Thermodynamical Aspects of Tropical Cyclone Formation

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TC Genesis

- Necessary conditions for genesis

  1. Cyclonic disturbance in the lower troposphere

  2. Weak vertical wind shear

  3. Warm SST

  4. Moist unstable air

It is not well understood how a TC-scale vortex is transformed in such an environment.

Questions

- *How does the synoptic-scale environment influence the mesoscale processes during TC genesis?*
- *How does a TC-scale vortex form within a synoptic-scale disturbance?*
- *Is there a preferred location for TC genesis within a synoptic-scale disturbance? If so, what thermodynamical conditions make it favorable?*

Marsupial Paradigm: Hypotheses

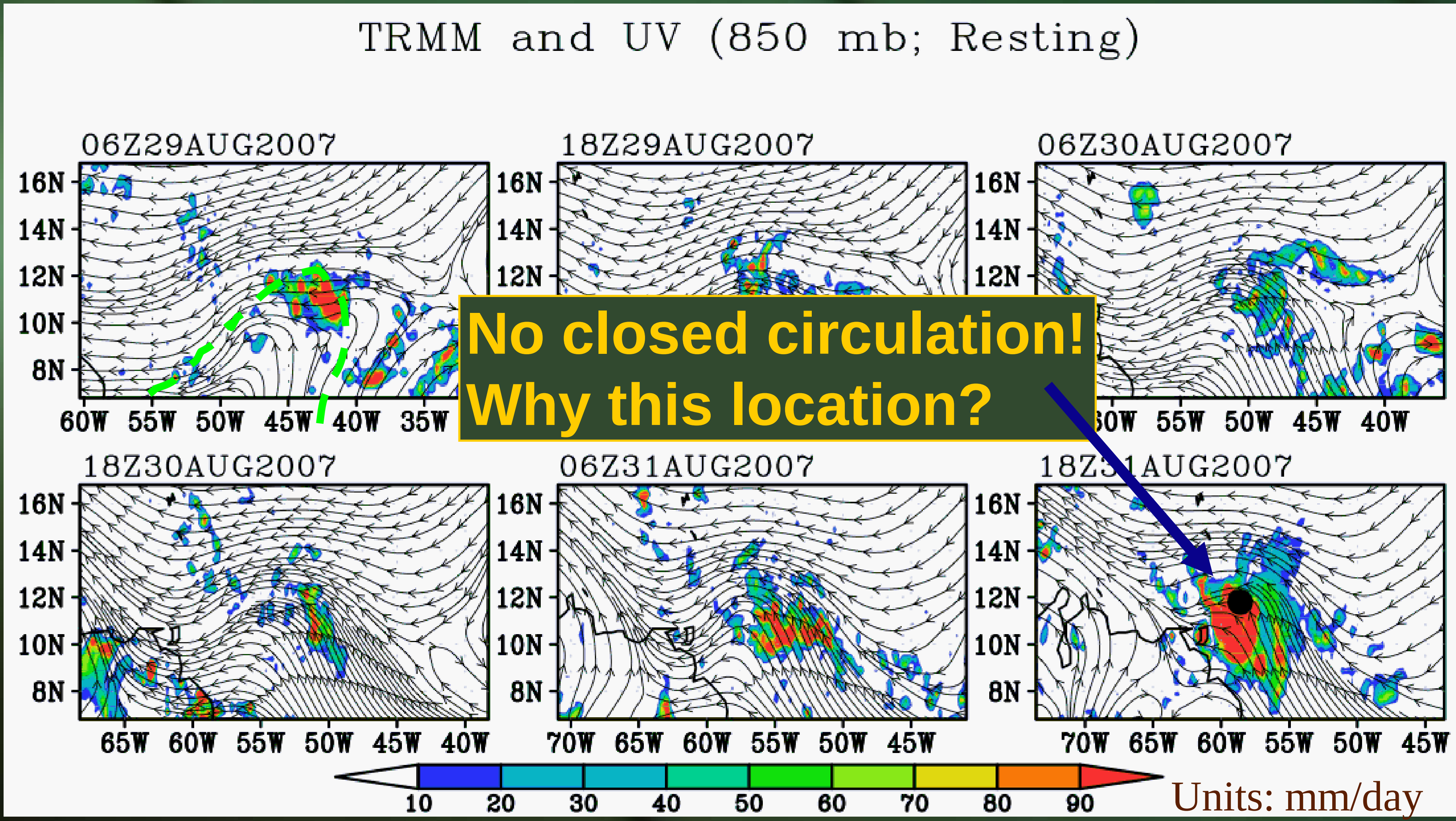
(Dunkerton, Montgomery and Wang 2009)

- H1: Wave breaking of the cyclonic vorticity near the critical surface provides a favorable environment for vorticity aggregation and TC formation.
- H2: The approximately closed circulation in the wave critical layer can prevent dry air intrusion to some extent.
- H3: The parent wave is maintained and possibly enhanced by MCV within the wave critical layer.

The region of closed circulation in the wave critical layer -- the "wave pouch"

