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Meteorological Research Institute

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Improvement of SST analysis and near sea-surface atmospheric predictions in the coupled atmosphere-ocean data assimilation system in JMA/MRI

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1. Introduction

Development of Coupled DA with Ocean and Atmospheric 4DVAR systems

Why coupled DA?

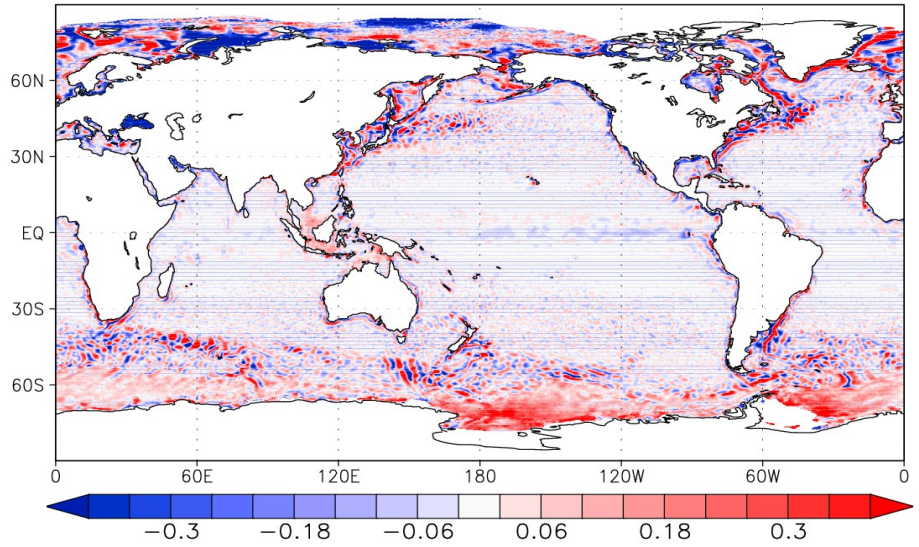
- CDA may represent atmosphere and ocean interaction more realistically, which may result in improved forecasts

  (e.g., SST-Precipitation relationship, development of tropical cyclones, MJO, etc.)

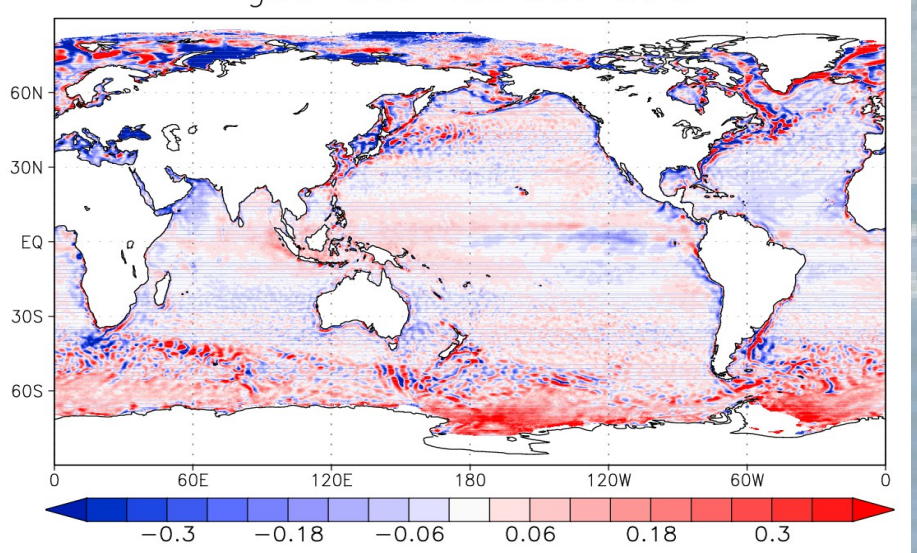
Why oceanic 4DVAR?

- 4DVAR reduces the absolute bias and RMSE of SST in the large part of the ocean (Fujii et al. 2022).
- We expect the better SST field by 4DVAR will improve the performance of the coupled DA system

SST Bias (4DVAR)



SST Bias (3DVAR)



SST bias of 4DVAR and 3DVAR version of the current JMA's operational global ocean DA system. (Fujii et al. 2022)

Configuration of the MRI coupled data assimilation system version 2 (MRI-CDA2)

Overview

- Coupled atmosphere-ocean NWP system developed based on three JMA operational systems.

Coupled Atmosphere-Ocean Model

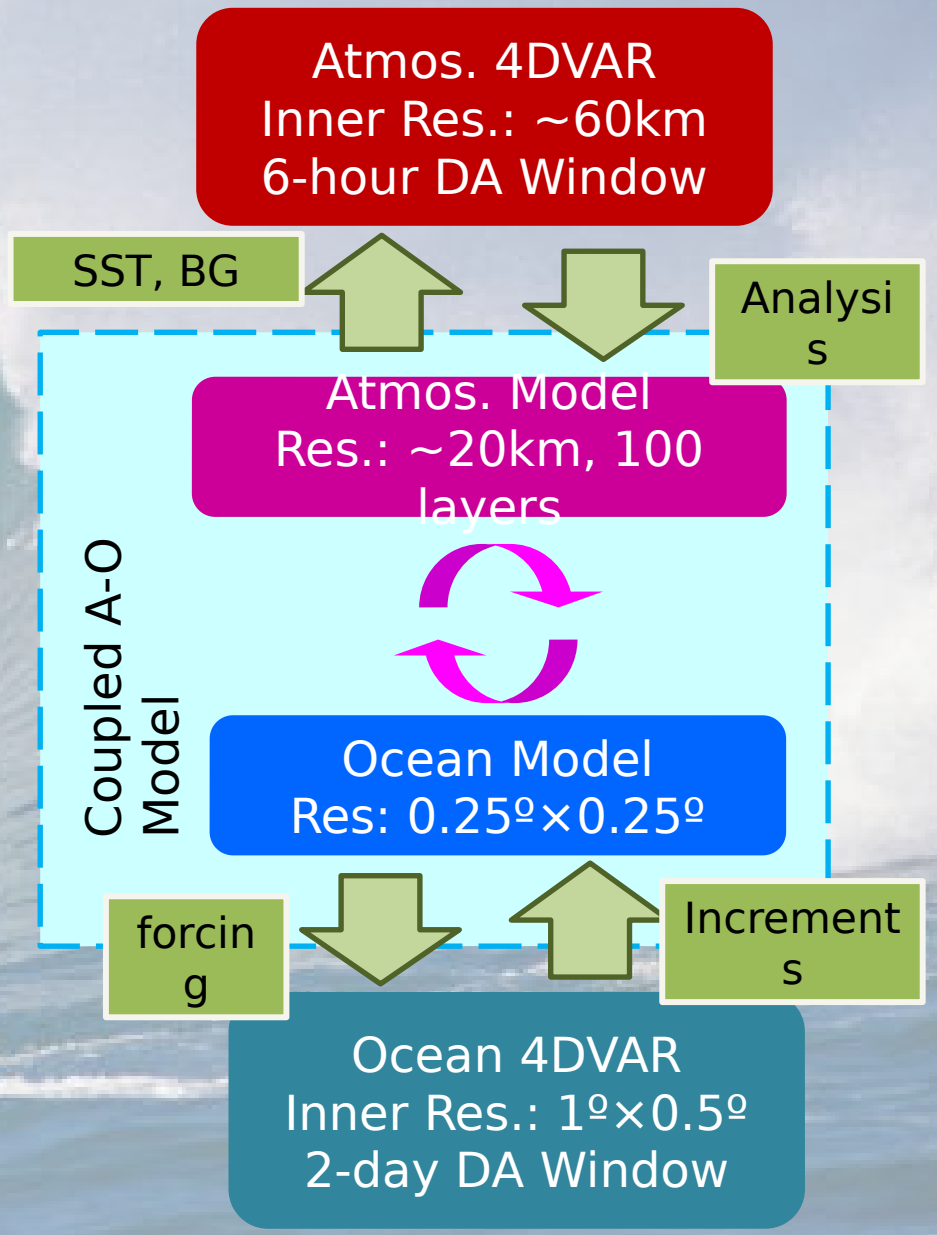
- JMA Global NWP Model + JMA Global Ocean Model.
- **Resolution:** Atmos.: 20 km, 100 layers/ Ocean: 0.25°.

