Tertiary eyewalls: Observations and Boundary Layer Response

Sergio F. Abarca[1], Yi-Ting Yang[2], Hung-Chi Kuo[2], Brian D. McNoldy[3] and Michael T. Montgomery[1]

[1]Naval Postgraduate School, Monterey, CA
[2]National Taiwan University, Taipei, Taiwan
[3]University of Miami, Coral Gables, FL

Tertiary eyewall essentials

Secondary eyewalls are common in nature, and have been the subject of observational and numerical modeling studies. In contrast, **Tertiary eyewalls**, are known to exist, but:

- How often do they occur?
- Any insight about their formation?

Observational Methodology

Objective method to identify concentric eyewalls (following Kuo et al. 2009; Yang et al. 2013):

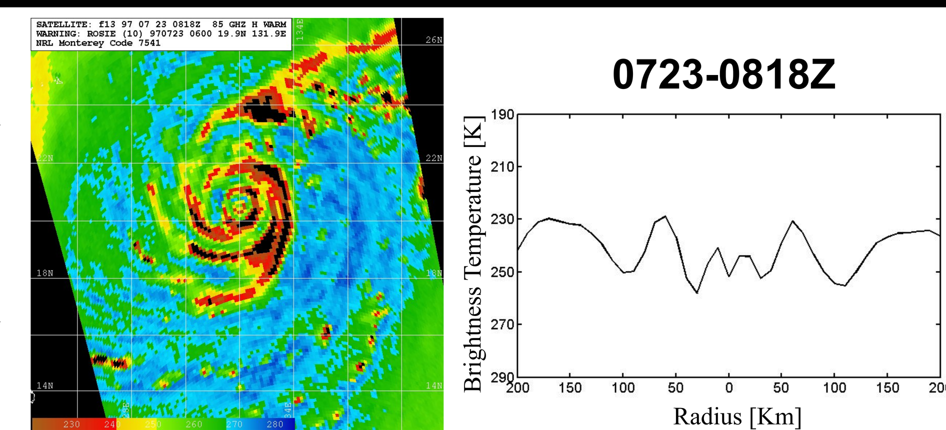
- Passive microwave imagery (85GHz)
  - Good indicator for ice above the freezing level in tropical deep convection
  - From Naval Research Laboratory (NRL, Hawkins et al. 2001)
    - Special Sensor (SSM/I)
    - TRMM Microwave Imager (TMI)
  - Imagery interpolated to a cylindrical coordinate
  - 5pixel-radial and 45^0-azimuthal bins considered
  - Averages presented
- JTWC Best track data
  - 1997-2011, **????** typhoons examined (Western Pacific)
- Five objective criteria:

Criteria	First moat	Second moat
1. Possible moat located Min-Max-Min in T_B	✔	✔
2. Significant moat $T_{Bmax} \geqq \sigma_{outer\_min} + T_{Bouter\_min}$ $T_{Bmax} \geqq \sigma_{inner\_min} + T_{Binner\_min}$	✔	x
3. Deep outer convection T_{Bouter_min}	≦ 230 K	≦ 240 K
4. Symmetric structure ≧ 5/8 sectors	✔	✔
5. Not a spiral out band The difference of two outer eyewalls ≦ 50 km	✔	✔

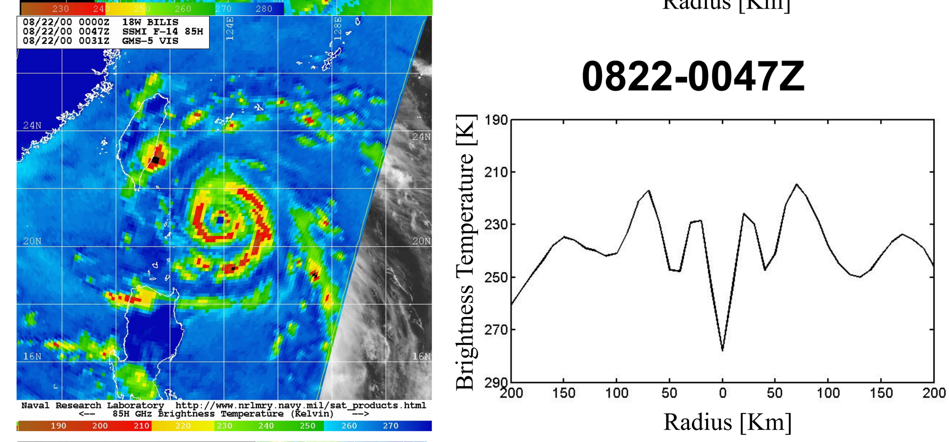
The algorithm is known to be sensitive to the convective depth of the outer eyewall (Kuo et al. 2009). But, as applied here, it seems to be a skillful discriminant of tertiary eyewall cases. Hawkins et al. (2008) classifies Sepat (2007) as a tertiary eyewall case but the objective algorithm rejects it (criteria 5).

