JMA's Seasonal Ensemble Prediction System

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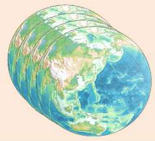
Outline

1. Recent upgrade and performance
2. Current issues and future challenges

Operational NWP global models at JMA

	Global Spectral Model (GSM)	Global EPS (GEPS)	**Seasonal EPS** (JMA/MRI-CPS3)
Domain			
Horizontal resolution	approx. 13 km	approx. 27 km（up to 18 days） approx. 40 km（up to 34 days）	Atmosphere: approx. **55 km** Ocean: approx. **25 km**
Forecast length (initial hours)	264 hours (00,12 UTC) 132 hours (06,18 UTC)	5.5 days (06,18 UTC) 11 days (00 UTC) 18 days (12 UTC) 34 days (12 UTC on Tue. and Wed.)	7 months (00 UTC)
Ensemble size	1	51 (up to 18 days) 25 (up to 34 days)	5
Main Products	Typhoon Forecasts, Three-hourly Forecasts, Daily Forecasts, Aviation Weather Forecasts and Warnings	Typhoon Forecasts, One-week Forecasts, Early Warning Information on Extreme Weather, Two-week Temperature Forecasts, One-month Forecasts	Three-month Forecasts, Warm/Cold Season Forecasts, El Niño Outlook
Initial conditions	**Hybrid 4D-Var**	Global Analysis + SV + LETKF	Atmos.: Global Analysis＋BGM **Ocean: 4D-Var** + perturbations calculated using 4DVAR minimization history
Sea Surface Temperatures conditions	Anomaly-fixed SST (MGDSST)	Anomaly-fixed SST and ensemble-mean SST by CPS3 after 6 days (two-tier method)	Predicted SST in the fully **coupled model** (one-tier method)

Major upgrade of Seasonal EPS : Coupled Prediction System (CPS)

Hirahara et al.(2023, JMSJ)

		CPS2 (June 2015)	CPS3 (February 2022)
Atmospheric model	Model version	GSM1011C	GSM2003C
	Horiz. resolution	TL159 (~110 km)	TL319 (~**55 km**)
	Vertical levels	60 levels	100 levels
Ocean model	Model version	MRI.COM v3.2	MRI.COM v4.6
	Horiz. resolution	1° (longitude) × 0.3-0.5° (latitude)	**0.25°**
	Vertical levels	52 levels with a bottom boundary layer	60 levels
Initial conditions	Atmosphere	JRA-55	Global Analysis (GA)
	Ocean/Sea ice	MOVE-G2	**MOVE-G3** *(detailed next)*
Ensemble generation	Size and Frequency	13 members per 5 days	**5 members per day**
	Perturbation	Stochastic physics in the atmosphere Breeding for the atmosphere	Stochastic physics in the atmosphere Breeding for the atmosphere New ocean perturbations

MRI.COM: Meteorological Research Institute Community Ocean Model.

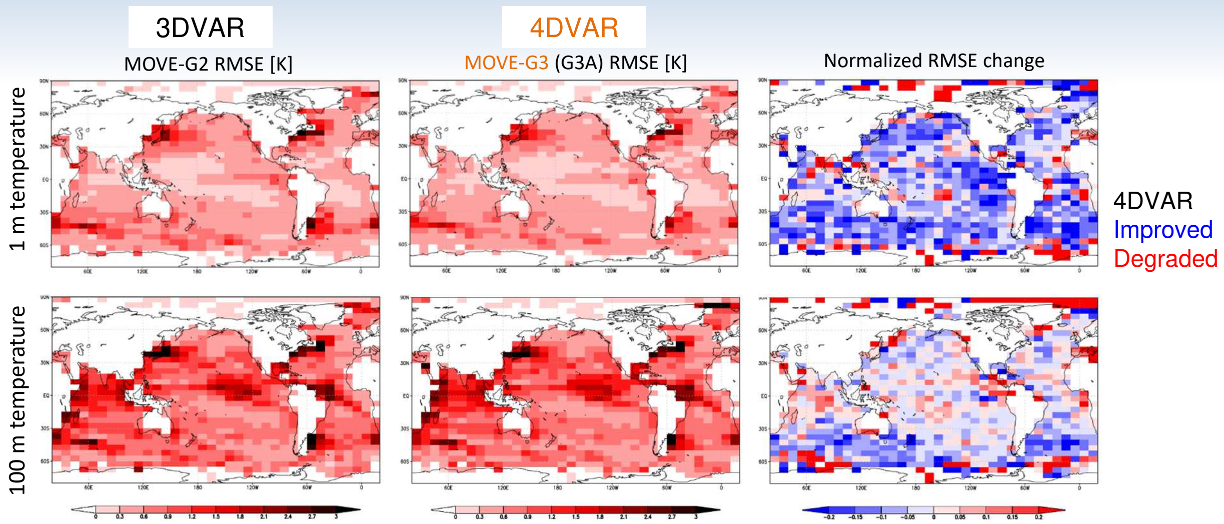
Major upgrade of Ocean data assimilation: MOVE

Fujii et al.(2023, Front. Clim.)

	MOVE-G2	MOVE-G3	
		G3A (4DVAR analysis)	G3F (initialization of fcst.)
Horizontal resolution	1.0° (lon) × 0.3-0.5° (lat)	1.0° (lon) × 0.3-0.5° (lat)	0.25°
Vertical layers	52 + Bottom Boundary Layer	60 + Bottom Boundary Layer	60
Temperature/Salinity analysis	3DVAR/FGAT+IAU	**4DVAR**+IAU	IAU to G3A Analysis *(detailed next)*
Sea Ice Concentration analysis	-	**3DVAR**+IAU	3DVAR+IAU
Assimilated Observations	Water temperature, Salinity, Sea surface height	Water temperature, Salinity, Sea surface height	-
	-	Sea ice concentration	
Atmospheric forcings	JRA-55	JRA-3Q (delayed) and Global Analysis (early)	
Analysis window	10 days	10 days	5 days
Observation window (= Analysis interval)	10 days	5 days	

MOVE: Multivariate Ocean Variational Estimation. IAU: incremental analysis updates.

