Investigation of tropical cyclone intensity change and genesis with cloud-resolving HWRF model and EOS observations

Bin Wang and X. Zhou Meteorology, University of Hawaii
Brian Kahn, JIFRESSE, UCLA
Hui Su, JPL

Goals

Modeling and understanding

- TC intensity change associated with inner core processes
- Multi-scale interaction in TC genesis

Methodology

- Utilize the diverse EOS satellite observations
- Modeling and experiments with cloud-resolving HWRF model

Foci and Objectives

- Intensity change associated with concentric eyewall and formation of annual hurricane (AH): ----understand mechanism for the formation of secondary eyewall and AH, and the factors governing intensity changes associated with eyewall replacement

- Multi-scale interactions leading to TC genesis:

  ----Interaction between hot towers, mid-level MSV, and destabilization of the environment

Concentric eyewalls and Annular Hurricanes

Issues

- Mechanisms of secondary eyewall formation:

  External forcing (Molinari and Vollaro (1990), Nong and Emanuel 2003)

  TC internal dynamics (Terway and Montgomery 2008, Zhou and Wang 2009)

- Intensity change associated with eyewall replacement is highly variable; prediction of it remains a challenge.

  Example: Anita (1977) and Typhoon Sarah (1956).

- AH formation processes remains elusive, especially the linkage between the concentric eyewall and AH.

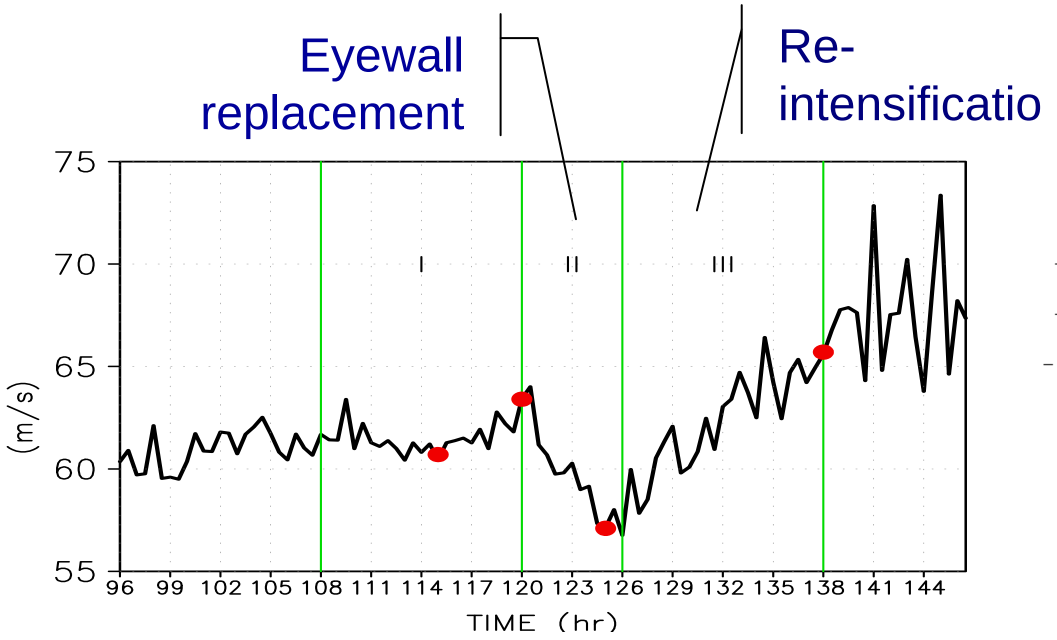
  Example: Hurricane Daniel (2006)

Preliminary results:
an idealized numerical experiment

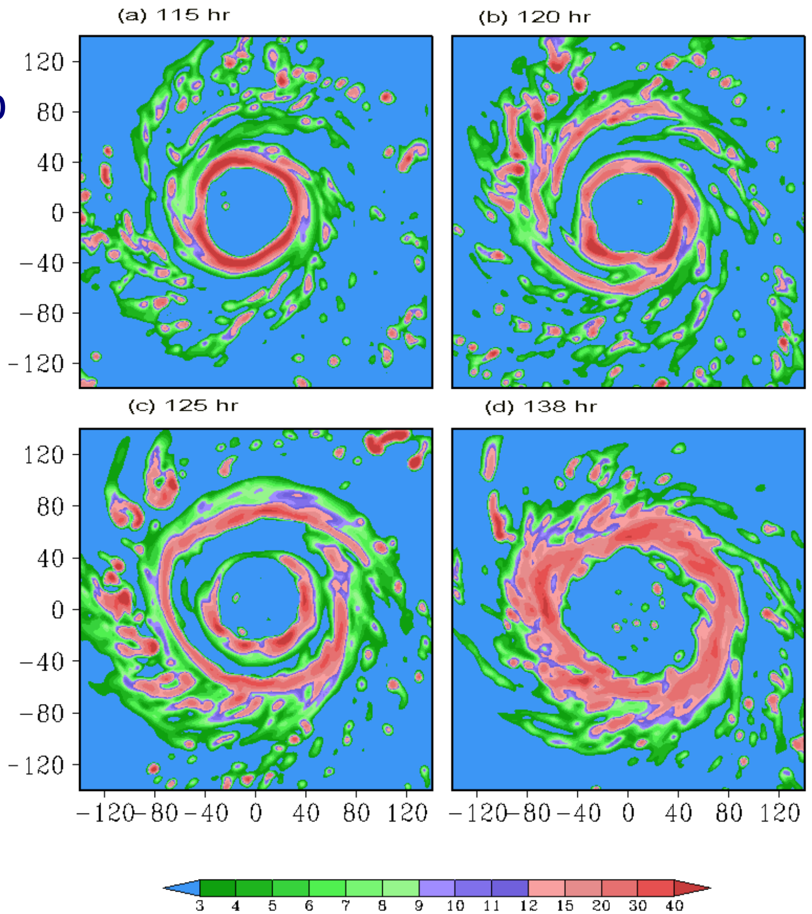
- WRF-ARW (WRFV2 and WRFV3)
- Quadruply nested, two-way interactive (2km, 6km, 18km, 54km)
- No cumulus scheme for two inner meshes
  Microphysics scheme: Lin et al (1983)
- Kain-Fritch scheme in two ourtermost meshes
- PBL: YSU Scheme
- Idealized: (f –plane, SST=29^{0}C, Rest)
  later: Real case
- Initial disturbances:
  a symmetric vortex with maximum tangential wind 15m/s at 150 km radius

