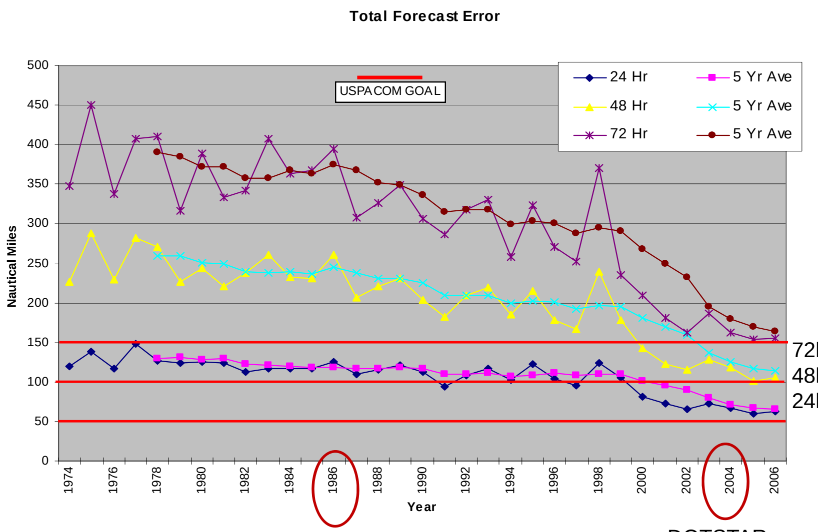
Typhoon Intensity Change, Theory and Forecasting

Asia Pacific Typhoon Workshop
Jan 27-28 2010
Manila, Philippines

Hung-Chi Kuo
Department of Atmospheric Sciences
National Taiwan University
Chinese Taipei

West Pac Track Errors cut in half since 1990



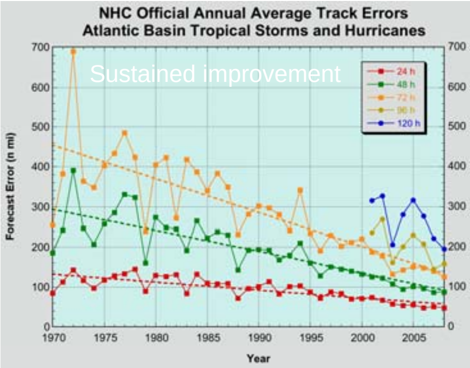
72h 200NM
48h 100NM
24h 50NM

Aircraft observation stopped

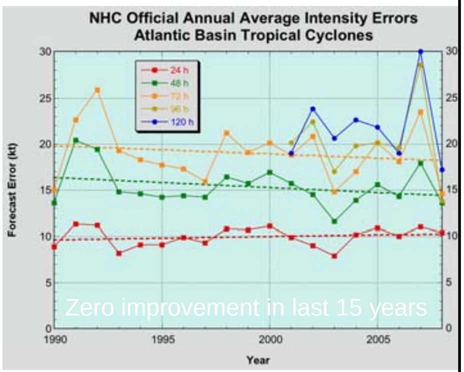
DOTSTAR

Edward Fukada
JTWC

Error cut in half since 1990



No progress in the last 20 years



www.nhc.noaa.gov/verification/verify5.shtml

Why such a big difference between track and intensity?

Courtesy of Dr. G. Holland

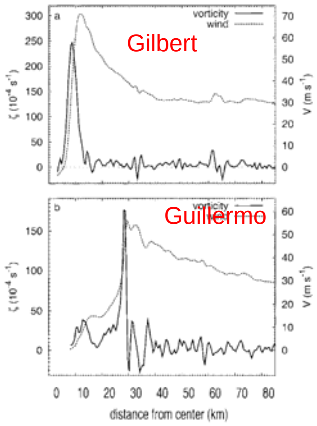
Environmental Factors

Typhoon weakens
over region of cold water or low ocean heat content,
over land or region of decreased humidity,
over region of strong vertical wind shear.

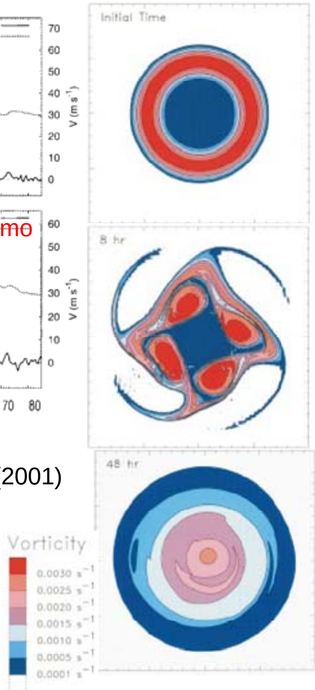
However, the variance of typhoon intensity change from climatology is not explained well by the synoptic-scale environmental conditions.

It is fairly typical for typhoons to strengthen or weakens rapidly without any clear commensurate changes in the environment.

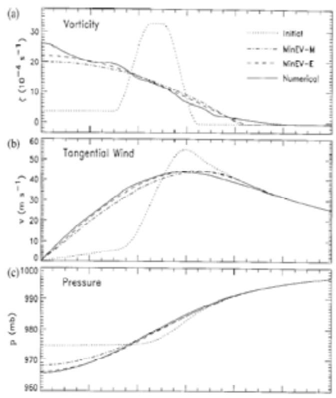
Internal meso-scale processes matter!