Roughly 5% of typhoons with secondary eyewalls exhibit tertiary eyewalls

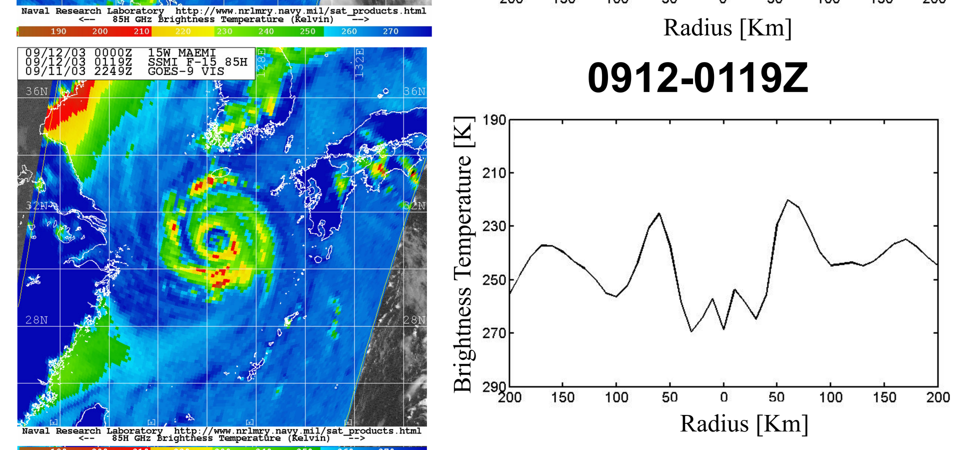
Rosie (1997)



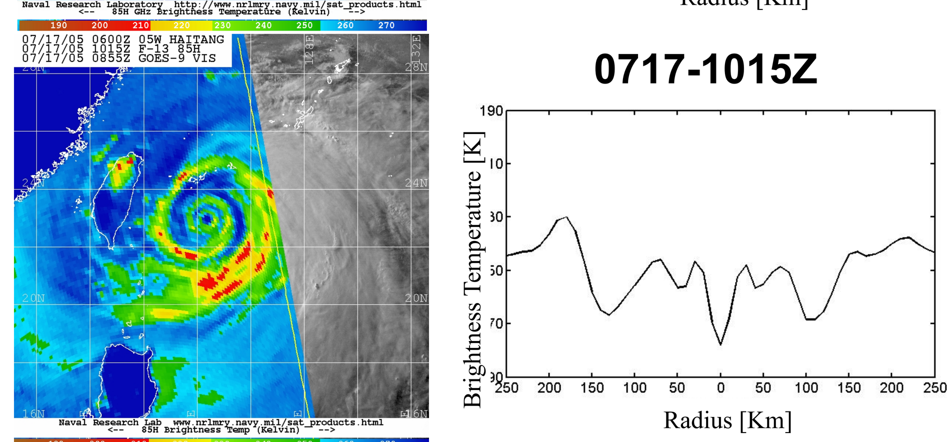
Bilis (2000)