Simulated concentric eyewall and transition to Annular Hurricane

- <u>Time series of hurricane intensity</u>



- <u>Rainwater distribution (0.1g/kg) in</u> 550 hPa

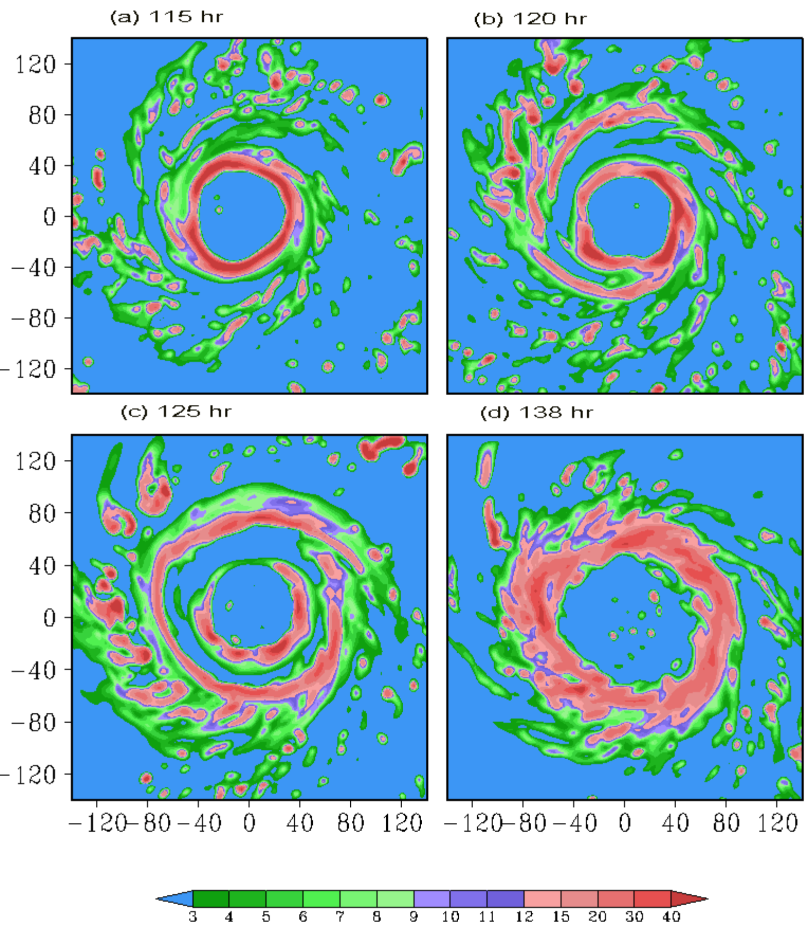


The storm contains typical annular hurricane features after concentric eyewall replacement

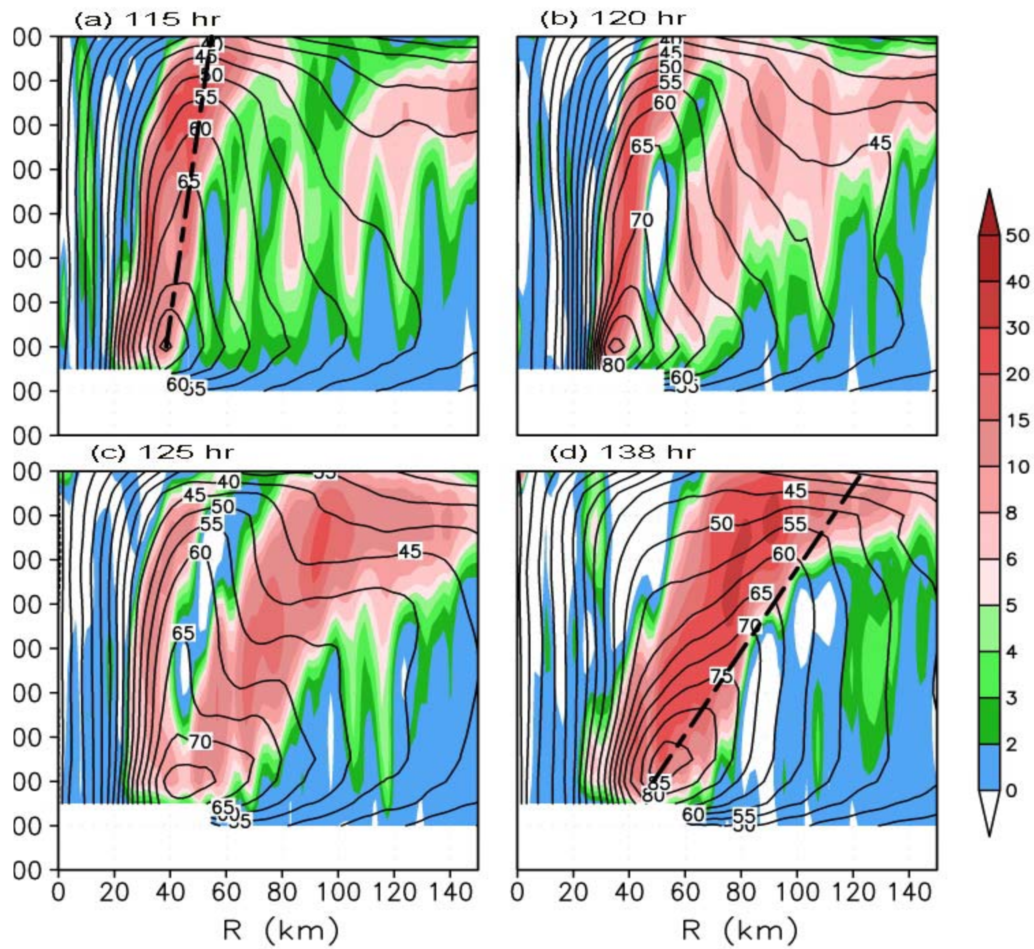
Zhou and Wang (2009), GRL

Secondary eyewall formation, eyewall replacement ,and fast transformation to AH

➢Rainwater distribution (0.1g/kg) in 550 hPa



➢Vertical-radial section of W (shading) and Vt contour



Zhou and Wang (2009), G.R.L

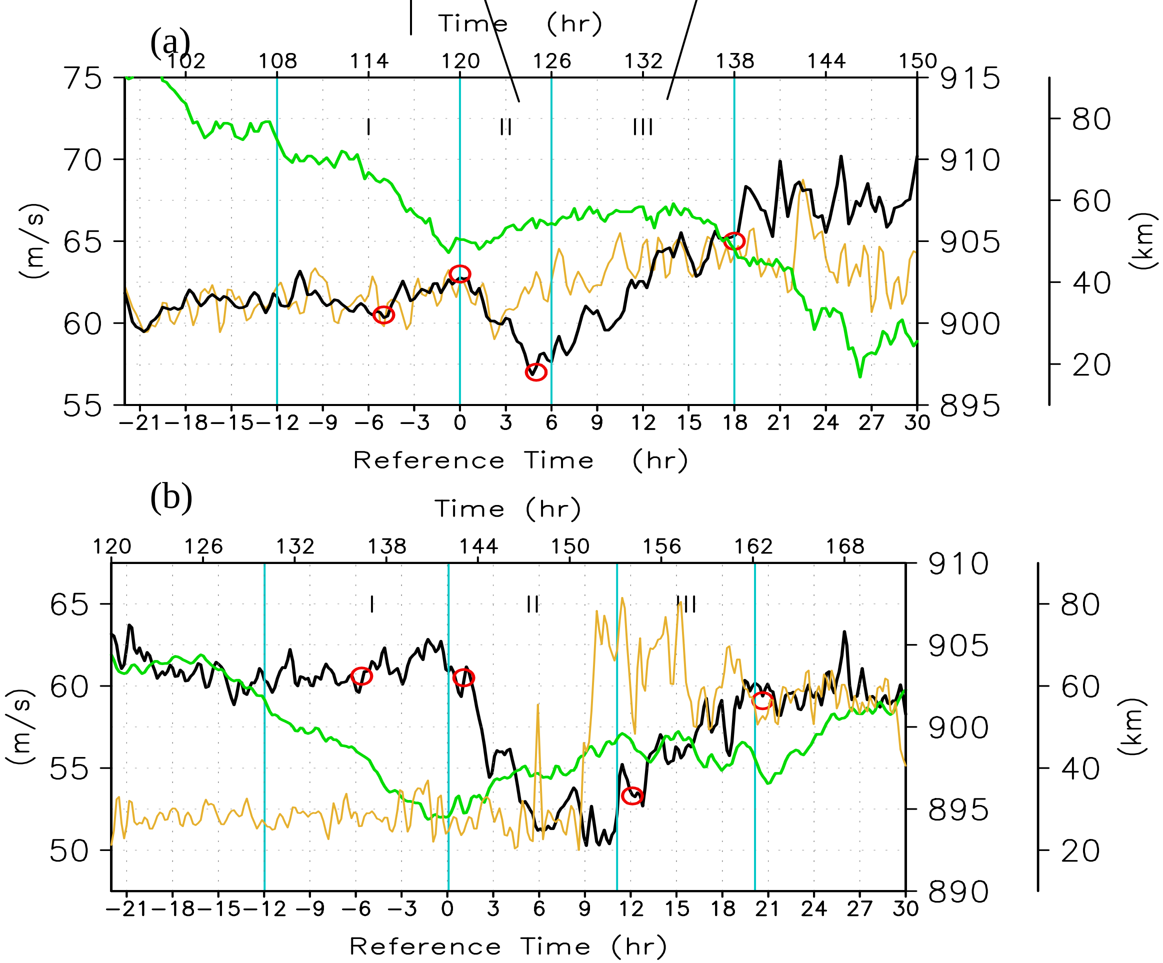
Different eyewall replacement cycles in two experiments: WRFV2 and WRFV3

