



From **Concentric Eyewall** to **Annular Hurricane**:

An Idealized Numerical Study with WRF model



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Outline



Introduction

- Concentric eyewall
- Annular hurricane



Experiment Design



Model Results



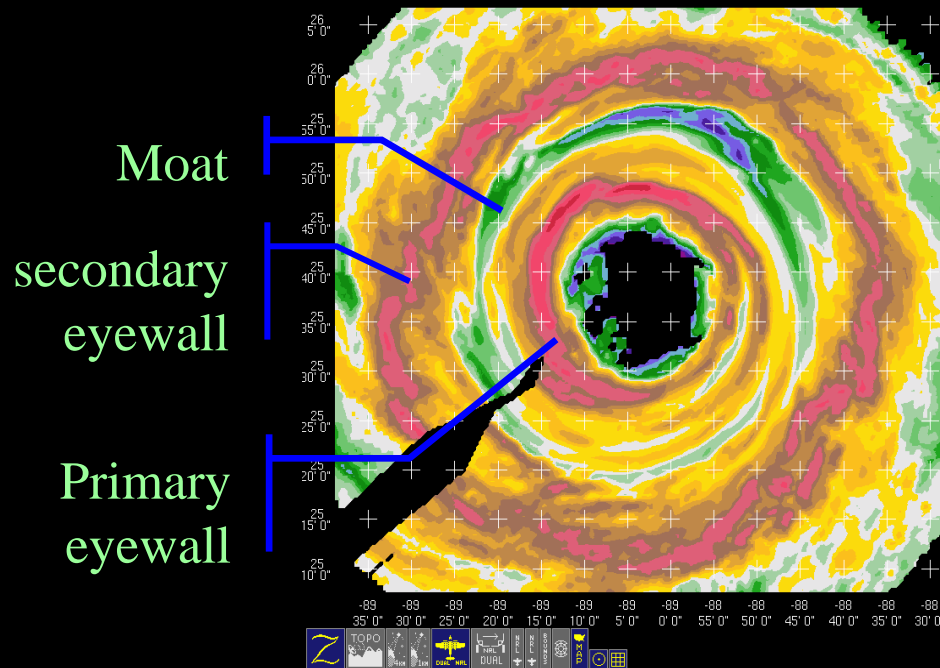
Summary and Discussion

Concentric eyewall

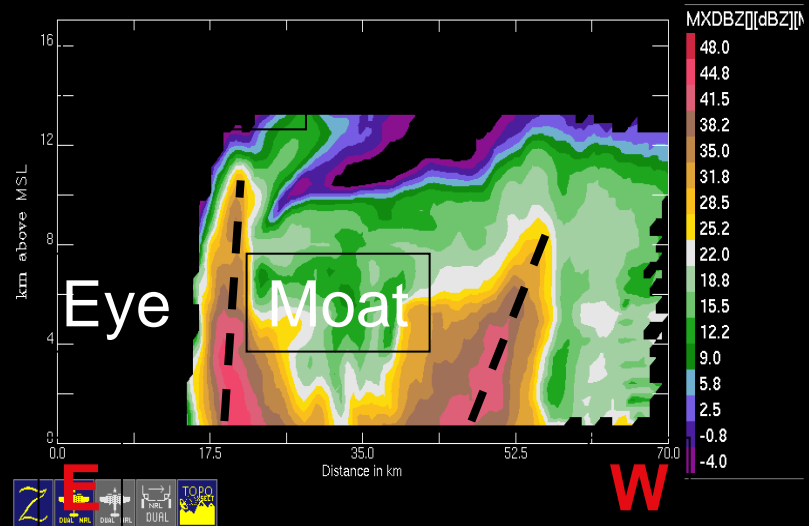
Willoughby et al (1982)

- Hurricane Rita (2005) Radar reflectivity (Houze and Smull 2008)

22-sep-2005,18:02:00 Eldora_ddop_jc MXDBZ filled contour.



22-sep-2005,18:11:30 Planar cross-section plot. Contour of MXDBZ using: eldora_ddop_jc. Contour of topo using: topo.



- Common in intense hurricanes
- Two convective rings with local tangential wind maximum
- Large intensity fluctuation during eyewall replacement
- Larger tilt of the outer eyewall

Concentric eyewall in numerical model

□ MM5

Houze et al (2007)

--Hurricane Rita (2005)

□ RAMS (Regional Atmospheric Modeling System)

Terwey and Montgomery (2008)

--Idealized numerical study

□ TCM4

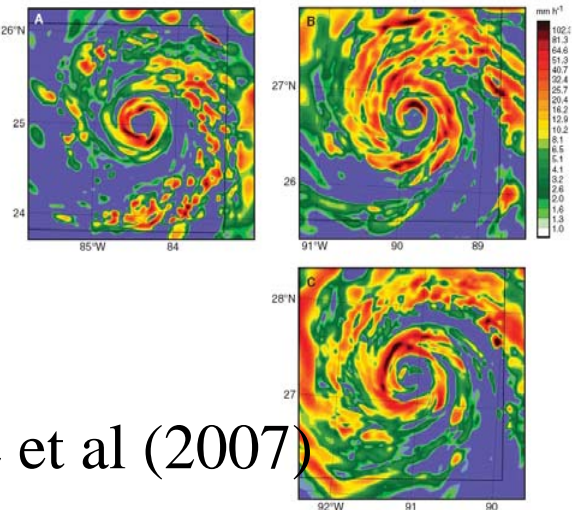
Wang (2006)

--Idealized numerical study

□ WRF?