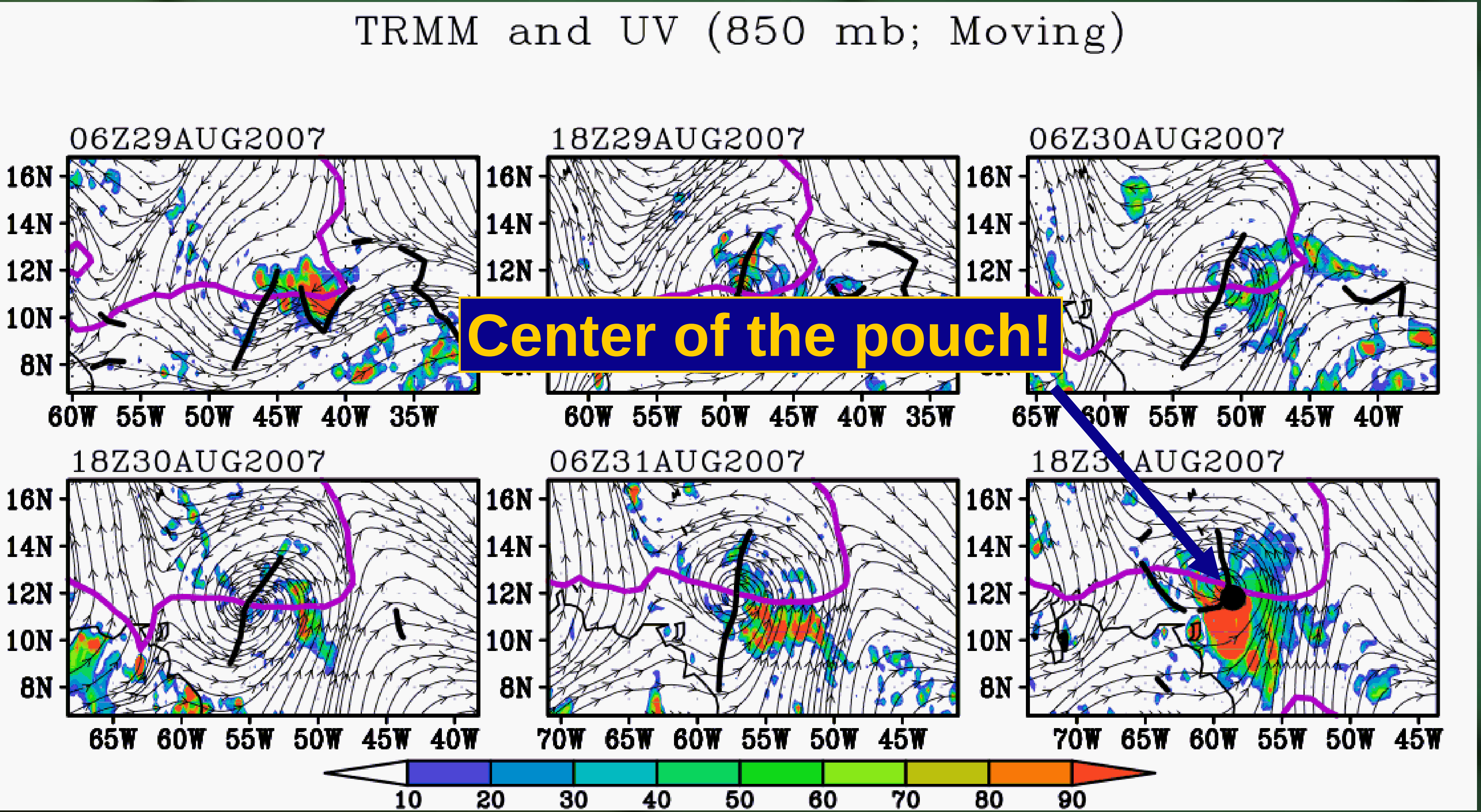
The wave pouch provides a locally favorable environment for the construction and development of the TC proto-vortex.

Felix: TRMM and 850 hPa streamlines (Resting; Day -2.5~Day 0)



