The long-lived concentric eyewall tropical cyclones with large moat and outer eyewall

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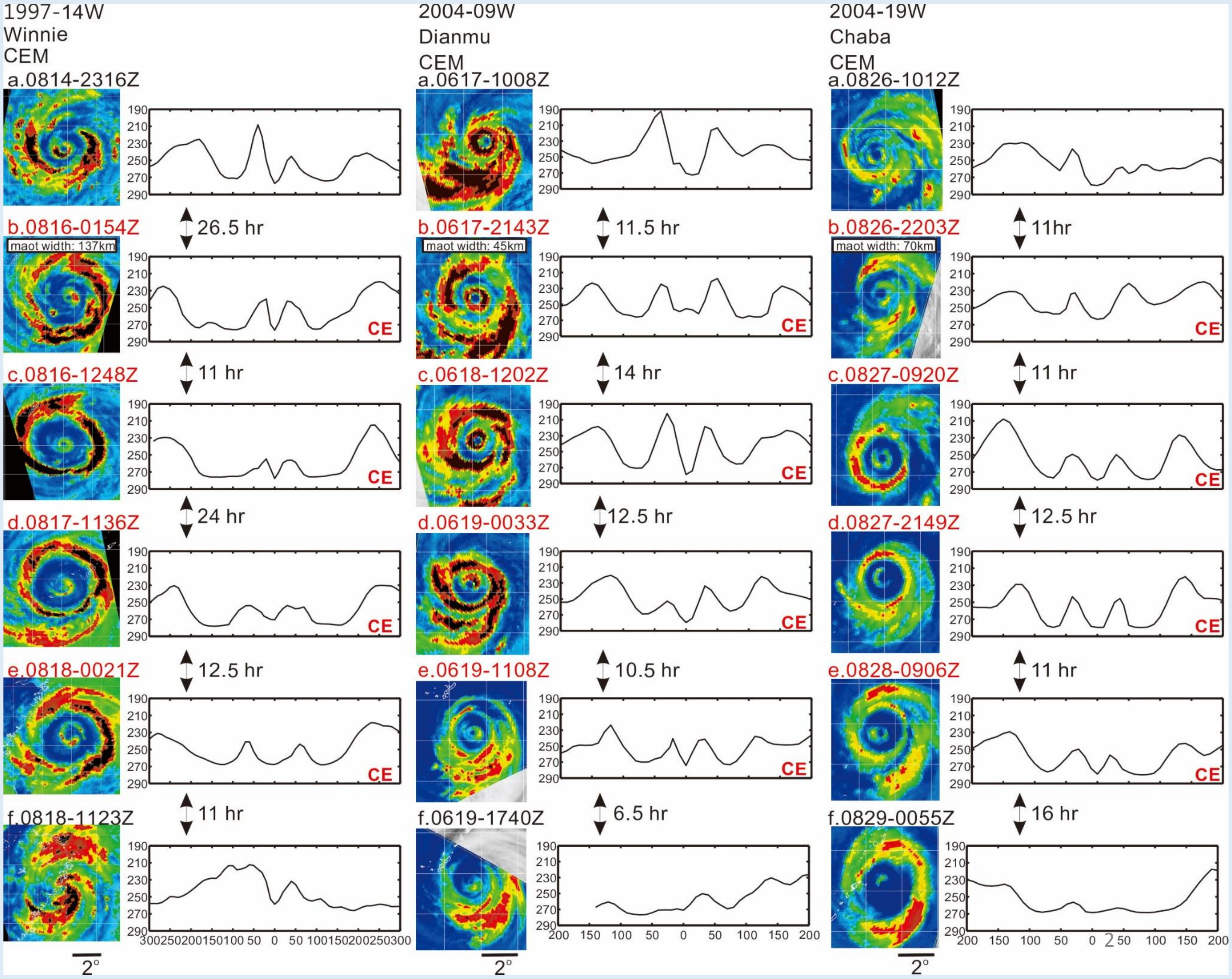
Introduction

- Long-lived CE TCs (maintain CE more than 20 h)
- 23% CE cases with long duration in the Western North Pacific basin
- Strong inner core, large moat and outer eyewall



Yang et al. (2013)

Why long-lived CE cases?

Why no stabilization effect of upper warm core in the CEM cases?

Large size:

✓Larger CE storms with longer ERC time

Large moat:

✓The interference of two eyewall convection/subsidence may be reduced

✓Less stabilization for outer eyewall

✓Difficult multiple shocks interaction in the BL

Thick outer eyewall:

✓Better stabilization for outer eyewall

Strong inner core:

✓Better stabilization for outer eyewall

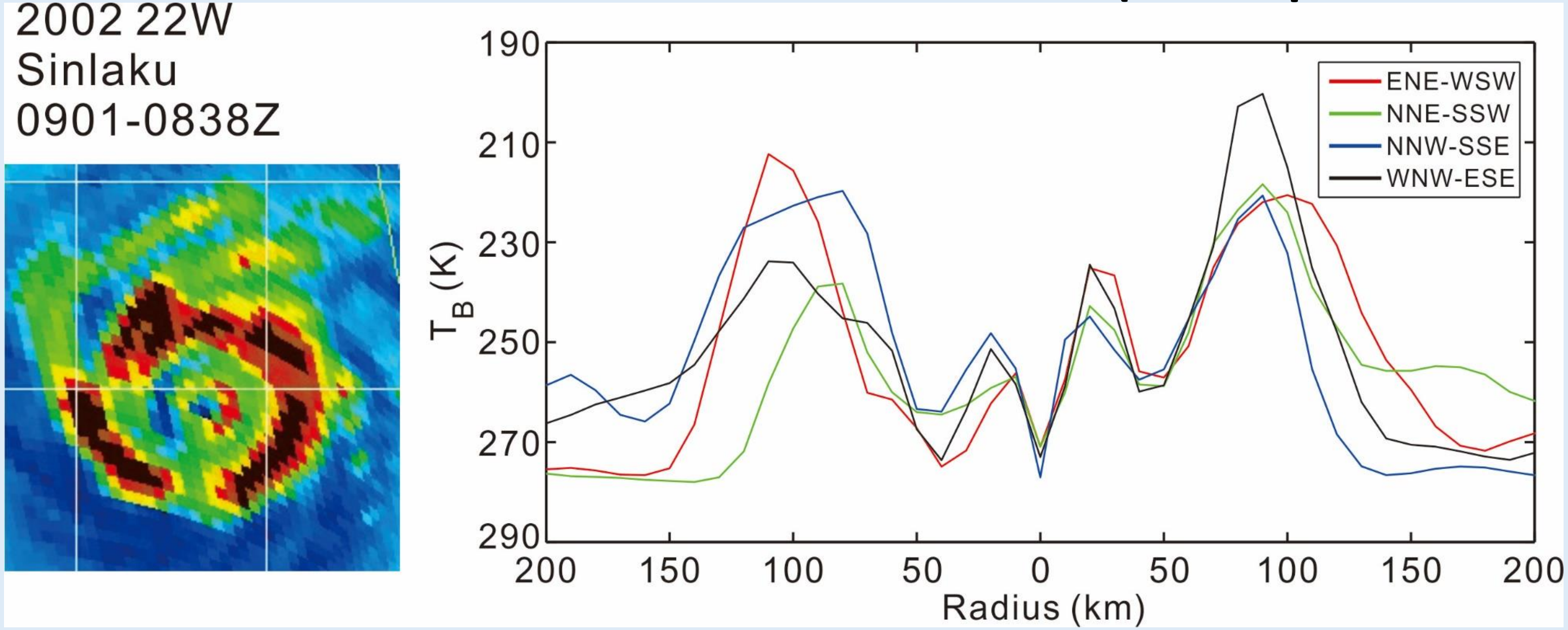
Data and Method

- Observation
  - 1997-2014
  - passive microwave SSM/I and TMI
  - Western North Pacific (WNPAC) and the Atlantic (ATL)
  - Blackbody brightness temperature (T_B) for size parameters
  - Cloud liquid water (CLW) of TC
- Dynamic energy efficiency method (Hack and Schubert 1986)

CE Objective Identification

In each 45^{o} sector

1. Min-Max-Min in T_B **(possible moat located)**
2. $T_{Bmax} \geqq \sigma_{outer\_min} + T_{Bouter\_min}$ **(significant moat)**
3. $T_{Bmax} \geqq \sigma_{inner\_min} + T_{Binner\_min}$ **(significant moat)**
4. $T_{Bouter\_min} \leqq 230K$ **(strong outer convection)**
5. $\geqq$ **5/8** sectors **(symmetric structure)**
6. The difference of two outer eyewalls $\leqq$ 50 km **(not a spiral out band)**

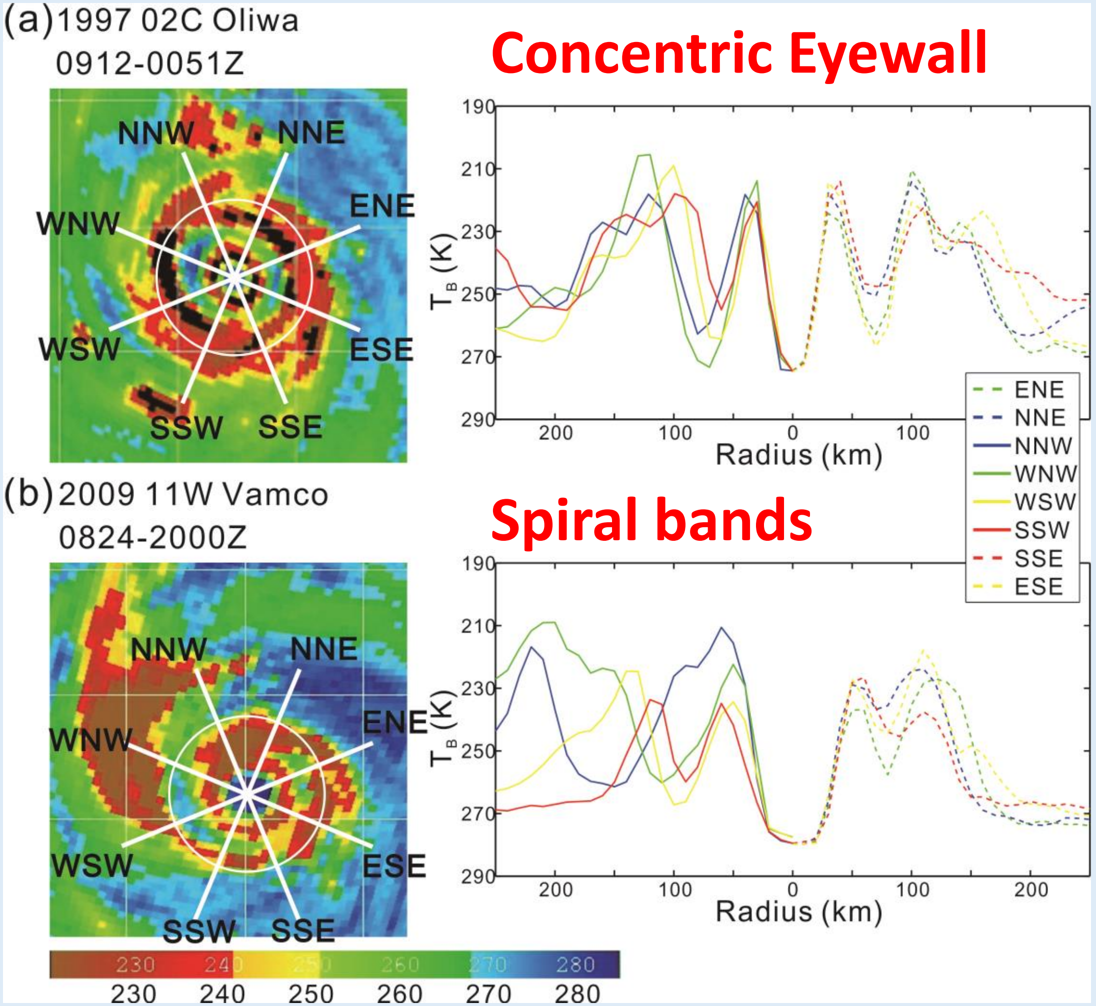


Yang et al. (2013)

