Assessing the feasibility for Atmosphere-Ocean Coupling of JMA's Global Ensemble Prediction System

TAKAKURA Toshinari[1,*], OCHI Kenta[1,2], ADACHI Yukimasa[3] and KOMORI Takuya[1]

1:Numerical Prediction Division, Japan Meteorological Agency, 2:European Centre for Medium-Range Weather Forecasts, 3:Meteorological Research Institute, Japan Meteorological Agency

E-mail: t-takakura@met.kishou.go.jp

1. Introduction

- ✓ The Japan Meteorological Agency (JMA) operates the Global Ensemble Prediction System (GEPS) to support medium- and extended-range forecasts with a two-tiered sea surface temperature (SST) approach (Takakura and Komori 2020) for lower boundary conditions.
- ✓ Two-tiered SST approach indirectly represents atmosphere-ocean interaction by combining SSTs prescribed as persisting anomalies from climatological SSTs and SSTs operationally precomputed using JMA's seasonal EPS.
- ✓ Several previous studies have reported examples of improved short- to medium-term forecasts from atmosphere-ocean coupling (e.g., Mogensen et al. 2017b).
- ■ In this study, feasibility for atmosphere-ocean coupling of GEPS (CplGEPS) was assessed toward the incorporation of more directly representative atmosphere-ocean interaction.

2. Experimental design and data

- ✓ Two reforecast-type experiments of the GEPS were conducted.

Table.1: Configurations of each reforecast-type experiment in the GEPS.

	GEPS	CplGEPS
Atmospheric general circulation Model (AGCM)	**Model:** GSM2103 with improved physical processes (Yamaguchi et al. 2022) **Resolution:** TQ479L128 (approx. 27 km)	
Oceanic general circulation model (OGCM)	N/A	**Model:** MRI.COM (Tsujino et al. 2017) **Resolution:** 0.25° x0.25° L60
Initial conditions	**Atmosphere:** JRA-3Q (Kobayashi et al. 2021) **Land:** Offline model runs (forced by JRA-3Q)	**Atmosphere:** JRA-3Q **Ocean:** MOVE/MRI.COM-G3 (Low-res. 4DVAR + High res. downscaling) **Land:** Offline model runs (forced by JRA-3Q)
Boundary conditions	**SST:** Two-tiered SST (Relaxation in the tropics and subtropics after 6 days from anomaly-fixed SST to bias-corrected ensemble mean SST of the seasonal EPS) **Sea ice:** Prescribed sea-ice concentration (using persisting anomaly with daily climatological sea ice concentration)	**SST**: Full coupling in the tropics and tendency coupling in the extratropics **Sea ice:** No coupling (Prescribed sea ice concentration) See below table for details
Initial perturbation	Singular vector (SV) method (initial and evolved SVs)	
Model ensemble	Stochastically Perturbed Physics Tendency (SPPT)	
Boundary perturbations	SST Perturbations (Hotta and Ota 2019)	ocean analysis perturbation
Ensemble size	5	
Forecast time	432 hours (18days)	
Initial dates	1/31, 2/25, 3/27, 4/26, 5/31, 6/30, 7/30, 8/29, 9/28, 10/28, 11/27, 12/27 from 1991 to 2020	

For reducing initial shocks

- ✓ The use of lower boundary conditions that are different from those used to create the initial atmospheric conditions cause initial shocks in the forecast.
- ✓ In CplGEPS, sea-ice coupling was switched off to reduce the initial shocks. Furthermore, tendency coupling (e.g., Mogensen et al. 2017a) was applied to SSTs at mid- and high latitudes in CplGEPS up to 5.5 days and linear relaxation to full coupling was applied from 5.5 to 11 days by adding the tendency of the SST in the ocean model to SST analysis values.

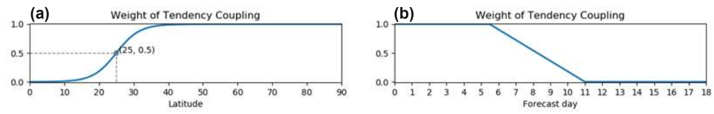

Fig.1: Weight of tendency coupling (a) in latitude and (b) in forecast time for CplGEPS. A weight of 1(0) means that it is absolutely tendency(full) coupling.

- ■ **An example of the deterioration of forecast accuracy in the early stages of forecast due to initial shocks.**

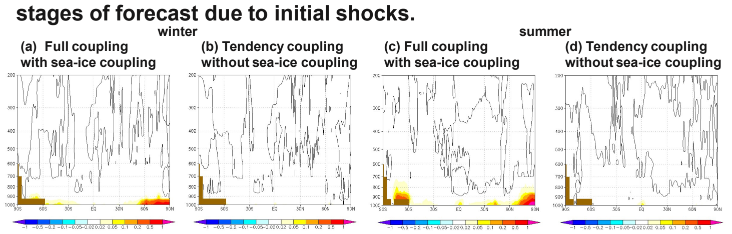

Fig.2: Root mean square error (RMSE) differences from uncoupled experiment against JMA's global analysis in zonal mean temperature (K) at lead times of 24 h in retrospective forecast experiments for (a), (b) winter 2019/20 and (c), (d) summer 2020. (a), (c) are full coupling with sea-ice coupling minus uncoupling and (b), (d) are tendency coupling without sea-ice coupling minus uncoupling. Black lines indicate a zero RMSE difference.

