2024/1/30 TCC seminar

Inter-annual variability of atmospheric circulations in the tropics relevant to seasonal prediction for FMA 2024

Shuhei MAEDA CPD/JMA

Outline of the lecture

1. Atmospheric features related to principal modes of inter-annual variability of climate system in the tropics, such as El Nino & IOD, and lagged influences of them
2. Current oceanic and atmospheric condition related to the modes
3. Seasonal prediction for FMA 2024 focusing on influences of the modes

The main purpose of the lecture is to give background knowledge on climate system variability in order to make the exercise more effective.

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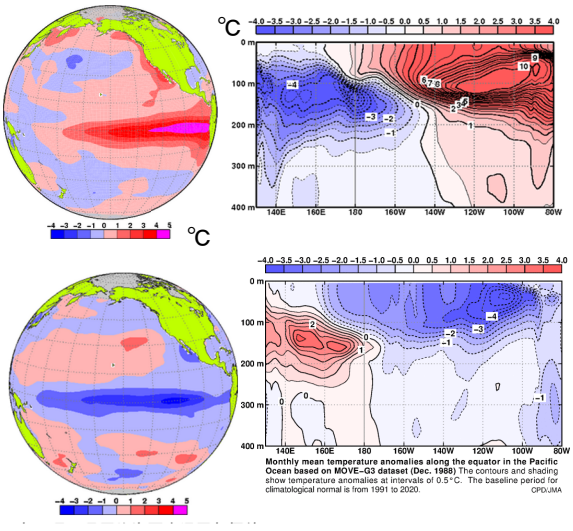
1. Atmospheric features related to principal modes of inter-annual variability of climate system in the tropics, such as El Nino & IOD, and lagged influences of them

3

1.1 El Niño and La Niña

SST anomalies

Sub surface sea water temperature anomalies averaged in the equatorial region in Pacific



in Nov. 1997

El Nino

in Dec. 1988

La Nina

Sub surface water temperatures in the equatorial Pacific also fluctuate as a part of El Nino and La Nina.

El Nino/La Nina is huge east/west thermal variation in the climate system

	Atmosphere	Ocean
Density	$1.2\text{-}1.3 kgm^{-3}$	$10^3 kgm^{-3}$ **about 1000 times of the atmosphere**
Mass /m^2	Top of atmosphere ～ surface: $10^4 kgm^{-2}$	Surface ～ 10m depth : $10^4 kgm^{-2}$ **Mass of all atmosphere is equivalent to the 10m-depth ocean!**
Specific heat	$10^3 Jkg^{-1}K^{-1}$	$4 \times 10^3 Jkg^{-1}K^{-1}$ **4 times of atmosphere**
Heat capacity / m^2	Top of atmosphere ～ surface: $10^7 JK^{-1}m^{-2}$	Surface ～ 2.5m depth : $10^7 JK^{-1}m^{-2}$ **Heat capacity of all atmosphere is equivalent to the 2.5m-depth ocean!**

Thermally, '1K warmer than normal to 250 m in the ocean surface layer' is equivalent to '100K warmer than normal in the atmosphere (top of the atmosphere to the surface)'!!

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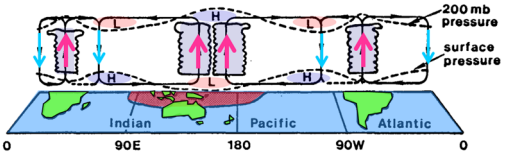
Walker Circulation along the equator during El Nino (lower panel) and La Nina (upper panel)

Webster and Chang 1988

La Nina



El Nino

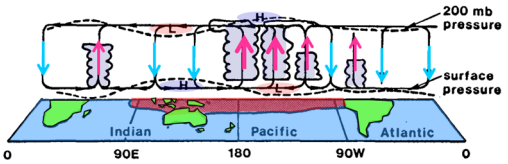


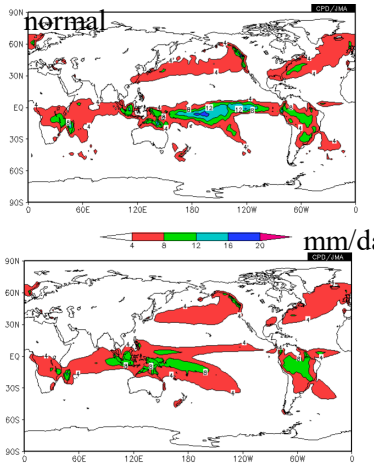
FIG. 1. Schematic view of the Walker Circulation along the equator during El Niño (lower panel) and La Niña (upper panel) periods that occur at the extremes of the Southern Oscillation. The shaded areas indicate sea surface temperatures warmer than 27°C and the dashed lines show relative horizontal pressure variations in the lower and upper troposphere. (From Webster, 1983)

Weak (strong) Walker circulation associated with El Nino (La Nina).

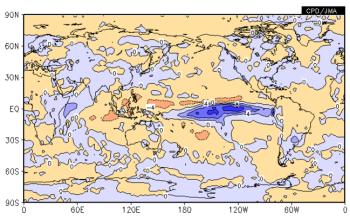
6

Precipitation in 1997/98 winter(DJF)