Wang et al. 2010a

Felix: TRMM and Translated 850 hPa Streamlines~Lagrangian Flow

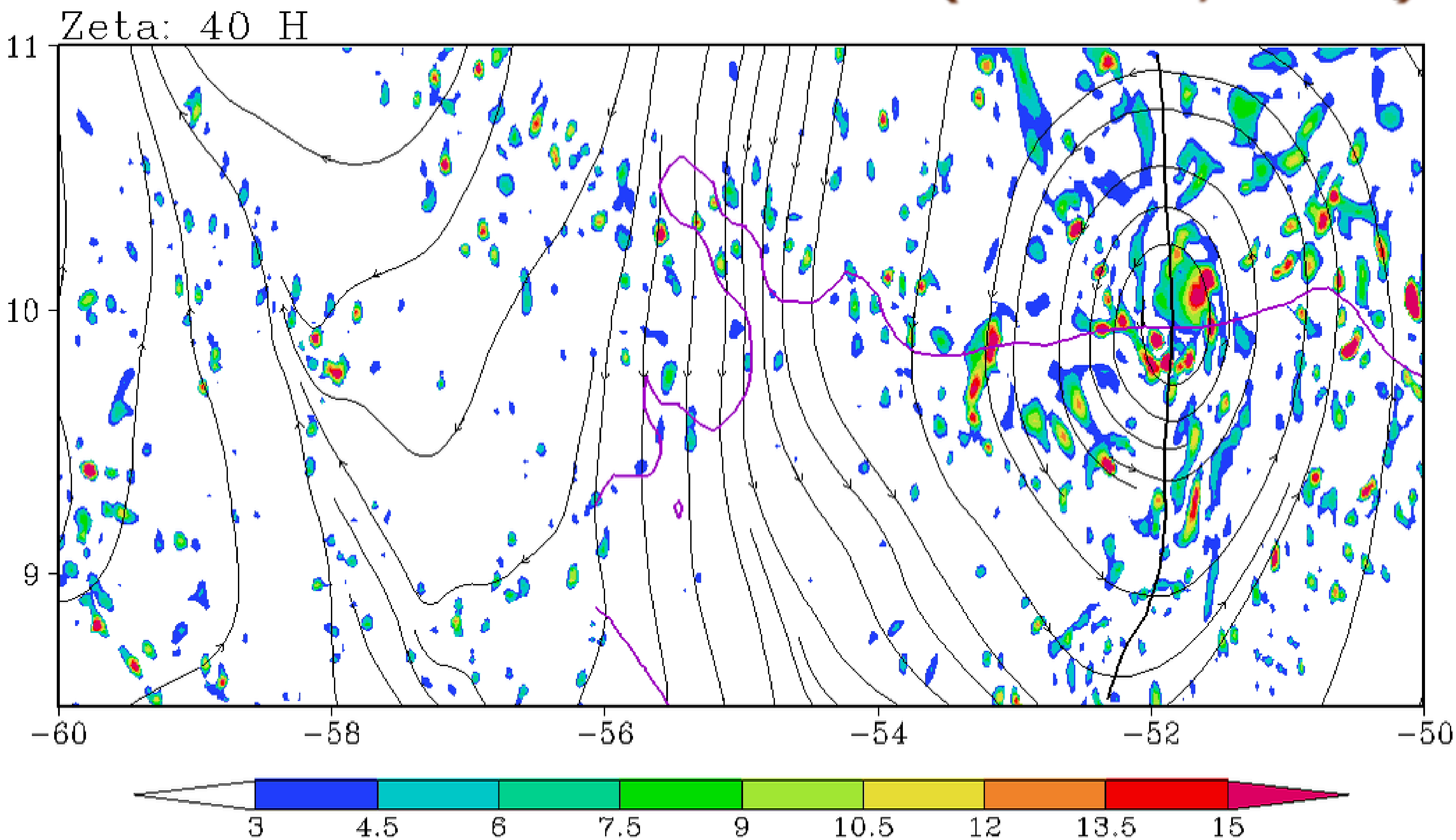


Wang et al. 2010a

Model Configuration

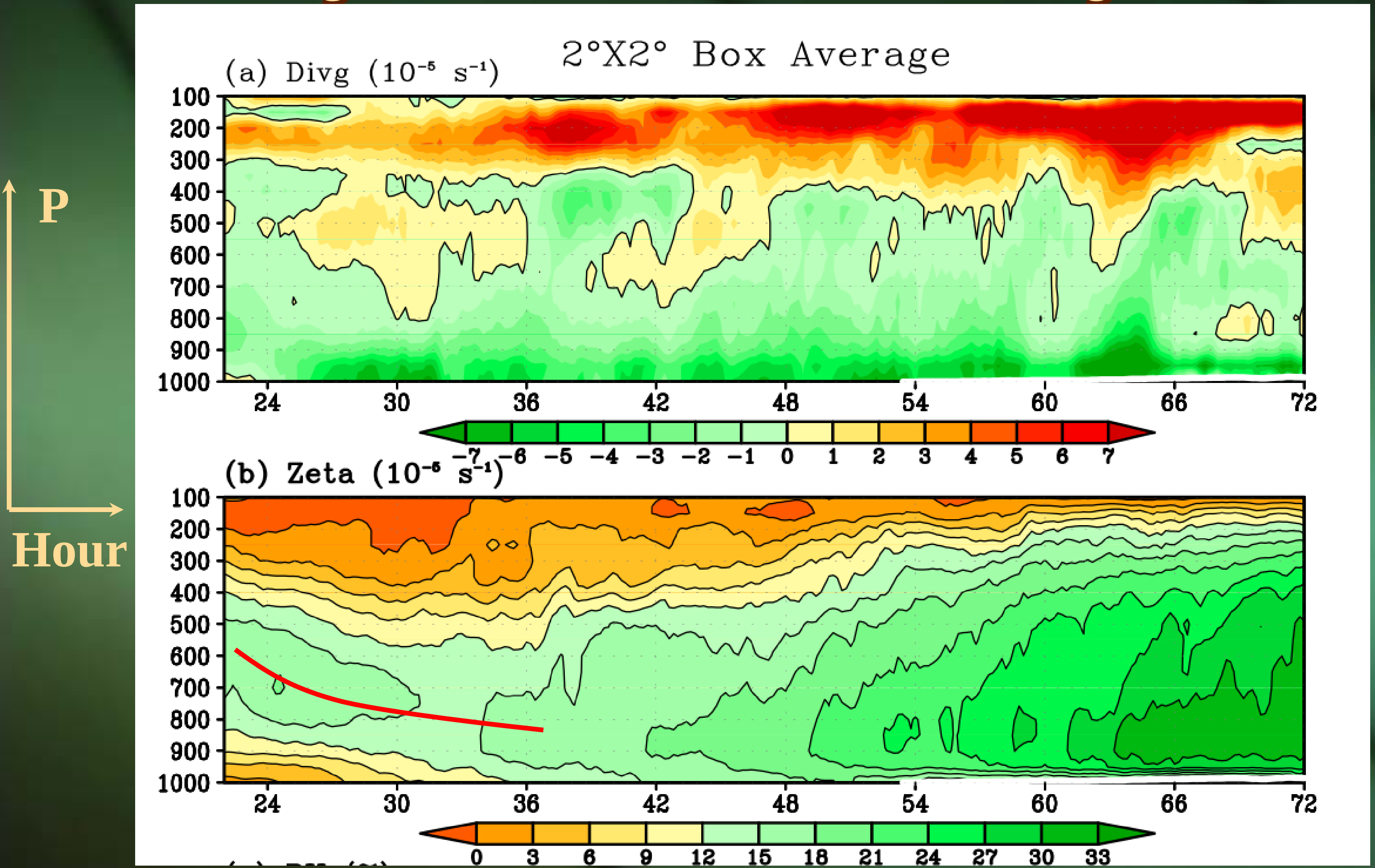
- **WRF version 3.0; 4-grid** nested run: 81-27-9-3 km
- **Initialized** at 00Z 29 Aug, 2007, about three days (69 H) prior to the NHC-declared genesis time (21Z 31 Aug, 2007)
- **Cumulus**: new Kain-Fristch cumulus scheme for the outer two grids, and cumulus convection is calculated explicitly for the inner two grids (9 and 3 km)
- **Other physics**: WRF single-moment, 6-class microphysics (Hong et al. 2006), YSU planetary boundary layer scheme, RRTM longwave radiation scheme and Dudhia shortwave radiation scheme

VHTs within the Pouch (movie; d04)



The pouch center serves as the focal point for vorticity aggregation.

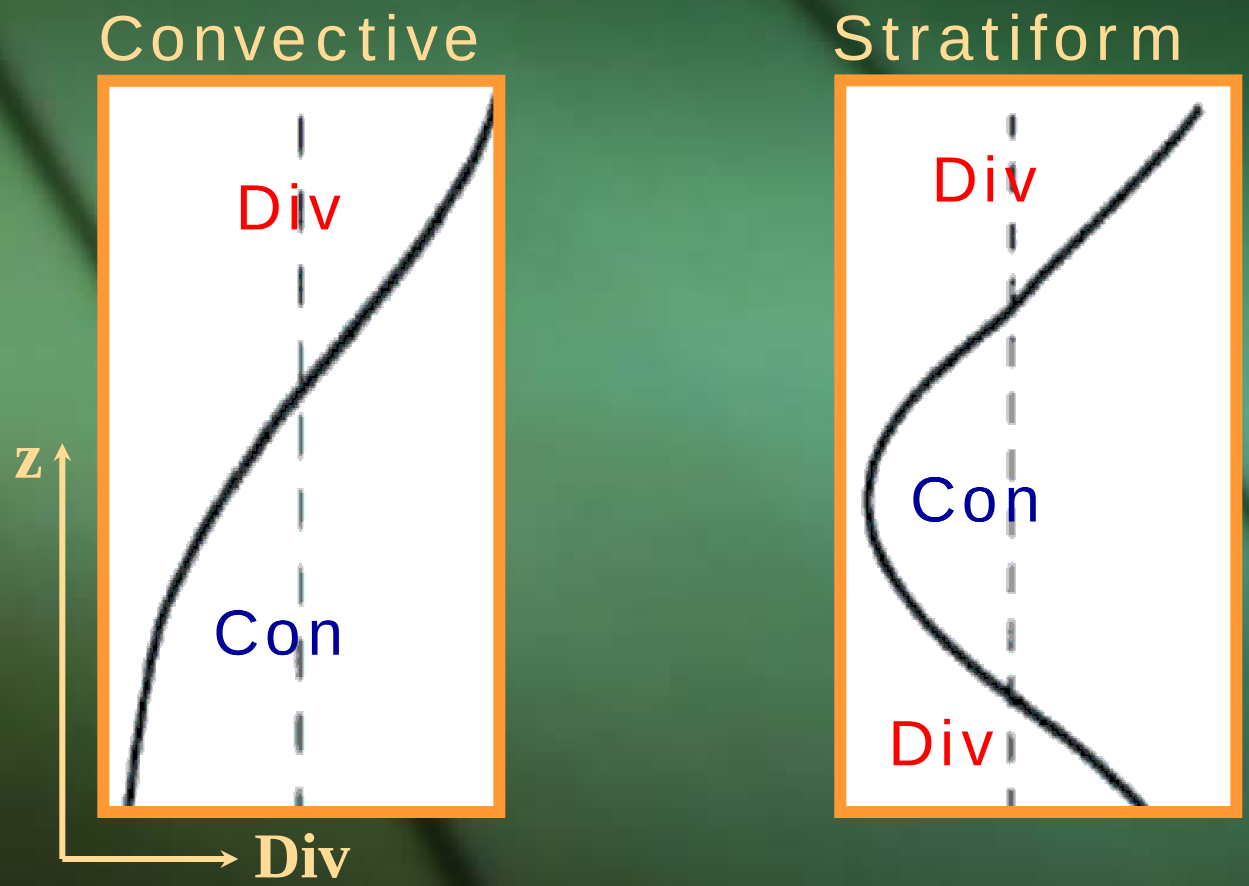
Time-height Cross Section: Divg and Zeta



Bottom-up development: Low-level convergence plays the key role in spinning up the cyclonic circulation near the surface.

