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# Ocean data assimilation systems in JMA and their representation of SST and sea ice fields

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## Outline

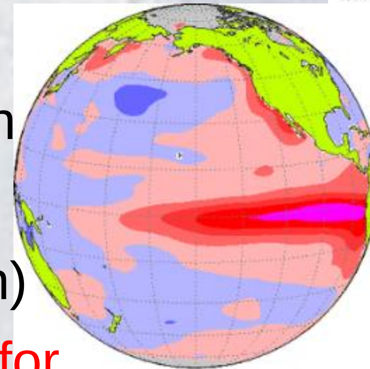
- SST analyses and ocean DA products, and their use in JMA's operation
- Development of a global ocean 4DVAR system in JMA and MRI
- Eddy resolving ocean data assimilation system and their future use in Numerical Weather Predictions (NWP)
- Coupled Prediction and Coupled Data Assimilation
- Other possible developments for improving SST fields in ocean DA systems

# SST analyses and ocean DA products, and their use in JMA's operation

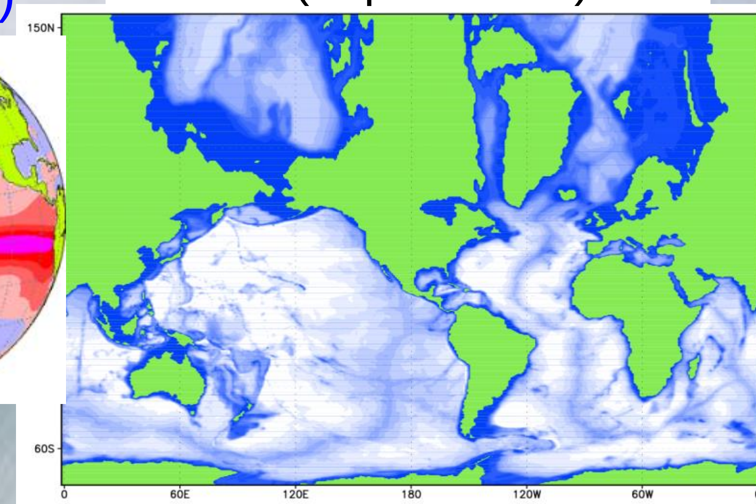
# ☆ SST (ocean) products in JMA's operation (global)

## MOVE/MRI.COM-G2 (Global Ocean DA system)

- ✓ Tripolar Grid, 1º × 0.3-0.5º
- ✓ 3DVAR-FGAT+ Bias Correction
- ✓ COBE-SST is assimilated.
- ✓ Sea Ice Model (No assimilation)
- ✓ Used in initialization of CGCM for seasonal and ENSO predictions (7 months)



G2 (Tripolar Grid)




## MGD-SST (Objective SST Analysis with satellite data)

- ✓ JMA's product for GODAE High Resolution SST (GHRSST)
- ✓ 0.25º × 0.25º, Daily, Bulk SST, Optimal Interpolation
- ✓ Used for sea surface boundary condition in NWP in JMA.

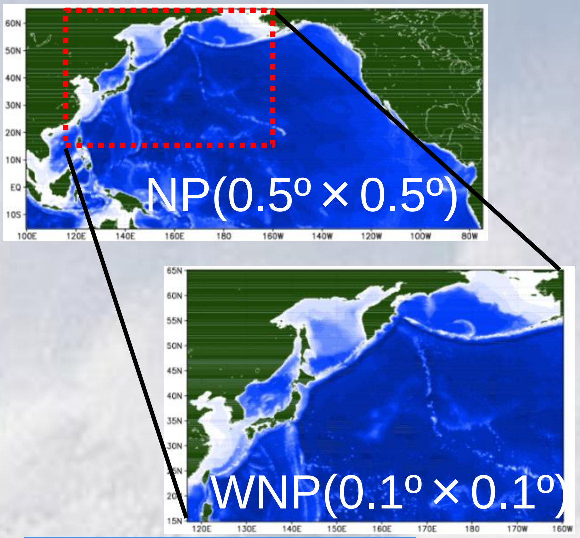
## COBE-SST (Objective SST Analysis without satellite data)

- ✓ 1º × 1º, Daily, Bulk SST, Optimal Interpolation
- ✓ Used in JMA's atmospheric reanalysis system, JRA55.

# ☆ Ocean products in JMA's operation (regional)

## MOVE/MRI.COM-NP/WNP (Ocean 3DVAR System)

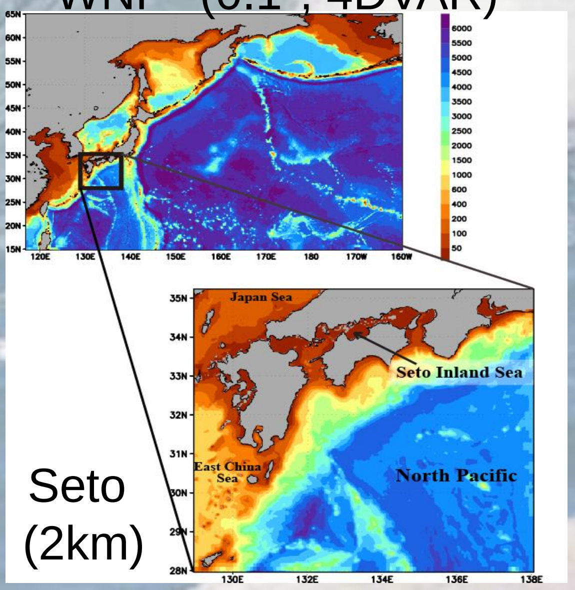
- ✓ WNP model (0.1º) is nested in NP model (0.5º)
- ✓ 3DVAR is applied in both models
- ✓ MGD-SST is assimilated
- ✓ Used for Kuroshio/Oyashio monitoring and ocean forecasting (1 week-1 month)




## MOVE/MRI.COM-WNP*/Seto (Ocean 4DVAR System)

(semi-operation)

- ✓ Seto model (2km) is nested in WNP model (0.1º)
- ✓ 4DVAR is applied in WNP model.
  (MGD-SST is assimilated)
- ✓ Seto model is initialized using assimilated TS fields of WNP model through IAU as a down-scaling technique.
- ✓ Used for monitoring of coastal phenomena and abnormal tide and ocean forecasting (-1 week)

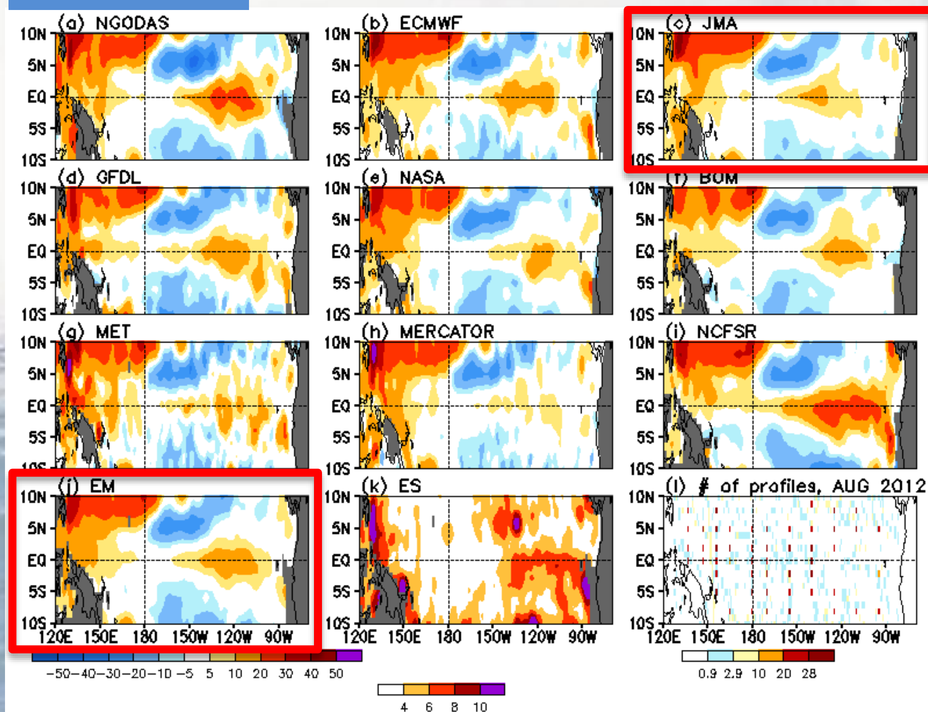


# ☆Real-Time Multi-ORA Intercomparison

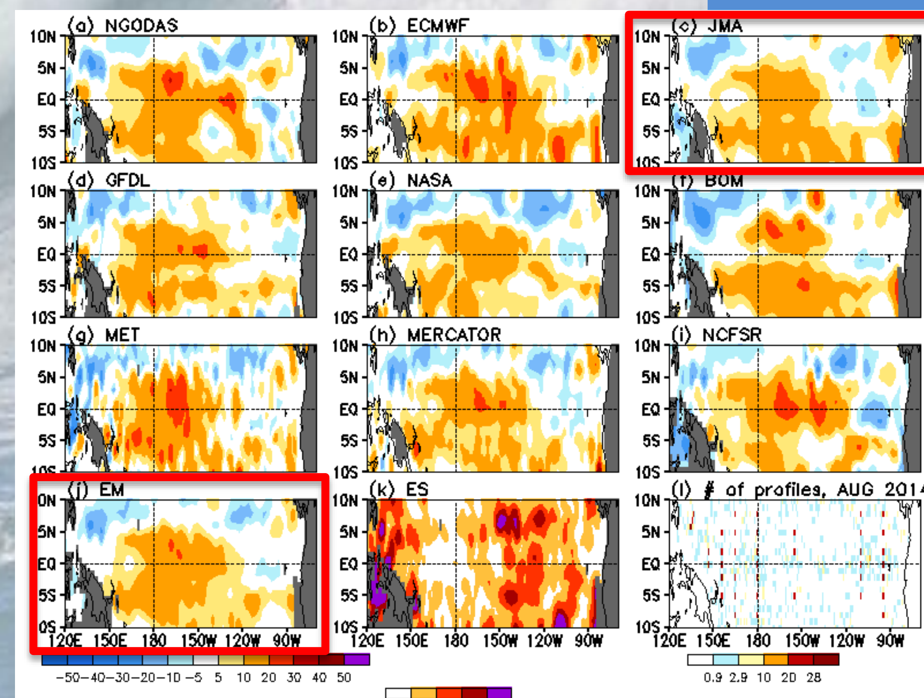
- ✓ Data of the global Ocean DA system, MOVE-G2, are provided to Real-Time Multi-ORA intercomparison. (Xue et al., 2017, ClimDyn, 10.1007/s00382-017-3535-y)
- ✓ Temp.: http://www.cpc.ncep.noaa.gov/products/GODAS/multiora_body.html
- ✓ Sal.: http://poama.bom.gov.au/project/salt_19812010
- ✓ Analyzed T fields in MOVE-G2 are well consistent with the ensemble mean.
  - ⇒ MOVE-G2 shows similar performance among state-of-the-art systems