Atmospheric DA

- Method: 4D-Var (Inner Res.: ~60km).
- DA Window: 6 hours.

Oceanic DA

- Method: 4D-Var (Inner Res.: 1º×0.5º)
- DA Window: 2 days



System Flow of MRI-CDA2



- Although DA window of DA-ocean is 2 days, it assimilates only ocean observations in the 2nd day.
- DA-ocean adjust TS in the first day by the analysis increment estimated by 4DVAR
- DA-atm is performed twice before and after ocean DA.

  (Ocean Inc. are applied to the second DA-atm runs.)

Quasi-strongly coupled DA?

Experimental Setting

- **TEST**

  Numerical weather prediction experiments using MRI-CDA2 (analysis and forecast).

- **CNTL**

  Numerical weather prediction experiments using the original JMA's NWP system (without coupled DA).

- **Experimental Period**

  May 26, 2020 – July 11, 2020

- **Evaluation Period**

  June 11, 2020 – July 11, 2020

  (First 16 days are considered as the spin-up period)

- **Regions**

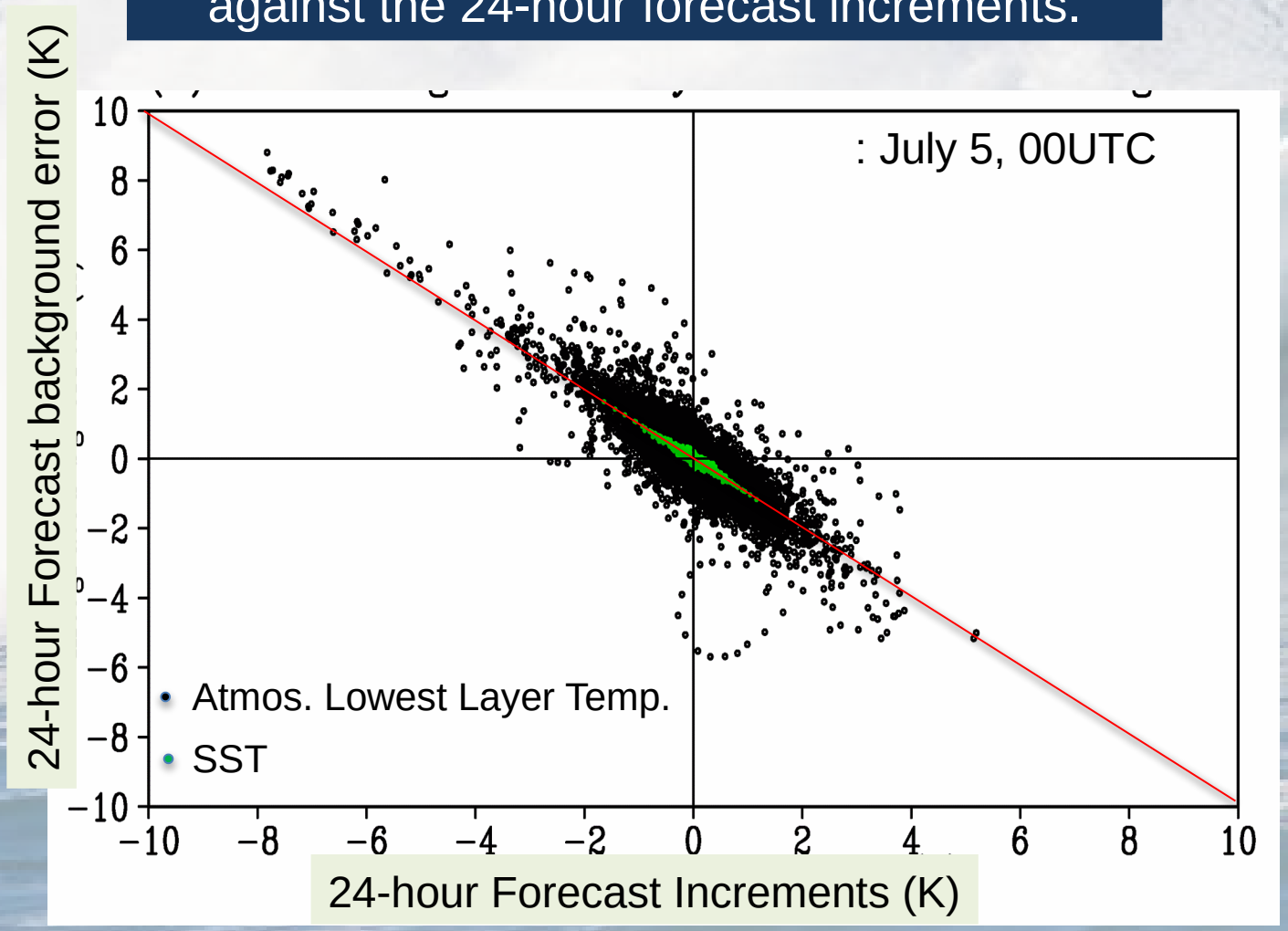
  SH: 90ºS-20ºS, Tropics: 20ºS-20ºN, NH: 20ºN-90ºN



2. Results

Consistency of the background errors and analysis increments of coupled DA

Plot of the 24-hour forecast background errors against the 24-hour forecast increments.



- 24-hour forecast increments:

  -

  Change of 24-hour forecast caused by the analyses between and which includes atmospheric analyses (and , and oceanic analysis for the day between and .)