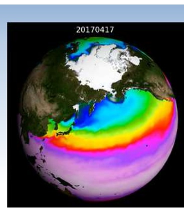
3DVAR vs 4DVAR: Error to independent (non-assimilated) Argo



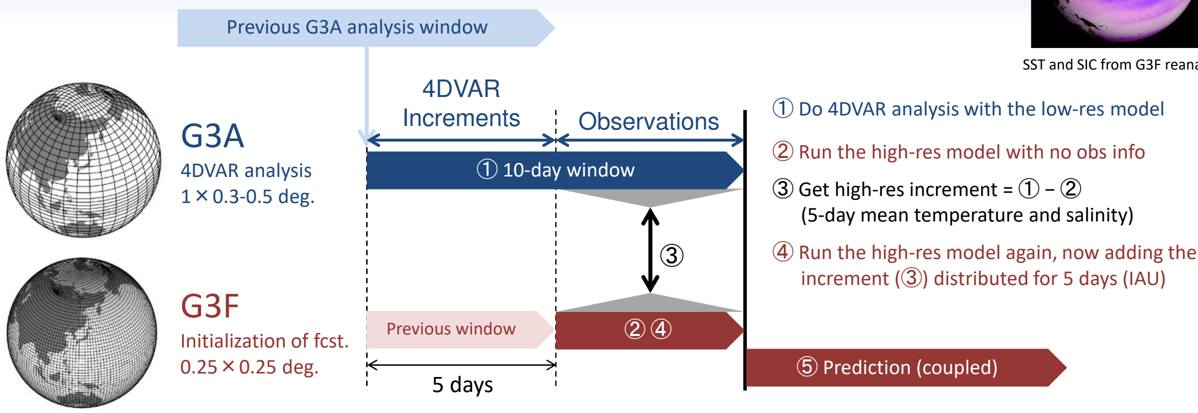
Reanalysis experiment (2005-2014)

*Verified with 20% of Argo withheld from assimilation

4DVAR and Downscaling with IAU

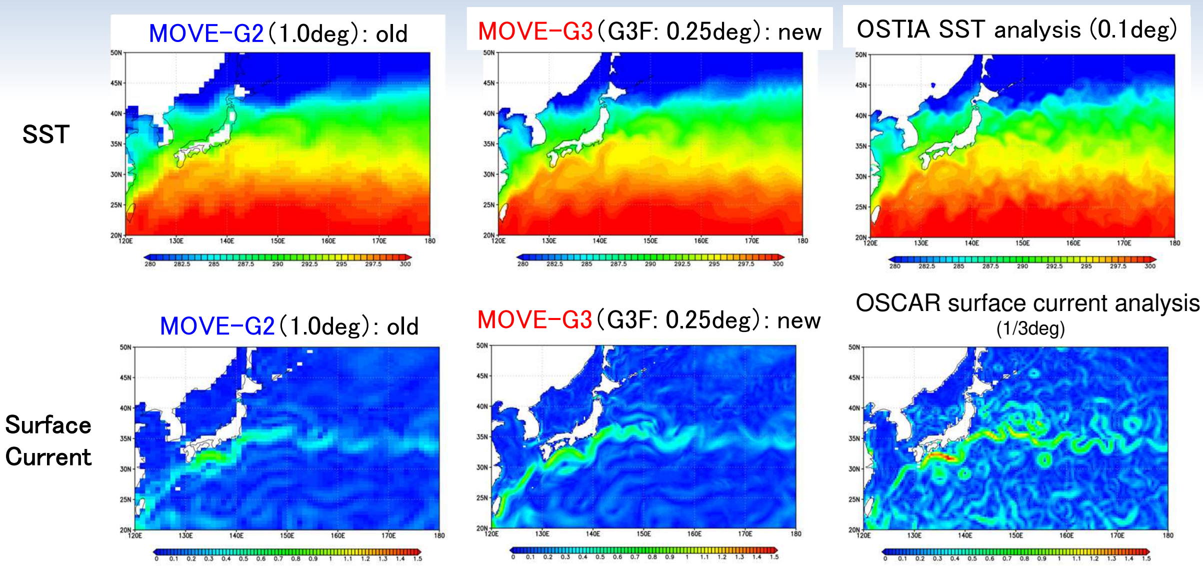


SST and SIC from G3F reanalysis



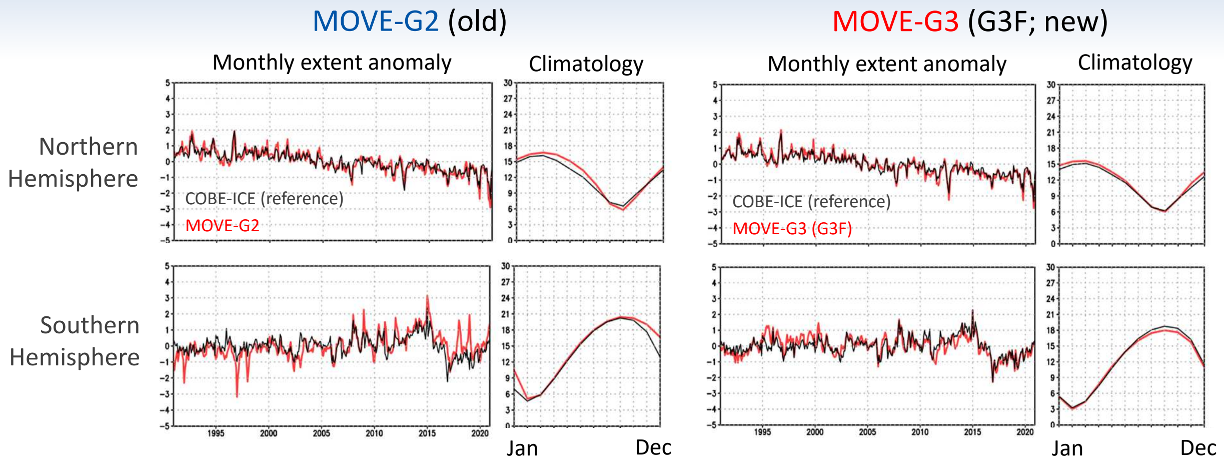
Experiments with a prototype system showed this setup outperforms straightforward 3DVAR with the 0.25-deg. model (with acceptable additional cost)

Midlatitude Oceanic Front around Japan: 1Dec2017



Large-scale feature including mainstream of the Kuroshio can be resolved, though there is still room for improvement.

