The 5th Research Meeting of Ultrahigh Precision Meso-scale Weather Prediction
Mar. 9 (Mon), 2015 Nagoya

Multiple Eyewalls and Wind Features in the 2012 Typhoon BOLAVEN

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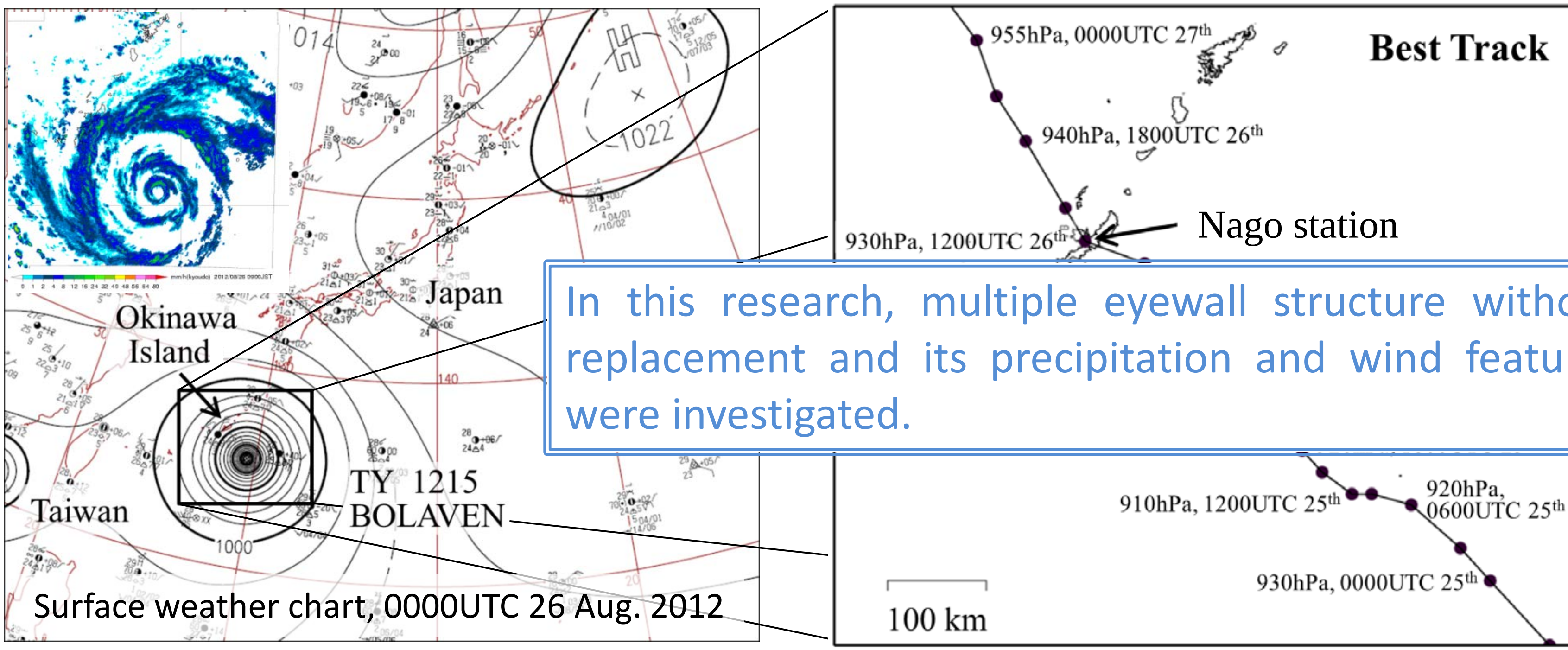
Background of research

- BOLAVEN passed the Okinawa Main Island, while moving northwestward. Multiple eyewall structure was clearly formed more than 24 hrs without eyewall replacement.
- In previous researches, many researches mainly performed in the event with eyewall replacement, and structure and feature of multiple eyewall without replacement didn't mostly understand.

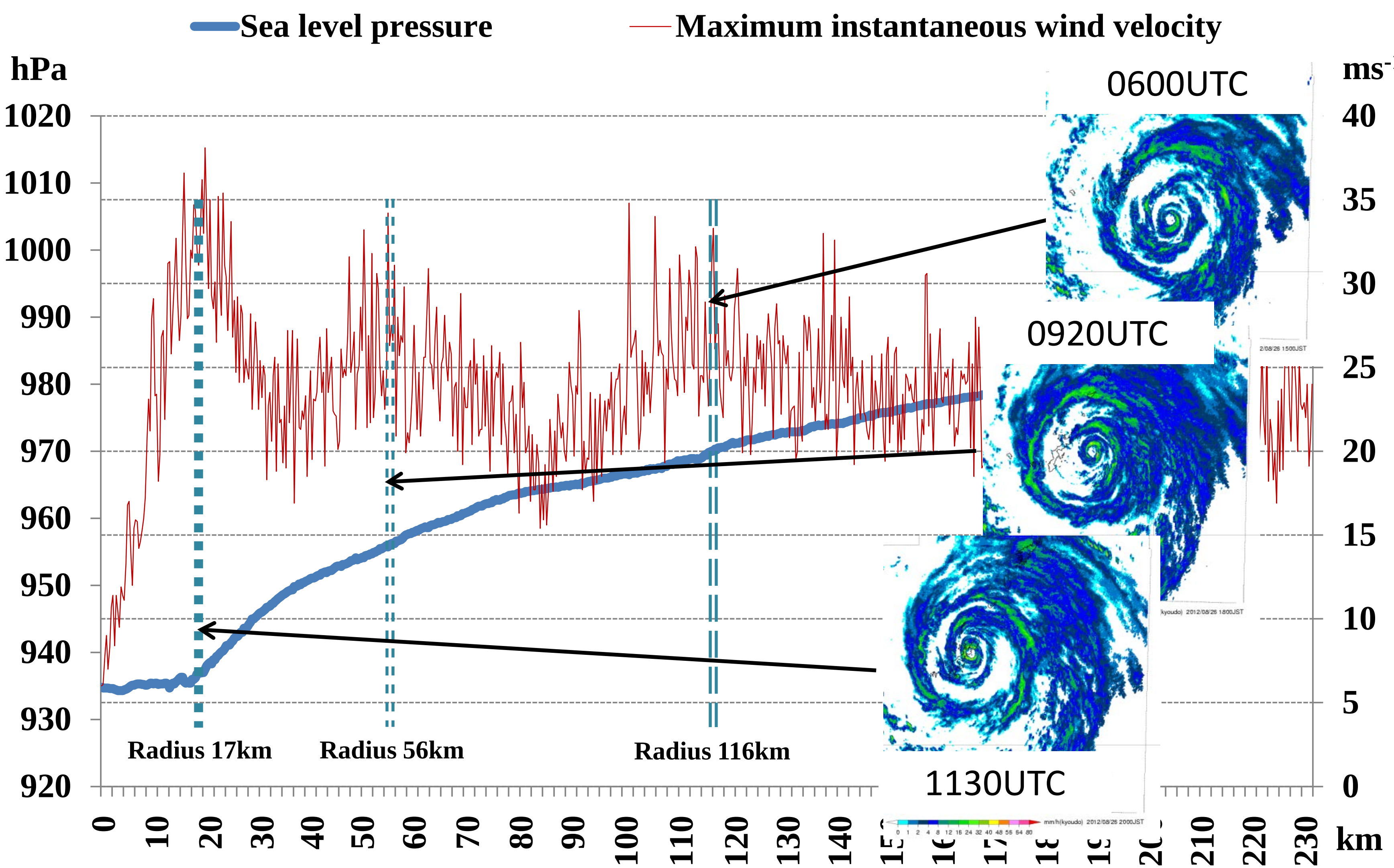


Surface weather chart, 0000UTC 26 Aug. 2012

In this research, multiple eyewall structure without replacement and its precipitation and wind features were investigated.

- MSM didn't reproduce the multiple eyewall structure, and the precipitation and surface wind speed predicted by the MSM were more intense than ones actually observed in the central region.
- Okinawa Meteorological Observatory held an unprecedented press conference before the approach of BOLAVEN to take greatest precautions for the local governments and inhabitants. However, severe damages didn't actually occur.