- 24-hour forecast background errors:

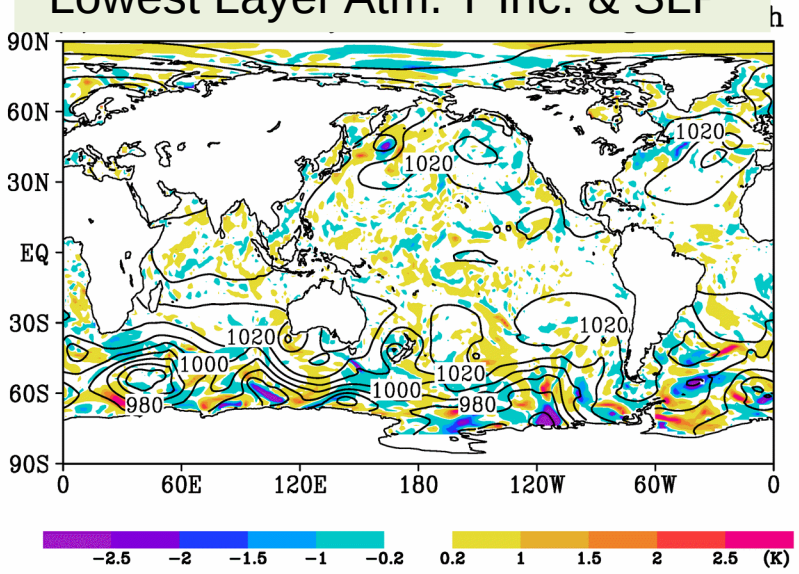
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  Errors of the forecast without the analyses between and .

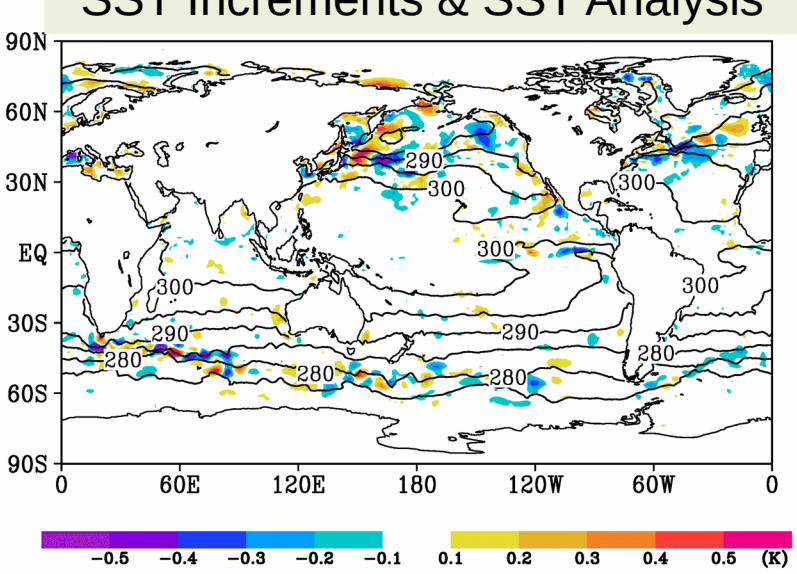
- The negative correlation of the forecast background errors and increments indicates that the errors were generally reduced by the analyses.