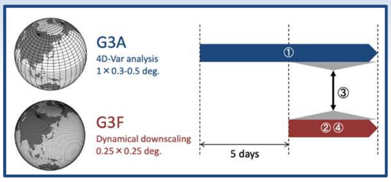
Sea Ice Extent in reanalysis (10^6 km^2, year-to-year and seasonal)



Year-to-year and seasonal variabilities get closer to the reference in both hemispheres

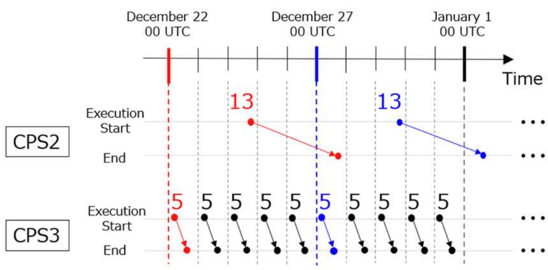
*Not an independent reference

Enhanced Operational Schedule



×(5 mutually independent, staggered streams)×(Early/Delayed analysis)

＝Daily initial conditions available with minimal delay and data loss



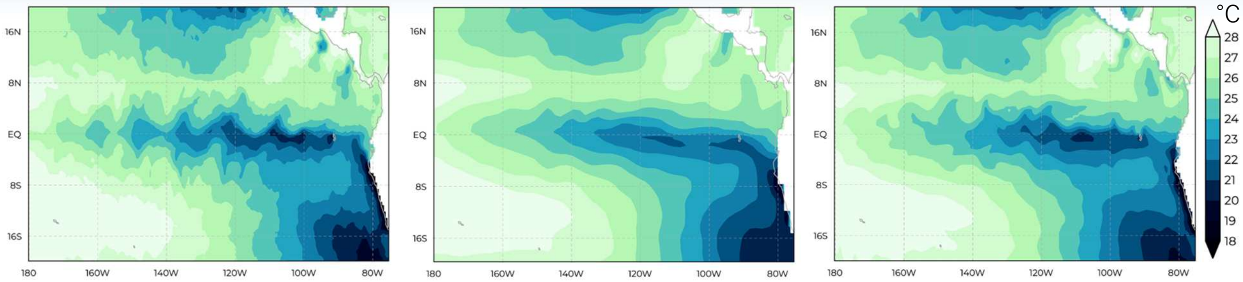
Operational schedule of prediction

	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

More timely initial conditions are beneficial for shorter lead time.

Tropical Instability Wave: Hindcast Case Study

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

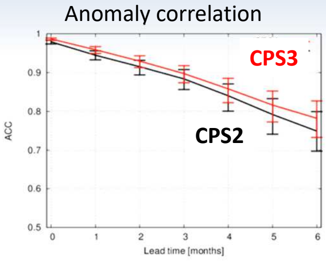


5-day mean SST valid on December 22-26, 1999.
(CPS2 and CPS3 are 11^{th}-15^{th} day of prediction.)

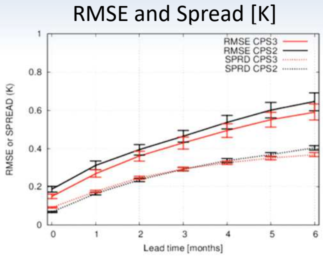
- With higher ocean resolution, CPS3 better reproduces the fine-scale TIW features.
- TIW is known to provide negative feedback to anomalous equatorial SST via meridional heat transport. This improved TIW may have alleviated over-development bias for ENSO found in CPS2.

El Nino Prediction: Hindcast

Anomaly correlation



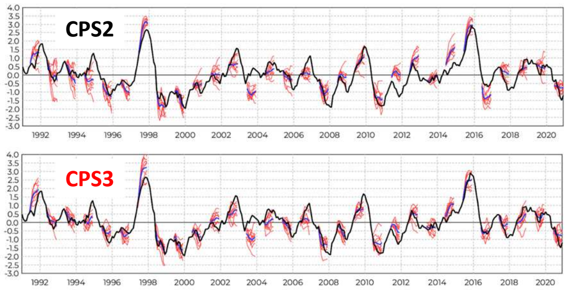
RMSE and Spread [K]



← Anomaly correlation, RMSE, and Spread of NINO 3.4 SST for different lead time. Based on 360 instances from hindcast (1991-2020).

*Verified with MGDSST

Timeseries of NINO 3.4 SST anomaly [K] →

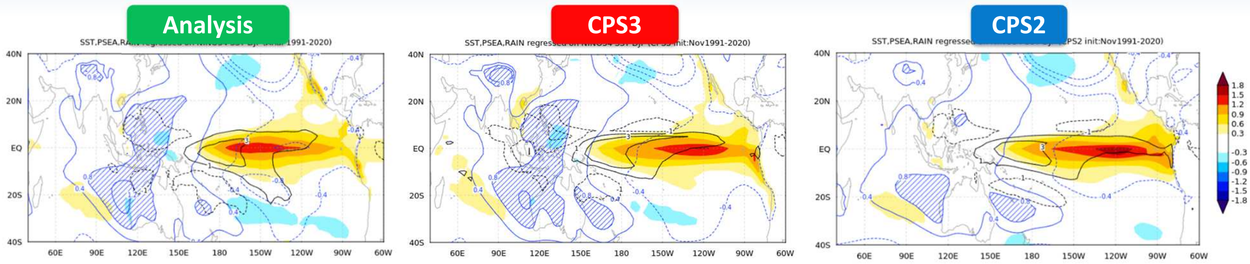


Black: MGDSST (reference)
Red: hindcast members (from April 11 and 26)
Blue: hindcast ensemble mean (10-member LAF)

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

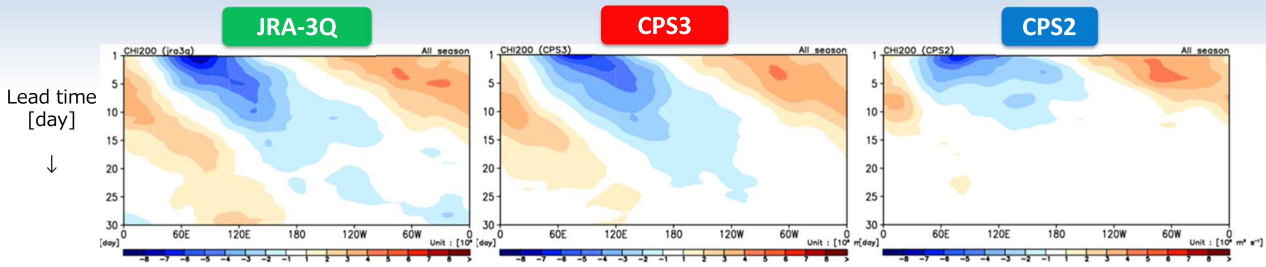
(Linear regression coefficients on NINO3.4 SST, DJF 1991-2020)

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

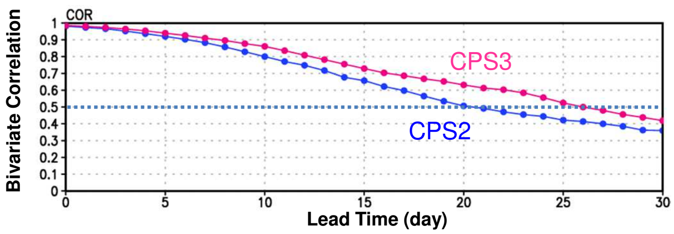


- Meridionally broader, less excessive warm anomalies in the eastern Pacific
  - Better resolved TIWs bring negative feedback to equatorial SST anomalies during ENSO events (Vialard et al. 2001; An 2008; Graham, 2014)
- Stronger SLP and precipitation response in the western Pacific
- Better representation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