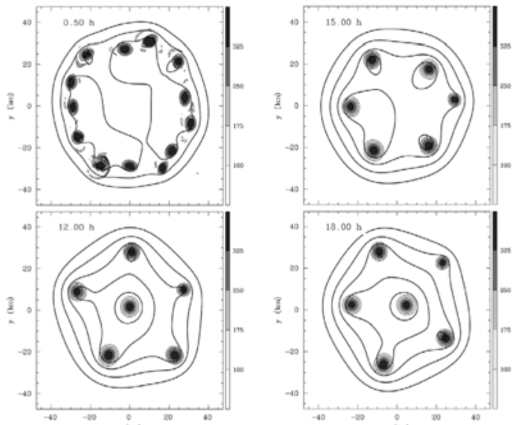
Kossin and Schubert (2001)



Schubert et al. (1999)



Vorticity mixing leads to Rapid Intensification !



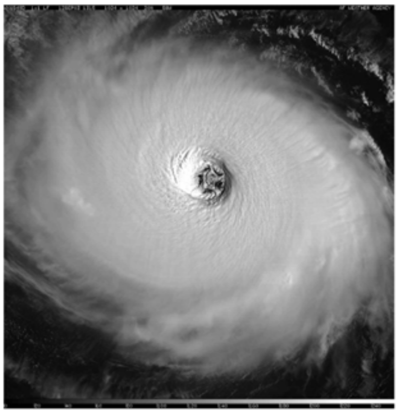


Fig. 1. Defense Meteorological Satellite Program (DMSP) image of Hurricane Isabel at 1315 UTC 12 Sep 2003. The starfish pattern is caused by the presence of six mesovortices in the eye—one at the eye center and five surrounding it.

Fig. 2. Evolution of vorticity (shaded) and streamfunction contours (bold) for the numerical experiment of Kossin and Schubert (2001). Values along the label bar are in units of 10^{-4} s^{-1}. The shape of the streamlines transitions from a pentagon to a hexagon and back to a pentagon over 6 h.

MESOVORTICES IN HURRICANE ISABEL

BY JAMES P. KOSSIN AND WAYNE H. SCHUBERT

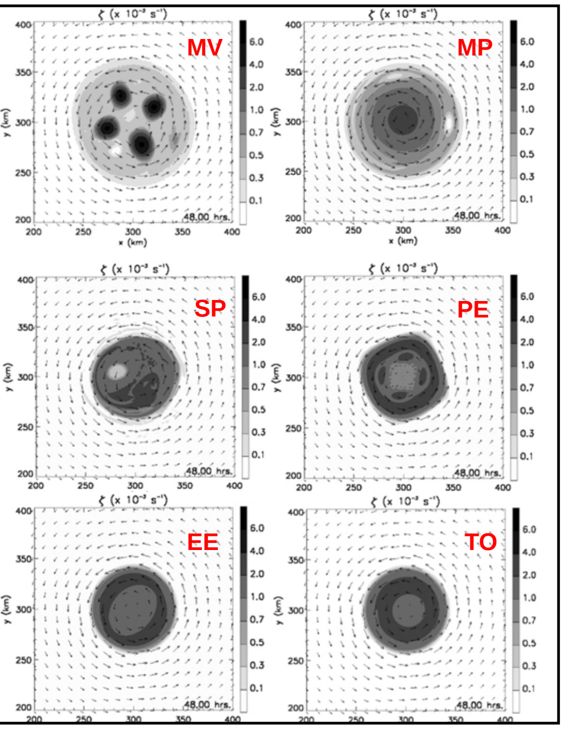
Importance of Asymmetric Vorticity Dynamics

A case where MPI theory failed! (Montgomery 2006)

6 End States

- TO: trochoidal oscillatior
  MP: monopole
  SP: slow monopole
  MV: mesovortices
  EE: elliptical eyewall
  PE: polygonal eyewall

Hendricks et al. (2009)



γ \ δ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85
0.9 (filled)							TO	EE	EE	EE	EE	EE	EE	EE	SP	SP	SP
0.8							TO	TO	EE	EE	EE	EE	EE	SP	SP	SP	SP
0.7							TO	TO	TO	EE	EE	EE	EE	SP	SP	SP	SP
0.6							TO	TO	TO	EE	EE	EE	SP	SP	SP	SP	MP
0.5							TO	TO	TO	PE	PE	PE	SP	SP	SP	MP	MP
0.4							TO	PE	PE	PE	SP	SP	SP	SP	MP	MP	MP
0.3							TO	PE	PE	PE	SP	SP	SP	SP	MP	MP	MV
0.2							TO	PE	PE	SP	SP	SP	SP	MP	MP	MV	MV
0.1							TO	PE	PE	SP	SP	SP	MP	MP	MP	MV	MV
γ (hollow)							TO	TO	PE	SP	SP	SP	MP	MP	MP	MV	MV

