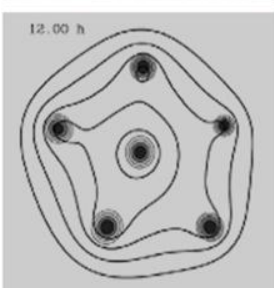
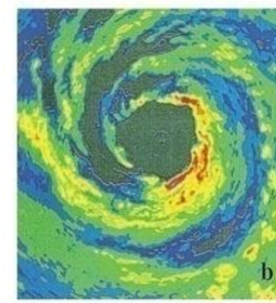
Tropical Cyclone Structural and Intensity Variability

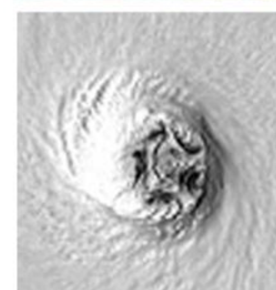


Hung-Chi Kuo[1]
Yi-Ting Yang[1]
Eric A. Hendricks[2]
Melinda S. Peng[2]

1*National Taiwan University, Taipei, Taiwan*
2*Marine Meteorology Division,*
Naval Research Laboratory, Monterey, CA, U.S.A.

AOGS Taipei, 8/12/2011



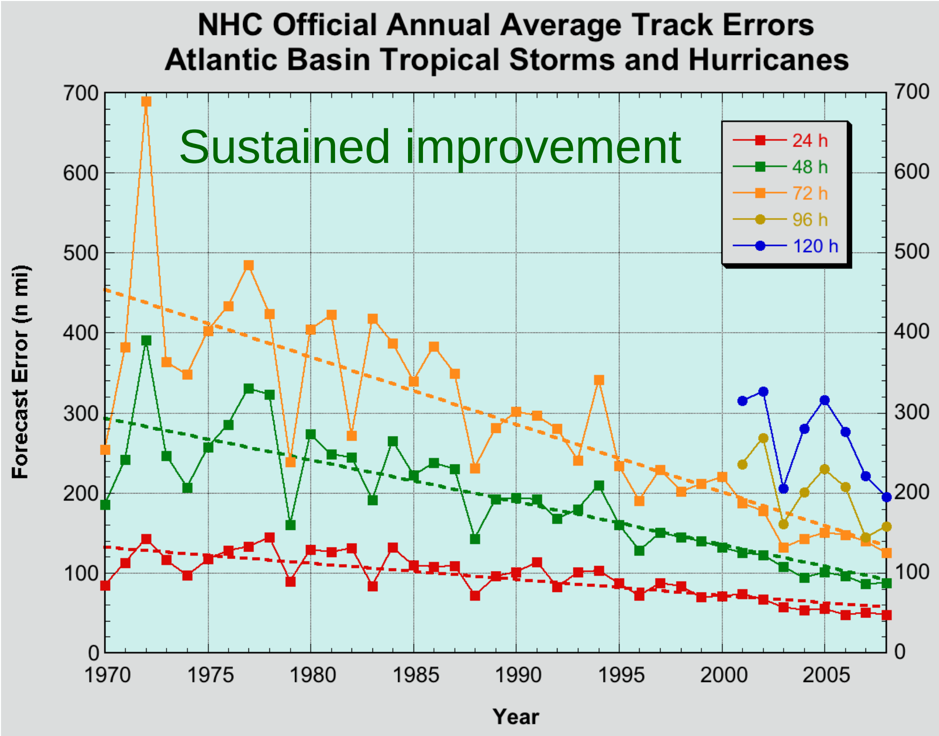


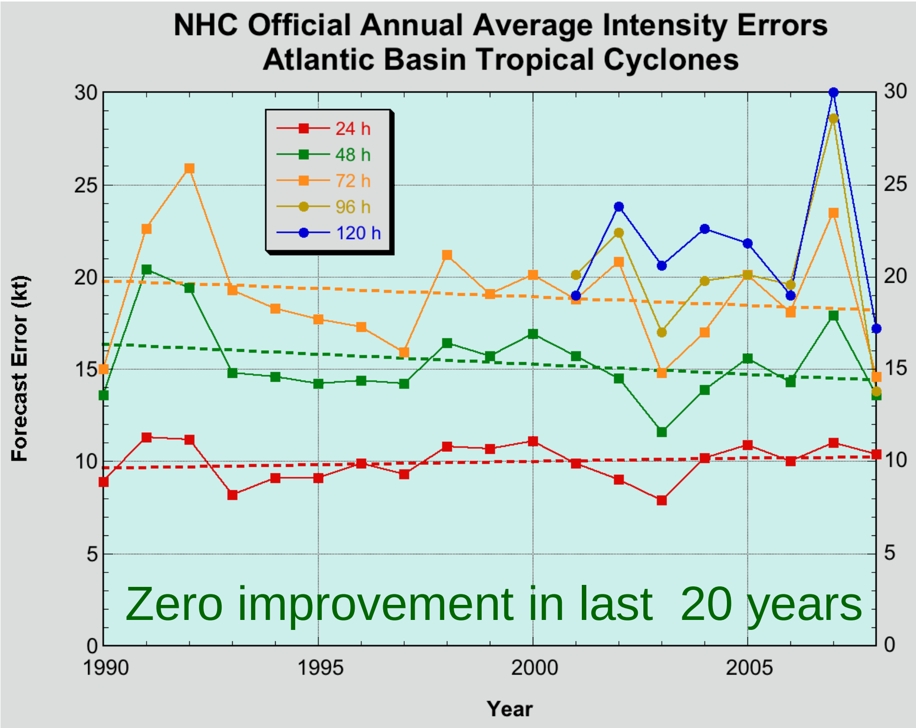
過去20年路徑誤差減半

過去20年強度預報沒改善

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?

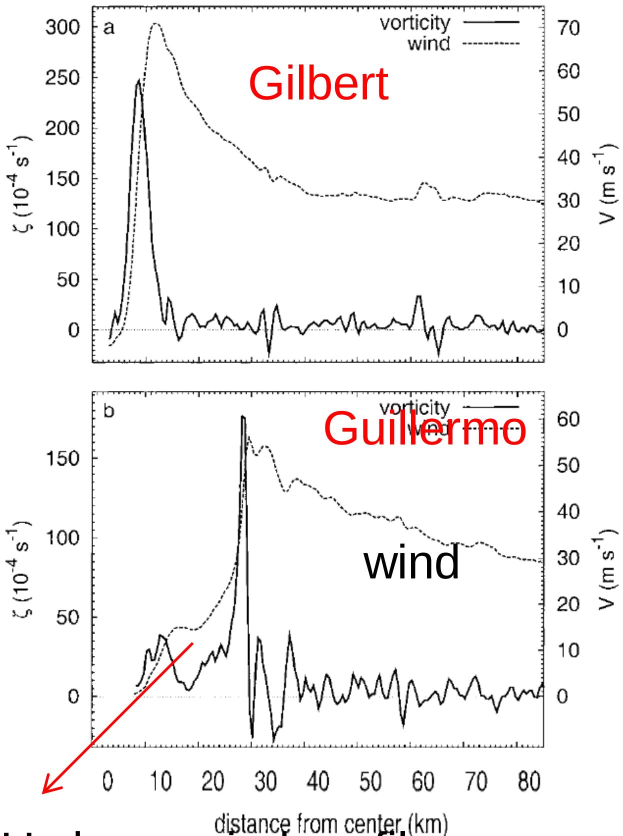
Courtesy of Dr. G. Holland

"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.強垂直風切 冷海水 海水熱容小 颱風變弱

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

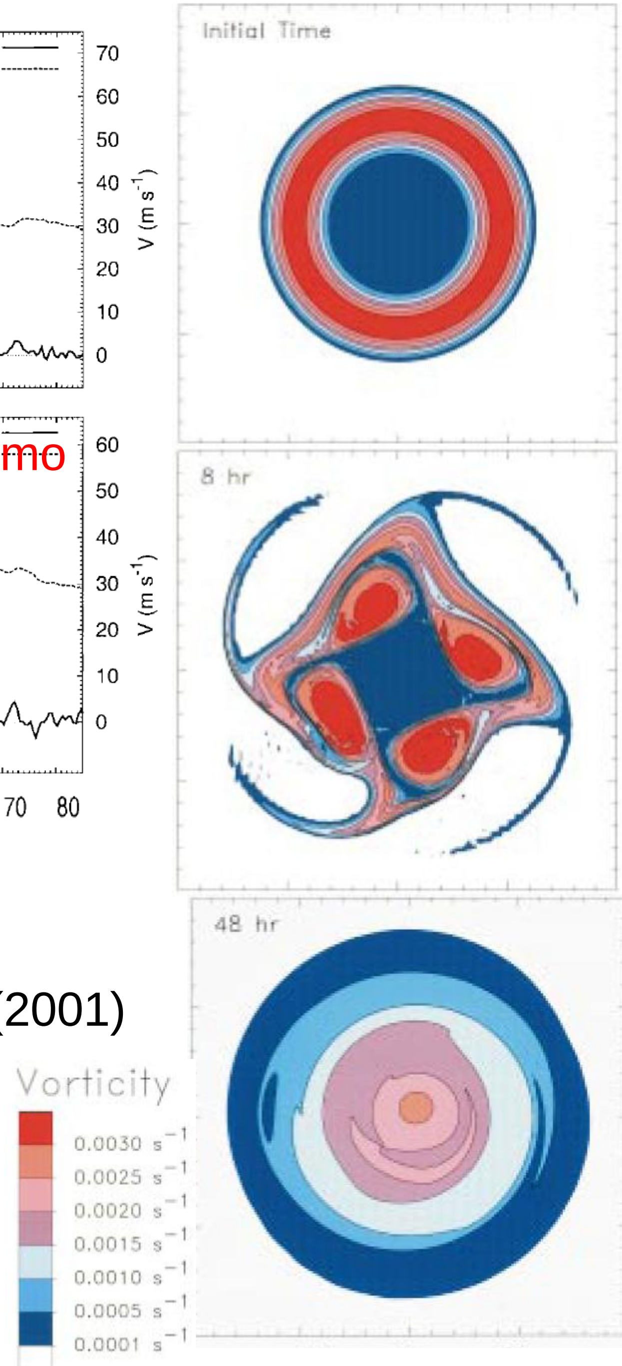
It is fairly typical for typhoons to strengthen or weakens rapidly without any clear commensurate changes in the environment."
Rozoff et al. 2009

Meso-scale processes matter!

