Recent Activities and Future Challenges of JMA's Sub-seasonal to Seasonal Prediction System

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- Operational seasonal forecasting systems have evolved to meet the increasing demand for seasonal forecast information
- International collaboration for Open Data and Near-real-time MME such as S2S*[1], WMO LRFMME*[2], C3S*[3] ...
- Latest system upgrade at JMA/MRI in 2022: JMA/MRI-CPS3
- Known issues and future challenges

*1 Vitart et al. 2017, *BAMS*
Kubo and Sumitomo 2023, *S2S News Lett. No. 22*

*2 https://wmolc.org/

*3 https://climate.copernicus.eu/

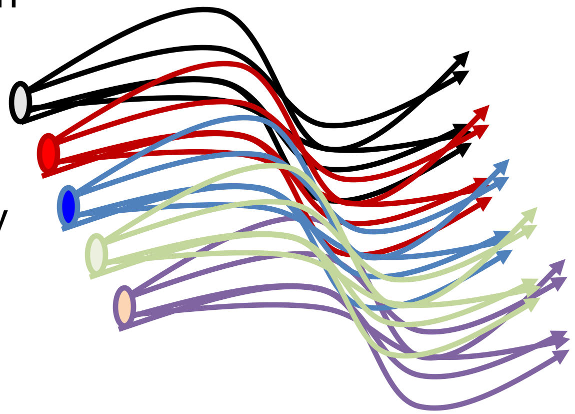
CPS3 and recent activities

Overview of the JMA/MRI-Coupled Prediction System(CPS)s

	Feb 2022 -	June 2015 –
	JMA/MRI-CPS3*1 (GSM2003C+MRI.COMv4.6*3)	**JMA/MRI-CPS2***2 (GSM1011C+MRI.COMv3.4*4)
Horizontal resolution	Atm. : 55km Ocean: 0.25 degrees	Atm. : 110km Ocean : 1.0×0.5-0.3 degrees
Vertical resolution	Atm. : 100 layers (top:0.01hPa) Ocean : 60 layers	Atm. : 60 layers (top : 0.1hPa) Ocean : 52layers+bottom boundary layer
Initial condition	Atm. : Global Analysis, JRA-3Q*5 Land : Offline simulation Ocean : MOVE-G3, 4DVAR(T,S,SSH) *7 Sea ice : MOVE-G3, 3DVAR (SIC)	Atm.: JRA-55*6 Land.: JRA-55 Ocean: MOVE-G2, 3DVAR (T,S,SSH)*8 Sea ice: -

5 members/day (25 members/5days)
240-day integration

00UTC 1st May
00UTC 2nd May
00UTC 3rd May
…



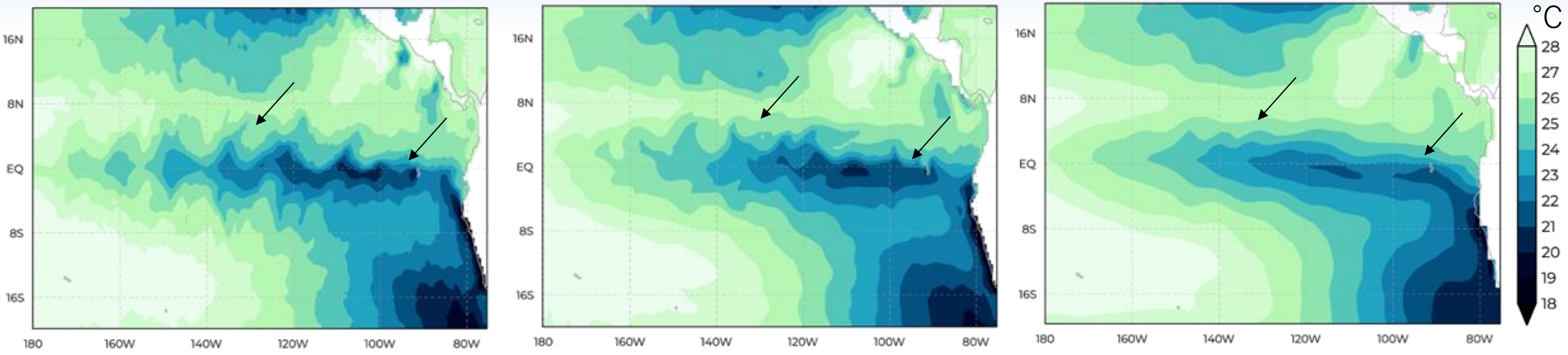
13 members/5days
240-day integration

00UTC 1st May
…
00UTC 6th May

*1 Hirahara et al. 2023, JMSJ
*2 Takaya et al. 2018, Clim. Dyn.
*3 Tsujino et al. 2017 MRI TR80
*4 MRI 2005, 2010 MRI TR47, TR59
*5 Kosaka et al. 2024 JMSJ EOR
*6 Kobayashi et al. 2015 JMSJ
*7 Fujii et al. 2023 Front. Clim.
*8 Toyoda et al. 2013 TAMJ

Improved reproducibility of the tropical ocean dynamics: Tropical Instability Waves (TIWs)

CCI SST (reference, 0.05°) | CPS3 (0.25°ocean) | CPS2 (1°×0.3-0.5°ocean)



5-day mean SST valid on December 22-26, 1999.
(CPS2 and CPS3 are 11th-15th day of prediction.)

- ✓ With higher ocean resolution, CPS3 better reproduces the fine-scale TIW features and, coastal and equatorial upwelling, such as off the coast of Peru and west of the Galapagos Islands
- ✓ TIWs are known to provide negative feedback to anomalous equatorial SST via meridional heat transport. The increased TIW-related variability help alleviate the CPS2's over-development bias for ENSO

Use of the 4DVAR ocean analysis for forecast initial conditions

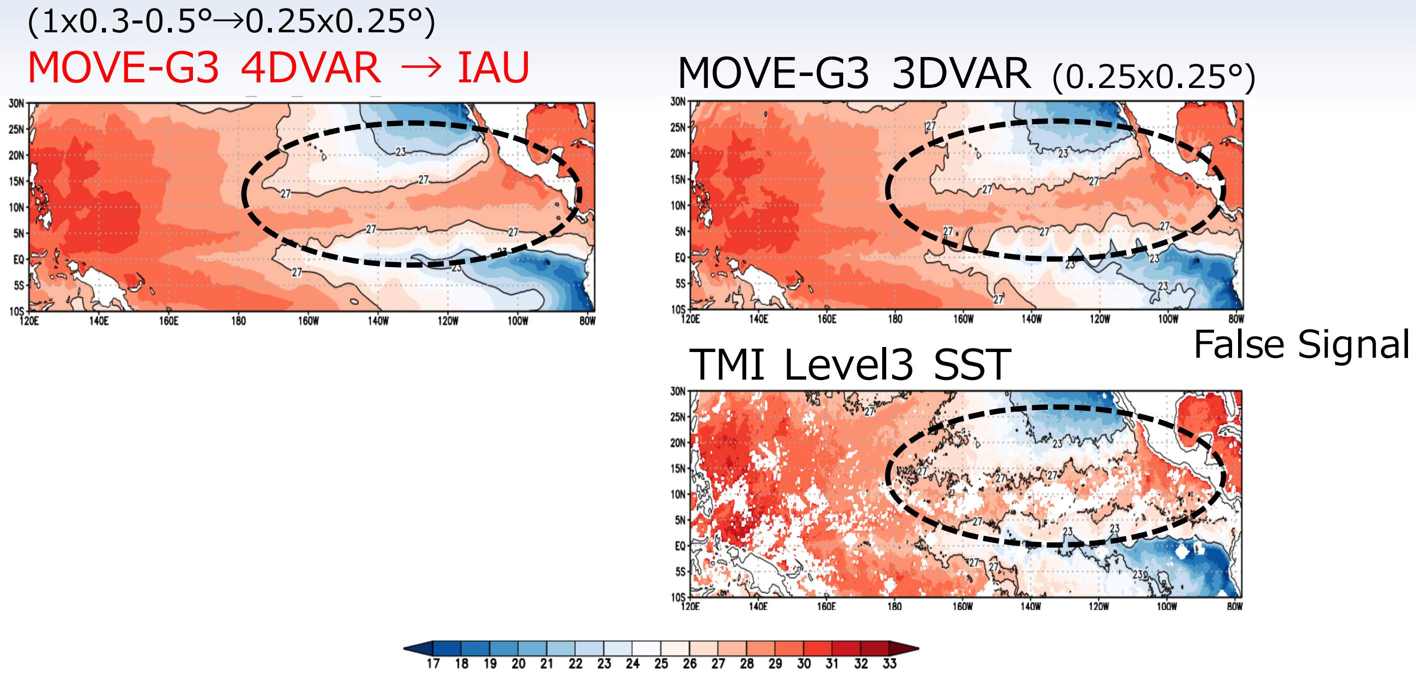
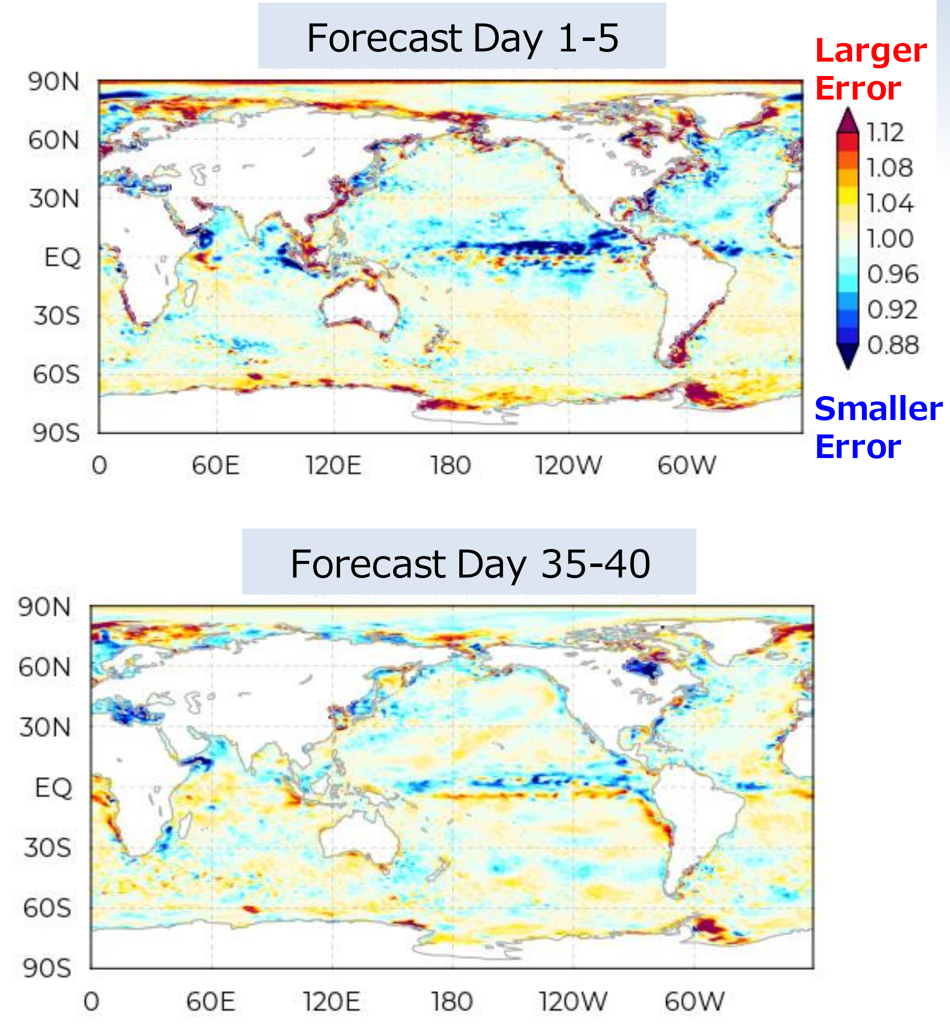


Fig Forecast initial SST in degrees Celsius at 30th July, 2010. For a reference, the bottom right panel shows 29Jul-31Jul average TRMM Microwave Imager (TMI) SST, which is not assimilated in any of the MOVEs.