Sub-seasonal variability in the tropics : MJO



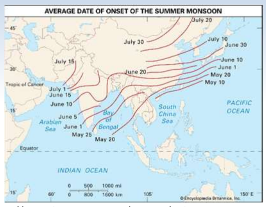
Longitude-time composite of equatorial velocity potential at 200hPa starting from the initial dates with the MJO phase in the Indian Ocean (all seasons)



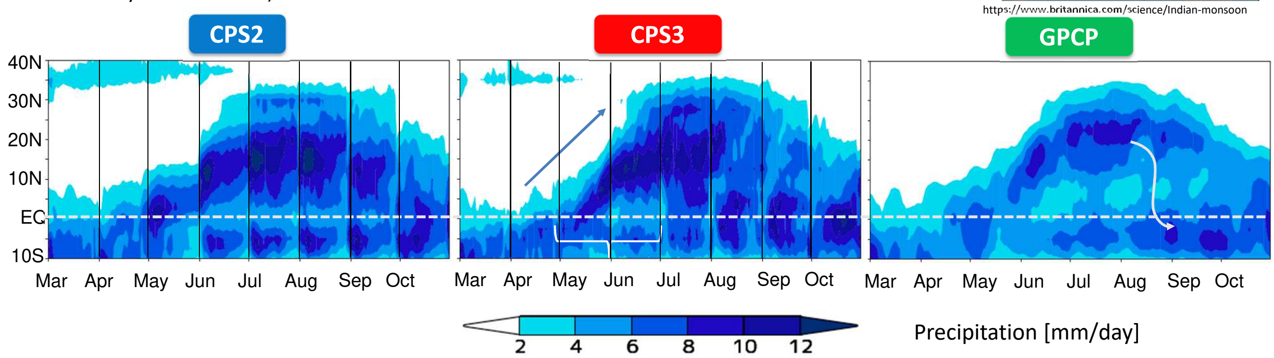
CPS3 improved the representation of MJO eastward propagation.

Seasonal progression of Indian Summer monsoon in the first lead time month

Latitude-time cross section of daily precipitation climatology around India (65-85E).
(1998-2020, 5-member forecasts starting from the last day of each month)



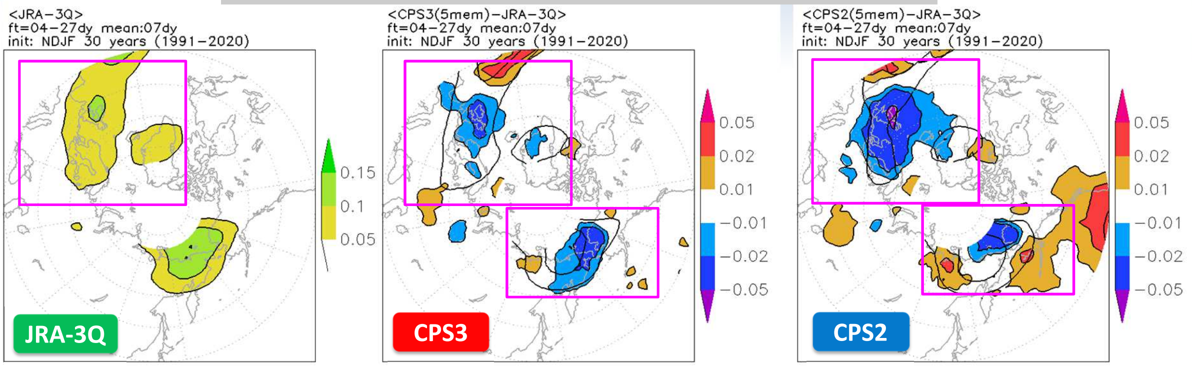
https://www.britannica.com/science/Indian-monsoon



- Northward march of South Asian monsoon precipitation well represented
- On the downside, excessive precipitation and earlier shift of precipitation band to the southern hemisphere

NH Winter Blocking Frequency

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

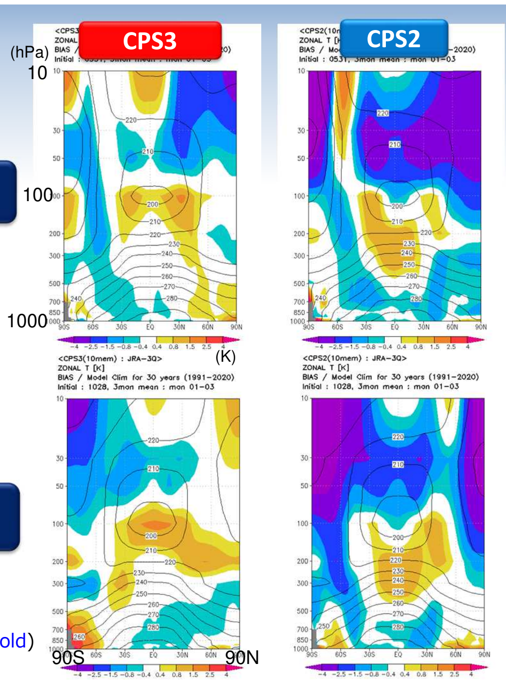


Contour: Frequency
Shade : Frequency bias (less frequent、more frequent)
Blocking detection: defined as a maximum within ±15° north-south direction of 500 hPa geopotential altitude (Scherrer et al. 2006)

- Underestimated blocking highs over 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)

Zonal mean temperature bias

May Initial JJA

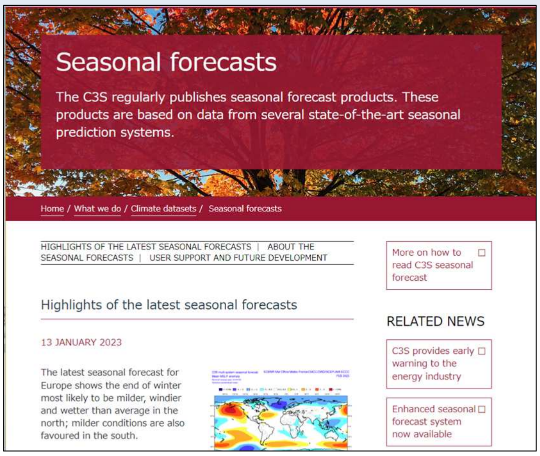


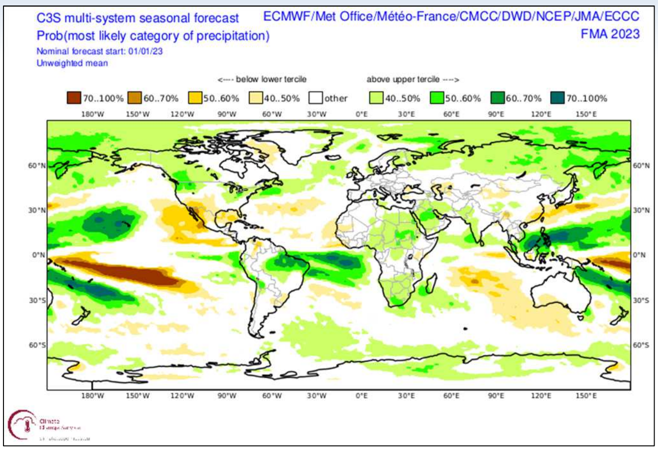
- Tropospheric temperature structure improves in the tropics to mid-high latitudes
- Improvement in the too-strong polar vortex bias in boreal winter
  - Cold bias in the lower-middle stratosphere in the northern polar region
  - Too-strong westerly wind (not shown)