Eyewall replacement

Re-intensification

WRFV3

WRFV2



Green-MSLP

Yellow-RMW

Black -Wind Maximum

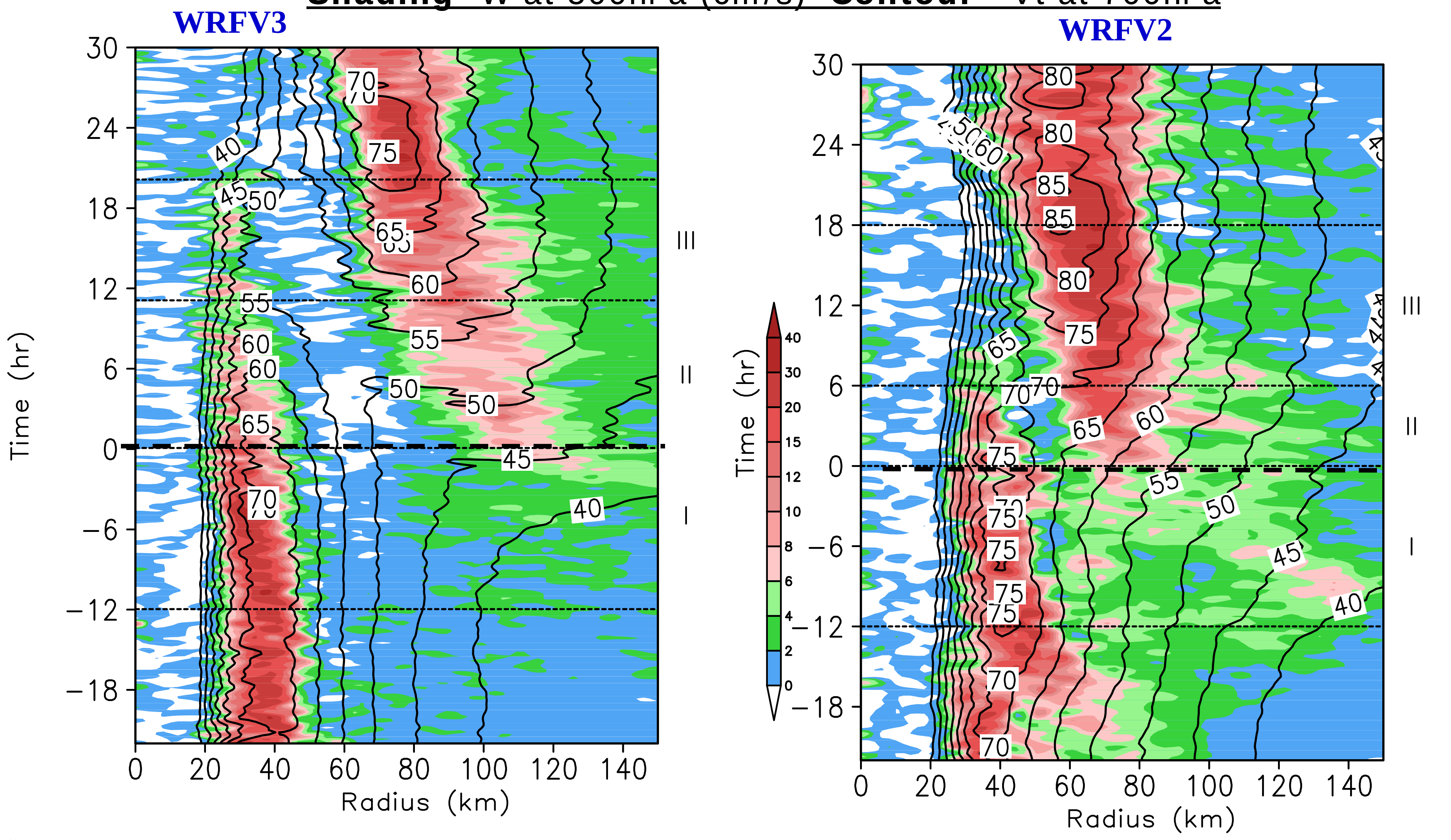
I: Pre-formation

II: Eyewall replacement

III: Re-intensification

Different eyewall replacement cycles in two experiments : symmetric structure change

Shading- W at 500hPa (cm/s) **Contour** - Vt at 700hPa



Questions

- How does the secondary eyewall formation depend on TC structure and environmental conditions?
- What determine intensity change during the eyewall replacement?
- Why does eyewall replacement sometimes result in AH formation and sometimes not?
- How does large-scale environment affect formation of secondary eyewall as well as AH?

Further model studies

- Sensitivity of the formation of concentric eyewall to
  Initial conditions
  Physical parameterizations Including microphysicas schemes, PBL et al
  Storm structures
  Environmental condition

- Diagnosis of the angular momentum, PV, energy, and thermodynamic budgets , vortex RW activity, and interaction between outer and inner rings to understand the role of internal dynamics in the eyewall replacement cycle

- Idealized numerical studies to explore the response of storm intensity to secondary eyewall heating

  Outer eyewall is considered as a stationary heat source superimposed in the outer region. A series of sensitivity experiments with varied heating profiles, locations

- Real case simulation (Daniel 2006)

Further observational analysis

Purpose: Document secondary eyewall formation processes

- Detection of ambient conditions and precursory convective structures
- Detection of intensity change with observed inner core cloud information during eyewall replacement

Methods

- Use more data such as hydrometeor profiles of cloud liquid water, precipitation water, cloud ice water, precipitation ice, vertical structure of clouds in TRMM, and other EOS datasets.
- Compile a dataset of historic TC concentric eyewalls, including the track, intensity change, cloud and rainband structures, and associated ambient conditions. Make an atlas for all concentric eyewall TC evolutions with available EOS data
- Preliminary analysis of two types intensity changes using

TC Genesis:
Multi-scale interactions

TC genesis: Warm core formation and intensification of the low-level cyclonic vorticity

Mesoscale –convective processes:

PV penetration :Ritchie and Holland 1997, Fritsch 1994

Convective warming: **Rogers and Fritsch 2001:**

Vortical Hot tower (VHT) theory: Montgomery and colleagues

"Shower-head" theory: Bister and Emanuel (1997)

Large scale forcing

Warm-core instability : **Kahn and Sinton 2008**

Low-level meridional shear of zonal wind

Focus: Interaction between hot towers, mid-level MSV, and destabilization of the environment

Preliminary results: Experiment design

- WRF-ARW
- Quadruply nested, two-way interactive (2km 6km 18km 54km)
- Microphysics scheme in the two inner domain: Lin et al (1983). No cumulus scheme for the two inner domains
- PBL: YSU Scheme
- f –plane
- SST=29^{0}C
- Rest environment
- Environmental T and Q profile:

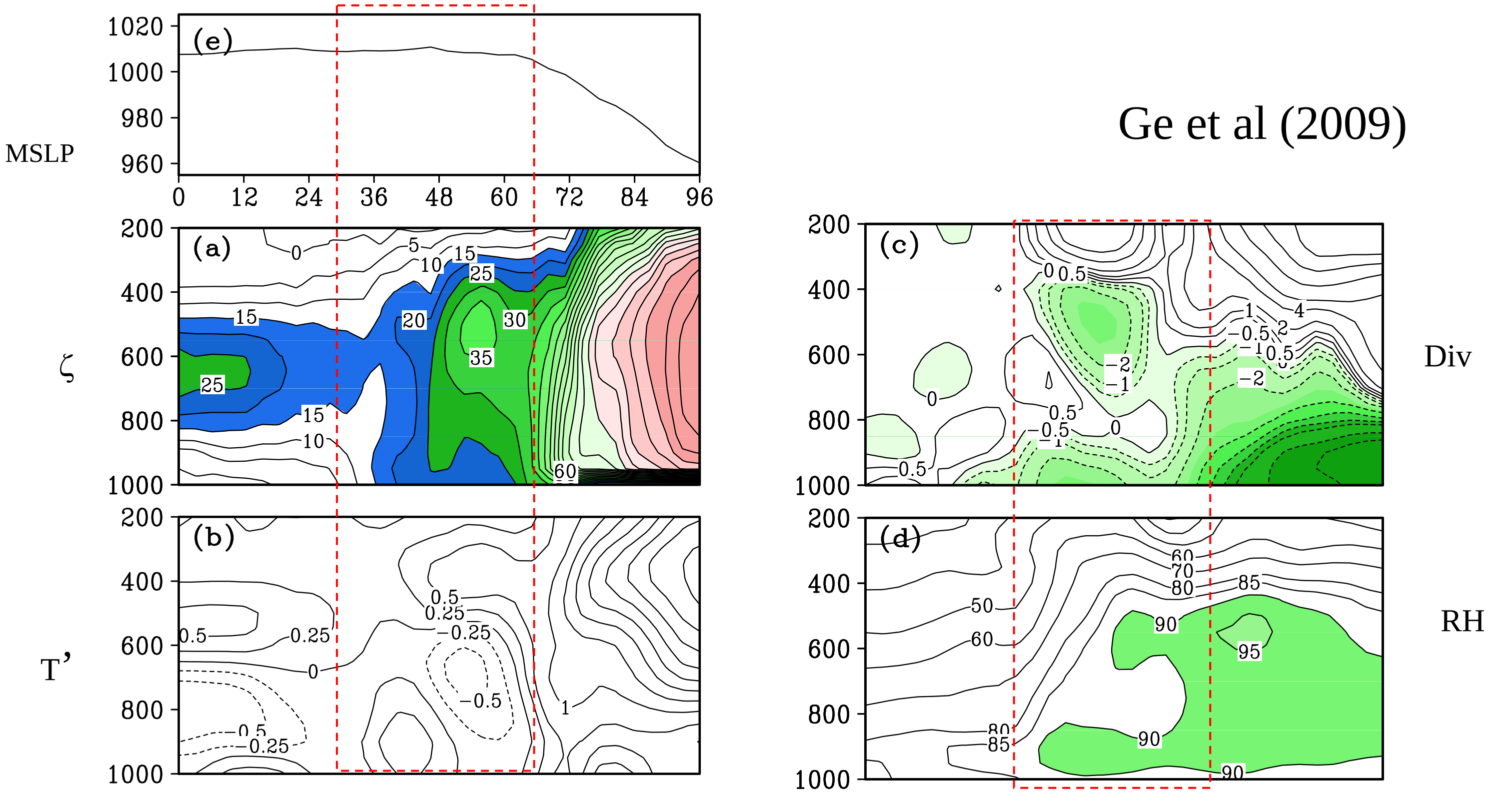
January mean at Willis Island, northeast of Australia (Holland 1997)

- Initial disturbances:

A weak vortex with maximum tangential wind 8m/s at 600hPa, and then gradually decreases both upward and downward. RMW 100km.

Simulated TC genesis from a mid-level MSV

Time-vertical cross section of inner-core variables
(100km×100km box averaged)



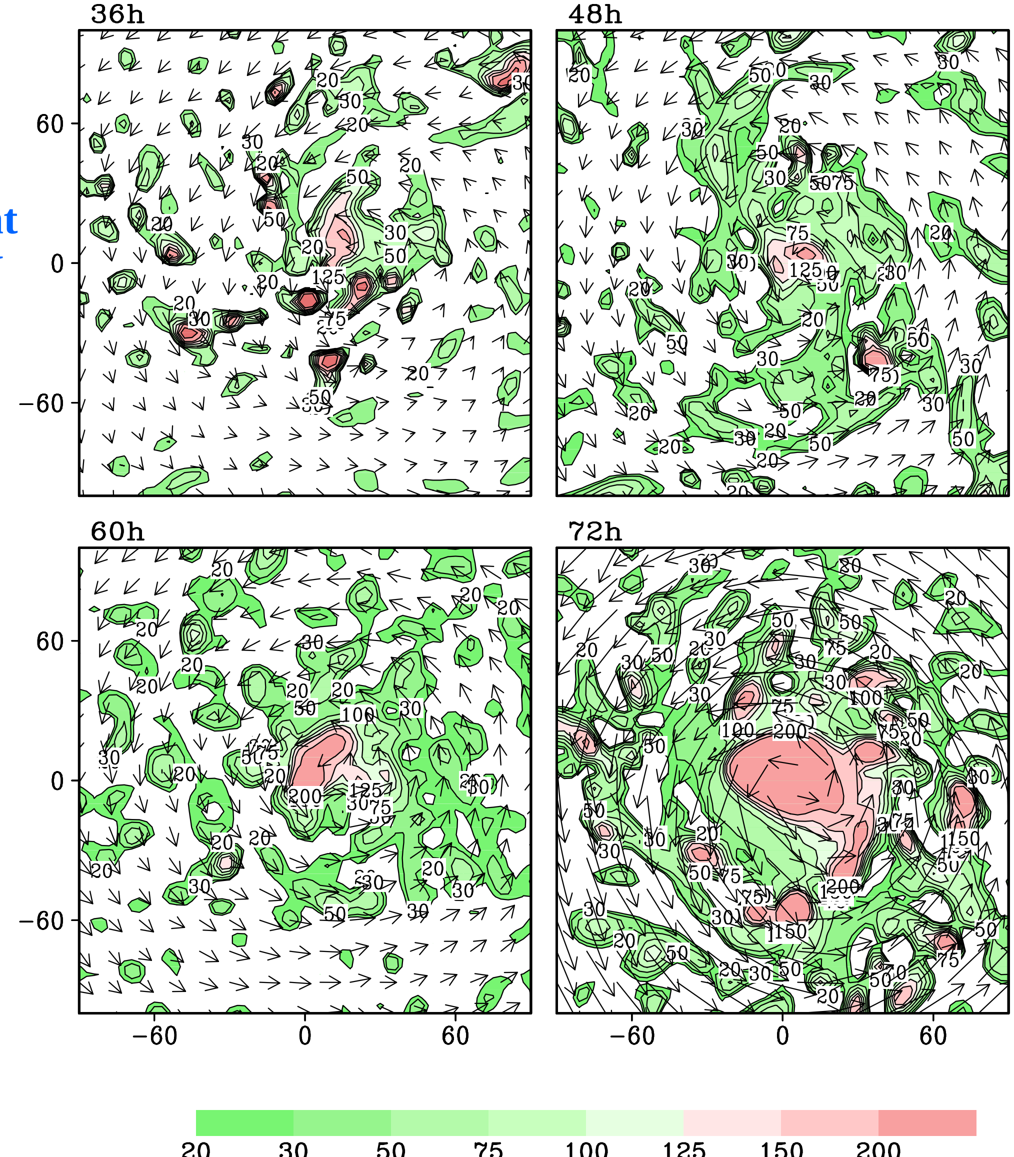
Enhancement of mid-level vortex (30-60hr) with (a) enhanced mid-level convergence, (b) enhanced cold core in the low levels and warm core in the upper level, (c) development of near-saturation through the entire depth of the vortex , and (d) development of BL convergence.

