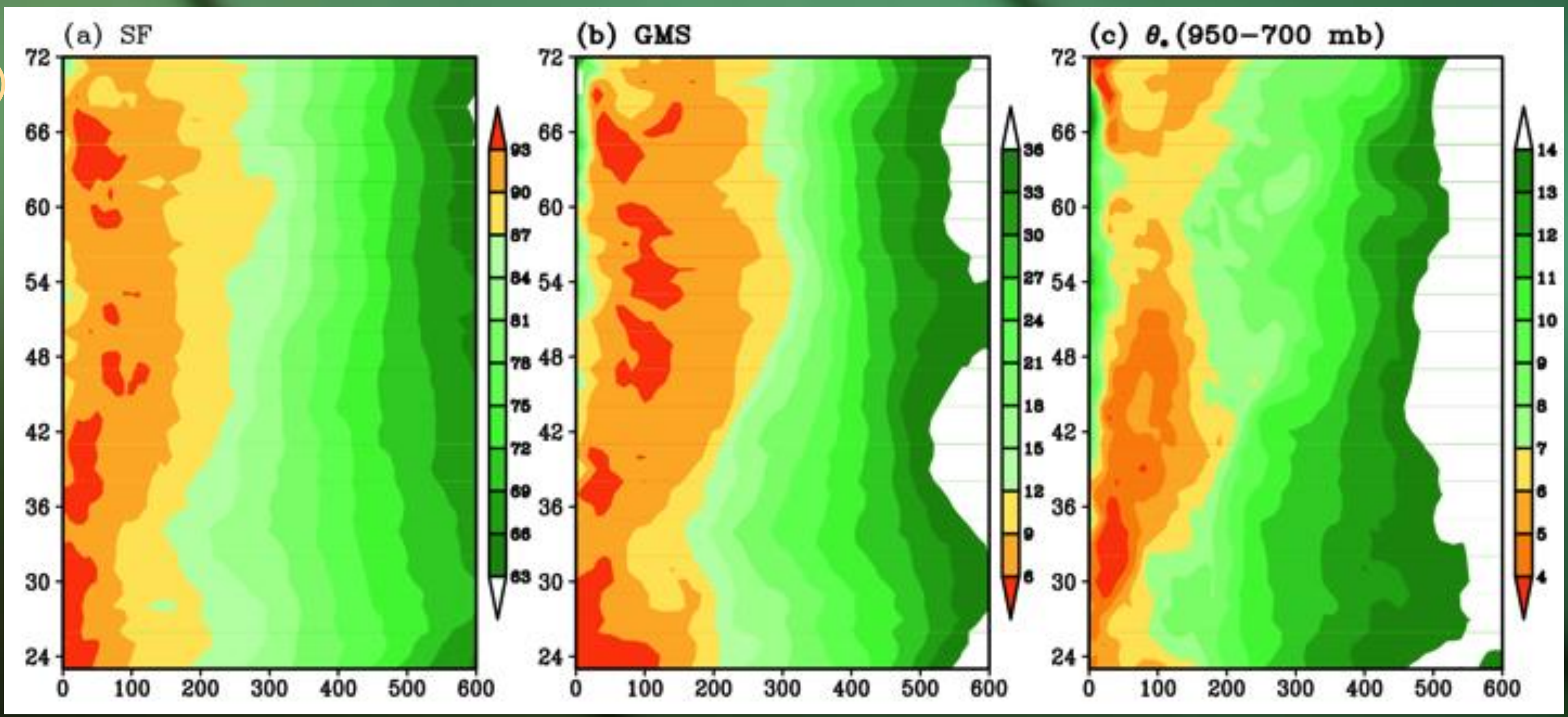
Time-Radius Plots of SF, GMS, $\Delta\theta_e$ deficient

Saturation Fraction (SF) = TPW / (saturated TPW)