Global Distribution of 24-hour forecast increments of SST at 00UTC, July 5

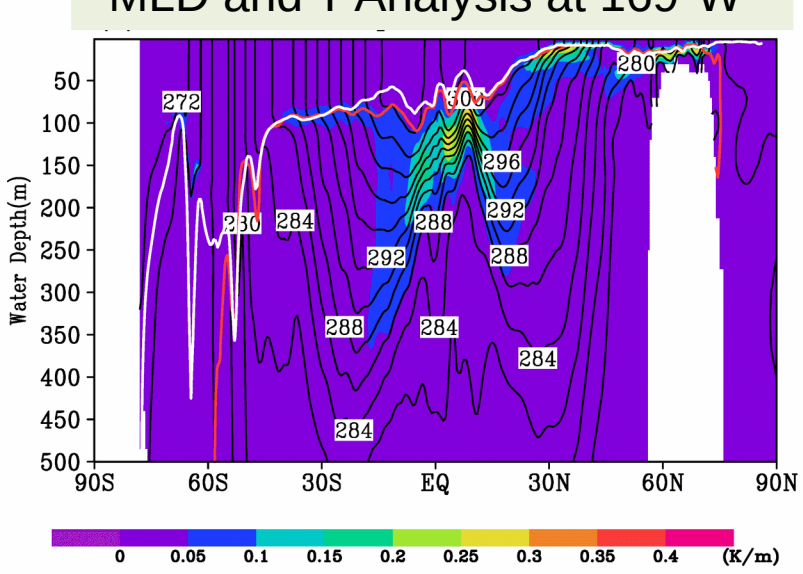
Lowest Layer Atm. T Inc. & SLP



SST Increments & SST Analysis



MLD and T Analysis at 169ºW

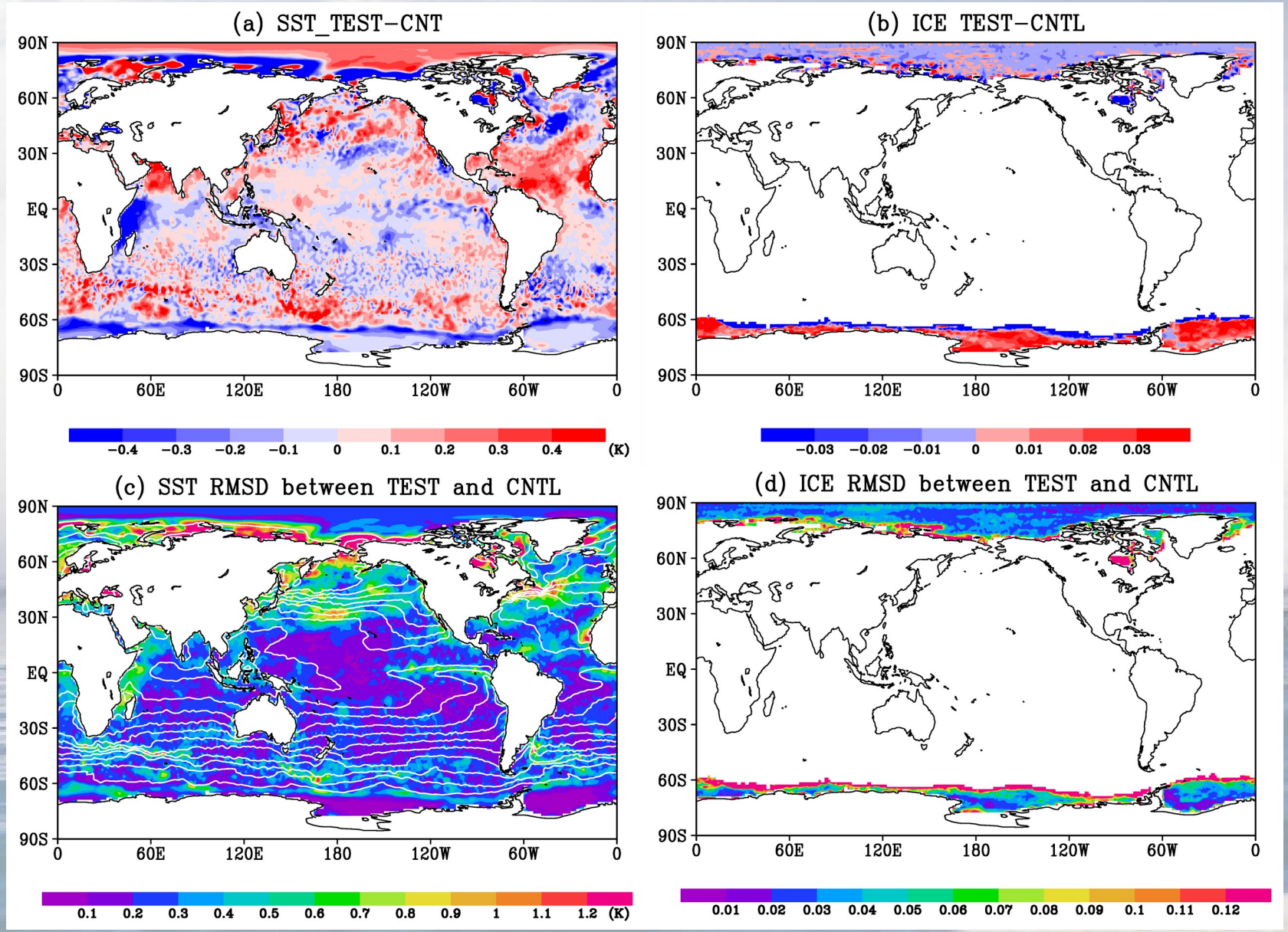


- The atmospheric temperature increments are larger in the Antarctic Circumpolar Current regions than in the Western Boundary Current (WBC) Regions (Kuroshio, and the Gulf Stream) in the summer hemisphere (NH).
- In contrast, SST increments are large in the WBC regions in the summer hemisphere (NH), where the oceanic mixed layer is shallow, and the horizontal SST gradient is large.
- The SST increments are not significant around the tropics or in the winter hemisphere (SH) due to the deep mixed layer.

Impacts of Coupling on SST and Sea Ice Concentration

- **SST Changes:**
  - NH: Large changes are found in the WBC regions and near the sea ice edge.
  - SH: Small-scale changes are prominent around ACC.
  - Changes are generally larger in NH (the summer hemisphere)

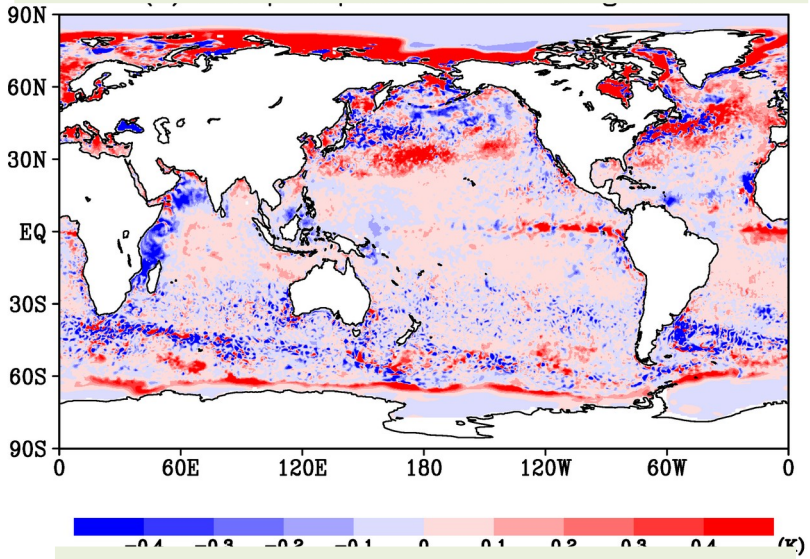
- **Sea Ice Concentration:**
  - Decreases in the Arctic region, while increases in the Southern Ocean. (reflecting the model bias?)



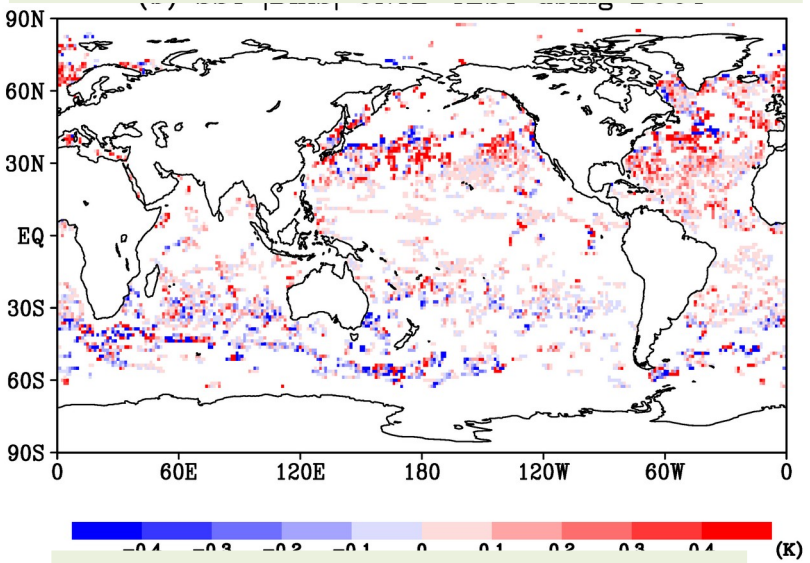
Improved consistency of SST analysis due to the coupled DA

- SST for TEST is JMA's objective SST map, MGDSST, which is used for the lower boundary condition of the uncoupled atmospheric model.
- RMSDs from OSTIA are reduced in the northern boundaries of the subtropics in NH, near the equator, and near the sea ice edge.
- Smaller features are dominant around the WBCs and ACC.
- RMSDs from drifters are generally reduced, and particularly in the northern part of the subtropics in NH.