Figures from the web page

Apr2012



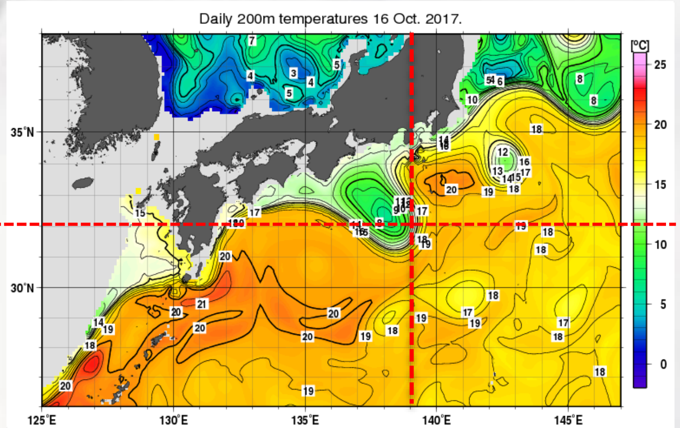

Apr2014



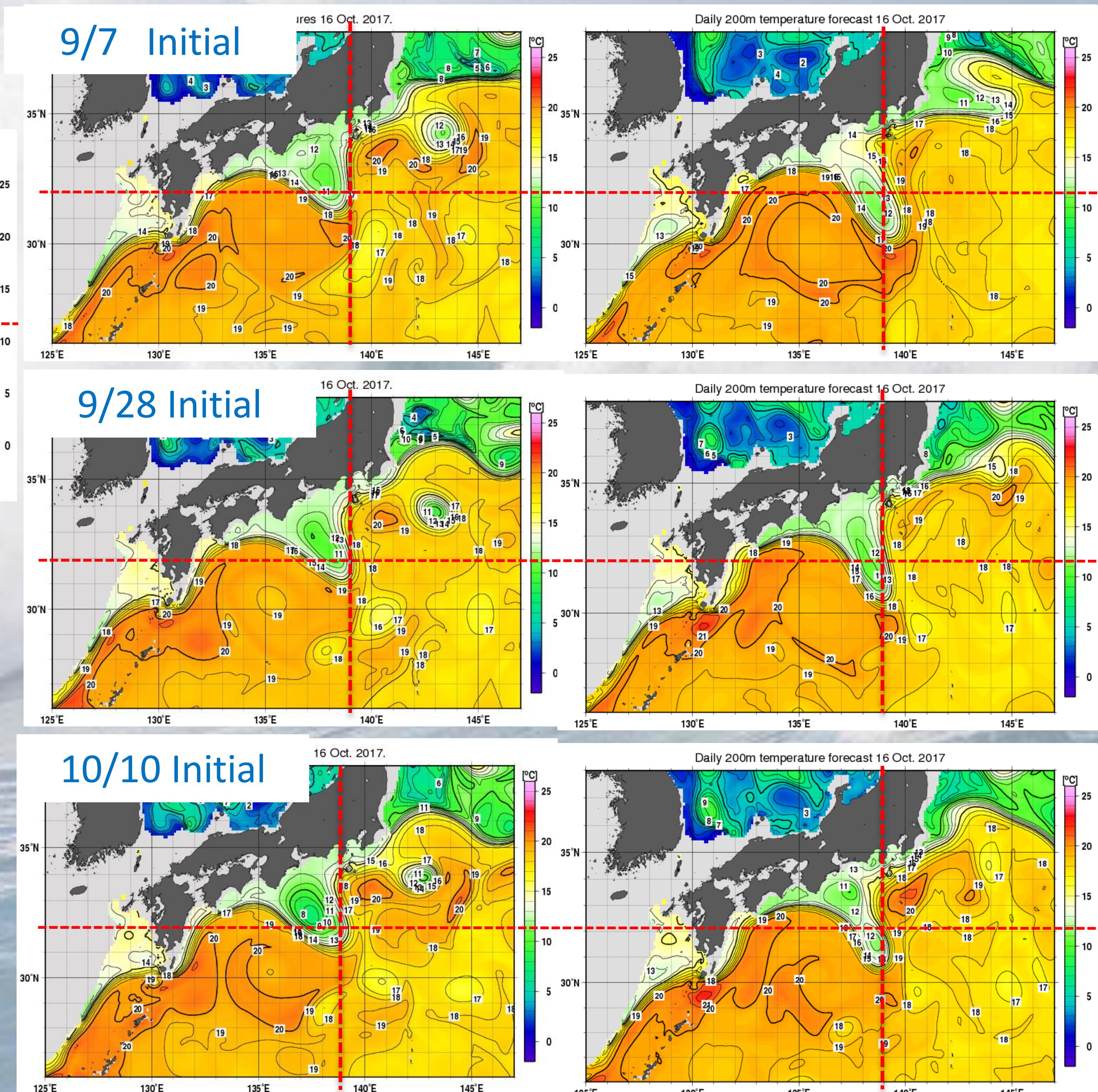

For T anomaly. Averaged in 0-300m.

# ☆ 2017 Kuroshio large meander (Prediction for 10/16)

Actual Status
(10/16, T200)




T200 in WNP* (4DVAR) T200 in WNP (3DVAR)




Predictions from 3DVAR tend to overestimate development and eastward advection of the meander, but predictions from 4DVAR adequately represent the large meander.

The prediction is successful even the lead time is longer than 1 month.

# Development of a global ocean 4DVAR system in JMA and MRI

# ☆Developments for future SST (ocean) products

◆ **Near Future**

- MGD-SST will be used in the next generation of JMA's atmospheric Reanalysis, JRA-3Q
- MGD-SST will be Improved by incorporating new satellite data

◆ **Mid Future**

- Ocean DA systems will provide SST data to NWP system
- Development of new global ocean DA systems

| | | MOVE-G2 (2014-) | MOVE-G3 (2021-) | MOVE-G4 (2026-) |
|---|---|---|---|---|
| Assimilation Scheme | Ocean | 3DVAR | 4DVAR | 4DVAR |
| | Sea Ice | Free | 3DVAR | 4DVAR |
| Resolution | Analysis model | 1º×0.5º | 1º×0.5º | 0.25º×0.25º |
| | Forecast model | | 0.25º×0.25º | 0.1º×0.1º |

- Improvements of regional ocean DA system (e.g., extension of the model domains)

◆ **Far Future**

- Coupled prediction and Coupled DA
  - Development of weakly coupled A-O DA system based on JMA's operational systems.
  - Test of coupled prediction (NWP, and 1-month prediction)

# ☆ Development of a global ocean 4DVAR System

## ◆ MOVE/MRI.COM-G3

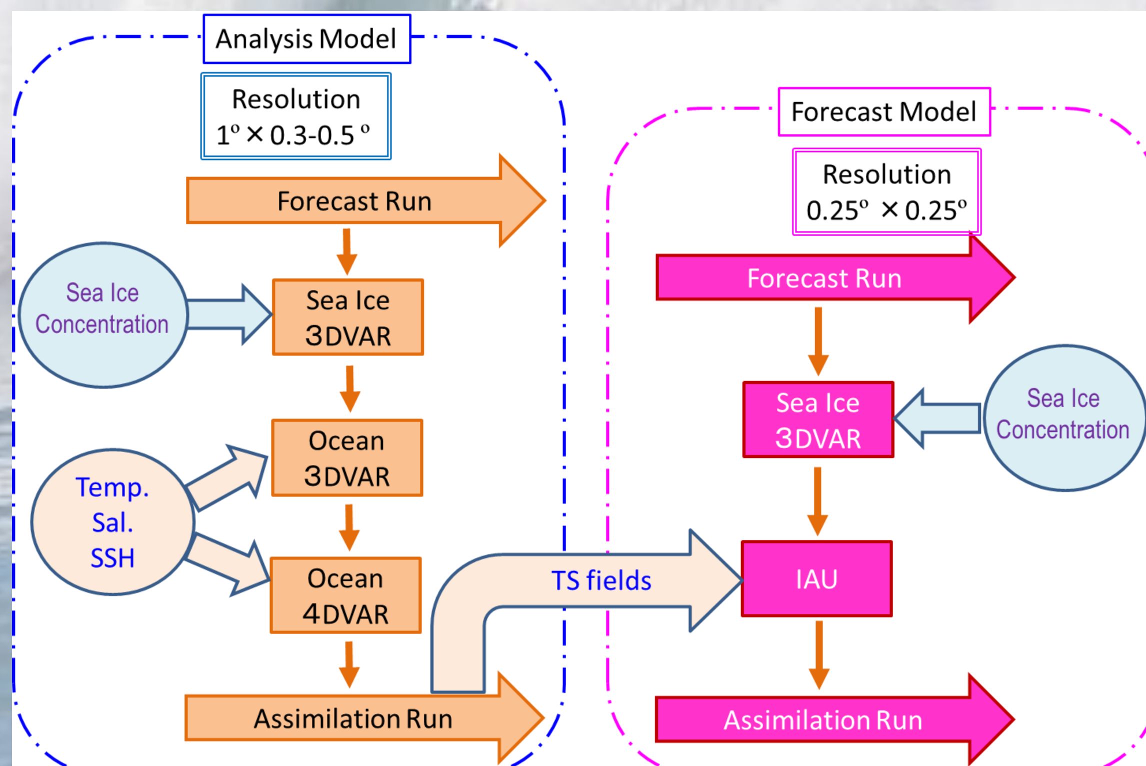
✓ Constituted of the analysis model (G3A) and the forecasts model (G3F)
(similar to an inner-model-outer-model system which uses an incremental method)

### ➢ Analysis Model (G3A)

- Global, Tripolar, Resolution: $1^{o} \times 0.3\text{-}0.5^{o}$
- **4DVAR** assimilation scheme for the oceanic temperature and salinity fields
- 4DVAR optimization starts from 3DVAR results
- **Sea Ice 3DVAR scheme**
  - ✓Separated from the 4DVAR
  - ✓Surf. Air Temp. is modified.

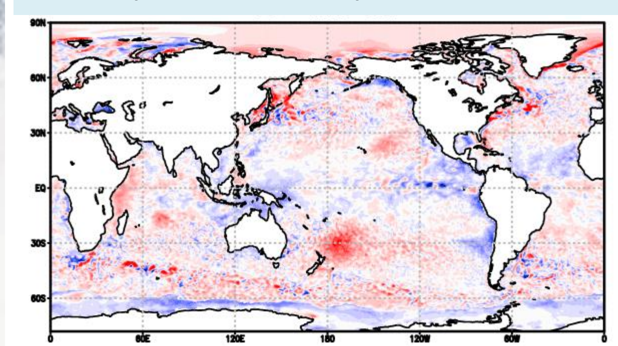
### ➢ Forecast model (G3F)

- Global, Tripolar
- Resolution: $0.25^{o} \times 0.25^{o}$
- Initialized with G3A through **IAU as a down-scaling technique**
- SIC are directly assimilated through **Sea Ice 3DVAR**.
- Used as a part of the initial condition of a coupled model in seasonal predictions.