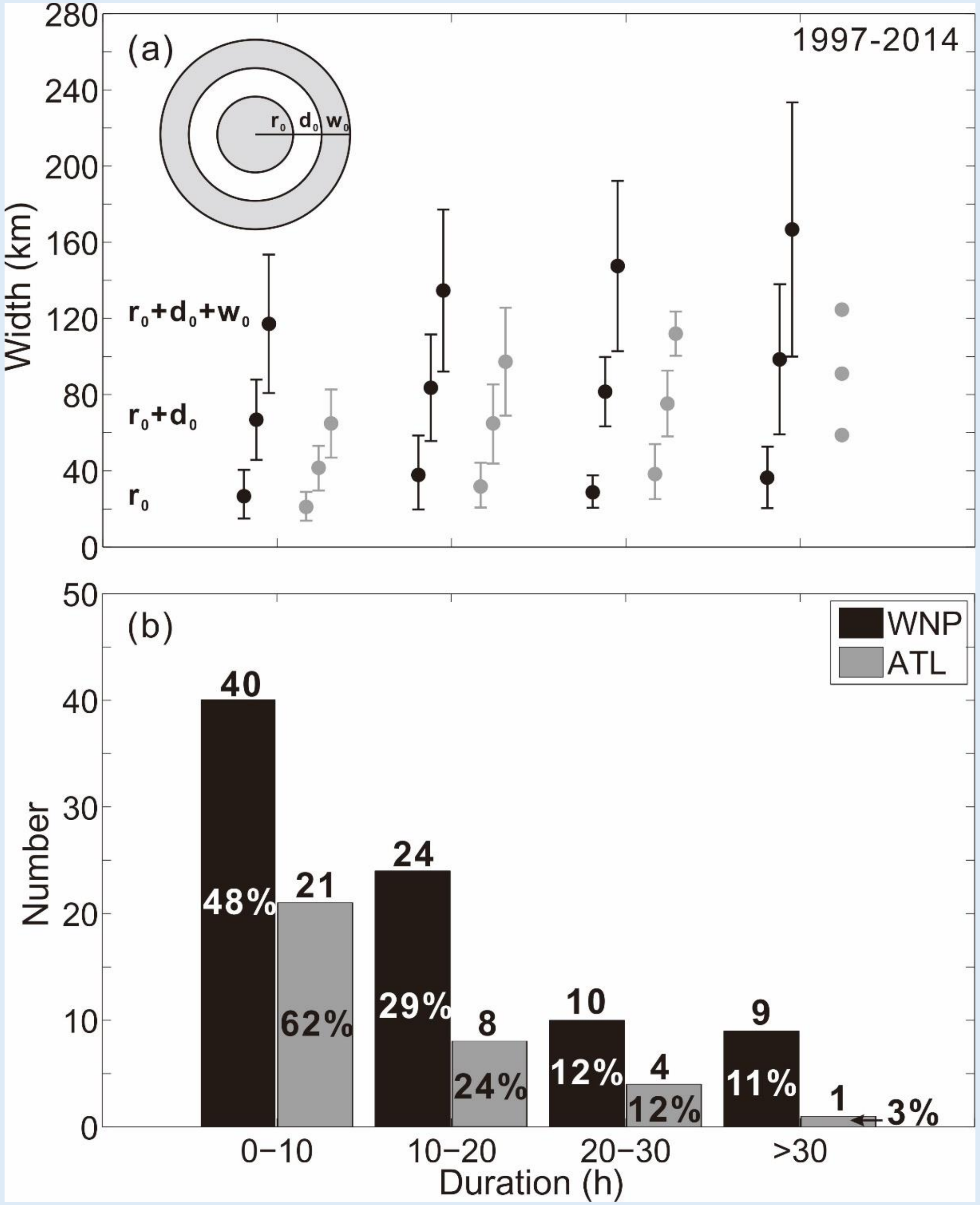
Aircraft dataset and microwave satellite images for determined CE

20 h criteria: CE in microwave image is 18 h after the outer wind max. in the aircraft observations (Sitkowski et al., 2011)

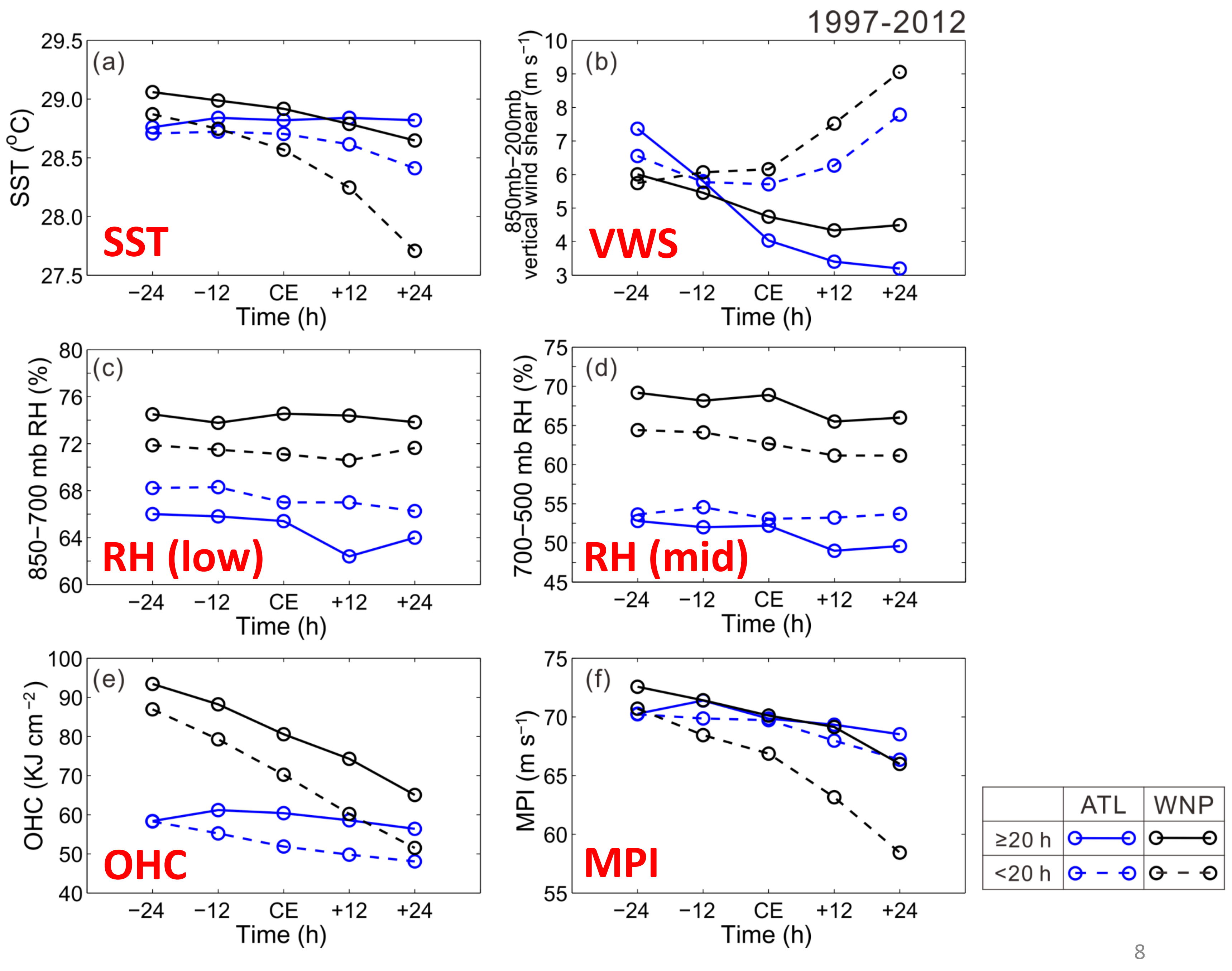
- 1998-2007; ATL basin
- Aircraft data (Sitkowski et al., 2011):
  - **20** ERC events
  - CE duration is **36 h** mean
- Microwave Satellite image (Objective method):
  - **35** CE cases
  - CE duration is **11 h** mean
- The difference of CE duration:
  - Bad Temporal resolution: 5 cases
  - Criteria: 15 cases (5 and 1 for significant moat and outer eyewall; 5 for symmetric; 3 for spiral bands)
  - No flight mission: 7 cases