Corbosiero et al (2008): no eyewall replacement and intensity fluctuation

Fig. 1. Forecast of surface rainfall intensity in Hurricane Rita. (A) 0715 UTC 21 September, (B) 1115 UTC 22 September, (C) 1715 UTC 22 September. Colors show the rainfall rate (mm h^{-1}) at the sea surface generated by the University of Miami's high-resolution, vortex-following, coupled atmosphere-wave-ocean version of the fifth-generation Pennsylvania State University/NCAR nonhydrostatic mesoscale model (MM5) (34) operating at a horizontal resolution of 1.67 km. Initial fields at 0000 UTC 20 September 2005 and lateral boundary conditions are from the NCEP global numerical forecast model (35).



Houze et al (2007)

Annular Hurricanes

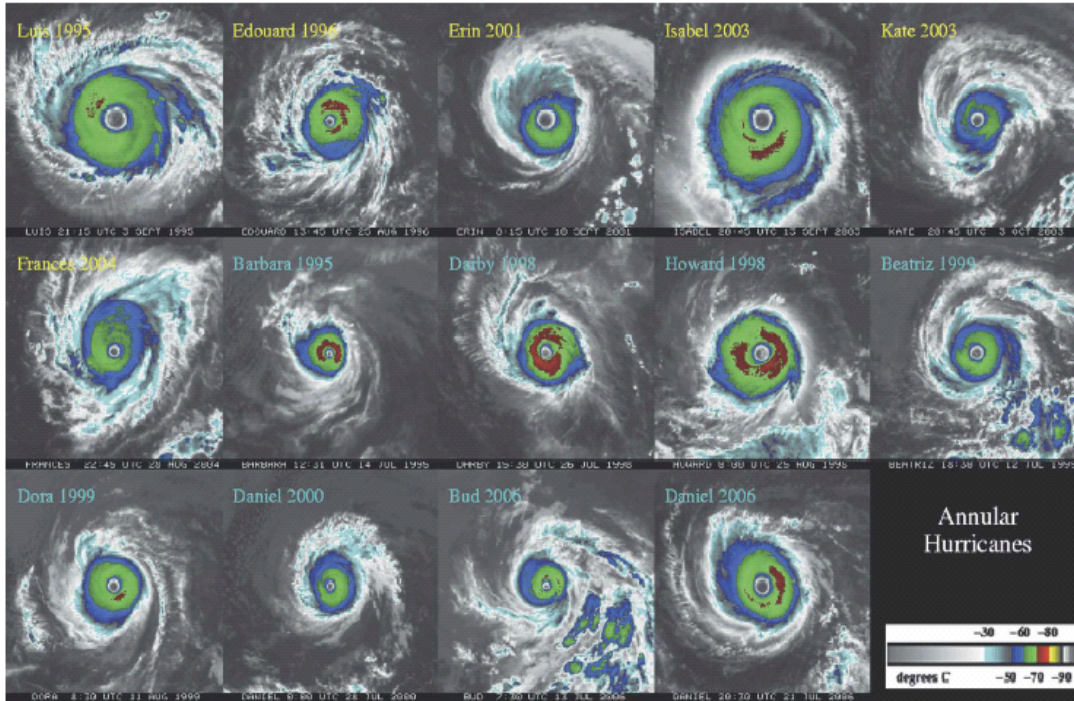
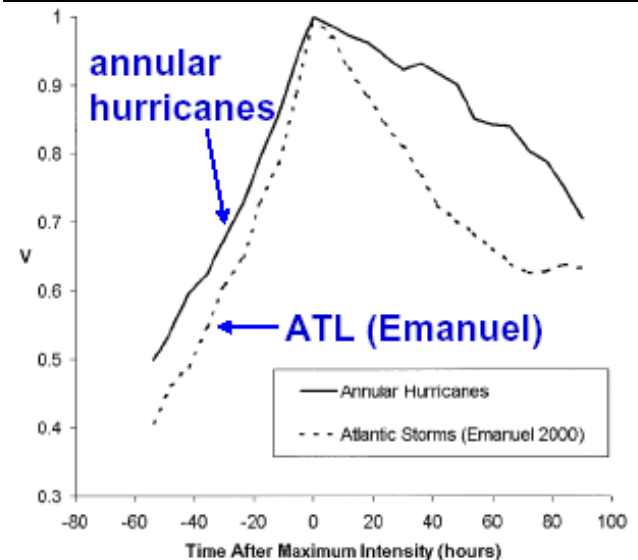


FIG. 2. Color-enhanced GOES IR satellite imagery of the 14 annular hurricane cases at or near peak visual annular characteristics. Storm names, dates, and times are given at the bottom of each individual image panel. In addition, storm names and years are listed in the upper left of each image panel with North Atlantic and eastern-central North Pacific storm names indicated by yellow and cyan text, respectively.