Upper：1997/98, lower：normal



Anomalies in 1997/98



mm/day

mm/day

Atmospheric heating by condensation

Latent heat rate：$2.5 \times 10^6 Jkg^{-1}$

Heat capacity of the atmosphere per $1m^2$: $10^7 JK^{-1}m^{-2}$

→4kg/day(=4mm/day) condensation heats the atmosphere 1K/day

Heating in the tropics forces atmospheric circulation　w ∝Q

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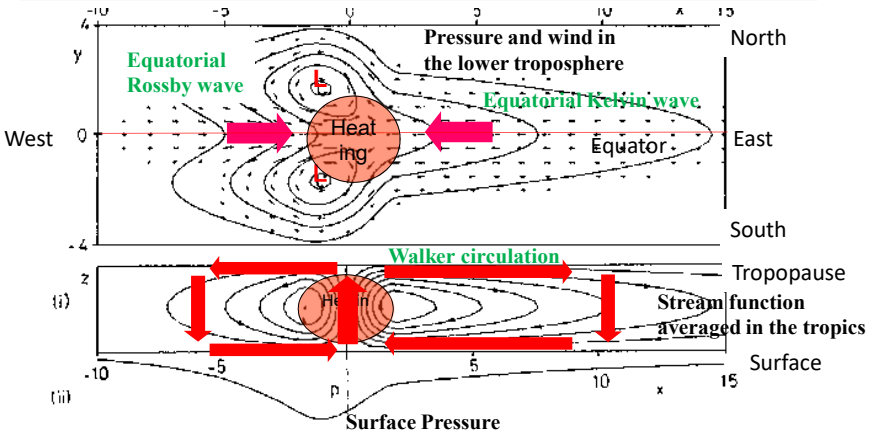
Matsuno-Gill response to heating

- Simple solution for tropical circulation induced by equatorial symmetric heating (β-plain, shallow water, rest atmosphere)
- Eqatorial Kelvin and Rossby waves respond to heat sources associated with convective activity



Gill, A. E., 1980: Some simple solutions for heat-induced tropical circulation. Quart. J. Roy.Meteor. Soc., 106, 447-462.より引用、加筆

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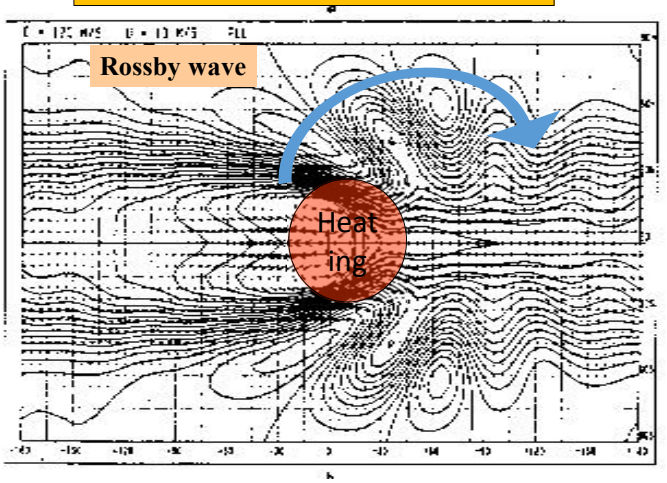
Impact of tropical heating on circulation in mid-latitudes

In the case of a westerly wind basic state, Rossby waves forced in the tropics propagate to the mid-latitudes.



Lim and Chang, 1983

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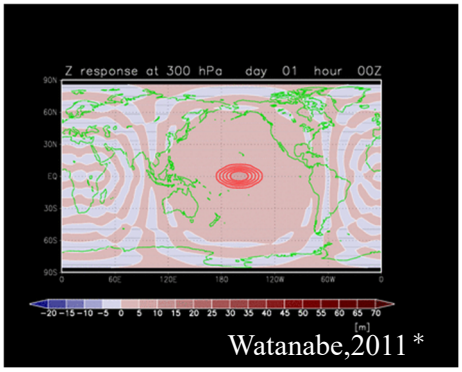
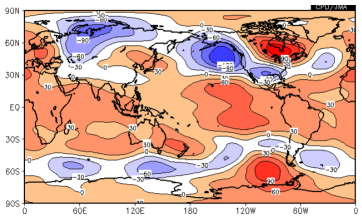
Global atmospheric response to condensation heating in the central equatorial Pacific



Numerical simulation of response to condensation heating in the central equatorial Pacific using a Leaner Baroclinic Model (LBM) Red contours : Forcing (heating rate), White contours:Responces (Geopotential height at 300hPa)

* from his presentation in "Twelfth Joint Meeting for the Seasonal Prediction of the East Asian Winter Monsoon"



Observed geopotential height anomalies at 300hPa in 1997/98 winter (DJF).

Localized condensation heating in the tropics forces Kelvin wave propagate eastward along the equator, and Rossby waves which propagate westward and to the mid-high latitudes.

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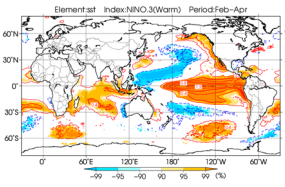
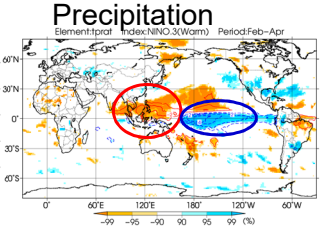
Statistical relationship between NINO.3 and atmospheric circulation fields in FMA

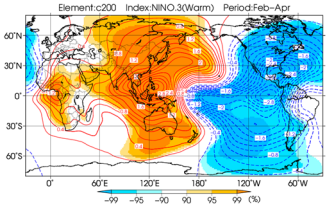
SST



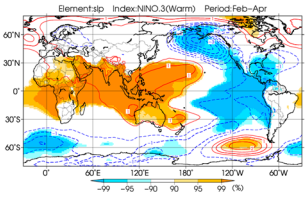
Precipitation



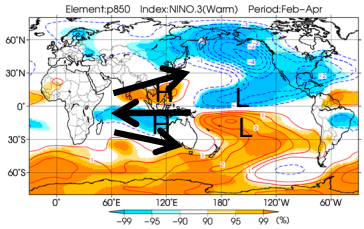
Velocity Potential at 200hPa



Sea Level Pressure



Stream Function at 850hPa



Contours show composite of atmospheric circulation anomalies in the positive (warm) phase of NINO.3 (Feb. – Apr.) Shading indicates the confidence level.
The base period for composite analysis is 1948 – 2021

https://ds.data.jma.go.jp/tcc/tcc/products/clisys/enso_statistics/index.html

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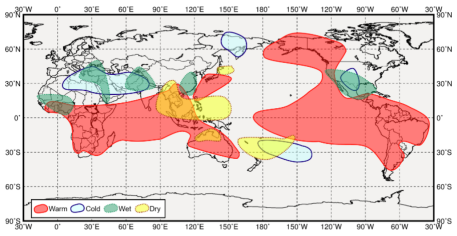
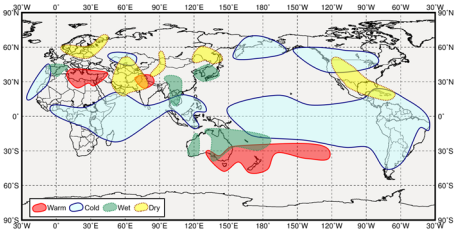
Climate tendencies during El Nino/La Nina