Alternative development of MSV and VHTs

850hPa wind field (vector) and relative vorticity (shaded)

VHT development After initial MSV

Enhancement of MSV (1): stratiform



Enhancement of MSV (2)

TC forms

Questions

- Is it common that the mid-level MSV enhances before TC genesis?
- Is there an interaction between the startiform MCV and VHTs? If so, how does this interaction leads to TC genesis?
- Can the alternative development of MCV and VHTs be found in satellite data?
- Can we distinguish developing and non-developing incipient disturbances based on their convective structures?

Further studies

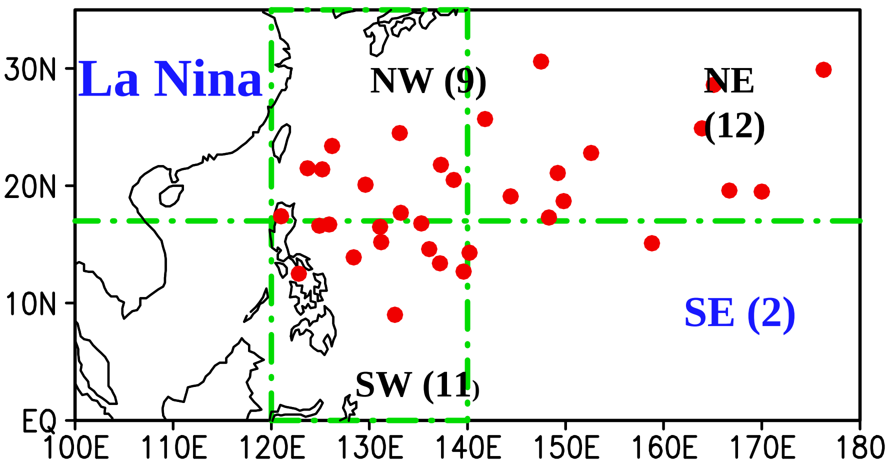
- Sensitivity of genesis to environmental temperature and water vapor profiles

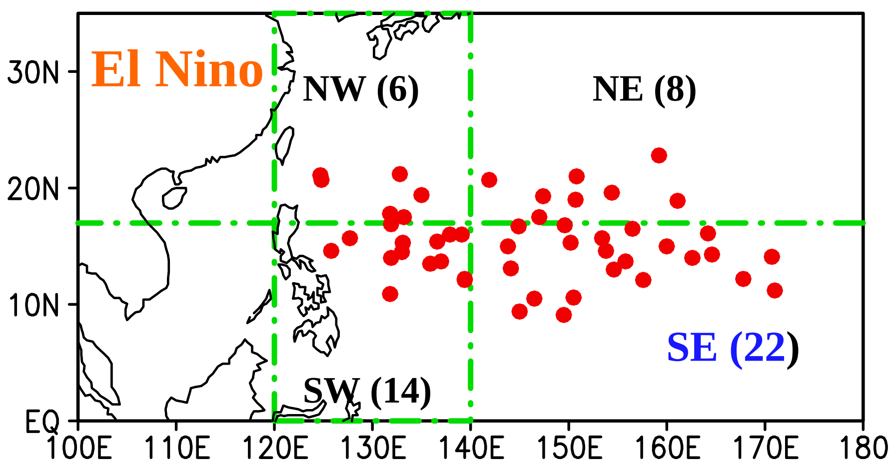
  AIRS will be used to quantify the spatial and temporal variability of thermodynamic profiles within oceanic basins climatologically favorable for TC development.

- Use of AIRS thermodynamic profile data to document the role of ambient forcing in TC genesis
- Use EOS data to detect presence and organization of hot towers embedded in the incipient disturbances to examine features and predictive value of VHTs. In TC genesis.
- Investigate TC genesis in the Nonhydrostatic ICosahedral Atmospheric Model (NICAM) 2004 experiments with 14km, 7km, 3.5km resolution.

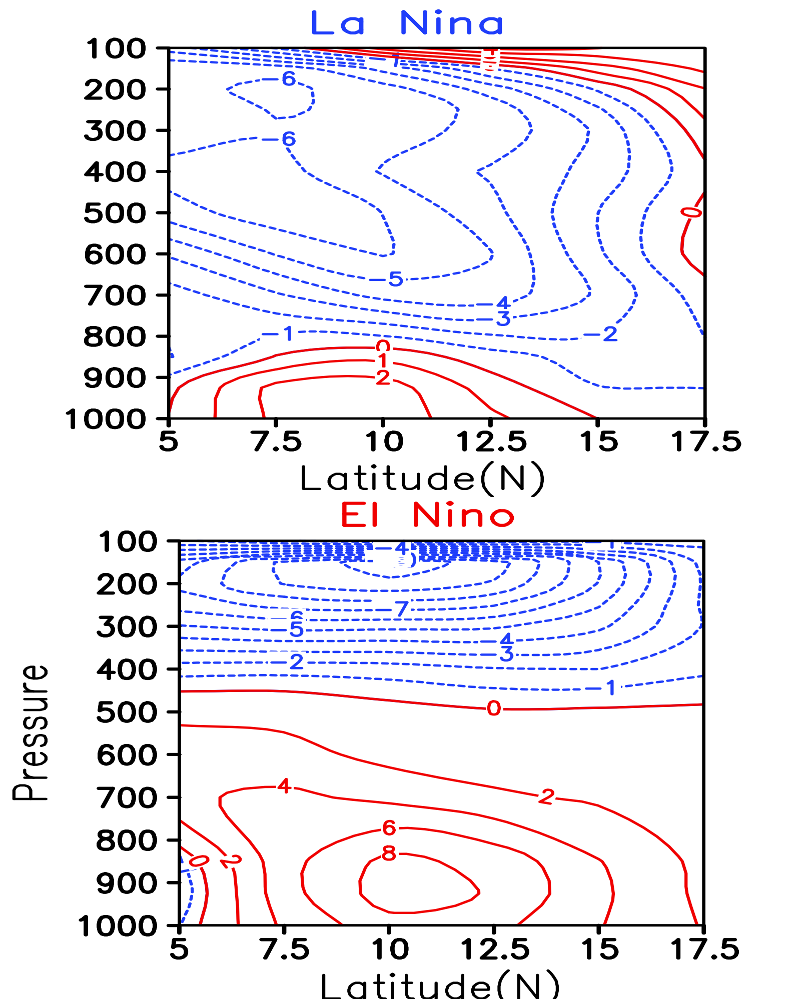
ENSO Induced meridional shear enhances RI

Contrasting TC RI
(Wang and Zhou 2008)