thick — thin

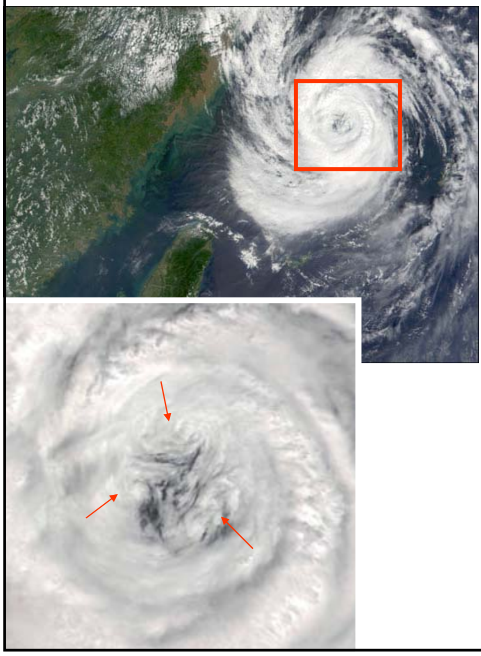
Δp_{min}

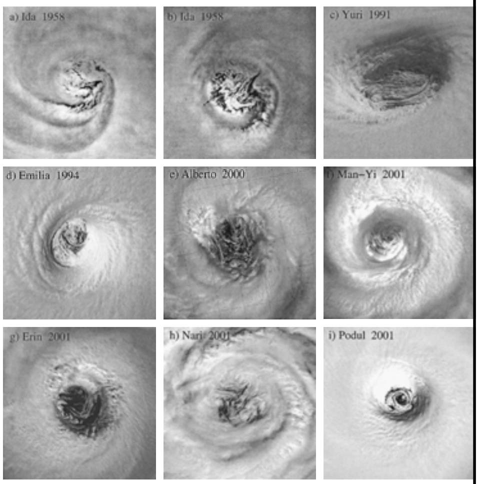
γ \ δ	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85
0.9 (filled rings)	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
0.8	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.0	-0.1	-0.3	-0.5	-0.4
0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-0.2	-0.4	-0.8	-0.8	-0.9	-2.1
0.6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-0.2	-0.9	-0.5	-2.1	-3.0	-3.4
0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	-0.5	-0.6	-1.2	-3.1	-3.7	-4.4	-5.0
0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-0.9	-1.6	-2.0	-4.4	-5.3	-5.8	-6.2
0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-0.3	-0.7	-1.2	-1.7	-3.9	-4.3	-5.7	-6.3	-6.9	-8.3
0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.1	-0.3	-1.9	-2.4	-2.8	[illegible]	-5.5	-6.5	-7.6	-8.0	-9.7
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-1.9	-3.0	-3.0	[illegible]	-6.4	-7.4	-8.3	-9.9	-1.7
0 (hollow rings)	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	-1.8	-3.4	-4.0	-5.8	-6.9	-8.1	-9.4	-11.2	-14.0

(thick rings) δ (thin rings)

Hendricks et al. (2009)

Meso vortices in Typhoon Nari

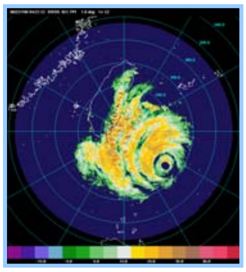




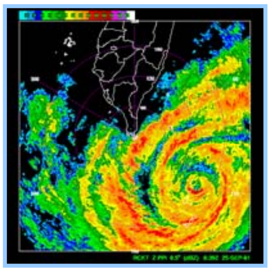
Vortical Swirls in Typhoon Eye Clouds

Kossin and Schubert 2002

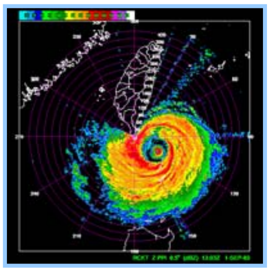
Concentric eyewalls near Taiwan



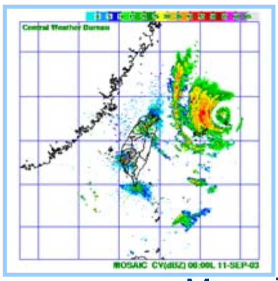
Bilis(2000)

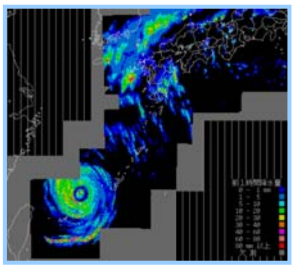


Lekima(2001)



Dujuan(2003)

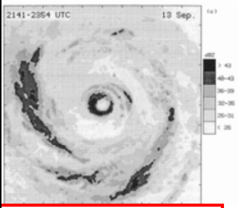


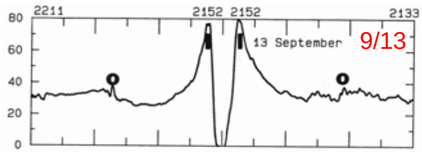


Maemi(2003)

A major issue in understanding changes in typhoon intensity

Black and Willoughby (1992)
Hurricane Gilbert (1988)



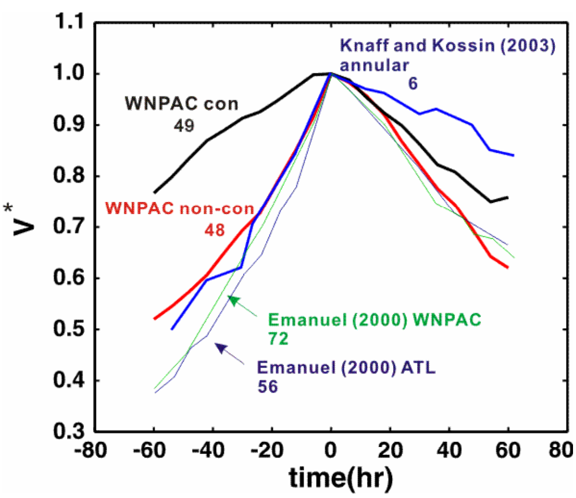


Development of symmetric structure from asymmetric convection in 12 hours

The contraction of the Outer tangential wind maximum

Core vortex intensity remains approximately the same during the contraction period