Surface observation data（Nago station）
Approaching period, ～ 1228UTC 26 Aug 2012



e. g. Kitabatake et al. 2013

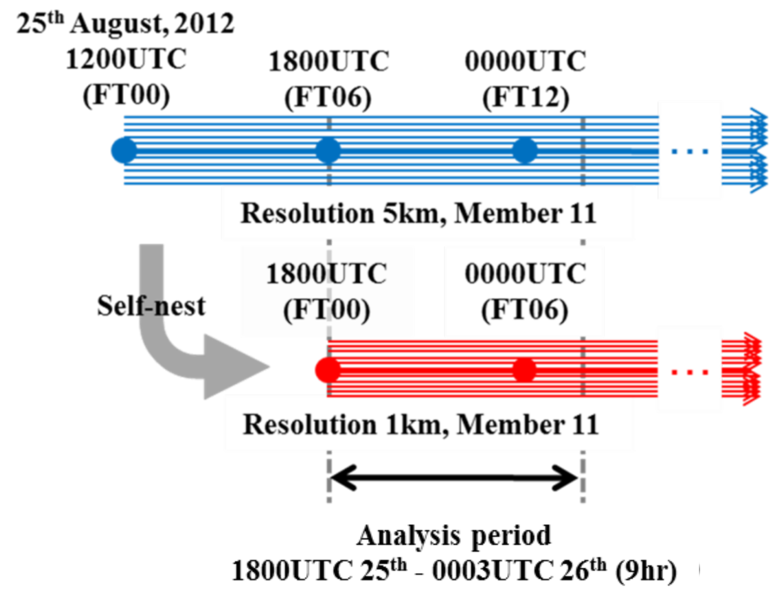
Design of cloud-resolving ensemble experiment

＜Model settings＞

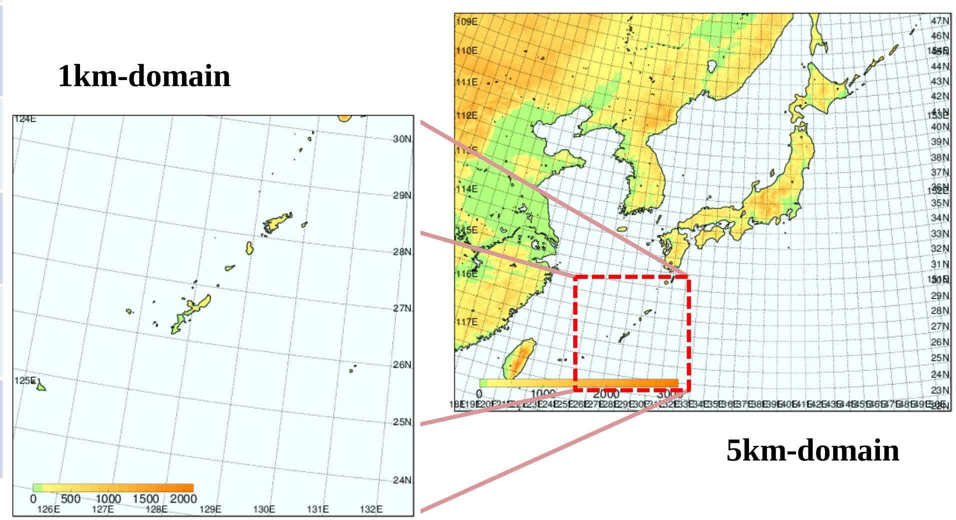
	5km-forecast	1km-forecast
Model	JMA-NHM	
Resolution・Grid size	5km・721x577x50	1km・800x800x60
Time step	24 sec	4 sec
Initial condition（Control run）	Meso analysis（NHM-4DVAR） Resolution 5km （Inner-loop 15km, Outer-loop 5km, Assimilation Window 3hr）	FT=06 of 5km forecast
Boundary condition（Control run）	GSM forecast（interval 1hr）	5km forecast（interval 1hr）
Initial condition（Perturbative member）	Meso analysis + perturbation of JMA weekly ensemble forecast	FT=06 of 5km forecast
Boundary condition（Perturbative member）	GSM forecast + perturbation of JMA weekly ensemble forecast	5km forecast（interval 1hr）
Member	11（Control run + Perturbative 10 members）	
Basic equation	Full compressible・Nonhydrostatics・Solution of HE-VI	
Cloud microphysics・Convective scheme	2-moment 3-ice bulk method ＋Kain-Fritsch scheme	2-moment 3-ice bulk method
Layer・Turbulent scheme	Mellor Yamada Nakanishi Niino Level3（2009）	Deardorff（1980）

This ensemble experiment was performed with the supercomputers Fujitsu ‘Kei’ and Hitachi ‘SR16000’

＜Ensemble forecast＞



＜Model domain＞

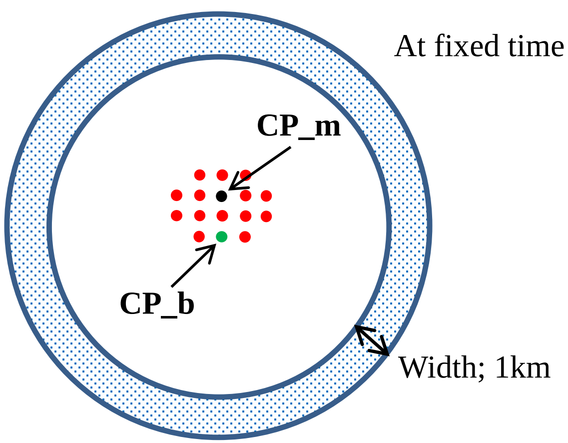


High-precision estimation of typhoon's central position

Because the picture of multiple eyewall significantly depends on the accuracy of central position, it was estimated based on Braun's method（Braun 2002）.

- Braun's method

CP_m; Grid point of minimum surface pressure
CP_b; Grid point estimated by Braun's method



$$Sp = \sum_{r=1(km)}^{100} \sigma_r(Psea)$$

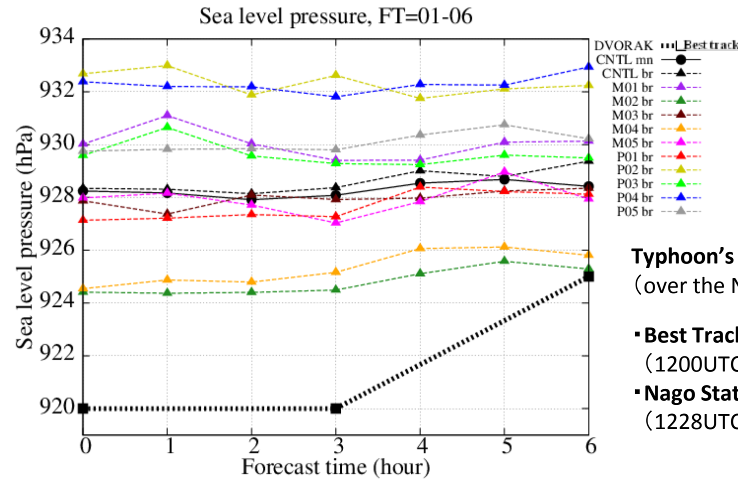
[σ_r: Standard deviation of Psea on the ring region of radius r, width 1 km]

①Grid point of minimum surface pressure is selected as first guess（CP_m）, and Sp is calculated at many points in the vicinity of CP_m.
②Geometric central position （CP_b） is decided at the point of minimum value of Sp.
③The position of grid point of CP_b is applied to all altitude.

Because BOLAVEN wasn't affected by jets and troughs, typhoon's center wasn't a tilt in the target period.

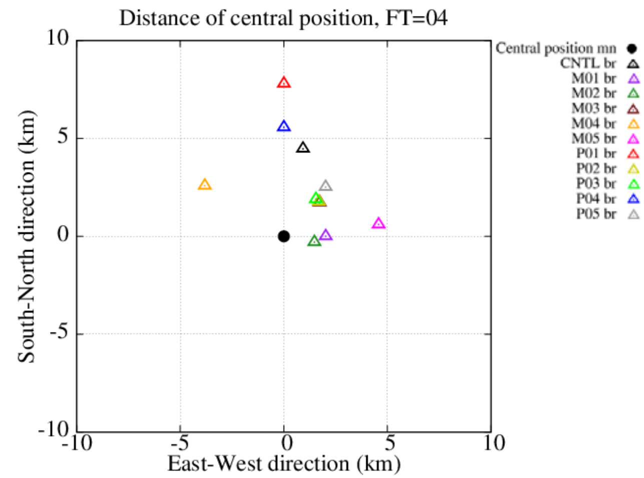
⬇

Geometric central position was estimated with information of the eyewalls



Typhoon's central pressure
（over the Nago, FT=18）

- **Best Track 930.0 hPa**
（1200UTC 26 Aug.）
- **Nago Station 934.8 hPa**
（1228UTC 26 Aug.）



The maximum and average distances of relative positions between minimum surface pressure and geometric center were 7.8 km and 3.8 km, respectively.（Difference of pressure was less than 0.5 hPa）

⬇

Analysis was affected by the difference of about 8 km.
➔ Typhoon's central position must be decided with Braun's method.

Objective evaluation of multiple eyewall

- Reproducibility was evaluated using the average of standard deviation of total water substance （Cloud water, Rain, Cloud ice, Snow, Graupel） within the ring, which has the shape of height from 0.5 km until 4 km and width 2km at the radius of local maximum tangential velocity.