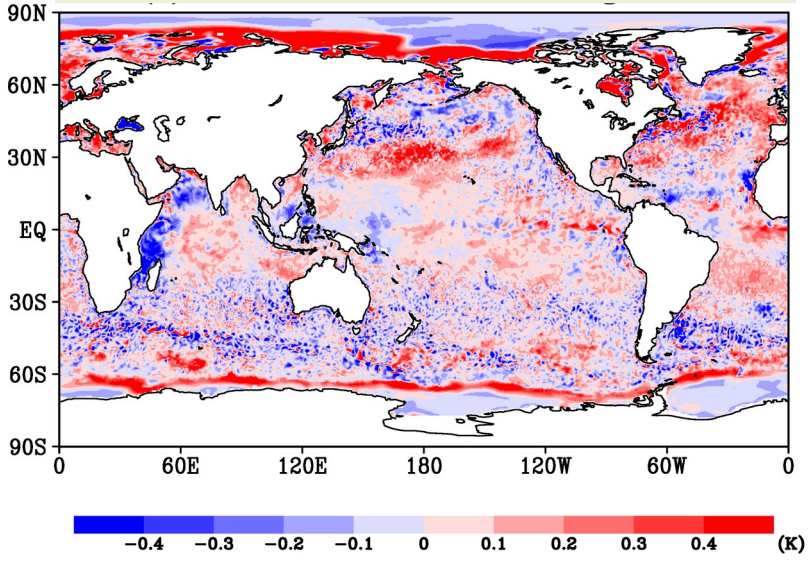
Reduction of Absolute bias from OSTIA (CNTL-TEST)



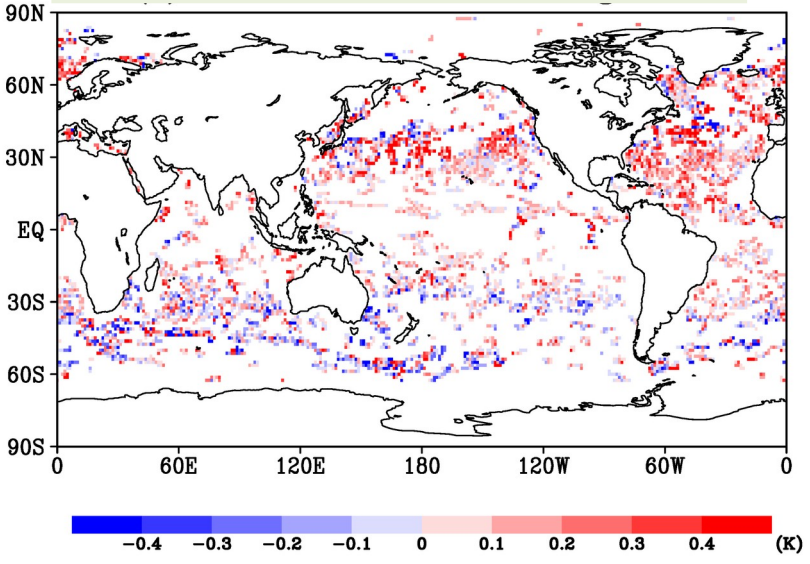
Reduction of absolute bias from drifters (CNTL-TEST)



Reduction of RMSD from OSTIA (CNTL-TEST)

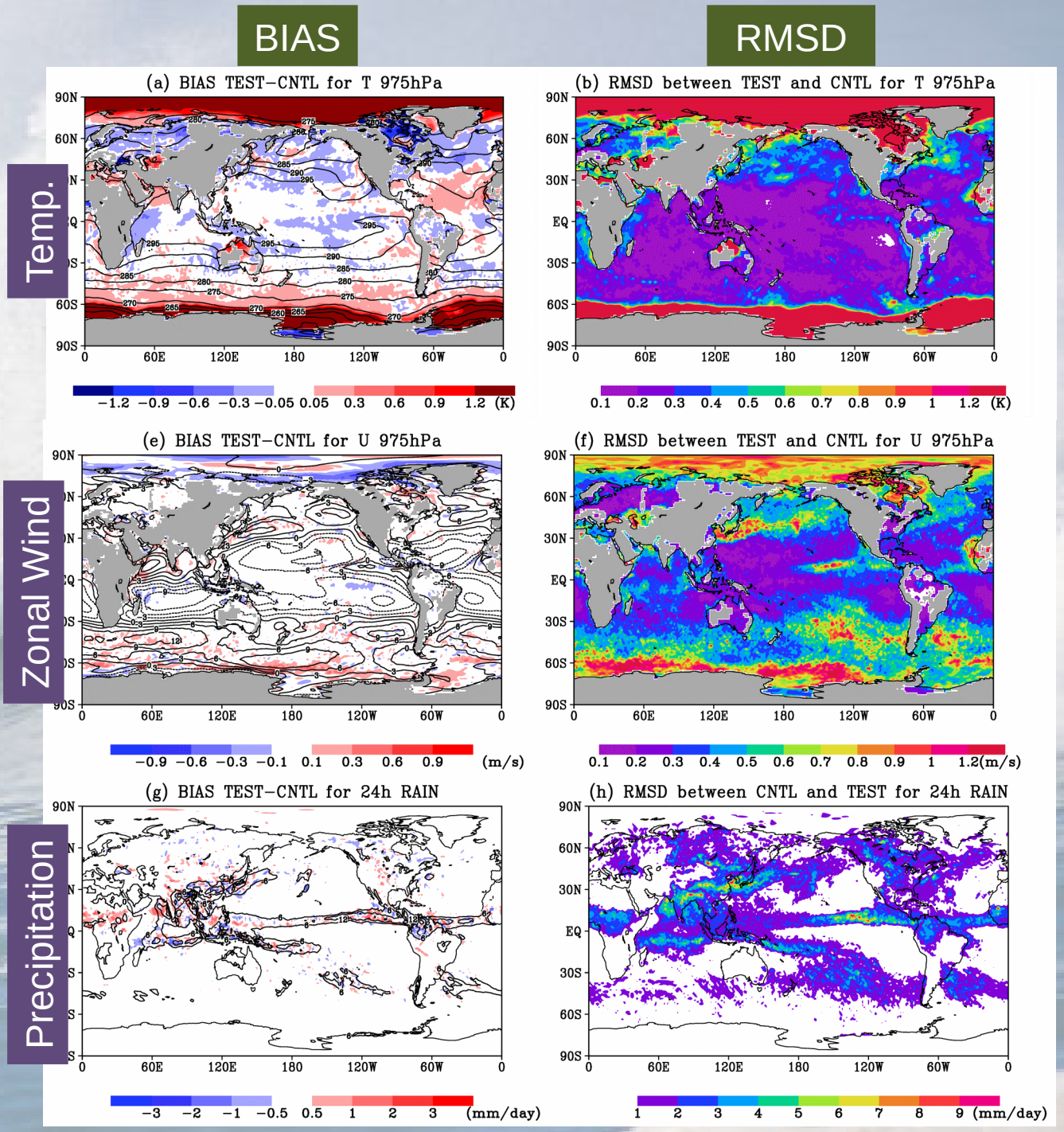


Reduction of RMSD from drifters (CNTL-TEST)