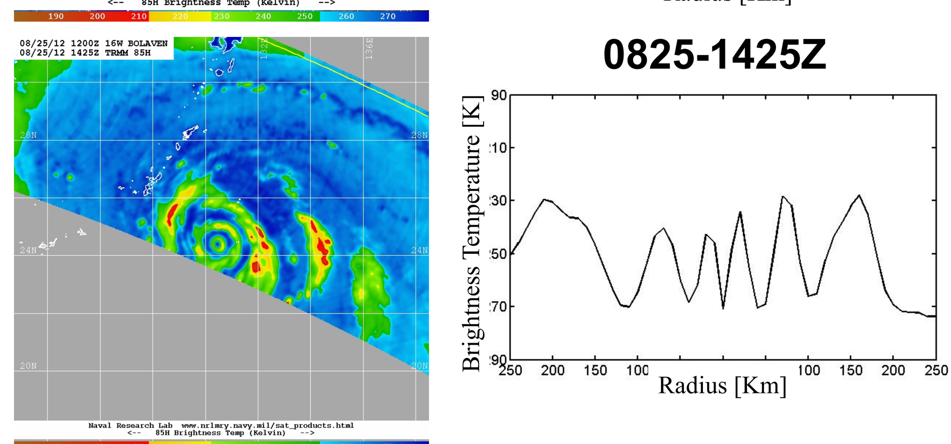
Maemi (2003)



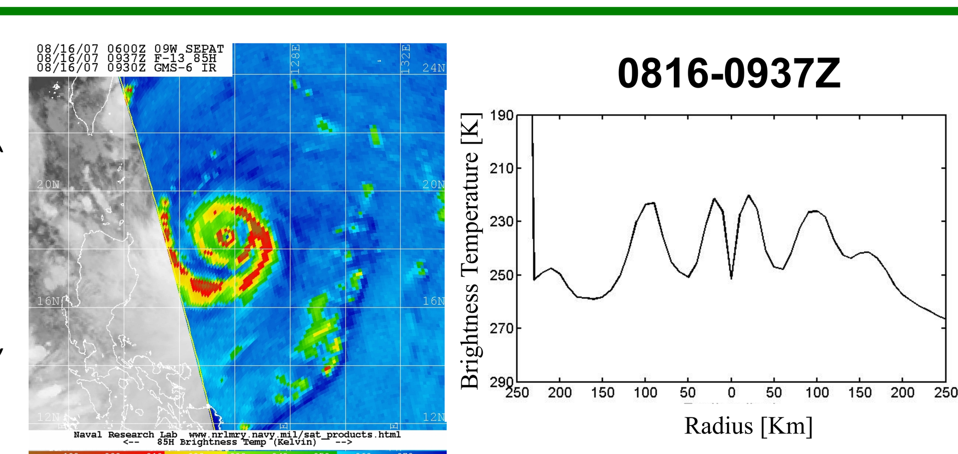
Haitang (2005)



Belaven (2012)



Sepat (2007)



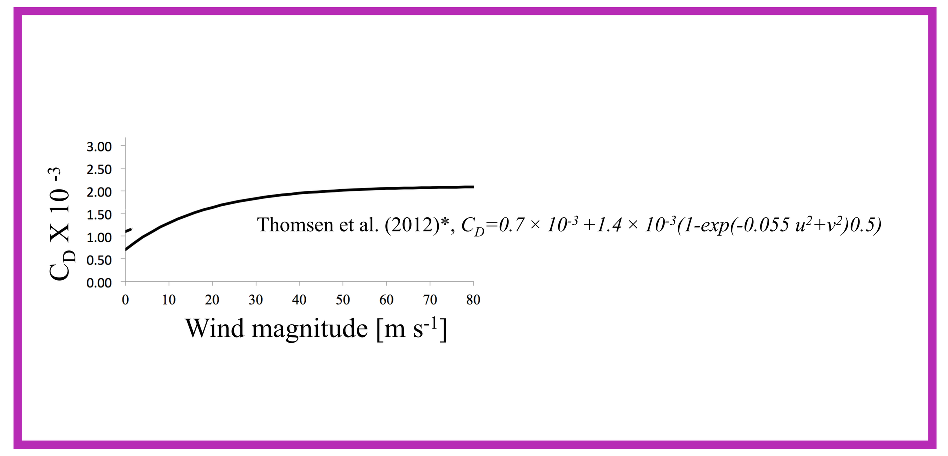
Slab boundary layer dynamics generate tertiary wind maxima in response to an observed hurricane radial structure with a secondary eyewall

Slab boundary Layer model

- Slab boundary layer model, based on Shapiro (1983)

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial r} + \frac{v^2}{r} + fv - \frac{C_D}{h}u\left(u^2+v^2\right)^{1/2} - K\left(\nabla^2 u - \frac{u}{r^2}\right) - \frac{1}{\rho}\frac{\partial p}{\partial r}$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial r} - u\frac{v}{r} - fu - \frac{C_D}{h}v\left(u^2+v^2\right)^{1/2} - K\left(\nabla^2 v - \frac{v}{r^2}\right)$$



