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Simultaneous optimization of air-sea exchange coefficients & initial condition around a tropical cyclone with JNoVA

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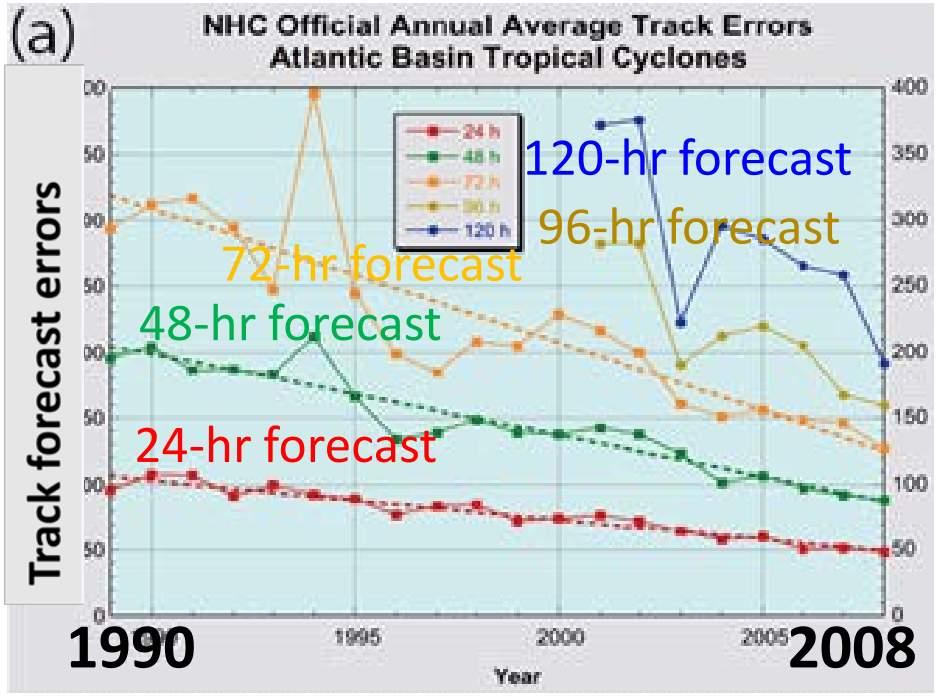
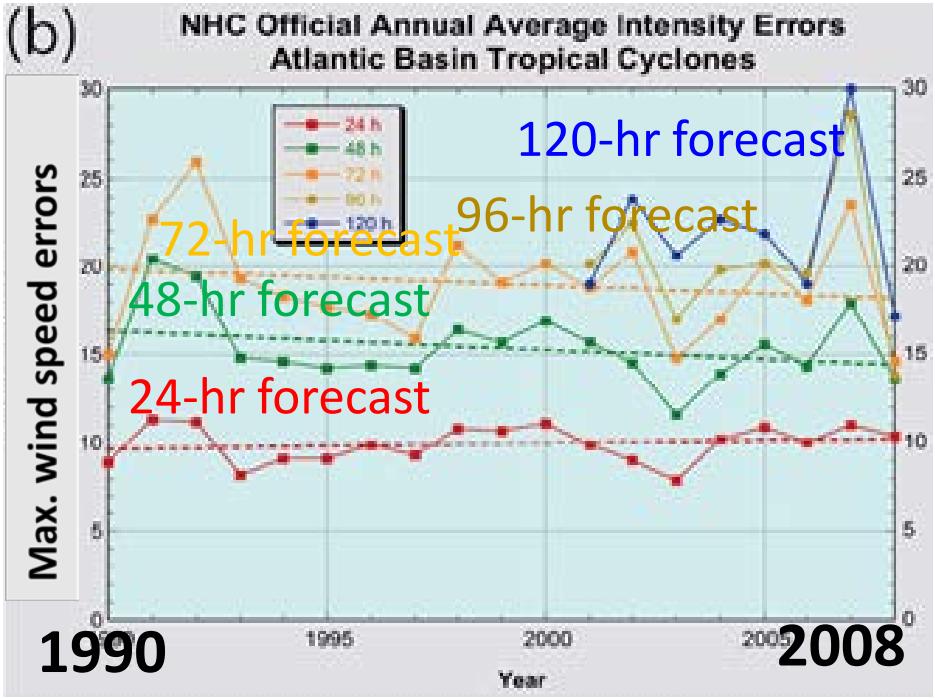
Tropical cyclone (TC) forecast skill in the recent 20 years





(National Hurricane Center website)

- Track: Error halved during the past 20 yrs
- Intensity: Not significant improvement

For the better TC intensity modeling

- Horizontal Resolution
  [Δx ~ a few kilometers, at least]
- Data assimilation
  [Optimization of air-sea exchange coefficients]

Significant impact on TC intensity; Highly uncertain

- Model physics
  [Coupling to the ocean model; Parameterization]

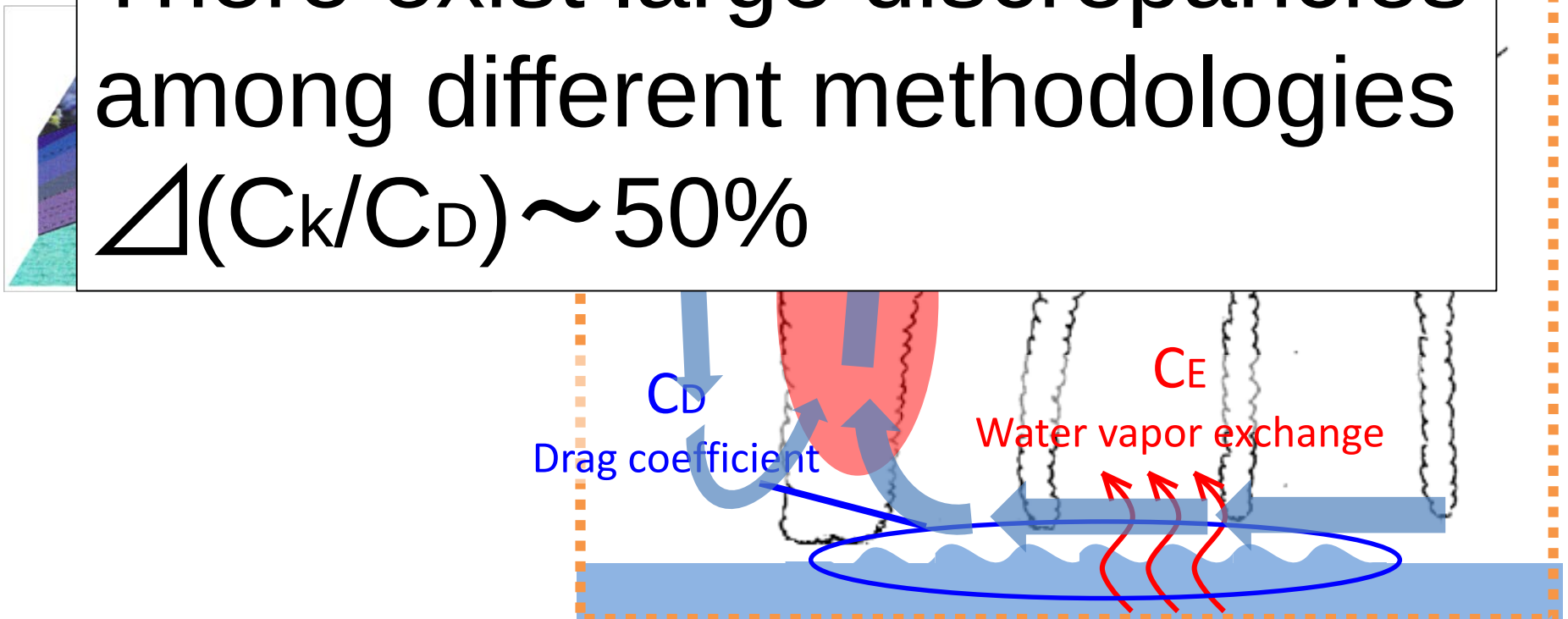
Max. wind speed in a mature stage (Emanuel, 1986)

$$V_{\max} = \sqrt{\frac{T_s - T_o}{T_o}\frac{C_k}{C_D}(k_o^* - k_a)}$$

- C_k: Heat exchange coefficient ($\sim C_E$)
- C_D: Drag coefficient (Determining the magnitude of friction)