Wang et al. 2010a

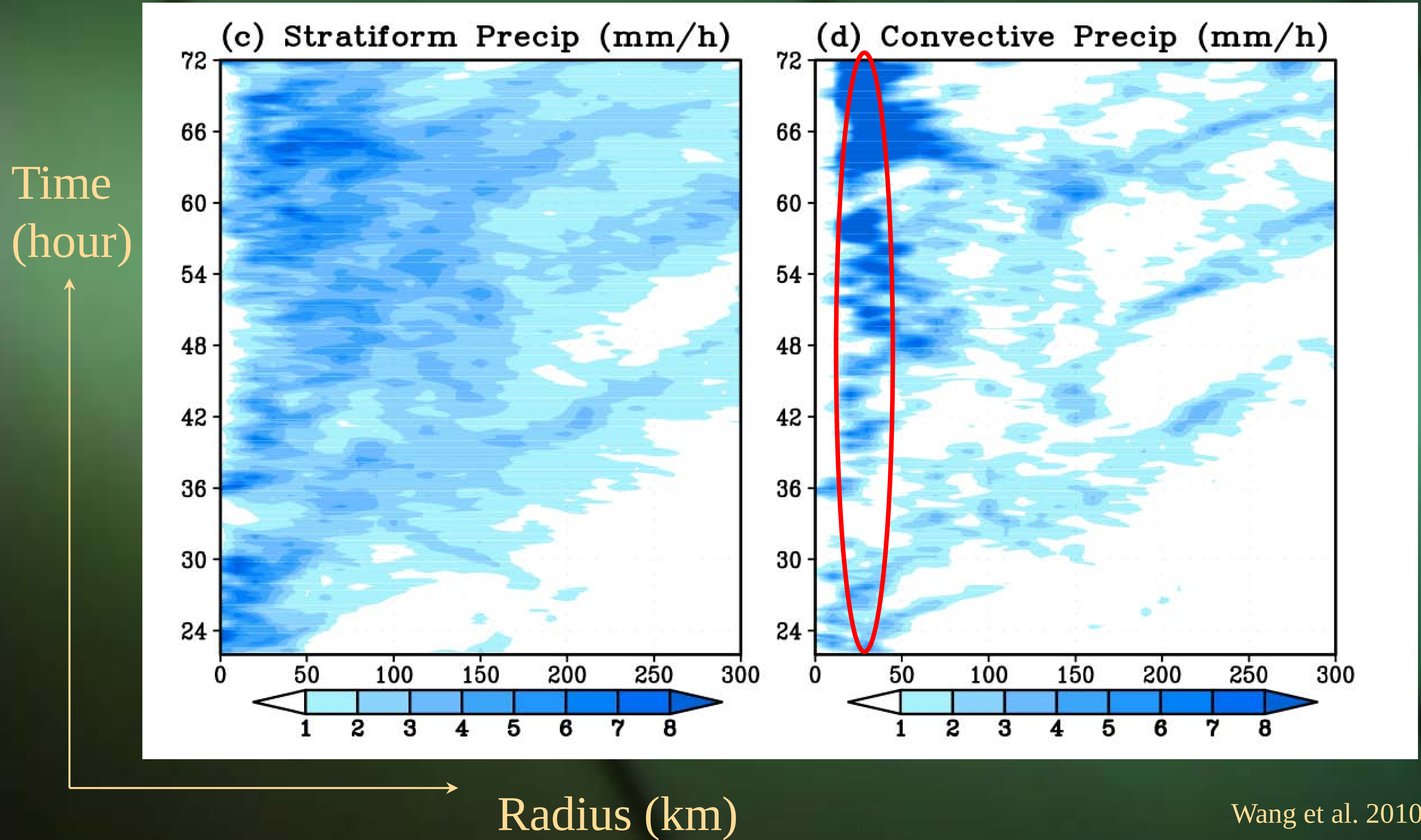
Stratiform vs. Convective Divergence Profiles



Stratiform process: favors the development of a mid-level vortex.

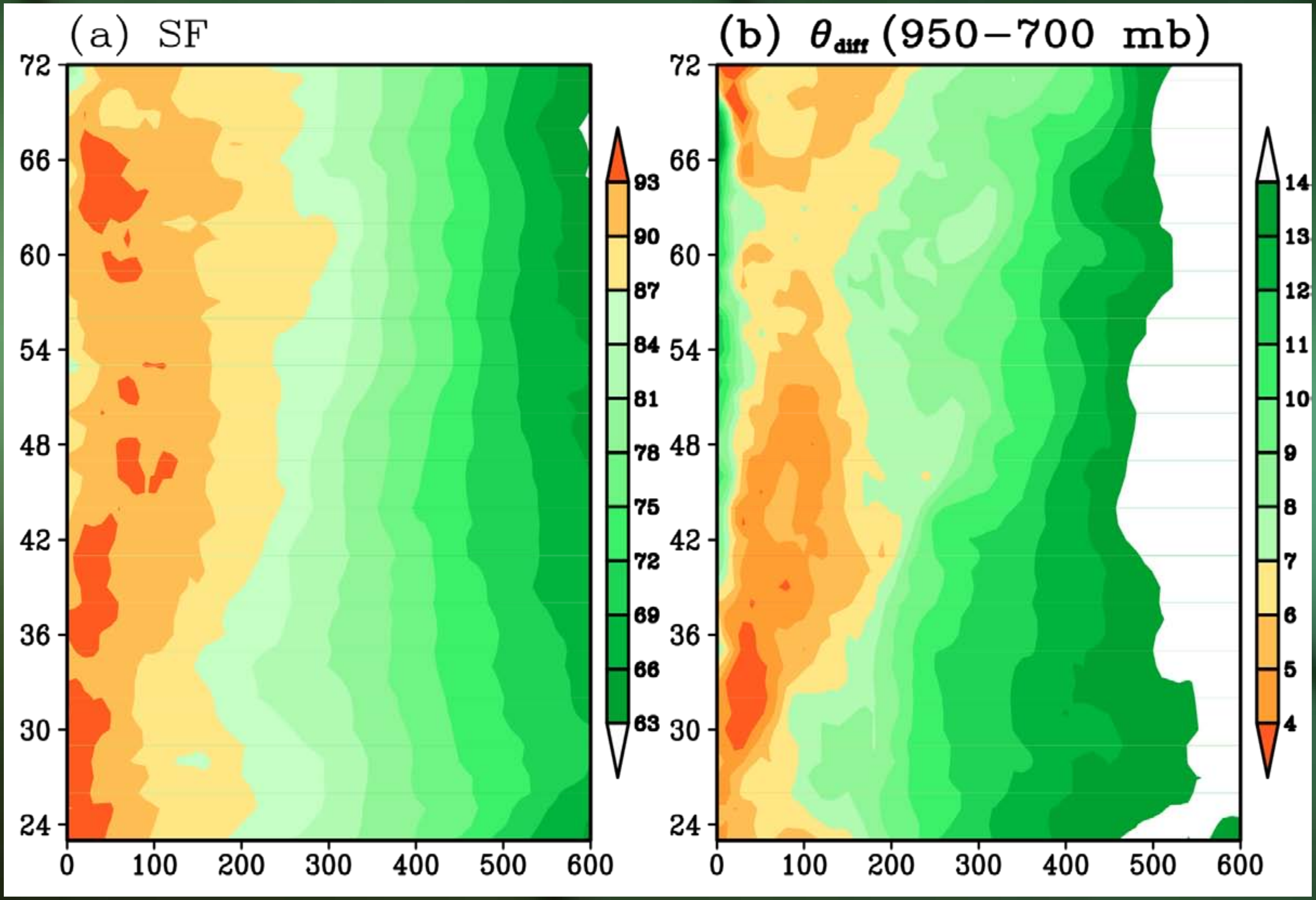
Convective process: favors the spin-up of the low-level circulation.