- Long duration CE cases have large size.
- More long-lived CEs in the WNPAC basin (19 and 23%) than that in the ATL basin (5 and 15%)



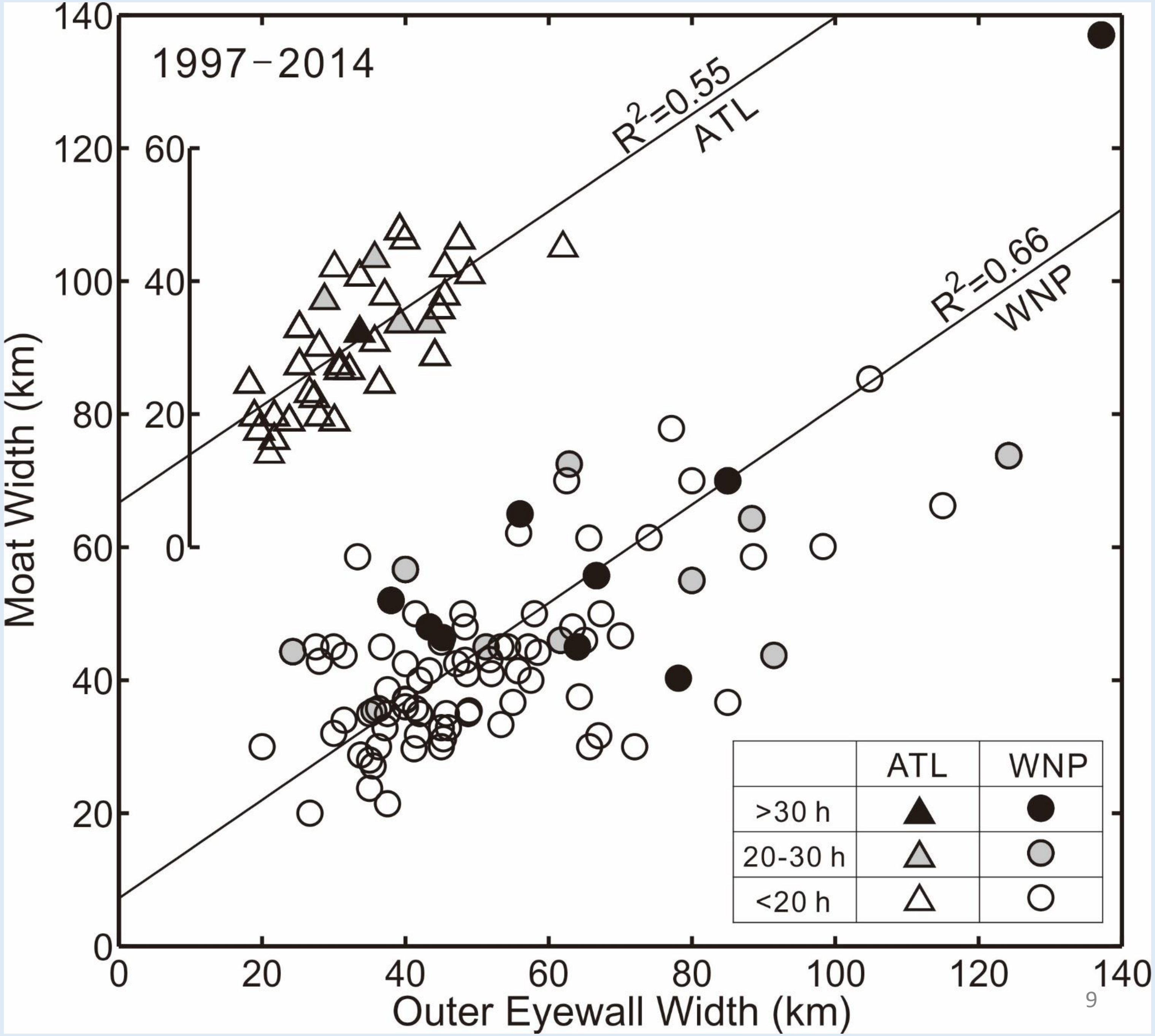
- Long-lived CE cases are under favorable environment



CE duration ≥ 20 h (solid line)
CE duration < 20 h (dash line)
WNP(black)
ATL(blue)

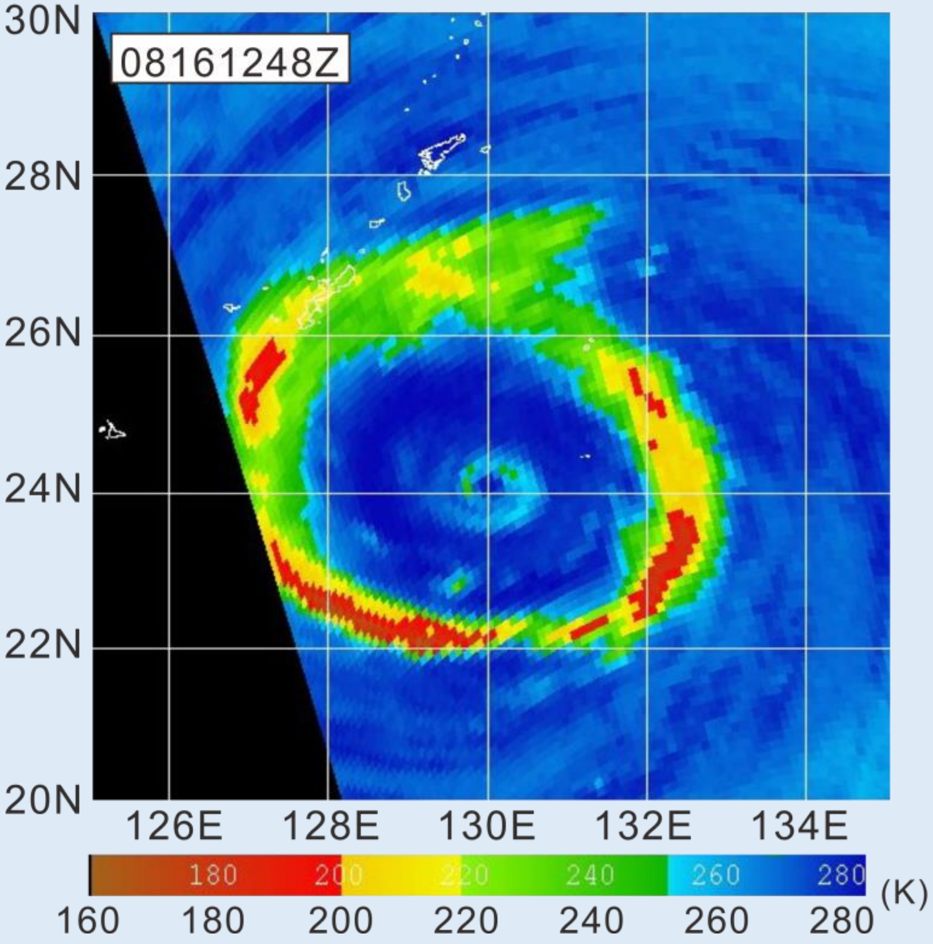
- The outer eyewall width and moat width are well correlated both in the WNPAC and ATL basins.