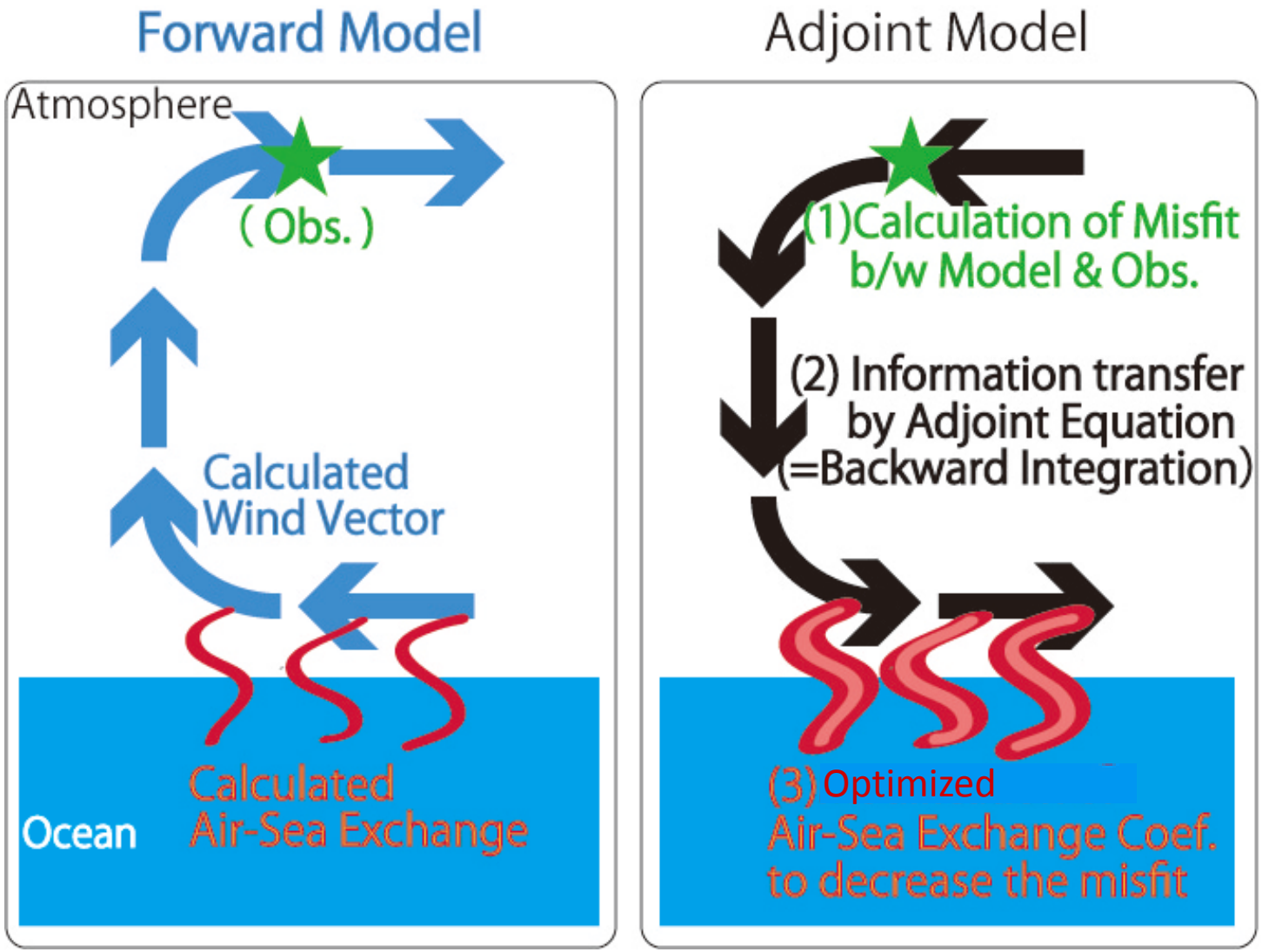
There exist large discrepancies among different methodologies

$\Delta(C_k/C_D) \sim 50\%$



Schematic diagram: Optimization of C_D and C_E

(For simplicity, consider an advection-diffusion eqs.)



Perfect Model Experiment (Ito et al., 2010)

- Simple coupled atmosphere-ocean model is employed to test the feasibility.
- We compare three experiments starting with wrong C_D, C_E and initial condition (IC).

NoAsm	No Data assimilation
Asm_NoCoef	IC adjusted
Asm_Coef	C_D, C_E and IC adjusted

Simple Coupled Model

Atmospheric Model

- ✓ Axisymmetric Non-hydrostatic Model [Rotunno and Emanuel, 1987]
- ✓ Warm-rain
- ✓ Smagorinsky Scheme
- ✓ T_{env}, q_{env}: Conditionally Unstable

Oceanic Model

- ✓ 1-dimensional Mixed Layer Model

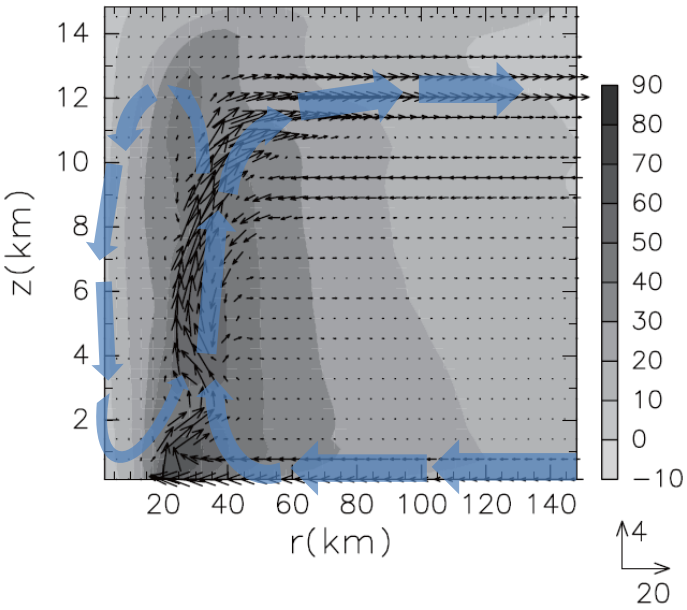
$$\frac{\partial \rho_{sea} h u}{\partial t} = |\boldsymbol{\tau}| = \rho_{air} C_D |\boldsymbol{U}|^2$$ [Schade & Emanuel 1999]

- ✓ Coupling: Same as in Emanuel (2004)

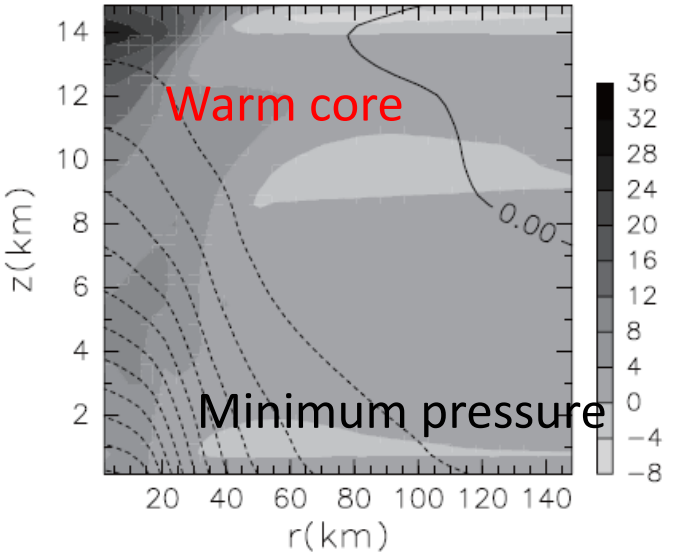
Model Setup

- ✓ ⊿r:3.75 km, ⊿z:313 m, time step:2 s
- ✓ $Vortex_{init}$: V_{max}=12 m/s
- ✓ SST_{env}: 30℃(day 0) → 27℃(day 10)
- ✓ Translation speed of TC: 6 m/s