“Doughnut”, “truck tire”

Features

- a) large eye,
- b) thick eyewall,
- c) Relatively fewer rainbands,
- d) high intensity (~ 108 knots)



Composite time series of TC intensity change (normalized by peak intensity)

Knaff et al 2003, 2008

Formation of annular hurricane

Knaff et al (2003) :

Typical environment conditions:

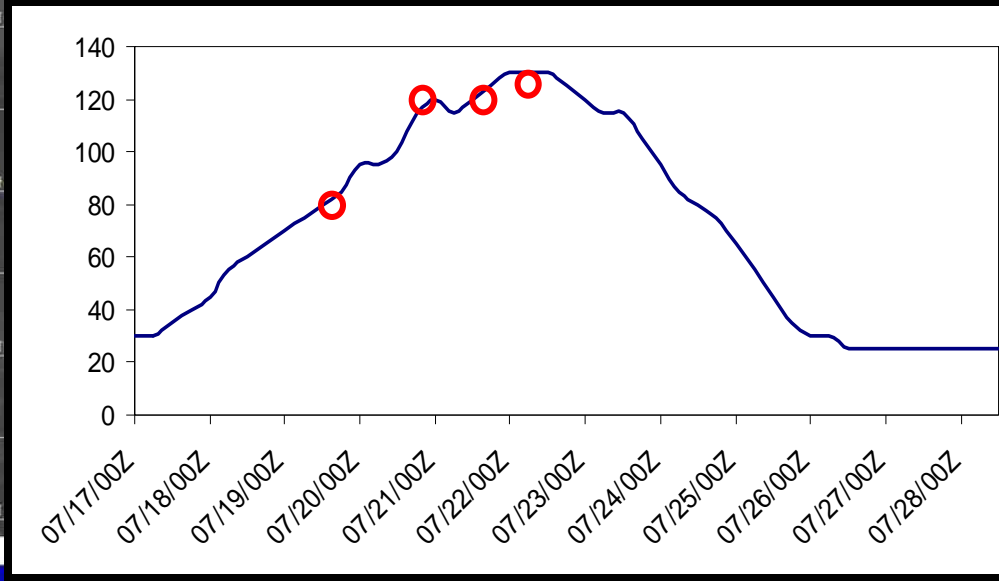
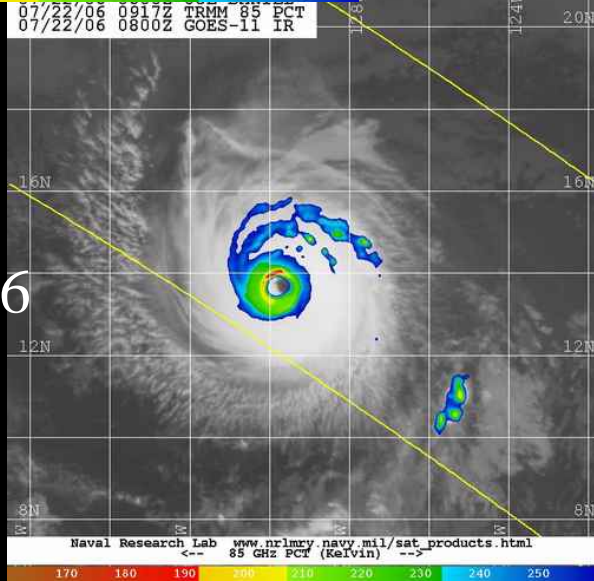
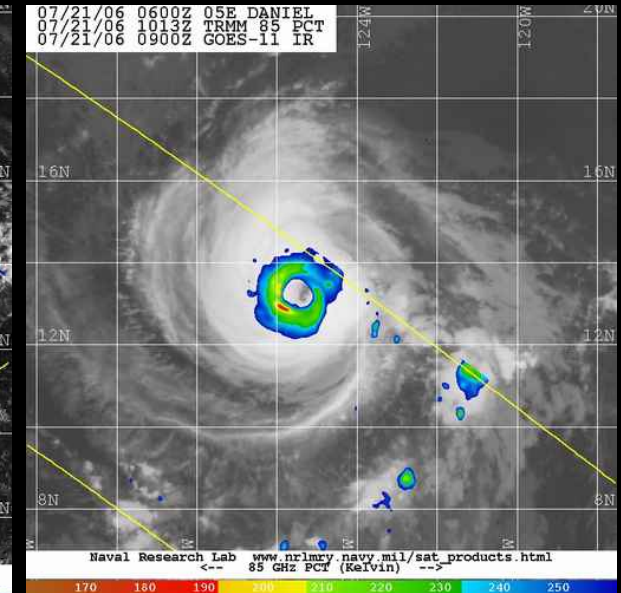
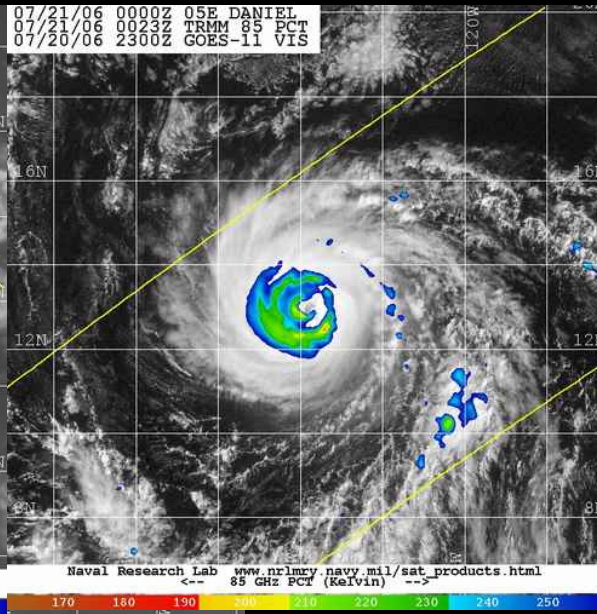
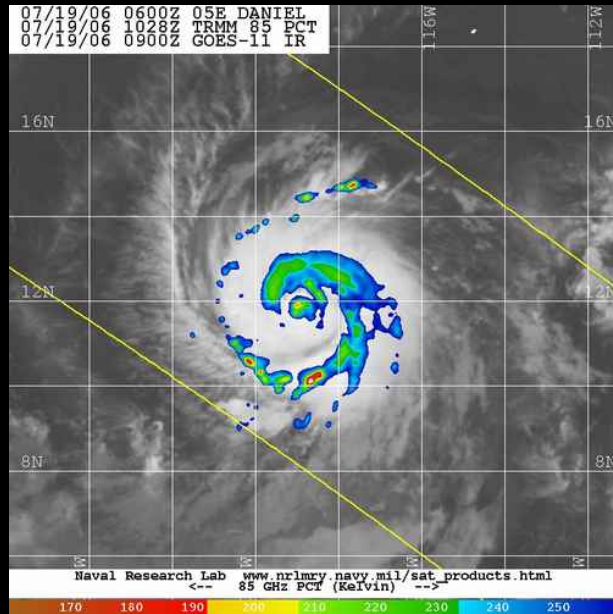
- 1) Weak easterly or southeasterly vertical shear easterly flow
- 2) Relative cold temperatures at 200 hPa
- 3) 25.4-28.5 SST
- 4) A lack of 200 hPa relative eddy flux convergence due to environmental interaction