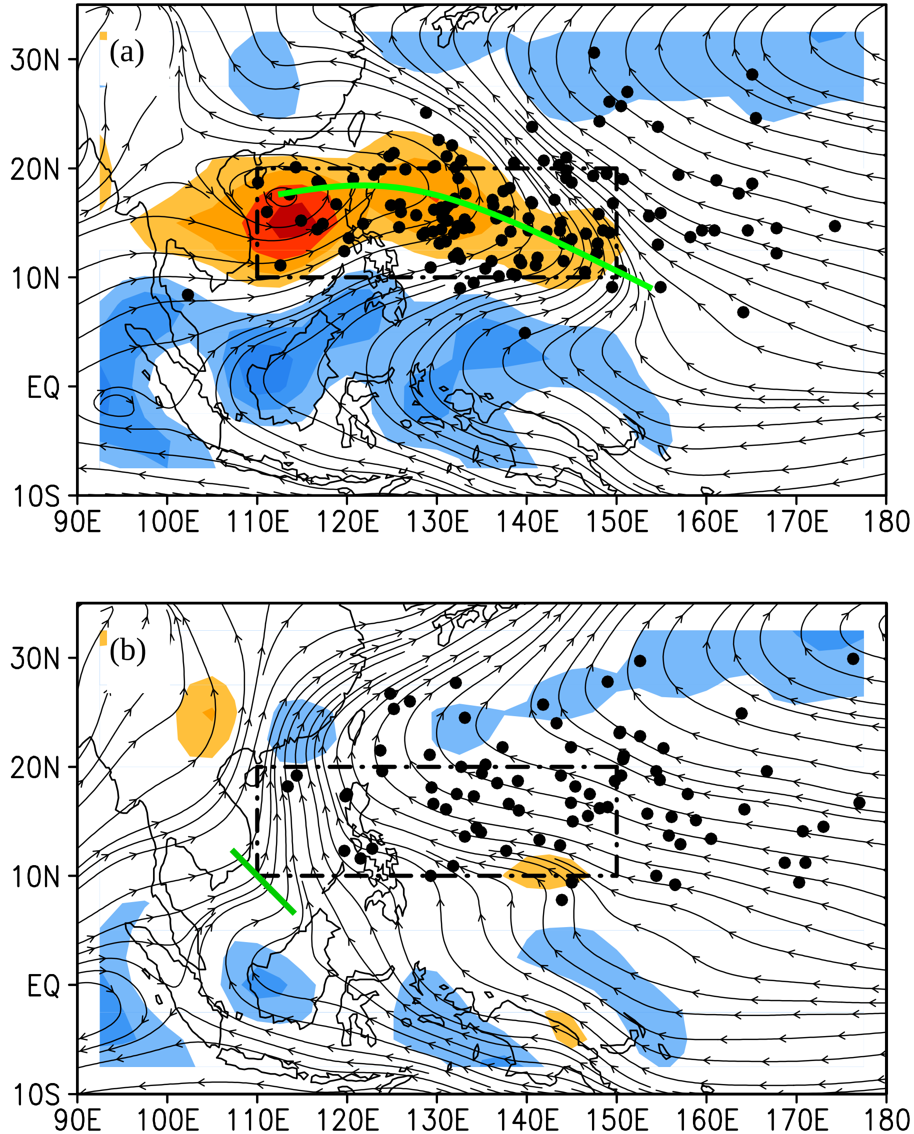
- Mean meridional shear of 850 hPa U in SE WNP

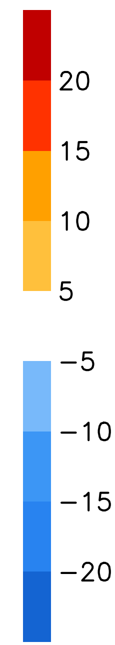


ISO induced cyclonic shear enhances RI

WNPMI>1m/s

WNPMI<1m/s





Shading: Composite 850 hPa wind and vorticity

Dots: the first me of RI reported.

Questions

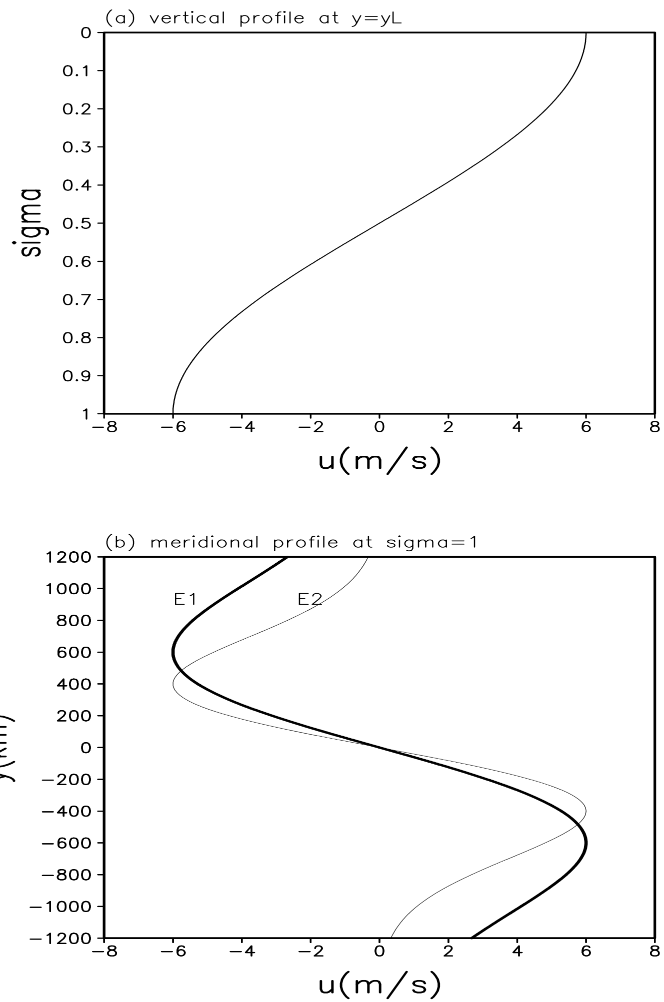
- How do large-scale zonal flow meridonal wind shear affect TC inner core convection , structure, and TC formation and intensification?

- How do the magnitude of the zonal wind meridonal shear and TC initial intensity and size affect RI?