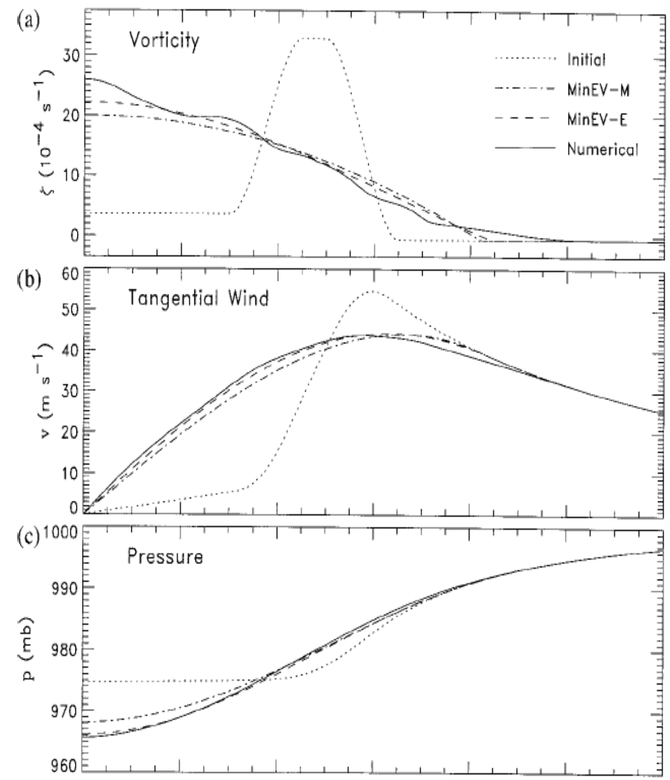


U shape wind profile

Kossin and Schubert (2001)

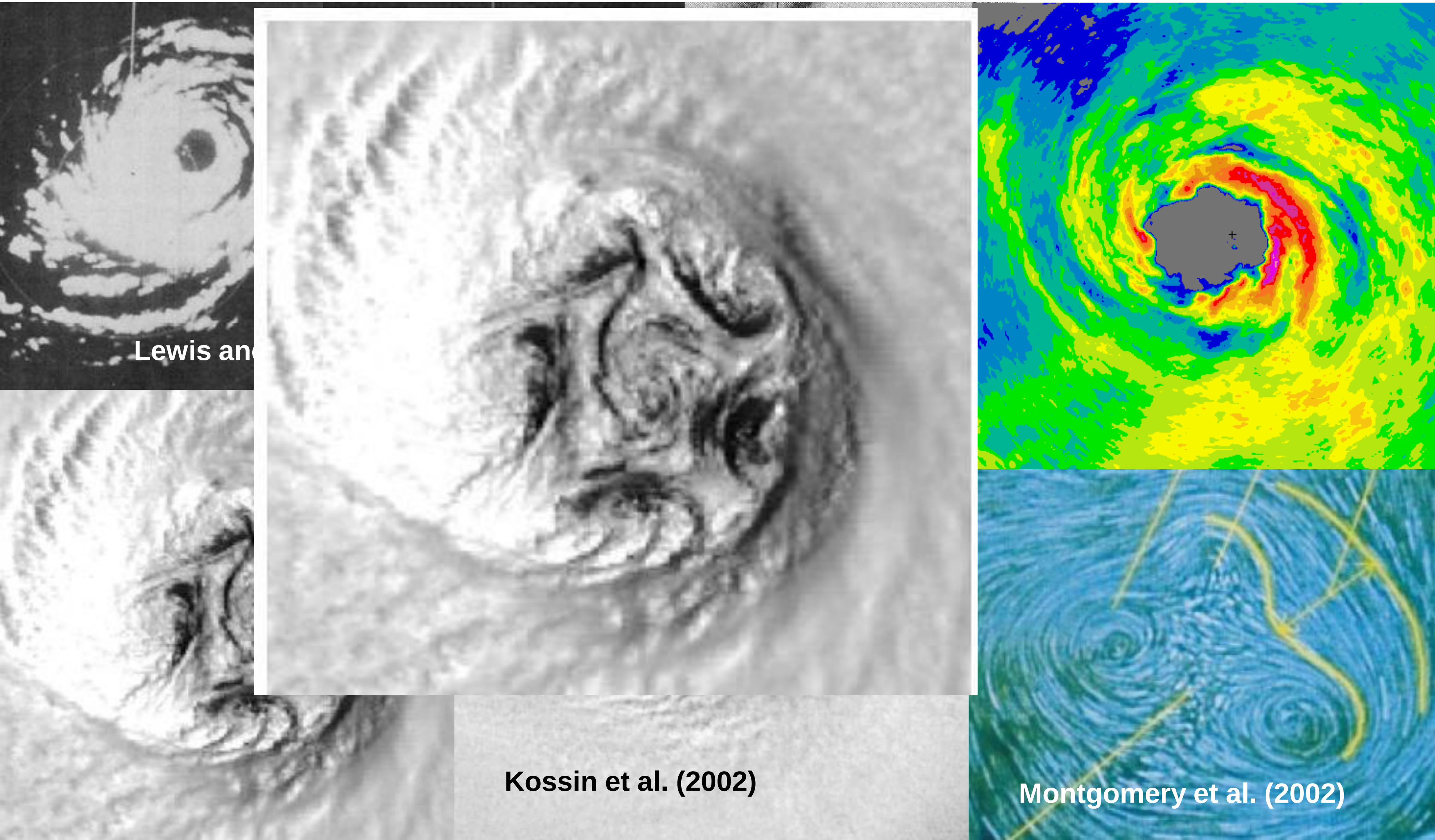


Schubert et al. (1999)

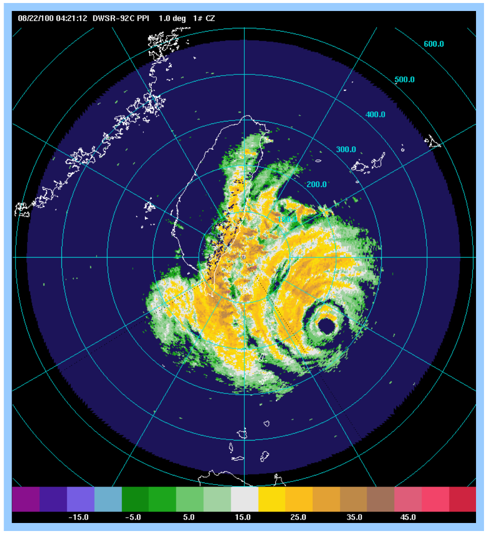


Vorticity mixing leads to rapid Intensification !

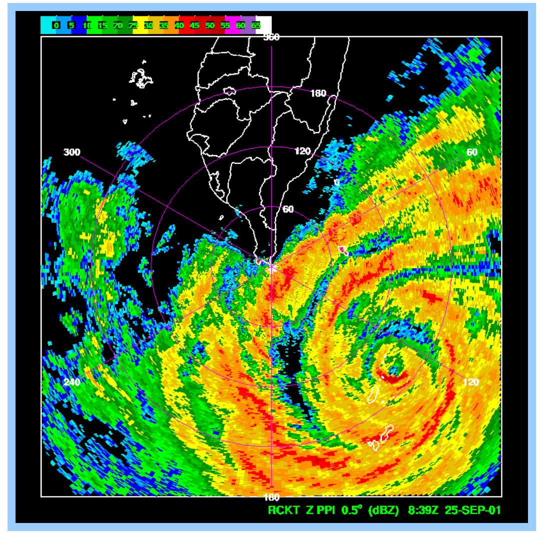
Polygonal eyewalls and eye mesovortices in hurricanes



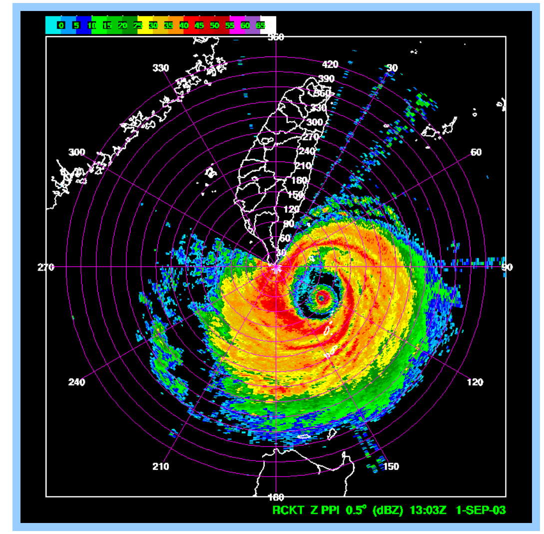
Concentric eyewalls near Taiwan



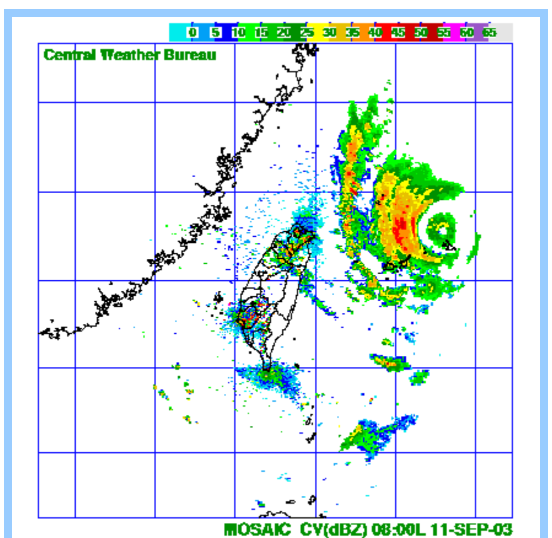
Bilis(2000)

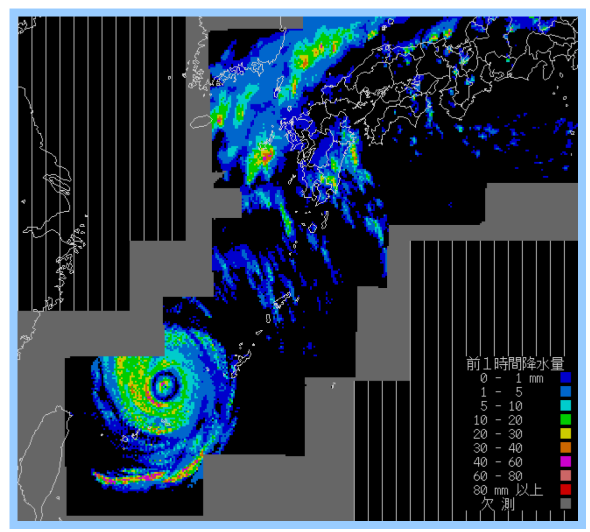


Lekima(2001)