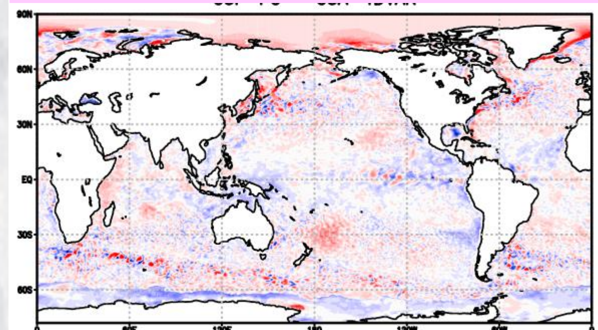


# ☆ Reduction of SST errors in assimilation data (2012/10/28-11/2)

G3A (1°x0.3-0.5°) First Guess

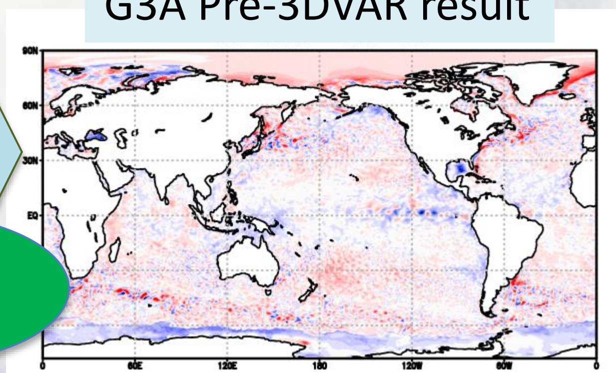


G3F (0.25°x0.25°) First Guess



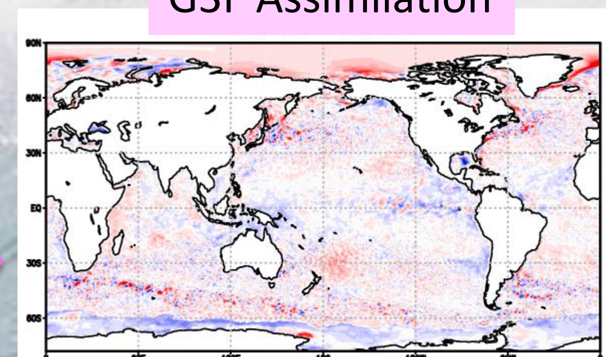
G3A Pre-3DVAR result

Pre-3DVAR



IAU

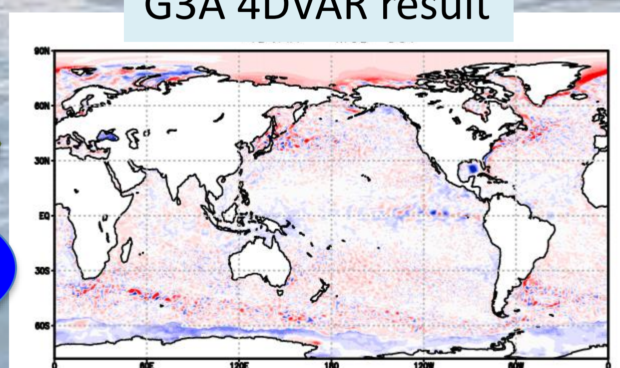
G3F Assimilation



-1.5 -0.9 -0.3 0.3 0.9 1.5

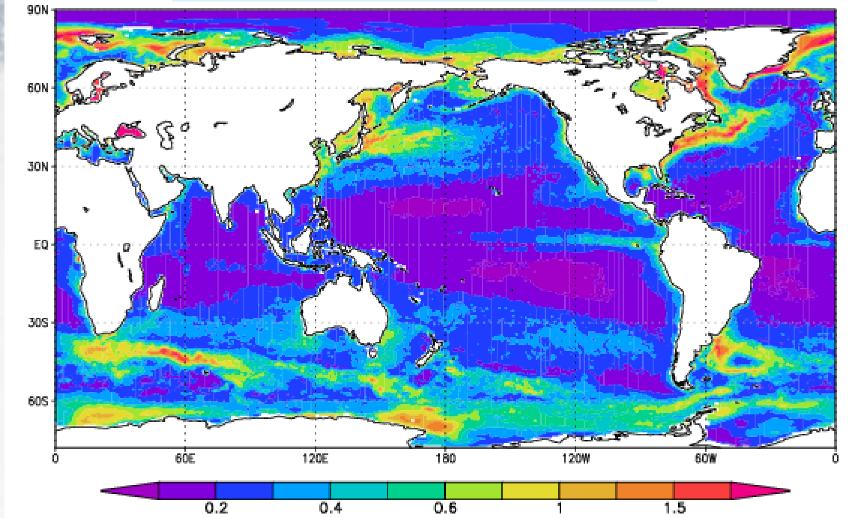
G3A 4DVAR result

4DVAR

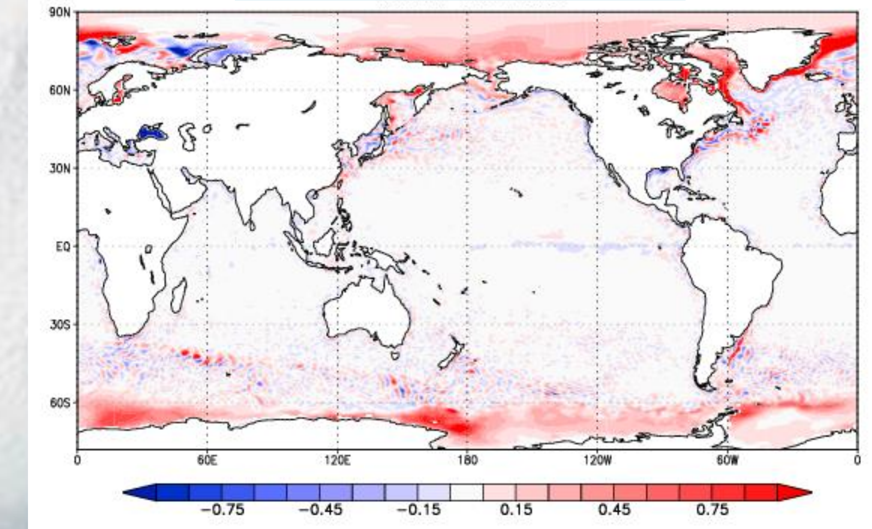


# ☆ SST RMSE and Bias in the 4DVAR System (2010-2015)

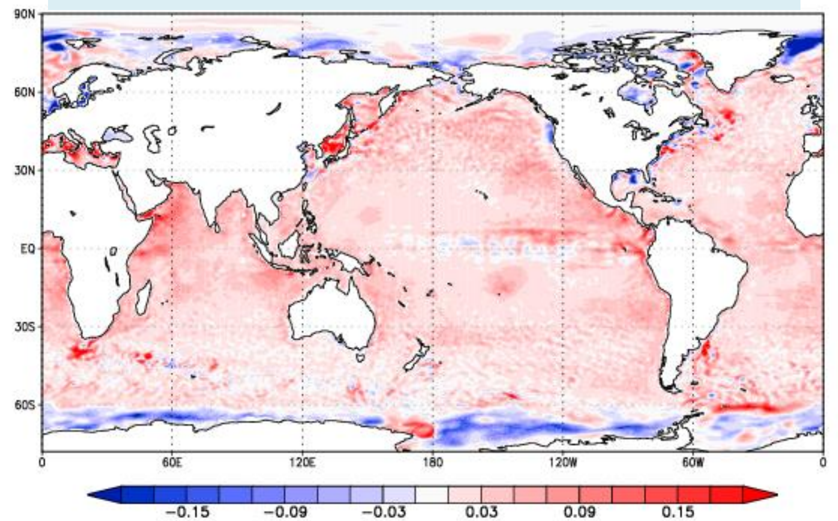
G3A-4DVAR SST RMSE




G3A-4DVAR SST Bias




Reduction of RMSE from 3DVAR result of the same model




- Errors are evaluated against MGD-SST.
- SST RMSE is less than 0.4°C, and absolute bias is less than 0.1°C in most tropical and subtropical regions.
- The errors are relatively large in the western boundary current regions, eastern equatorial Pacific, and polar regions.
- SST RMSE in the 4DVAR system is reduced from the 3DVAR result of the same model in most area except for polar regions.

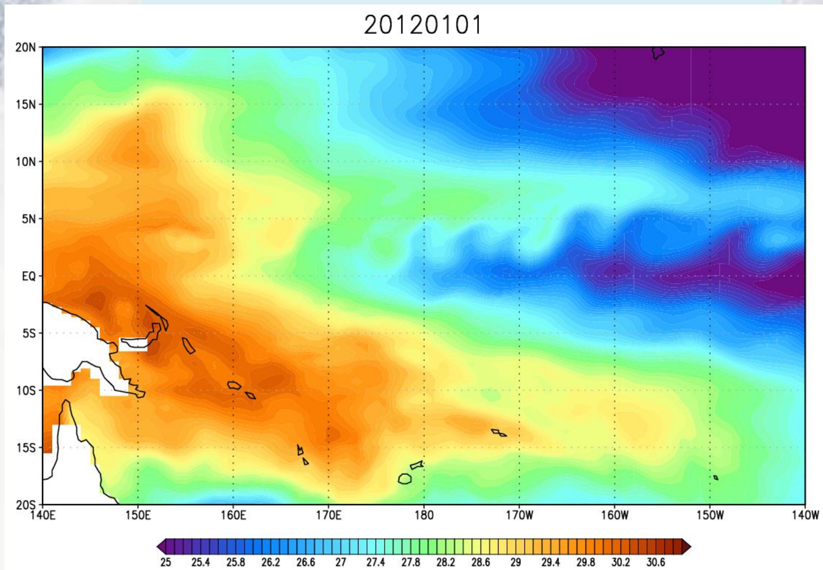
# ☆ Validation using non-assimilated Argo data (2010-2015)

| Region | Depth | RMSE | | | Correlation | | Bias | |
|---|---|---|---|---|---|---|---|---|
| | | Clim. | 3DVAR | 4DVAR | 3DVAR | 4DVAR | 3DVAR | 4DVAR |
| Whole Domain | 10m | 0.973 | 0.609 | 0.593 | 0.761 | 0.773 | 0.037 | 0.036 |
| | 50m | 1.358 | 0.989 | 0.979 | 0.675 | 0.684 | 0.021 | 0.028 |
| | 100m | 1.414 | 1.035 | 1.029 | 0.675 | 0.682 | -0.004 | 0.003 |
| Eastern Equatorial Pacific | 10m | 1.127 | 0.415 | 0.395 | 0.927 | 0.934 | 0.039 | 0.029 |
| | 50m | 2.540 | 1.373 | 1.322 | 0.843 | 0.854 | 0.127 | 0.042 |
| | 100m | 2.327 | 1.236 | 1.195 | 0.850 | 0.859 | 0.150 | 0.089 |
| Western Subtropical North Pacific | 10m | 0.813 | 0.481 | 0.448 | 0.797 | 0.826 | 0.029 | 0.017 |
| | 50m | 1.122 | 0.795 | 0.763 | 0.704 | 0.734 | 0.051 | 0.066 |
| | 100m | 1.341 | 0.896 | 0.858 | 0.744 | 0.767 | 0.051 | -0.047 |

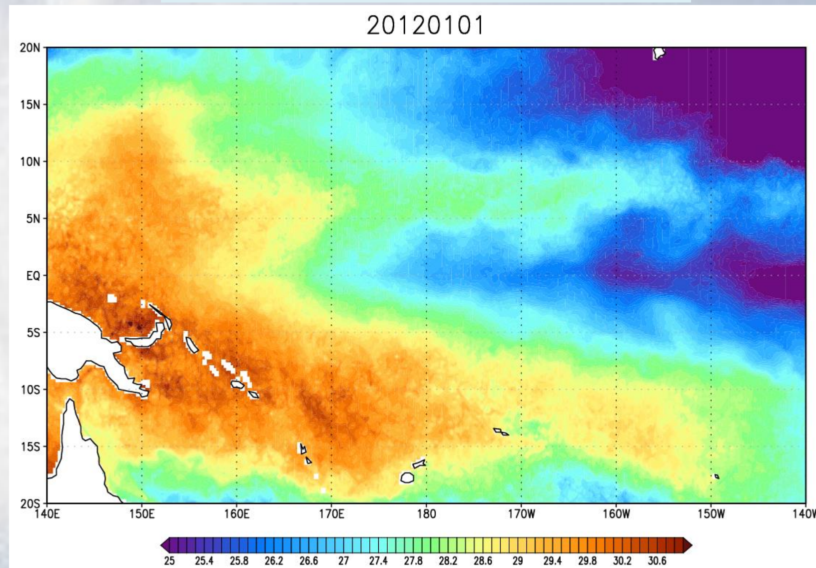
- 162,113 Argo profiles are withheld in the assimilation runs and used in this validation.
- 4DVAR reduces RMSEs and increases correlation of temperature above 100 m in the whole domain from 3DVAR.
- The improvement of near-surface temperature fields from 3DVAR to 4DVAR is farther apparent in the eastern equatorial Pacific and western subtropical North Pacific.