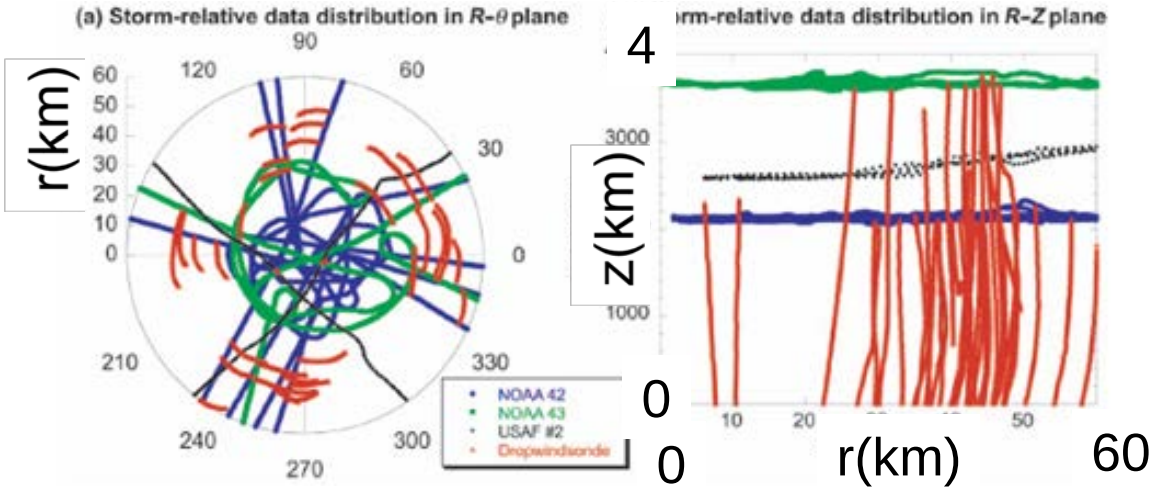
Wind field



θ' and P



Experimental Setup	
Adjoint eqs.	Same as forward eqs. except that processes associated with sound wave and microphysics are not included.
Assim. window	4 days (Day 6.0 - Day 10.0)
Obs. variable	Horizontal wind velocity, water vapor mixing ratio, and mixed layer momentum
Obs. Quantity	Every grid within r<100 km, z<5 km (every 12 hour)
Settings of C_D & C_E	[For True] CD: Powell et al.(2003), CE: Arbitrary [For NoAsm] CD, CE: Large & Pond (1981) (V≦30m/s)
Bg. err. cov. mat. **B**	Prescribed: Variance in time of True run→ Magnitudes 2D-Fourier analysis of perturbed True runs → Scales
Obs. err. cov. mat. **O**	Prescribed: Diagonal matrix. Magnitudes are 1/20 of diagonal components of **B**.



Dropsonde obs. project by NOAA/HRD (Montgomery et al., 2006)

Adjusted C_D and C_E

Run with "wrong" C_D and C_E

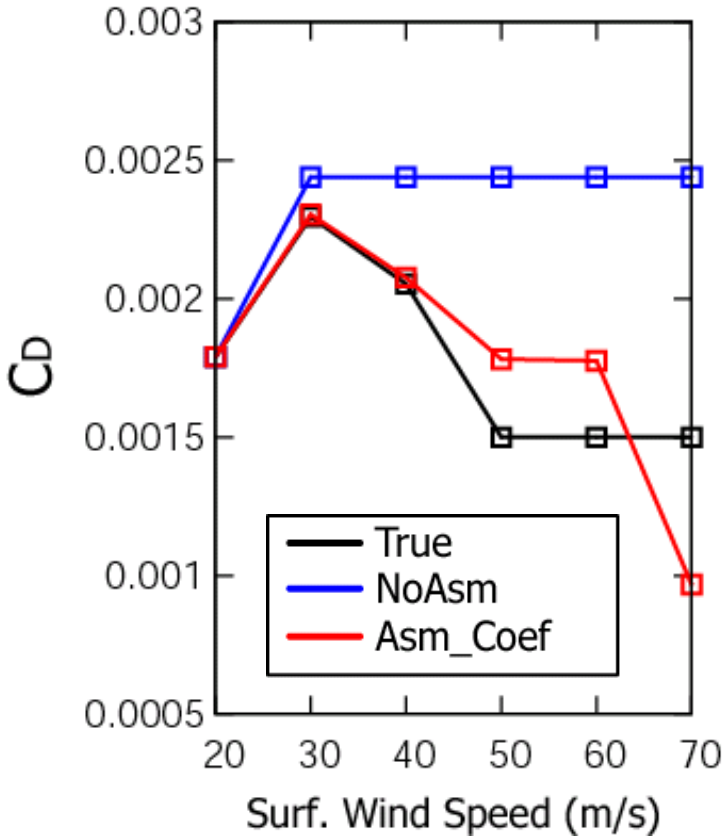
Dropsonde obs.

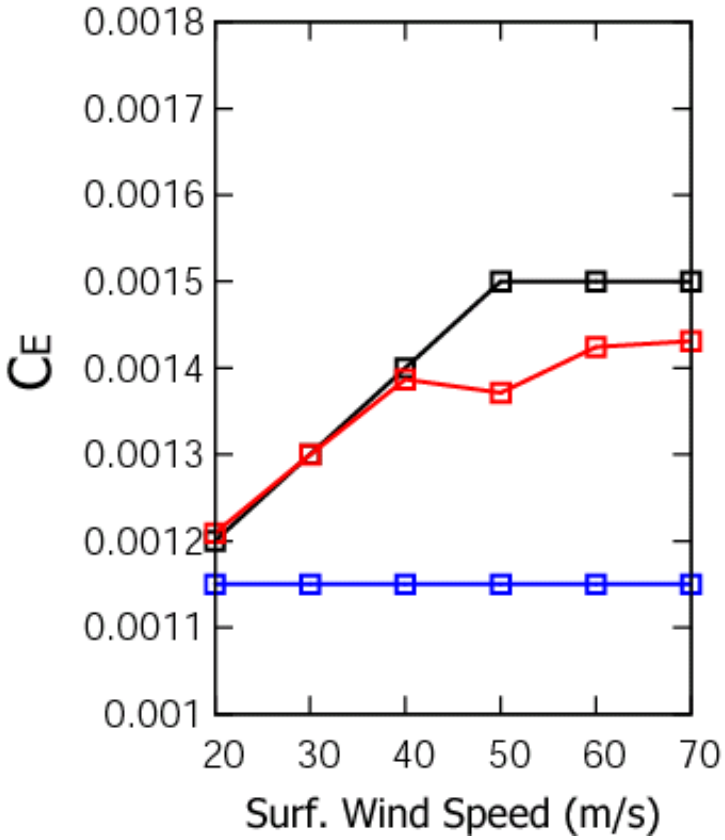
Adjoint-based Data Assimilation

updated C_D and C_E

.||.