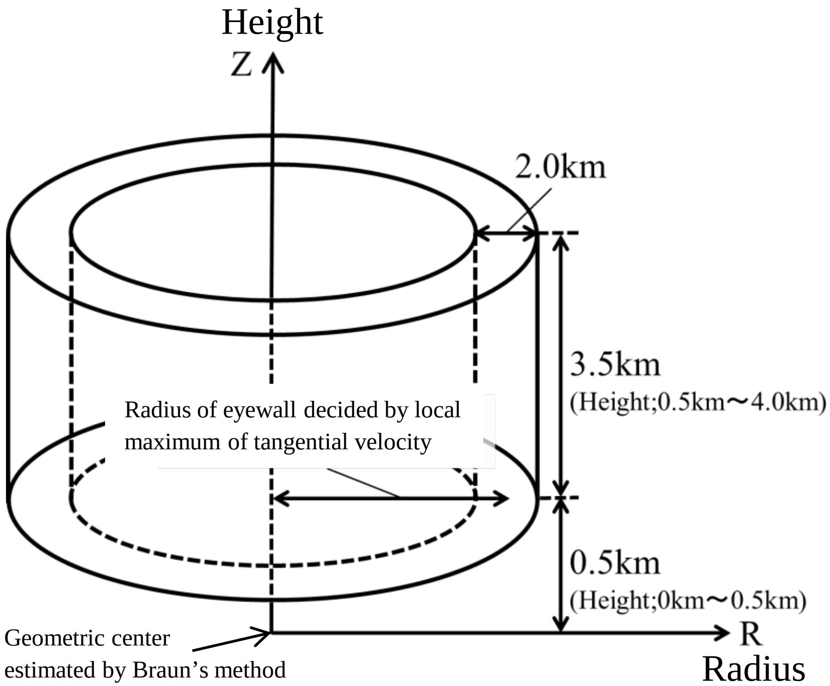
Multi-eye index（MEI）

$$\mathrm{MEI}=\frac{1}{M}\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Tw_i-M)^2}\quad\left(M=\frac{1}{N}\sum_{i=1}^{N}Tw_i\right)$$

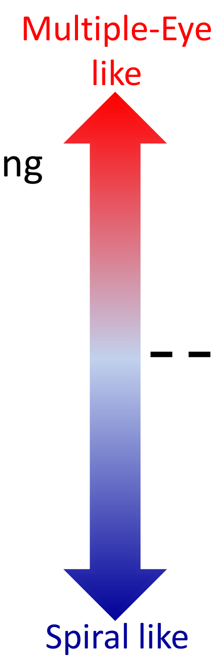
$$Tw_i=(Qc+Qr+Qi+Qs+Qg)_i$$

N: Grid number within the ring

M: Average of total water substance within the ring



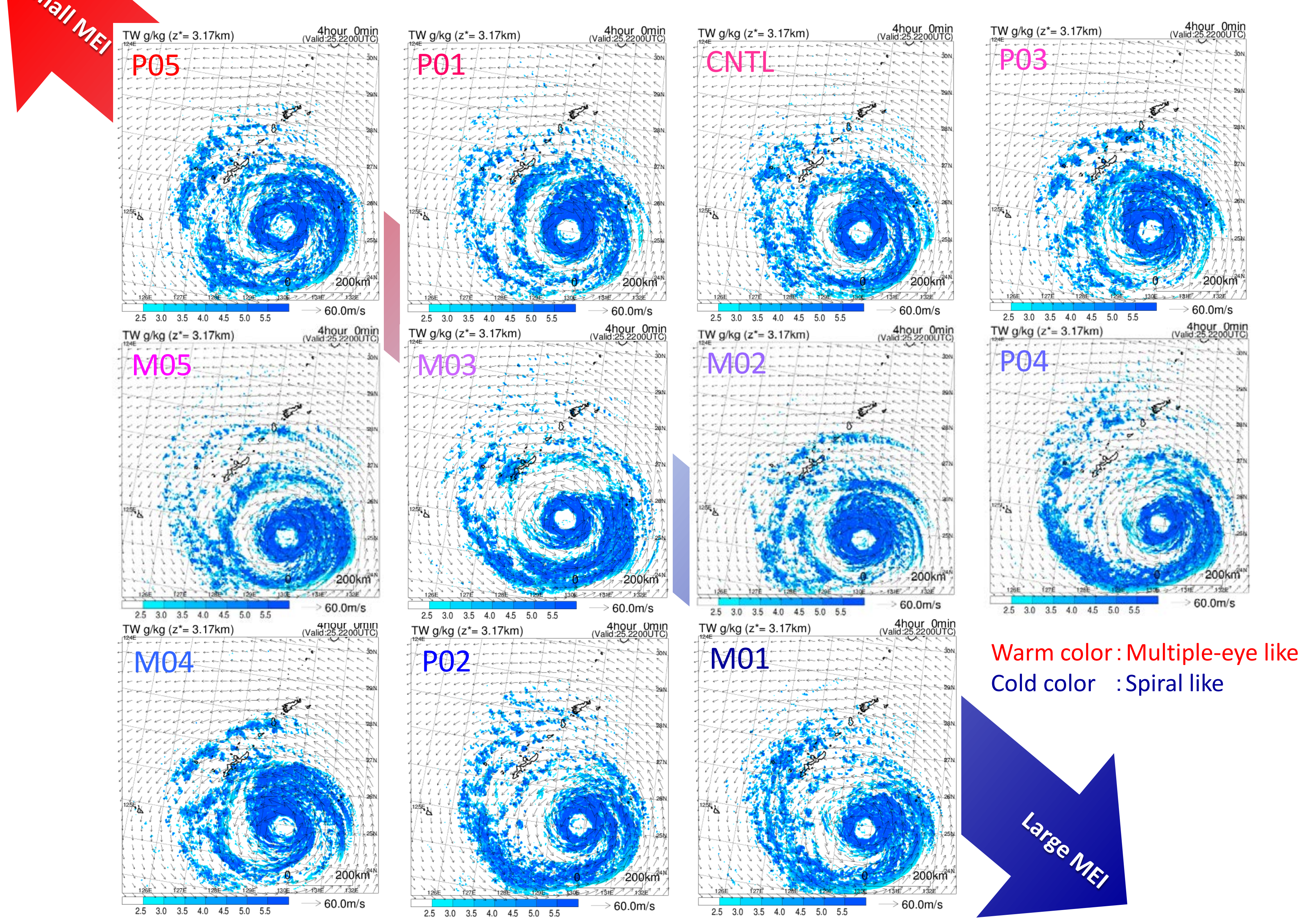
Reproduction criteria: $\mathbf{MEI \leq 0.80}$



Member	Radius of local maximum tangential velocity（km）	MEI
P05	133.0	0.58
P01	120.0	0.64
CNTL	140.0	0.69
P03	148.0	0.76
M05	134.0	0.79
M03	139.0	0.83
M02	114.0	0.89
P04	135.0	0.91
M04	124.0	0.96
P02	140.0	1.08
M01	132.0	1.17

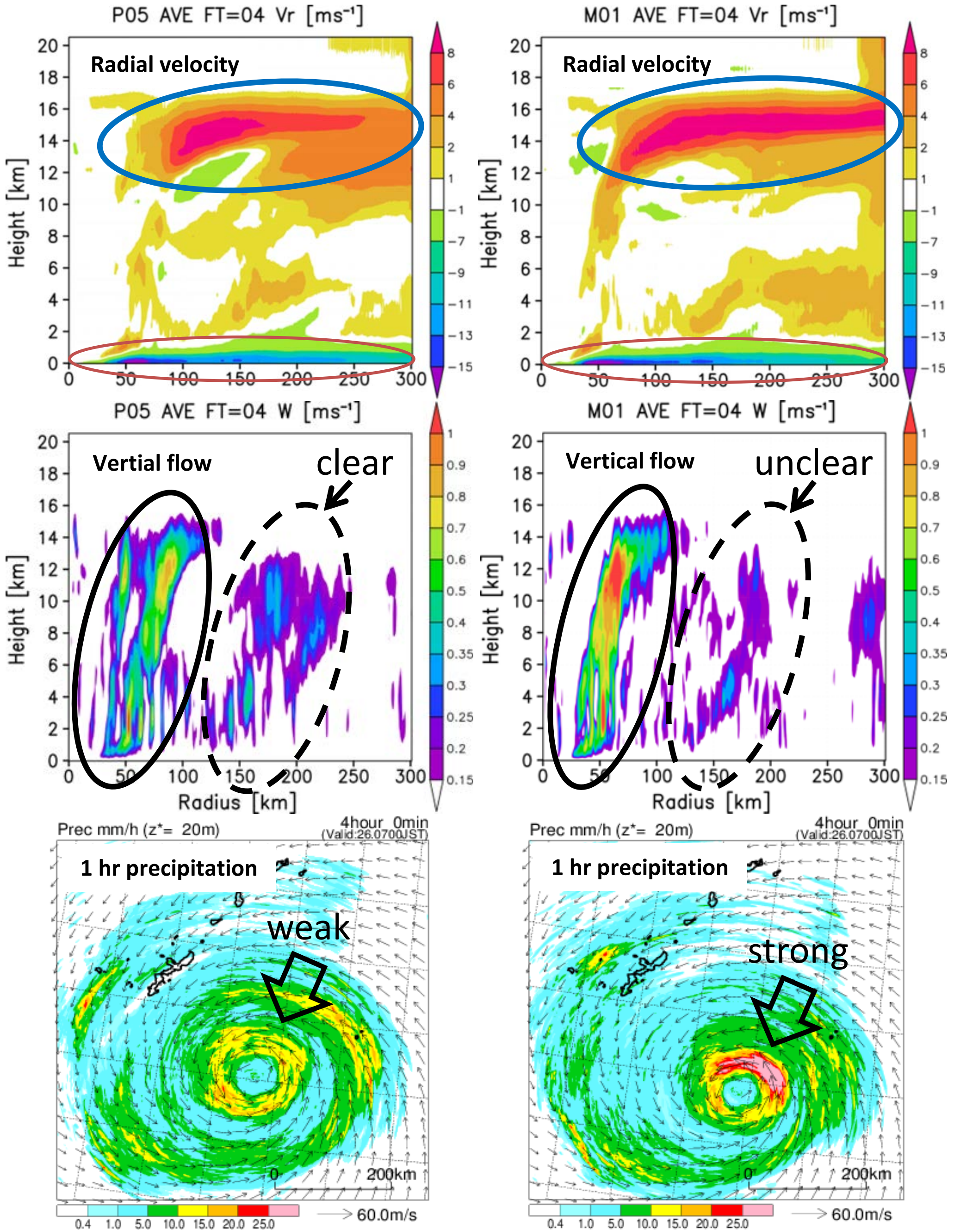
Small MEI indicates high-reproducibility of multiple eyewall structure.