# ☆ Representation of Tropical Instability Waves

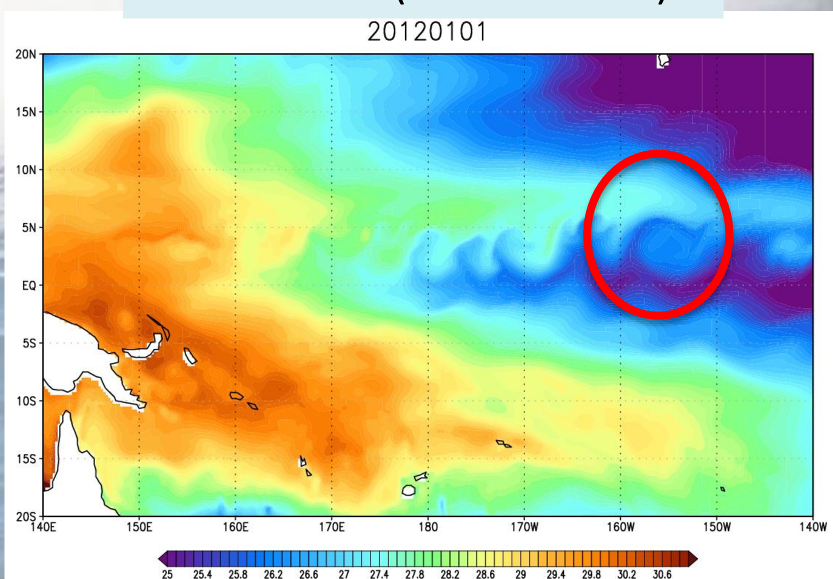
G3A-4DVAR SST (1° × 0.3-0.5°)



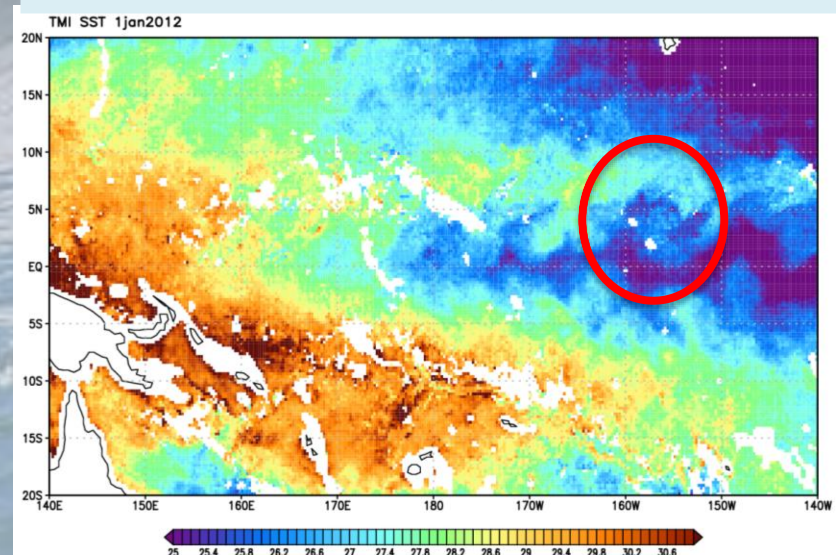

MGD-SST (0.25° × 0.25°)




G3F-IAU SST (0.25° × 0.25°)




TRMM Microwave Imager (0.25° × 0.25°)



# ☆ Sea Ice 3DVAR Scheme with Surf. Air T Correction

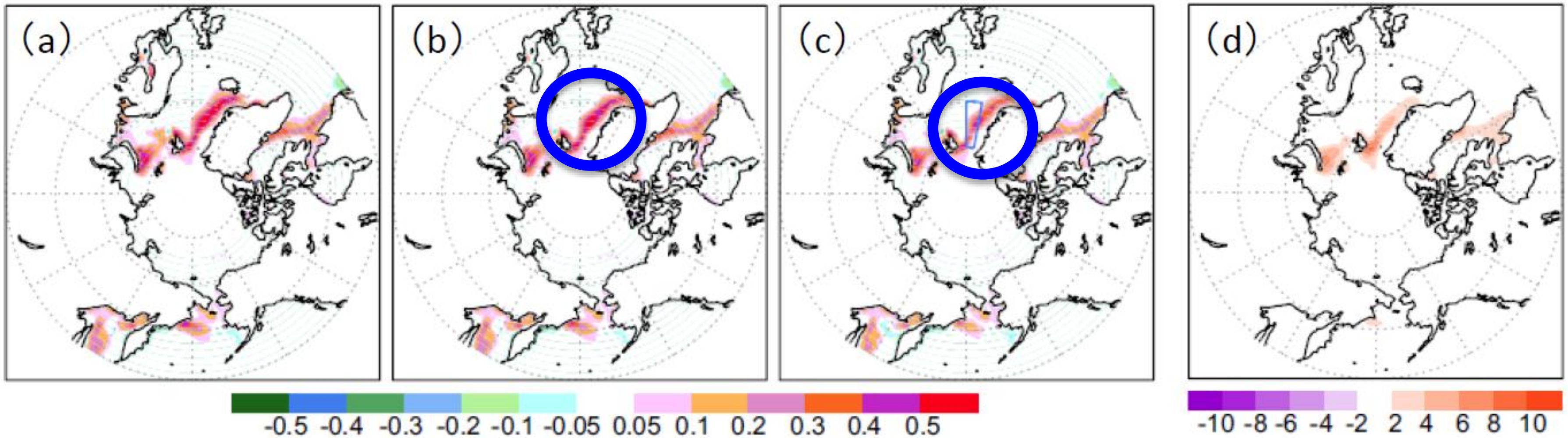
SIC Bias against observation data in March

SAT Correction in Exp. 3

Exp.1: Assim. TS only

Exp. 2: Assim. TS + SIC

Exp. 3: TS+SIC+SAT Corr.

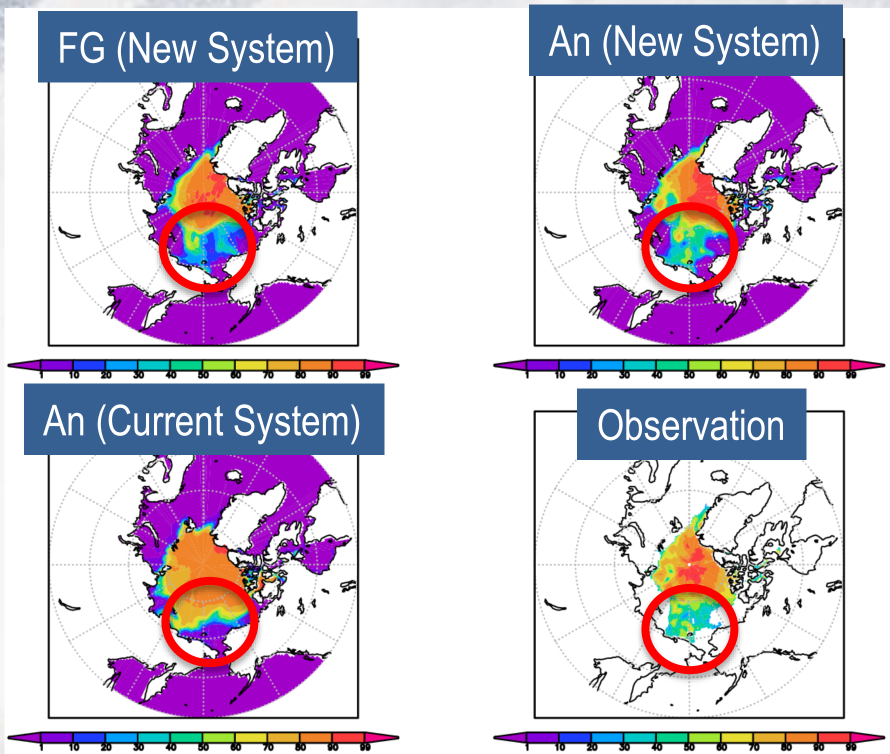



From Toyoda et al. 2015

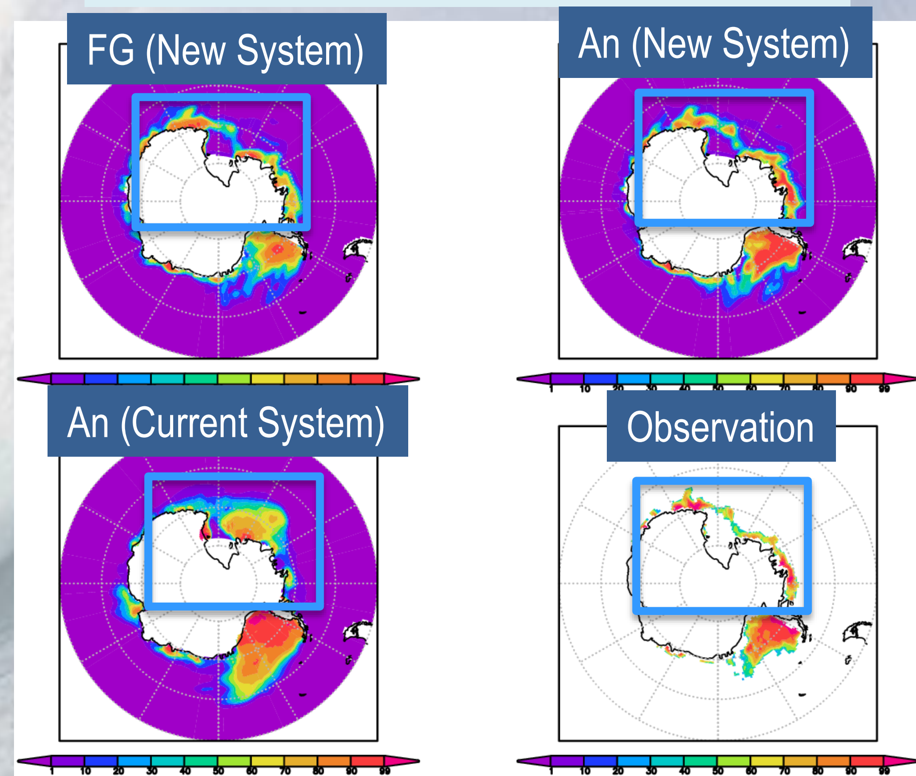
- Sea surface Air Temperature (SAT) is affected by Sea Ice Concentration (SIC) due to warmer temperature at the sea surface than on the ice top. On the other hand, SAT strongly constrains the SIC fields.
- Therefore, SAT should be corrected simultaneously when SIC is changed by DA.
- Introducing SAT correction according to SIC changes (Exp. 3) improves SIC fields over the experiment without SAT correction (Exp. 2).
- The correction of SAT is also consistent with other studies.

# ☆ Comparison of Sea Ice Concentration Fields

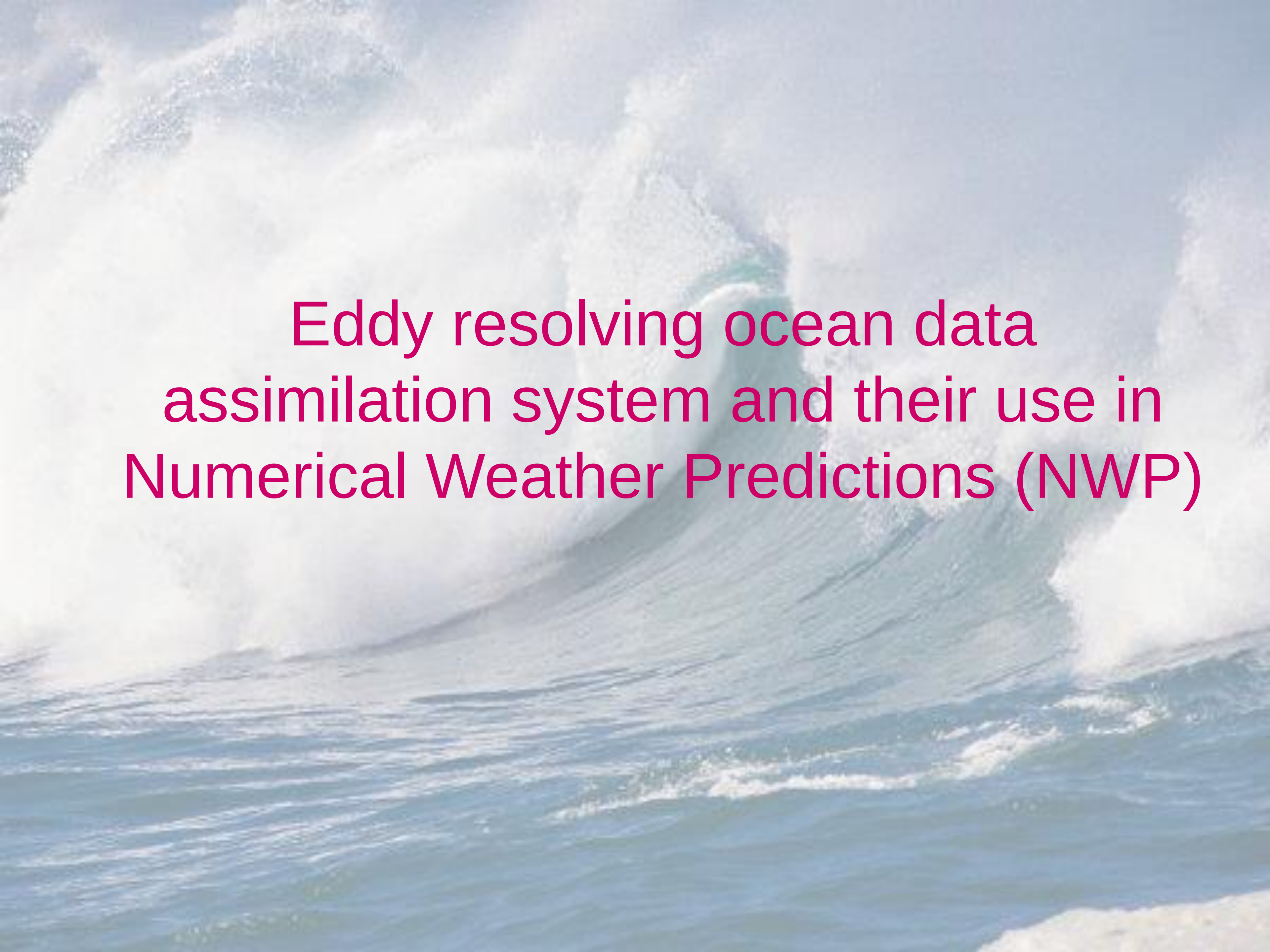
Arctic Region (30Jul-03Aug, 2012)