Dujuan(2003)

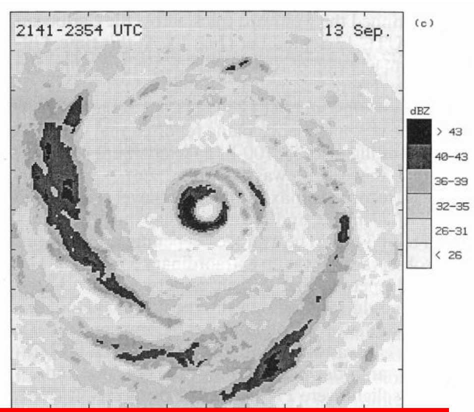


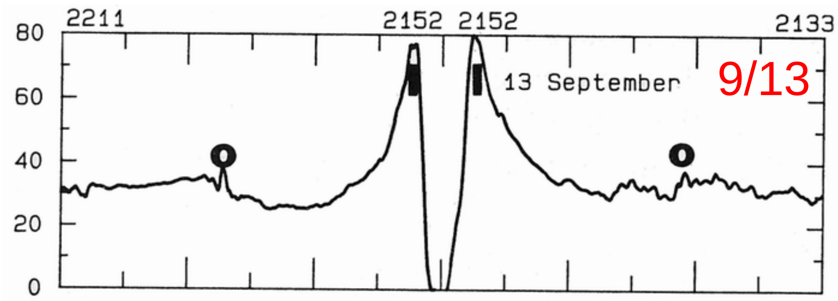


Maemi(2003)

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

Potential Vorticity Equation

$$\frac{\partial P}{\partial t} + u\frac{\partial P}{\partial x} + v\frac{\partial P}{\partial y} + w\frac{\partial P}{\partial z} = P(\frac{\partial \dot{\theta}}{\partial \theta})_{\zeta} + F$$

Dynamics Diabatic effect

The stiff aspect (PV 2D dynamics) and the non-stiff aspect (PV ~0, soft and changeable, loose self-organization).

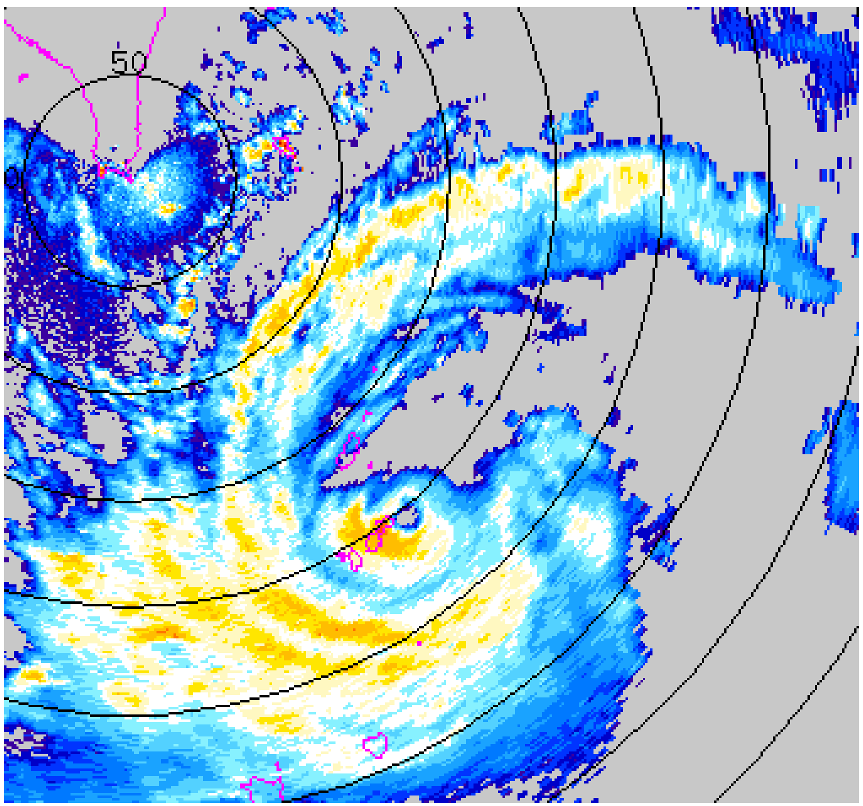
Stronger PV near the tropical cyclone core interact with convective heating favors the inward increase of PV (contraction).

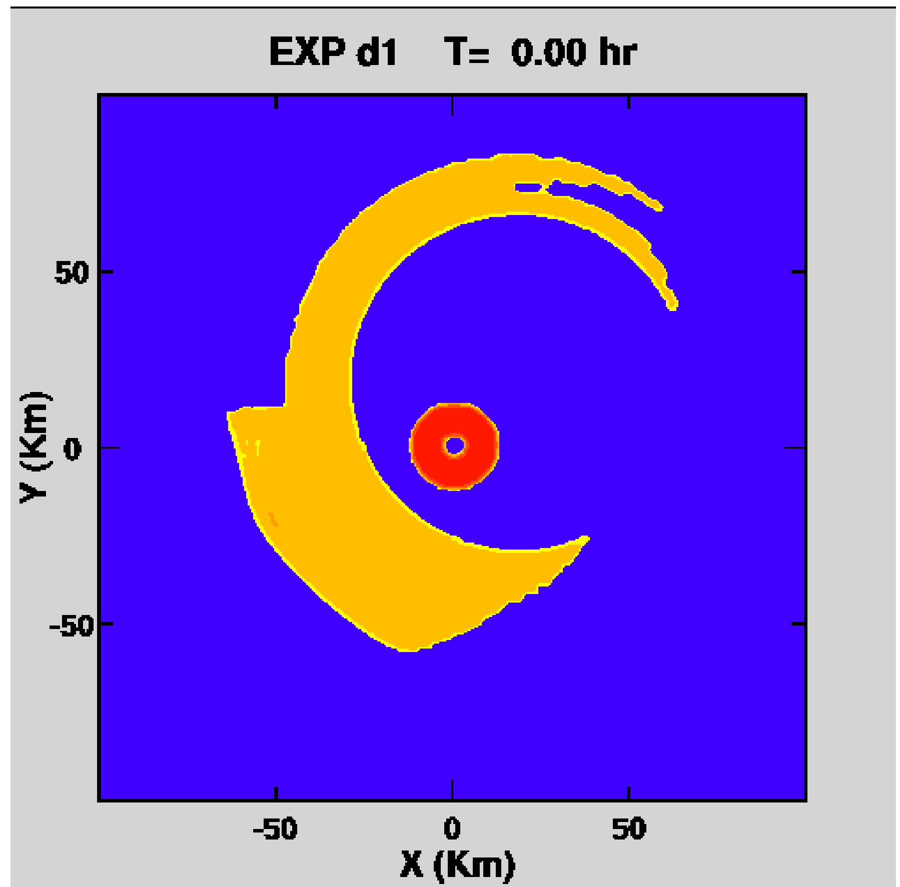
Symmetric and asymmetric dynamics
Dynamics interact with convections
PBL dynamics

Concentric Eyewall formation

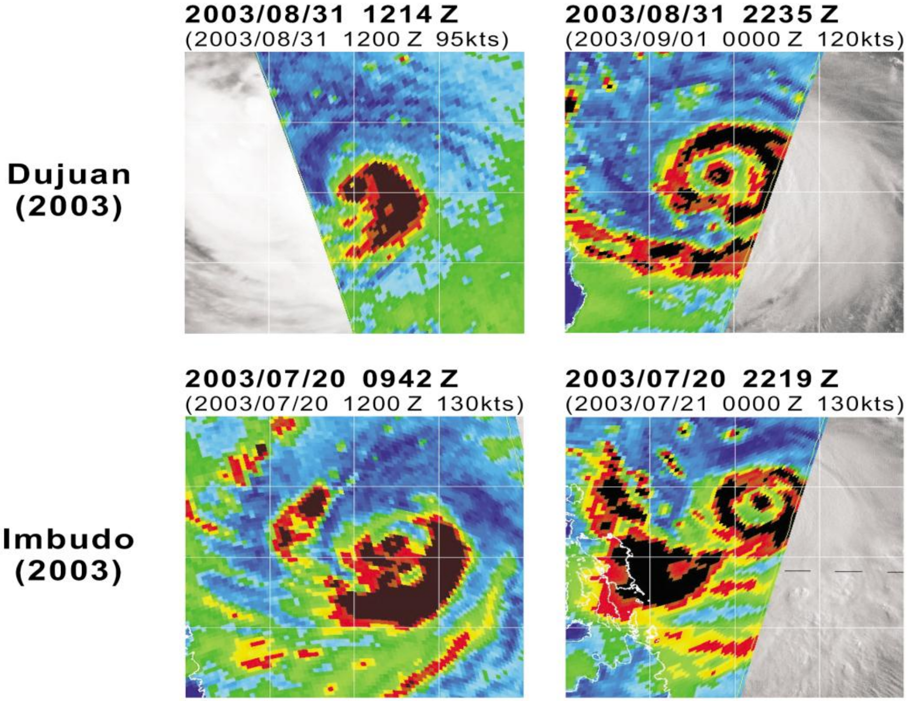
Kuo, H.-C., L.-Y. Lin, C.-P. Chang, and R. T. Williams, 2004: The formation of concentric vorticity structure in typhoons. *J. Atmos. Sci.*, **61**, 2722-2734.
Kuo, H.-C., W. H. Schubert, C.-L. Tsai, and Y.-F. Kuo, 2008: Vortex interactions and barotropic aspects of concentric eyewall formation. *Mon.Wea. Rev.,* **136,** 5183–5198.
Kuo, H.-C., C.-P. Chang, Y.-T Yang, and H.-J. Jiang, 2009: Western North Pacific typhoons with concentric eyewalls. *Mon. Wea. Rev.*, **137,** 3758-3770.