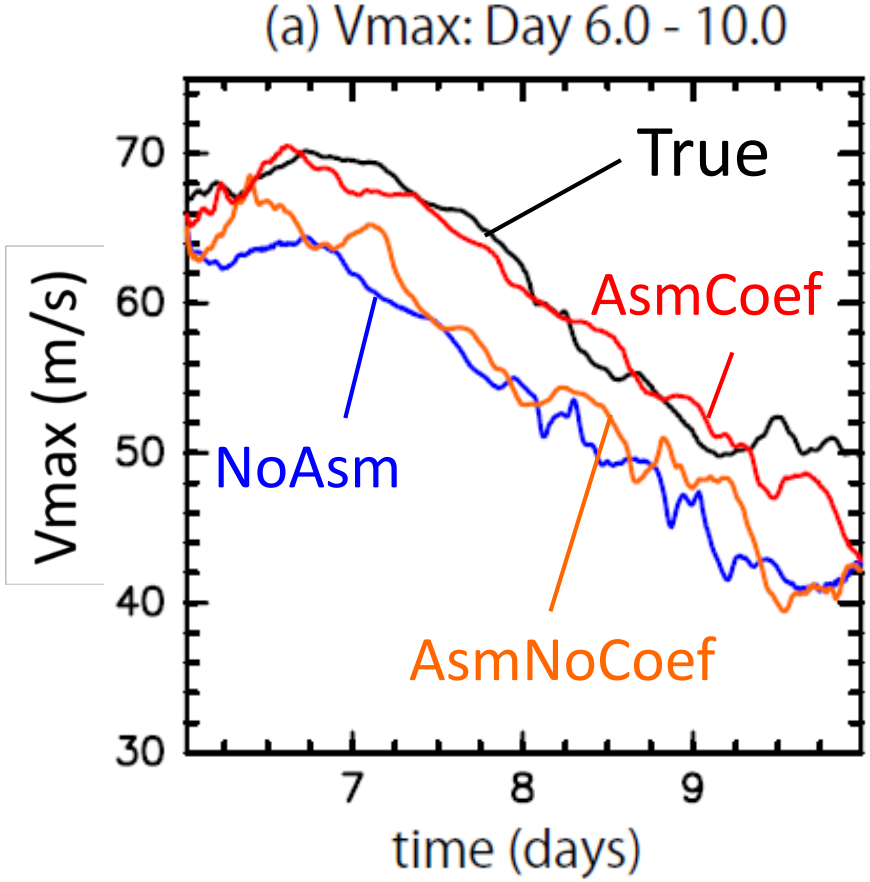
"true" C_D and C_E

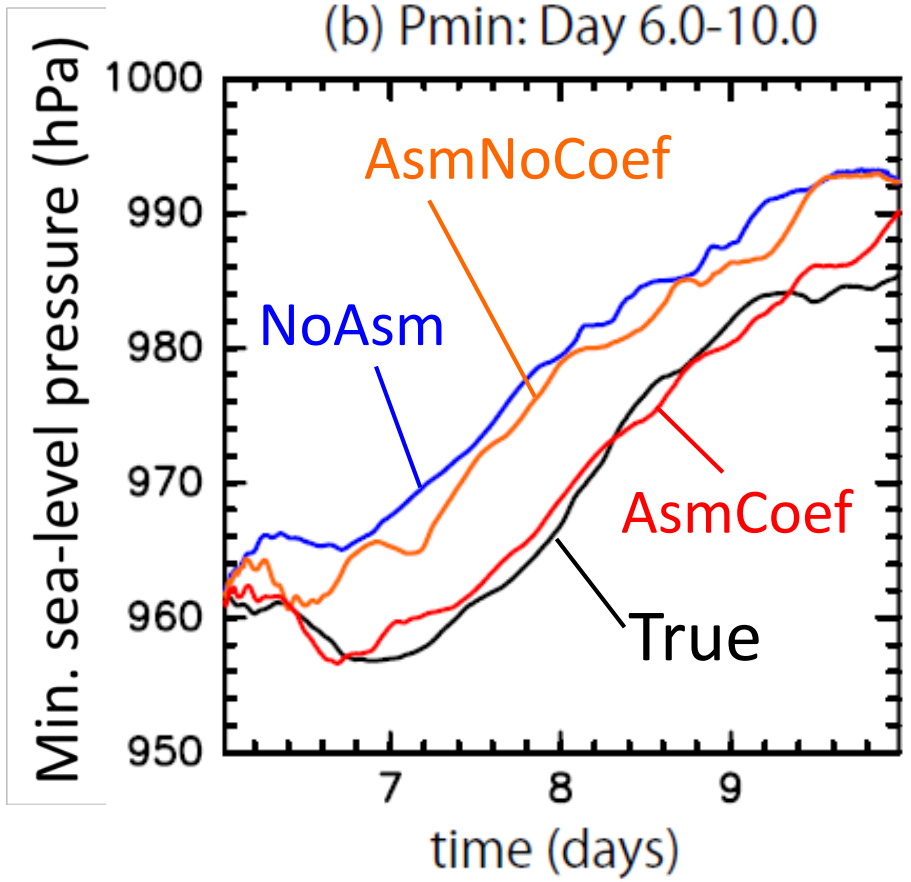




Optimial estimate: TC intensity

True ~ Asm_Coef > Asm_NoCoef > NoAsm



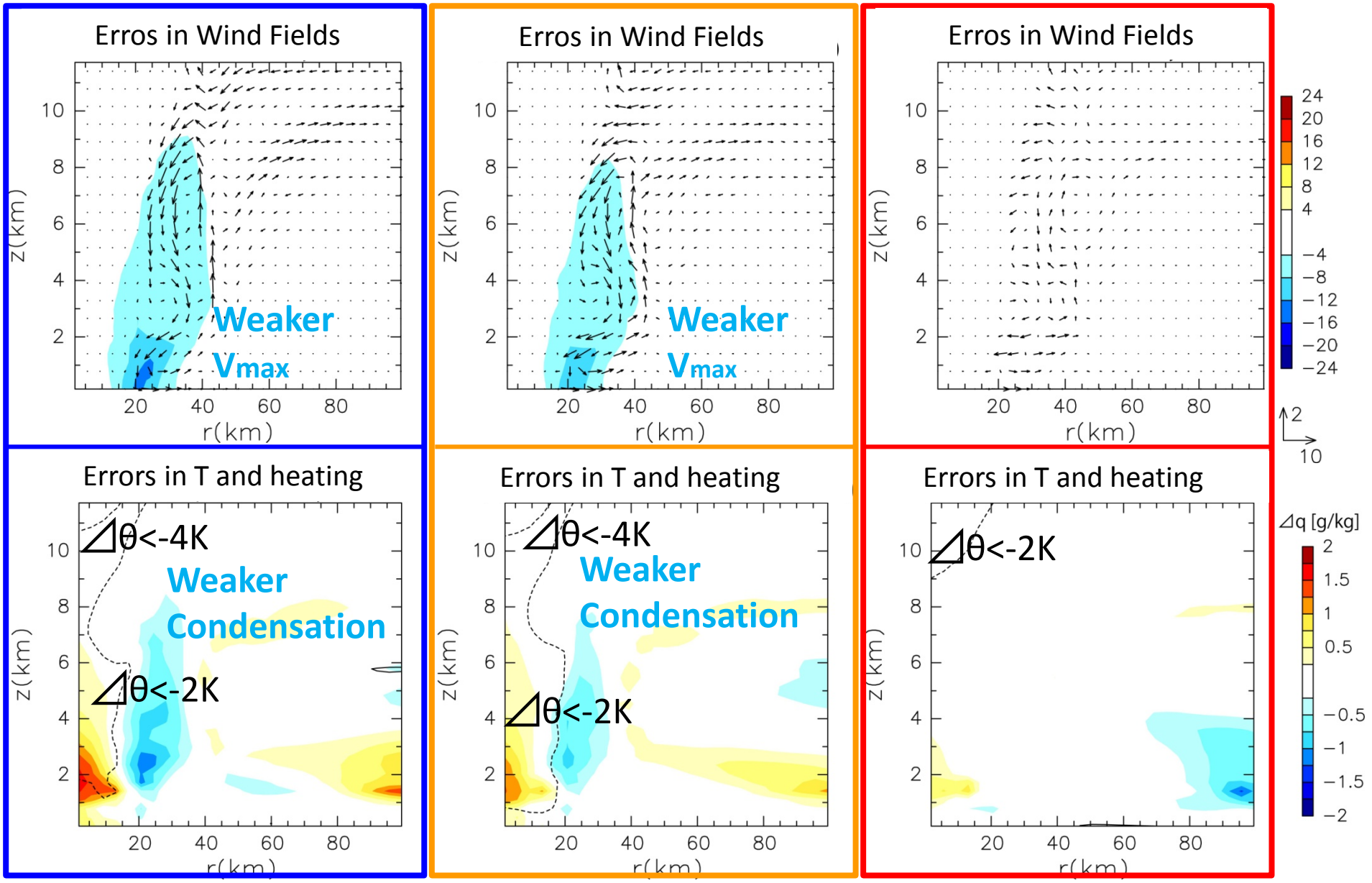


Errors in wind, temperature & humidity

NoAsm

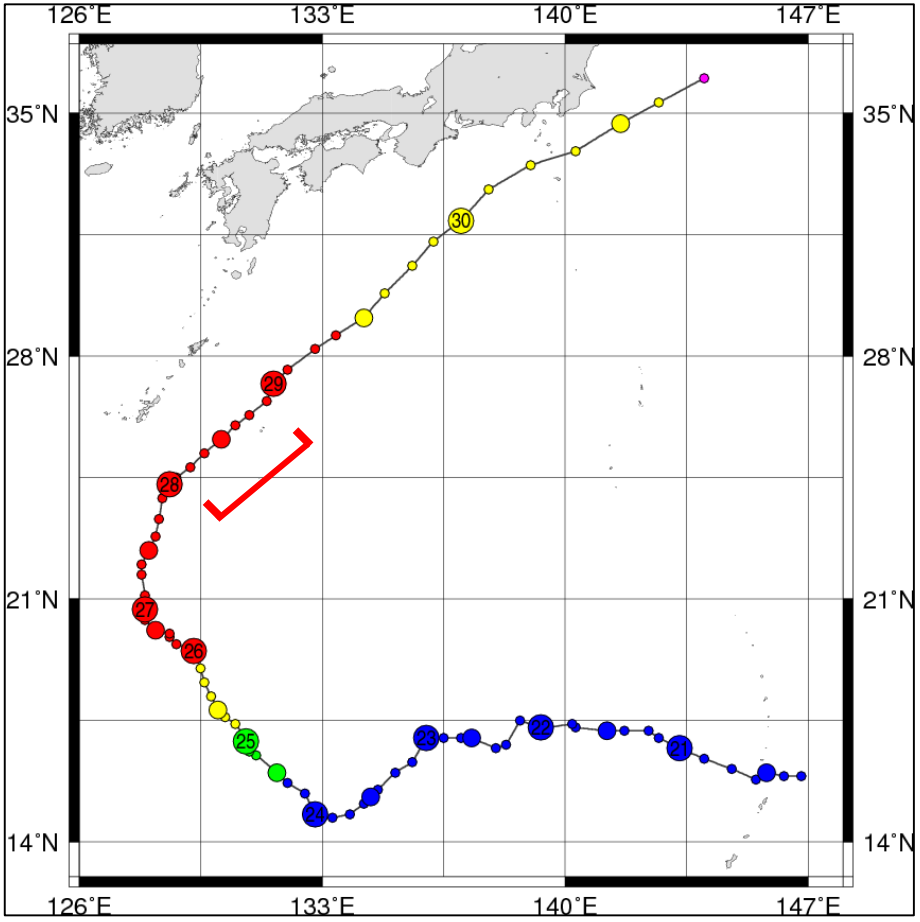
Asm_NoCoef

Asm_Coef

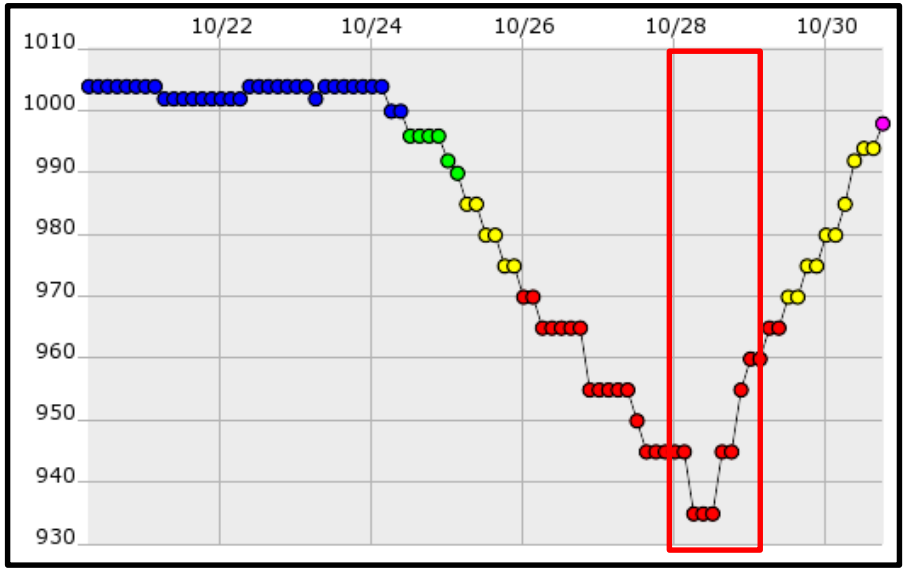


Application to the operational mesoscale DA system (JNoVA) used in JMA: TC Chaba (2010)

Typhoon Chaba's track



Minimum sea level pressure (hPa)



（Digital Typhoon Archives）