SST Forecast RMSE Ratio (4DVAR/3DVAR)

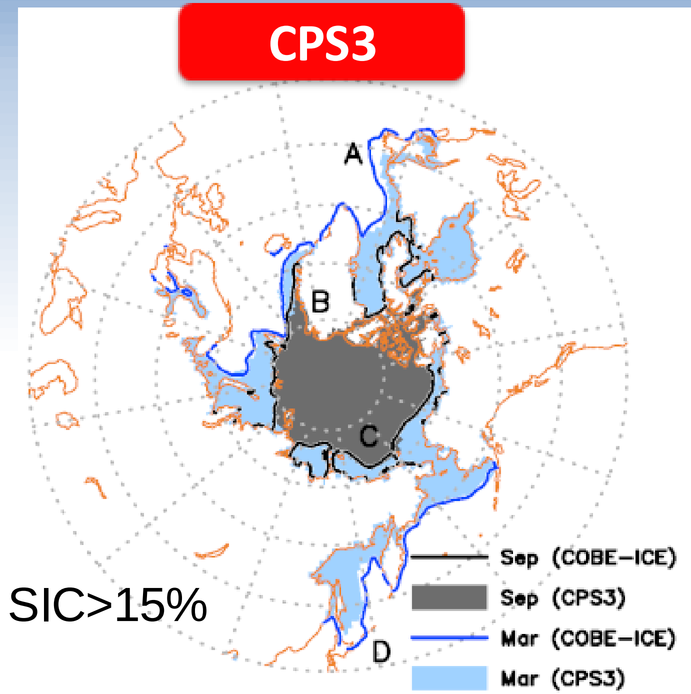


low-resolution 4DVAR, combined with high-resolution downscaling

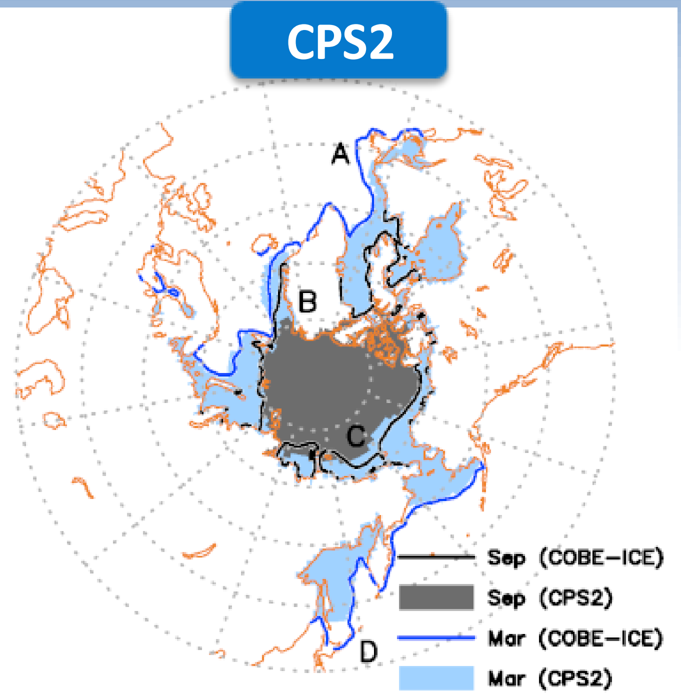
> Computationally efficient, dynamically balanced analysis

Sea ice area at the 1st lead time month

→ Reduced ice edge bias due to the newly introduced assimilation scheme



W/ sea ice data assimilation (Toyoda et al. 2016)

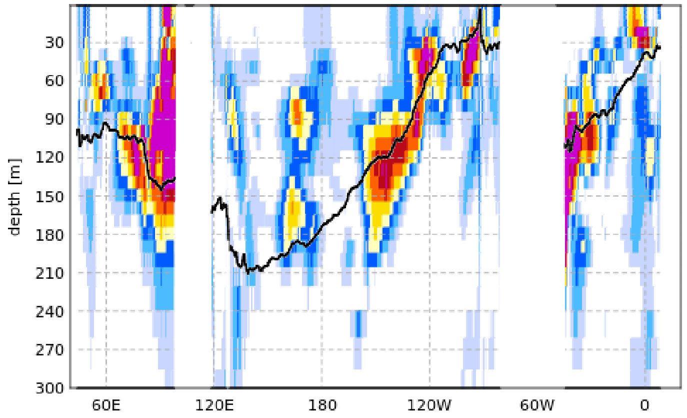


W/o sea ice data assimilation (only SST-constraint)

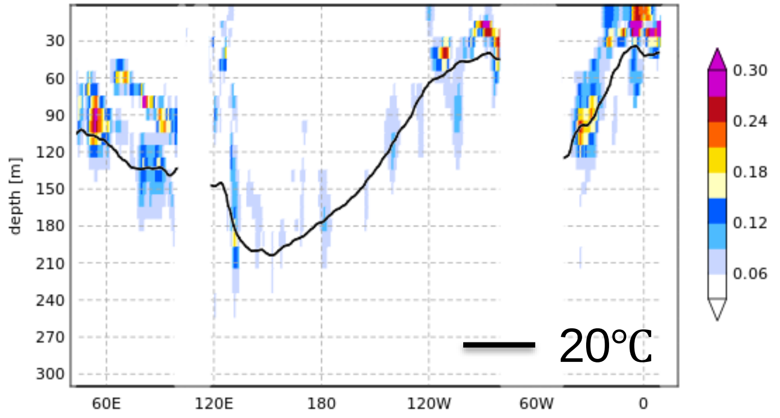
Initial Water temperature spread along the equator

(Init. 31May 2012)

→ reflects uncertainty in ocean analysis



Perturbations reflecting the magnitude and distribution of 4DVAR analysis errors (Fujii et al., 2023)



Ocean Response to Initial Atmospheric Perturbations (Takaya et al. 2018)

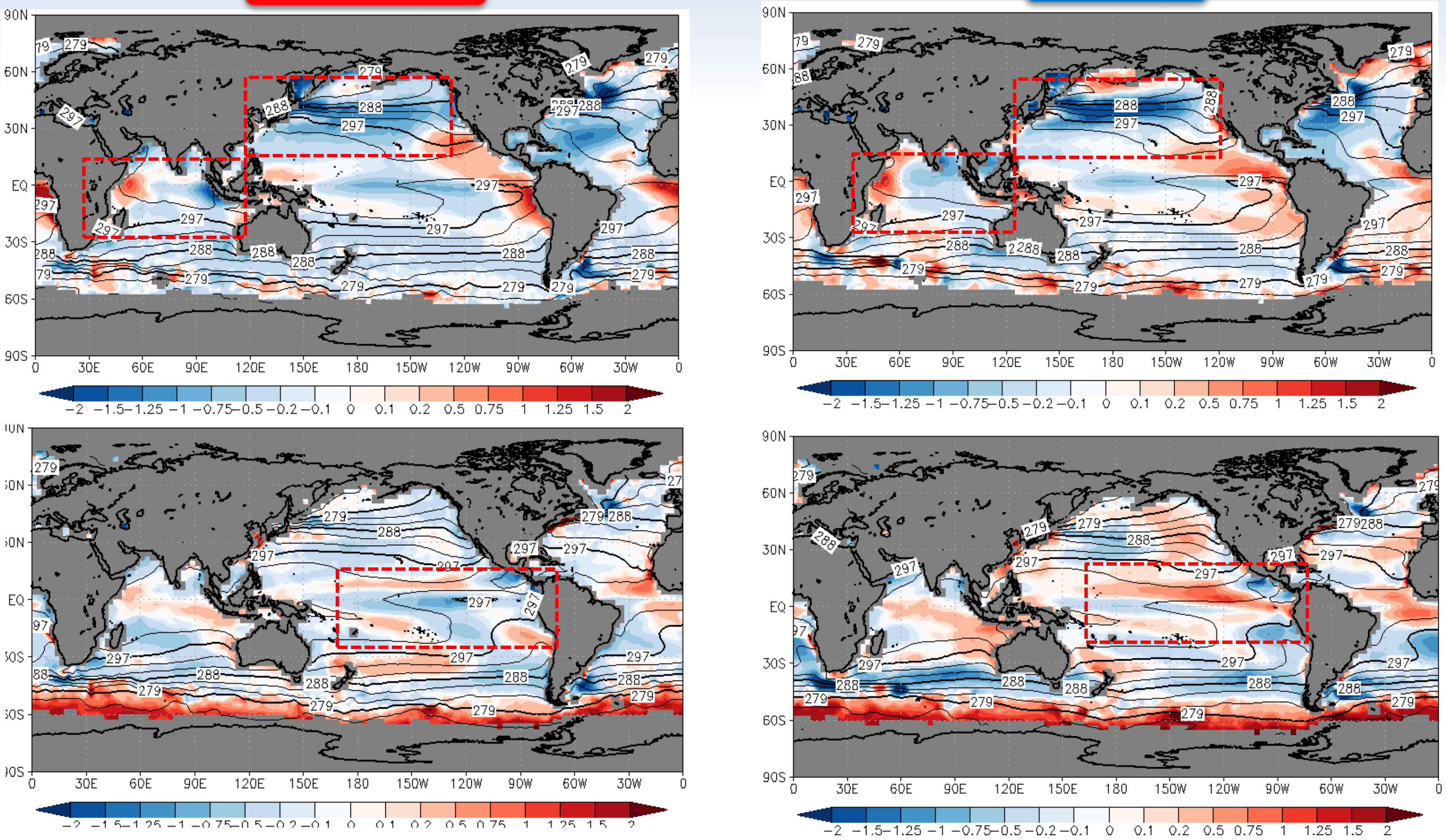
SST bias w.r.t. MGDSST

(1991-2020)