Time-Radius Plots of Stratiform vs. Deep Convective Precipitation



Wang et al. 2010b

Time-Radius Plots of SF and θ_e Diff



Time (hour)

Radius (km)

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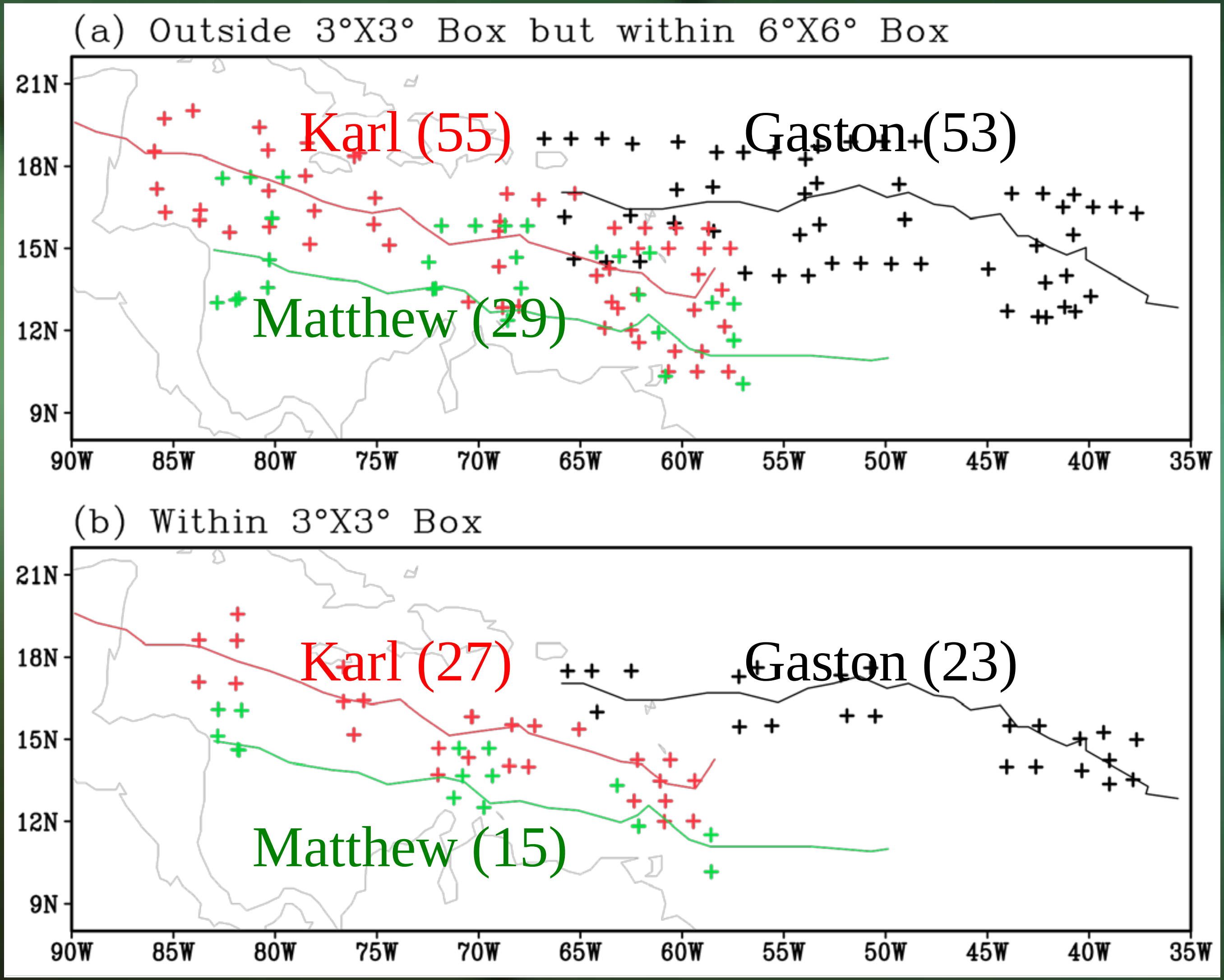
Field Experiments in 2010

- A tri-agency collaboration:
  - PREDICT: *Pre-Depression Investigation of Cloud-systems in the Tropics* (PREDICT) experiment sponsored by the NSF
  - GRIP: *Genesis and Rapid Intensification Processes* experiment sponsored by NASA
  - IFEX: NOAA's *Intensity Forecast Experiment*
- Aircrafts: NCAR G-V, P-3, Global Hawks
- Data available at:
  - http://catalog.eol.ucar.edu/predict
  - http://grip.nsstc.nasa.gov/data.html
  - http://www.aoml.noaa.gov/hrd/HFP2011/IFEX.html