Inner core dissipate, TC weakens

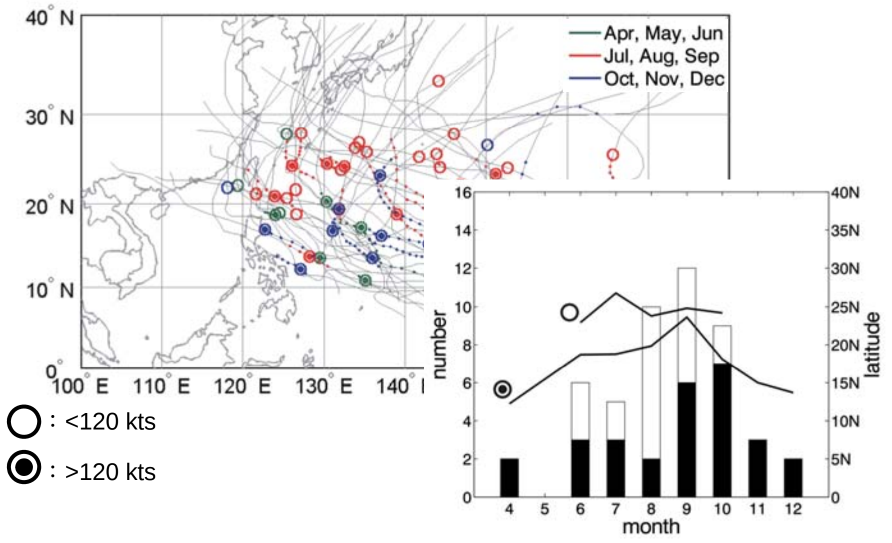


Key feature of concentric eyewall formation appears to the maintenance of a relative high intensity for a longer duration prior to formation, rather than a rapid intensification process that can reach a high intensity.

Kuo et al. 2009

WNPAC Concentric eyewalls formation locations, intensity, and tracks

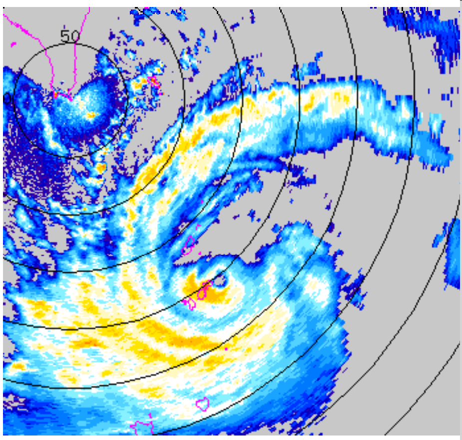
Kuo et al. (2009)



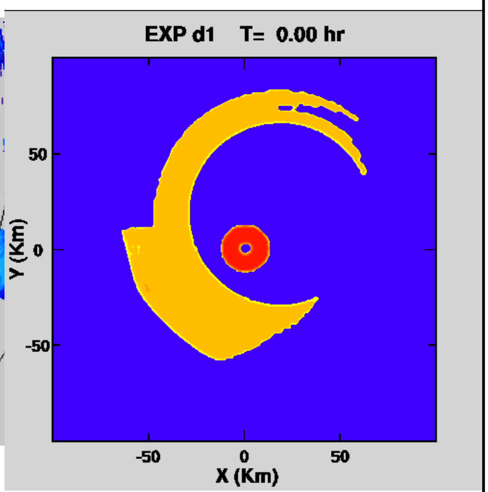
Concentric Eyewall formation

Kuo, H.-C., L.-Y. Lin, C.-P. Chang, and R. T. Williams, 2004: The formation of concentric vorticity structure in typhoons. *J. Atmos. Sci.*, **61**, 2722-2734.
Kuo, H.-C., W. H. Schubert, C.-L. Tsai, and Y.-F. Kuo, 2008: Vortex interactions and barotropic aspects of concentric eyewall formation. *Mon.Wea. Rev.*, **136**, 5183–5198.

0935-1935 LST



Typhoon Lekima (2001)

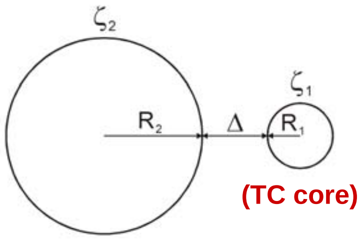


Binary vortex interaction

Kuo et al. (2004,2008)

【Variables】

$R_1, R_2;\ \Delta;\ \zeta_1, \zeta_2$ Beta-skirt



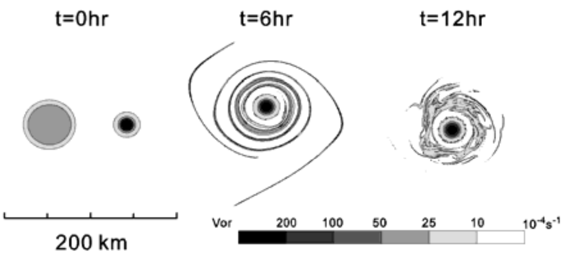
【Parameters】

- Vortex radius ratio $(r) = \frac{R_1}{R_2}$
- Dimensionless gap $(\frac{\Delta}{R_1})$
- Vortex strength ratio $(\gamma) = \frac{\zeta_1}{\zeta_2}$