CPS3 | **CPS2**

May Initial
JJA

Oct. Initial
DJF



JJA : cold bias in the Kuroshio/Oyashio extension, warm-west cold-east bias (positive IOD bias) in the tropical Indian Ocean

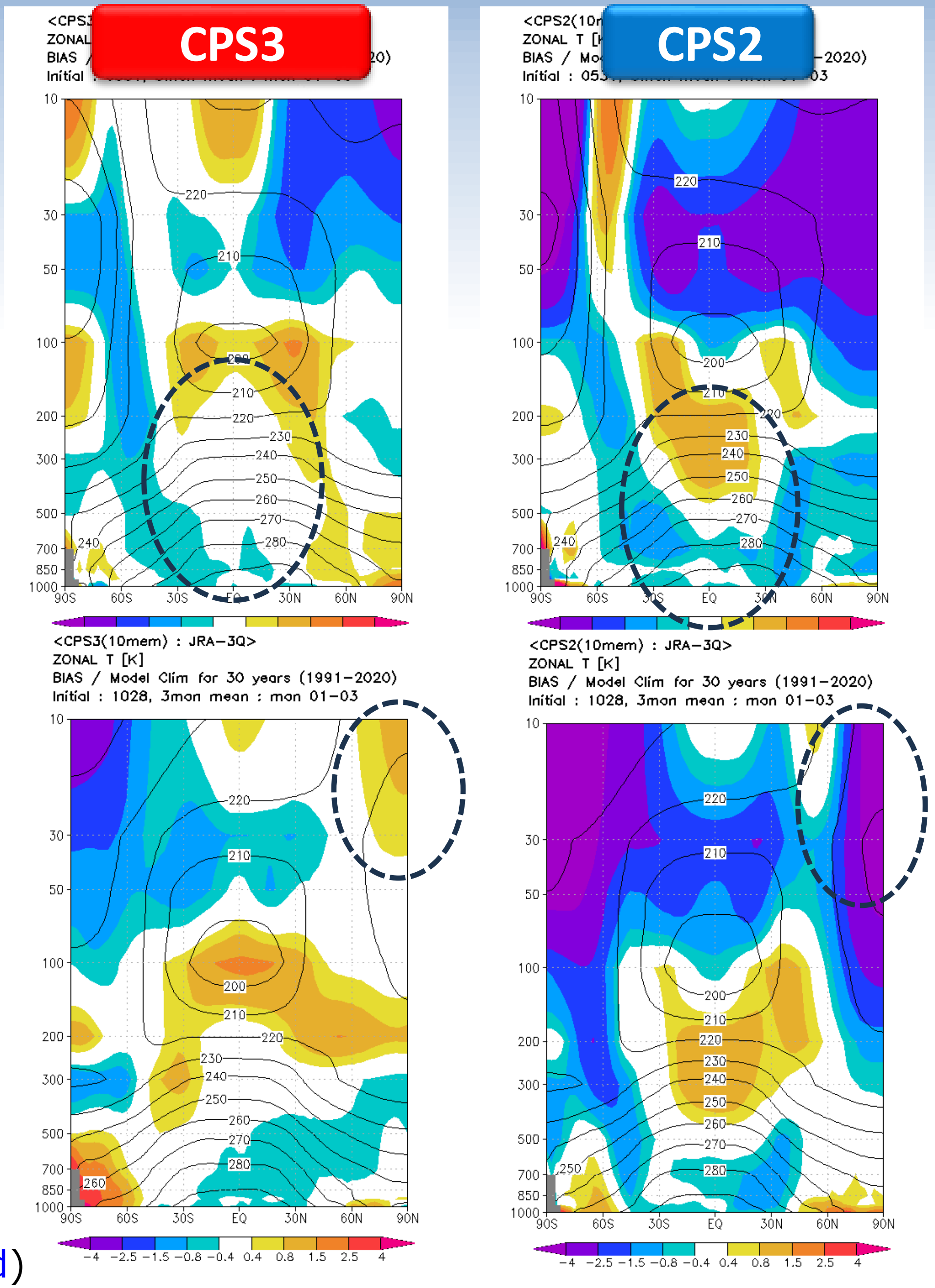
DJF: warm bias in the ITCZ region (e.g., eastern Pacific) has improved. There is room for improvement in the cold tongue bias.

Zonal mean air temperature bias

May Initial
JJA

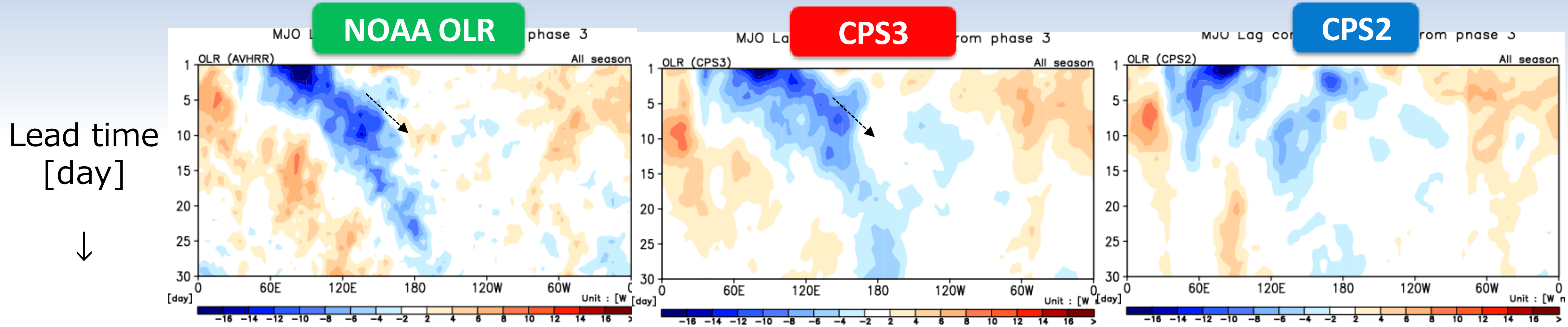
- Improved reproducibility of tropospheric temperature structure
- Too-strong polar vortex bias in boreal winter
  - Cold bias in the lower-middle stratosphere in the north pole
  - too-strong westerly (not shown)

Oct Initial
DJF



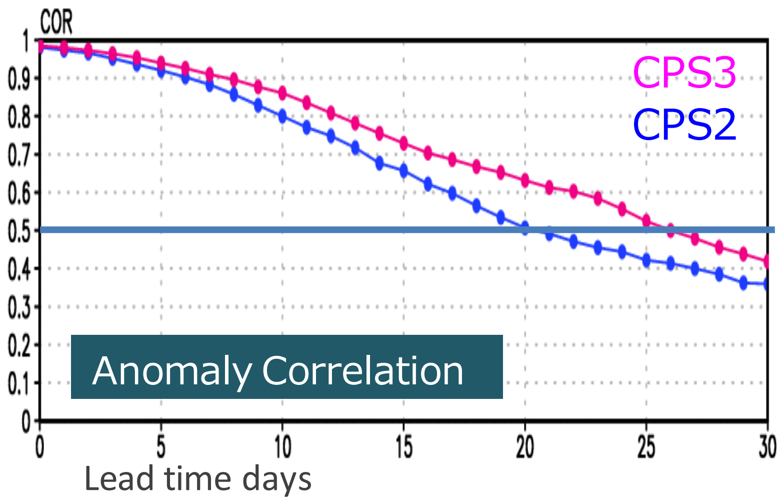
Contour : climatology
Shade : bias w.r.t. JRA-3Q(warm、cold)

Sub-seasonal variability in the tropics ー MJO ー



Longitude-time composite of equatorial OLR of forecasts starting from MJO phase 3 (all seasons)

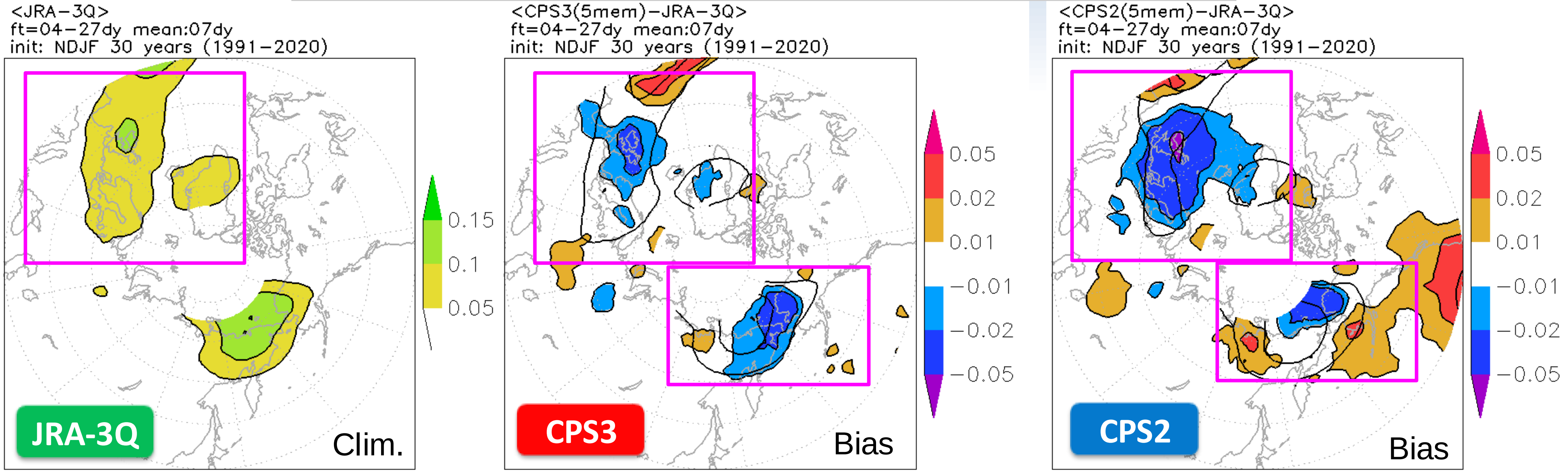
- Eastward propagation is more clearly visible in CPS3
- CPS3 uses the latest weather forecast models at the time (GSM2003) and additional improvements in atmospheric physical processes, including cumulus convection
  - Dry suppression effect of deep convection, a short-live shallow cumulus
- 6 days more skillful compared to the previous system (The number of lead days before the MJO anomaly correlation skill falls below 0.5 increases from 20 days to 26 days)
- Consistently, week 2 forecast skill for Z500 in NH and SH shows overall improvement