The moat widths of CE cases in the Atlantic basin are plus 60 km for clarity.

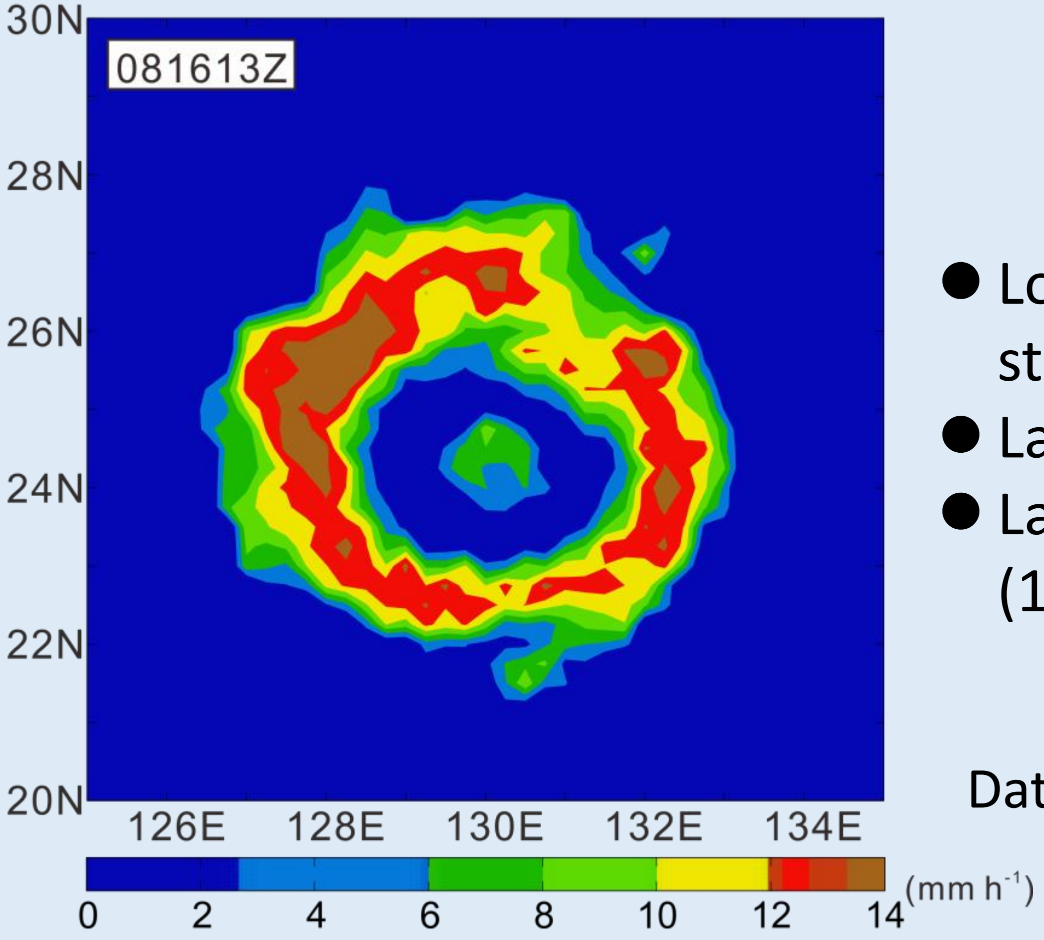


1997 Typhoon Winnie

(a) Brightness temperature



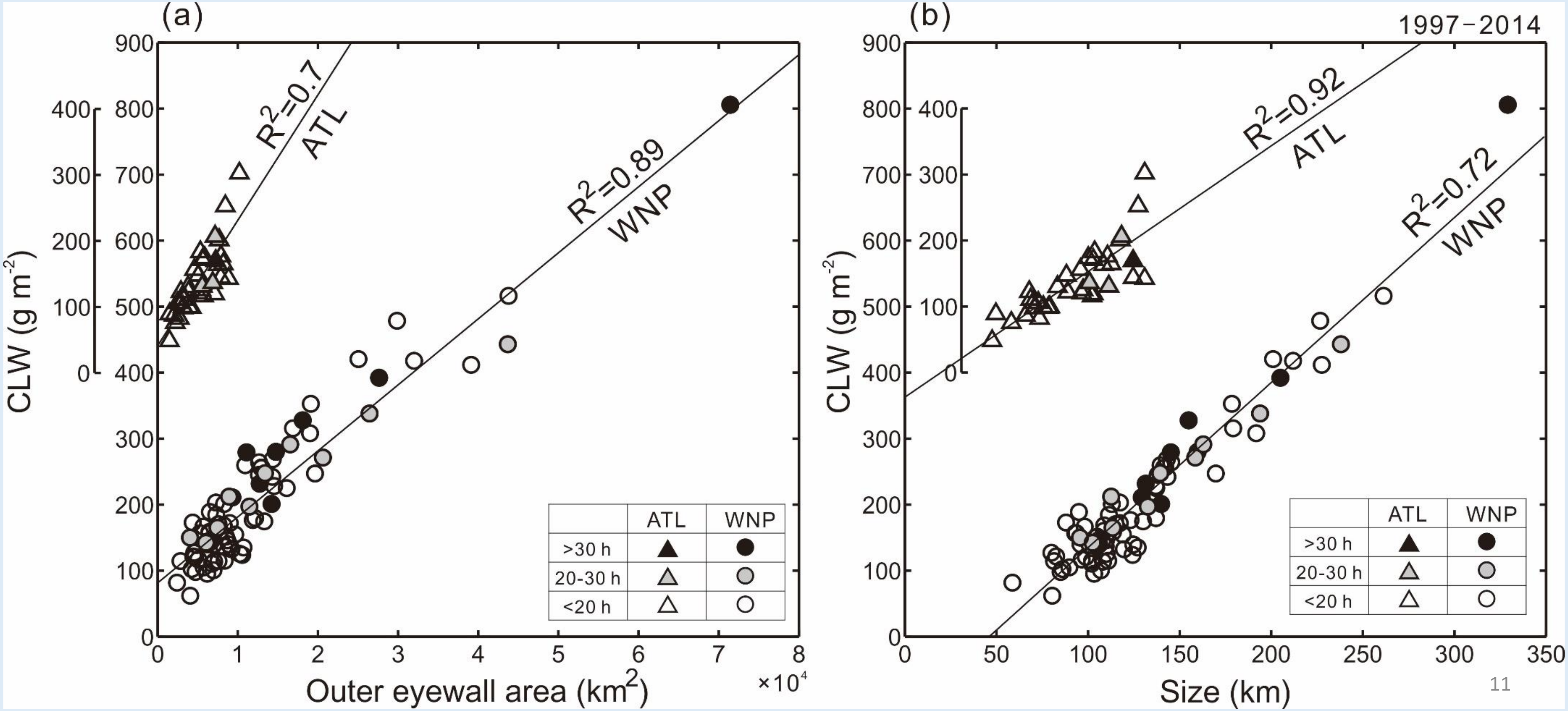
(b) Hourly rainfall



- Long-lived CE structure (46 h)
- Large moat (135 km)
- Large outer eyewall (135 km)