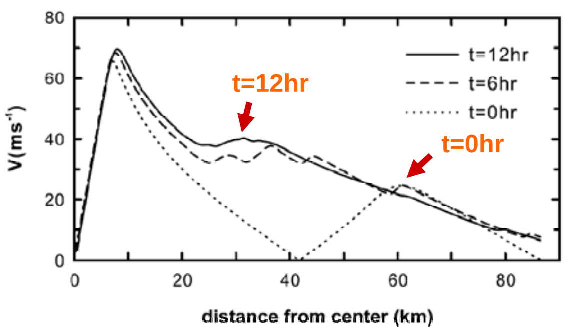
- **An extension of Dritschel and Waugh's (1992) work.**
- **In addition to the radii ratio and the normalized distance between the two vortices, the vorticity ratio is added as a third external parameters.**

$\alpha = 0.7$ $\gamma = 7$ $r = 1/4$ $\Delta/R_1 = 5$

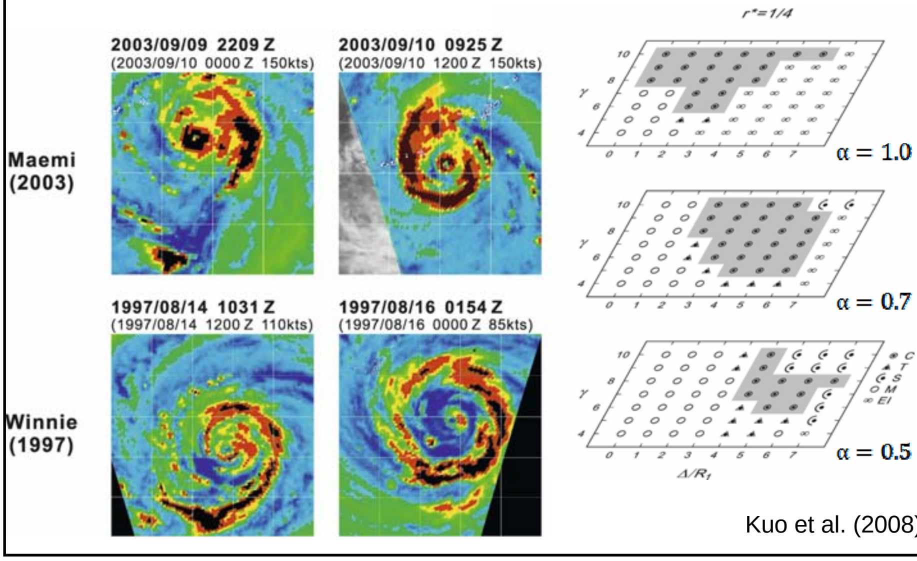
The formation of concentric eyewalls



The contraction of the secondary wind maximum by nonlinear advection dynamics.



Double eyewall of different sizes maybe explained by the binary vortex interaction with skirted parameter



Kuo et al. (2008)

D12112 TERWEY AND MONTGOMERY: MODELED SECONDARY EYEWALL FORMATION D12112

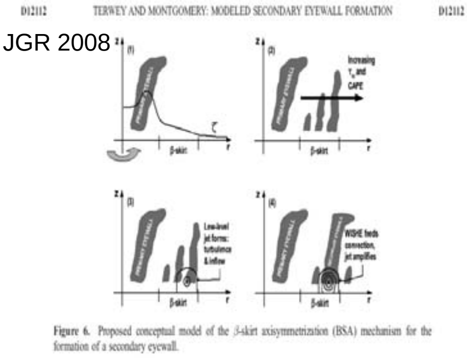
JGR 2008

Table 1. List of Secondary Eyewall Formation Hypotheses With Summary of Relevance to our Modeled Hurricanes[a]

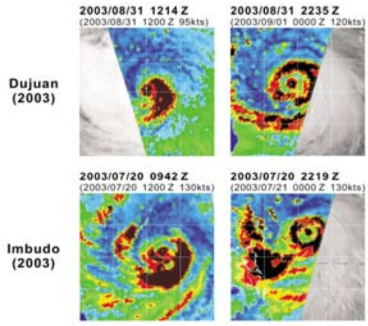
Authors	Hypothesis Summary	Relevance to Current Model Results	Type
Willoughby et al. [1982] borrowing from the squall line research of *Zipser* [1977]	Downdrafts from the primary eyewall force a ring of convective updrafts.	Few downdraft-forced updrafts during this time in the simulations.	O
Willoughby [1979]	Internal resonance between local inertia period and asymmetric friction due to storm motion.	No systematic storm motion in the simulated storms.	A
Hawkins [1983]	Topographic effects	No topographic forcing in the simulations.	O
Willoughby et al. [1984]	Ice microphysics	"Warm-rain" (no-ice) sensitivity case also produces secondary eyewall.	A
Molinari and Skubis [1985] and *Molinari and Vallaro* [1989]	Synoptic-scale forcings (e.g., inflow surges, upper-level momentum fluxes)	No synoptic-scale forcings in the simulations	O
Montgomery and Kallenbach [1997], *Camp and Montgomery* [2001] and *Terwey and Montgomery* [2003]	Internal dynamics-axisymmetrization via sheared vortex Rossby wave processes; collection of wave energy near stagnation or critical radii	Possible explanation	N
Nong and Emanuel [2003]	Sustained eddy momentum fluxes and WISHE feedback	Possible explanation	A
Kuo et al. [2004, 2008]	Axisymmetrization of positive vorticity perturbations around a strong and tight core of vorticity.	Possible explanation	N

[a]The type column refers to the type of model or observations that were used to formulate the hypothesis. O stands for observationally-based; A stands for axisymmetric model; N stands for nonaxisymmetric model.