(Defined with EOF1 and EOF2 modes of time-filtered U200 and U850; Matsueda and Endo, 2011)

— NH Winter Blocking Frequency —

Day 4-27, Blocking High Existence Frequency [number/day] (**NDJF**)



Contour: Frequency

Shade：Frequency bias（less frequent、 more frequent)

Blocking detection: defined as a maximum within ±15° north-south direction of 500 hPa geopotential altitude （Scherrer et al. 2006)

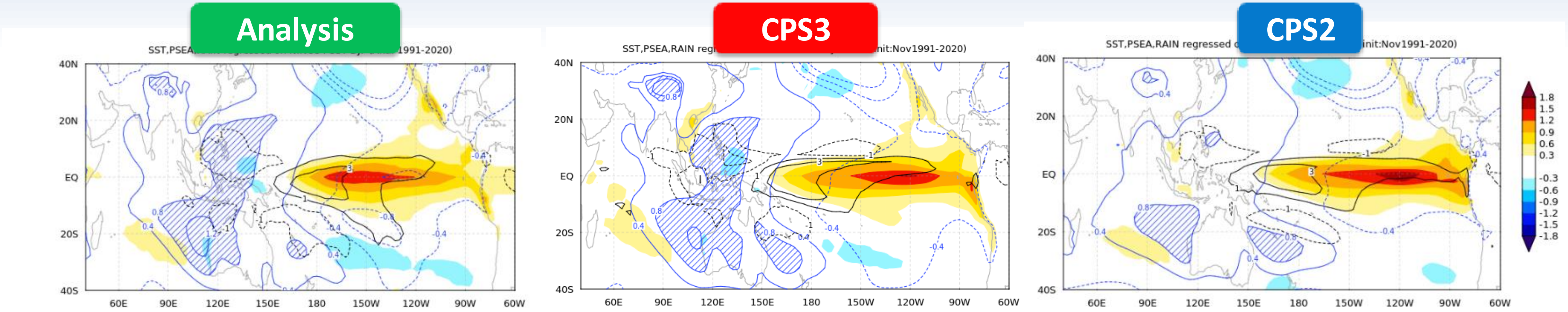
- Underestimated blocking highs in the Atlantic becomes less evident
  - Reduced atmospheric model bias, higher resolution atmosphere, SST gradient, orography

    (Nakamura et al. 2004, Anstey et al. 2013, Berckmans et al. 2013; Schiemann et al. 2017; Athanasiadis et al. 2020, Kleiner et al. 2021)
- The Pacific bias remains roughly unchanged
  - Summertime Pacific blocking improves with resolution, not for winter (Schiemann et al. 2020). Upstream jet bias ? (Nakamura and Huang, 2018)

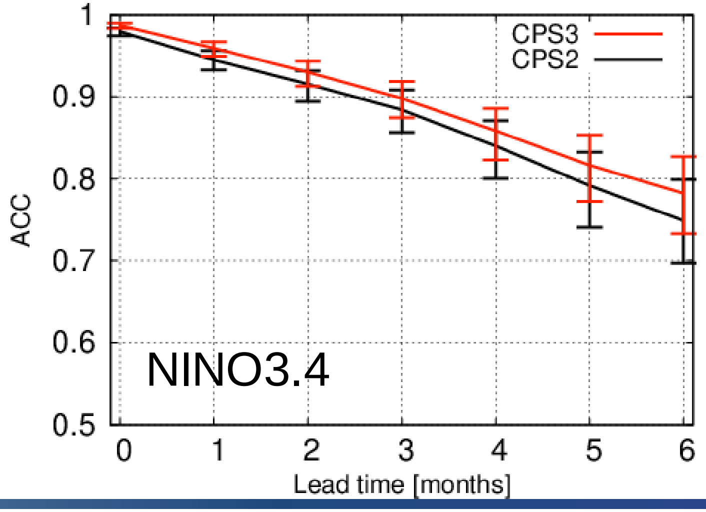
Comparison of SST, SLP, and precipitation patterns associated with El Niño events

(Linear regression coefficients on NINO3.4 SST, DJF 1991-2020)

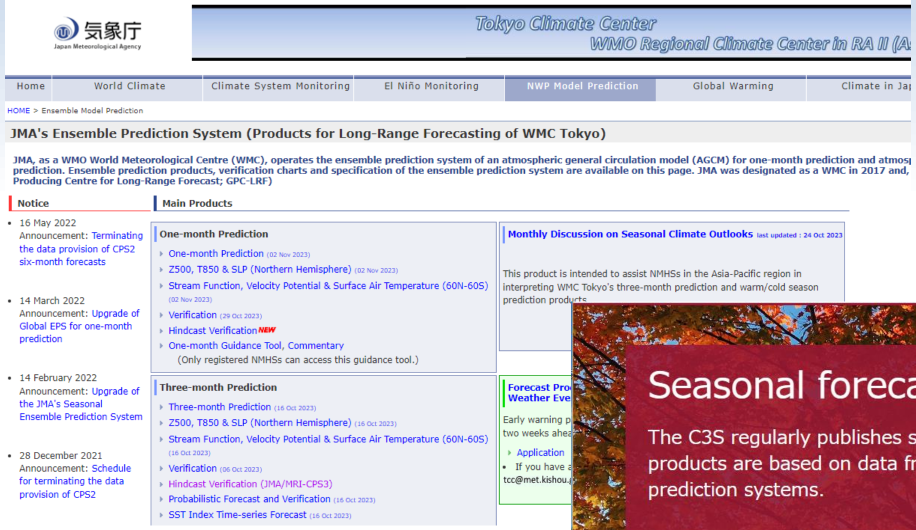
Shade : SST
Contour : SLP, Precipitation (solid-positive、dashed-negative)



- Meridionally broader, less excessive warm anomalies in the eastern Pacific
  - Better resolved TIWs bring negative feedback to equatorial SST anomalies during ENSO events (Vialard et al. 2001; An 2008; Graham, 2014)
- stronger SLP and precipitation response in the western Pacific
- Better representation of ENSO asymmetry (not shown)

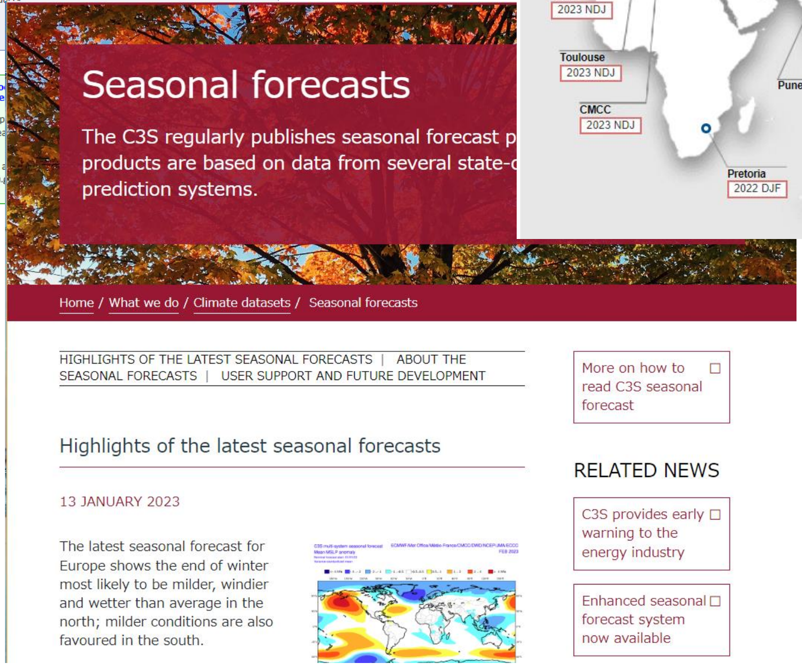


CPS3 Product distribution and data exchange (Feb. 2022-)