GMS: Gross Moist Stability

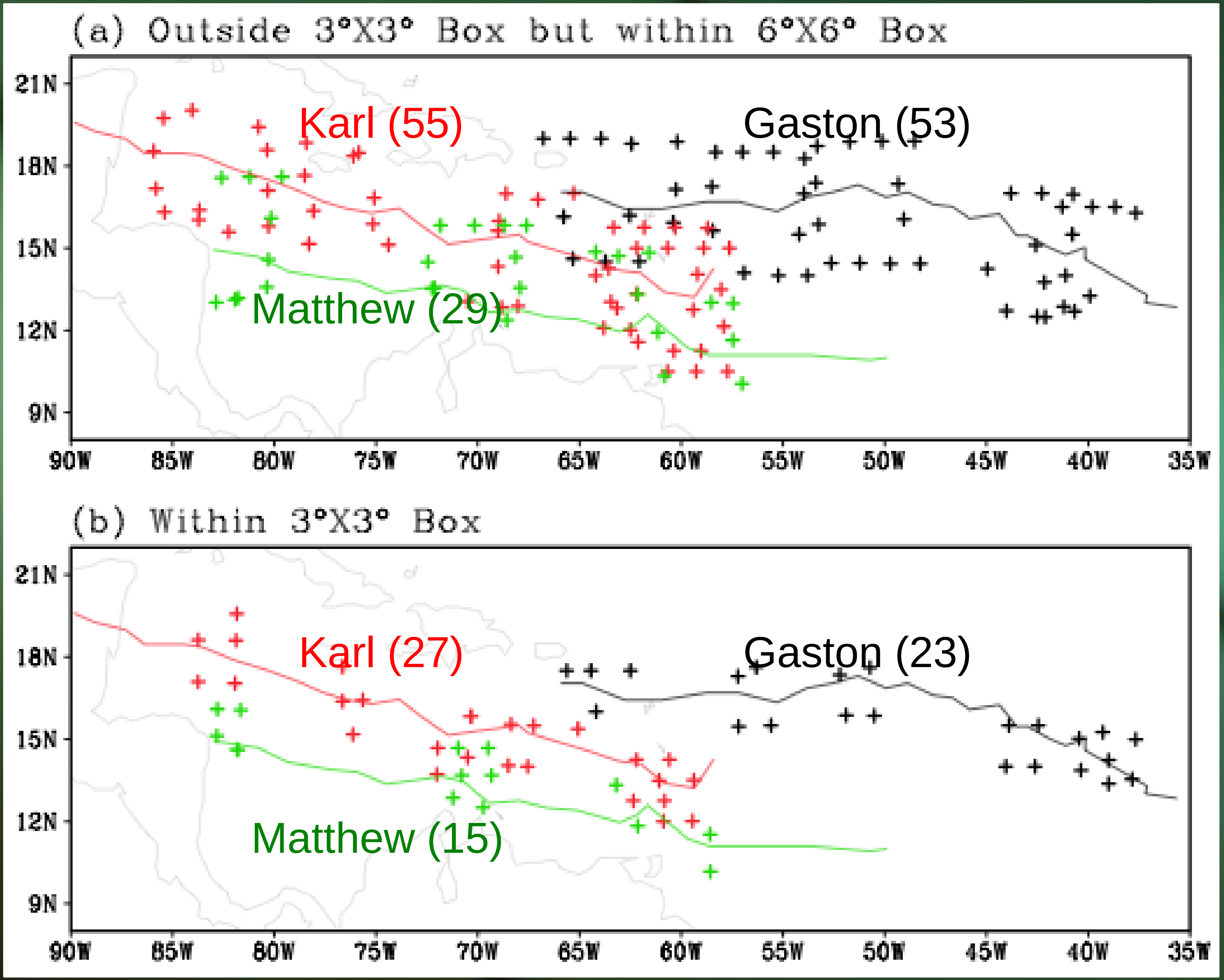
$\Delta\theta_e = \theta_e(950\text{ mb}) - \theta_e(700\text{ mb})$

Time (hour)