Figure Courtesy of Mike Montgomery

PREDICT GV Dropsondes



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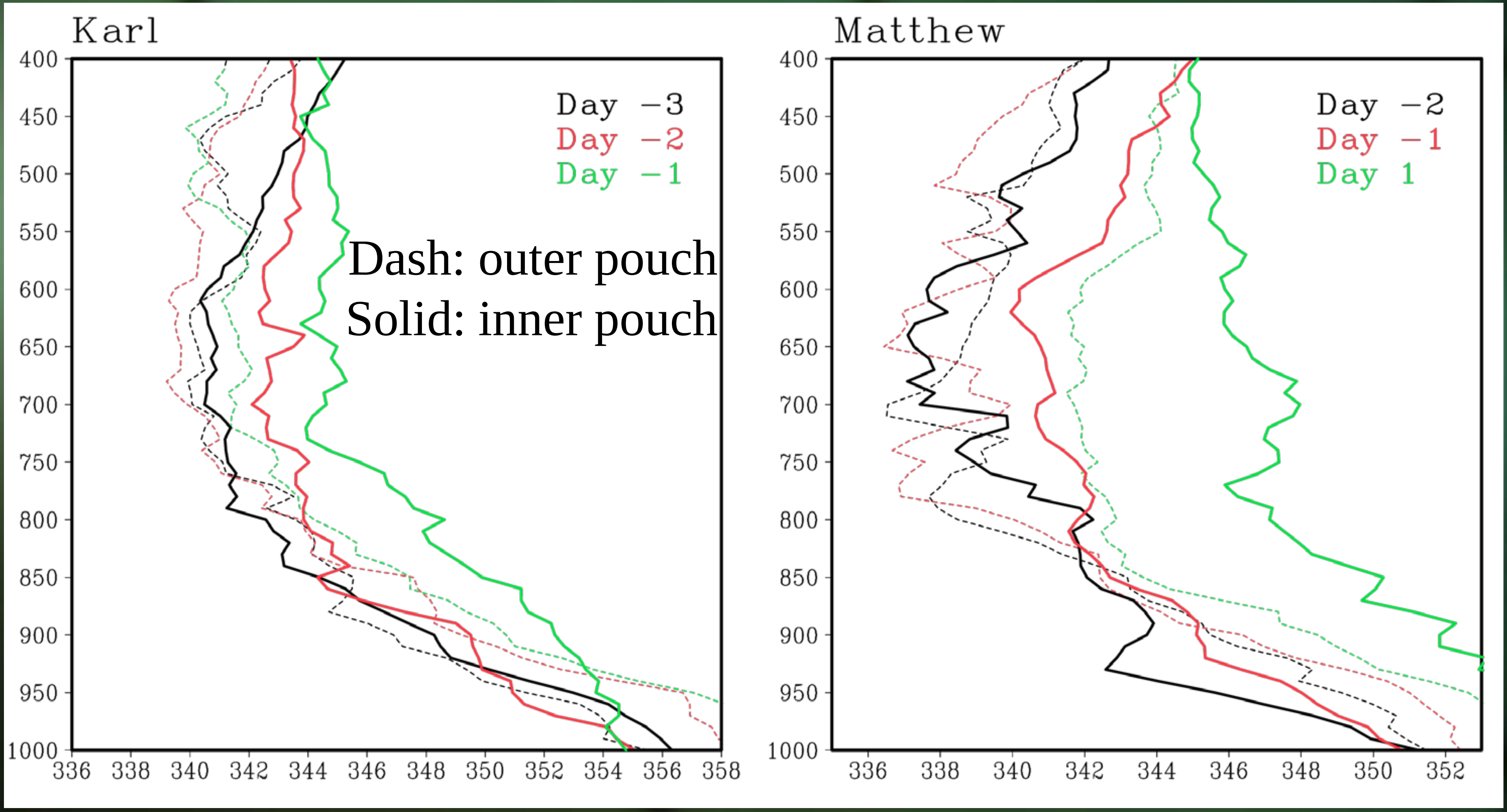
Data from NCAR EOL

Equivalent Potential Temperature: Karl and Matthew



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Conclusions

- The thermodynamic conditions near the pouch center are particularly favorable for moist deep convection. The strong radial gradient of the convective heating can effectively drive the secondary circulation and spin up a surface vortex.

- PREDICT dropsondes showed that the mid-level θe near the pouch center becomes 3-5 K warmer than that at the outer pouch region one to two days prior to genesis – an indicator of genesis?

- The thermodynamic conditions near the pouch center are thus critically important for TC formation but may be masked out if a spatial average is taken over the pouch scale.

Future Work

- Further diagnosis using the dropsonde data from TCS-08 and GRIP (2010)
- HS3: HAMSE, HIRAD, HIWRAP, AVAPS
  - Different thermodynamic conditions at the inner and the outer pouch regions
  - Evolution of convective vortices near the pouch center
  - Environmental impacts on convection at the inner pouch region: such as dry air
- Satellite detection of the inner-pouch moistening?

Publications

1. Wang, Z., M. T. Montgomery, and T. J. Dunkerton, 2010: Genesis of Pre-hurricane Felix (2007). Part I: The Role of the Wave Critical Layer. J. Atmos. Sci., 67, 1711-1729.
2. Wang, Z., M. T. Montgomery, and T. J. Dunkerton, 2010: Genesis of Pre-hurricane Felix (2007). Part II: Warm core formation, precipitation evolution and predictability. J. Atmos. Sci., 67, 1730-1744.
3. Wang, Z., T. J. Dunkerton, and M. T. Montgomery, 2012: Application of the Marsupial Paradigm to Tropical Cyclone Formation from Northwestward Propagating Disturbances. Mon. Wea. Rev., 140, 66-76.
4. Wang, Z., M. T. Montgomery, and C. Fritz, 2012: A first look at the structure of the wave pouch during the 2009 PREDICT-GRIP "dry run" over the Atlantic. Mon. Wea. Rev., in press.
5. Wang, Z., 2012: Thermodynamic Aspects of Tropical Cyclone Formation. J. Atmos. Sci., accepted with revision.
6. Fritz, C. L., and Z. Wang, 2012: A Numerical Study about the Impacts of Dry Air on Tropical Cyclone Formation. J. Atmos. Sci., , accepted with revision.