JGR 2008



Kuo et al. 2008



Importance of the vorticity axisymmetrization dynamics + convections.

Need to understand both the vorticity generating meso-scale processes in the TC environment and the detail core structure.

Filamentation time (Rozoff et al.,2006)

$$\frac{D}{Dt}(\nabla\zeta) = -J(\nabla\psi,\zeta)$$

$$\frac{1}{2}S_1 = u_x - v_y \text{, stretching deformation}$$

$$\frac{1}{2}S_2 = v_x + u_y \text{, shearing deformation}$$

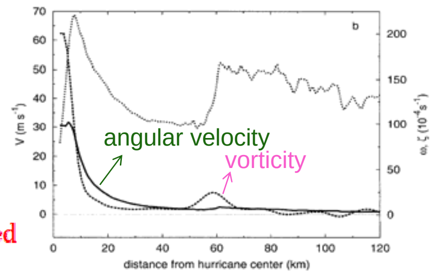
(i) when $S_1^2 + S_2^2 - \zeta^2 < 0$, **rotation dominated**

$$\nabla\zeta(t) \propto \exp\left[\frac{1}{2}i(\zeta^2 - S_1^2 - S_2^2)^{\frac{1}{2}}t\right]$$

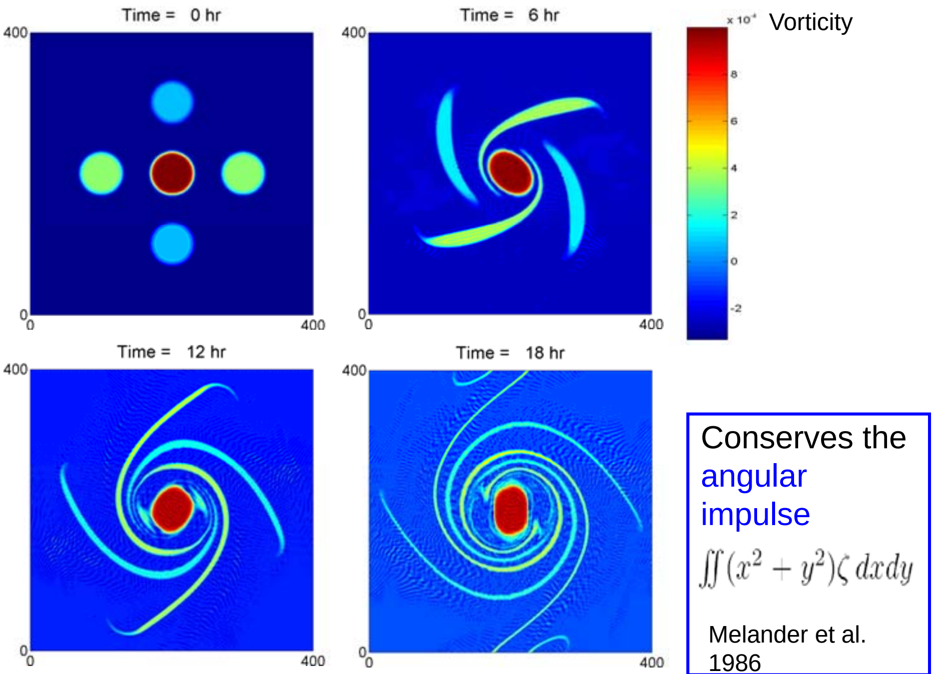
(ii) when $S_1^2 + S_2^2 - \zeta^2 > 0$, **strain dominated**

$$\nabla\zeta(t) \propto \exp\left[\frac{1}{2}(S_1^2 + S_2^2 - \zeta^2)^{\frac{1}{2}}t\right]$$

- $\tau_{fil} = 2(S_1^2 + S_2^2 - \zeta^2)^{-1/2} < 30\,\text{min}$: rapid filamentation time