El Nino in boreal spring



La Nina in boreal spring



The maps show the regions where climate tendencies observed during El Niño/La niña episodes are statistically significant in boreal spring.

https://ds.data.jma.go.jp/tcc/tcc/products/climate/ENSO/iobwc.html

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1.2 Lagged El Nino/La Nina influence

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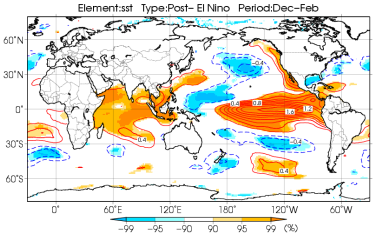
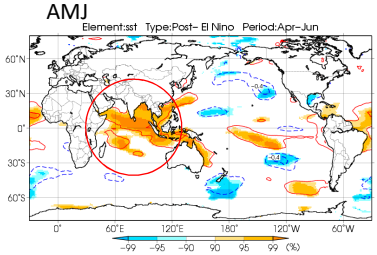
Lagged El Nino influence on Indian Ocean

SST composite in Post El Nino Years

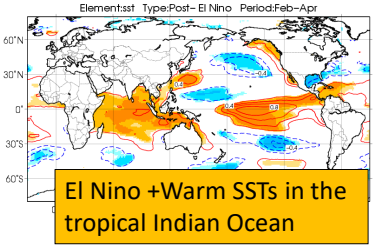
DJF



AMJ

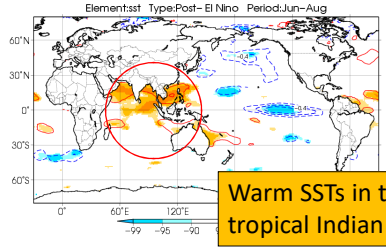


FMA



El Nino +Warm SSTs in the tropical Indian Ocean

JJA



Warm SSTs in the tropical Indian Ocean

Contours show composite of SST anomalies in the post El Nino years. Shading indicates the confidence level.
The post El nino years are 1964,1966, 1970, 1973, 1977, 1983, 1988,1992, 1998, 2003, 2010

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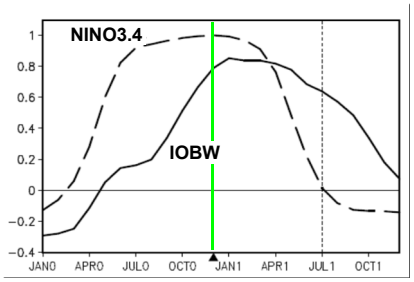
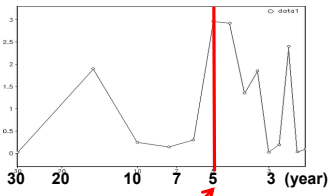
Lagged El Nino influence on Indian Ocean



IOBW: Indian Ocean Basin Wide SST anomalies averaged in 20N-20S,40E-100E

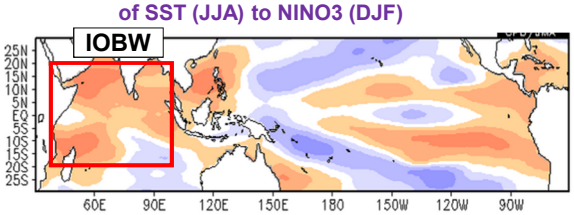
Time evolution of correlation coefficient to NINO3.4 in December

Power spectrum for IOBW (JJA)



Synchronize with ENSO?

6-month lag correlation coefficient of SST (JJA) to NINO3 (DJF)



SSTs in the tropical Indian Ocean rise/drop about one season later than those in the eastern equatorial Pacific.

From Umeda's lecture slide

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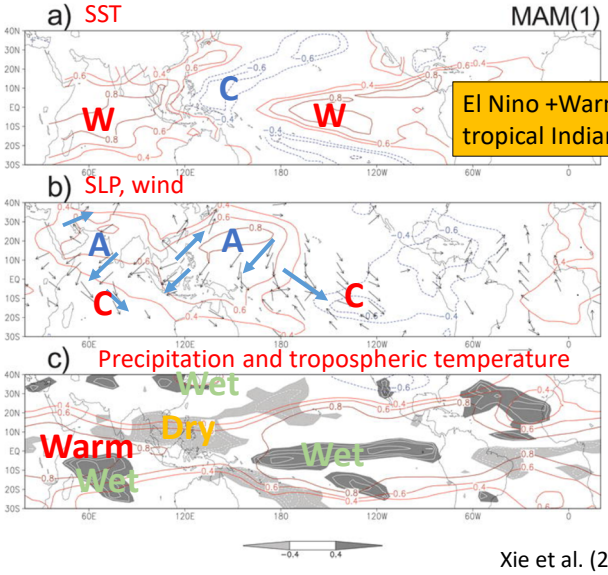
Lagged atmospheric influence of ENSO in spring(MAM)

MAM(1) correlation with the NDI(0) Nino3.4 SST



El Nino +Warm SSTs in the tropical Indian Ocean

Precipitation (gray shade at intervals 0.1), tropospheric temperature(contours)

Xie et al. (2010)