TCC

https://ds.data.jma.go.jp/tcc/tcc/

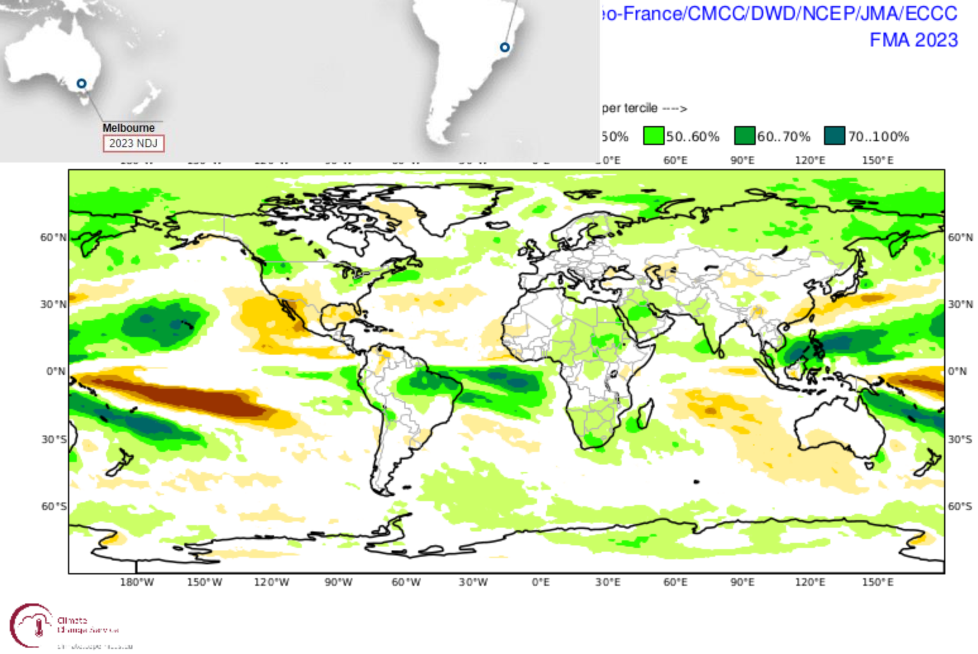


C3S

https://climate.copernicus.eu/seasonal-forecasts

LRFMME

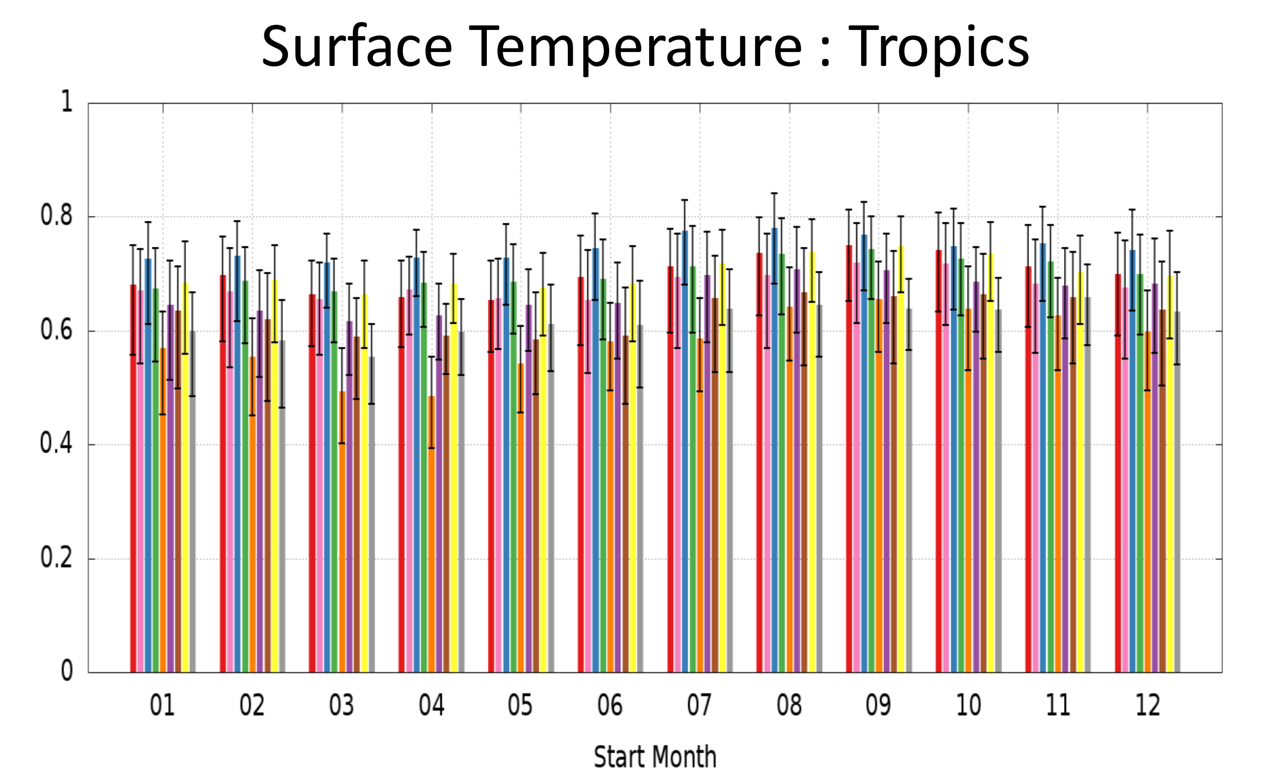
https://www.wmolc.org/

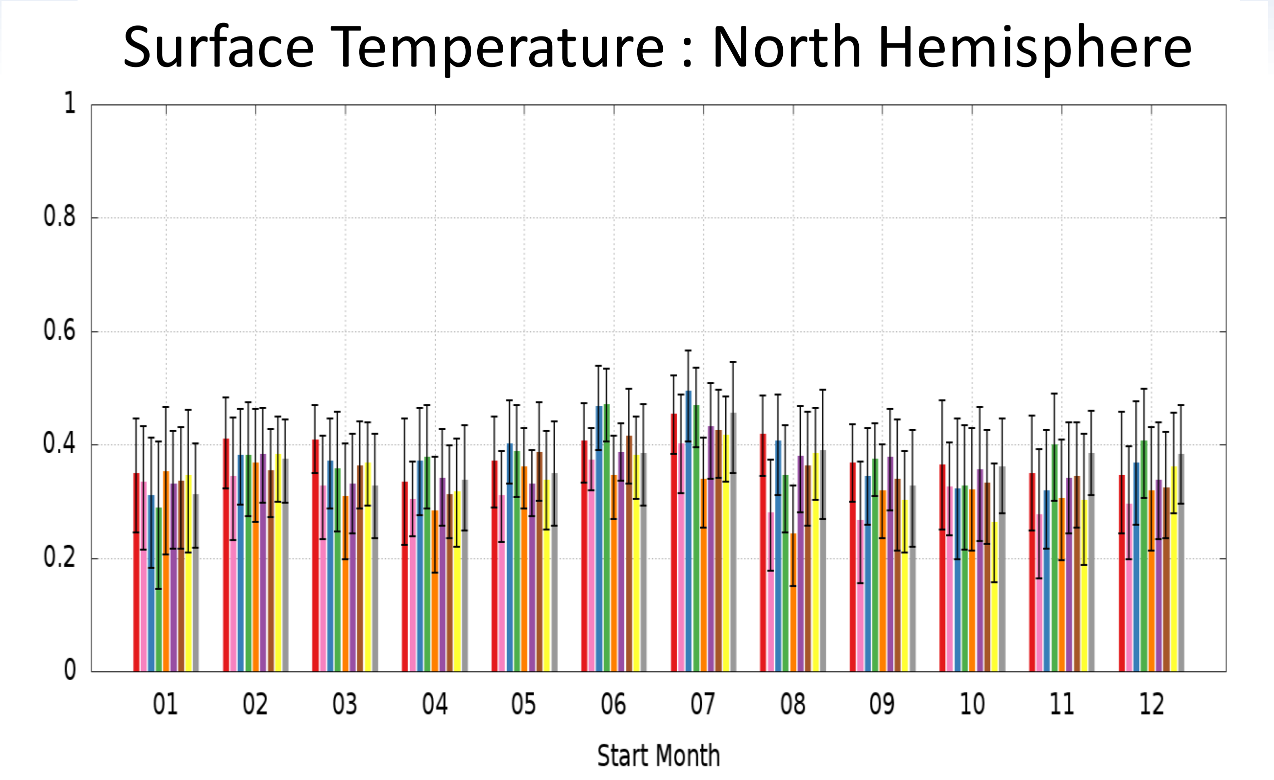


- ➢ JMA provides daily updates of 5member forecasts on the TCC website
- ➢ Monthly updates of 51-ensemble member, lagged ensemble forecasts on LRFMME, C3S