0935-1935 LST

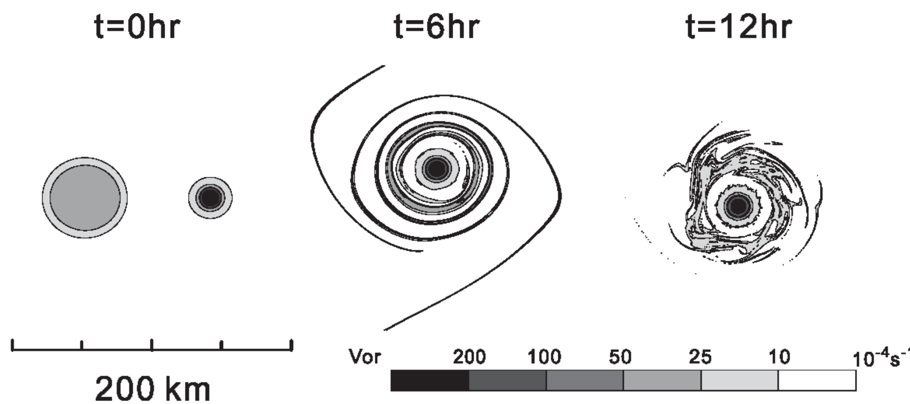




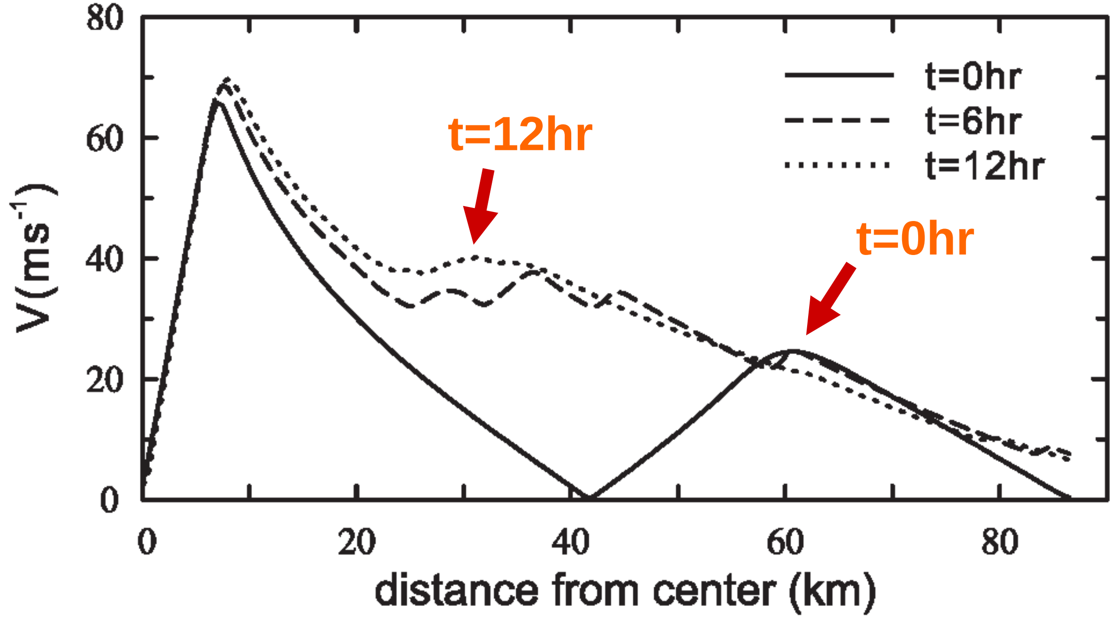
Typhoon Lekima (2001)



Courtesy of NRL

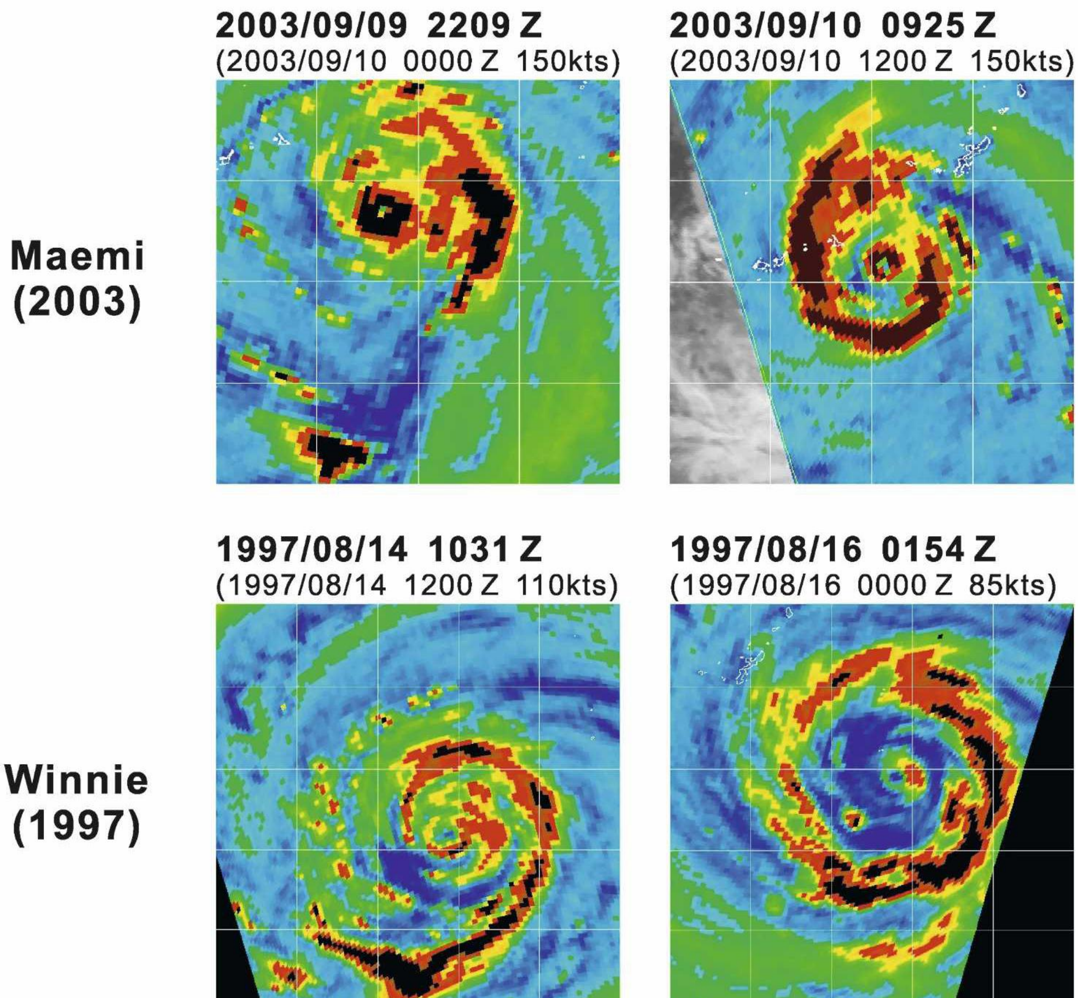


The contraction and the increase of the secondary wind maximum by nonlinear advection dynamics.

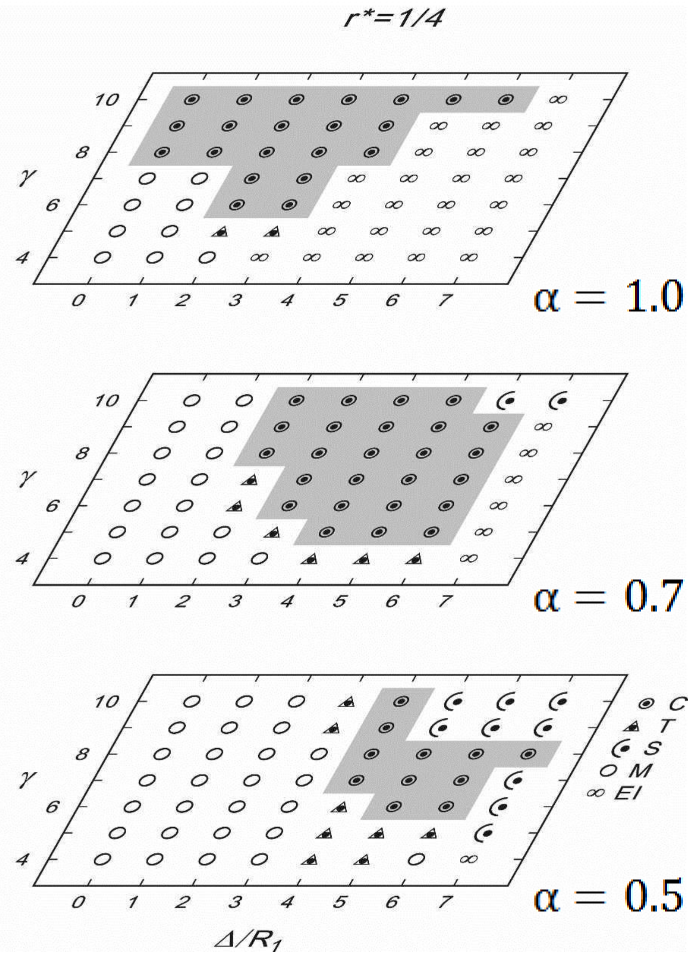


Double eyewall of different sizes maybe explained by the binary vortex interaction with skirted parameter

渦旋結構影響及雙眼牆大小



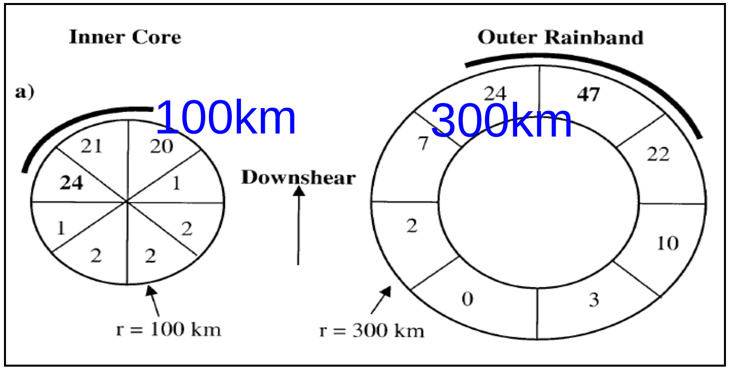
Courtesy of NRL



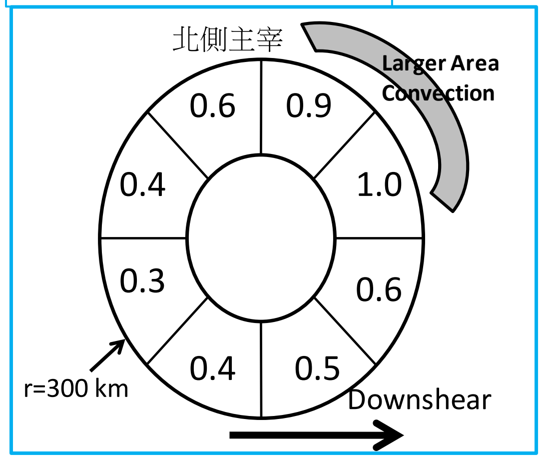
Kuo et al. (2008)