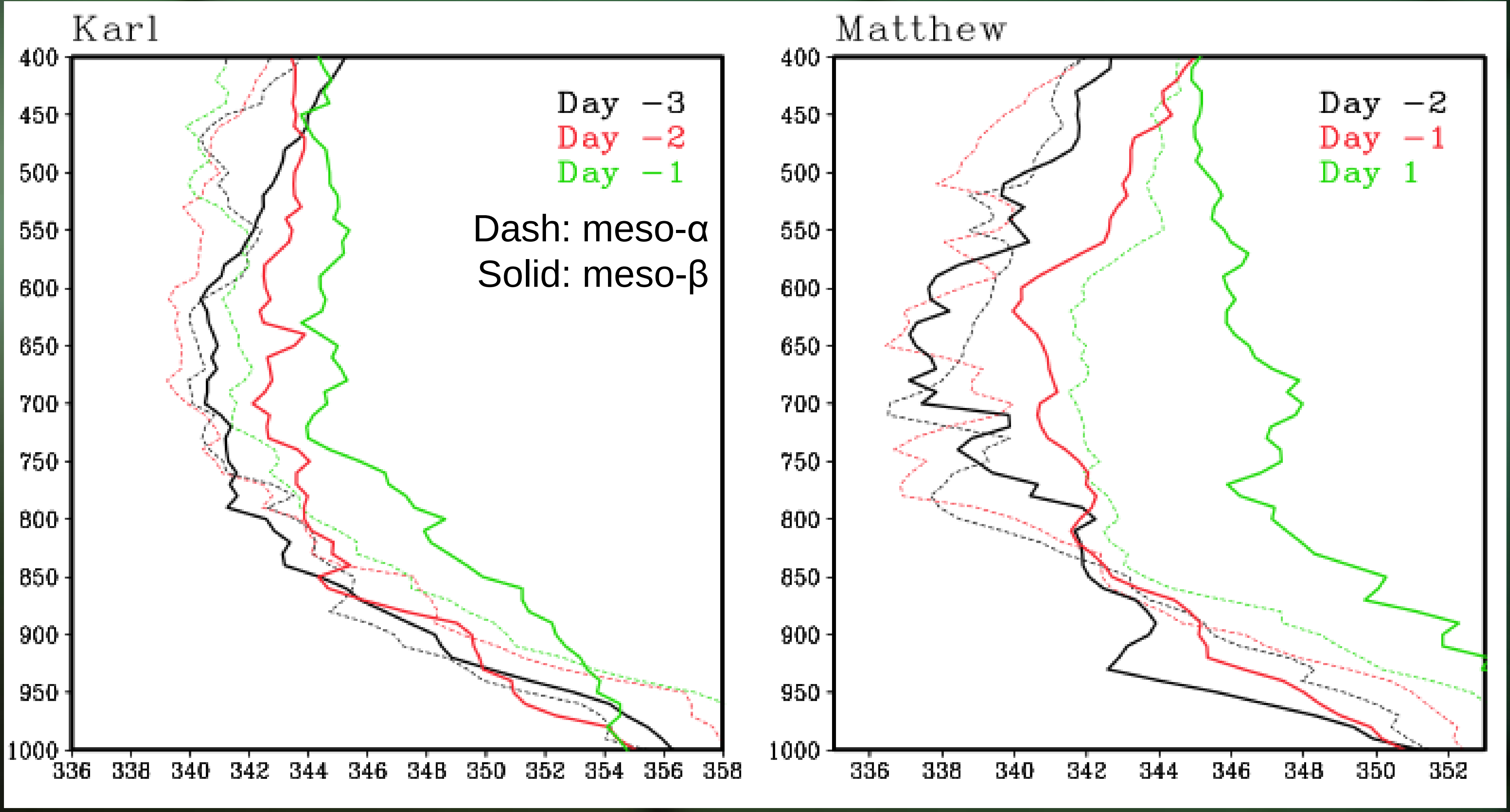
Radius (km)