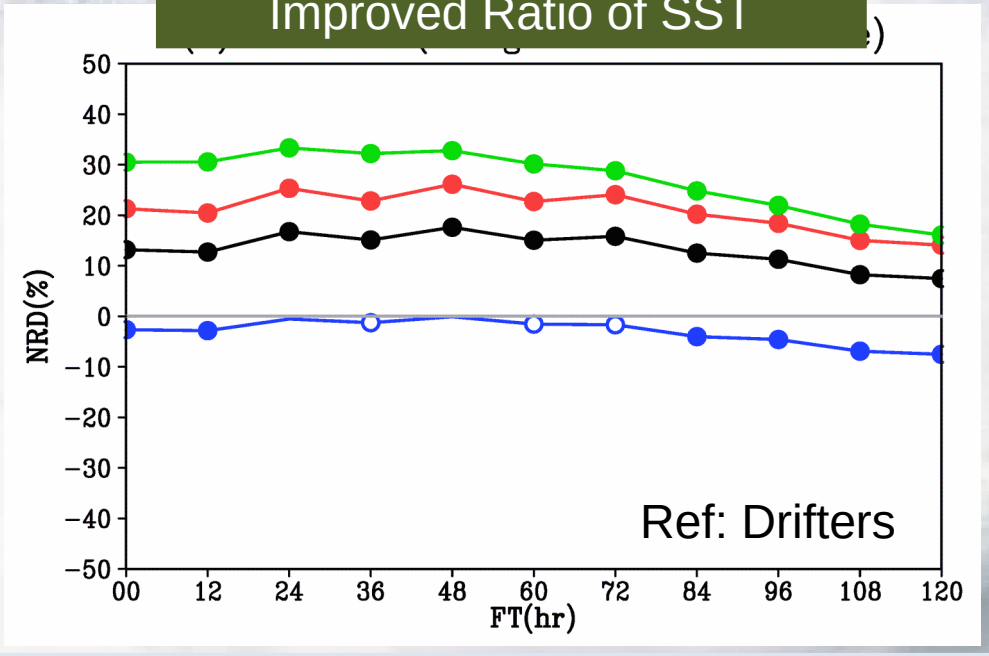
Impacts of the coupled DA on atmospheric variables at 975hPa

- The Coupled DA increases the temperature over the sea ice areas, which is not consistent with the SST and SIC changes in SH.
- Temperature changes consistently with SST in the Noarth Atlantic, the equatorial Pacific, and around ACC, but not in the North Pacific Subarctic region.
- Zonal winds are strengthened in the Baiu frontal zone and around the Antarctica.
- Although there are relatively large RMSDs of precipitation in the ITCZ, SPCZ, the monsoon and Baiu frontal zones, the average of precipitation is only slightly increased in those region.