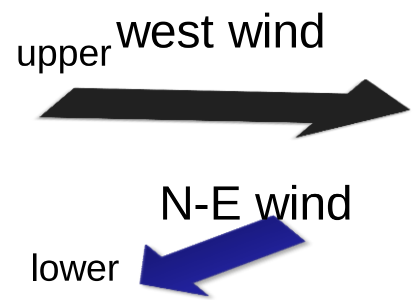
Vertical Wind Shear and Convective Region in CE typhoons

Corbosiero and Molinari, 2003



North dominated

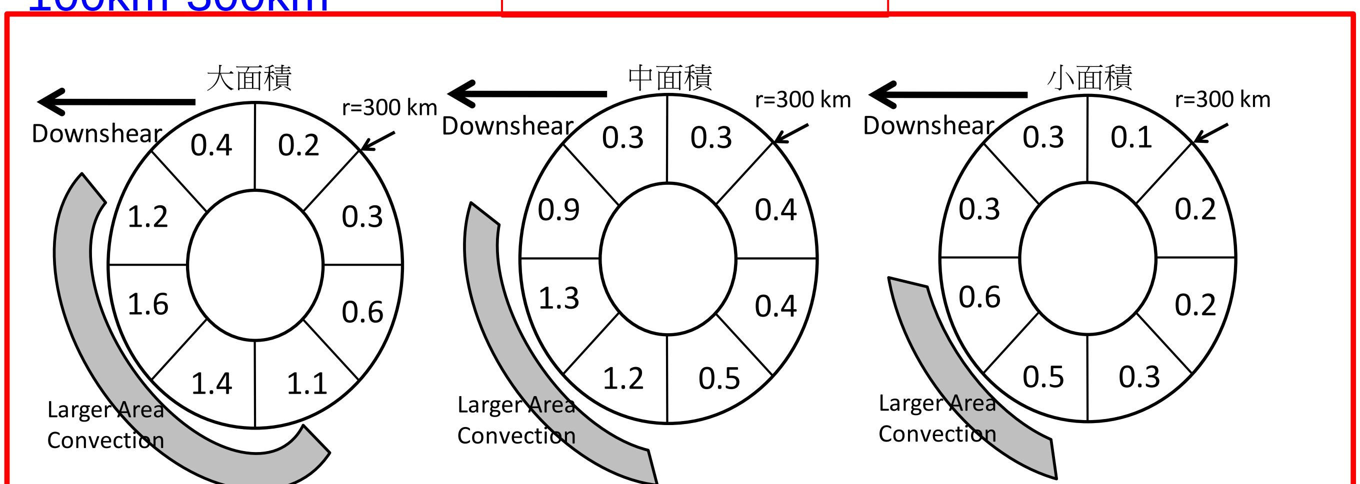


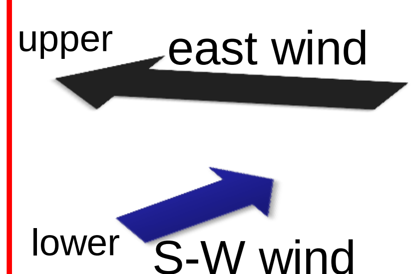


100km-300km

South dominated

100km-300km





The outer region (r=100-300km) convections happen mostly in **down shear left**. Kuo 2011

Importance of convections + the vorticity axisymmetrization dynamics.

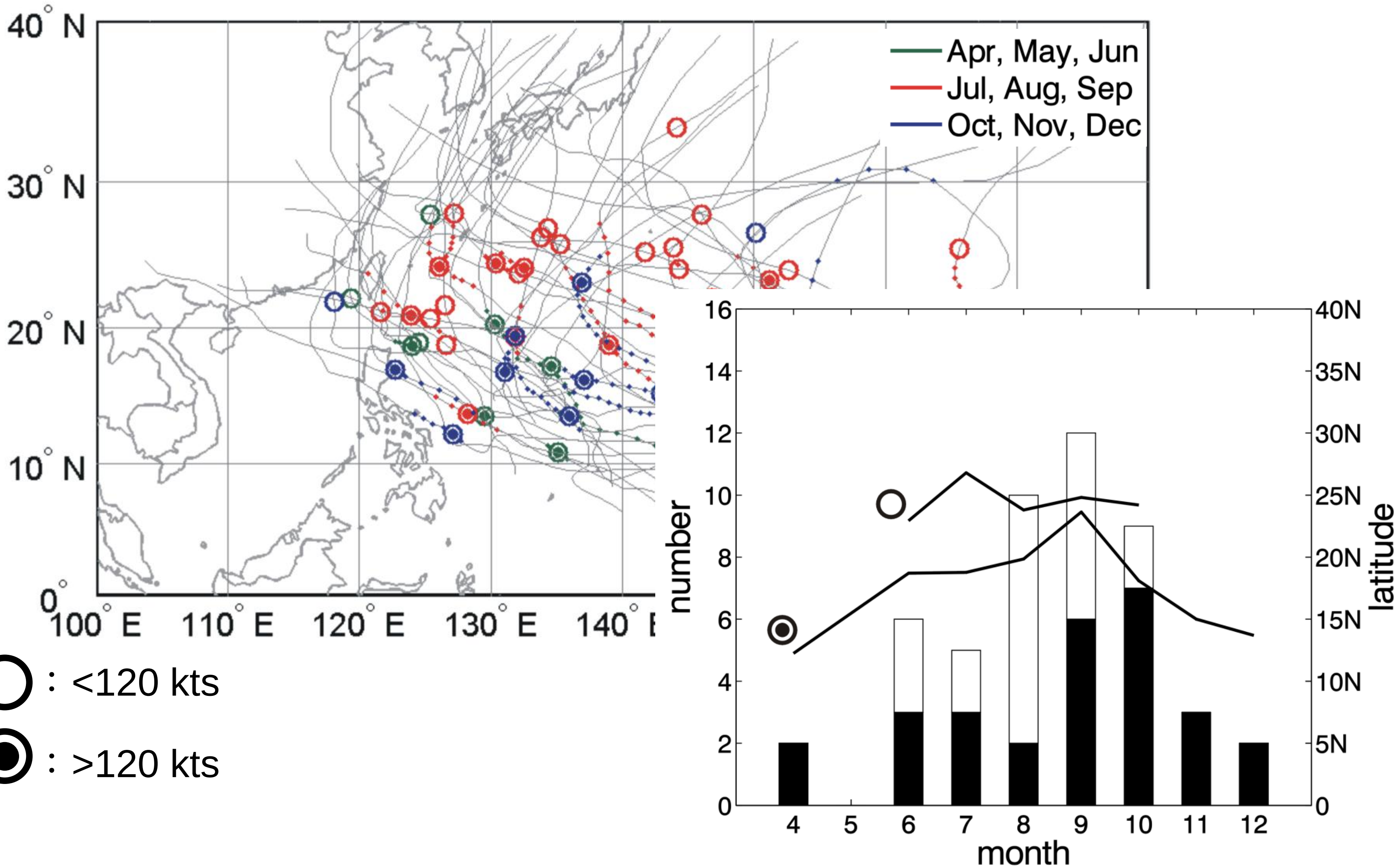
Kuo et al. (2004, 2008): Axisymmetrization of positive vorticity perturbations around a strong and tight core of vorticity.

Vertical Shear induced convection (the down-shear to the left convection) may also be a pathway to CE.

Vortex Rossby waves coupled to the boundary layer and convections may contribute to the expansion of the tangential wind field. *The unbalanced boundary layer response to an expanding swirling wind field is considered a very important mechanism for concentrating and sustaining deep convection in a narrow supergradient-wind zone in the outer-core vortex region.* (Huang et al. 2011)

WNPAC Concentric eyewalls formation locations, intensity, and tracks 1997-2006

Kuo et al. (2009)