Framework of DA experiments

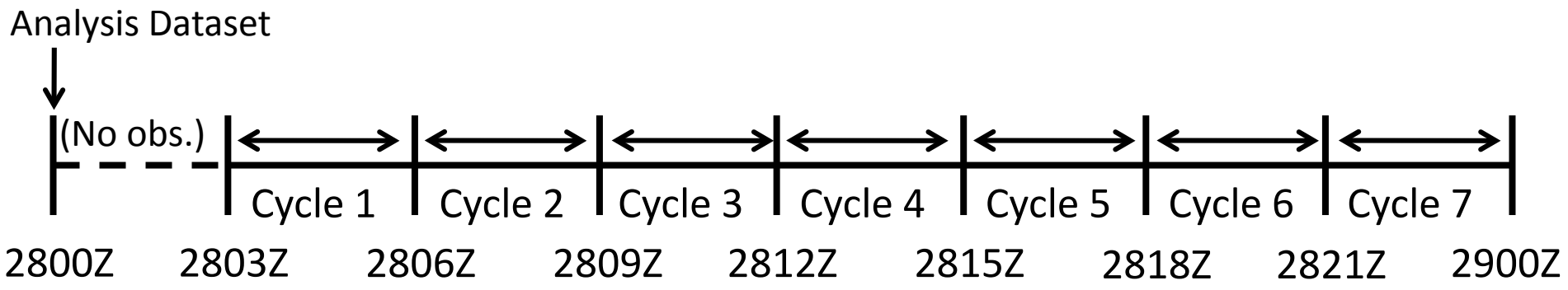
- JMA Nonhydrostatic Variational DA system (JNoVA) used for daily forecasts. ⊿x = 5km (outer loop)

  "NoCoef": Optimization of initial condition alone

  "Coef": Optimization of C_D, C_E and initial condition

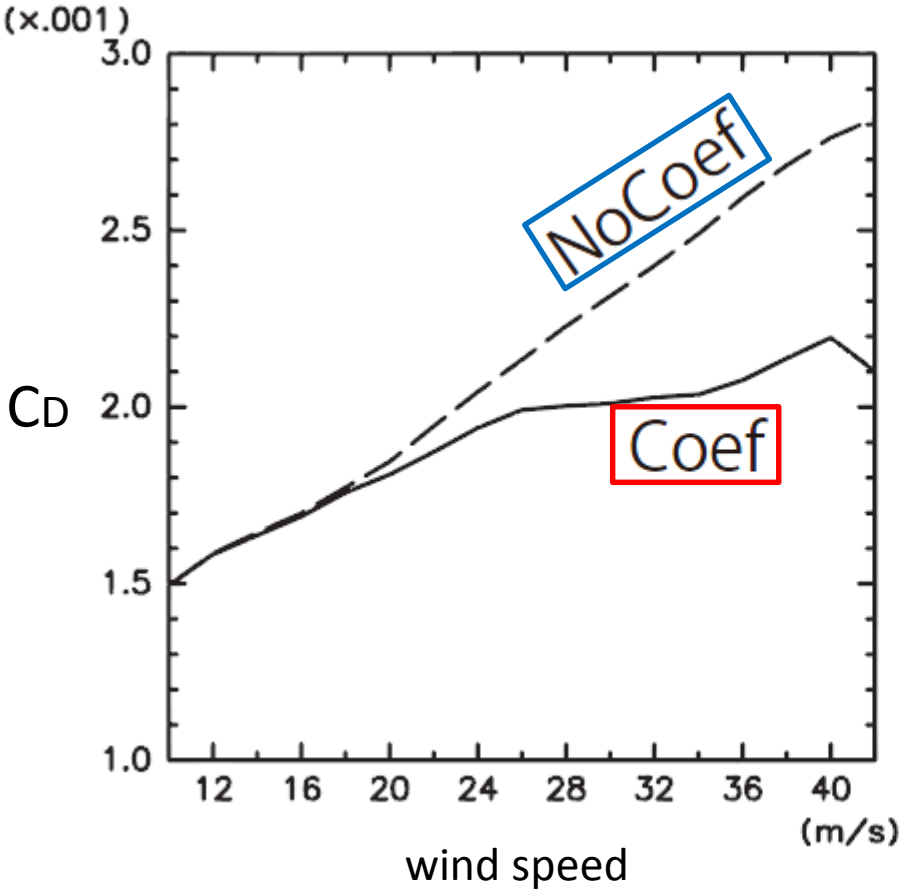
- Observational Dataset :
  Same as operational forecast archived at Japan Meteorological Agency

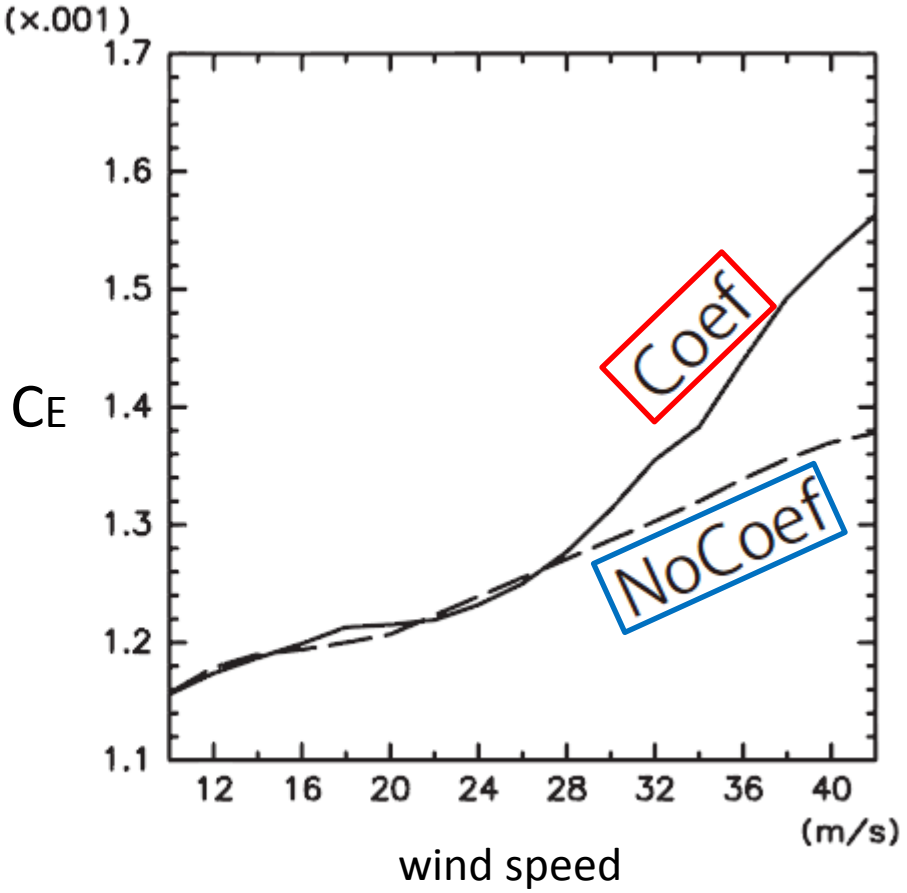
- Period of DA experiments : 21 hours => 7 Cycles
  (from 03UTC October 28 to 00UTC October 29)