Data source: SSM/I

- Cloud liquid water content is proportional to the outer eyewall width
- Wider outer eyewall may be with larger latent heat release from the cloud convection



The Dynamic efficiency of heat

Eliassen-Sawyer Equation

$$\mathbf{L}\psi = \frac{\partial}{\partial r}\left(A\frac{\partial r\psi}{r\partial r} + B\frac{\partial \psi}{\partial z}\right) + \frac{\partial}{\partial z}\left(B\frac{\partial r\psi}{r\partial r} + C\frac{\partial \psi}{\partial z}\right) = \frac{g}{\theta_0}\frac{\partial Q}{\partial r} - \frac{1}{r^2}\frac{\partial 2mF}{\partial z}$$

$\rho A = \frac{g}{\theta_0}\frac{\partial \theta}{\partial z}$ (Static stability) $\rho B = -\frac{g}{\theta_0}\frac{\partial \theta}{\partial r} = -\frac{1}{r^3}\frac{\partial m^2}{\partial z}$ (Baroclinity) $\rho C = \frac{1}{r^3}\frac{\partial m^2}{\partial r}$ (Inertial stability)

$\frac{\mathrm{d}\mathbf{P}}{\mathrm{d}t} = \mathbf{H} - \mathbf{C}$ $\frac{\mathrm{d}\mathbf{K}}{\mathrm{d}t} = \mathbf{C} + \mathbf{D}$ (Hack and Schubert, 1986)

$\mathbf{P} = \int \rho C_{\mathrm{p}} T\, r\mathrm{d}r\, \mathrm{d}z$ (total potential energy) $\mathbf{K} = \int \frac{\rho v^2}{2} r\mathrm{d}r\, \mathrm{d}z$ (kinetic energy)

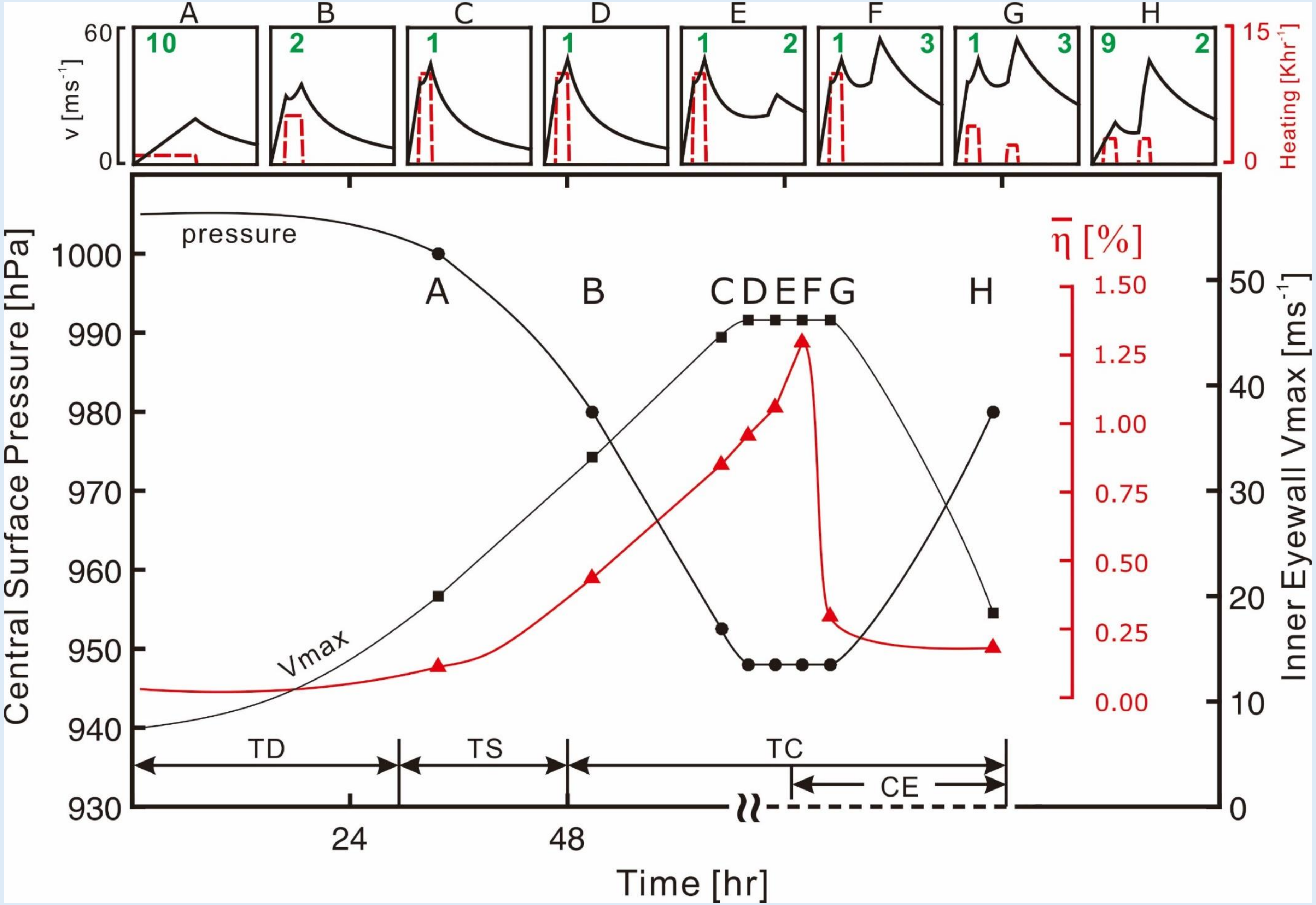
$\mathbf{H} = \int \rho c_p \Pi Q r\mathrm{d}r\, \mathrm{d}z,$ (diabatic heating) $\mathbf{D} = \int \rho F v r\mathrm{d}r\, \mathrm{d}z$ (dissipation)