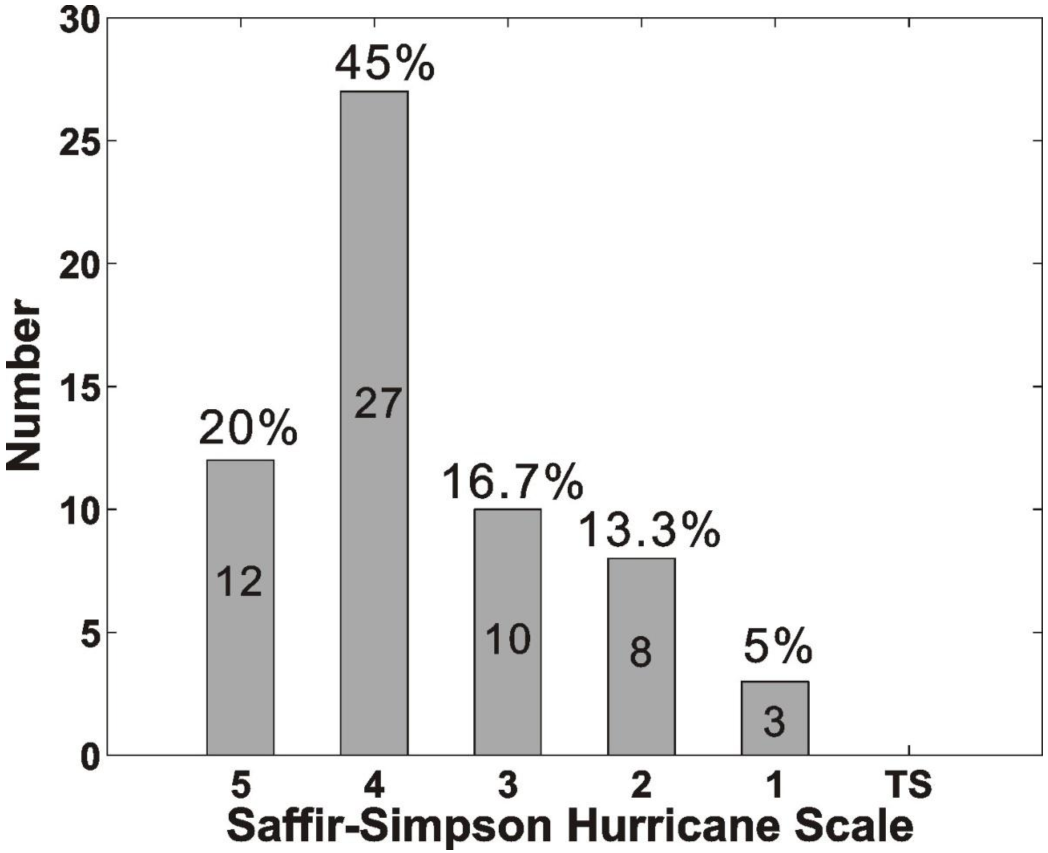
○ : <120 kts

◉ : >120 kts

spatial distribution ---- 67.2% cases in the west of 140 °E

Intensity at formation time

WNPAC 1997-2006

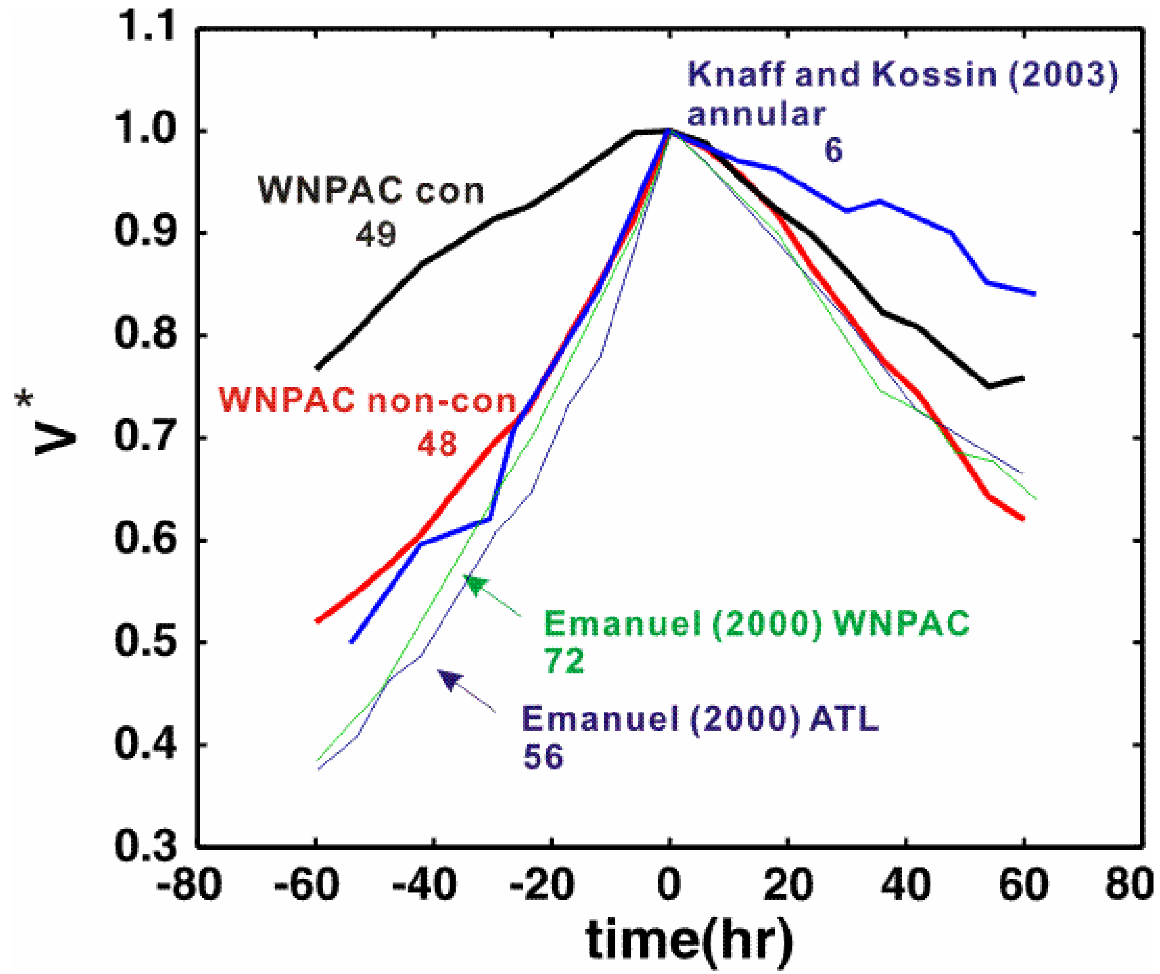


category 5 (135+ kts)
category 4 (114-135 kts)

category 3 (96-113 kts)
category 2 (83-95 kts)

category 1 (64-82 kts)
TS(63- kts)

- **65% in categories 4 and 5**



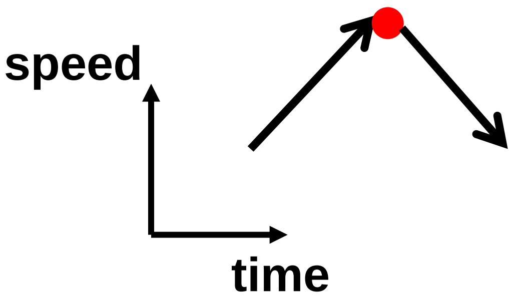
Key feature of concentric eyewall formation appears to the maintenance of a relative high intensity for a longer duration prior to formation, rather than a rapid intensification process that can reach a high intensity.

Kuo et al. 2009

Intensity change 24h before and after the formation of concentric eyewalls

+:intensity increase (P)   - : intensity decrease (N)

+-



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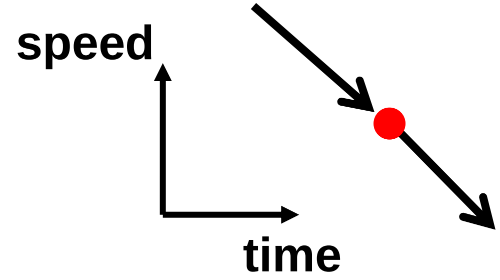

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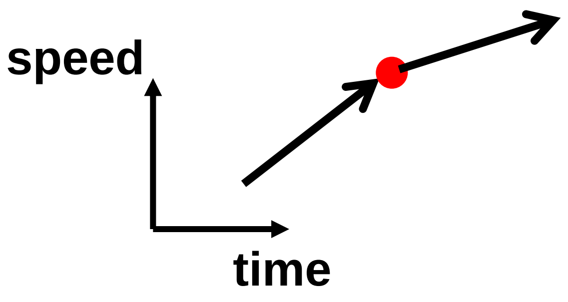

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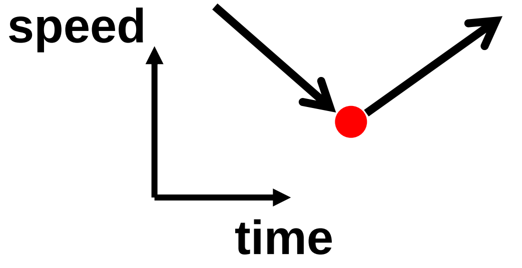


It is possible that the large moat size may delay the eyewall replacement cycle and thus affect the TC intensity change.