Wang (2008):

A result of several cycles of inward contraction of the inner spiral rainband



From Concentric eyewall to annular hurricane



EP
Hurricane
Daniel 2006

Experiment design

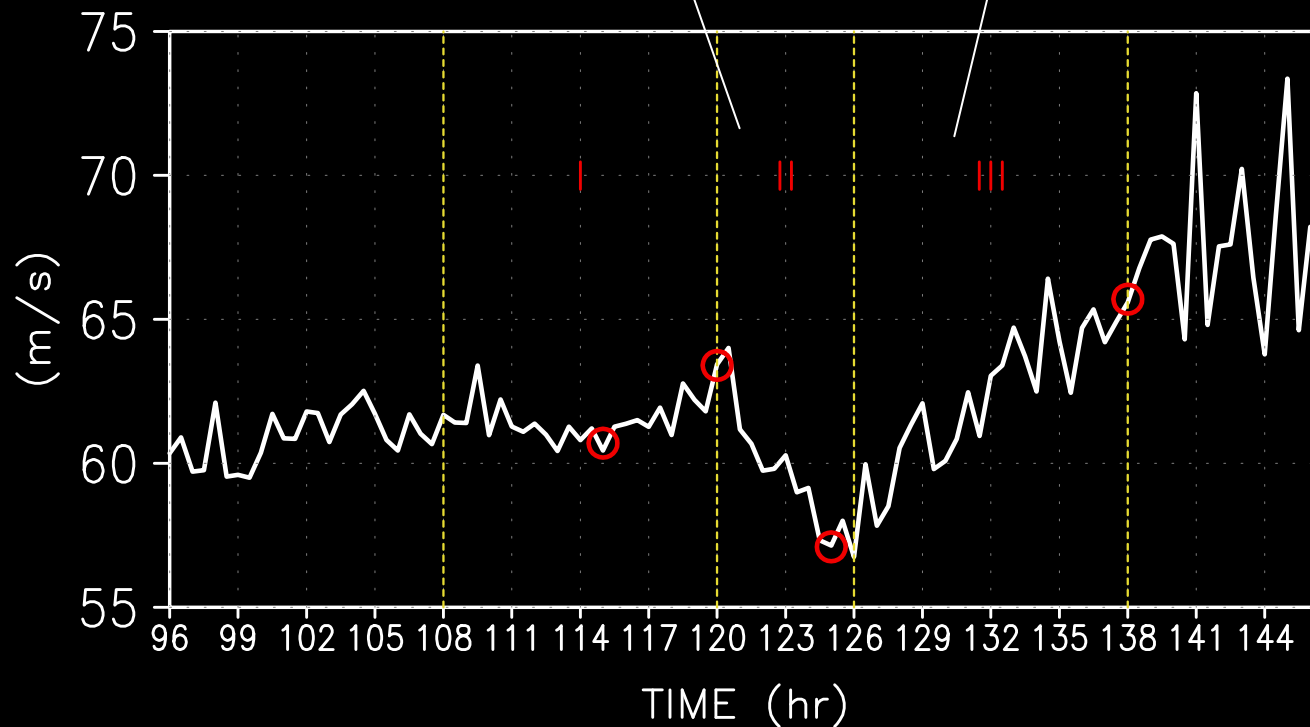
- WRF-ARW model
- 4 domains (2km 6km 18km 54km)
- Microphysics scheme: Lin et al (1983)
- No cumulus scheme for fine domains
- f -plane
- SST=29°C
- Rest environment
- Initial disturbances:

A weak vortex with maximum tangential wind 15m/s

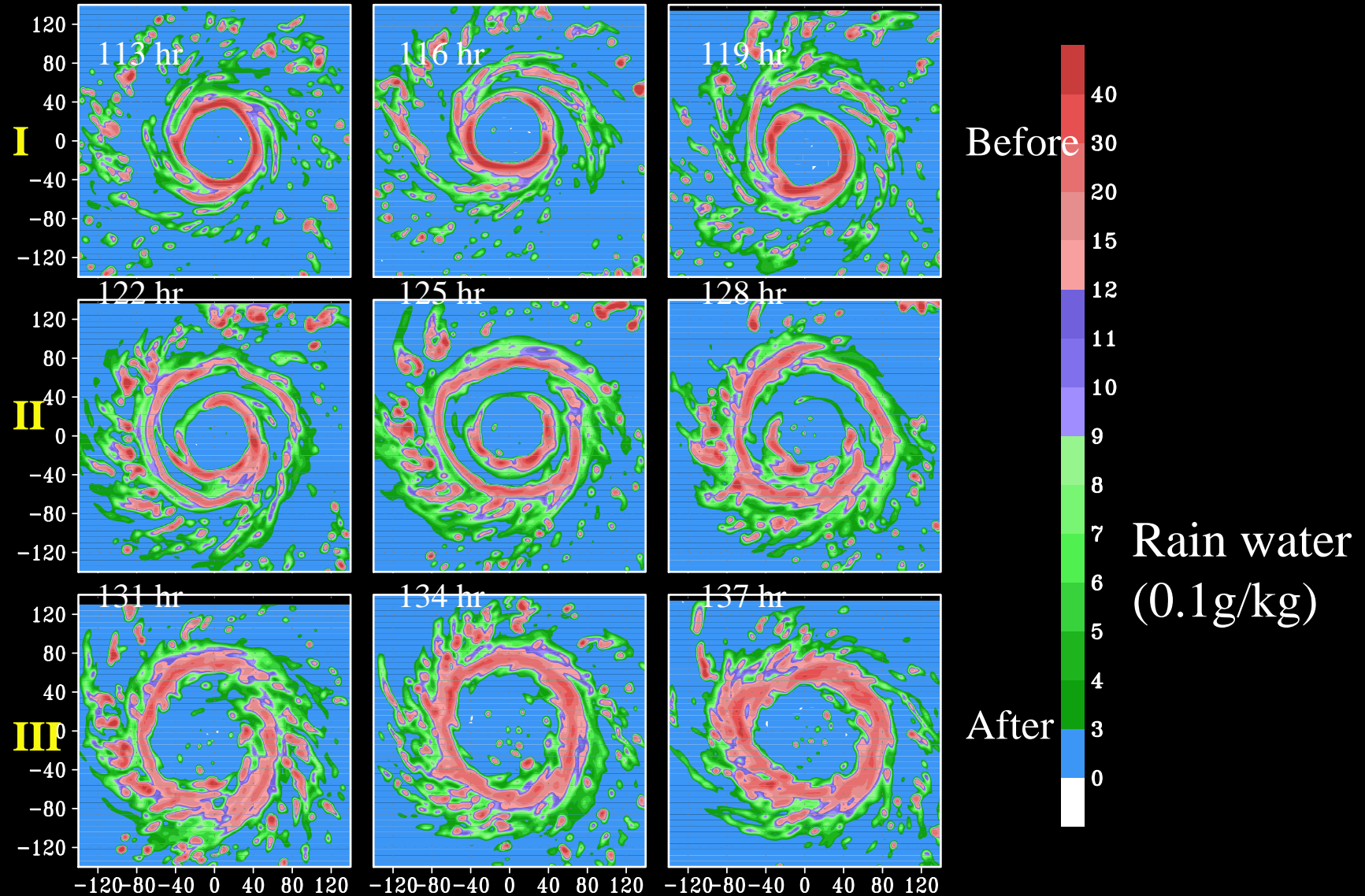
Time series of hurricane intensity

Eyewall replacement

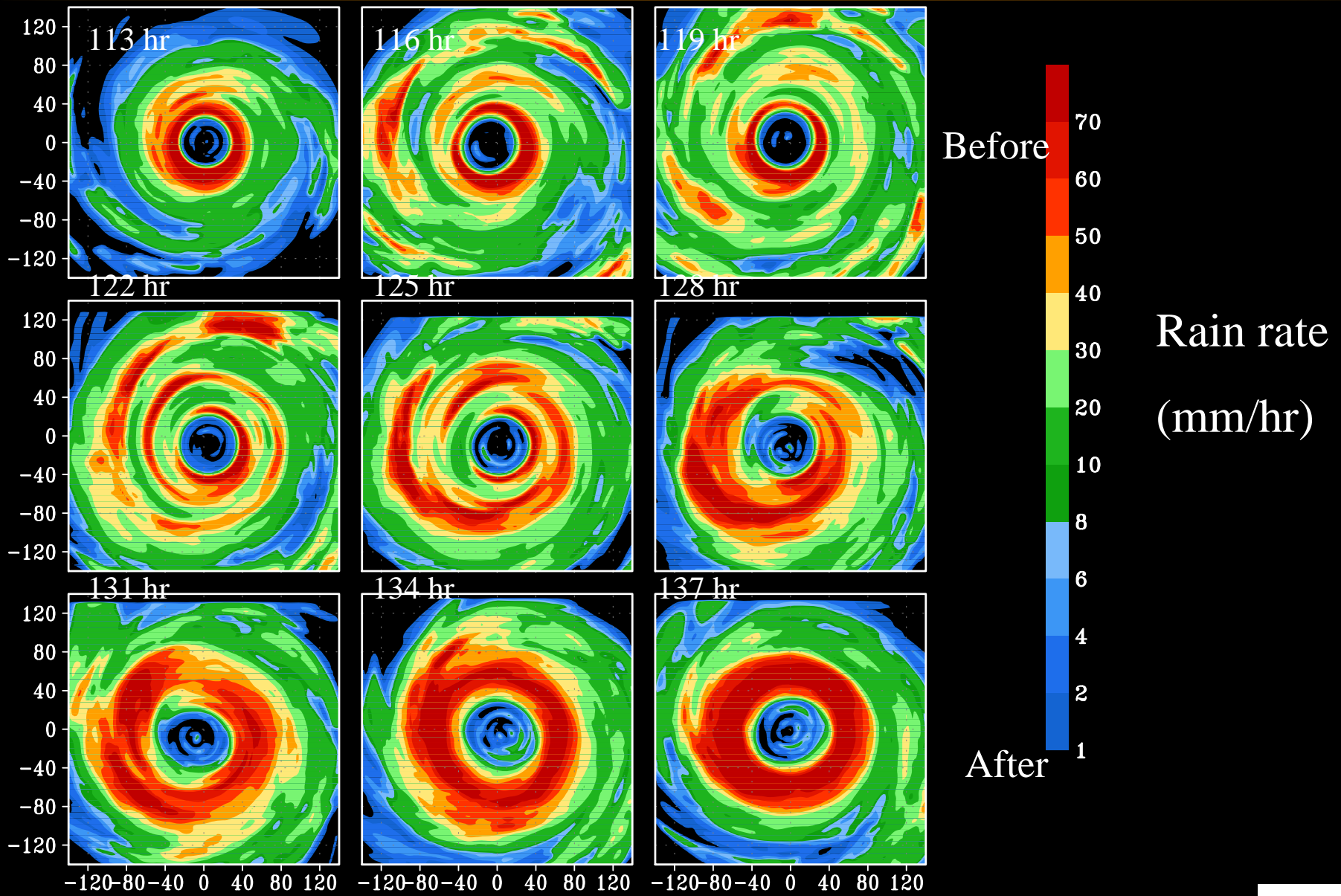