$\mathbf{C} = \int \frac{g}{\theta_0} w\theta\, \rho r\mathrm{d}r\, \mathrm{d}z = \int c_p \Pi Q \eta_H\, \rho r\mathrm{d}r\, \mathrm{d}z + \int F v\, \eta_f\, \rho r\mathrm{d}r\, \mathrm{d}z$ (conversion rate) $\eta_h = \frac{g}{\rho c_p T_0}\frac{\partial \chi}{\partial r}$

η_H: The conversion rate of the convective heating to the kinetic energy of the TCs

Efficiency during ERC

- Heating in the outer eyewall is less efficient than that in the inner eyewall



Total heating of system is fixed

Refer to

1. T_B profile of Typhoon Winnie
2. Tangential wind of MM5
3. JTWC

for vortex wind profile

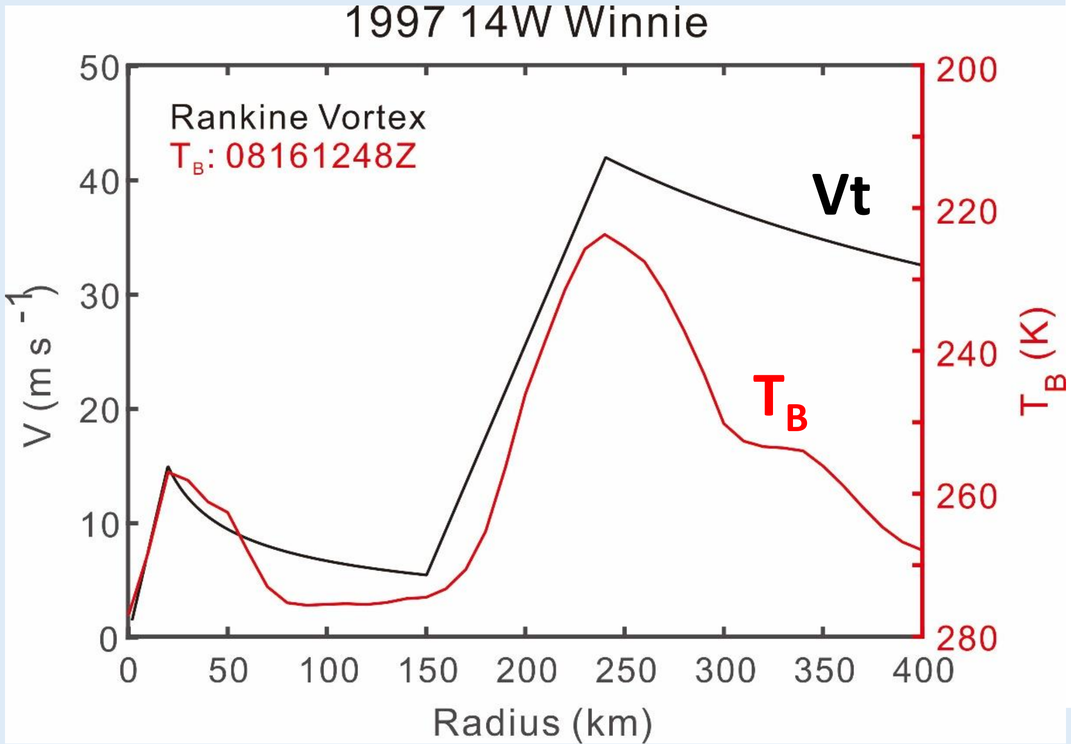
Refer to hourly rainfall of Typhoon Winnie

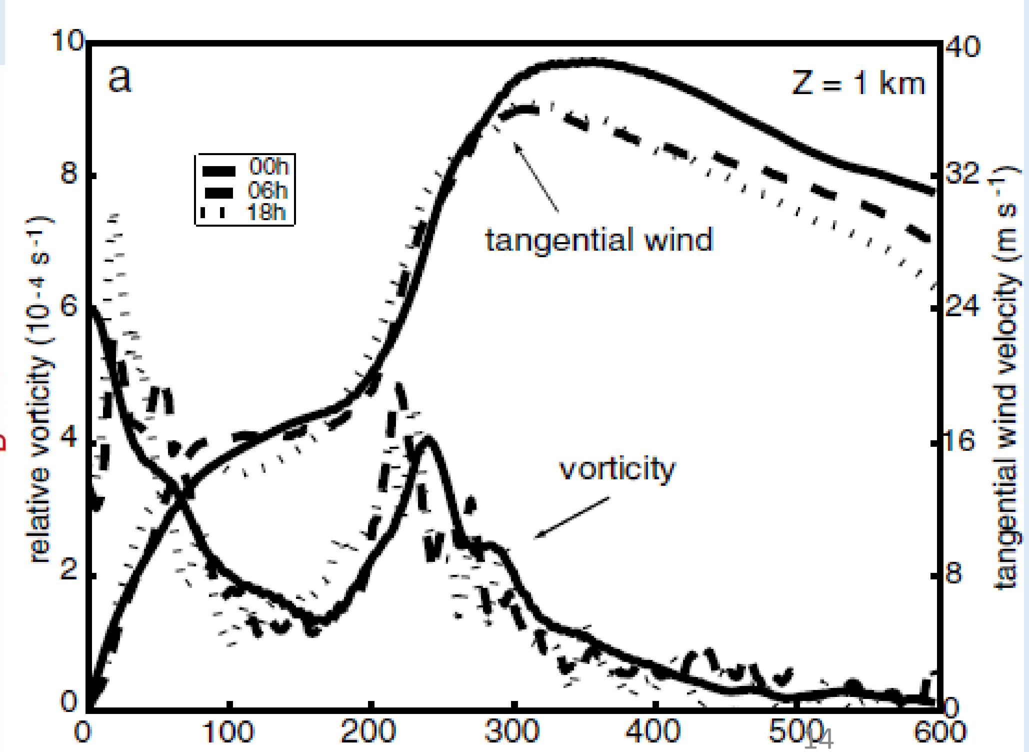
for diabatic heating profile

$$V_r = \begin{cases} v_1\left(\frac{r}{r_1}\right), & (r \le r_1) \\ v_1\left(\frac{r_1}{r}\right)^{\alpha_1}, & (r_1 < r \le r_{\text{moat}}) \\ v_1\left(\frac{r_1}{r_{\text{moat}}}\right)^{\alpha_1} + \left[\frac{v_2 - v_1\left(\frac{r_1}{r_{\text{moat}}}\right)^{\alpha_1}}{r_2 - r_{\text{moat}}}\right](r - r_{\text{moat}}), & (r_{\text{moat}} < r \le r_2) \\ v_2\left(\frac{r_2}{r}\right)^{\alpha_2}, & (r_2 < r \le 150\,\text{km}) \end{cases}$$