Antarctic Region (30Jul-03Aug, 2012)



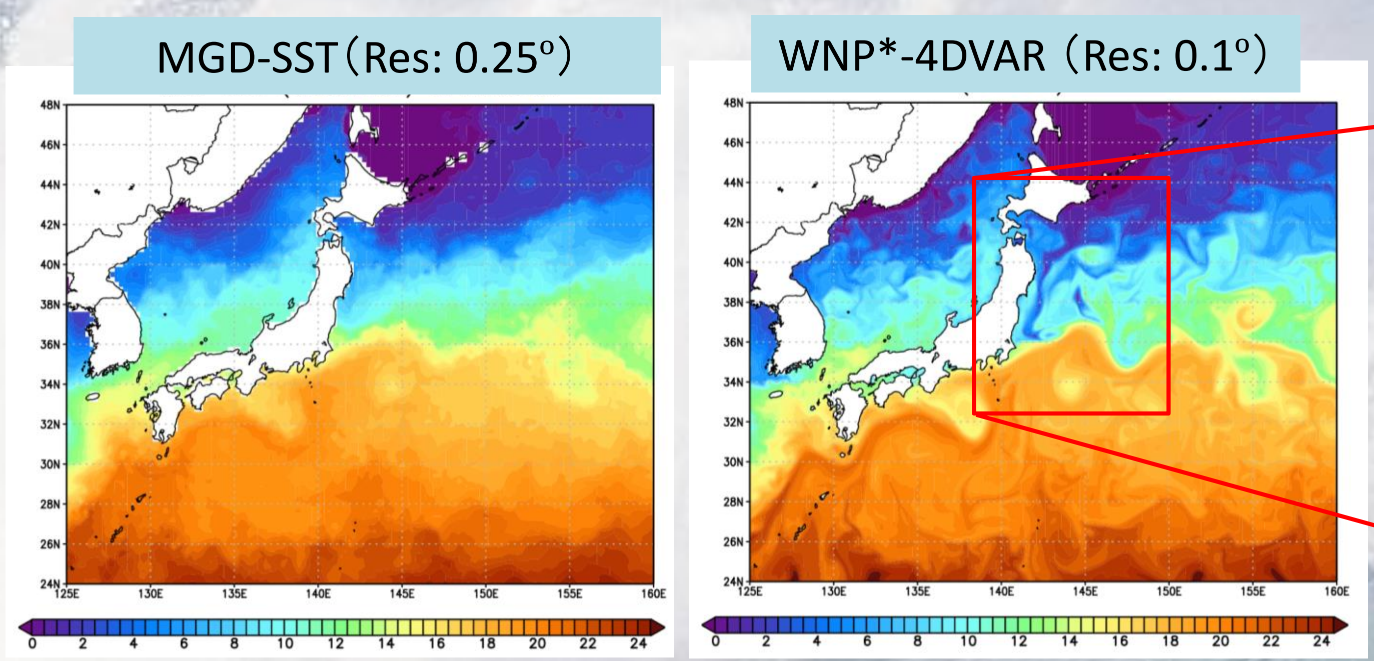

- Sea Ice data are not assimilated in the current operational system
- By assimilating Sea Ice concentration data, the distribution of the sea ice field is much improved in the new system.
- The extension of the sea ice area in red circles is much improved. And it is effectively modified in the analysis step.
- The distribution in the Antarctic region in austral summer is also effectively improved.

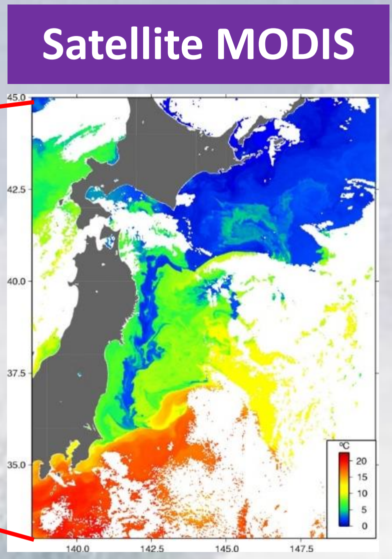


# Eddy resolving ocean data assimilation system and their use in Numerical Weather Predictions (NWP)

# ☆ Resolution and reproducibility of SST variation

**SST at Mar. 7th, 2005**




From the web page of EORC: http://www.eorc.jaxa.jp/imgdata/topics/2005/tp050408.html

- The 4DVAR system **(WNP*-4DVAR)** reproduces the narrow southward intrusion of Oyashio to 37.2°N observed by satellite MODIS even though the narrow Oyashio is not represented in MGD-SST.
- Thus, if an ocean 4DVAR system has a resolution of 0.1°, representation of SST field can be much improved. Therefore, atmospheric prediction may be improved by using those SST fields from the ocean 4DVAR system instead of objective SST analysis (MGD-SST).

# ☆ Impact of using SST from ocean DA in NWP (Setting)

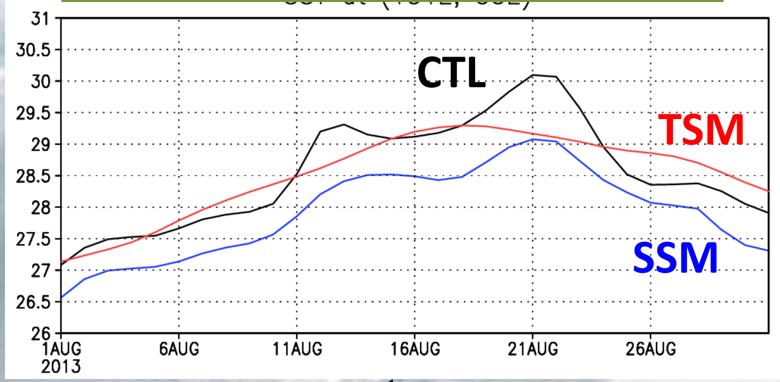
Model: Nonhydro Regional Atmospheric Model in JMA/MRI (Resolution 2km)

Target: 23-25, August, 2013 (Extreme rain event in Shimane prefecture)

SST Data

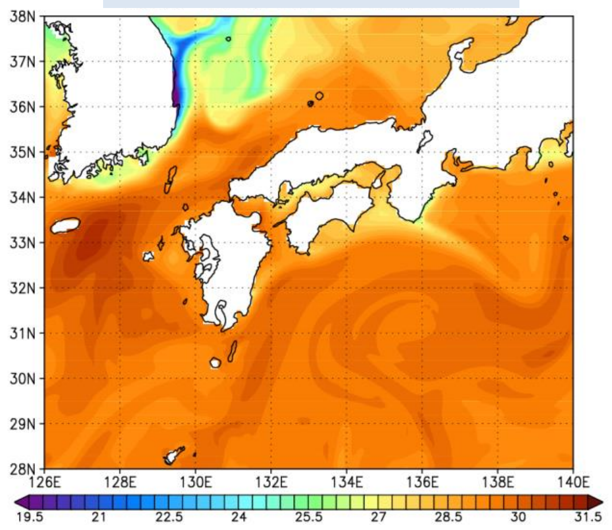
- **Exp-CTL**: From a regional ocean 4DVAR system with 0.1$^{o}$ resolution
- **Exp-TSM**: Same as Exp-CTL but a 7-day temporal Gaussian filter is applied.
- **Exp-SSM**: Same as Exp-CTL but a 100km spatial Gaussian filter is applied.