Oct Initial DJF

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

C3S Multi-model Long-range Forecast



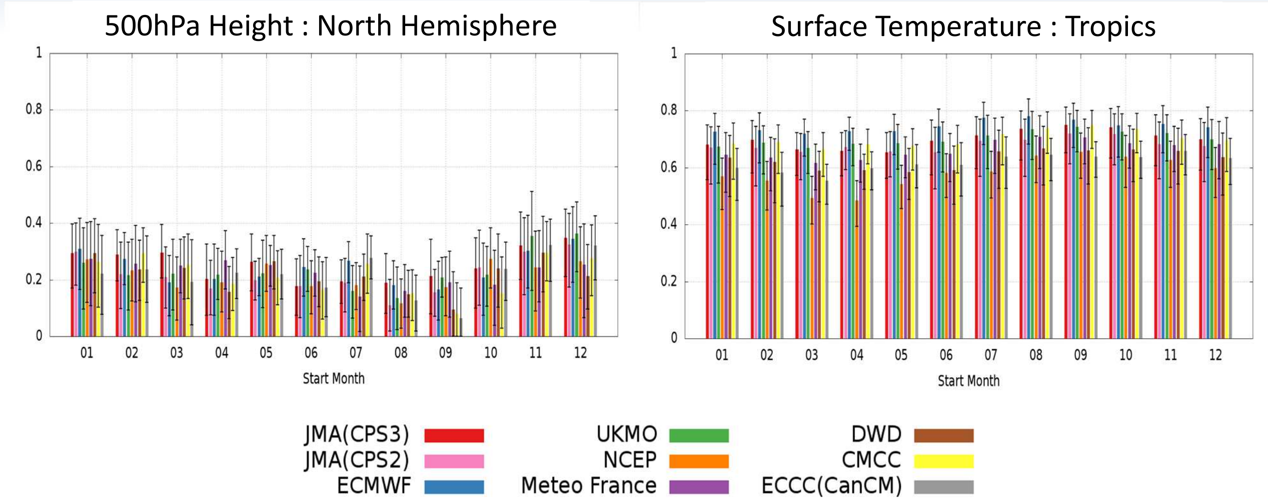


https://climate.copernicus.eu/charts/c3s_seasonal

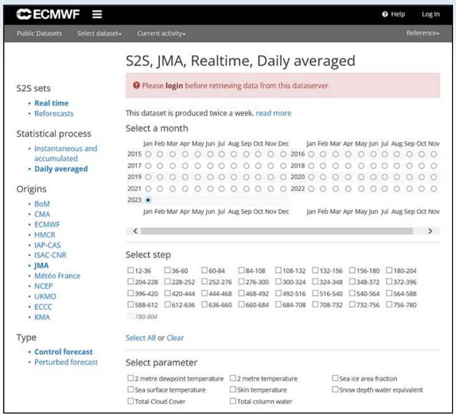
JMA provides 6-month forecast data on the TCC website. The provision on C3S website is once a month.

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

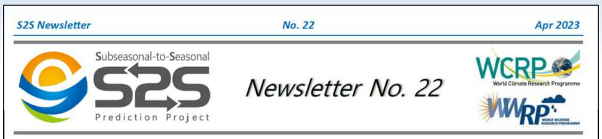
Verification against ERA5

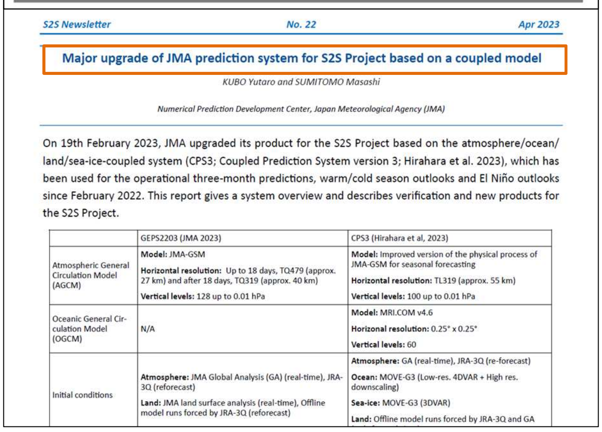


S2S Archived Data for Research



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





S2S Newsletter No. 22 Apr 2023

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

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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

- S2S products have 3-week delay from the operations.
- In Feb 2023, JMA prediction system for S2S was upgraded to the new Seasonal EPS (CPS3).

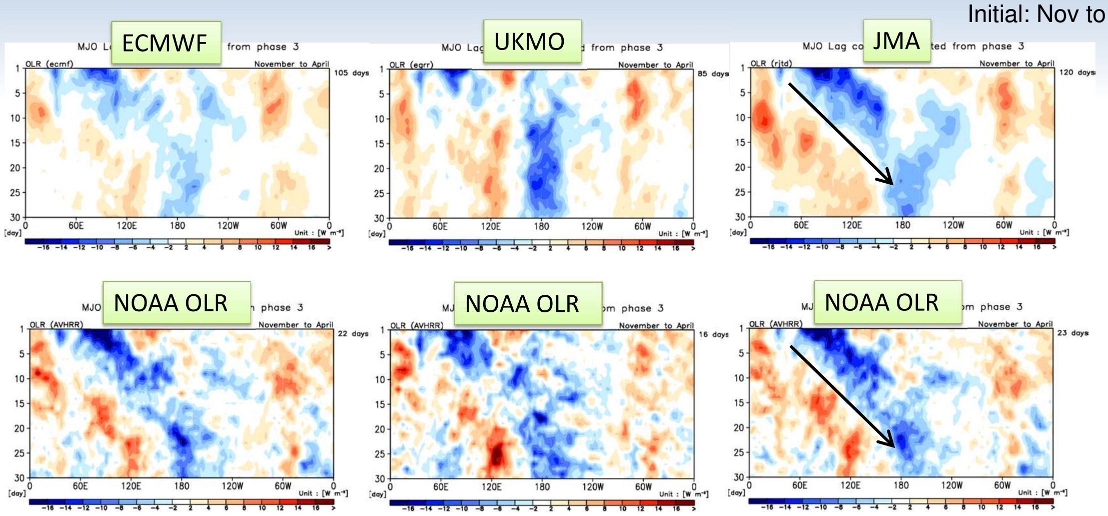
Configuration of Intercomparison: ECMWF, UKMO and JMA