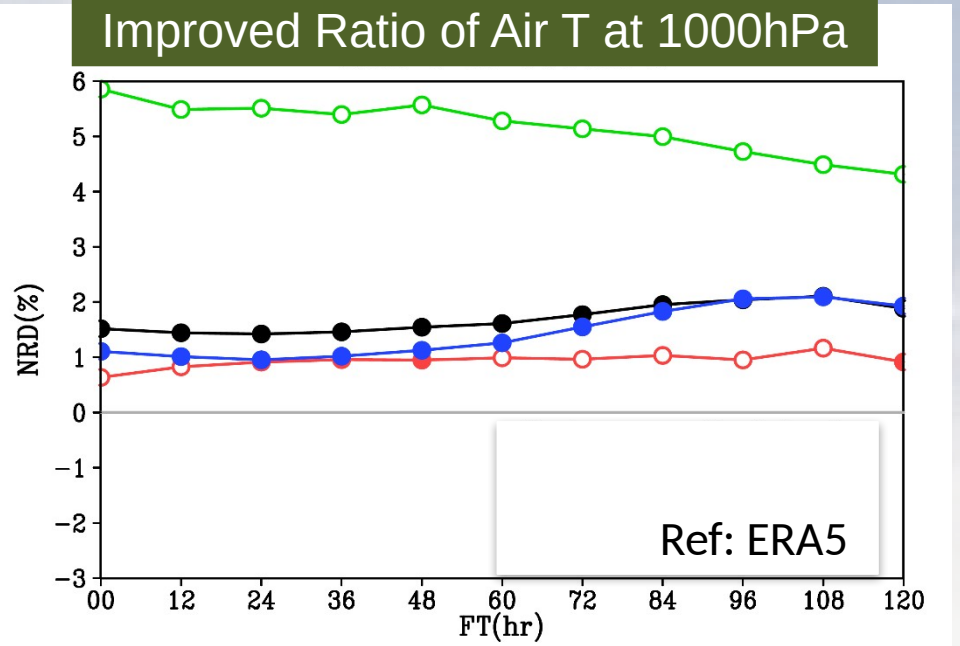


Impacts on the forecasts of SST and Air Temperature at 1000hPa

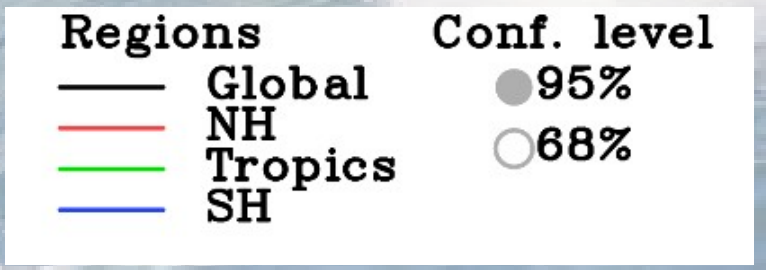
Improved Ratio of SST



Improved Ratio of Air T at 1000hPa

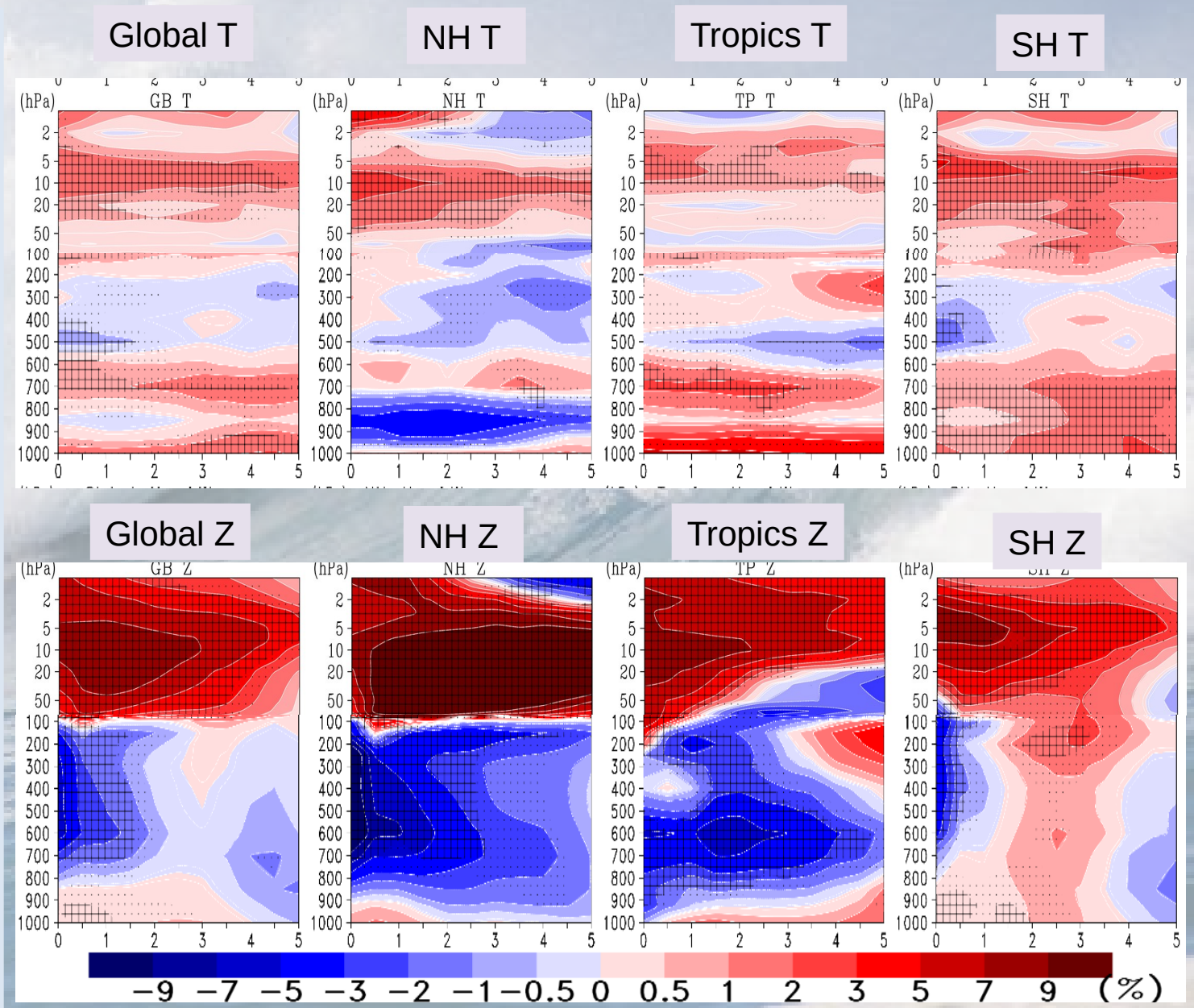


- Improvements of 0-5-day forecasts of global SST and 1000hPa T are significant at 95% confidence level.
- SST forecasts are significantly improved in Tropics and NH, but are neutral in SH.
- 1000hPa T forecasts are significantly improved for SH with all lead times and NH with 24-48-hour lead times.
- In the tropics, the ratio of improvements for 1000hPa T is relatively large (~ 5%) although they are not significant.



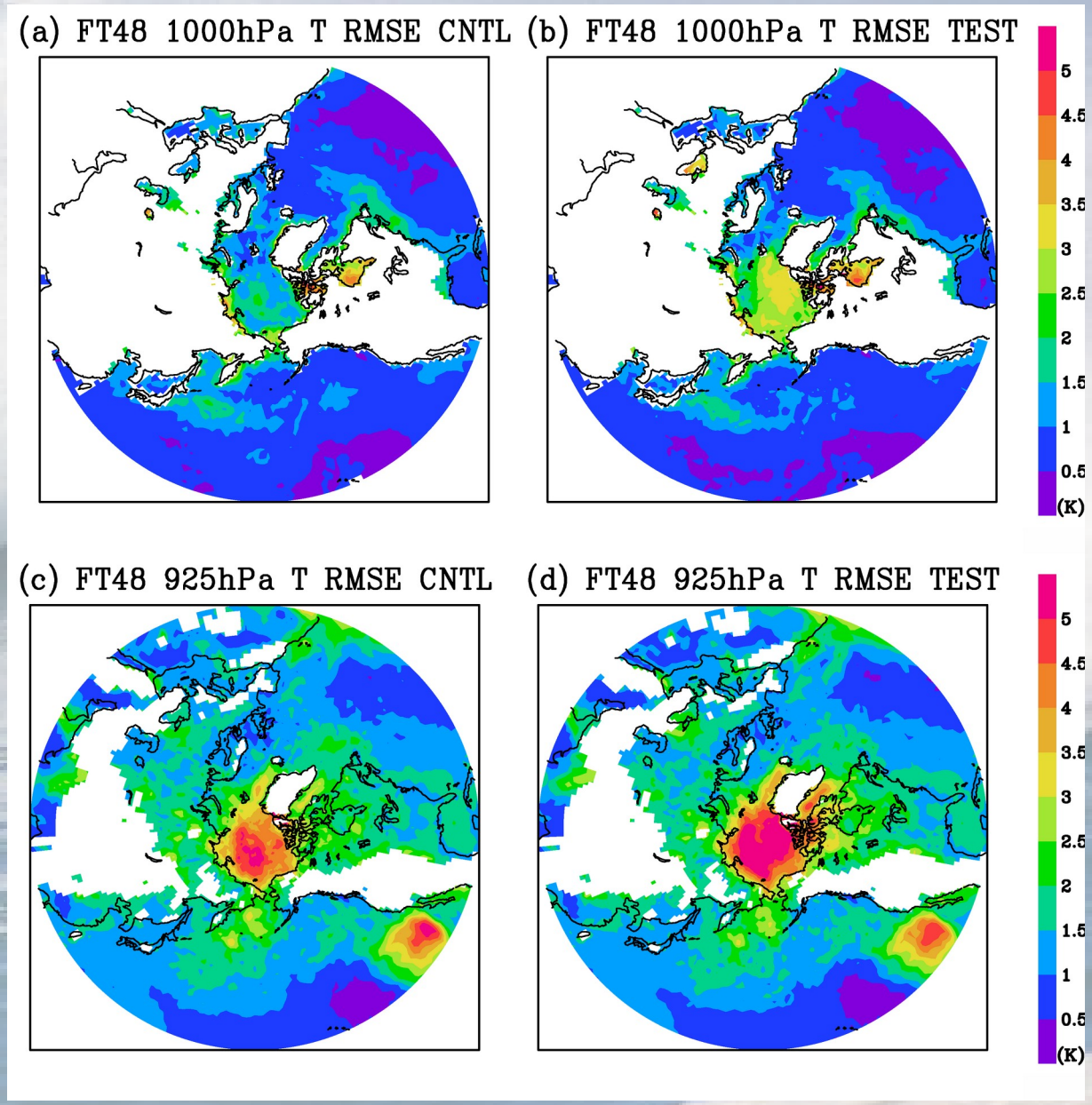
Impacts of coupled DA on the atmospheric T and geopotential height forecasts

- Vertical axis: pressure (1-1000 hPa))
  Horizontal axis: lead time (0-5 days)
- Near surface temperature forecasts are improved in all regions.
- Temperature forecasts are generally improved from the surface to the top in the tropics and SH.
- Temperature forecasts improved near the surface and in the stratosphere, but degraded in the mid and upper troposphere in NH.
- Geopotential height forecasts are also degraded in the mid and upper troposphere in NH and the tropics because the barotropic mode response to the SST change improves them in the stratosphere, but intensifies the original model bias at the mid and upper troposphere



Forecast Degradation in the Arctic Region

- The degradation in the NH was primarily located over the Arctic sea ice region.
- Warmer SST in the coupled DA analysis fields intensified the warm bias of the atmospheric model.
- Improvements of the sea-ice, ocean, and atmosphere model is a future challenge.
  - ✓ Improvements of the sea-ice and ocean models and data assimilation.
  - ✓ Better utilization of observations over sea ice.
  - ✓ Better use of sea ice information (e.g., sea ice thickness) in the atmospheric model
  - ✓ Tuning of the atmospheric model for the coupled DA.



