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Image by Digital Typhoon (http://agora.ex.nii.ac.jp/digital-typhoon/)
Introduction

• It is important for Eyewall Replacement Cycle (ERC) to suppress water vapor supply associated with the low-level inflow in PBL (Houze et al., 2007).

• Yang et al. (2013, MWR) indicated that ERC does not always occur even if Concentric Eyewall (CE) forms, using many satellite data.

Illustration of concentric eyewalls (Houze et al., 2007).
Typhoon Bolaven (T1215)

- Clear multiple eyewalls.
- Maintaining the eyewalls for over one day.
- Without eyewall replacement cycle.
Typhoon Bolaven (T1215)

- Clear multiple eyewalls.
- Maintaining the eyewalls for over one day.
- Without eyewall replacement cycle.
Typhoon Bolaven (T1215)

Azimuthal mean of precipitation (JMA Radar)

About 1 day

2012082512Z

1. Radius (km)

[mm h⁻¹]
Motivation

• Why could CE of Bolaven maintain for over one day?
• To understand the ERC, Maintaining CE must be also investigated.
• We investigate how the difference of CE with and without replacement has.
  – We focus on the relationship between structure and replacement of CE in TCs.
Contents

• Numerical experiment of Bolaven’s CE.
  – Three-dimensional non-hydrostatic model (CReSS).

• The characteristic structure of Bolaven’s CE.

• A hypothesis of CE maintenance.
  – On the basis of Sawyer-Elliassen response and Rossby deformation radius.

• Idealized experiment of replacement of CE.
Model setting

• **Physical process**
  – Surface process: Bulk aerodynamic formula (Kondo (1975)).
  – Ocean: one-dimensional, vertical mixing process.
  – Turbulence: 1.5-order closure of turbulent kinetic energy.
  – Cloud physics: Parameterization of the bulk cold rain.
    (calculating mixing ratio and number concentration).

• **Data set**
  – Terrain: NASA SRTM 30 data.
  – SST: JMA MGDSST data.
Calculating domain

- **1\textsuperscript{st} domain**
  - 5km x 5km
  - JMA-GSM
    - 2012/08/22 00Z
    - 6 days

- **2\textsuperscript{nd} domain**
  - 2.5km x 2.5km
  - 1\textsuperscript{st} domain
    - 2012/08/23 06Z
    - 4 days

- **3\textsuperscript{rd} domain**
  - 1km x 1km
  - 2\textsuperscript{nd} domain
    - 2012/08/24 12Z
    - 2.5 days
Result (30 hour)

Pressure and precipitation [mm h^{-1}] (030:00)
Time series of CE

Azimuthal mean precipitation

2012082412Z
Time series of CE

Azimuthal mean precipitation

Maintaining the CE for over “one day”.

2012082412Z
Structure of simulated Bolaven’s CE

azimuthal mean $W$ and $V_r$ (026:30)
After forming the outer eyewall...

- The outer eyewall is **tilted outward**, relative to the inner eyewall.
- The vertical flow (W) of the outer eyewall is **weaker** than that of the inner eyewall.
  - Weak W of the outer is related to supply of watar vapor into the inner continuously.
- These characters are consistent with the result of Yang et al. (2013).
A hypothesis of maintaining CE
- Based on Sawyer-Eliassen response -

• Rossby deformation radius: \[ R \sim \frac{N}{I} \]
  \[ N = \text{vertical stability}, \quad I \sim \frac{v}{r} \quad \& \quad \frac{\zeta}{r} = \text{horizontal stability} \]

Around the outer eyewall...
• \( R = \text{large} \Rightarrow \frac{u}{w} = \text{large} \Rightarrow \text{outward tilted} \)
  \Rightarrow \text{maintenance (without replacement)},
• \( R = \text{small} \Rightarrow \frac{u}{w} = \text{small} \Rightarrow \text{more upright} \)
  \Rightarrow \text{replacement}.

Thus, a condition of maintaining CE is that (for TCs of sub-equal intensity)
• the vertical stability is strong,
• the position of the outer eyewall is far from the center of TC.
Idealized Experiments

• Weak axisymmetric vortex.
• Tropical sounding data.
• SST = 302 K (Constant).
• Horizontal grid interval = 2 km.
• $f$–plane (15 degree N)

Sweeping parameter is sounding temperature.
• “ST302” experiment = sounding temperature + 3 K.
  – ST302 is more stable than CTL.

The definition of our vertical stability: $T_{\text{top}} - \text{SST}$

$T_{\text{top}}$ is the temperature of the tropopause.
In ST302, the structure of the outer eyewall is similar to that of Bolaven.
Idealized Experiments

azimuthal mean $w$ (CTL)  

azimuthal mean $w$ (ST302)
Idealized Experiments

Eyewall replacement ~100 km

Maintaining CE ~200 km
Summary

• We conducted numerical experiment of Bolaven, using CReSS model.
  – Simulated CE maintained for over one day (without eyewall replacement).
• Simulated Bolaven’s outer eyewall was (relative to the inner eyewall)
  – outward tilted,
  – weak updraft.
• A hypothesis of maintaining CE, based on Sawyer-Eliassen response.
  – Vertical stability is strong.
  – The position of the outer eyewall is far from the center of TC.
• Idealized experiments of CE.
  – CE of the maintaining experiment had the same structure of Bolaven’s CE.