ACC of 3-month prediction for C3S hindcasts: 10 member

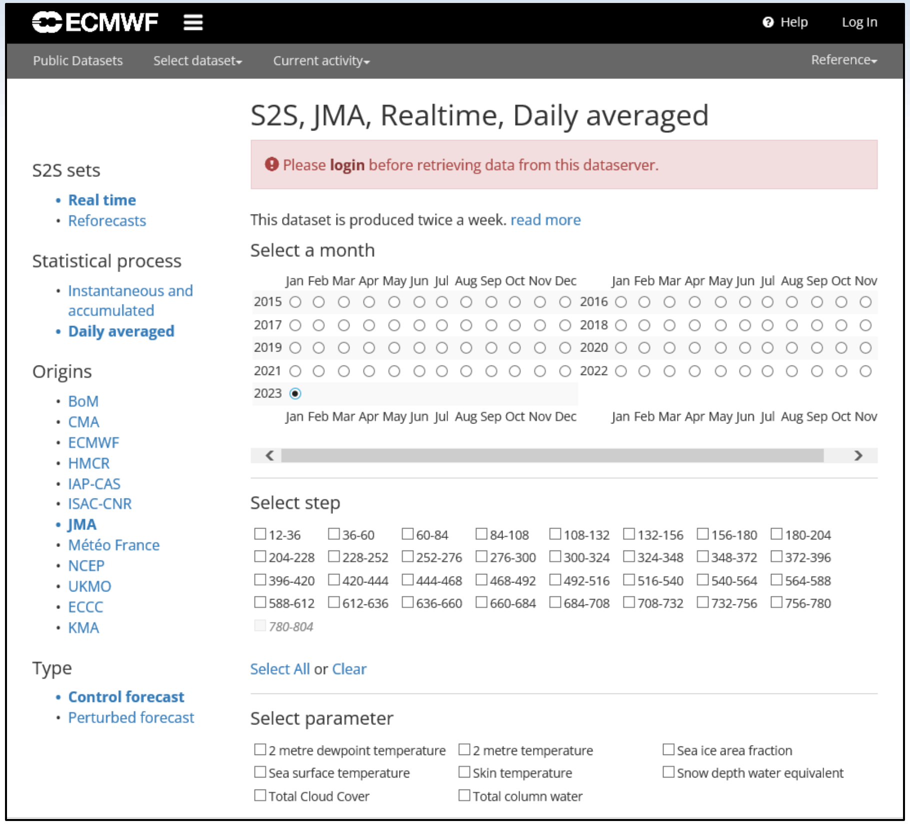
Verified against ERA5



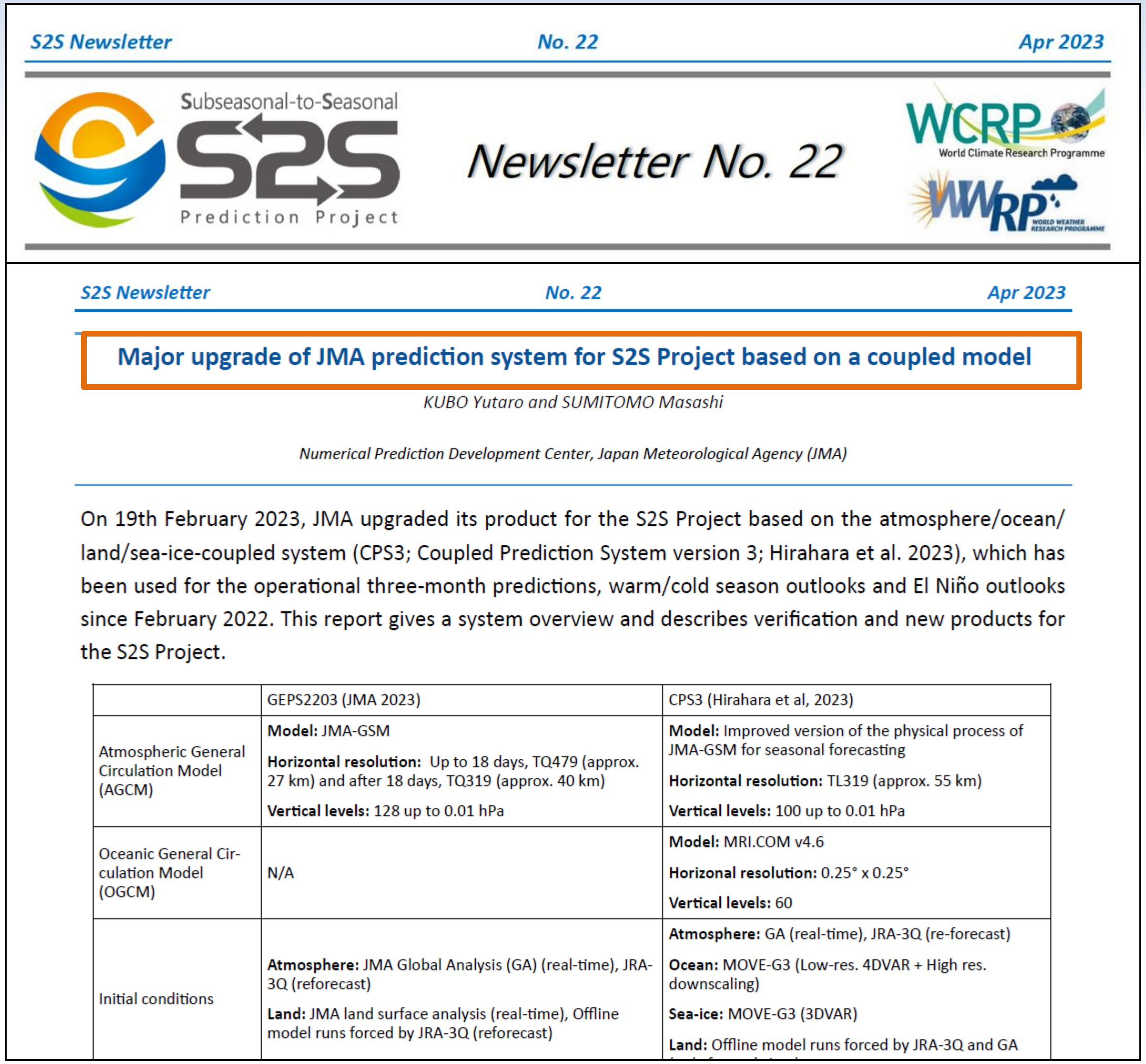


- ACC scores improved in almost all initial months compared to CPS2
- Enhancing the performance of each individual model leads to a more skillful forecast of the MME

S2S Archived Data for Research



https://apps.ecmwf.int/datasets/



S2S Newsletter No. 22 Apr 2023

Subseasonal-to-Seasonal S2S Prediction Project

Newsletter No. 22

WCRP World Climate Research Programme

WWRP

S2S Newsletter No. 22 Apr 2023

Major upgrade of JMA prediction system for S2S Project based on a coupled model

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Numerical Prediction Development Center, Japan Meteorological Agency (JMA)

On 19th February 2023, JMA upgraded its product for the S2S Project based on the atmosphere/ocean/land/sea-ice-coupled system (CPS3; Coupled Prediction System version 3; Hirahara et al. 2023), which has been used for the operational three-month predictions, warm/cold season outlooks and El Niño outlooks since February 2022. This report gives a system overview and describes verification and new products for the S2S Project.

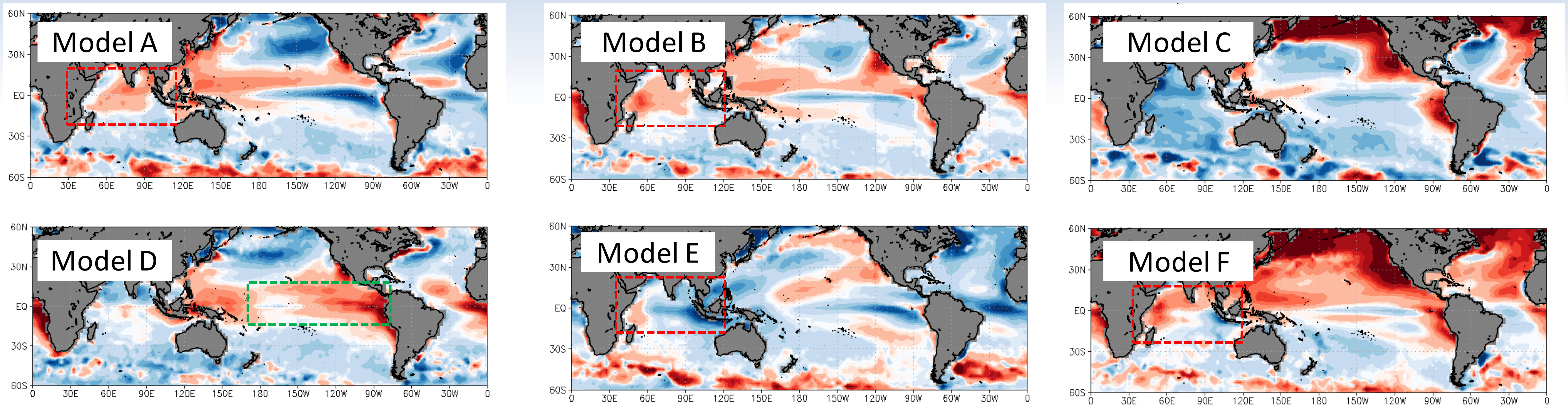
	GEPS2203 (JMA 2023)	CPS3 (Hirahara et al, 2023)
Atmospheric General Circulation Model (AGCM)	**Model:** JMA-GSM **Horizontal resolution:** Up to 18 days, TQ479 (approx. 27 km) and after 18 days, TQ319 (approx. 40 km) **Vertical levels:** 128 up to 0.01 hPa	**Model:** Improved version of the physical process of JMA-GSM for seasonal forecasting **Horizontal resolution:** TL319 (approx. 55 km) **Vertical levels:** 100 up to 0.01 hPa
Oceanic General Circulation Model (OGCM)	N/A	**Model:** MRI.COM v4.6 **Horizonal resolution:** 0.25° x 0.25° **Vertical levels:** 60
Initial conditions	**Atmosphere:** JMA Global Analysis (GA) (real-time), JRA-3Q (reforecast) **Land:** JMA land surface analysis (real-time), Offline model runs forced by JRA-3Q (reforecast)	**Atmosphere:** GA (real-time), JRA-3Q (re-forecast) **Ocean:** MOVE-G3 (Low-res. 4DVAR + High res. downscaling) **Sea-ice:** MOVE-G3 (3DVAR) **Land:** Offline model runs forced by JRA-3Q and GA

- ➤ In Feb 2023, JMA began to provide CPS3 to S2S
- ➤ Can be used for research with a 3-week time lag from real-time

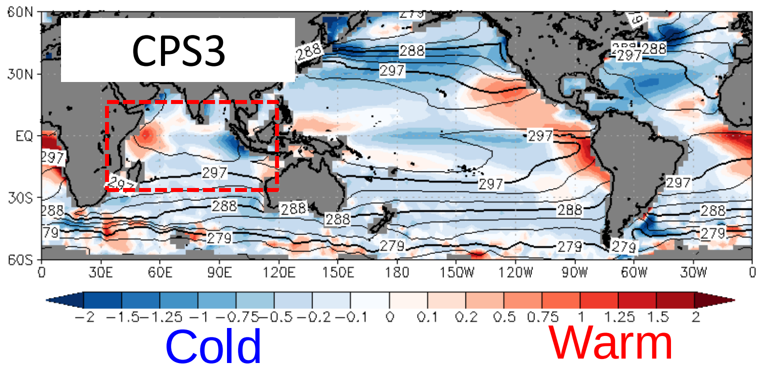
Current issues and future challenges

Boreal Summer (JJA) **SST** bias in C3S models

Init: 1st May, 93-16



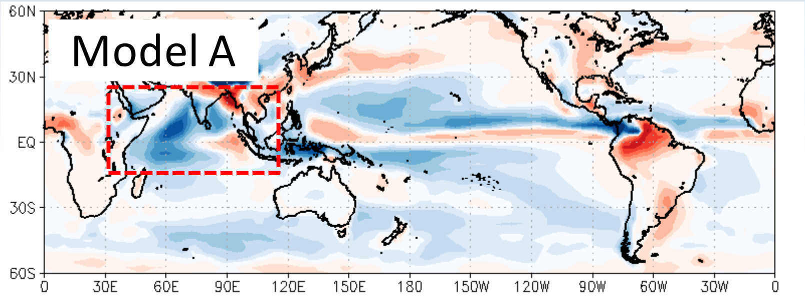
- **The Pacific cold tongue bias and the positive IOD bias are common in the latest generation operational models**
- **The IOD bias is seasonally locked and grows with time in boreal summer-autumn**
  - The biases grow with a similar feedback mechanism as in inter-annual IOD

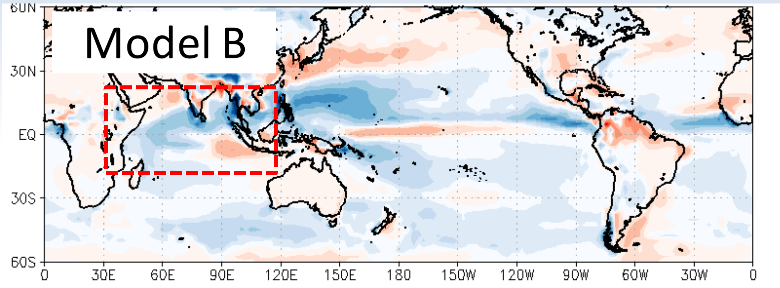


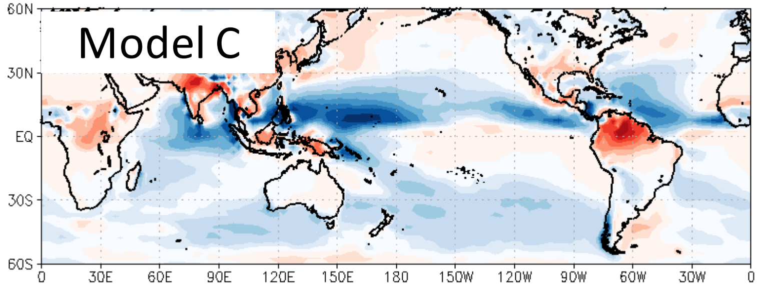
Biases w.r.t. MGDSST (Kurihara et al. 2006)

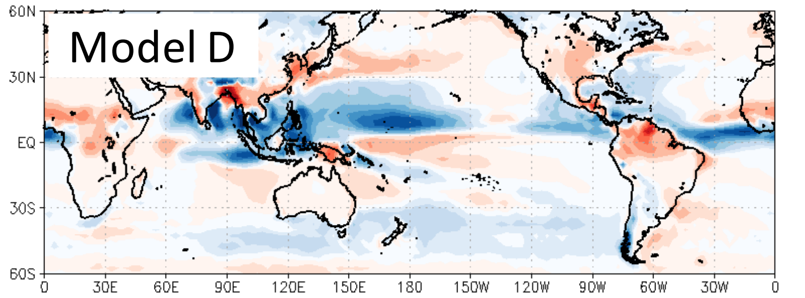
Boreal Summer (JJA) **Precipitation** bias in C3S models