Verification data

- ✓ Atmosphere analysis data: JRA-3Q (Kobayashi et al. 2021)
- ✓ SST analysis data: MGDSST (Kurihara et al. 2006)
- ✓ Precipitation data: Global Precipitation Climatology Project (GPCP: Huffman et al. 2001)

Summary

Reforecast-type experiment of the GEPS with atmosphere-ocean coupling has been conducted.

- ● Tendency coupling for SSTs mainly up to 5.5 days and sea-ice uncoupling was applied to mitigate initial shocks.
- ● Atmosphere-ocean coupling has improved the accuracy of atmospheric predictions in many respects.
  - Improvements were seen in basic scores, MJO forecast and SST-precipitation relationship.
- ■ **Future challenges:** Improve SST predictions, Coupled assimilation for reducing initial shocks, Optimization SST spreads, GPU acceleration of OGCM

3. Result

Score of SST prediction

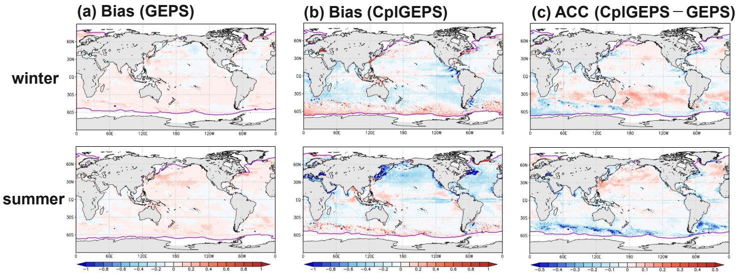

Fig.3: (a),(b) Bias and (c) anomaly correlation coefficient (ACC) differences of ensemble-mean SST over week 1.5 against MGDSST in (upper panels) winter and (lower panels) summer. Areas of sea-ice presence are masked, with purple lines indicating mask boundaries.

- ✓ The cold SST bias was widely seen in CplGEPS (consistent with Seasonal EPS).
- ✓ While the ACC improved mainly in the summer hemisphere, it deteriorated near the ocean currents (probably due to lack of horizontal resolution in OGCM).

Correlation of SST and precipitation

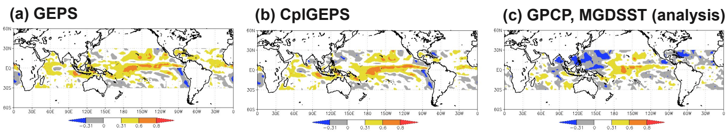

Fig.4: Correlation of SST and precipitation over week 1 on 29 August: (a) GEPS, (b) CplGEPS and (c) GPCP and MGDSST.

- ✓ The correlation of SST and precipitation was closer to that of analysis mainly in the Asian monsoon region (alothough there is still room for improvement).
- ✓ This result demonstrates, the relationship between SST and precipitation was improved by the incorporation of more directly representative atmosphere-ocean interaction.

MJO (Madden-Julian Oscillation) forecast

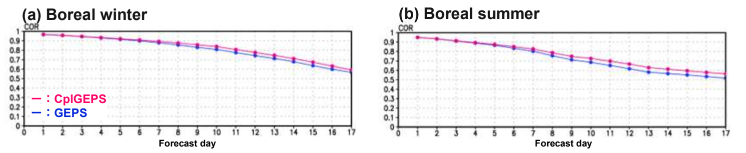

Fig.5: Correlation of MJO index (Matsueda and Endo 2011) at initial date in (a) boreal winter (from November to April) and (b) boreal summer (from May to September). Red line is CplGEPS and blue line is GEPS.

- ✓ CplGEPS outperformed GEPS in the MJO forecast.

Scores of upper and lower atmosphere

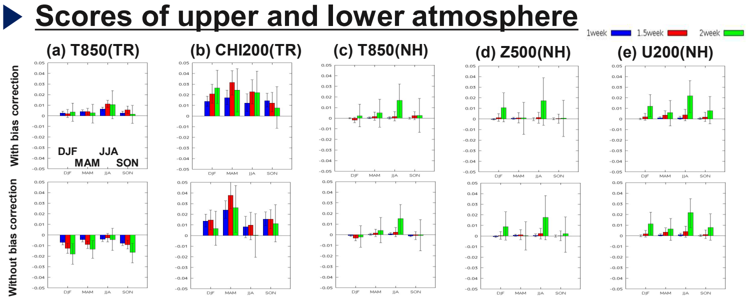

Fig.6: Anomaly correlation coefficient (ACC) differences (top) with bias correction and (bottom) without bias correction for winter (DJF), spring (MAM), autumn (SON) and summer (JJA). (a) and (b) are in the tropics (TR; 20° S－20° N), and (c), (d) and (e) are in the northern hemisphere (NH; 20－90° N). Each figure shows (a), (c) 850-hPa temperature, (b) 200-hPa velocity potential (d) 500-hPa height and (e) 200-hPa zonal wind. Positive values represent ACCs of CplGEPS exceeding those of GEPS. Error bars indicate two-sided 95% confidence levels.

- ✓ The bias-corrected ACCs of CplGEPS were superior to those of GEPS for many atmospheric scores in the hindcast experiments.
- ✓ ACC without bias correction also shows better scores except for 850 hPa temperatures in the tropics, where there is an influence from the SST bias of CplGEPS.