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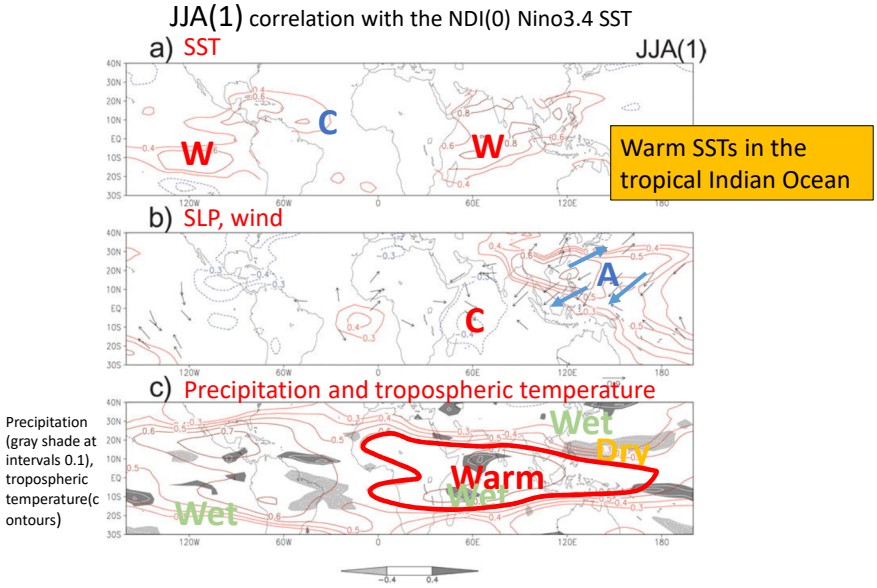
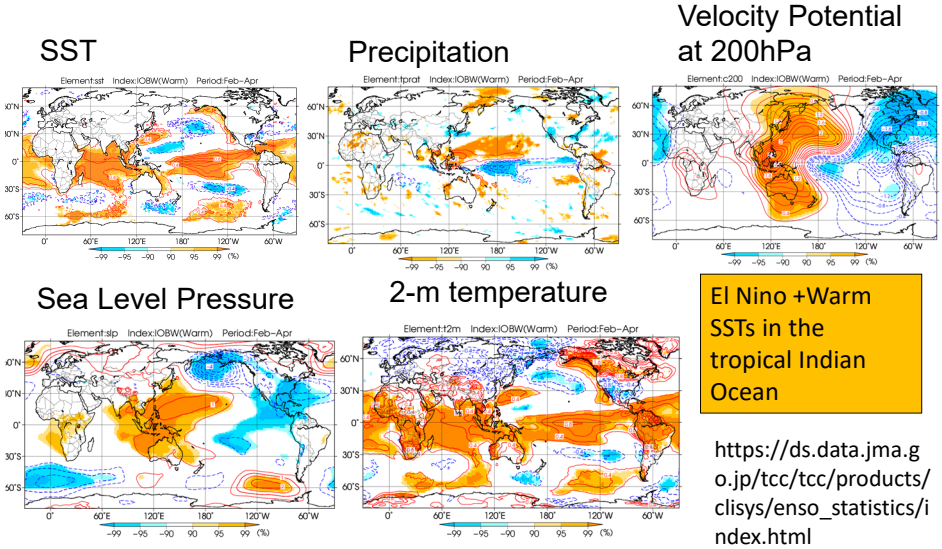
Lagged atmospheric influence of ENSO in spring(JJA)



Warm SSTs in the tropical Indian Ocean

Xie et al. (2010)

Statistical relationship between IOBW and atmospheric circulation fields in FMA

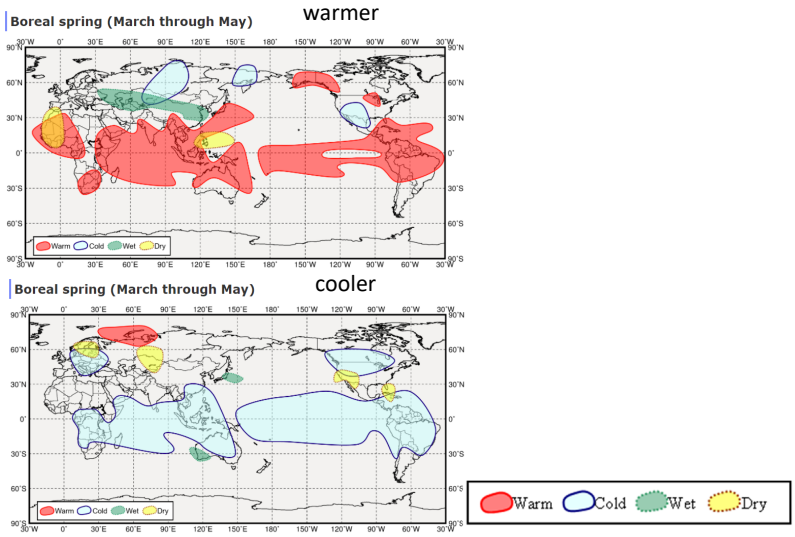


El Nino +Warm SSTs in the tropical Indian Ocean

https://ds.data.jma.go.jp/tcc/tcc/products/clisys/enso_statistics/index.html

Contours show composite of atmospheric circulation anomalies in the positive (warm) phase of IOBW (Feb. – Apr.) Shading indicates the confidence level. The base period for composite analysis is 1948 – 2021

Climate tendencies during warmer/cooler IOBW in boreal spring



The maps show the regions where climate tendencies observed during warmer/cooler IOBW episodes are statistically significant in boreal spring.

https://ds.data.jma.go.jp/tcc/tcc/products/climate/ENSO/iobwc.html

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1.3 Indian Ocean Dipole (IOD) and its lagged influence

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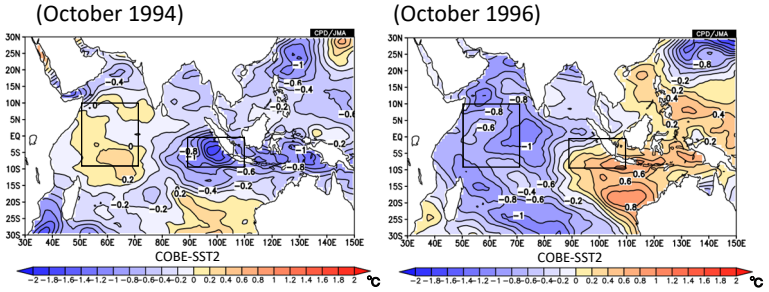
Indian Ocean Dipole (IOD)