Model parameters, and Integration

- Boundary layer depth
  - h=2 km
- Drag coefficient (Thomsen et al. 2012)
  - $C_D=0.7\times10^{-3}+1.4\times10^{-3}(1-\exp(-0.055 <u>^2+<v>^2)0.5)$
- Eddy diffusivity
  - $K=1\times10^4$ m^2 s^{-1}
- 3 km radial grid spacing
  - With constant grid spacing, interpolated from the original Juliette data taken with 30-s frequency
- 50 radial grid points in the domain
- Coriolis parameter taken at 17.5^0 of latitude (as in the real case)

Juliette (2001) observations

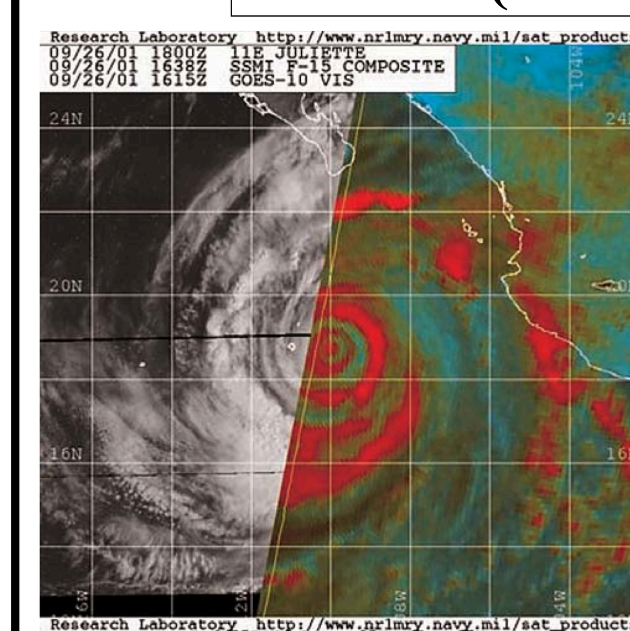


Figure. SSM/I 85-GHz composite microwave imagery showing upper-level heavy precipitation (red) and low-level clouds and moisture bands (green). See Hawkins et al. (2001) and McNoldy (2004) for details.