- Hindcast period: 2002-2016
- Ensemble size: 5 member
- Verification datasets: ERA5, MGDSST, GPCPv1.3, NOAA OLR
- Verification grid: 2.5deg

	ECMWF (CY47R3)	UKMO (GloSea6)	JMA (CPS3)
Initial dates (MMDD)	0117 0131 0210 0224 0310 0328 0411 0425 0516 0530 0616 0630 0714 0728 0815 0829 0912 0929 1013 1027 1110 1128 1212 1226	0117 0125 0209 0225 0309 0325 0409 0425 0517 0525 0617 0625 0717 0725 0817 0825 0909 0925 1009 1025 1109 1125 1209 1225	0116 0131 0210 0225 0312 0327 0411 0426 0516 0531 0615 0630 0715 0730 0814 0829 0913 0928 1013 1028 1112 1127 1212 1227

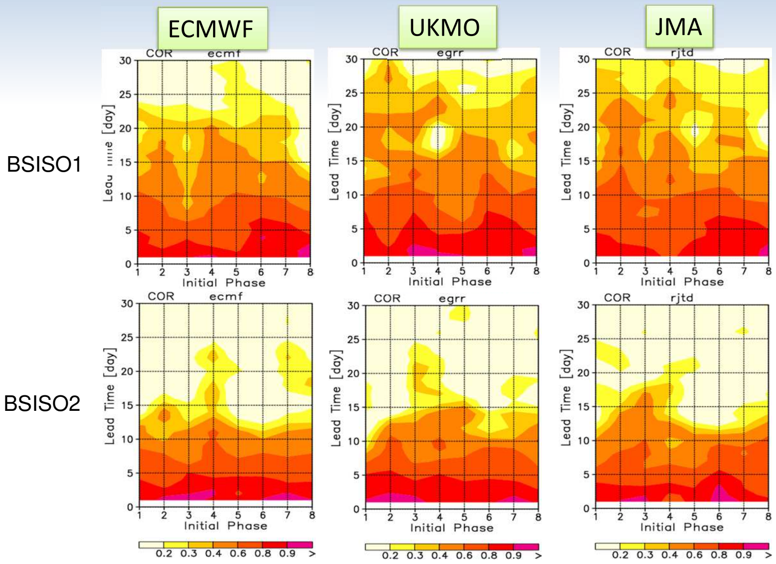
MJO Hovmöller Diagram: OLR Composite started from Phase3

Initial: Nov to Apr



JMA has clear eastward propagation with reasonable amplitude from the Indian Ocean to the date line.

Boreal Summer Intra-Seasonal Oscillation (BSISO)

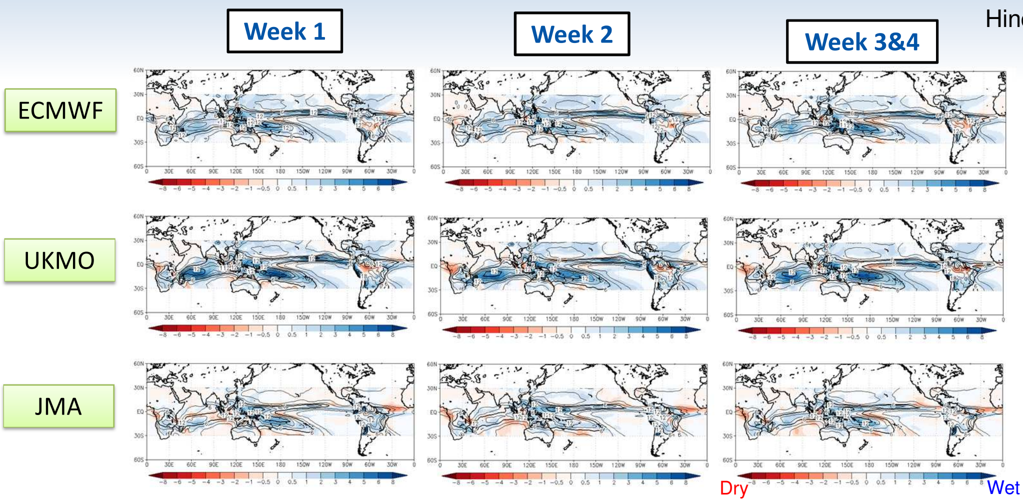


Bivariate Correlation

- Cases of initial amplitude >= 1.5 are verified from May to September using ERA-5.
- JMA model (CPS3) well reproduced BSISO1, the northward/northeastward-propagation mode with 30-60 days cycle.
- BSISO2, related to the pre-monsoon and monsoon-onset with 10-30 days cycle, is relatively not well reproduced by all models.

Boreal Winter (DJF initial) Precipitation bias

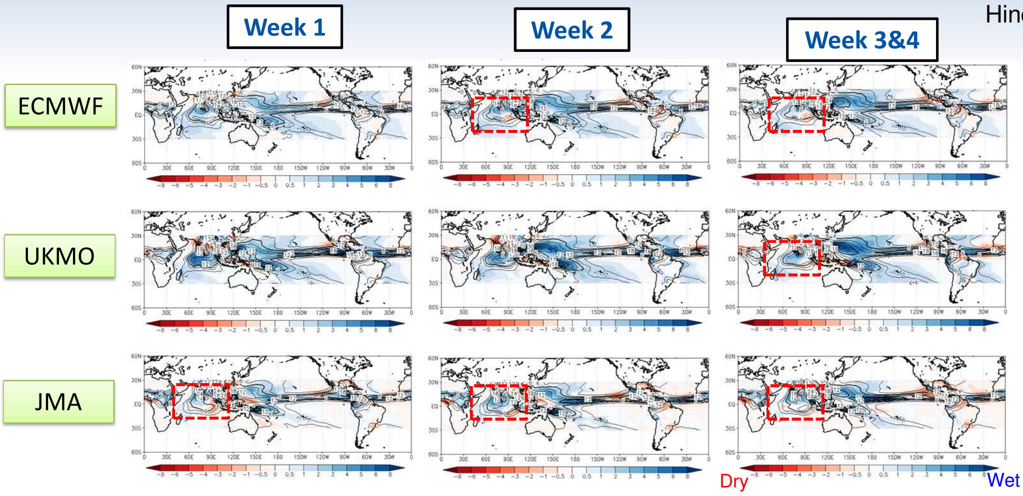
Hindcast 2002-2016



- Excessive precipitation is commonly seen over the tropics from week-1.