**SST Time-series at 35ºE, 131ºE**

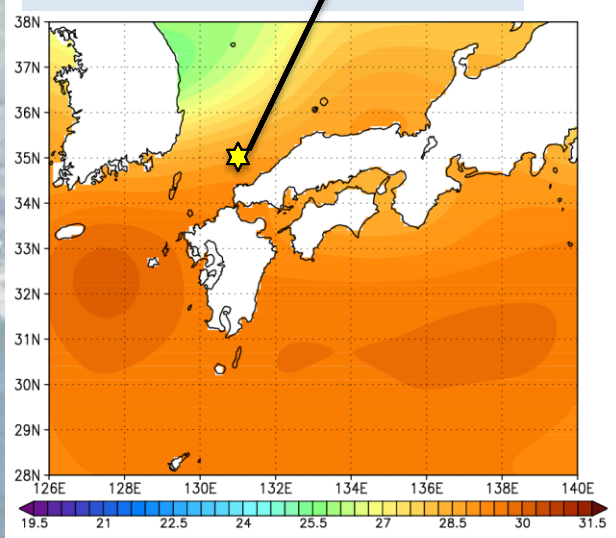



**SST field on August 23**

**Exp-CTL**



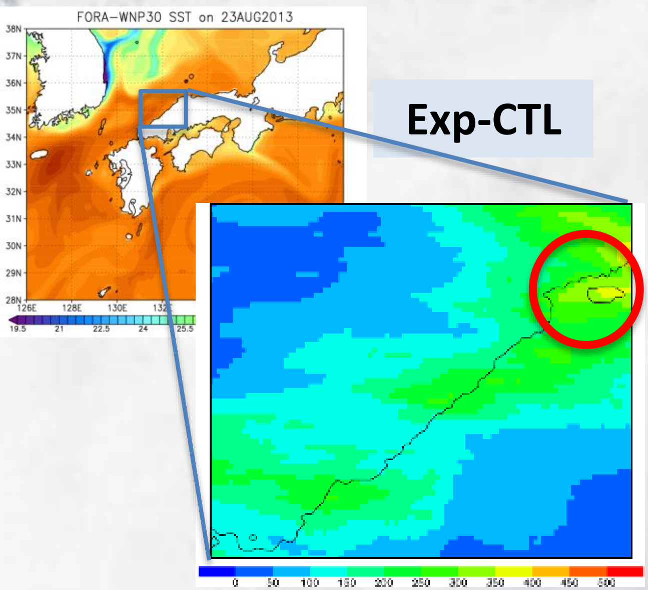

**Exp-SSM**



# ☆ Impact of using SST from ocean DA SST in NWP (Result)

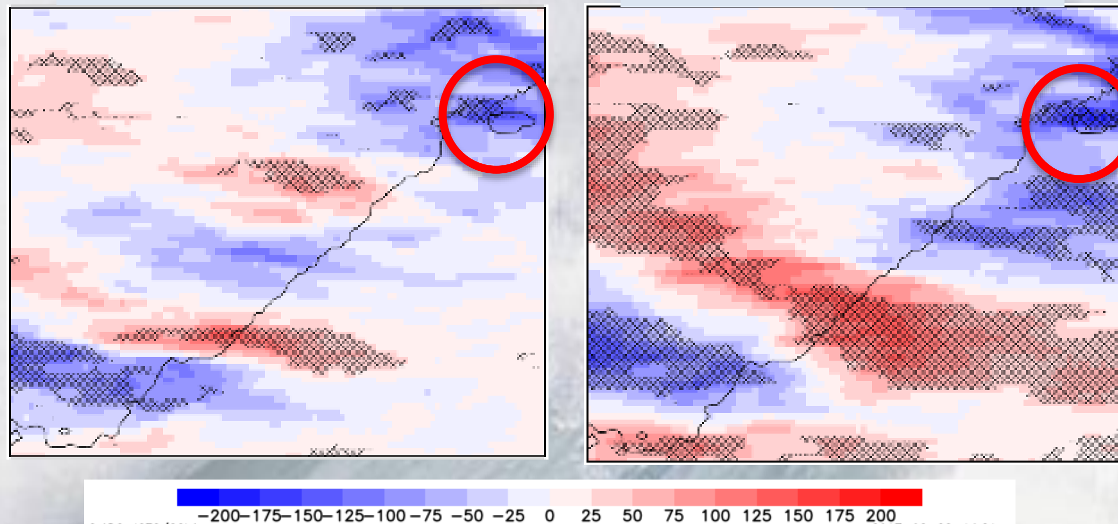
## Precipitation for 3 Days

**Exp-CTL**

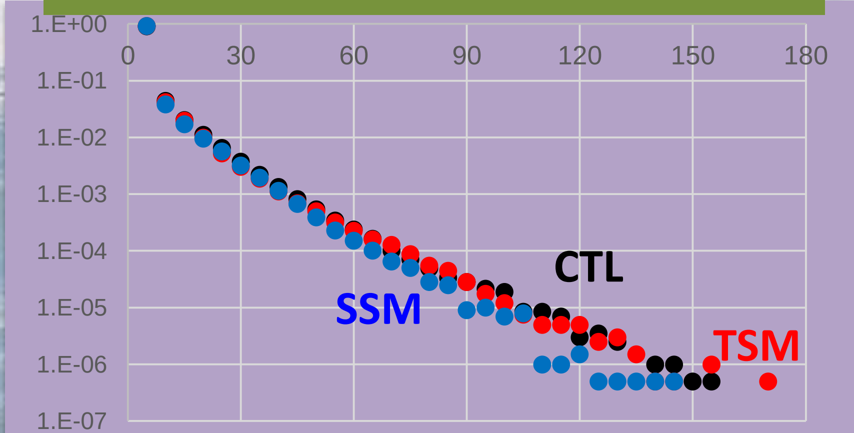



## Difference from Exp-CTL

**Exp-TSM – Exp-CTL** | **Exp-SSM – Exp-CRL**




## Occurrence frequency of 1-hour precipitation in the area




| Max Precipitation in the area (mm) | |
|---|---|
| Exp-CTL | 401 |
| Exp-TSM | 266 |
| Exp-SSM | 277 |
| Obs. | 474 |

# Coupled Prediction and Coupled Data Assimilation

# ☆ Test of coupled prediction using JMA's NWP system (1)

**Experimental Design**

Test cases: 91 cases (every 5 days from Jun 2016 to Aug 2017)

Deterministic forecast , 1-day averaged data, verified against JRA-55

**Uncoupled atmospheric model:**

Based on JMA's operational model (as of Jun 2017), Resolution: TL159L100

Prescribed SST and sea-ice (MGD-SST)

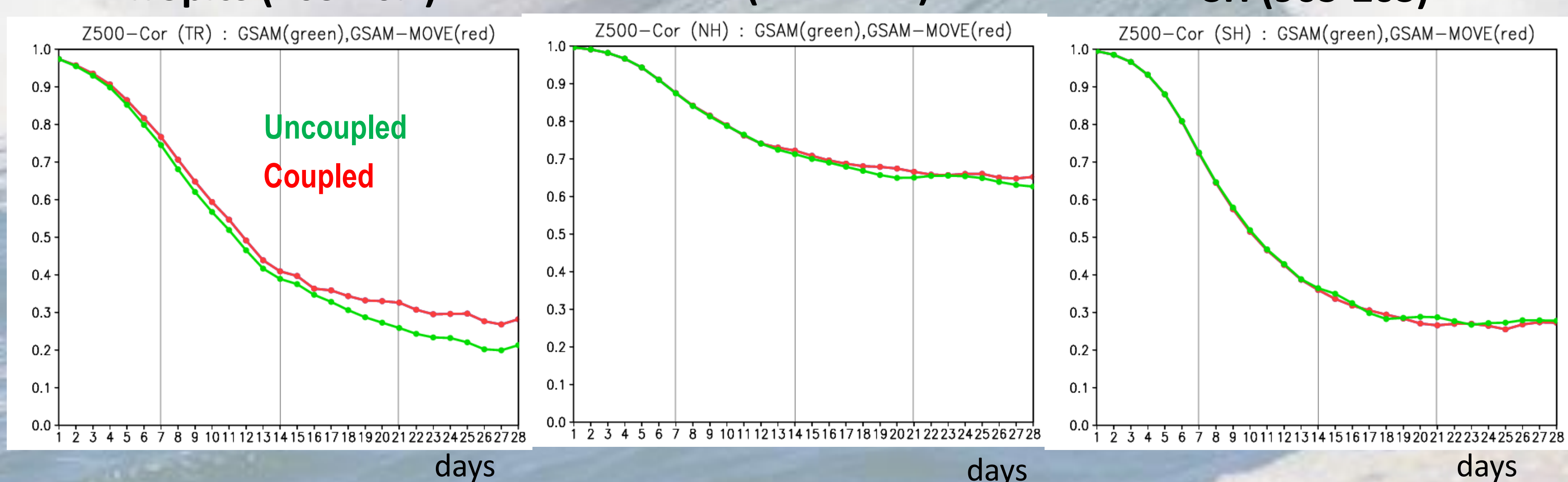
**Coupled model:**

Ocean and sea-ice coupling with the ocean model of MOVE-G2

Resolution TL159L100 (atmosphere) + 1$^{o}$ × 0.3-0.5$^{o}$ L52 (Ocean)

**Tropics (20S-20N)** **NH (20N-90N)** **SH (90S-20S)**

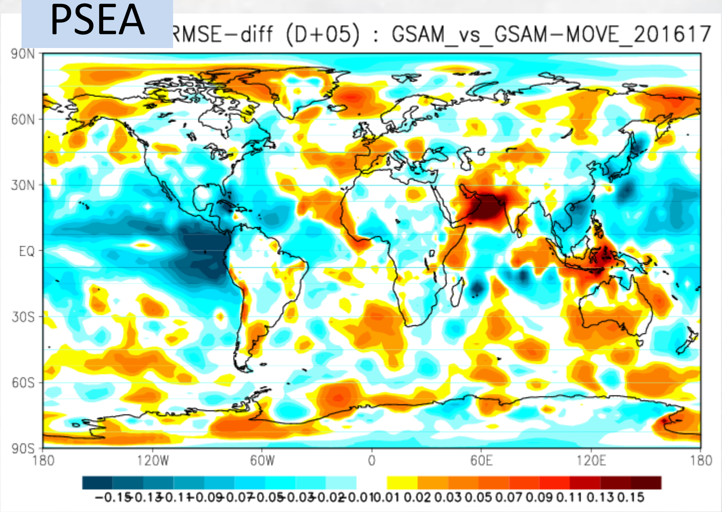
**Z500 ACC**



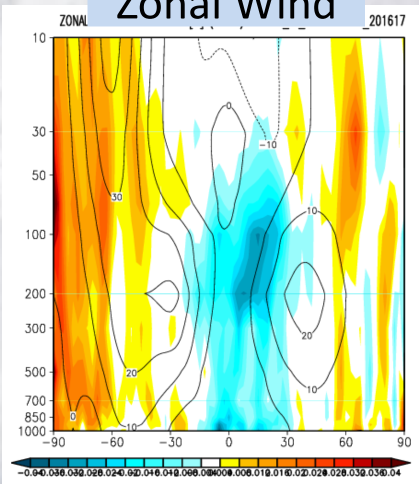
# ☆ Test of coupled prediction using JMA's NWP system (2)

Normalized RSME difference (coupled - uncoupled) of 5-day forecasts.

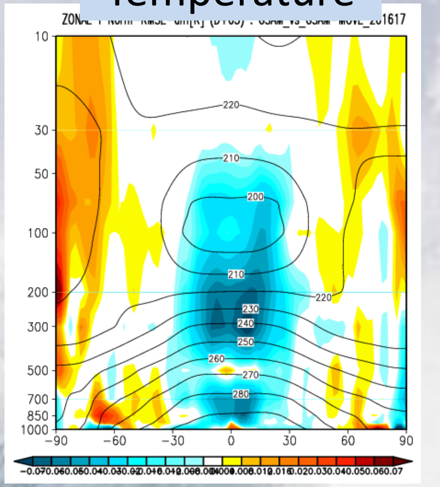
PSEA



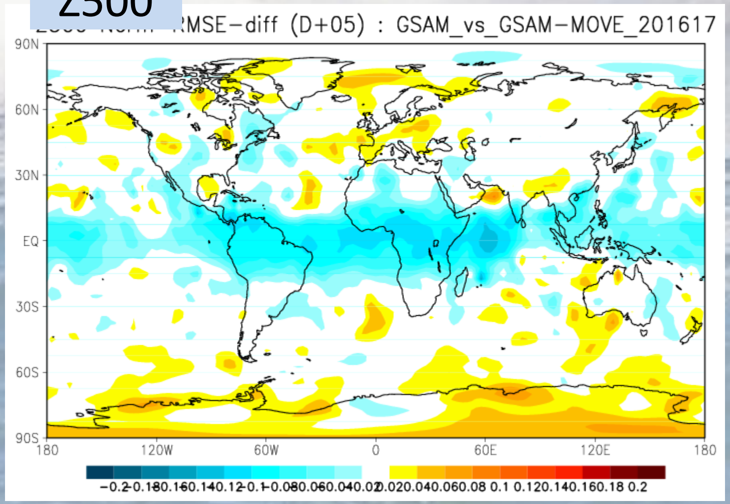

Zonal Wind




Temperature

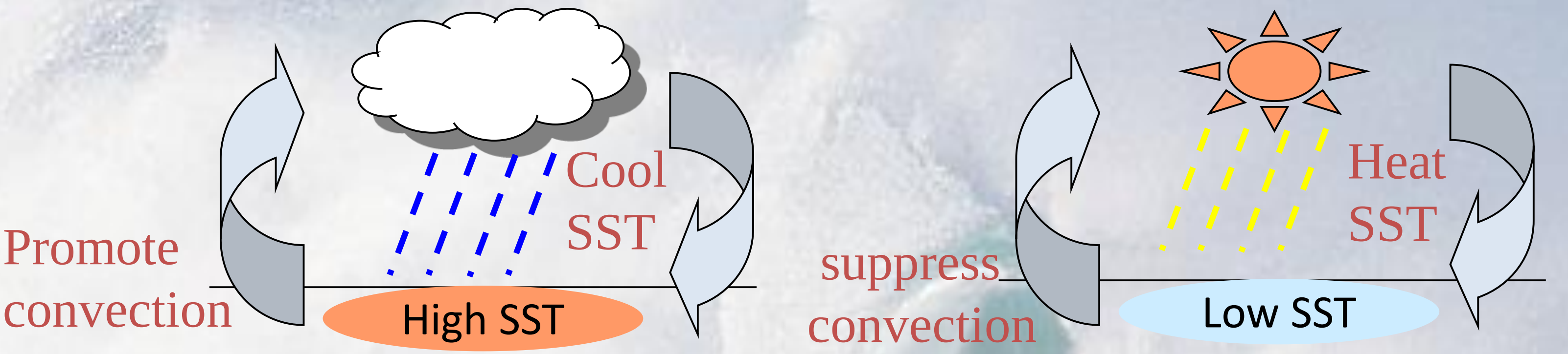



Z500



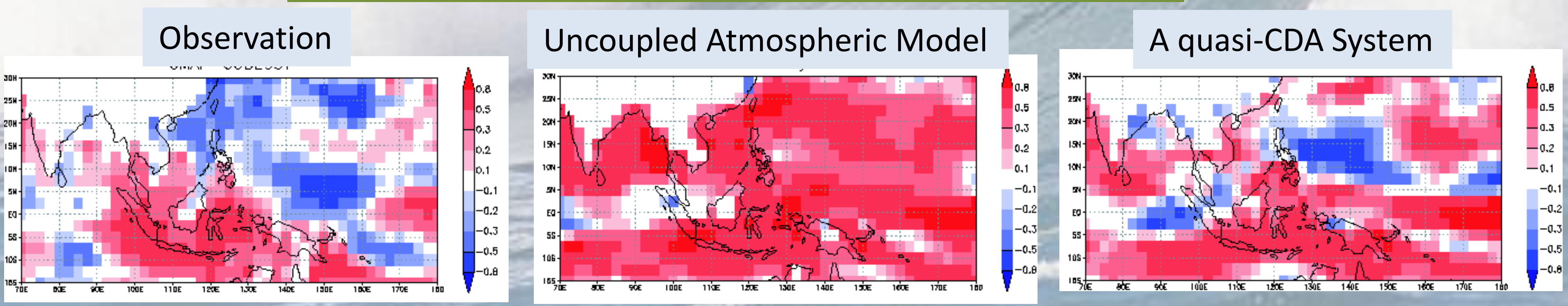

- Here, blue colors means coupled predictions are better.
- The prediction of tropical atmospheric fields by the coupled model has smaller RMSE than the prediction by the uncoupled model.
- This result is consistent with the result of coupled prediction in ECMWF over tropics (Balsamo et al. 2017)