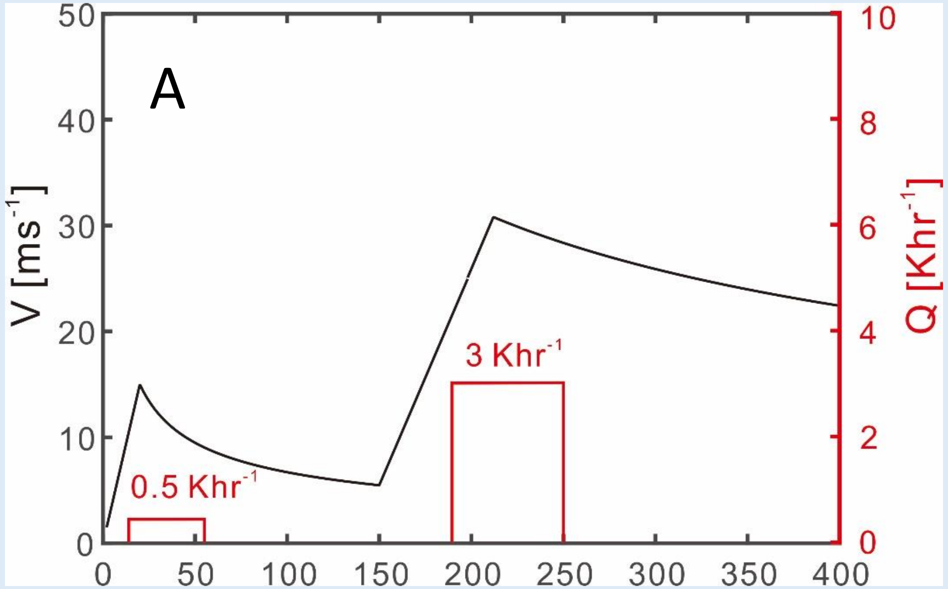
$\alpha_1 = 0.5;\ \alpha_2 = 0.5;\ r_1 = 20\ km;\ r_2 = 240km;\ r_{moat} = 150\ km$

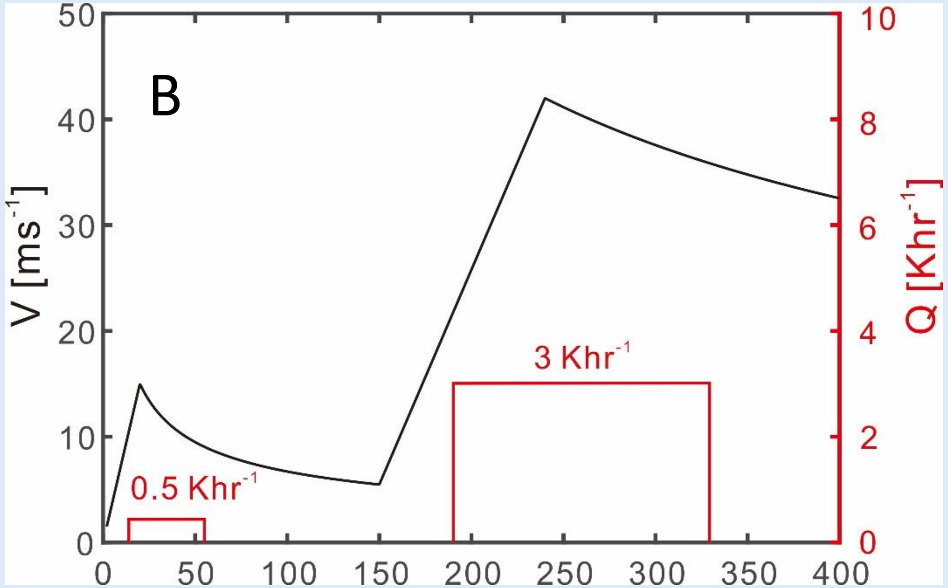
$V_1 = 15ms^{-1};\ V_2 = 42ms^{-1}$



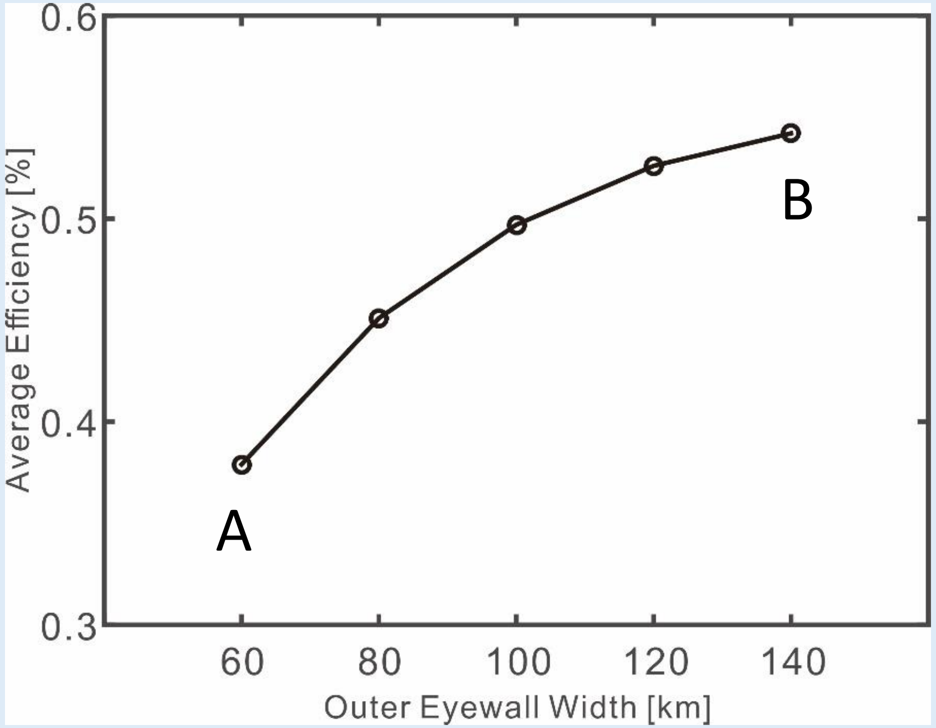


Zhang et al. 2005





- Energy efficiency increases with the outer eyewall width
- Wider outer eyewall width may help to gain sufficient kinetic energy for the long-lived CE TCs



Summary

Observation

- More long-lived CEs in the WNPAC basin (19 and 23%) than that in the ATL basin (5 and 15%)
- Long-lived CE cases have large moat and outer eyewall and are under favorable environment .
- The outer eyewall width and moat width are well correlated both in the WNPAC and ATL basins (R^2=0.7 and 0.6).
- Larger outer eyewall contain more CLW may be with larger latent heat release.

Numerical result

- Even the heating in the outer eyewall is less efficient than that in the inner eyewall, but the wider outer eyewall width may help to gain sufficient kinetic energy for the long-lived CE TCs