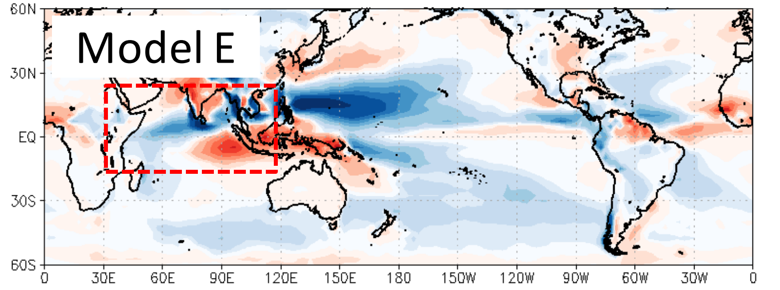
Init: 1st May, 93-16

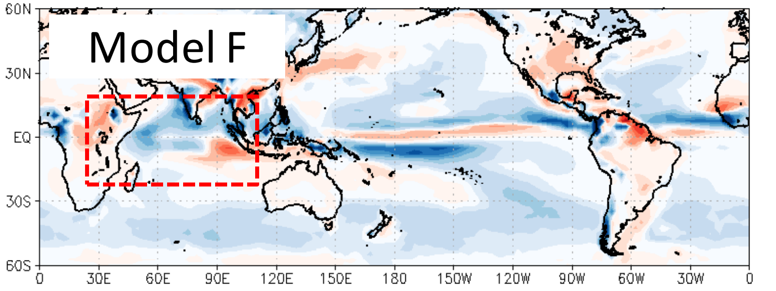




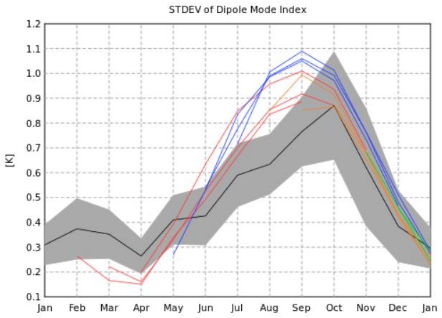


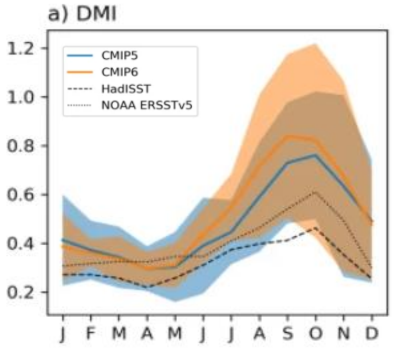




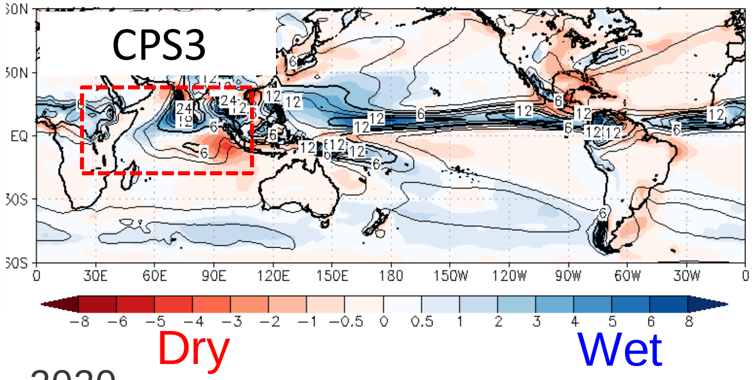


- **Dry bias in the EIO and wet bias from North India to the western North Pacific**
- **Related to the IOD-like mean-state bias, the peaks of interannual IOD comes earlier than observation**
- **IOD-ish biases can be found in generations of CMIP models** (Cai and Cowan, *GRL*, 2013; McKenna et al., *Sci.Rep.*, 2020)





McKenna et al. , *Sci. Rep.*, 2020

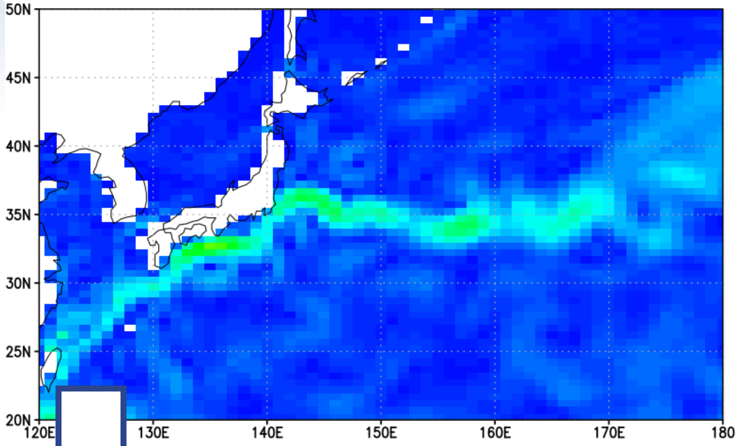


Biases w.r.t. GPCP2.3 (Adler et al. 2016)

Current Issue 2: Global Ocean Analysis （Surface Current） : 23Mar2011

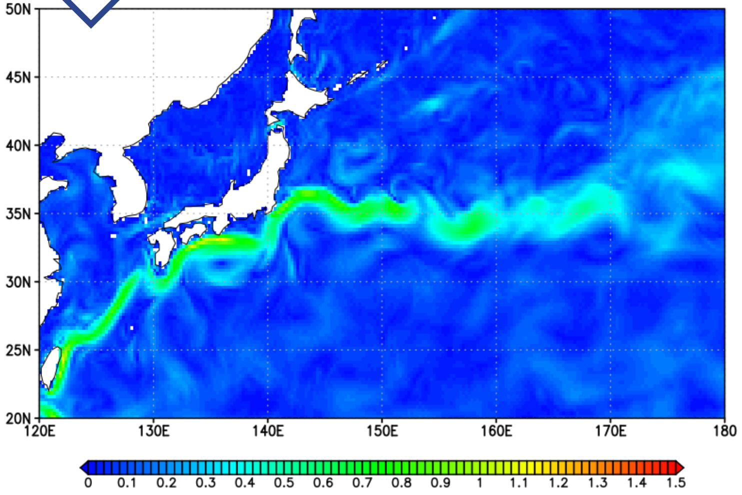
CPS3

G3A-4DVAR (1.0deg)

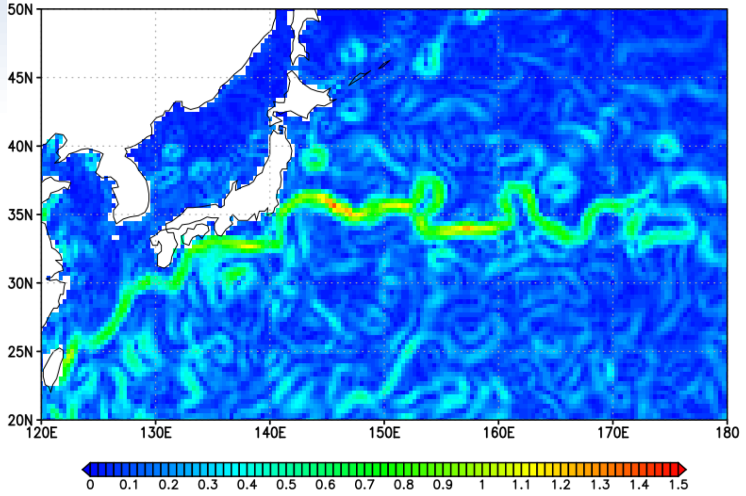


Downscaling

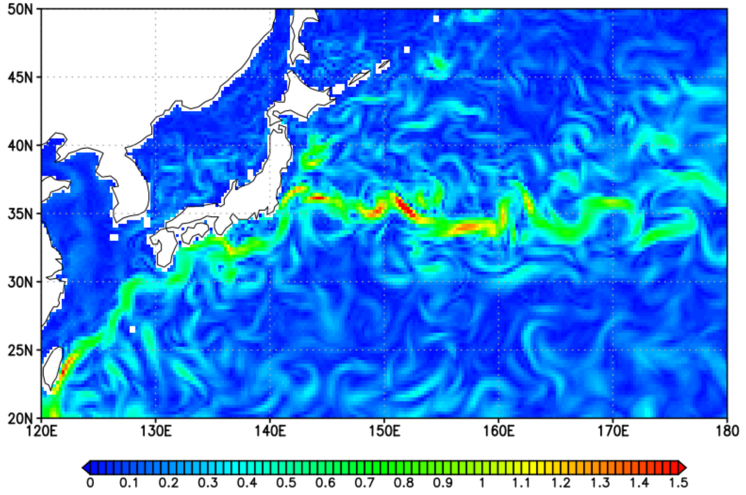
G3F-IAU (0.25deg)



OSCAR Surface Current Analysis (1/3deg)

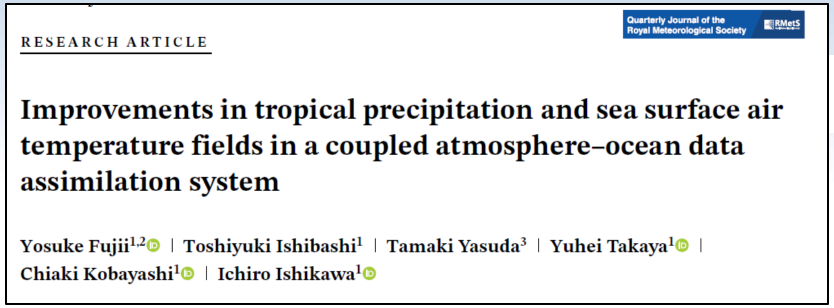


TEST-4DVAR (0.25deg)



- Currently using the combination of low resolution 4D-Var (1.0x0.3-0.5deg.) and high-resolution IAU (0.25deg.)
- Only large-scale features such as mainstream of the Kuroshio current are resolved by the current 4D-Var system.
- Finer resolution (0.25deg) Ocean 4DVAR is currently under development