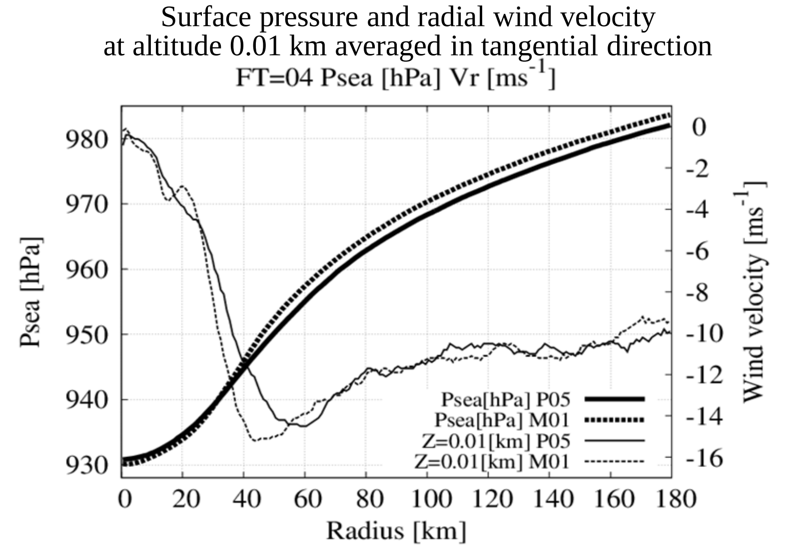
Reproduction result of each member   TW Height 3.17km FT=04

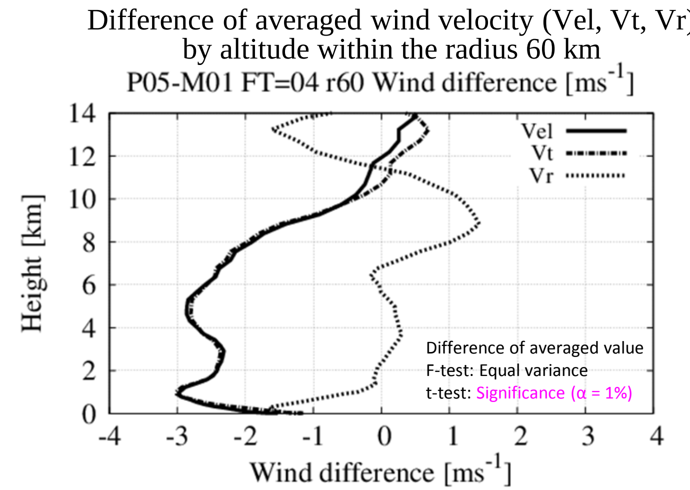


Warm color : Multiple-eye like
Cold color : Spiral like

Difference of multiple eyewall structure（P05）and spiral structure（M01）





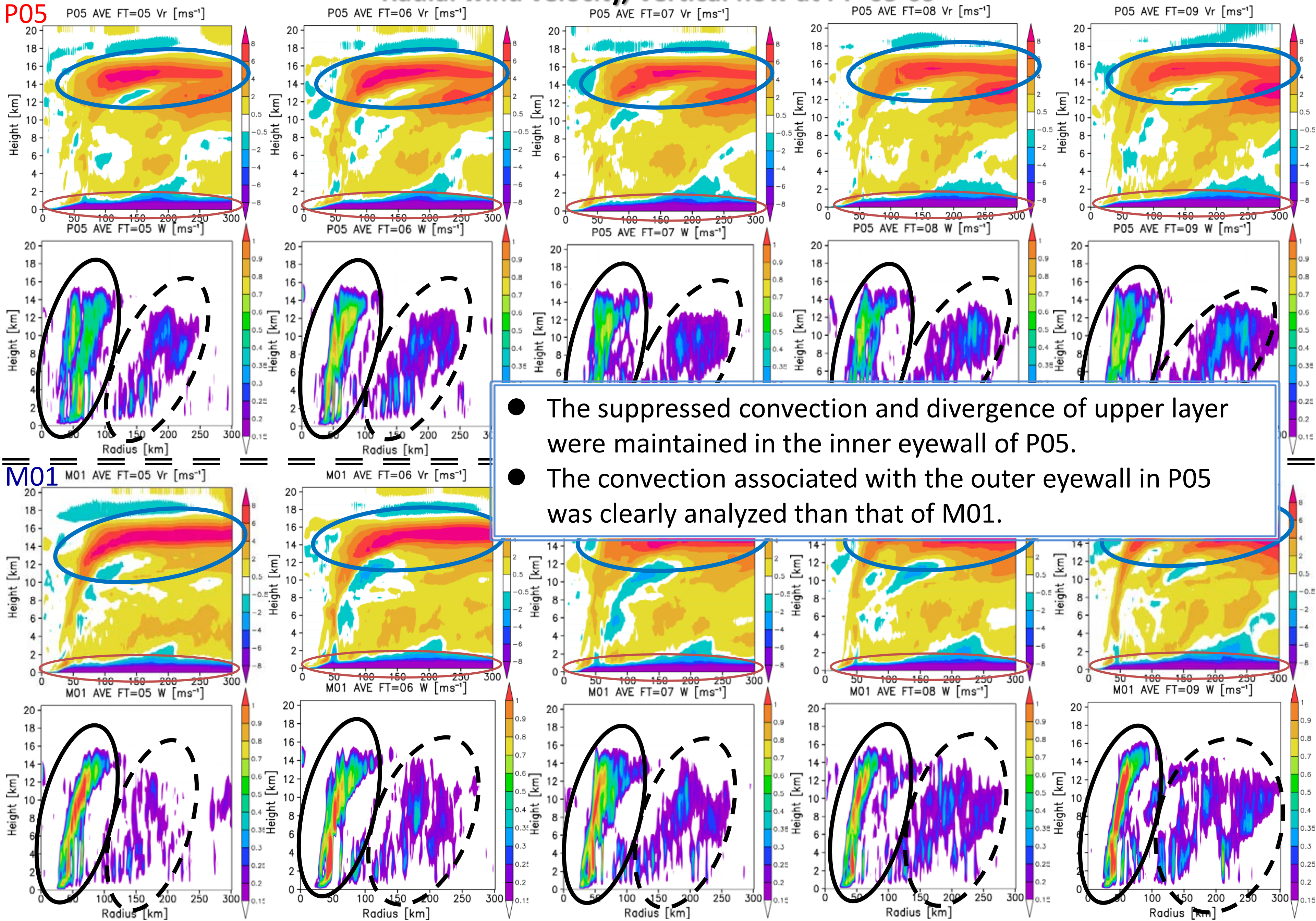


Compared with the typhoon of spiral structure（M01）, the typhoon of multiple eyewall structure（P05）had …

- gentle pressure gradient near the surface in the central region
- weak inward inflow below the altitude of 1 km
- weak convection and divergence of upper layer in the inner eyewall
- the suppressed precipitation and wind velocity in the central region