SST anomalies for positive IOD (October 1994)

SST anomalies for negative IOD (October 1996)

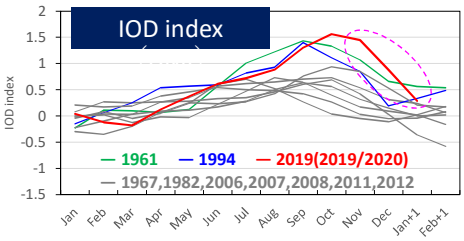


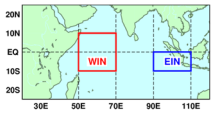
Indian Ocean Dipole (IOD) is a coupled ocean-atmosphere phenomenon in the Indian Ocean. Positive (Negative) IOD is characterized by anomalous cooling (warming) of SST in the south eastern equatorial Indian Ocean and anomalous warming (cooling) of SST in the western equatorial Indian Ocean.

From Umeda's lecture slide

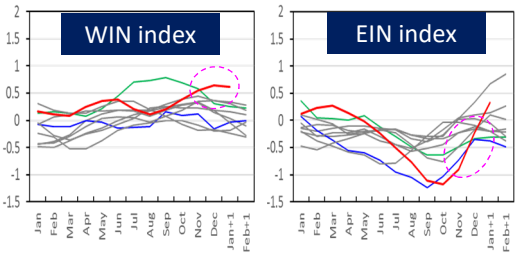
IOD is observed only from summer to autumn. 21

Time series of IOD index (DMI)

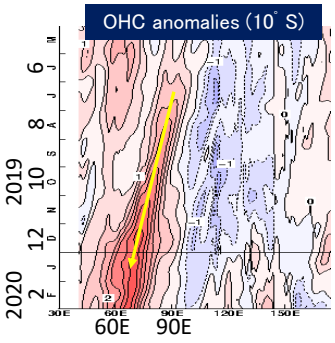




DMI=WIN index−EIN index
Index values are 3-month running means.

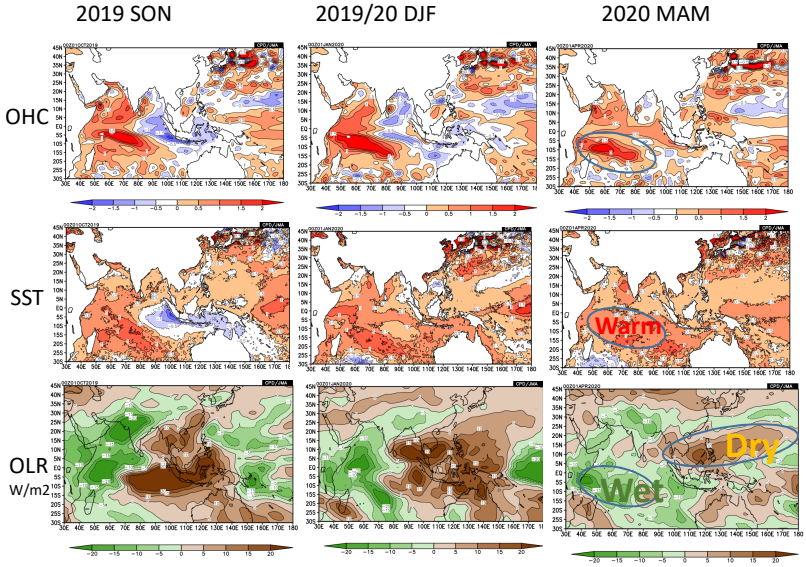


From Umeda's lecture slide



Due to the significant IOD from summer to autumn of the previous year, a significant warm Rossby wave propagated westward around 10˚ S in the Indian Ocean. This contributed to the persistence of positive SST anomaly in WIN. For this reason, the decline in DMI in winter 2019/2020 was slower than in past cases.

Lagged influences of IOD in 2019



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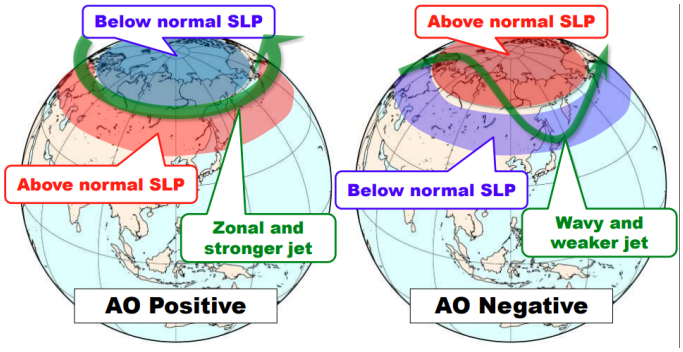
1.4 Arctic Oscillation (AO)(for JMA and NAMEM)

- A seesaw-like oscillation of pressure anomalies between the Arctic and mid-latitudes which dominates climate variability in boreal winter.
- In a positive phase of AO, cold air mass tends to be confined in the Polar region, leading to a warm winter in mid-latitudes.
- In a negative phase of AO, cold air mass flows southward from the Polar region, leading to a cold winter in mid-latitudes.