PREDICT GV Dropsondes

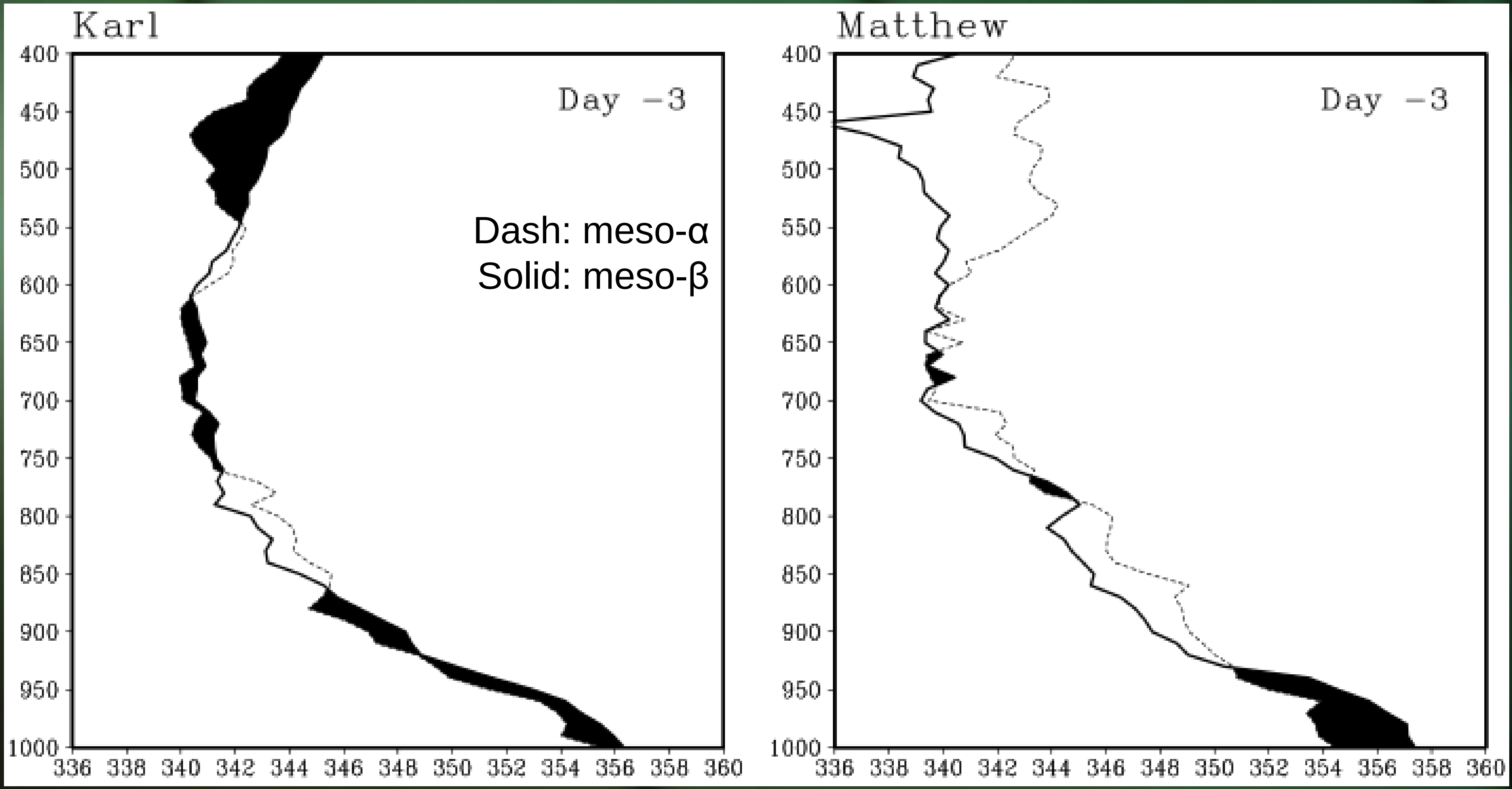


Data from NCAR EOL