Atmosphere-Ocean Coupled DA



MRI-CDA1

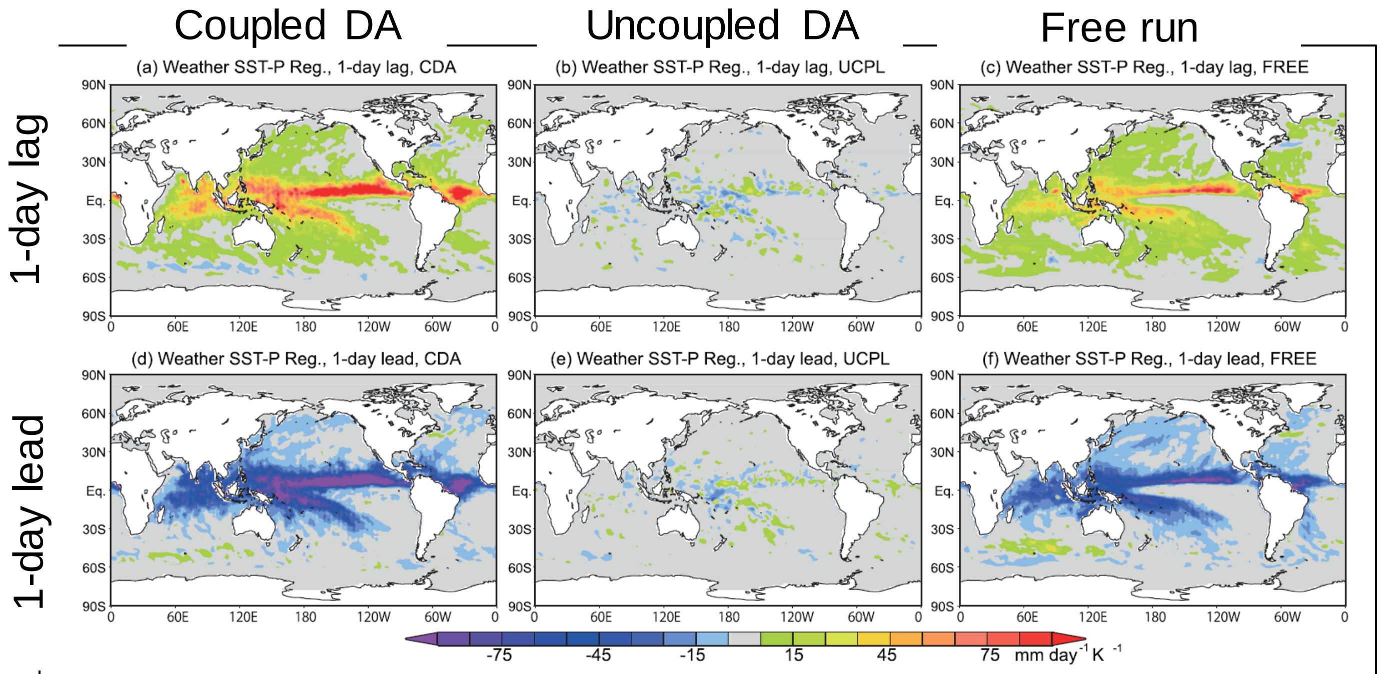
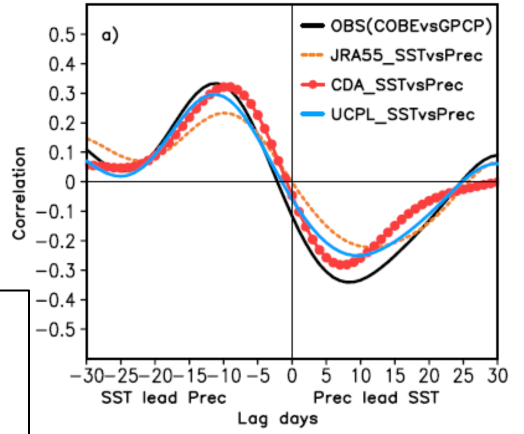


FIGURE 16 Distributions of the precipitation regression coefficients with a 1-day lag (a–c) and a 1-day lead (d–f) on SST at each horizontal point for the weather-timescale variations in CDA-Exp (a, d), UCPL-Exp (b, e) and FREE-Exp (c, f). Units are mm day^{-1}·K^{-1}

Fujii et al. 2021, QJRMS, DOI:10.1002/qj.3973



Kobayashi et al.(2021, ClimDyn)

- JMA and its research institute, MRI, have a close O2R/R2O collaboration, which involves the development of atmosphere-ocean coupled DA.
- Coupled DA (MRI-CDA1: Fujii et al. 2021) could reproduce SST-Precipitation relationship with negative feedback in short and sub-seasonal time scale.
- As a next step, development of MRI-CDA2 is ongoing now

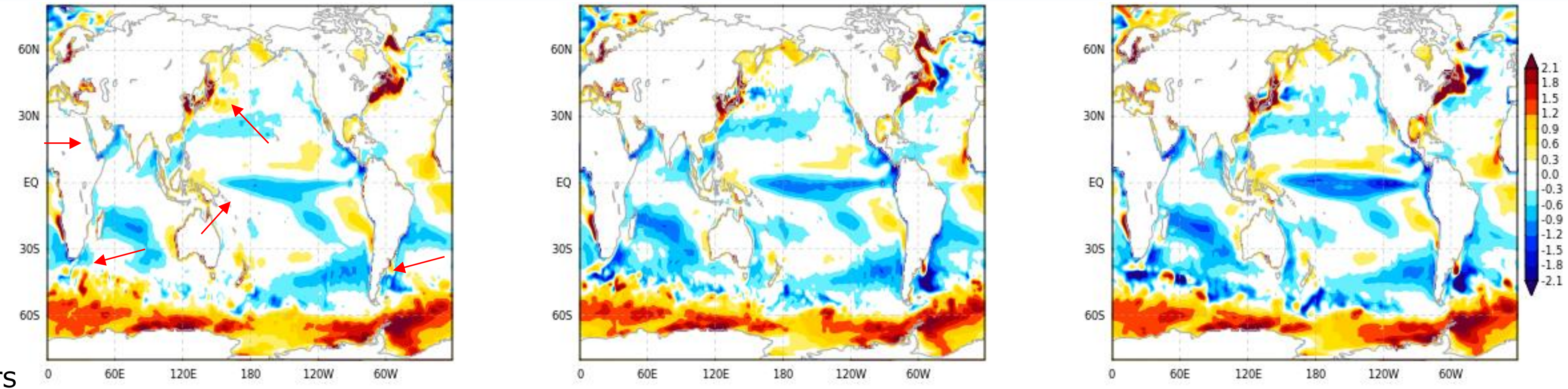
Global eddy-resolving ocean model

SST bias

DJF
FT=4-6month

Init: 15Jul, 30Jul
1991-2020
10 member, 30-years hindcast

55km Atm.-10km Ocn. | **55km Atm.-25km Ocn.** | **55km Atm.-100km Ocn.**



* w.r.t. MGDSST

*5mem.x2initial dates=10 memmbers

With increased resolution, mesoscale phenomena in the ocean are better resolved and the bias of the SST improves incertain ocean areas: Central equatorial Pacific, Kuroshio/Oyashio Extension, Gulf stream, Agulhas current..

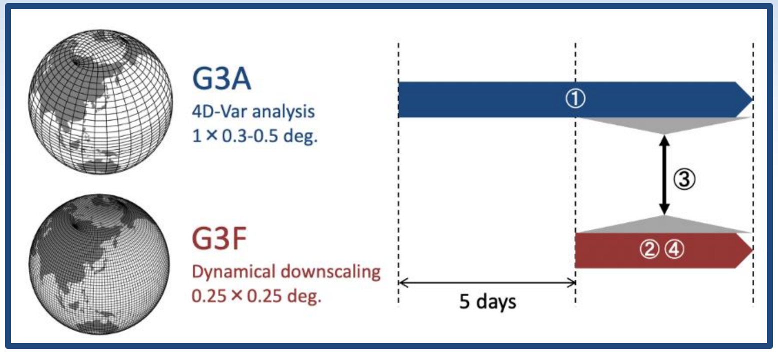
The 10-km coupled model requires about 6 times more node-time than the 25-km model

Summary

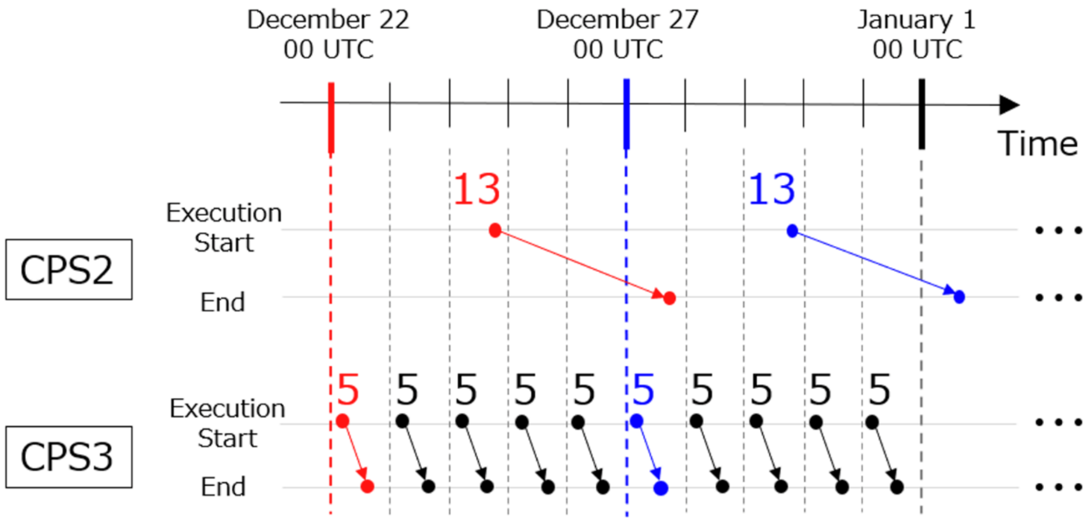
- Recent activities
  - February 2022: Major upgrade of Seasonal EPS - CPS3 → TCC, LRFMME, C3S
  - February 2023: Upgrade of JMA prediction system for S2S based on the Seasonal EPS

- Challenges/Issues towards next step
  - IOD-ish bias
  - Increasing resolution of ocean DA: Testing Ocean 4VDAR with 0.25deg
  - Atmosphere-ocean coupled DA might be an option towards next step
  - An eddy-resolving ocean model as a futher step forward in the future

Operational Schedule with enhanced usability



×(5 mutually independent, staggered Ocn. DA cycles)
＝Daily initial conditions available
×(Early/Delayed Atm. DA)
with minimal time delay/data loss



Operational schedule of prediction

	Integration starts	Whole integration available at	Frequency
CPS2	Init + 2 days	Init + 5 days	Every 5 days
CPS3	Init + 6 hours	Same day	Every day

Near real-time initial conditions are beneficial for shorter lead time forecasts