Re-intensification



Formation of concentric eyewall and AH



Formation of concentric eyewall and AH

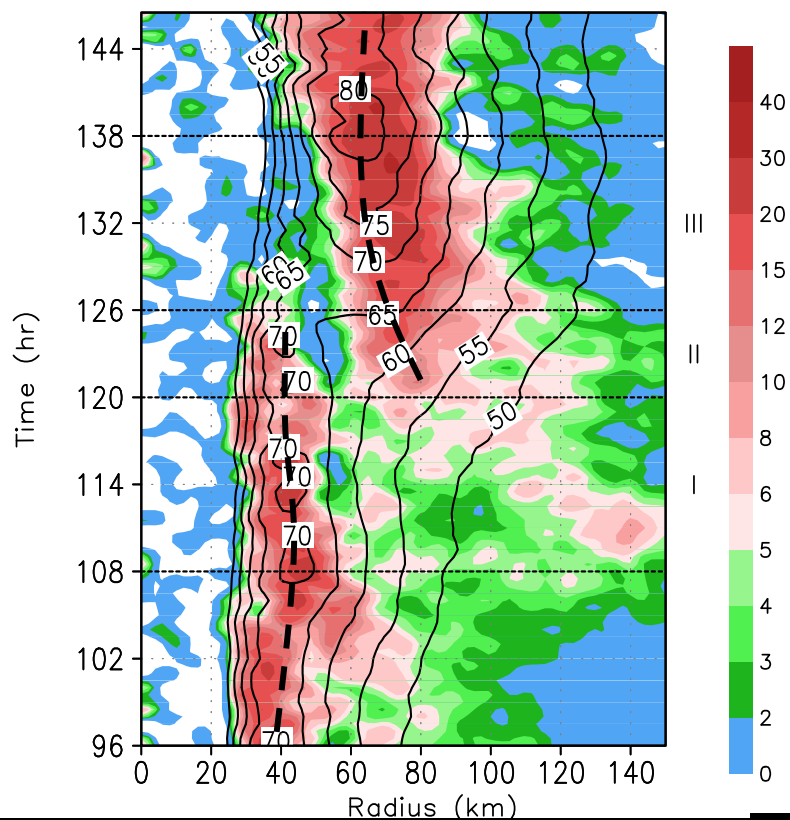


Symmetric structure

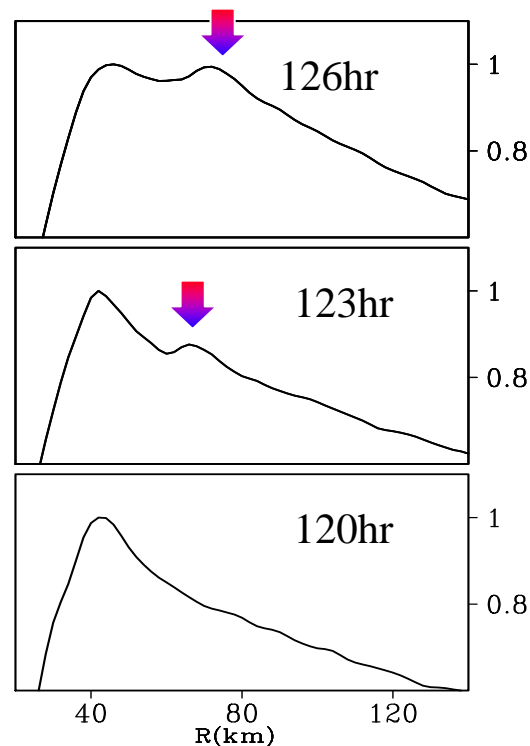