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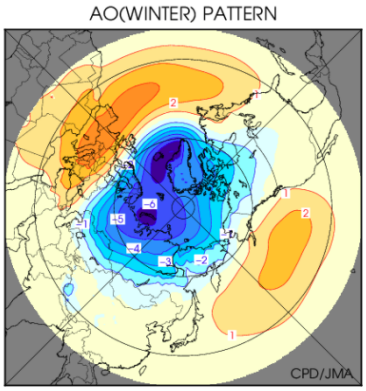
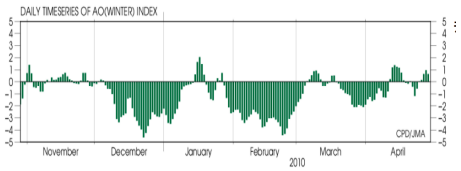
A case of negative AO winter

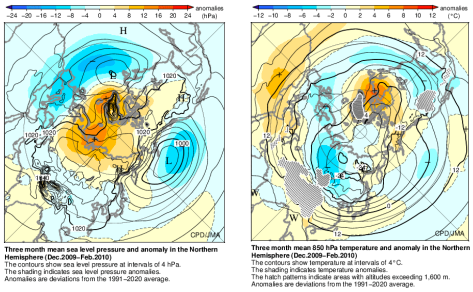
In the operational analysis at JMA, the AO pattern is defined as the leading mode of Empirical Orthogonal Function(EOF) analysis of monthly mean SLP



Daily AO index from Nov. 2009 to Apr. 2010



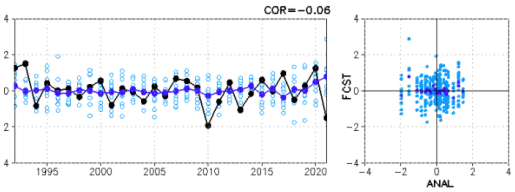
Left) SLP, right) T850 in DJF 2009/10



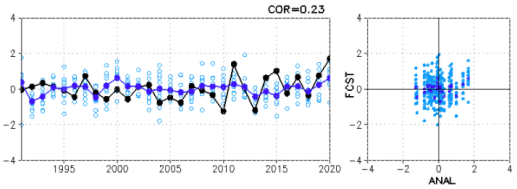
Skill of AO prediction by JMA/MRI-CPS3

Time series/scatter diagram of predicted and observed AO index

DJF (initial dates: 28th Oct. from 1991 to 2020)



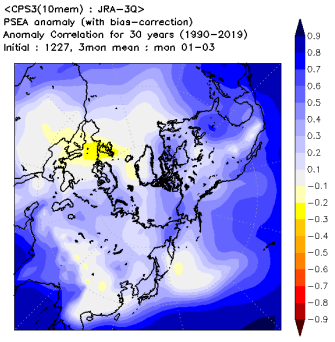
FMA (initial dates: 27th Dec. from 1991 to 2020)



Black:JRA-3Q, blue:CPS3, dark blue: ensemble mean

Prediction skill SLP

FMA (initial dates: 27th Dec. from 1991 to 2020)



2. Current oceanic and atmospheric condition related to the modes

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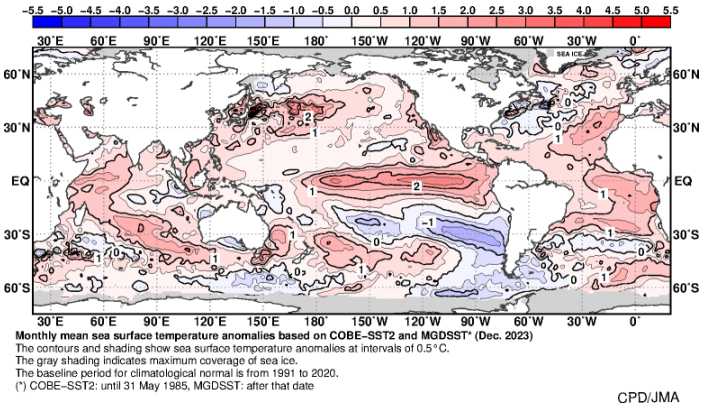
SST

SST anomaly in Dec. 2023



El Nino +positive IOD-like SSTs

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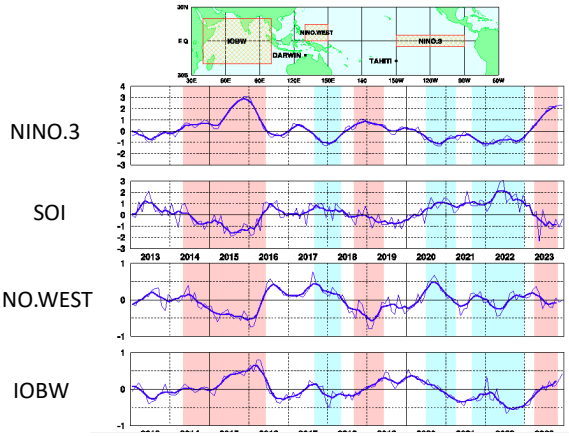
ENSO monitoring indices

ENSO monitoring indices



Time series of sea surface temperature (SST) deviations from the climatological mean based on the latest sliding 30-year period for NINO.3, (the 2nd panel), Southern Oscillation Index (the 3rd panel), SST deviations for NINO.WEST (the 4th panel), and SST deviations for IOBW (the bottom panel). (each region is shown in the top panel).Thin lines indicate a monthly mean value, and smoothed thick curves, a five-month running mean. Red shaded areas denote El Niño periods, and blue, La Niña ones.

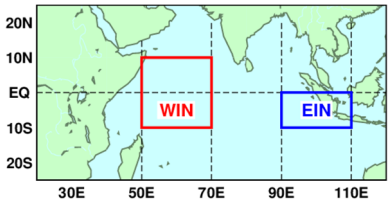
In December 2023, SST for the NINO.3 region was above normal with a deviation of +2.3° C, which was almost the same since it became +2.2° C in August.
El Nino peak

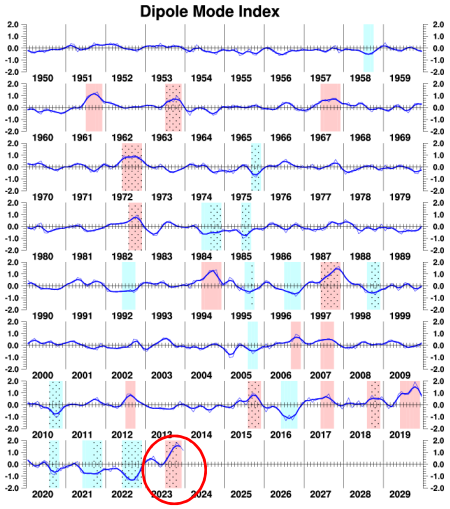
Table El Niño Monitoring Indices.

