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)

No closed circulation!
Why this location?

Units: mm/day

Wang et al. 2010a
Felix: TRMM and Translated 850 hPa Streamlines—Lagrangian Flow

TRMM and UV (850 mb; Moving)

Center of the pouch!

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.
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

(c) Stratiform Precip (mm/h)

(d) Convective Precip (mm/h)

Time (hour)

Radius (km)

Wang et al. 2010b
Time-Radius Plots of $SF$ and $\theta_e$ Diff

(a) $SF$

(b) $\theta_{\text{diff}} (950-700 \text{ mb})$

Wang 2012, JAS
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

Figure Courtesy of Mike Montgomery
PREDICT GV Dropsondes

Data from NCAR EOL Wang 2012, JAS
Equivalent Potential Temperature: Karl and Matthew

Dash: outer pouch
Solid: inner pouch

Wang 2012, JAS
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 $\theta_e$ 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


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 $C_p=U$ 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

(a) Rain Rate (mm/h) (Hour 40)

(b) Rain Type (Hour 40)

Green: stratiform
Organe: convective

Wang et al. 2010b
Contoured Frequency by Altitude Diagrams (CFAD) of Vertical Velocity

Wang 2012, JAS
Non-developer: ex-Gaston

Wang 2012, JAS