Shading: W (1cm/s) in 500hPa

Contour: V_t (m/s) in 700hPa

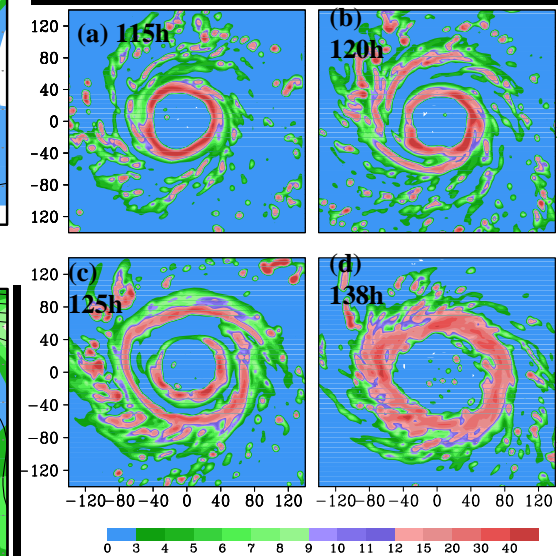
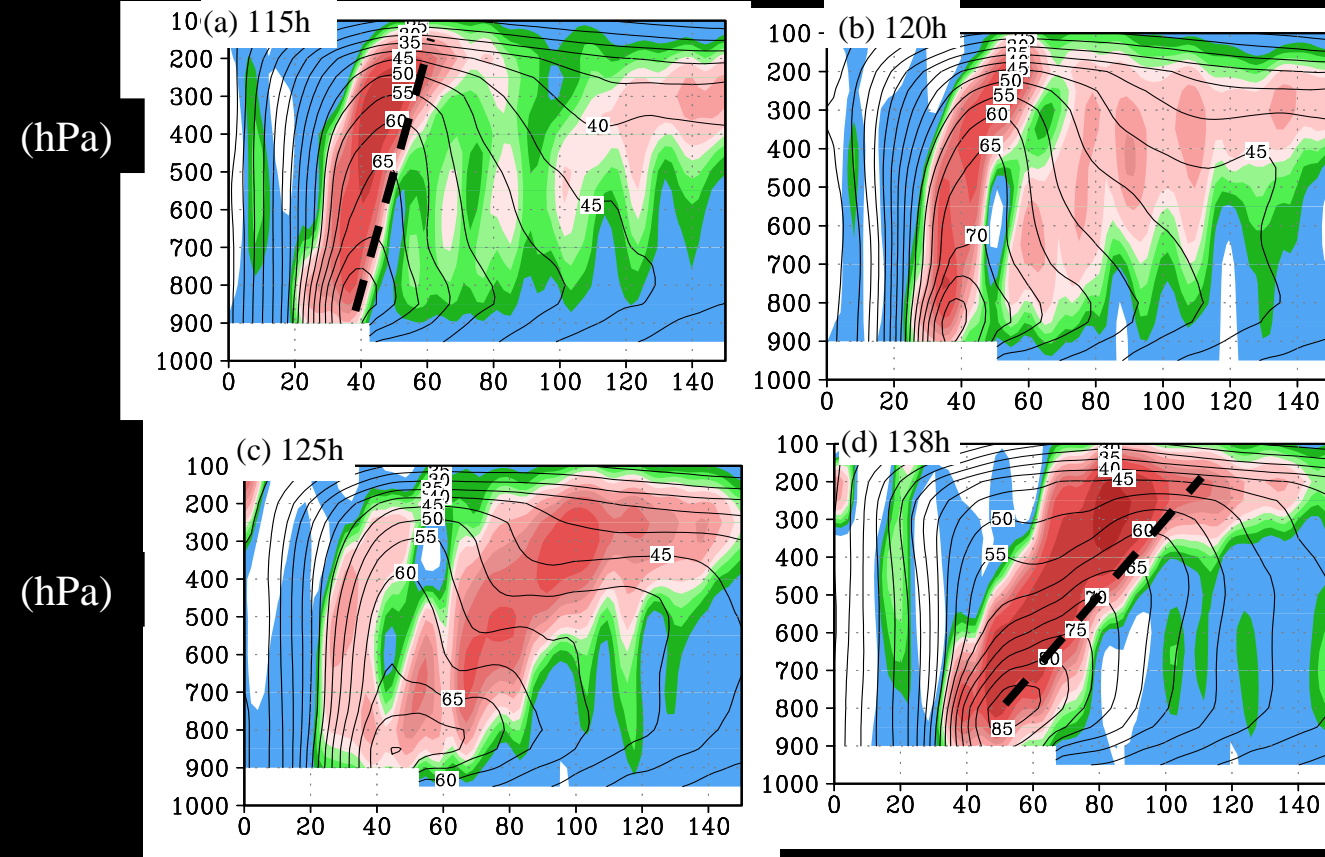
V_t (m/s) in 700hPa normalized by the maximum wind