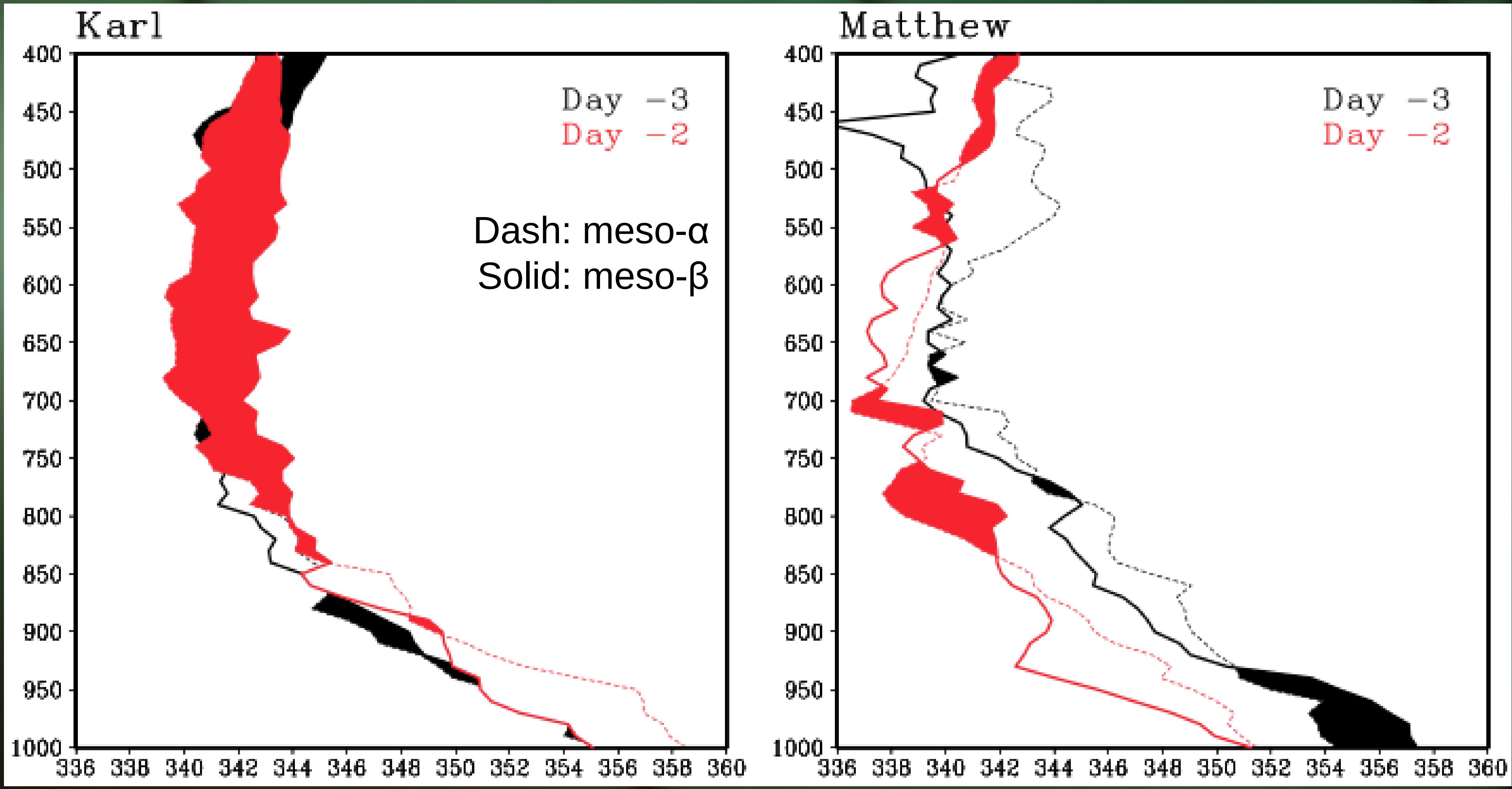
Equivalent Potential Temperature: Karl and Matthew