Maintenance of multiple eyewall structure（P05）and spiral structure（M01）

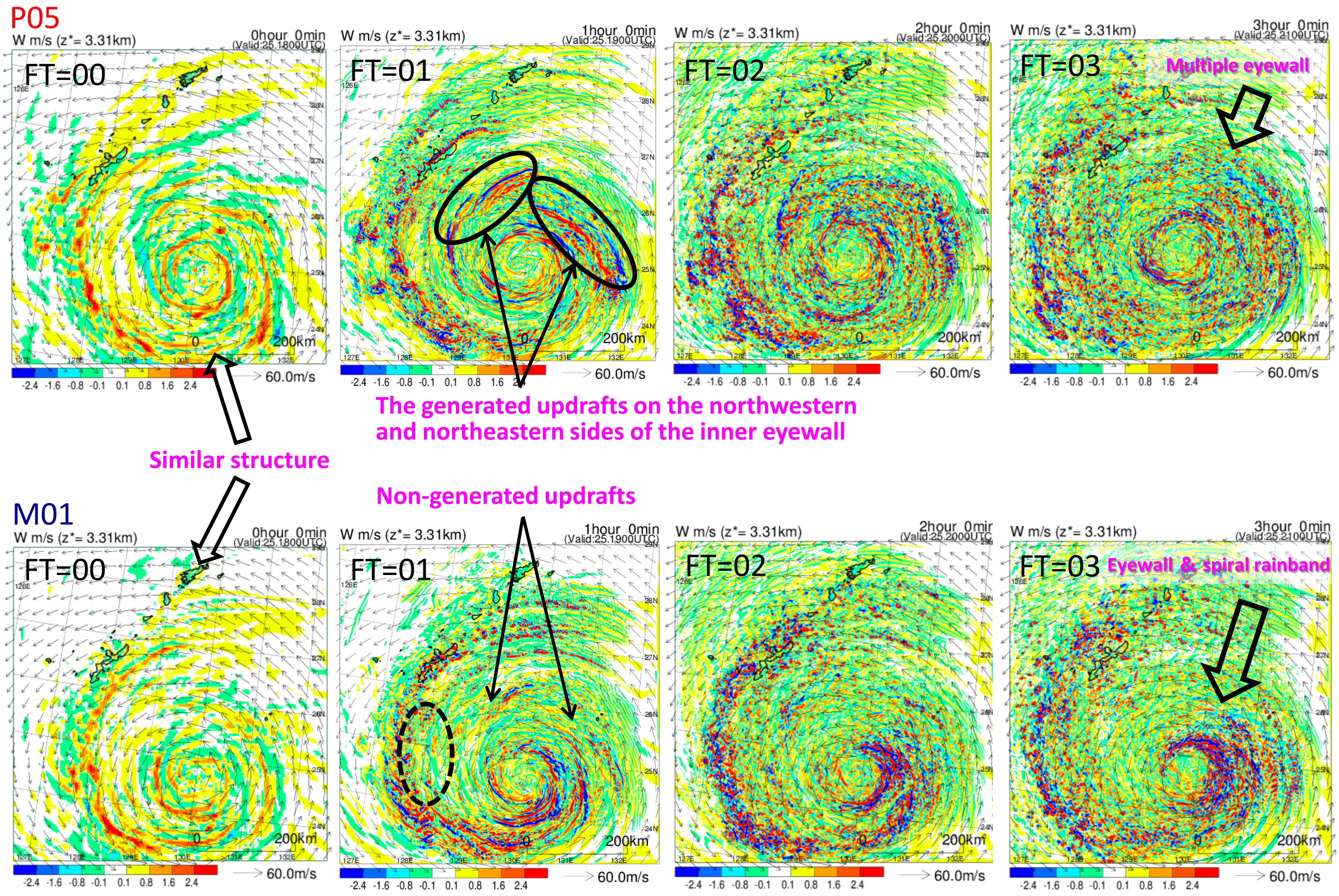
Radial wind velocity, Vertical flow at FT=05-09



- The suppressed convection and divergence of upper layer were maintained in the inner eyewall of P05.
- The convection associated with the outer eyewall in P05 was clearly analyzed than that of M01.

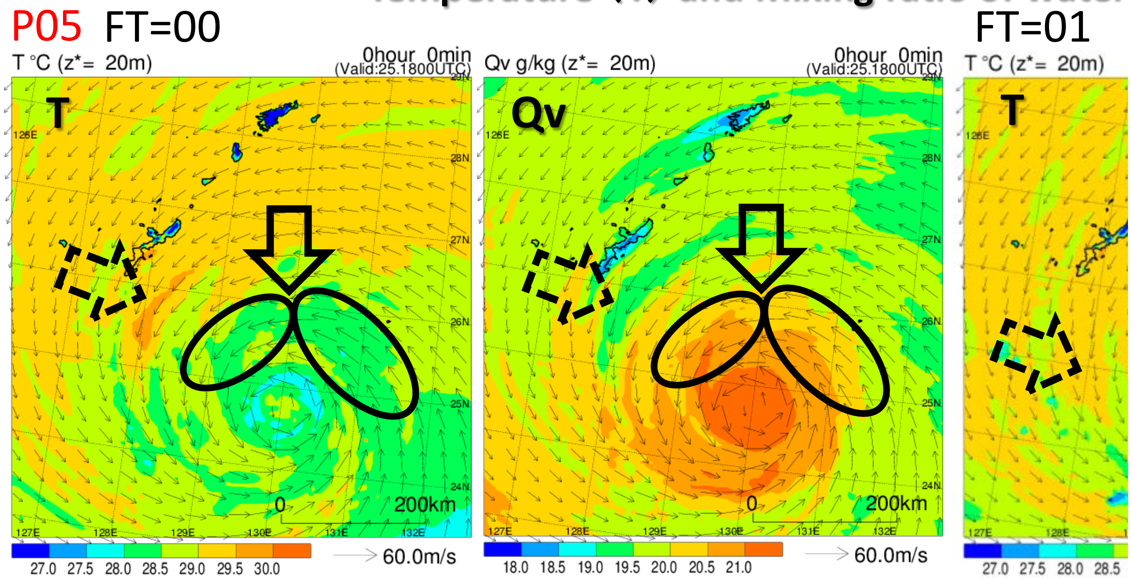
Formation process of multiple eyewall structure（P05）and spiral structure（M01）

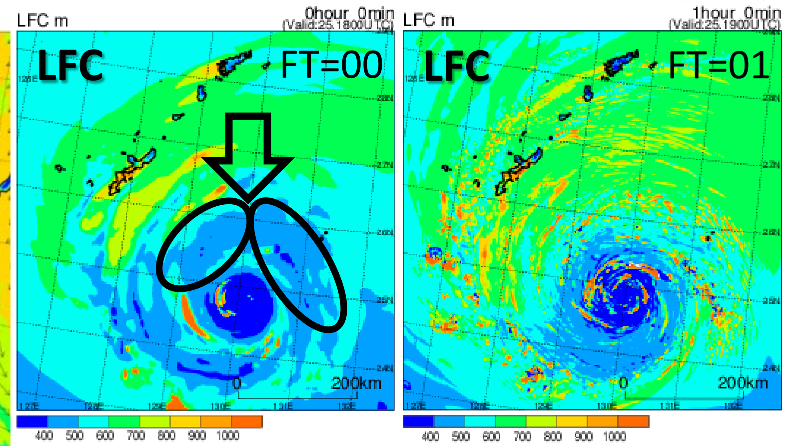
Vertical flow（W）at Z*=3.31km



Formation process of multiple eyewall structure（P05）and spiral structure（M01）

Temperature（T）and Mixing ratio of water vapor（Qv）at Z*=20m

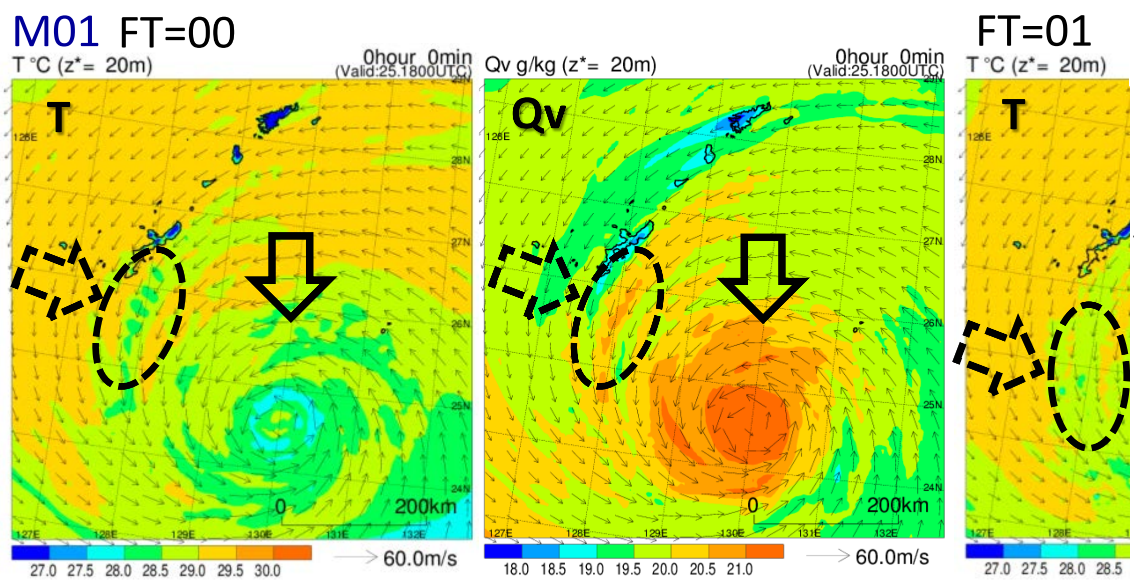


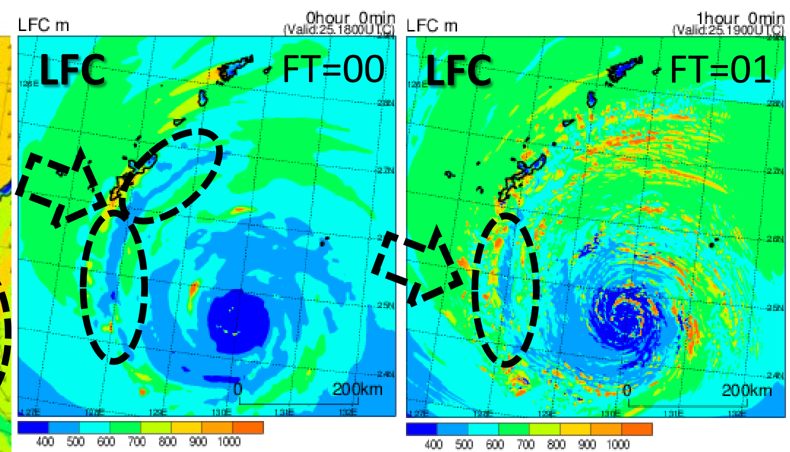


The LFC in P05 became lower than that of M01 in the solid-line circle, and the convections easily created.