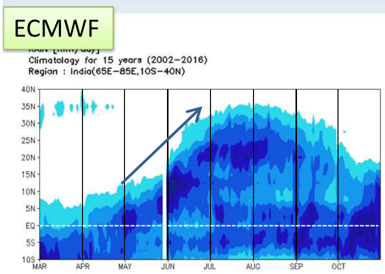
Boreal Summer (JJA initial) Precipitation bias

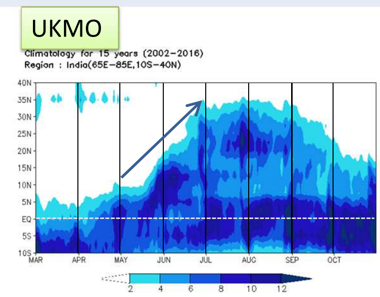
Hindcast 2002-2016

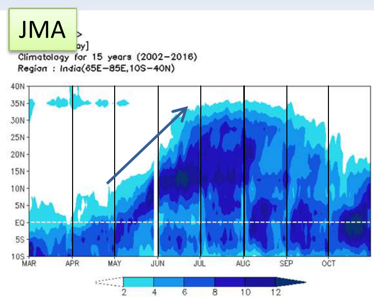


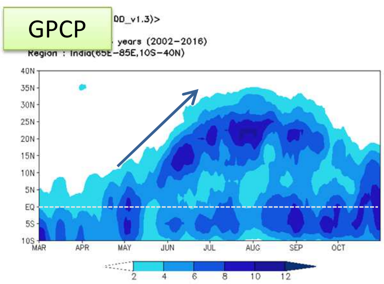
- All 3 models have excessive precipitation over the tropics and IOD-bias is emerging (detailed later).

Seasonal progression of Indian Summer monsoon in the first lead time month



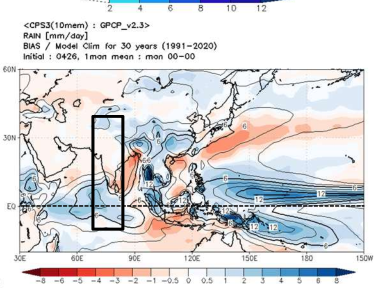






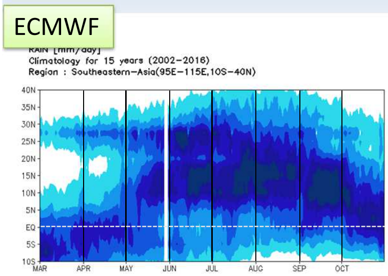
Latitude-time cross section of daily precipitation climatology around India (65-85E).

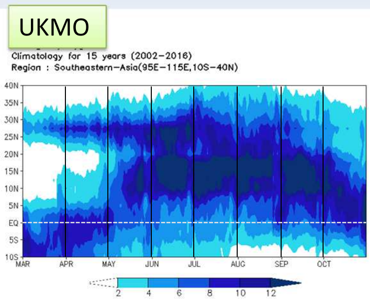
(2002-2016, 5-member forecasts starting from the last day of each month)

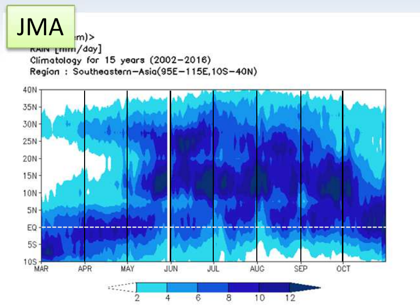


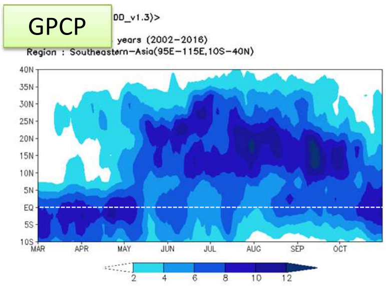
- Northward march and onset of Indian monsoon in May and June are well represented
- Excessive precipitation is seen over 5S-5N for UKMO and 5-20N for JMA, respectively

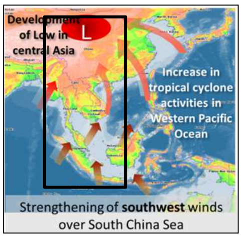
Seasonal progression of Southeast Asian Summer monsoon in the first lead time month











From MSS webpage
http://www.weather.gov.sg/learn_winds/#atmosphere3

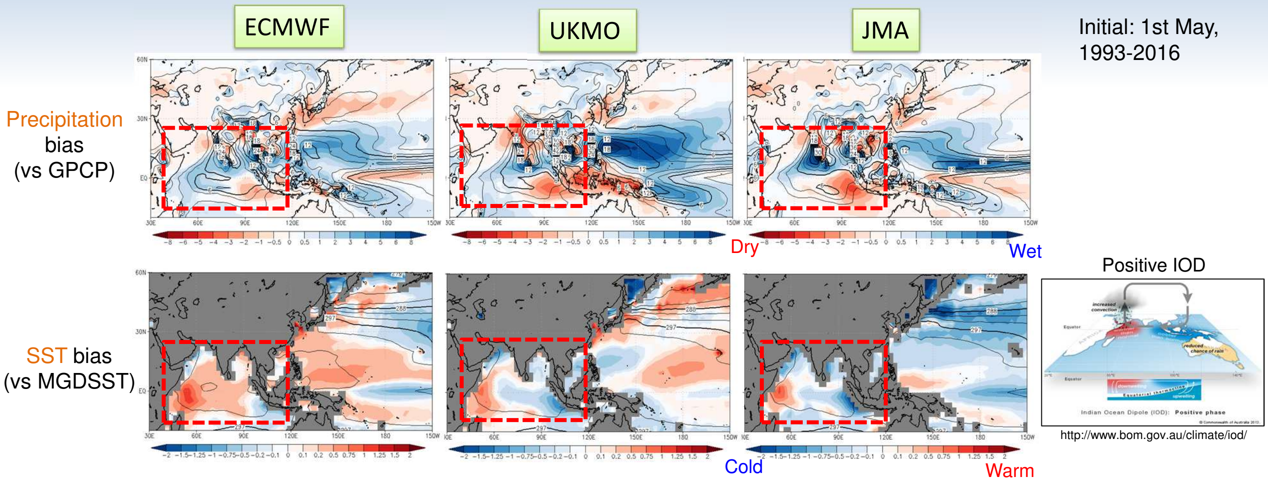
Latitude-time cross section of daily precipitation climatology around India (65-85E).
(2002-2016, 5-member forecasts starting from the last day of each month)

- For Southeast Asian monsoon, all models represent excessive precipitation
- Is there still room for improvement?