# ★ A possible advantage of CDA for SST analysis




- This feedback severely affects tropical precipitation fields.
- It is not reproduced in an uncoupled model where SST is prescribed.
- But the feedback can be better represented in a CDA system

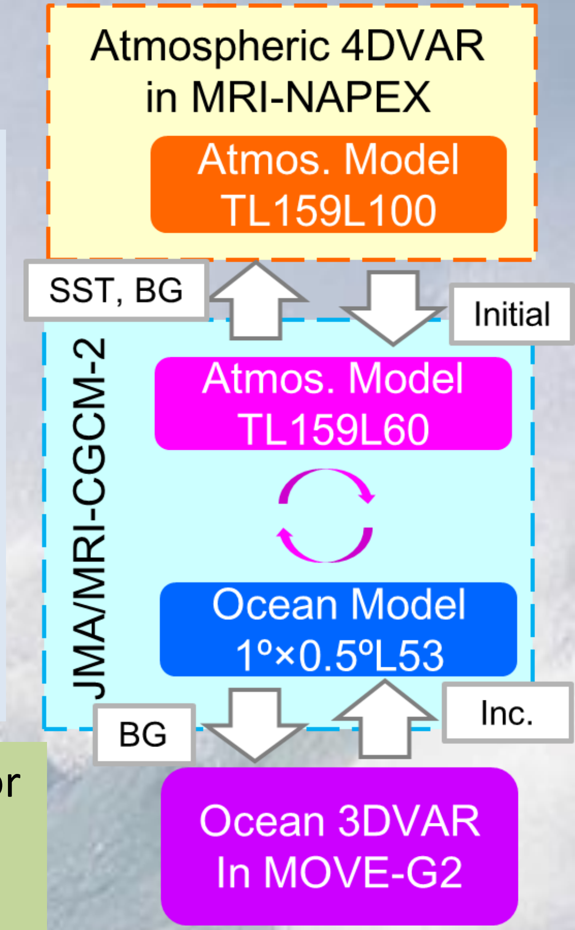
Correlation between SST and precipitation in Jun-Aug



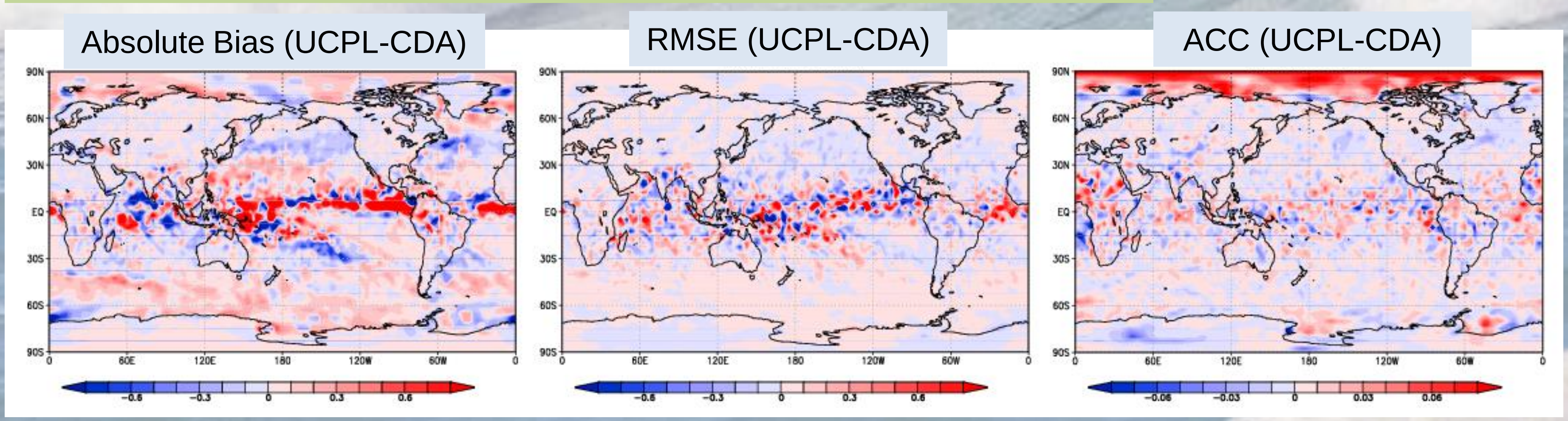

The negative correlation in western tropical Pacific caused by the negative feedback is not reproduced in the uncoupled run, but recovered by a CDA system in which only ocean data are assimilated. (Fujii et al., 2009; 2011)

# ☆ Development of a CDA System in JMA

- Weekly coupled DA system (MRI-CDA1)
- Based on the operational ocean DA system, MOVE/MRI.COM-G2, as well as the operational atmosphere DA systems and the operational coupled model.
- The coupled model is used as the outer model for the atmospheric 4DVAR.
- Comparison of the coupled reanalysis with the uncoupled version of it indicates that precipitation fields are slightly improved by coupled DA.

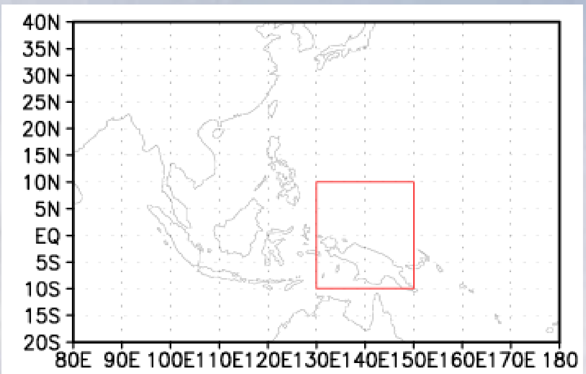


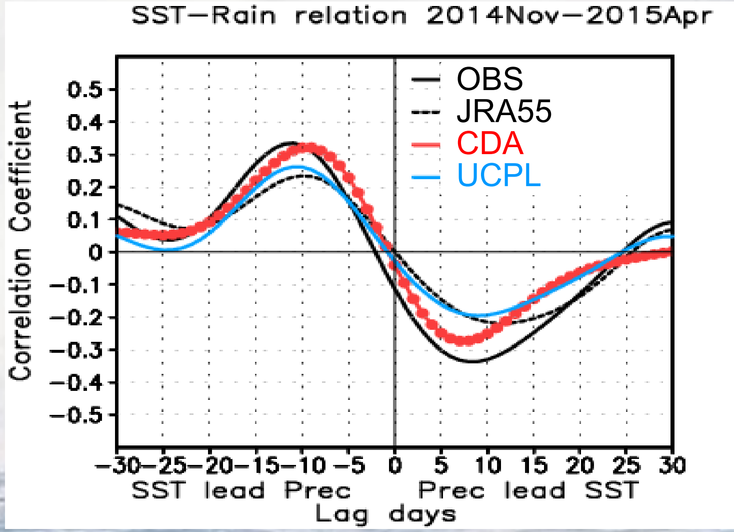

Difference of 5-day averaged precipitation scores against CMAP for Dec. 2014-Nov. 2015 between the coupled reanalysis (CDA) and uncoupled version (UCPL)

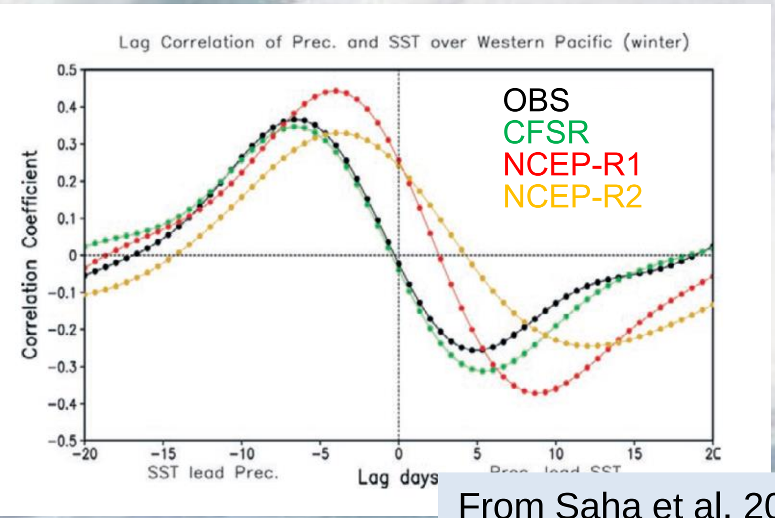


# ☆Validation for SST-precipitation Feedback (1)

- ✓ lagged correlation between SST and precipitation averaged in 10S-10N, 130-150E is examined.
- ✓ Bandpass-filtered for 20-100 days.
- ✓ In the real world, precipitation change lagged behind SST change due to the feedback in this area.



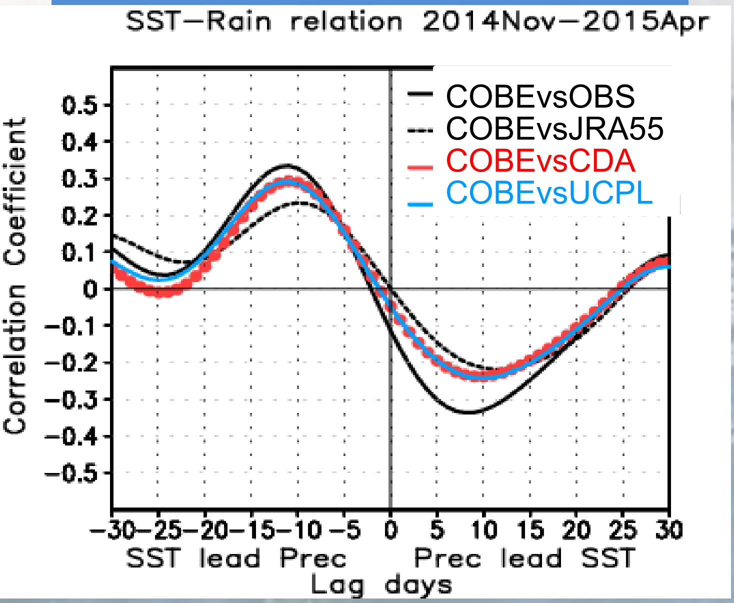

From Saha et al. 2010

- ✓ CDA represents lagged correlation of precipitation behind SST better than JRA-55 and uncoupled version of the system (UCPL).
- ✓ A similar improvement in CFSR over NCEP-R1 and R2 was reported.
- ✓ Does this mean that the negative feedback is reconstructed?

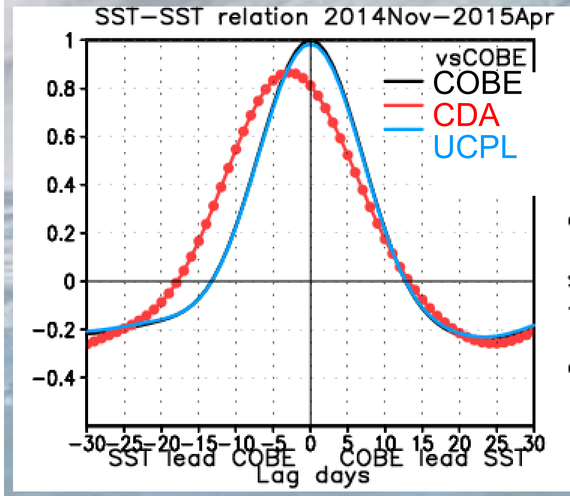
# ☆Validation for the SST-precipitation feedback (2)

- ✓ However, the correlation of the precipitation with a common reference SST data (COBE-SST) is very similar between CDA and UCPL because precipitation changes in CDA and UCPL are similar to each other.
- ✓ Variation of SST in CDA leads the variation of the reference SST data.
- ✓ A similar result is reported for NCEP reanalyses by Kumar et al. (2013).
- ✓ SST in CDA is adjusted to the atmospheric (precipitation) fields, which are strongly constrained by data assimilation (?).
- ✓ SST change does not affect the atmospheric fields (?).