The low-level temperatures in P05 were relatively lower than those of M01, while

- **Formation of the outer eyewall on northwestern and northeastern sides of the inner eyewall**





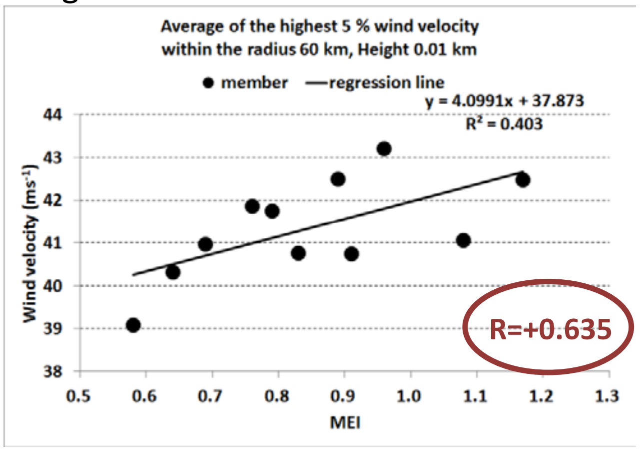
The LFC in M01 became lower than that of P05 in the dotted-line circle, and the convections easily created.

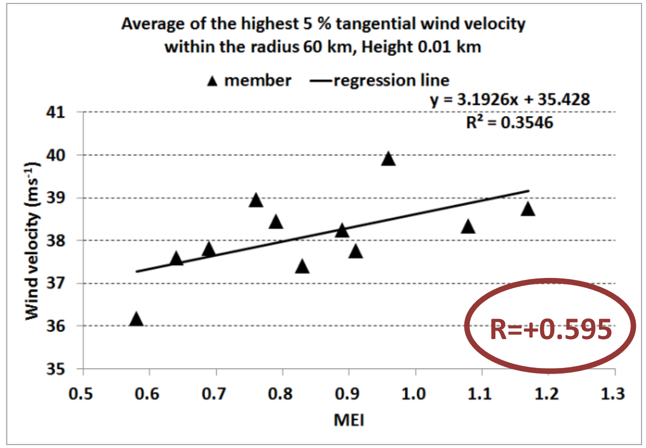
The relatively cold and humid region that extended from the south of Okinawa M
was located just at the eastern side of the spiral rainbands of M01.

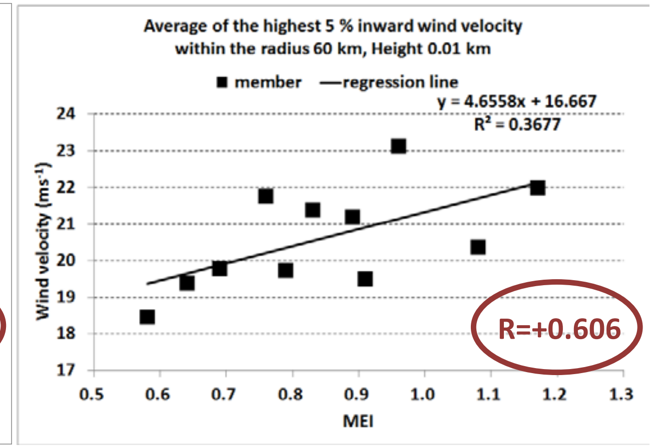
- **Maintenance of the generated spiral bands**

Each correlation between MEI and highest top 5 % wind velocity (tangential and inward wind velocities) within radius 60 km at FT=04

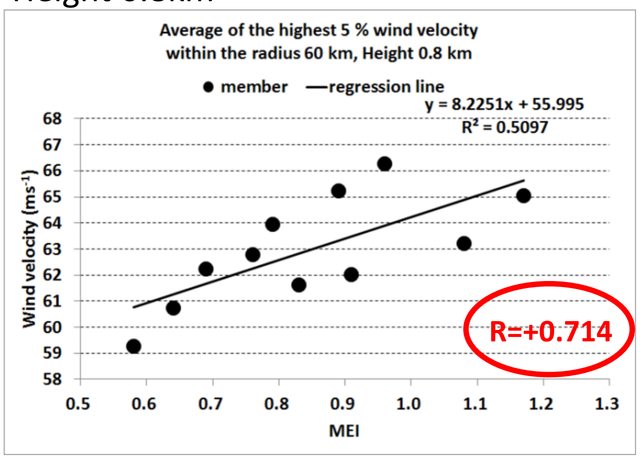
Height 0.01km

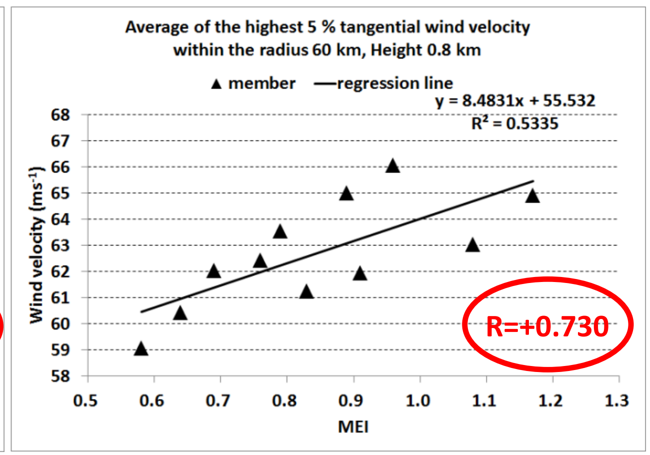


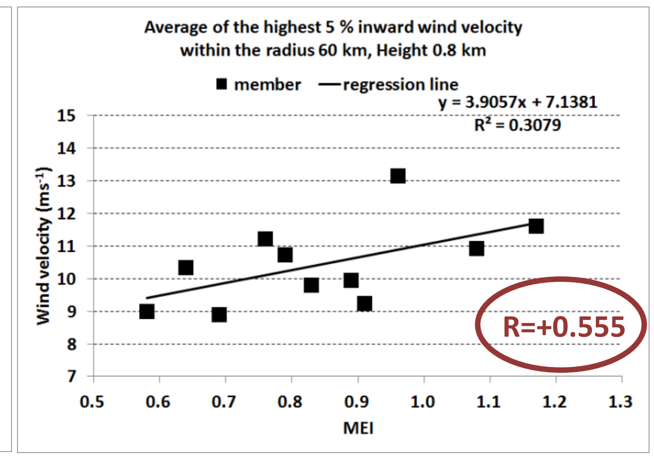




Height 0.8km







- Below the altitude of 1 km, correlations between MEI and wind velocity (tangential and inward wind velocities) were larger than positive medium correlation.
- The positive strongest correlation indicated with wind veocity and tangential wind velocity at the altitude of 0.8 km.

Test of correlation coefficient: **Significance (α = 5%)** for the wind velocity (tangential and inward wind velocities) below the altitude of 1 km.

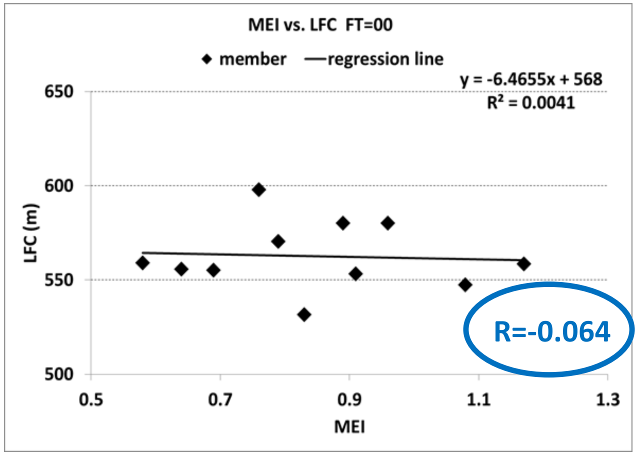
Correlation coefficient R

$|R| \geq 0.7$ (strong correlation)
$0.5 \leq |R| < 0.7$ (medium correlation)
$0.3 \leq |R| < 0.5$ (weak correlation)
$|R| < 0.3$ (no correlation)

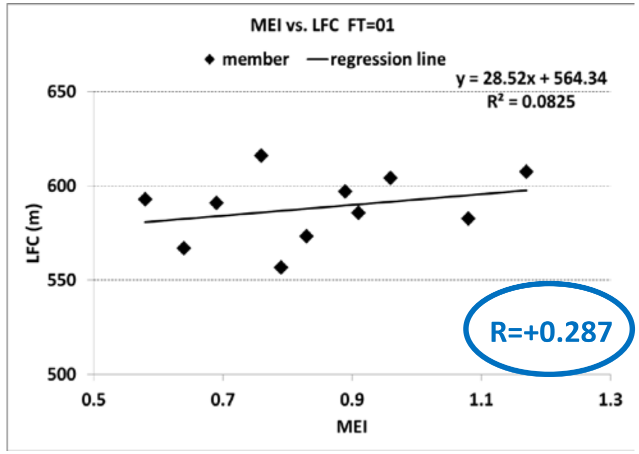
➡ **The strong winds near the surface in the central region trend to be suppressed statistically, as the degrees of multiple eyewall structure are larger.**