		2023										
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
NINO.3	Monthly mean SST (°C)	25.1	26.3	27.7	28.1	28.2	27.9	27.6	27.3	27.1	27.2	27.3	27.4
	SST deviation (°C)	-0.4	0.0	+0.5	+0.5	+1.1	+1.3	+1.8	+2.2	+2.2	+2.2	+2.3	+2.3
	5-month mean (°C)	-0.3	0.0	+0.3	+0.7	+1.0	+1.4	+1.7	+1.9	+2.1	+2.2	not yet	not yet
	SOI	+1.0	+1.0	-0.1	+0.3	-2.3	+0.5	-0.6	-1.2	-1.3	-0.4	-1.1	-0.4

29

Dipole Mode Index



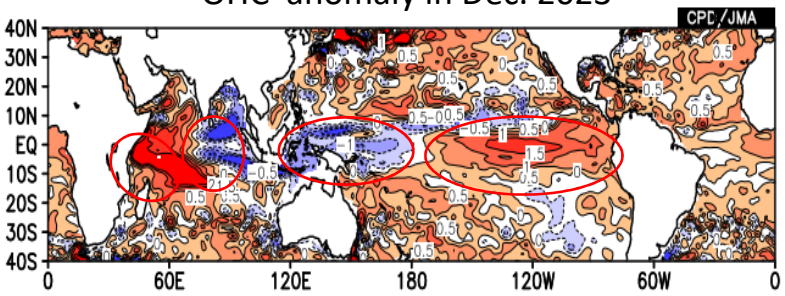


Strong positive IOD in summer and autumn in 2023

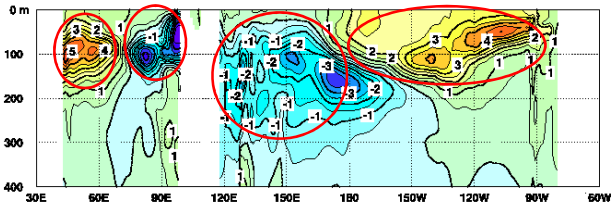
30

Sub surface ocean

OHC anomaly in Dec. 2023



Temperature anomaly along the Equator (Depth - Longitude)

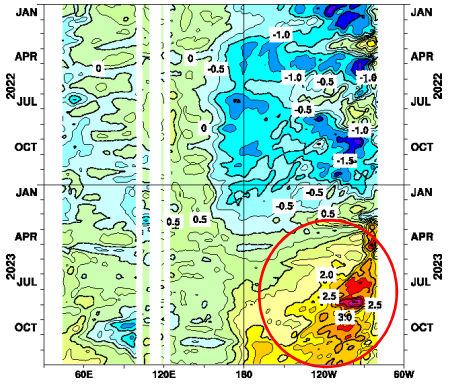


Subsurface temperatures were above normal in the central and eastern equatorial Pacific, and below normal in the western equatorial Pacific.

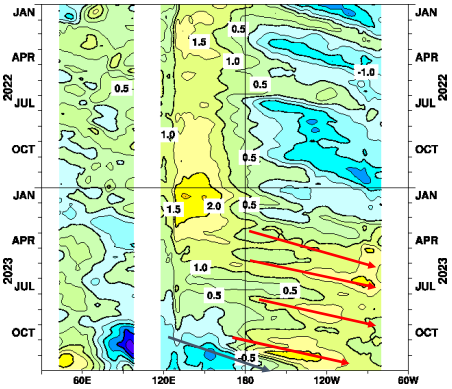
31

Time variation of oceanic condition along the Equator

Sea Surface Temperature Anomalies along the Equator (Time - Longitude)



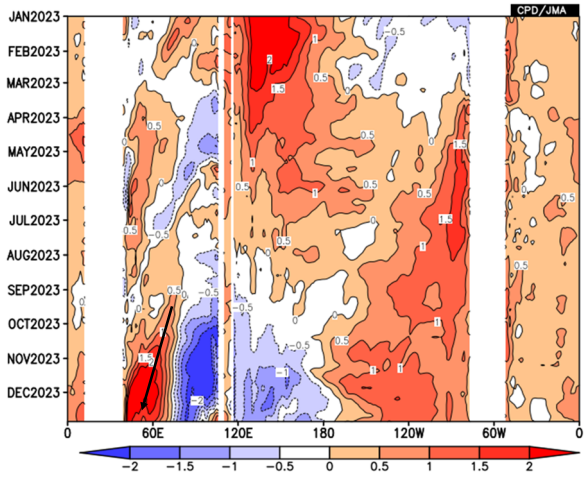
Ocean Heat Content Anomalies along the Equator (Time - Longitude)



32

Time variation of oceanic condition along 6S

Ocean Heat Content Anomalies along 6S(Time - Longitude)

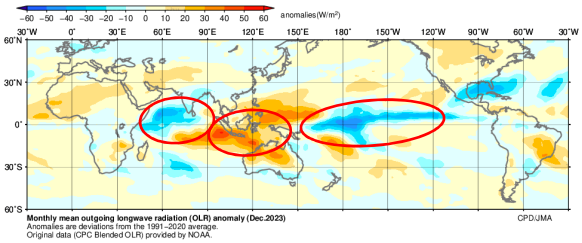


A strong warm Rossby wave is propagating westward off the equator in the southern Indian Ocean.