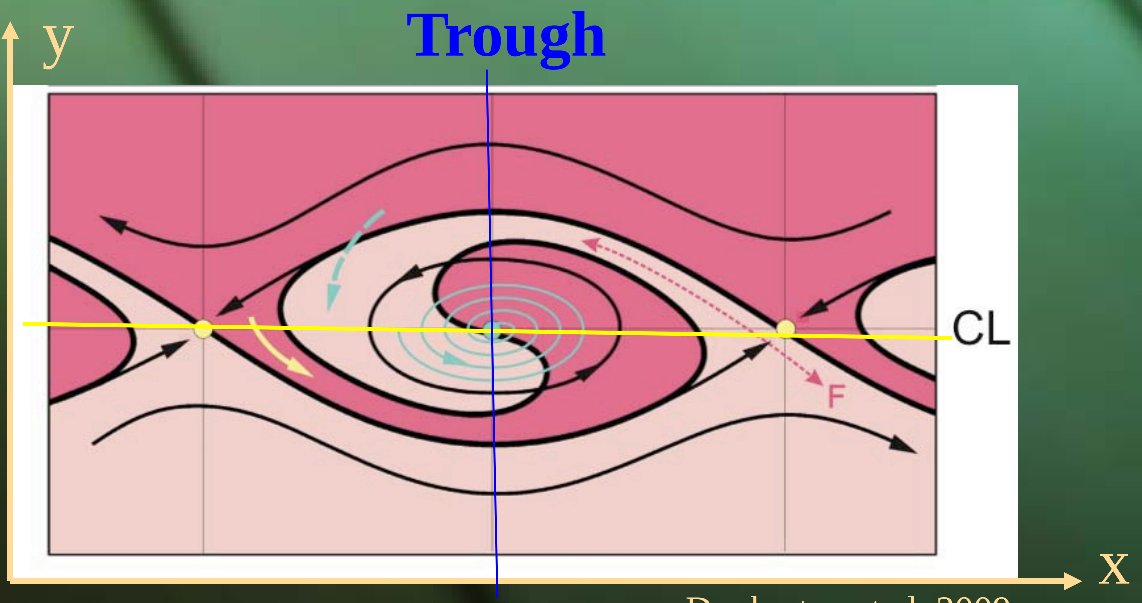
End of presentation.
Thank you!

Tropical Easterly Waves

- Phase speed: 6-10 m/s westward propagation
- Vertical structure: trapped in the lower troposphere
- A majority of TCs form from TEWs over the Atlantic.

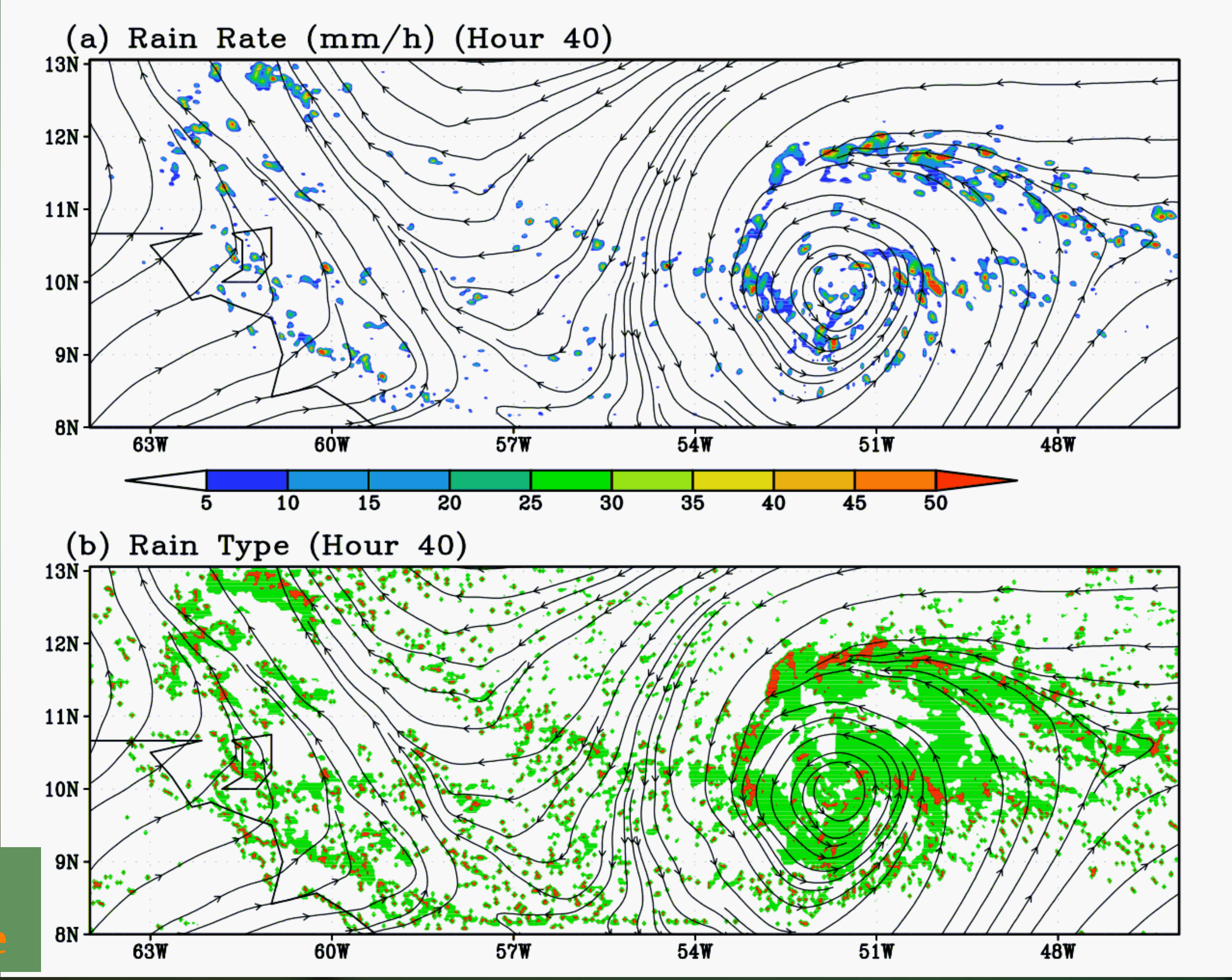
Critical Layer

- Critical surface/latitude (*linear*): where *Cp=U* or the wave intrinsic frequency = 0
- Wave critical layer (*nonlinear*)
  - A layer with finite width due to the nonlinear interaction of the wave with its own critical surface
  - A region of approximate closed circulation, where air parcels are trapped and the flow is isolated from its surrounding