C_D and C_E: Dependency on wind speed

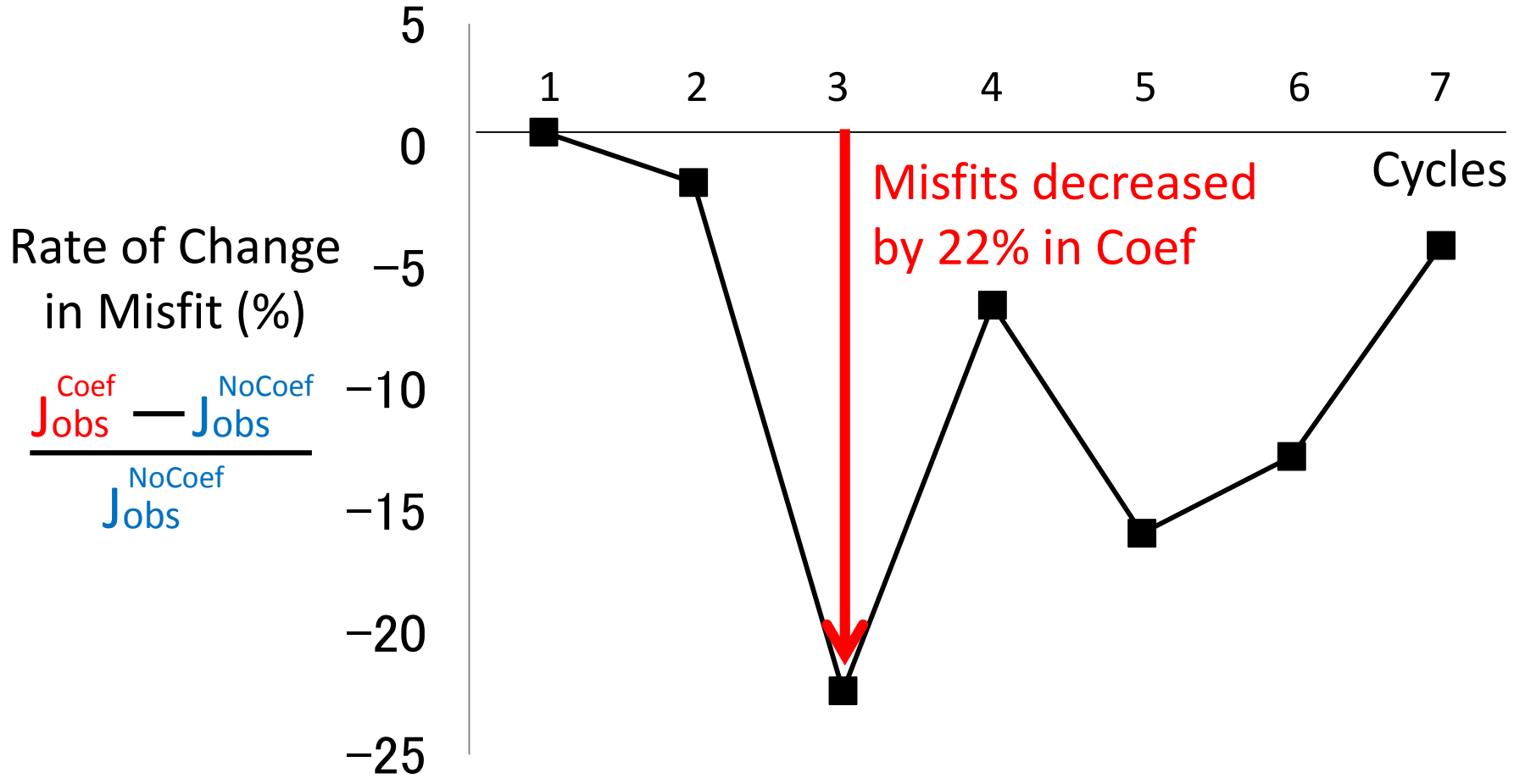
- C_D in Coef: Saturated over the wind speed of 24 m/s.
- C_E in Coef: Further enhanced (in comparison to NoCoef)





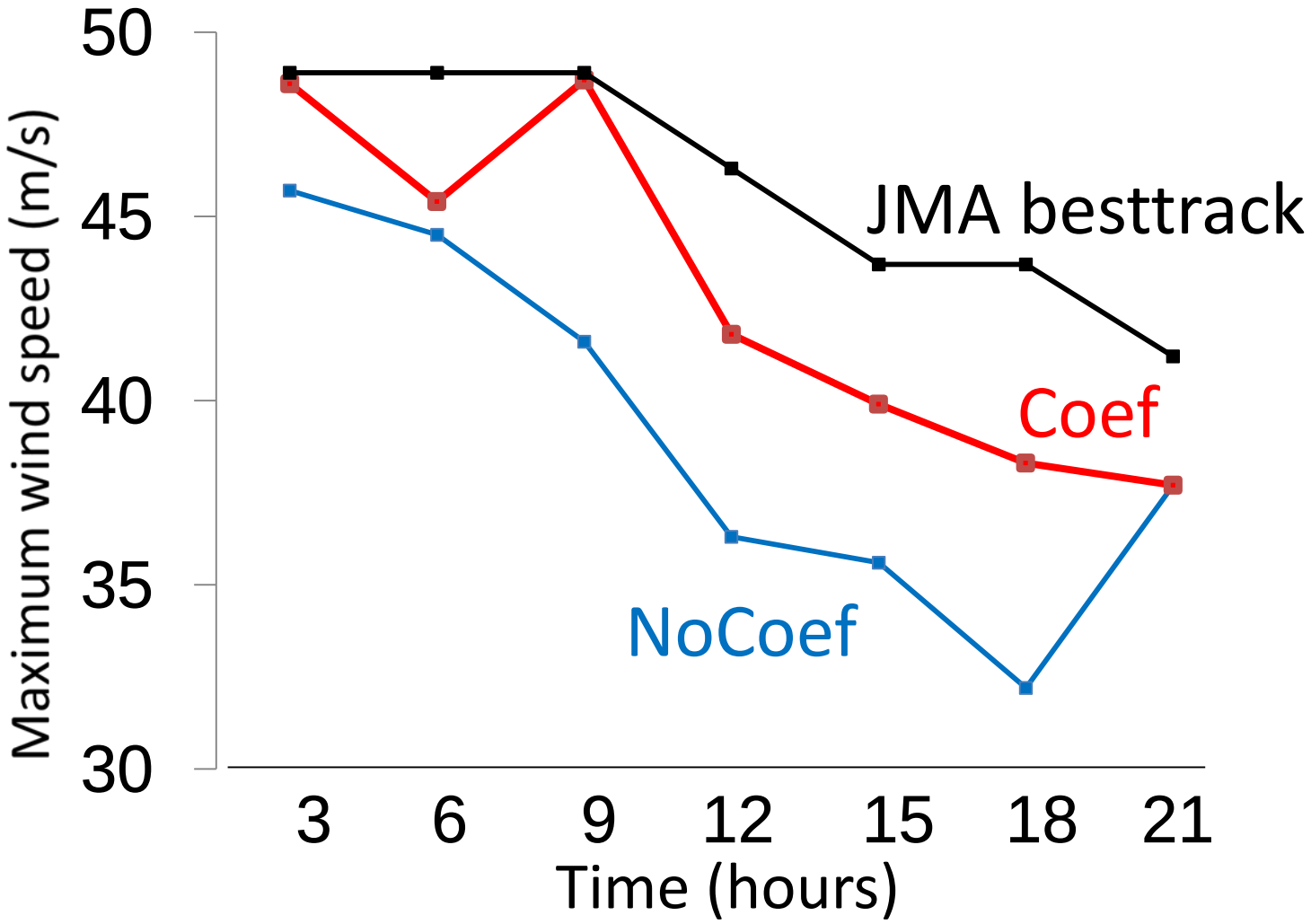
Misfits between model results and observations integrated over the calculation domain

- Significantly decreased (up to 22%) in Coef compared with that in NoCoef experiment.