- The strong differential rotation associated with the core vortex



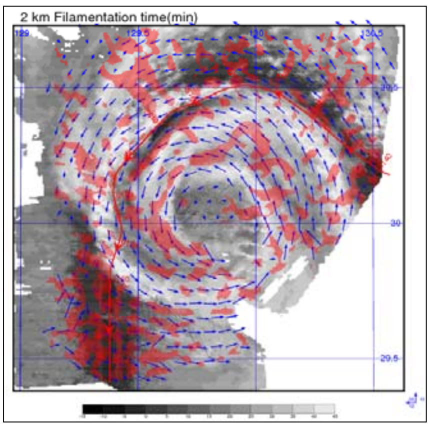
Conserves the angular impulse

$$\iint (x^2 + y^2)\zeta \, dx dy$$

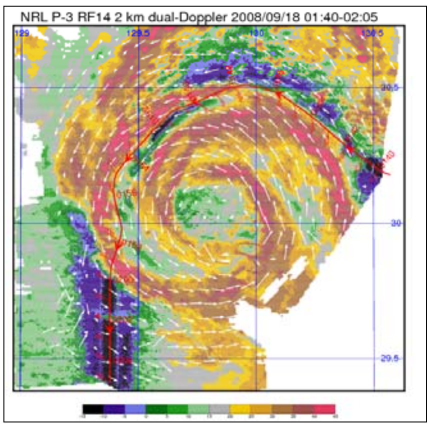
Melander et al. 1986

TCS08: Typhoon Sinlaku
ELDORA Doppler radar data,
Flight level data, Dropsondes

Fliamentation time



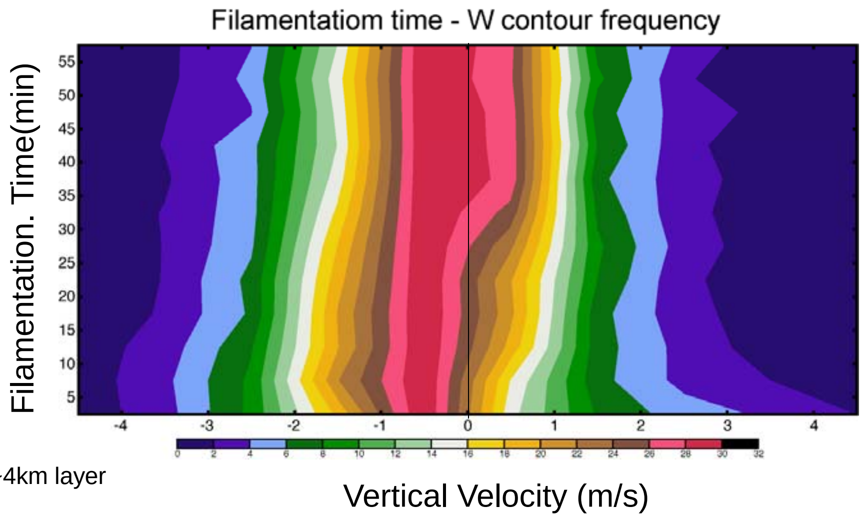
Reflectivity and wind field



T<20min are shaded

2km

Kuo et al. 2010

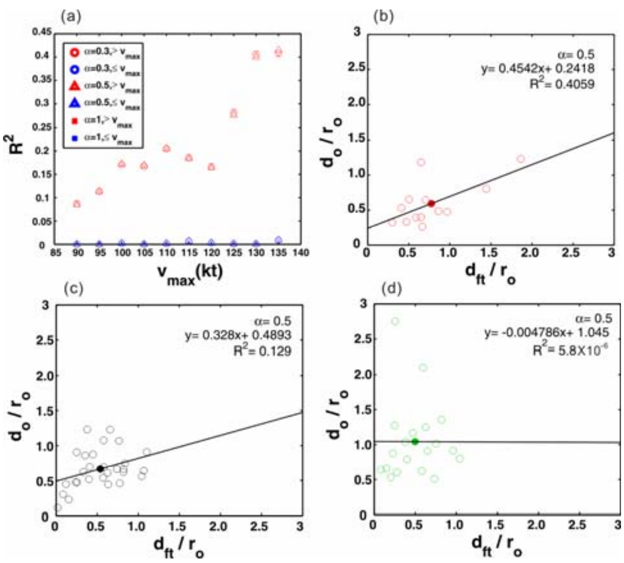


2~4km layer

Convections in strong differential rotation environment,
weak updraft is diminished.

Kuo et al. 2010

1997-2006
62 CE cases



Cat 5

Cat 4

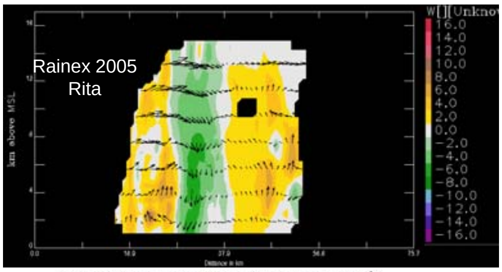
else

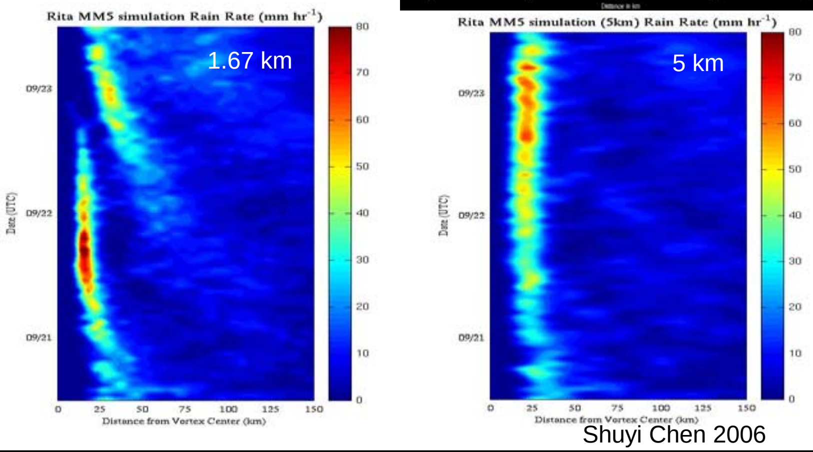
The rapid filamentation process tends to make an important contribution to the organization of the moat in strong typhoons, especially in cases where the maximum winds are greater than 130 kts.