Numerical model studies

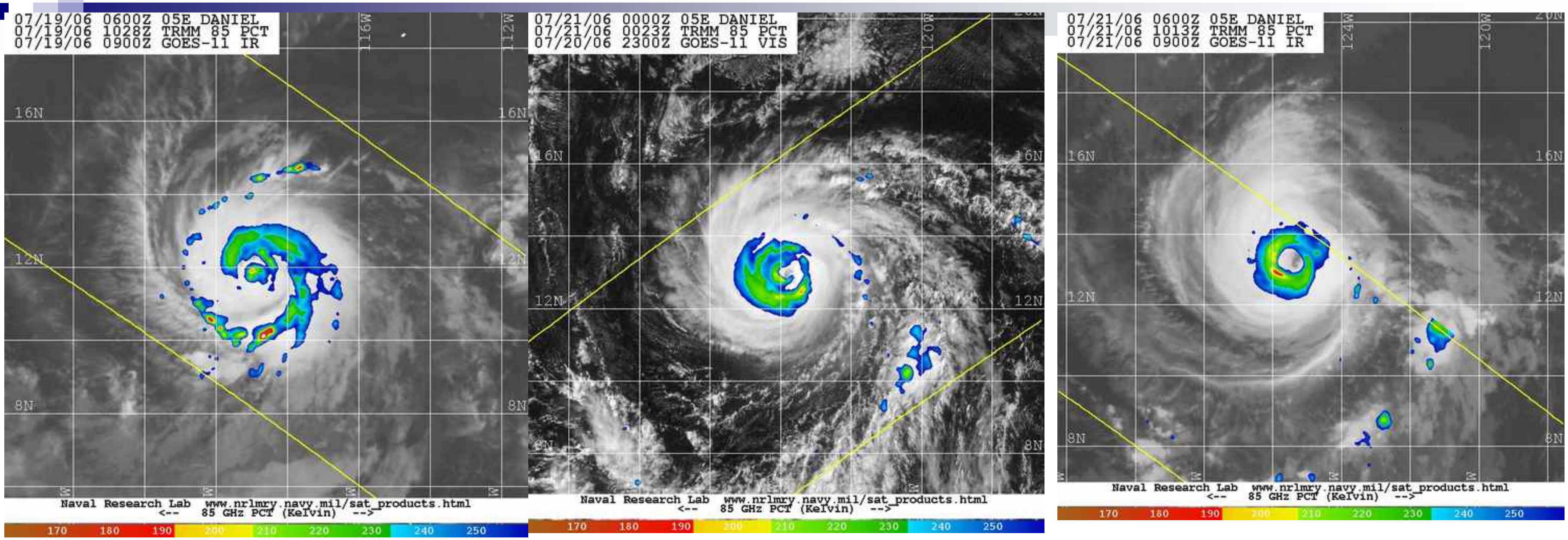
Idealized experiment

Exp.	Bogus vortex	Environmental flow
E0	$r_{\max} = 150km$ $V_{\max} = 10ms^{-1}$	No
E1	$r_{\max} = 150km$ $V_{\max} = 10ms^{-1}$	$u(y,\sigma) = u_0 + u_1 \bullet (\frac{y-y_0}{y_L}) \exp[1 - \frac{(y-y_0)^2}{y_L^2}] \cos \pi\sigma$ $u_0 = 0, u_1 = 6ms^{-1}, y_L = 600km$
E2	$r_{\max} = 150km$ $V_{\max} = 10ms^{-1}$	$u(y,\sigma) = u_0 + u_1 \bullet (\frac{y-y_0}{y_L}) \exp[1 - \frac{(y-y_0)^2}{y_L^2}] \cos \pi\sigma$ $u_0 = 0, u_1 = 6ms^{-1}, y_L = 400 km$
E3	$r_{\max} = 150km$ $V_{\max} = 10ms^{-1}$	$u(y,\sigma) = u_0 + u_1 \bullet (\frac{y-y_0}{y_L}) \exp[1 - \frac{(y-y_0)^2}{y_L^2}] \cos \pi\sigma$ $u_0 = 0, u_1 = 6ms^{-1}, y_L = 600 km$

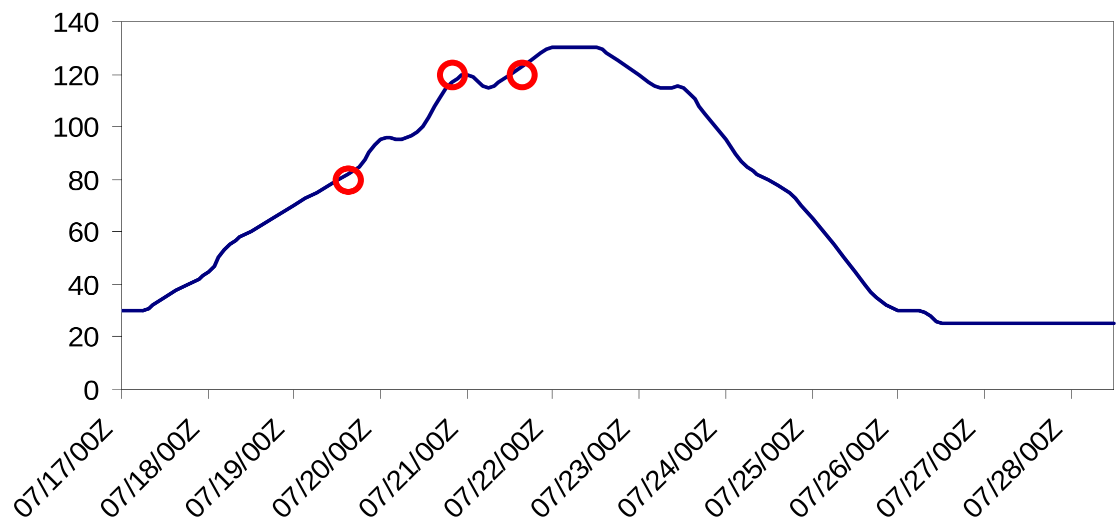


Thank you

From Concentric eyewall to annular hurricane



EP Hurricane Daniel (2006)

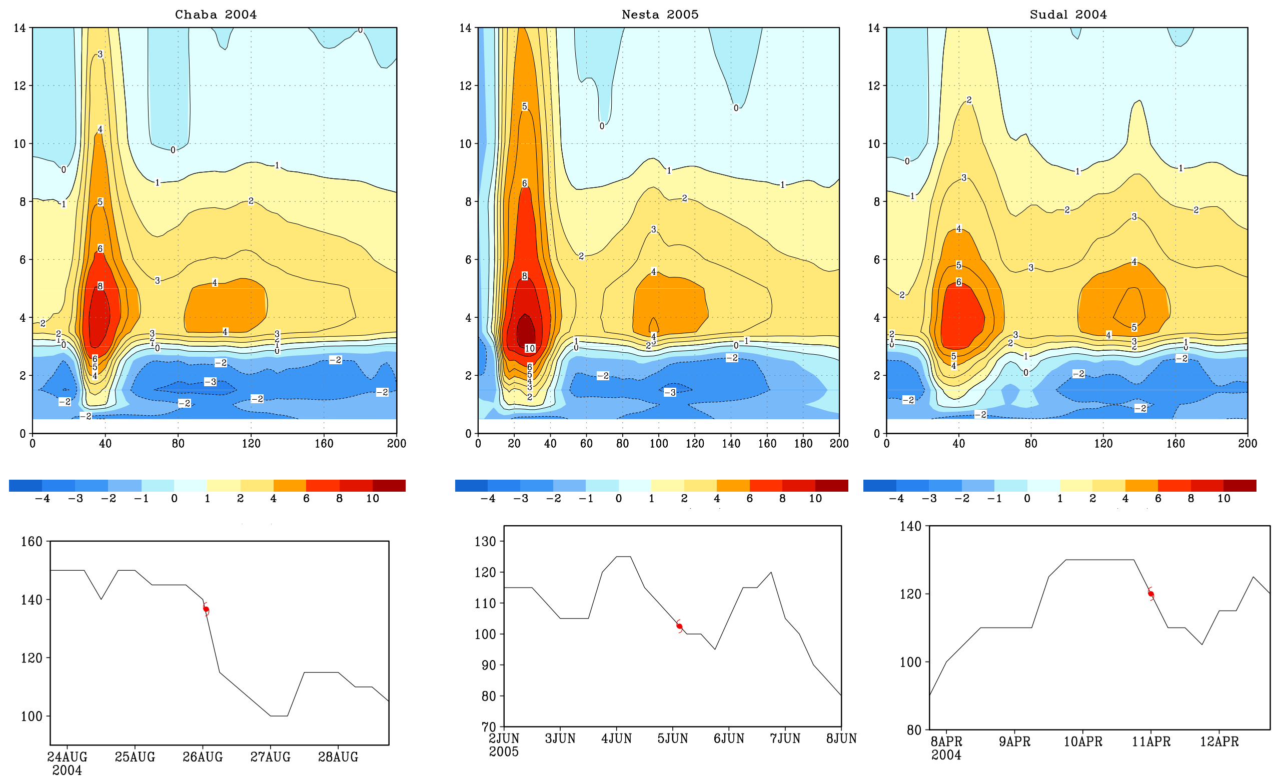


General questions

- Can we distinguish TC genesis disturbance based on their convection features?
- VHTs play important role in TC formation. How do “VHTs” develop in MCV? What determines the convective burst in stratiform region?