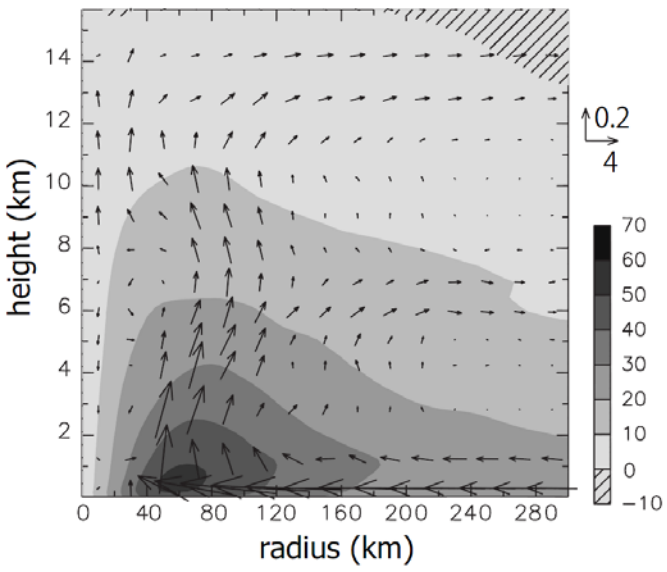
Maximum Wind Speed

- JMA Besttrack: Based on satellite and statistical data.
- Differences: |Coef-JMA|=3.6m/s, |NoCoef-JMA|=7.5m/s

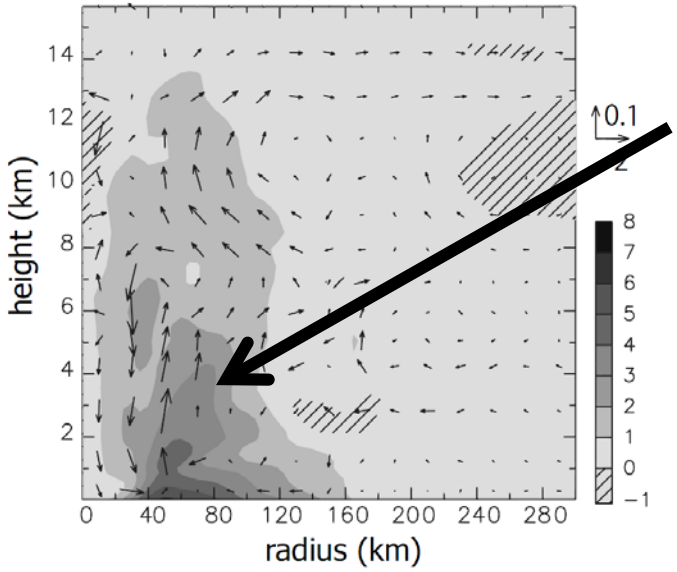


Structual Changes in typhoon Chaba

Wind field [Coef]

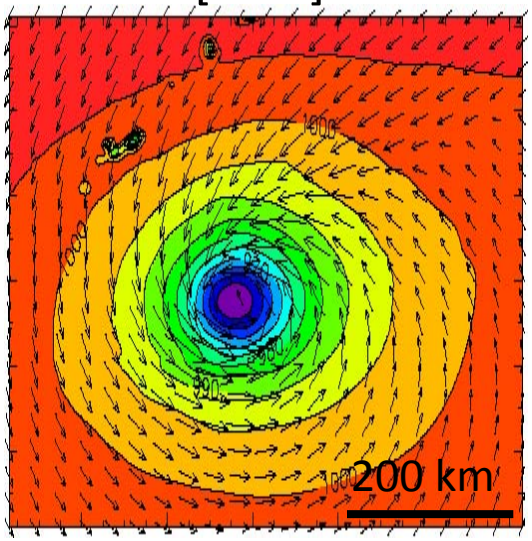


Wind field [Coef - NoCoef]

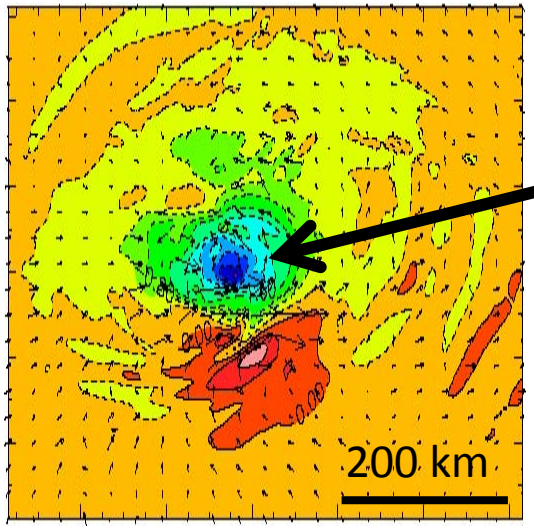


Vmax changes as in idealized experiment

Psrf, (Usrf, Vsrf) [Coef]



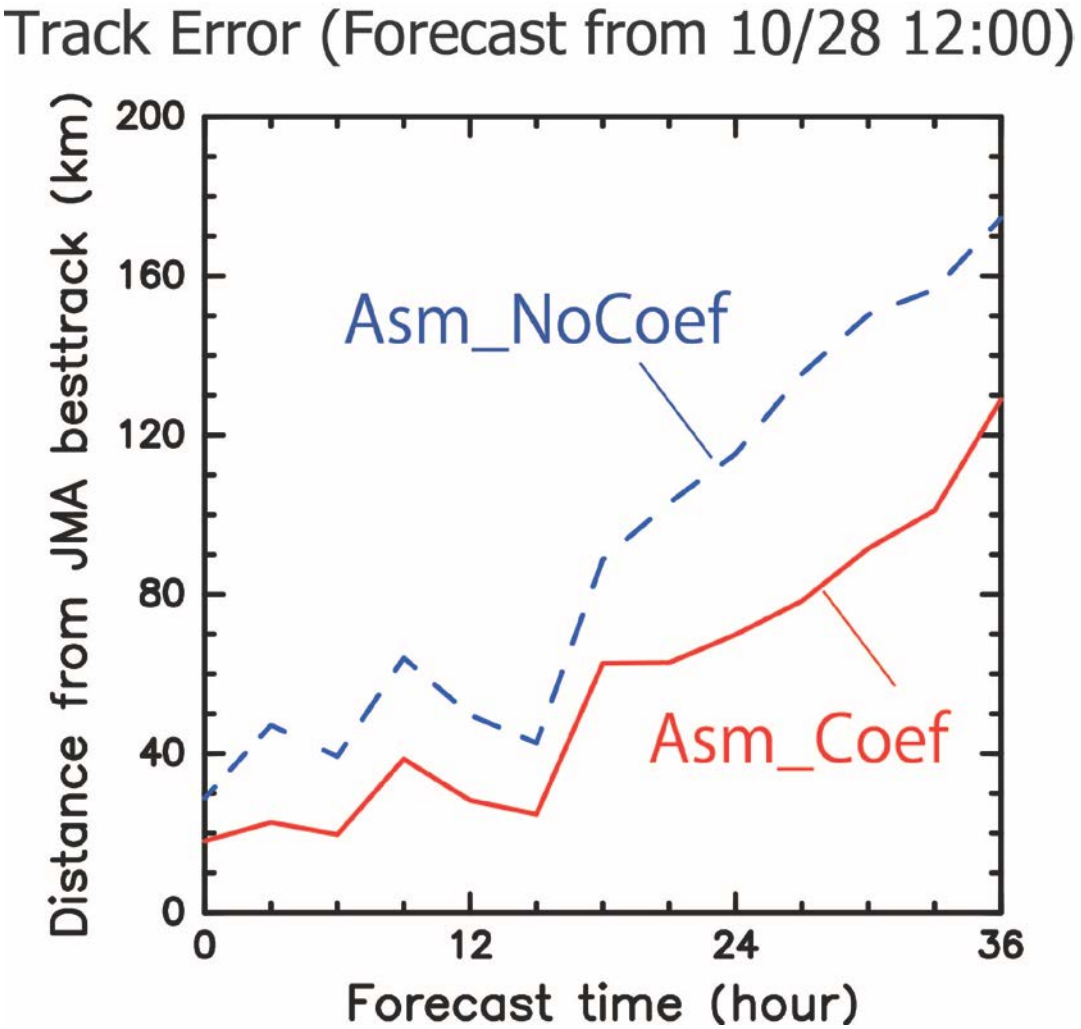
⊿Psrf, (⊿Usrf, ⊿Vsrf) [Coef - NoCoef]



Decrease in the pressure field & Northward displacement of Chaba in the Coef experiment

Potential impact on TC track forecast

- Simultaneous optimization yields the better track forecast.