Summary and Future Plan

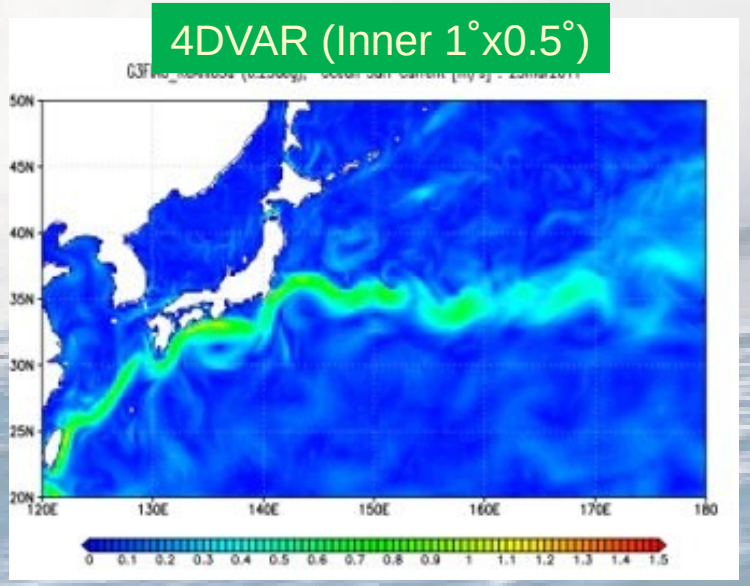
Summary

- **System Development & Evaluation**:
  - Developed a coupled atmosphere-ocean NWP system (MRI-CDA2) for joint state estimation and forecasting, and evaluated its operational accuracy.
  - Built by extending JMA's operational systems, enabling a direct performance comparison against the uncoupled operational baseline.
- **Impacts on SST Analysis**:
  - Consistency with independent SST products (OSTIA and Drifter data) is improved in the NH and Tropics, but showed a degradation trend in the SH.
- **Impacts on Atmospheric Forecasts**:
  - Forecast accuracy improved globally, particularly for lower-tropospheric temperature.
  - Improvements were also observed in the stratosphere, whereas degradation was found in the mid and upper tropospheric geopotential height fields.
- **Identified Challenges**:
  - The temperature degradation in the NH (except the lowest layer) was primarily located over the Arctic sea ice region, indicating a need for improved sea ice treatments.

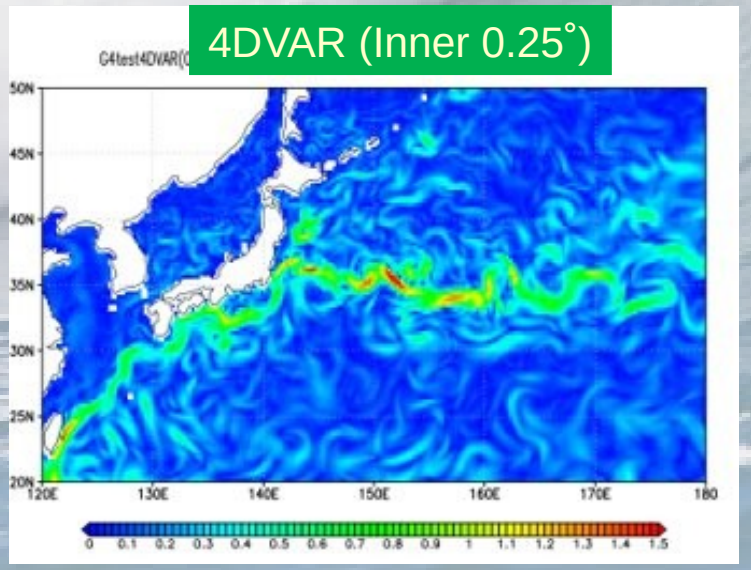
Future Plan

- Improvement of the sea ice treatment
- Estimation of SST in the atmospheric 4DVAR (coupled atmosphere-SST analysis, in which more satellite radiation channels can be used.)
- Introducing a higher-resolution (1/4^{o}) inner model in the ocean 4DVAR
- Improving SST data assimilation in the oceanic 4DVAR
  (Assimilation of L2/L3 data. Incorporation of the warm layer & cool skin scheme.)

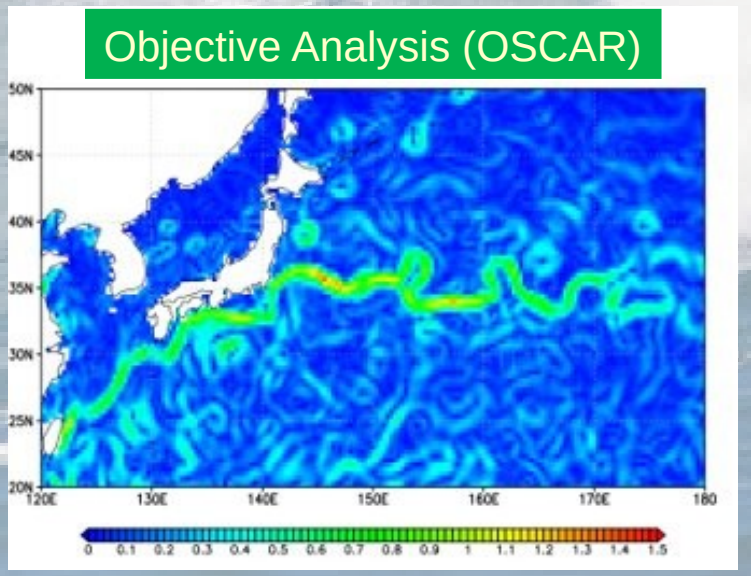
4DVAR (Inner 1˚x0.5˚)



4DVAR (Inner 0.25˚)



Objective Analysis (OSCAR)



Test of the 4DVAR with the 0.25˚ inner model. Showing the current speed at the surface on 21 Mar. 2011.


THANK YOU