Outline

1. Recent upgrade and performance
2. Current issues and future challenges

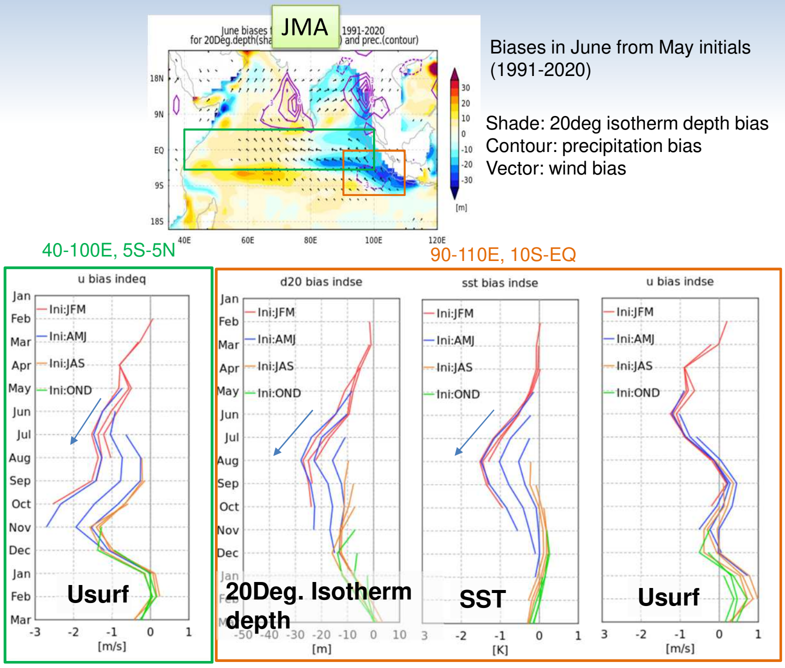
Current Issue 1: Boreal Summer (JJA) bias for C3S models



- All 3 models have common positive-IOD bias with dry and cold-SST area over southeastern Indian Ocean
- This bias is seasonally locked and grows with time in boreal summer-autumn

Current Issue 1(cont'd): Time dependence of Surface wind, D20 and SST bias

- Surface zonal wind bias leads the cold SST bias over south-eastern Indian Ocean in spring
- The equatorial easterly wind bias shallows the thermocline in the south-eastern Indian Ocean through upwelling Kelvin waves, preconditioning the IOD bias in summer
- From the Monsoon onset in Apr, climatological flow becomes easterly in the south-eastern Indian Ocean, reinforcing the cold SST bias through Bjerknes feedback, i.e., D20-SST-wind
- Remote wind forcing from the central Indian Ocean and local reinforcement in the south-eastern Indian Ocean seem influencing factors



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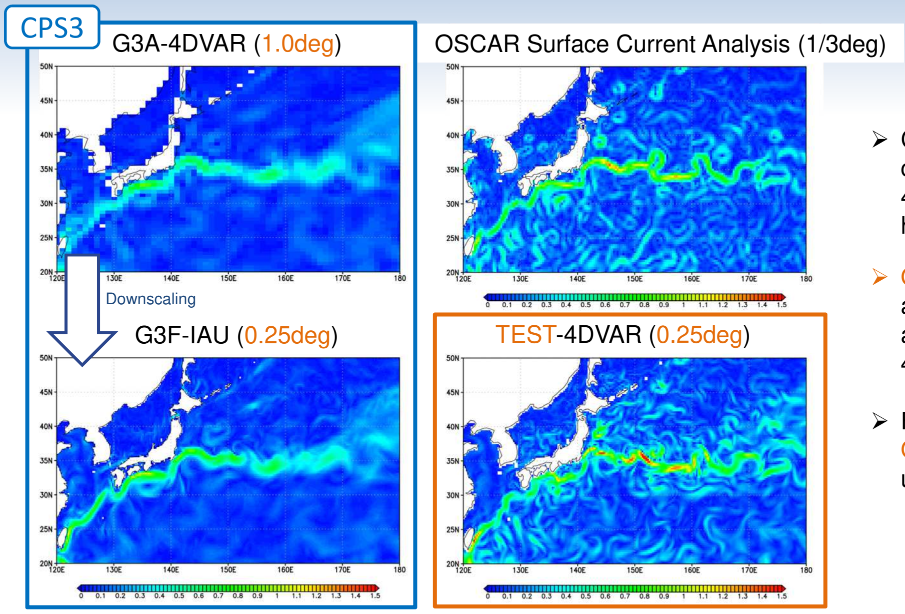


- Currently using the combination of low resolution 4D-Var (1.0x0.3-0.5deg.) and high-resolution IAU (0.25deg.)
- Only large-scale features such as mainstream of the Kuroshio are resolved by the current 4D-Var system.
- Finer resolution (0.25deg) Ocean 4DVAR is currently under development

Future challenge with MRI/JMA: Coupled DA

RESEARCH ARTICLE

Improvements in tropical precipitation and sea surface air temperature fields in a coupled atmosphere–ocean data assimilation system

Yosuke Fujii[1,2] | Toshiyuki Ishibashi[1] | Tamaki Yasuda[3] | Yuhei Takaya[1] | Chiaki Kobayashi[1] | Ichiro Ishikawa[1]

MRI-CDA1

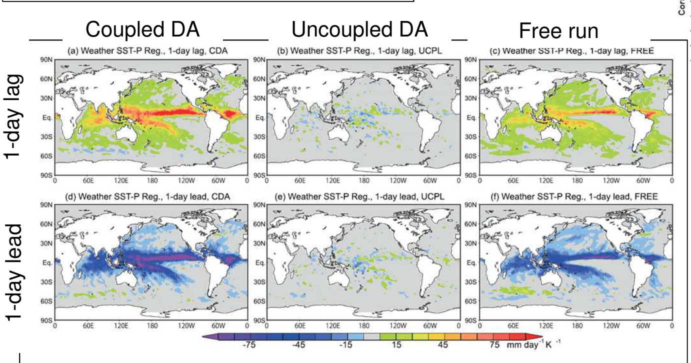
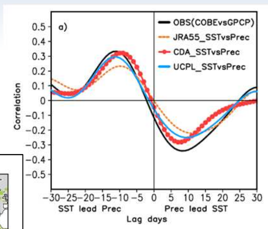


FIGURE 16 Distributions of the precipitation regression coefficients with a 1-day lag (a–c) and a 1-day lead (d–f) on SST at each horizontal point for the weather-timescale variations in CDA-Exp (a, d), UCPL-Exp (b, e) and FREE-Exp (c, f). Units are mm day⁻¹·K⁻¹

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, including 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!

Summary

Seasonal EPS: JMA/MRI-CPS3

- Major upgrade in February 2022
- Enhanced atmosphere and ocean resolution with ocean 4DVAR
- Better prediction skill for ENSO, TIW, MJO, BSISO, monsoon propagation etc.
- IOD-type bias for precipitation and SST