Summary

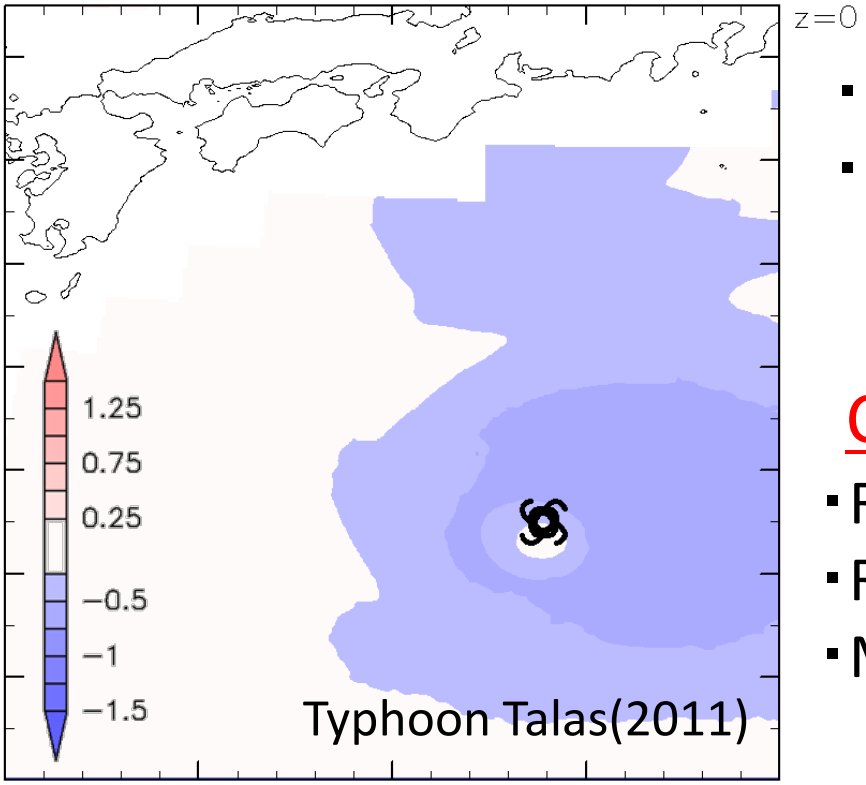
(Ito et al., 2010, SOLA; Ito et al., JMSJ, in minor revision)

- Tropical cyclone (TC) intensity (particularly in a mature stage) largely relies on uncertain parameter C_D & C_E.
- Simultaneous optimization of C_D, C_E and initial condition through a 4D-VAR.
- Experiments exhibit the improvements in reproducing the TC intensity, inner-core structure and track.
- Forecast in a decay stage is more challenging.

JNoVA using a coupled atmosphere-ocean model

- 1-D ocean mixed layer model (Price et al., 1986) is coupled.
- For the case of TC Talas (2011), SST decreases by 1-2 K in the right of TC pathway (consistent with the satellite observation).

Analysis field: ⊿SST (K)

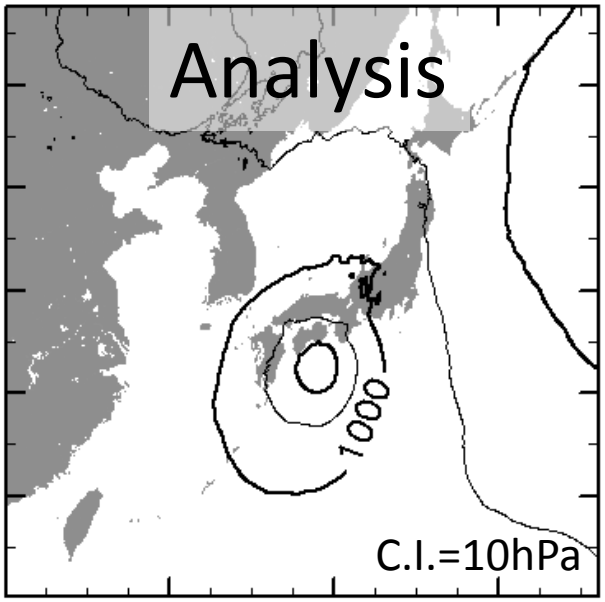


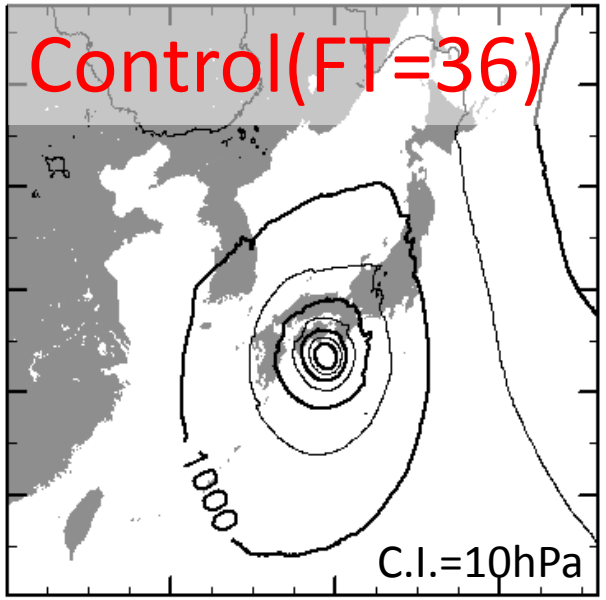
Initial condition (Ocean)

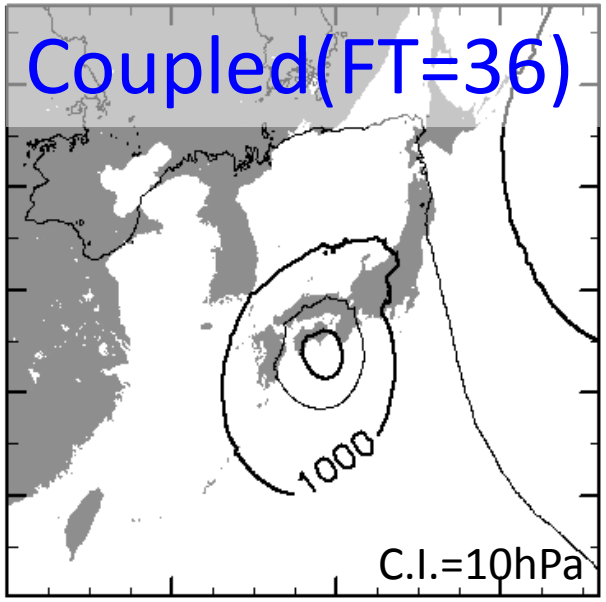
- SST: As in the original JNoVA
- SSS, subsurface water property: Climatology (WOA 2009)

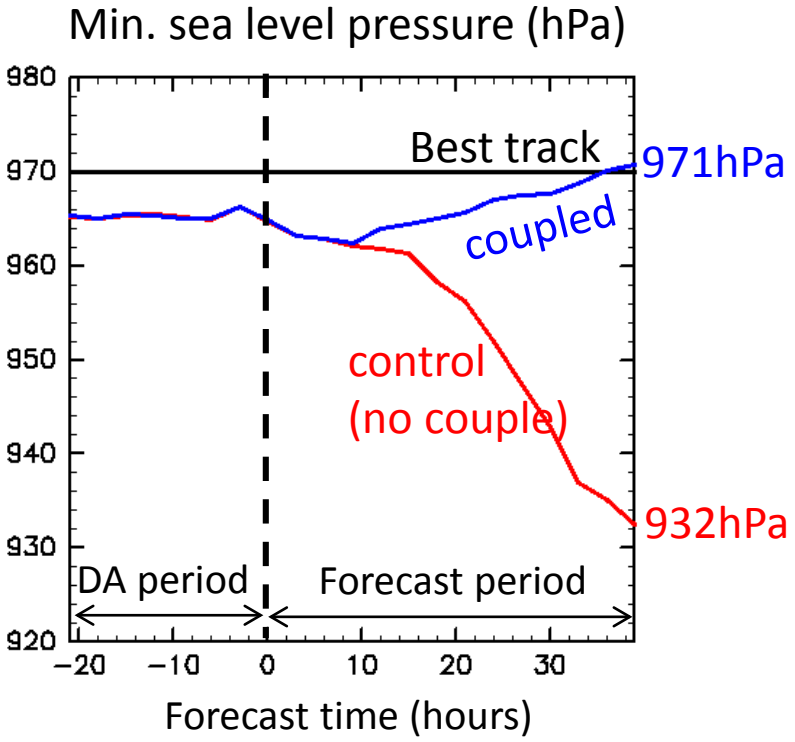
Ctrl VS Coupled (8 DA cycles)

- RMSE of Vmax: 2.26m/s → 1.72m/s
- RMSE of Pmin: 4.77hPa → 4.67hPa
- Mean of minimized J: 2431 → 2408


Analysis
1000
C.I.=10hPa


Control(FT=36)
1000
C.I.=10hPa


Coupled(FT=36)
1000
C.I.=10hPa


Min. sea level pressure (hPa)
980
970
960
950
940
930
920
Best track
971hPa
coupled
control
(no couple)
932hPa
DA period
Forecast period
−20
−10
0
10
20
30
Forecast time (hours)

Thank you.