Group one: TCs with large intensity fluctuation

Chaba (2004) Nesta (2005) Sudal (2004)



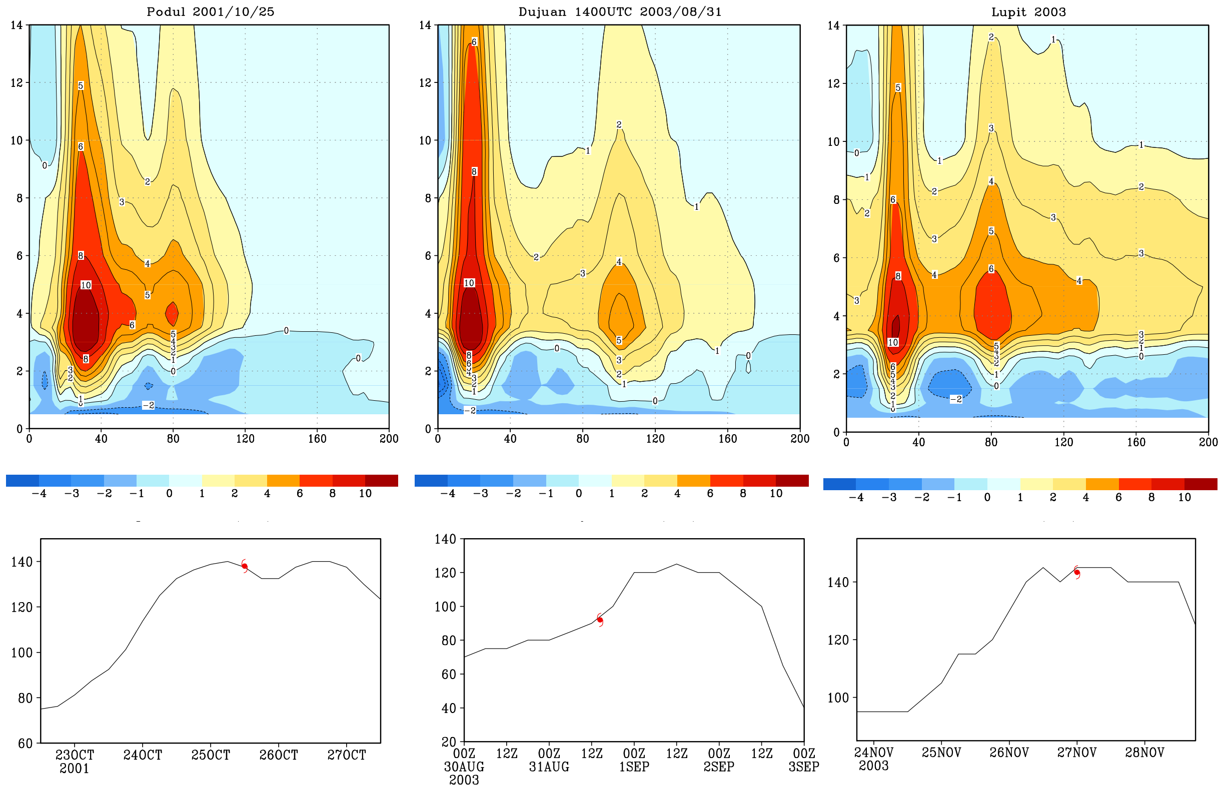
Symmetric heating (degree/day)

Intensity

- Dramatic decrease of storm intensity with the appearance of concentric eyewall
- Significant diabatic cooling below melting level

Group two: TCs without significant intensity change

Podul (2001) Dujuan (2003) Lupit (2003)



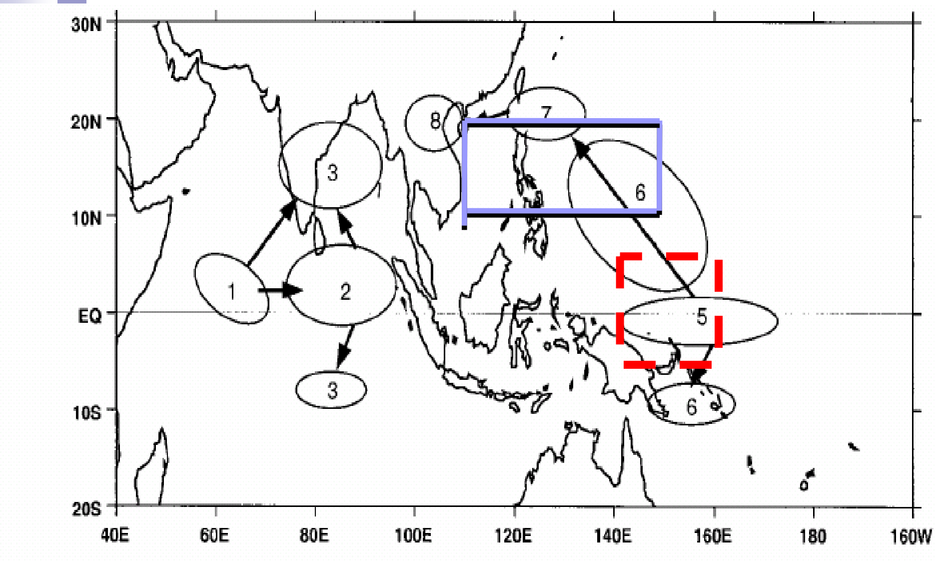
Symmetric heating (degree/day)

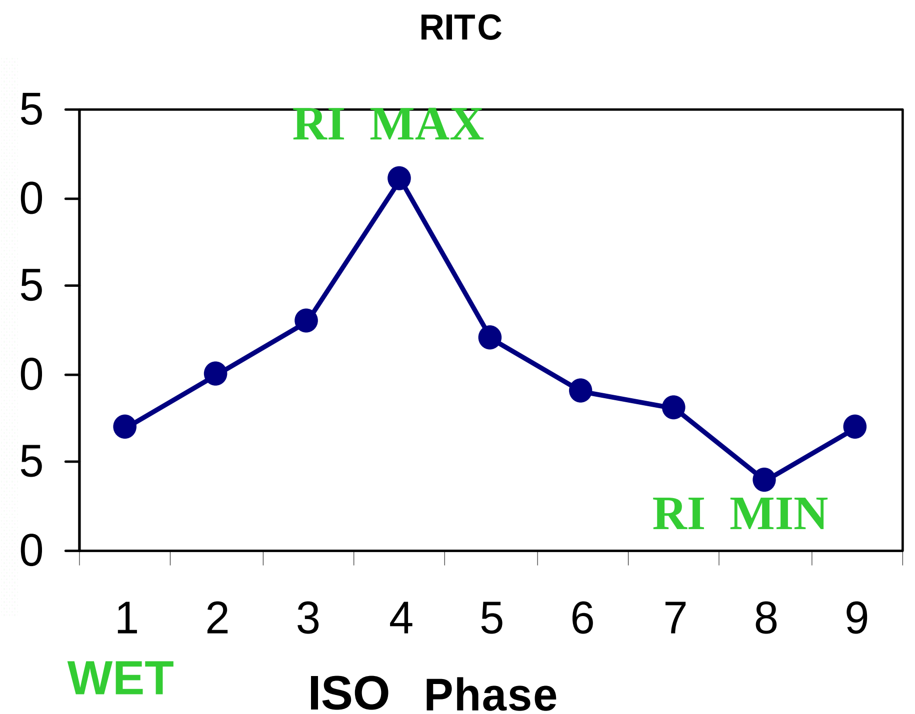
Intensity

Diabatic heating is stronger and deeper and the cooling at the low levels is much weaker

How do Low-level Meridional Shears of Zonal Flows Impact TC Rapid Intensification

Intraseasonal prediction of occurrence of RI





ISO life cycle (Aug-Oct)
Kemball-Cook and Wang (2001)

Red color box: EWP ISO index: 30-60-day filtered OLR anomalies

Number of RI over the WNP (Blue box) varies with the EWP ISO phases. The MAX (MIN) Occurrence of RI lags the peak wet phase of EWP ISO by 12 (28) days.