Correlation between MEI and LFC, FT=00-04

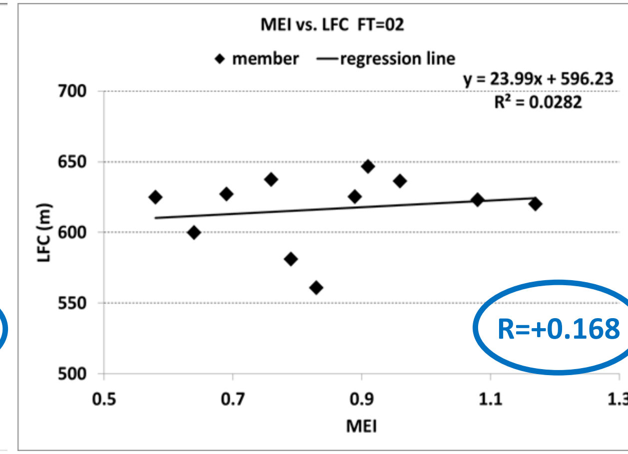
FT=00



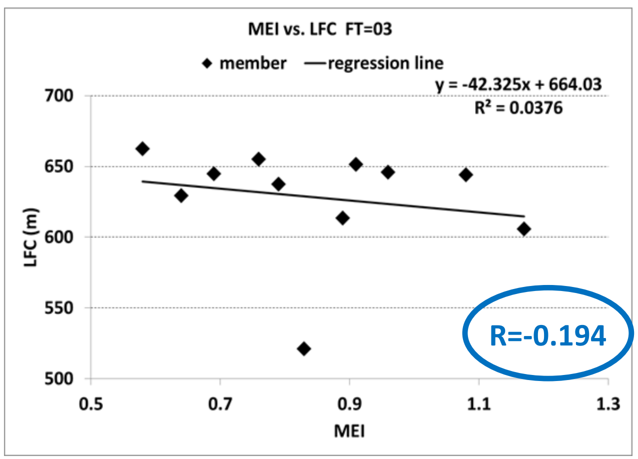
FT=01



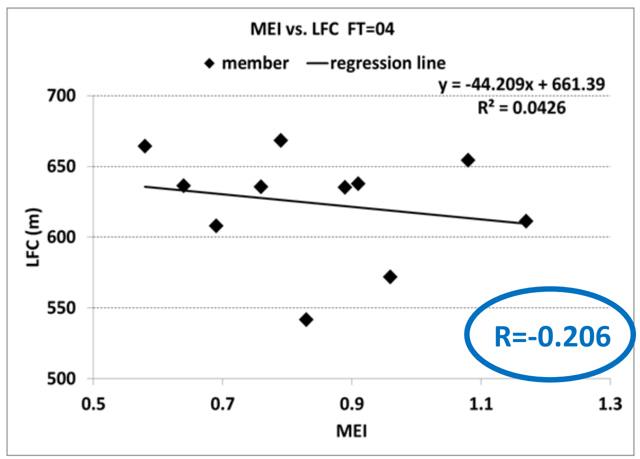
FT=02



FT=03



FT=04



Correlation coefficients between MEI and LFC which were averaged in the typhoon region were 'no correlation' below 0.3 in all times from FT=00 to 04.

The effects of the environment (LFC) on the eyewall structure were small, and it suggests that factors that affected the degree of multiple eyewall structure were the formation mechanism in the central region of typhoon itself.

Correlation coefficient R

$|R| \geq 0.7$ (strong correlation)

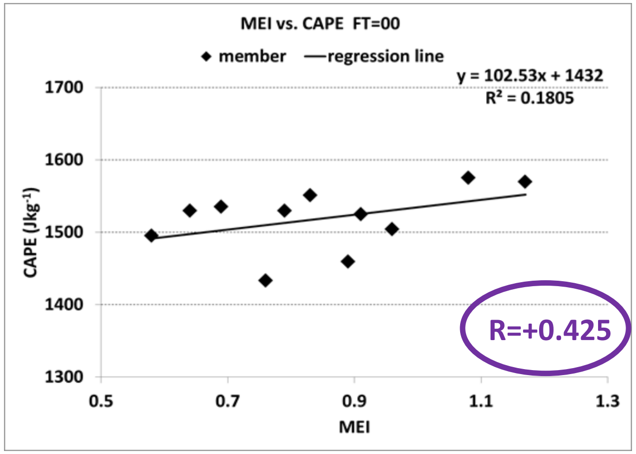
$0.5 \leq |R| < 0.7$ (medium correlation)

$0.3 \leq |R| < 0.5$ (weak correlation)

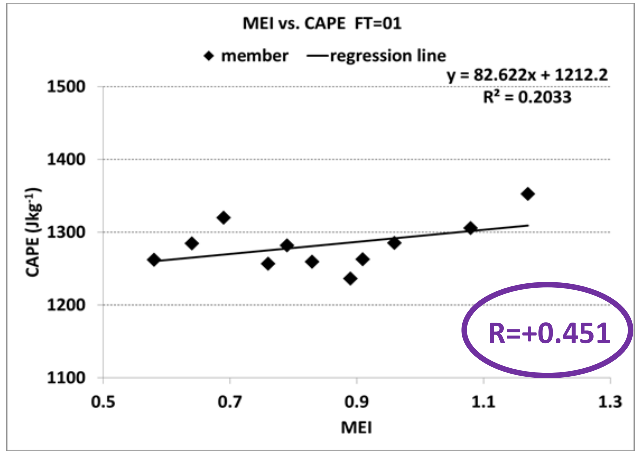
$|R| < 0.3$ (no correlation)

Correlation between MEI and CAPE, FT=00-04

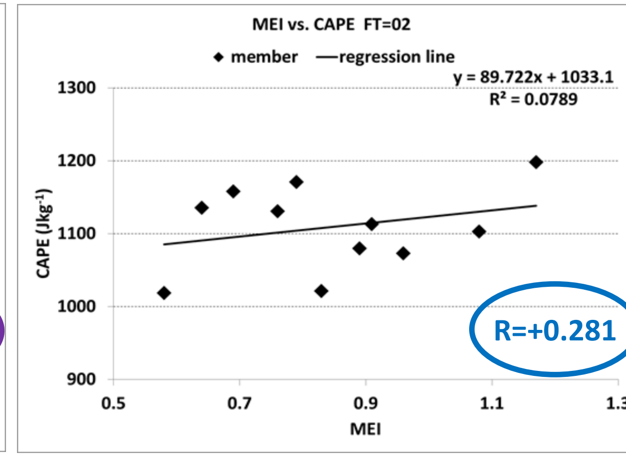
FT=00



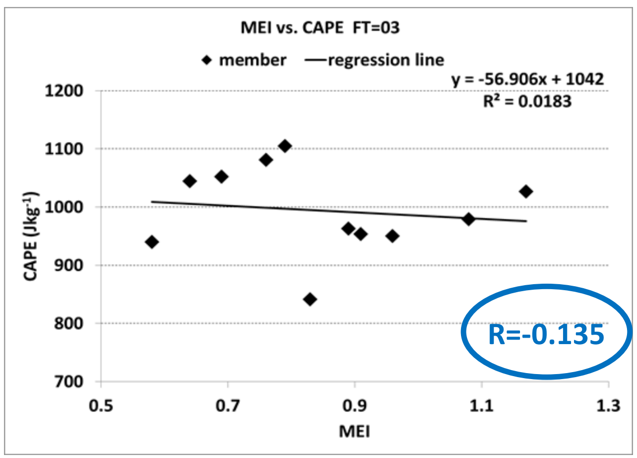
FT=01



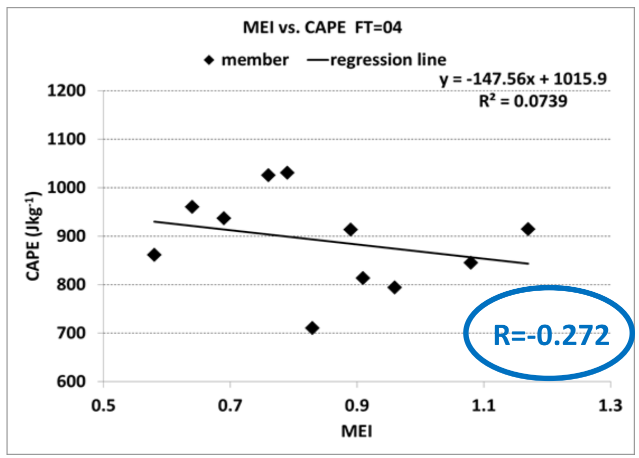
FT=02



FT=03



FT=04



Although the ‘positive weak correlat-ions’, which the environment around the spiral structure trended to enhance the convections slightly, were seen in FT=00 and 01, correlation coefficients in other times showed ‘no correlation’.

The effects of the environment（CAPE）on the eyewall structure were small, and it suggests that factors that affected the degree of multiple eyewall structure were the formation mechanism in the central region of typhoon itself.