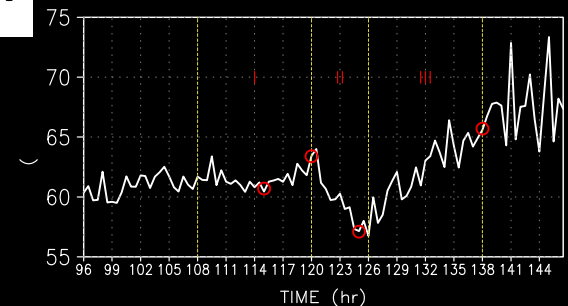
Phase II



Vertical structure



Symmetric W (1cm/s) and Vt (m/s)

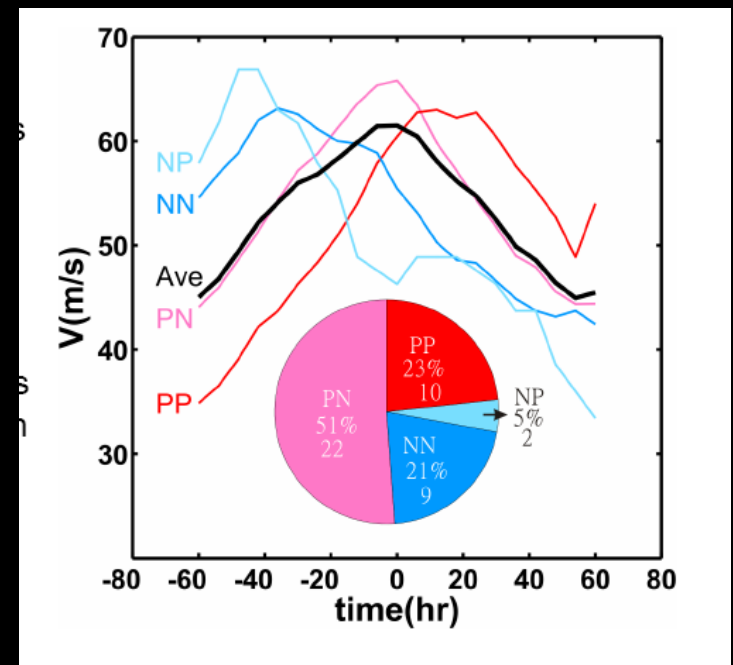


Summary and Discussion

- 1) The WRF model successfully produce the concentric eyewall, the eyewall replacement and accompanied intensity change
- 2) The replacement process is quite fast (about 6hr) and the intensity does not have dramatic fluctuation (8-10 m/s) during the eyewall replacement
- 3) Concentric eyewall is a route to the formation of an annular hurricane

Average: -5m/s in 10hrs

P: increase; N: decrease



Composite time series of the intensity change before and after the concentric eyewall (Kuo et al 2007)



Thank you