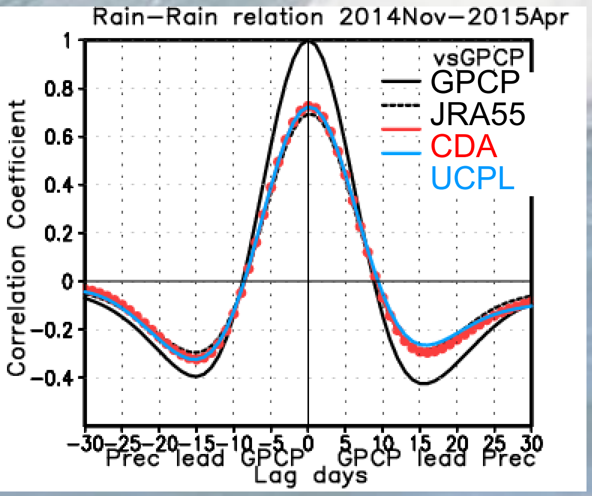
Lagged correlation coef. of precipitation against COBE-SST




Lagged correlation coef. of SST against COBE-SST




Lagged correlation coef. of precip against GPCP

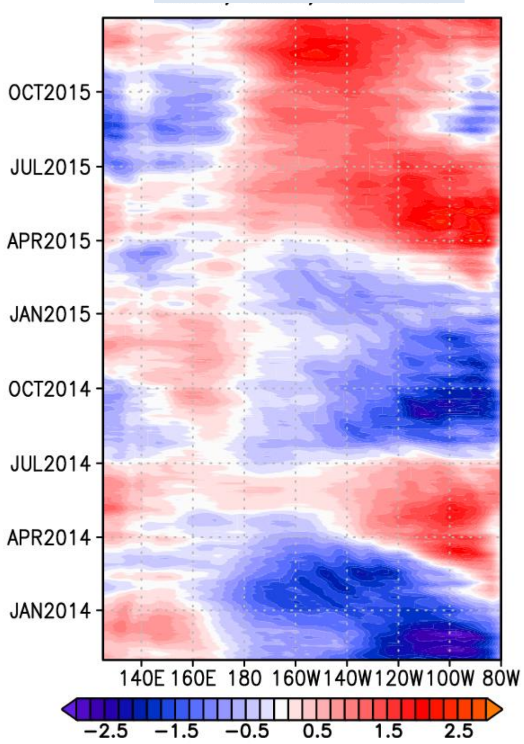


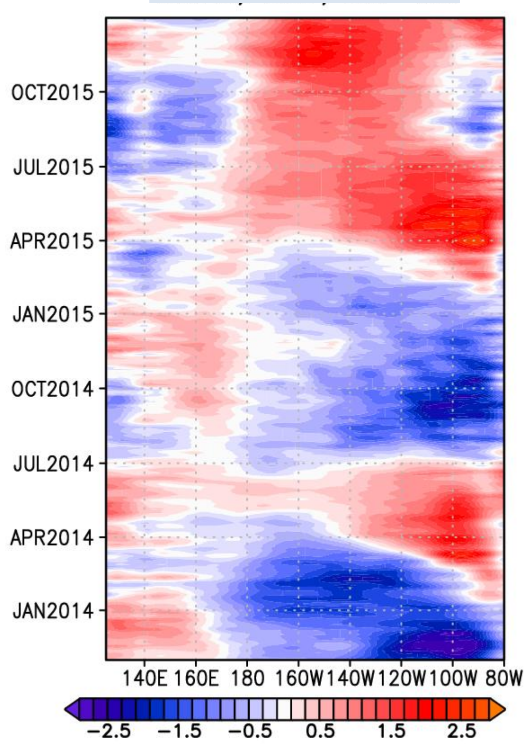
# ☆Validation of SST variation in the tropical Pacific

SST variation in the tropical Pacific (averaged in 5°S-5°N)

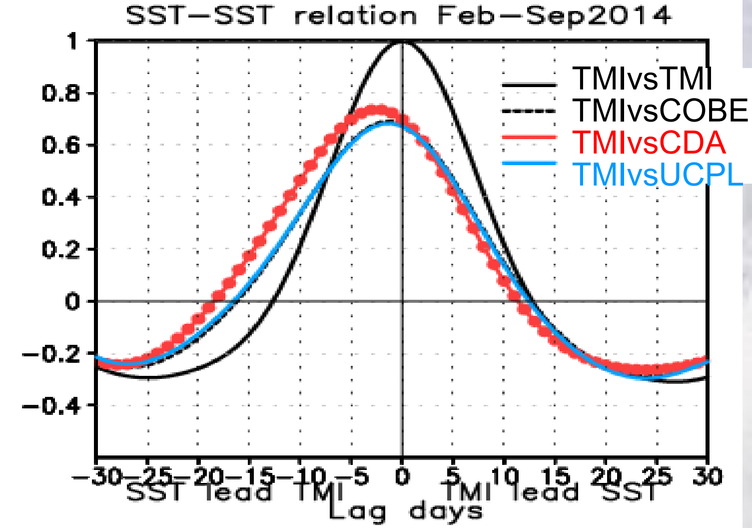
CDA

UCPL




Lagged correlation coef. of SST against SST observed by TRMM Microwave Imager (TMI)




- ✓ The westward propagation of anomaly in the eastern equatorial Pacific is well seen in CDA, but not clear in UCPL.
- ✓ More consistent with the atmospheric fields?

- ✓ The Maximum correlation coef. of CDA is higher than that of COBE and UCPL although a lag exists for CDA.
- ✓ CDA may reasonably reproduce high frequency variability of SST.

# ☆ Forecast experiments with CDA

**Experiments**

**EXP-CDA**: CDA initial conditions

**EXP-CTRL**: JRA-55 (atmosphere, land), MOVE/MRI.COM-G2(ocean, sea-ice) (the same as the JMA's operation)

**Period**

2013/11/17-2016/01/01 (85 cases)

**Model**

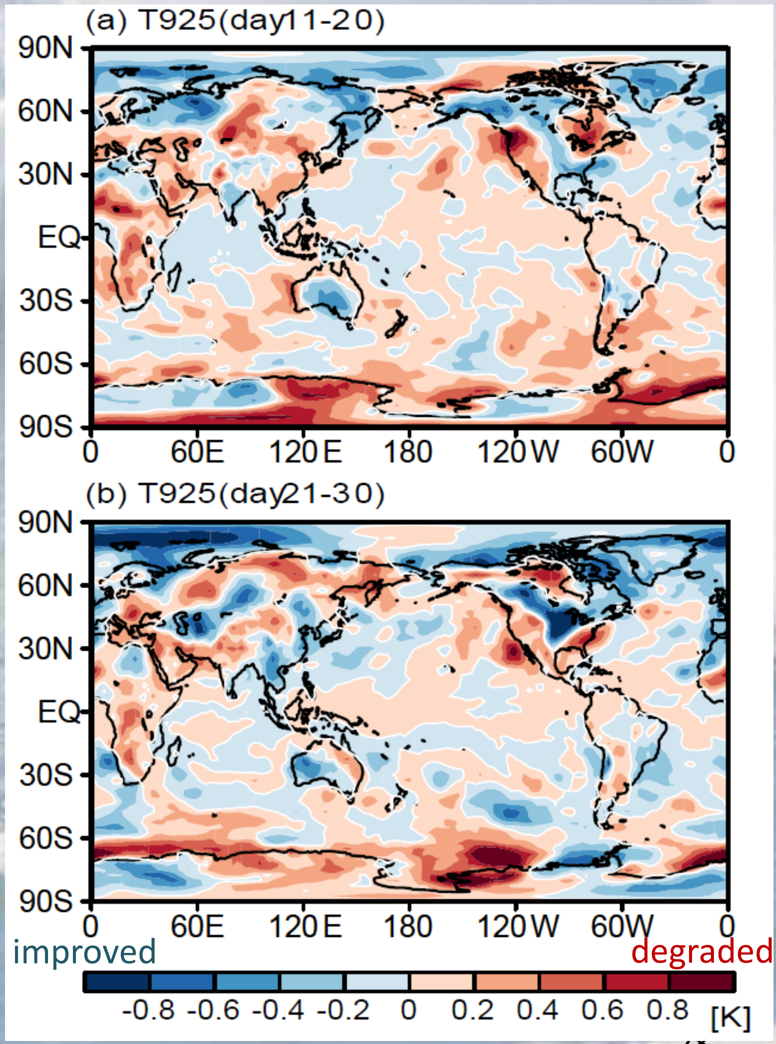
JMA's operational coupled model for SF

**Verification data**

JRA-55 analysis

- Prediction score of temperature in the lower troposphere is improved by CDA in the arctic region.
- Sea ice estimation in CDA may have some impacts on 10-to-30-day predictions

**Differences of mean absolute errors (T925, EXP-CDA – EXP-CTRL)**



# Other possible developments for improving SST fields in ocean DA systems

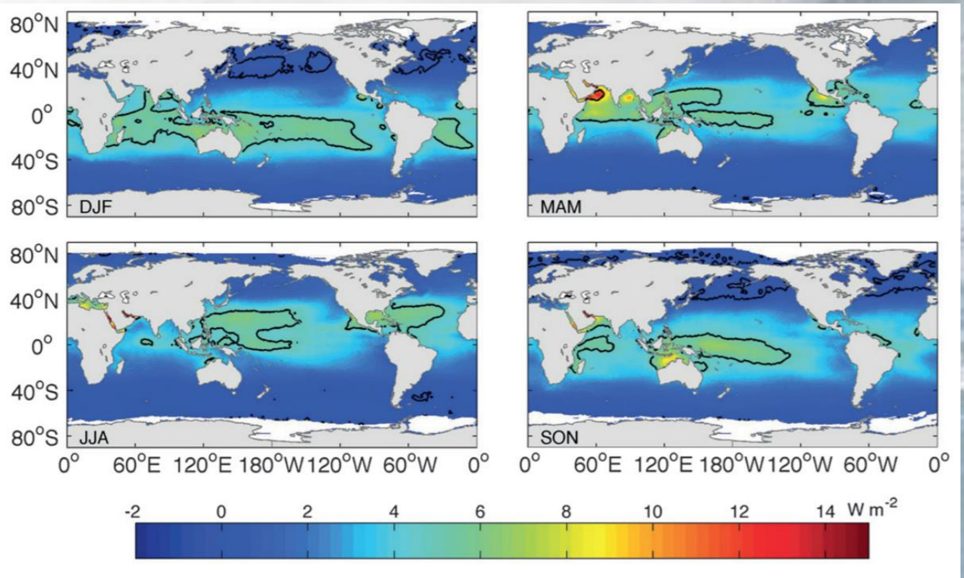
# ☆ Other possible direction for improving SST field

## ◆ Improve assimilation of SST data in ocean/coupled DA systems

- ✓ Direct assimilation of satellite SST data without performing objective analysis
- ✓ Modification of sea surface fluxes through an adjoint method
  (Since SST is strongly affected by sea surface flux, they must be consistently modified.)
- ✓ Develop SST assimilation scheme with consideration of air-sea coupling in coupled DA
- ✓ Consider Ocean Surface wave effects

## ◆ Reproduce diurnal cycles of SST in an ocean DA system.

- ✓ Modeling of diurnal cycle in an ocean model (Skin SST scheme)
- ✓ Improve the SST assimilation scheme with consideration of diurnal cycles




Seasonal average of the total heat flux errors when diurnally cycles are not considered. (Clayson and Bogdanoff,2013)

- ➢ The errors are larger than 5 W even for seasonal average. Thus, considering diurnal cycle of SST is important for climate predictions.


Thank you