Correlation coefficient R

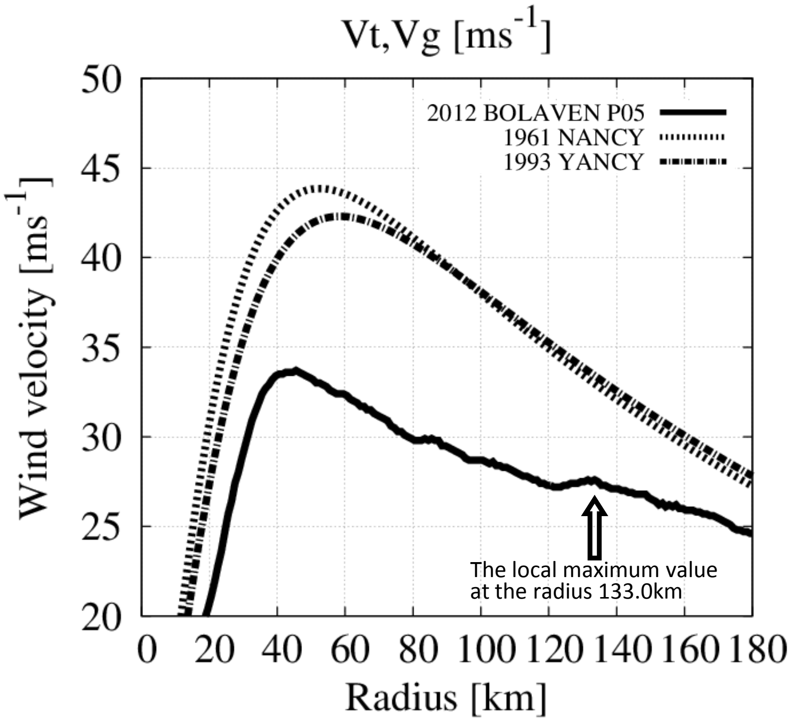
$|R| \geq 0.7$ （strong correlation）

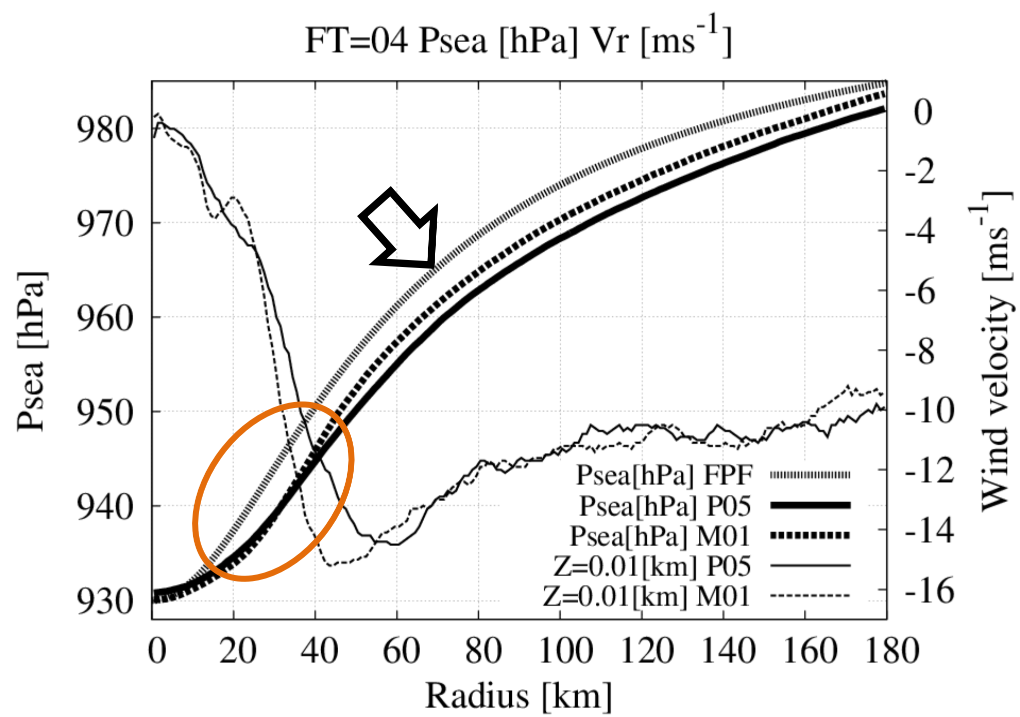
$0.5 \leq |R| < 0.7$ （medium correlation）

$0.3 \leq |R| < 0.5$ （weak correlation）

$|R| < 0.3$ （no correlation）

Gradient velocities of actual typhoons and tangential wind velocity of simulated P05





- **Surface gradient wind velocity** (Tomitaka 1985)

The surface gradient wind velocities of actually observed typhoons NANCY in 1961 and YANCY in 1993 were obtained using Fujita's pressure formula.

$$V_g = \frac{1}{2}\left\{-fr + \sqrt{f^2r^2 + \frac{4r}{\rho}\cdot\frac{\partial P}{\partial r}}\right\} \qquad \frac{1}{\rho} = \frac{R^*}{P}\left\{\frac{T}{1-0.378(e/P)}\right\}$$

T: Temperature e: Pressure of water vapor
R^*: gas constant of air

➢ The tangential wind velocity of P05 in the typhoon's central region was weaker than the surface gradient wind velocities of the typhoons NANCY and YANCY.

- **Fujita's pressure formula** (FPF; Fujita 1952)

$P(r)$ shows the pressure distribution of the ordinary typhoon

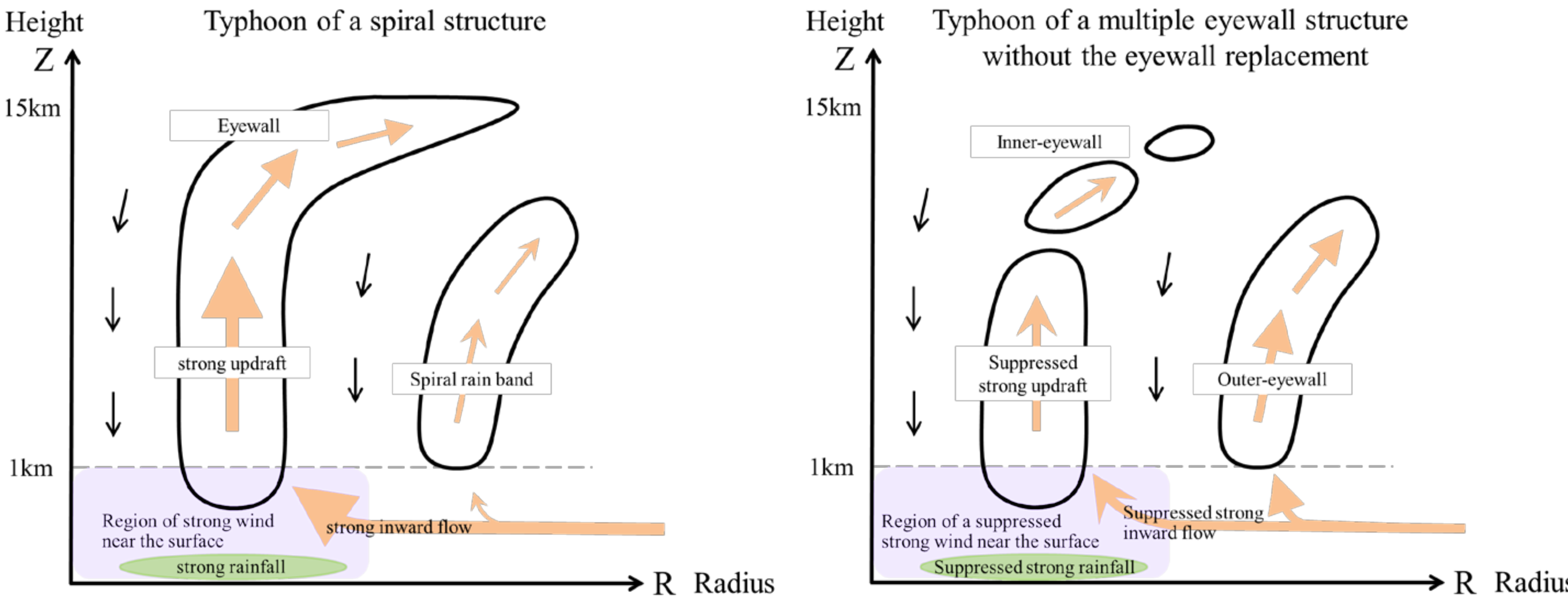
$$P(r) = P_\infty - \frac{P_\infty - P_0}{\sqrt{1 + (r/r_0)^2}}$$

P_0: Typhoon's central pressure P_∞: Radius of influence of typhoon
r_0: Spread of horizontal direction

Compared with the typhoon of the simulated P05, FPF that was estimated using the data of the simulated P05 had …

➢ the narrower region around the center of typhoon
➢ more sharp slope at the radius of between 20km and 40km

Summary



Compared with the typhoon of single eyewall and spiral rainbands, the typhoon of multiple eyewall have the following features;

- The gentle pressure gradient near the surface in the central region
- The suppressed inward inflow below the altitude of 1 km by formation of outer eyewall
- The weak convections and unclear divergence of upper layer in the inner eyewall
- The suppressed surface wind velocity and precipitation in the central region
- The appropriately maintenance of convection in the outer eyewall by the supplied lower moist inflow from the outside of typhoon

The effects of the environment on the eyewall structure were small, and the factors that affected the degree of multiple eyewall structure were the formation mechanism in the central region of typhoon itself.