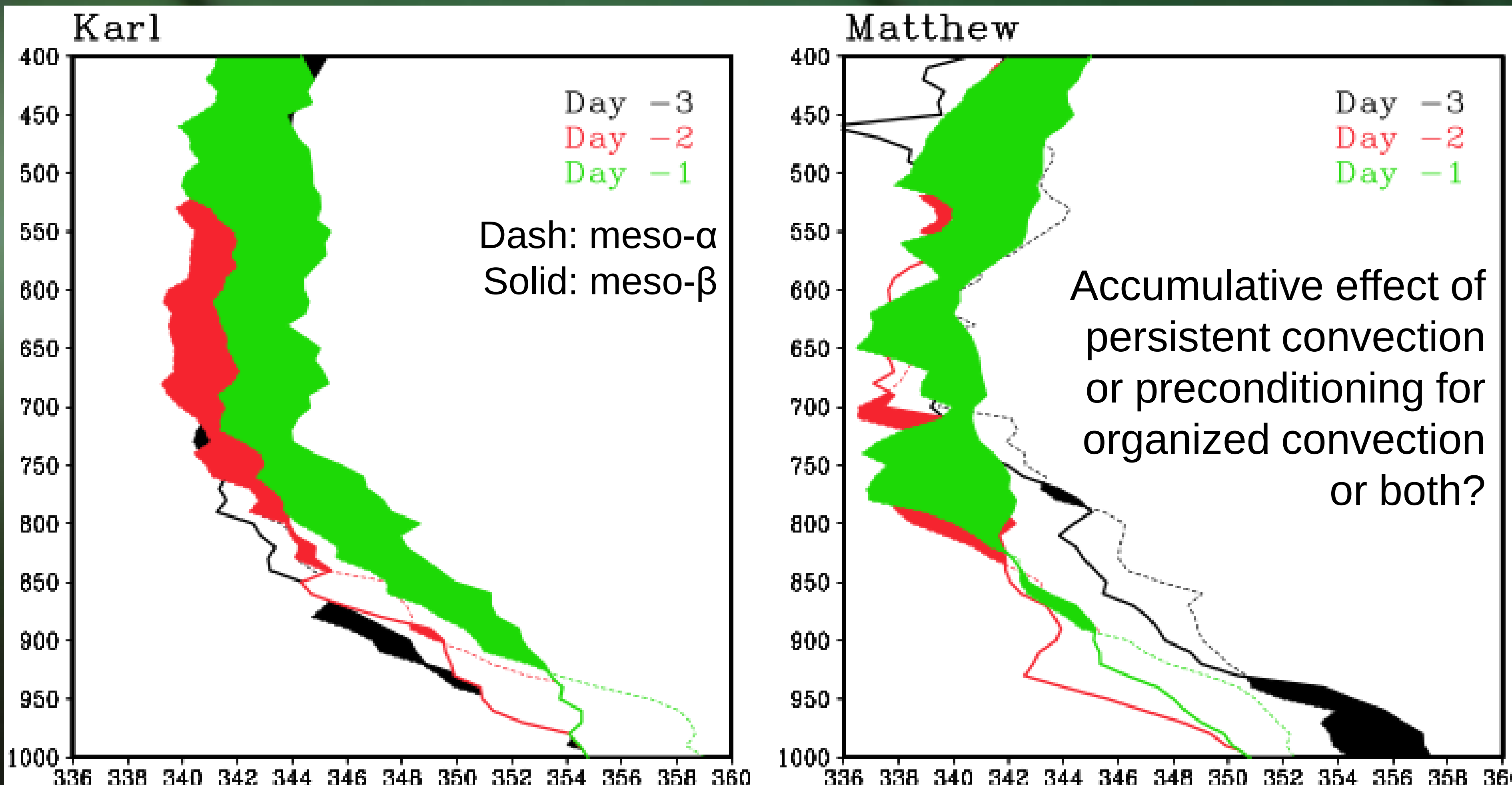
Equivalent Potential Temperature: Karl and Matthew, Day -3