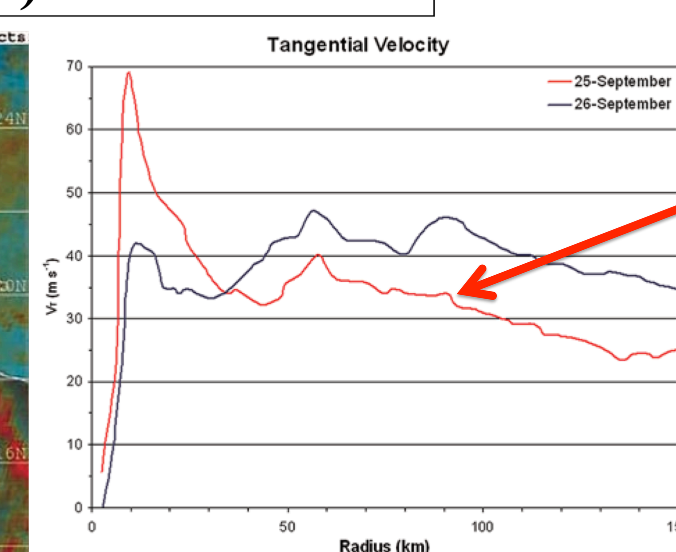
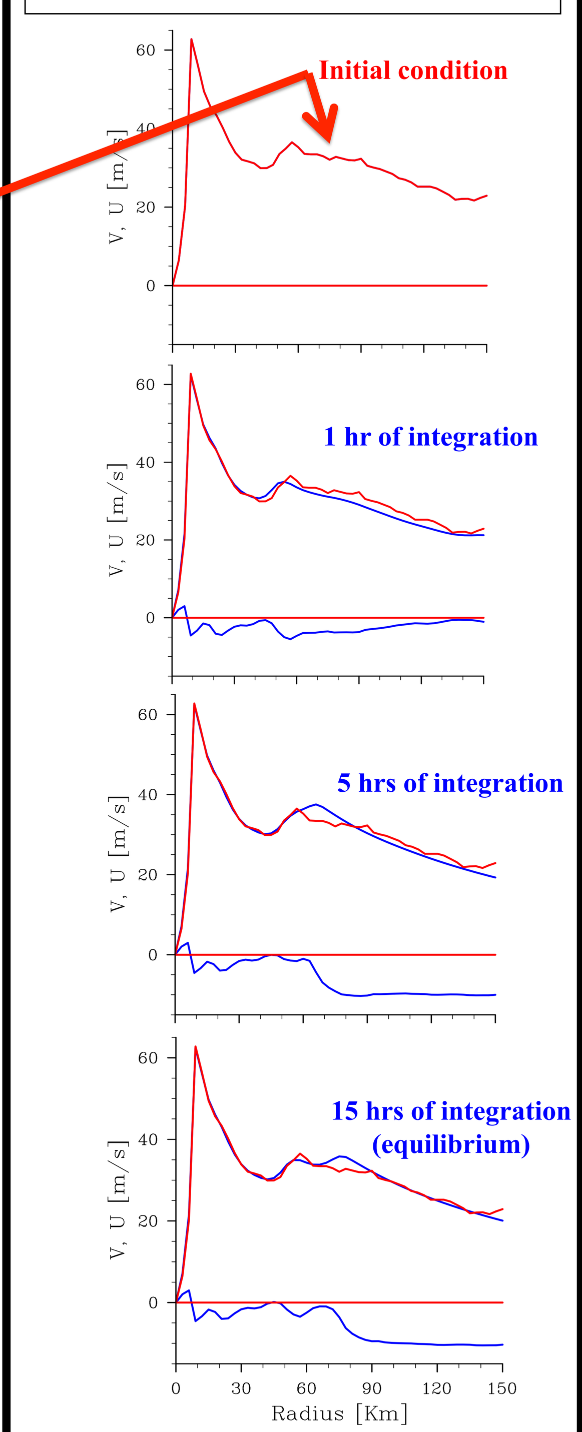
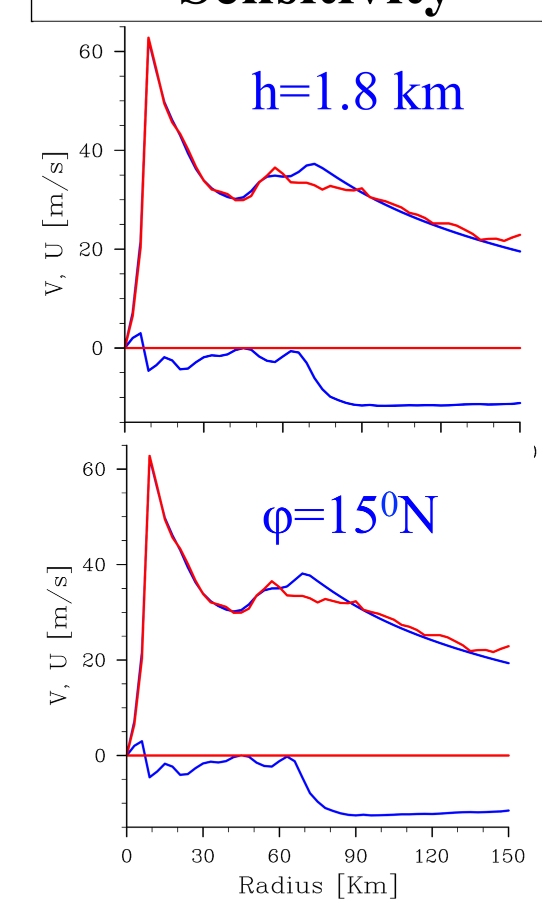


Figure. Tangential velocity radial profiles through the northwest quadrant on 25 and 26 Sep at 1819–1849 and 1722– 1755 UTC. The northwest quadrant is representative of the other three measured but was chosen for its higher resolution and better quality data on both days. Adapted from McNoldy (2004)

Control simulation



Sensitivity



Reducing latitude to 15^0N, or boundary layer height to 1.8 km, results in a more pronounced tertiary eyewall at equilibrium, with merger with the secondary eyewall.

References & Acknowledgements

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