Dunkerton et al. 2009

Rain Rate and Rain Type



Green: stratiform
Organe: convective

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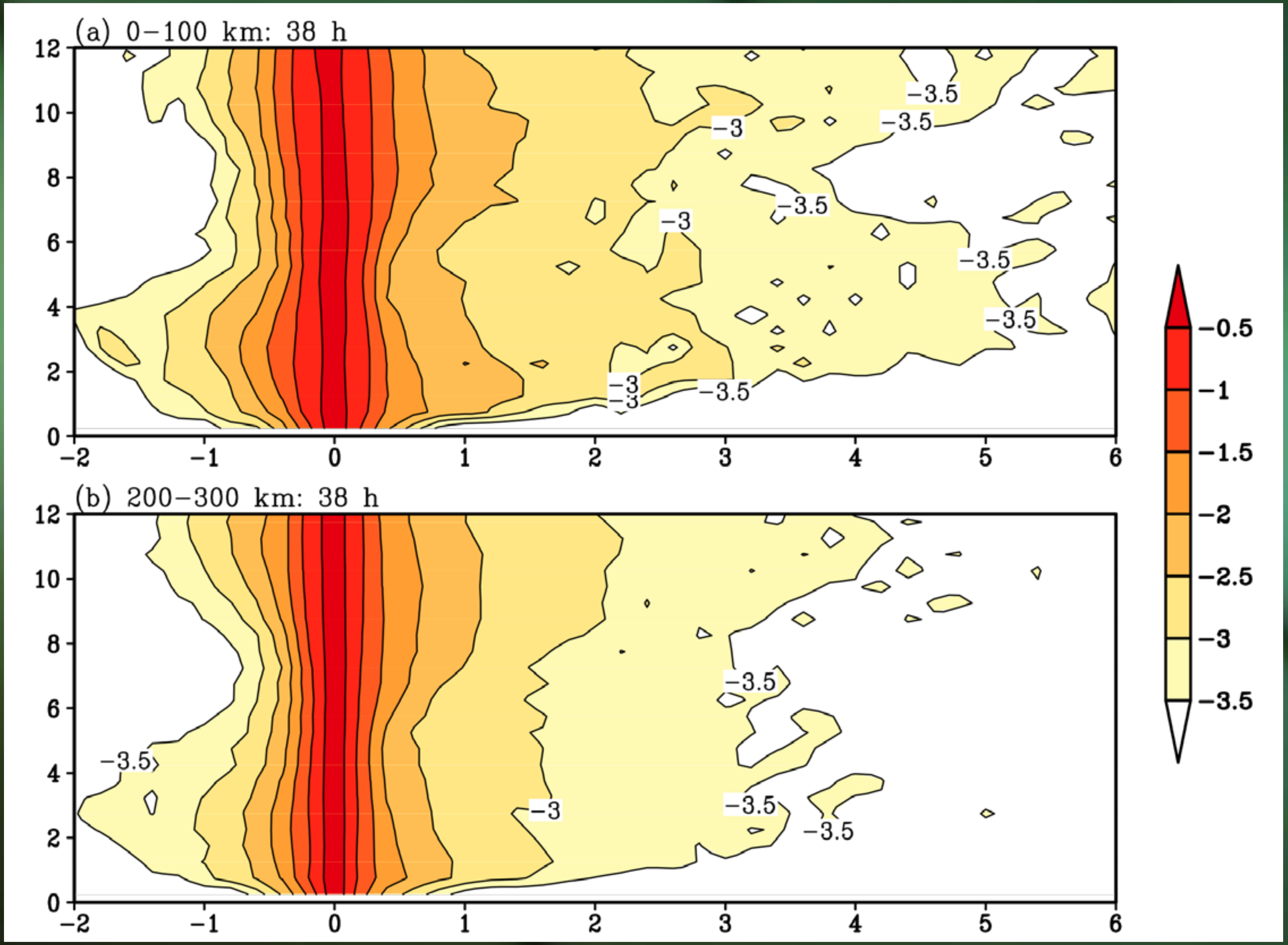
Contoured Frequency by Altitude Diagrams (CFAD) of Vertical Velocity

Height (km)



Height (km)

W (m/s)

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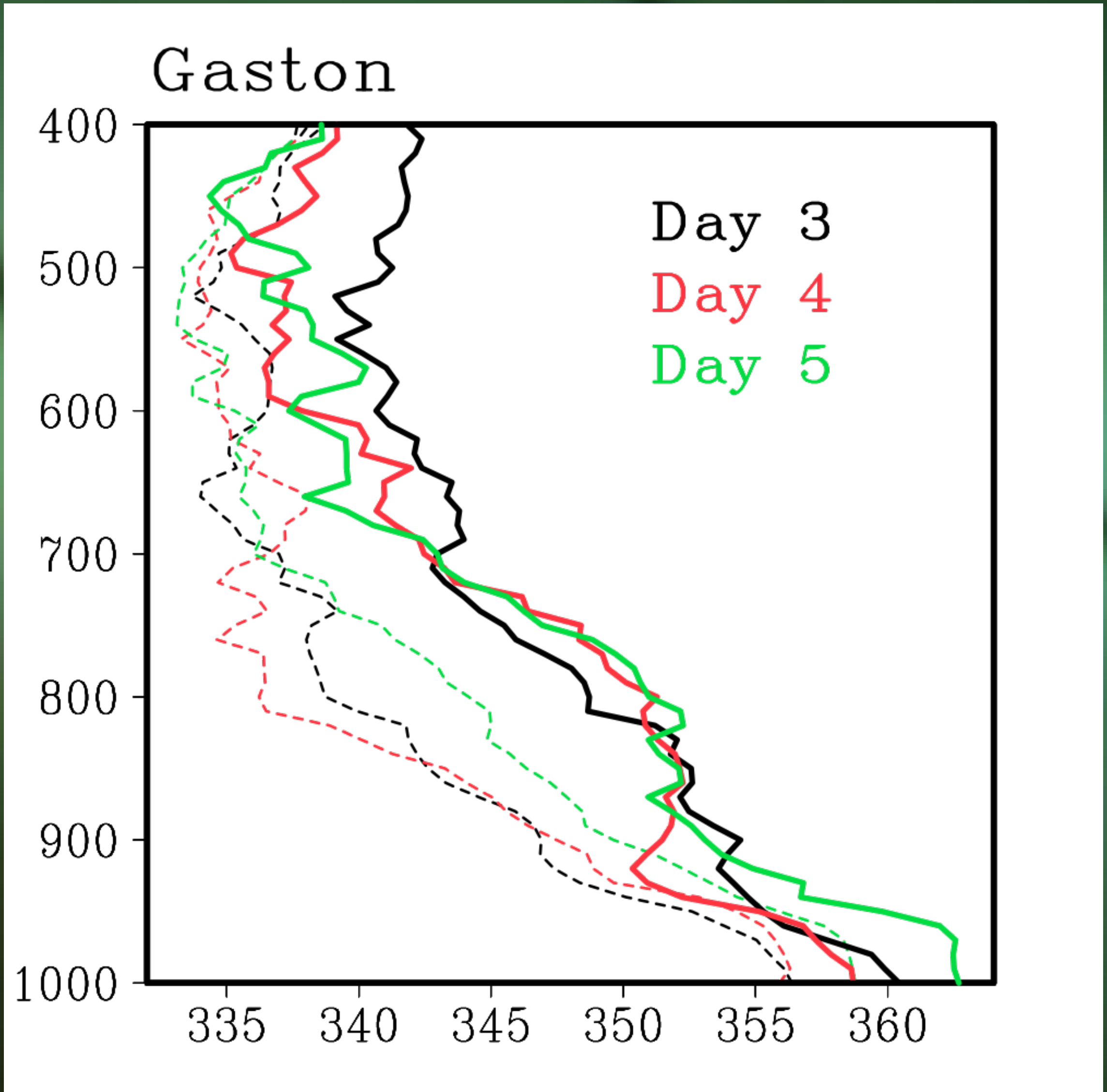
Non-developer: ex-Gaston



Wang 2012, JAS