Equivalent Potential Temperature: Karl and Matthew, Day -2

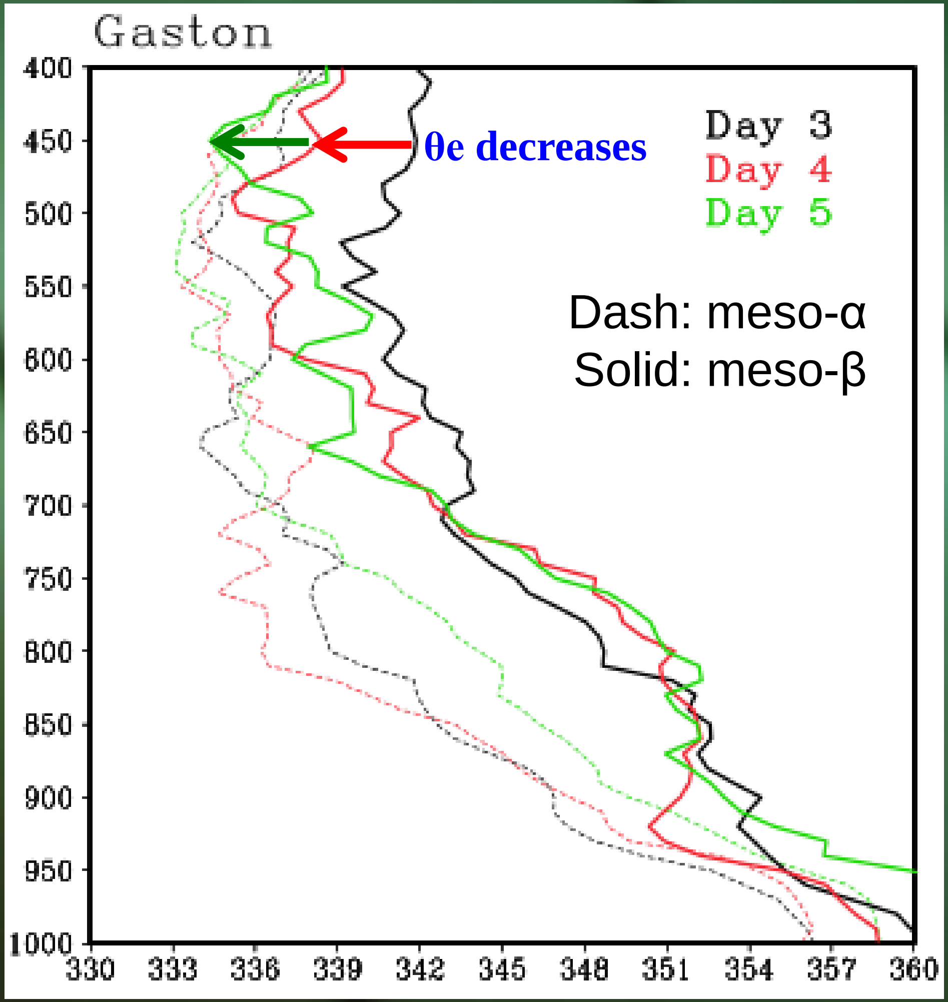


Equivalent Potential Temperature: Karl and Matthew, Day -1



Accumulative effect of persistent convection or preconditioning for organized convection or both?

Equivalent Potential Temperature: ex-Gaston



Conclusions

- The meso-β scale region near the center of the wave pouch provides a thermodynamically favorable environment for deep convection.
- The low-level convergence associated deep convection more than offsets the boundary layer friction and stratiform divergence at the meso-β scale, and it spins up proto-vortex near the surface.
- Stratiform process is dominant over the meso-α scale wave pouch during the TC formation; it contributes to the mid-level spin-up at this spatial scale and makes the vertical structure of the circulation different from that at the meso-β scale.
- PREDICT dropsondes showed that θe near the pouch center becomes warmer than the pouch mean and $\Delta\theta e$ is reduced one or two days prior to genesis – an indication of genesis?

END OF TALK. THANKS!