Kuo et al. (Nov. 2009 MWR)

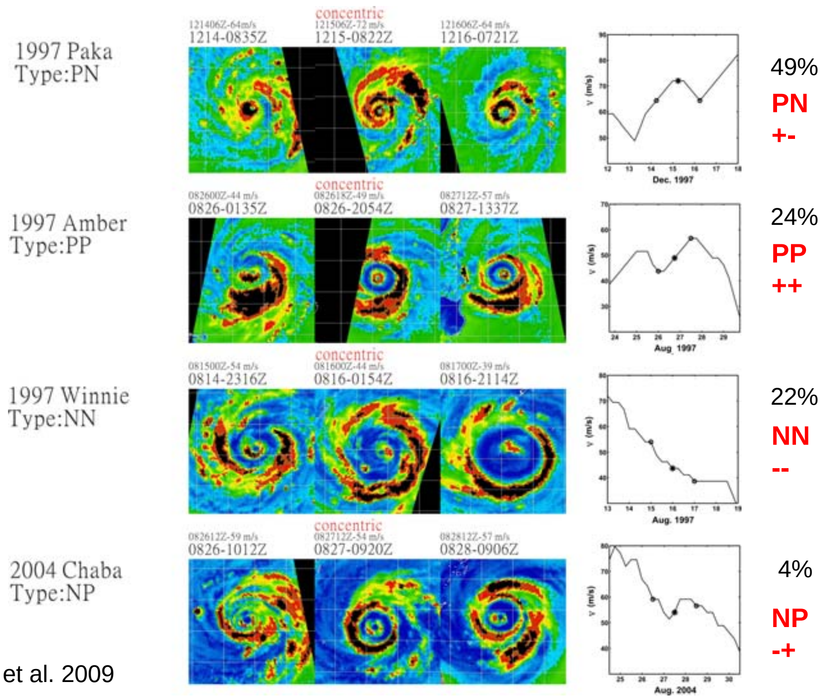
Large variability in vertical motion.

High resolution appears to be crucial in concentric eyewall simulation.



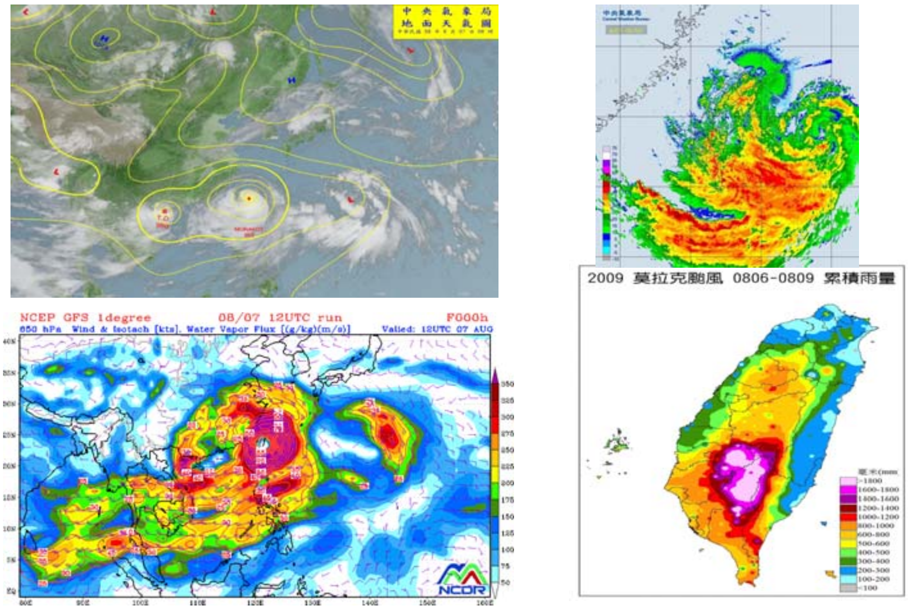


Shuyi Chen 2006



Kuo et al. 2009

Typhoon Morakot (2009) a disaster case with multiple scale interactions



Research Issues in Typhoon Intensity (and Structure)

Spatial correlation of potential vorticity and diabatic heating;

Why no concentric eyewall in some intense typhoons? Why different intensity change in CE;

Multiple scale interactions;

Triggering mechanism for outer bands dissipation before RI;

Inertial gravity wave radiation from the inner core;

Target observation and data assimilation;

Air-sea interaction;

Many more………….

Typhoon Intensity Forecasting with Limit Resources

Multiple scale interactions in the model;

High resolution model with explicit convection (expensive!);

Data assimilation, bogus vortex initialization;

High resolution deterministic and low resolution probabilistic forecasts;

Relevant details of air-sea interaction (parametric or explicit);

More observations and to fully utilize observations in the models;

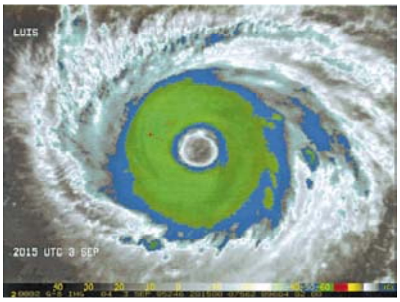
Many more…………..

Thank you!

A painting with filamentations!

Knaff and Kossin (2003)

- color-enhanced IR image of Hurricane Luis (1995) at 2015 UTC 3 Sep



dimensionless	24-h weakening
ATL(56)	0.14
Annular hurricanes(6)	0.05