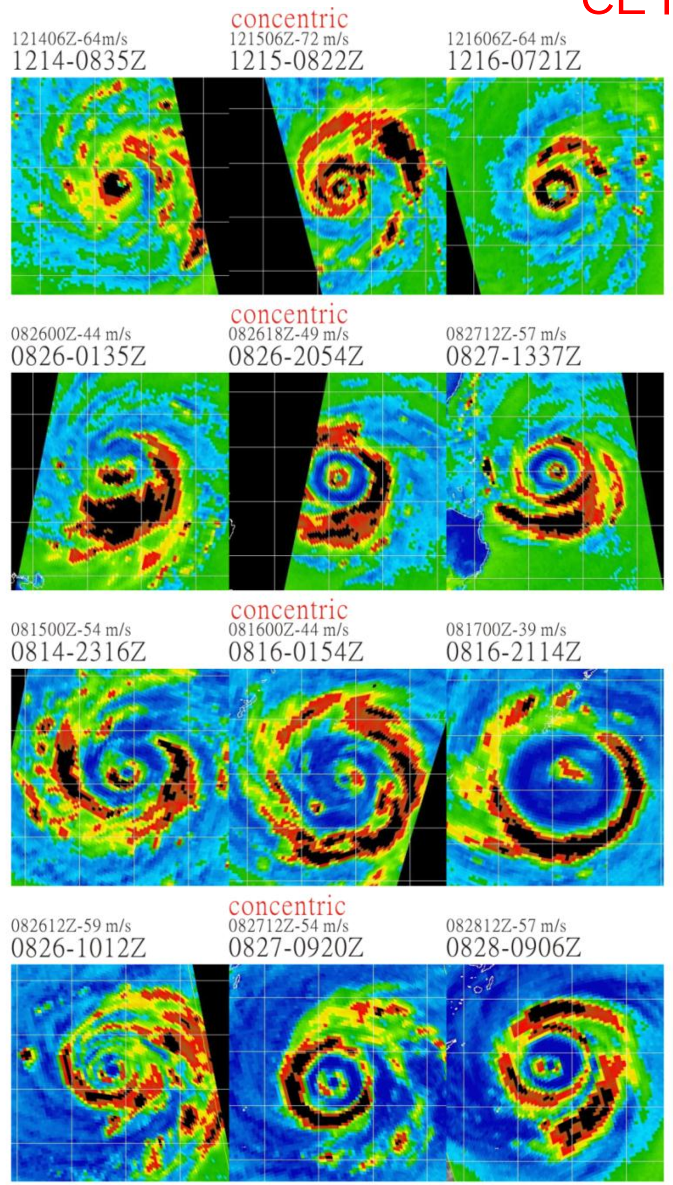
CE Intensity Change patterns

1997 Paka
Type:PN

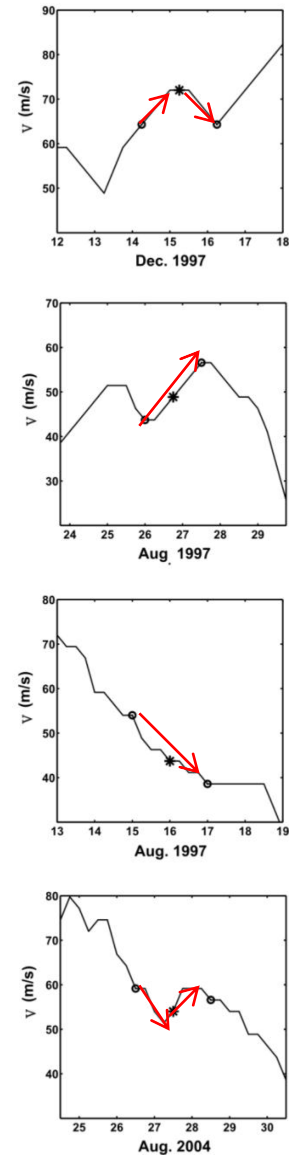
1997 Amber
Type:PP

1997 Winnie
Type:NN

2004 Chaba
Type:NP



Courtesy of NRL



PN
+-
50%

PP
++
24%

NN
--
22%

NP
-+
4%

larger moat size

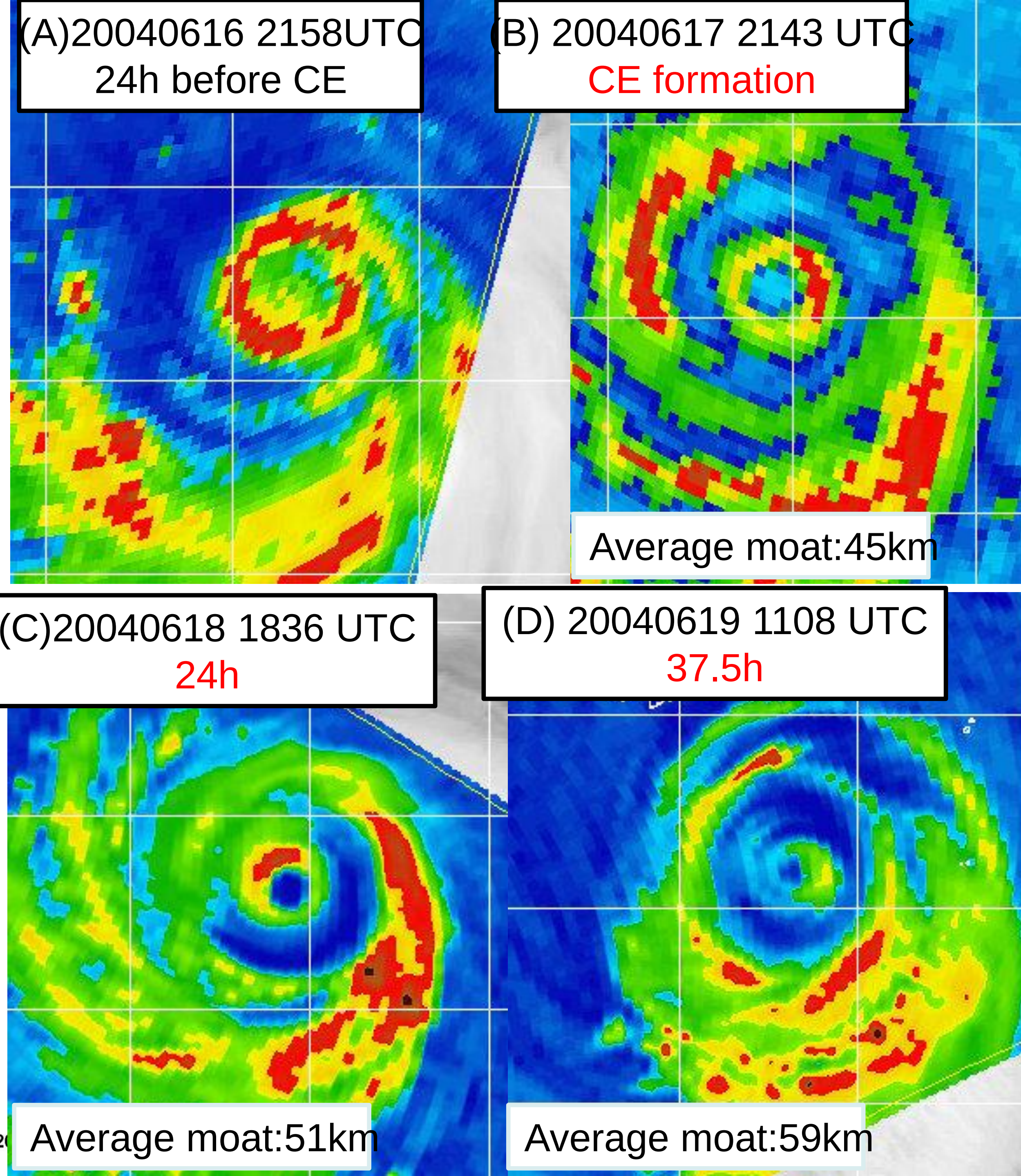
50%

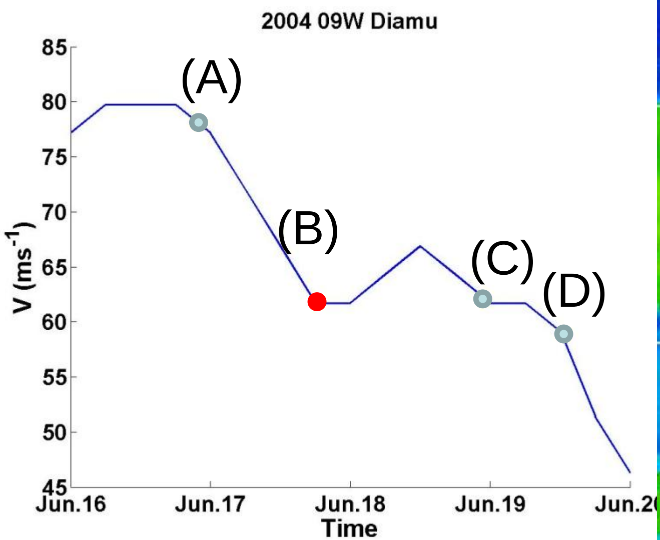
larger moat size

Kuo et al. 2009

2004
09W Diamu

Slow ERC





New Objective Method
CE cases extend to 2010.
(Yang et al. 2011)
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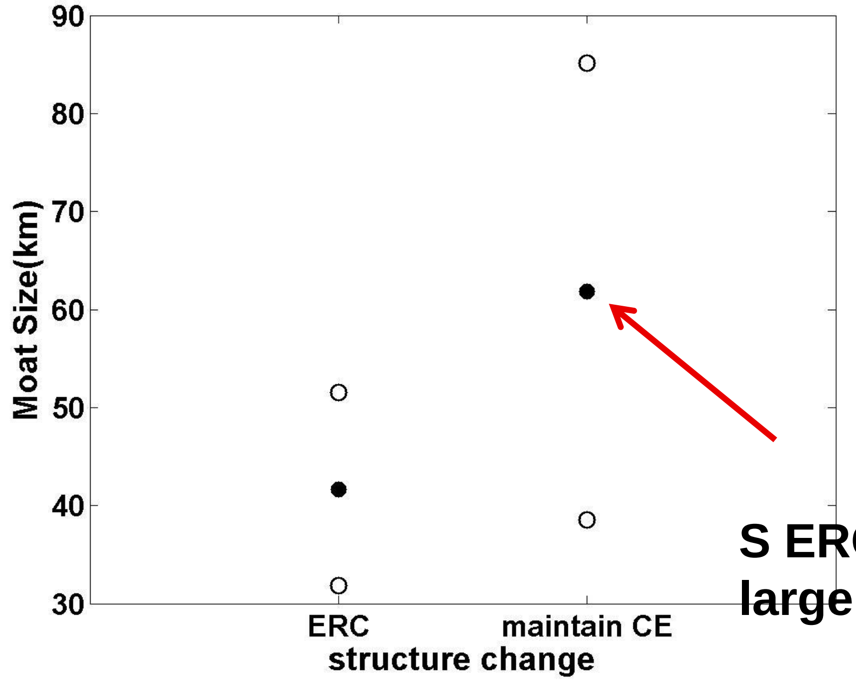
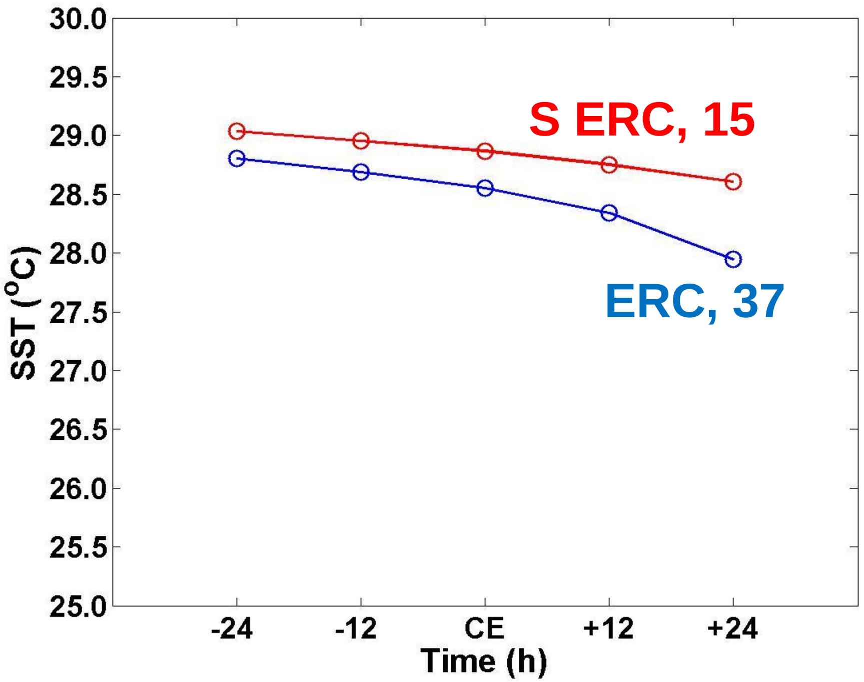
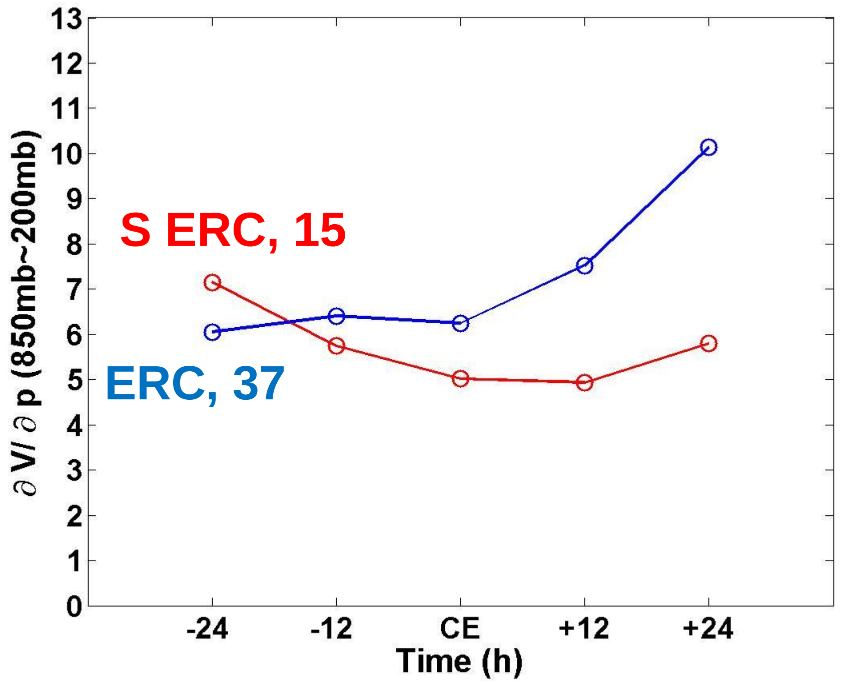
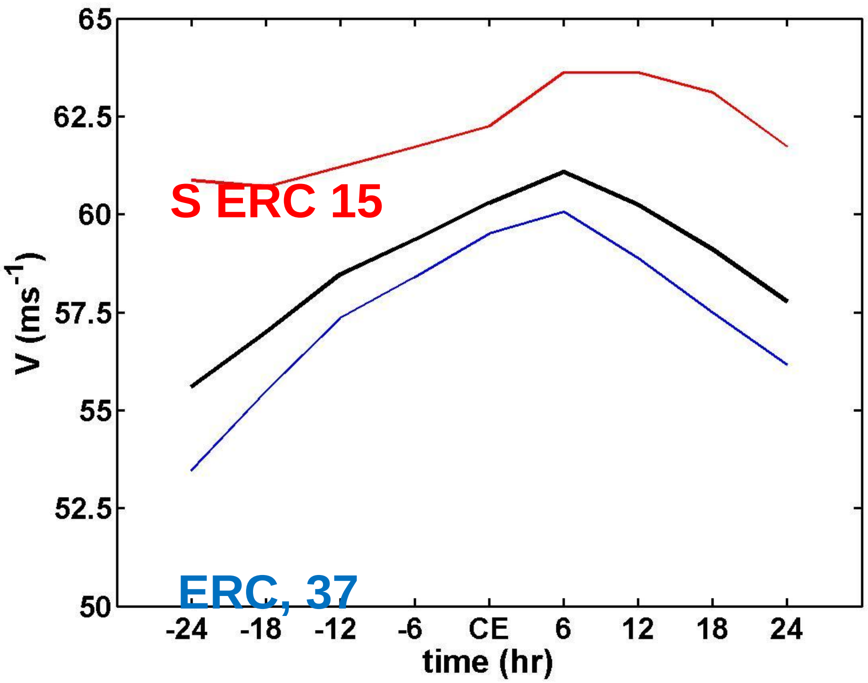
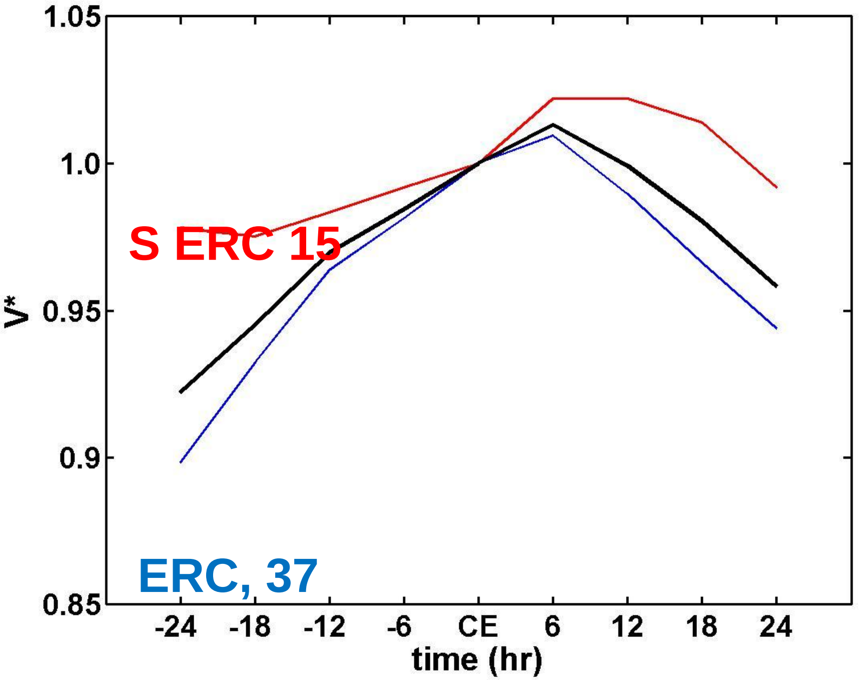


S ERC larger moat larger variability

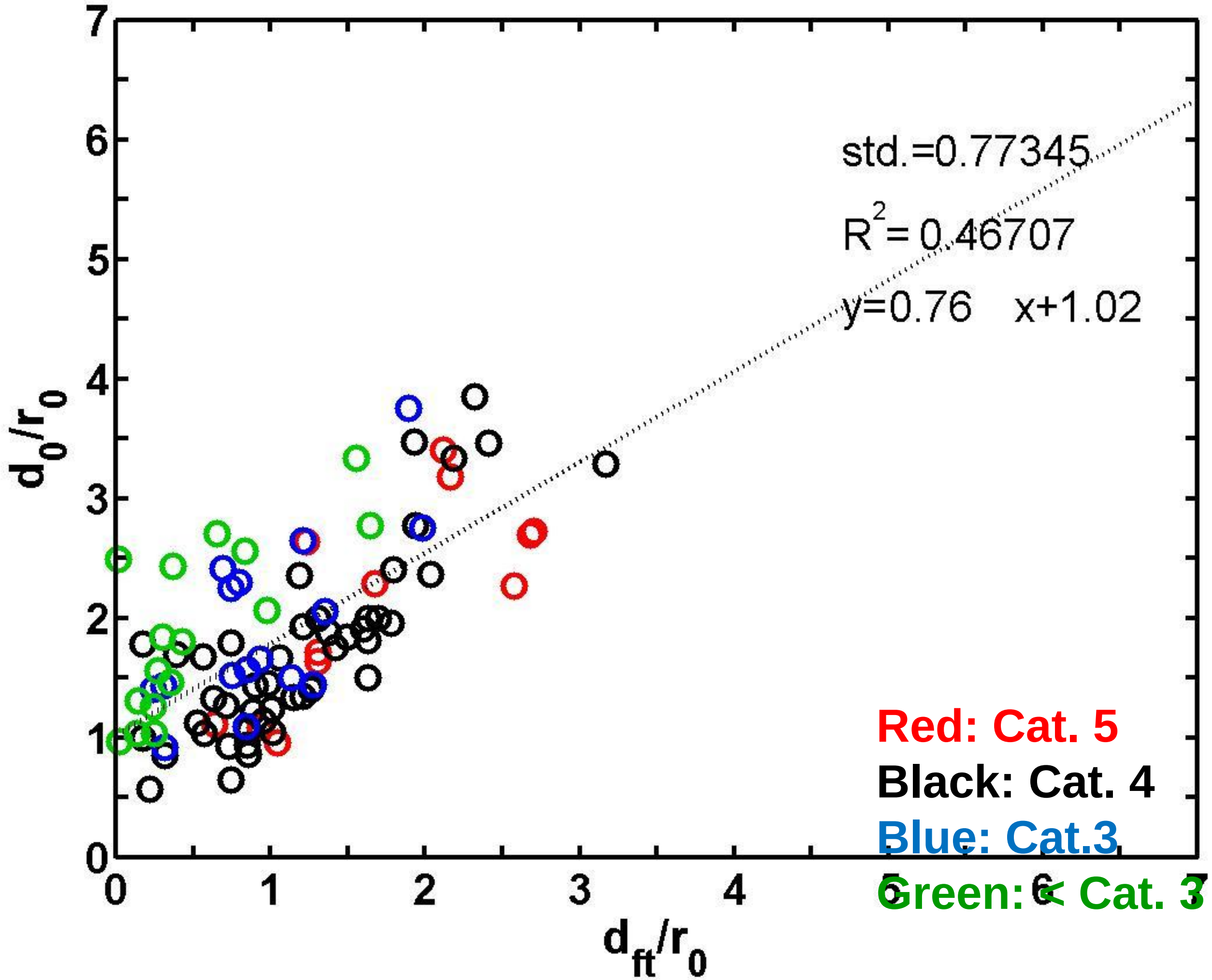








Yang et al. 2011



The rapid filamentation process tends to make an important contribution to the organization of the moat size. Yang et al. 2011

Summary

Importance of the vorticity axisymmetrization dynamics (and the contraction of secondary wind maximum) + convections.

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

The rapid filamentation process tends to make an important contribution to the organization of the moat size.

The barotropic idealization can yield insight into some of the organizational aspects of CE, it falls well short of vertical motion, the frictional boundary layer, and diabatic processes.

We found that the slow ERC cases are with larger moats, higher local SST and larger vertical shears 24 hours before CE formation.

This leads to a hypothesis that the larger vertical shear may contribute to a larger subsidence area, therefore a larger moat width. A larger moat width with a higher SST may cause the slow ERC.