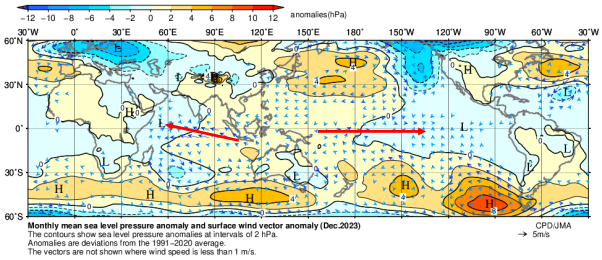
33

Atmospheric conditions

OLR anomaly in Dec. 2023



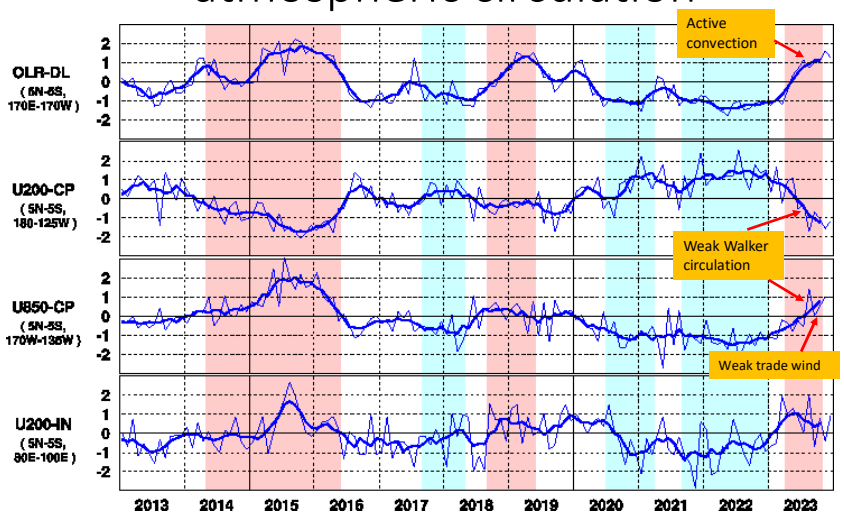
SLP and surface wind vector anomaly in Dec. 2023



In the atmosphere, convective activity over the central equatorial Pacific was above normal and easterly winds in the lower troposphere (i.e., trade winds) over the central equatorial Pacific were weaker than normal.

34

Time series of monitoring index of tropical atmospheric circulation



35

Diagnosis of principal modes in climate system -ENSO and IOD-

- Oceanic and atmospheric conditions over the equatorial Pacific indicate mature El Niño conditions.
- In Indian Ocean, a strong positive IOD event occurred during summer and fall in 2003. Associated with the event, a strong warm Rossby wave is propagating westward off the equator in the southern Indian Ocean.

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3. Seasonal prediction for FMA 2024 focusing on influences of the modes

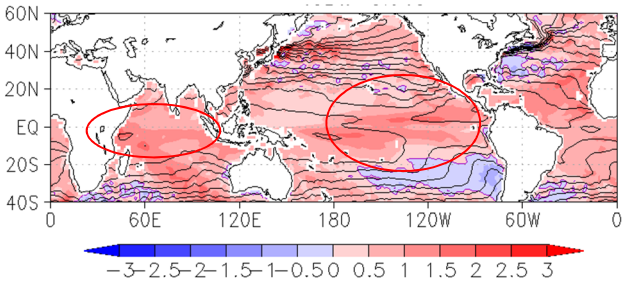
Model : JMA/MRI-CPS3
Initial date : 2024/1/14
Ensemble size: 51
Normal : 30-year (1991-2020) mean of predicted fields
Evaluation : 30-year hindcast with 10 ensemble member

https://ds.data.jma.go.jp/tcc/tcc/products/elnino/index.html
https://ds.data.jma.go.jp/tcc/tcc/products/model/indices/3-mon/indices1/shisu_forecast.php
https://ds.data.jma.go.jp/tcc/tcc/products/model/hindcast/CPS3/nino/ts/index.html
https://ds.data.jma.go.jp/tcc/tcc/products/model/index.html

37

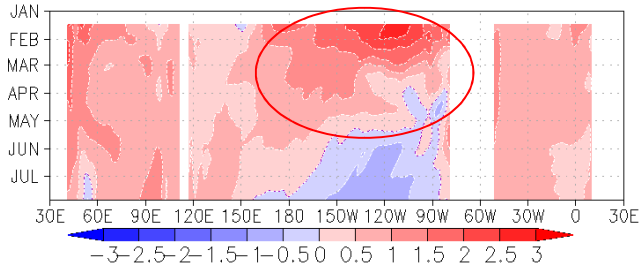
SST

SST and anomaly in FMA



The key point to consider is how the atmospheric will be affected by the El Niño event and tropical Indian Ocean SSTs.

Time-longitude cross section of SST anomaly along the Equator

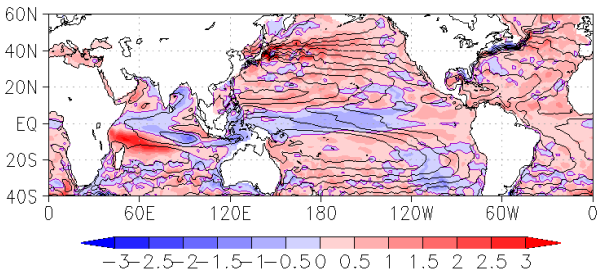


El Nino, which peaked in this early winter, will gradually decay into summer.

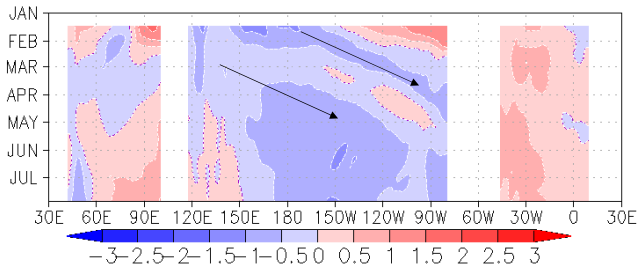
38

Ocean Heat Content

OHC anomaly in FMA



Time-longitude cross section of OHC anomaly along the Equator

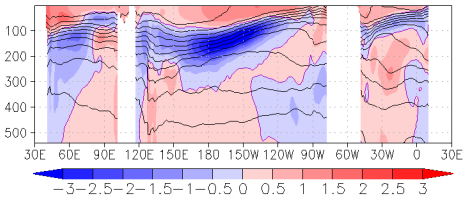


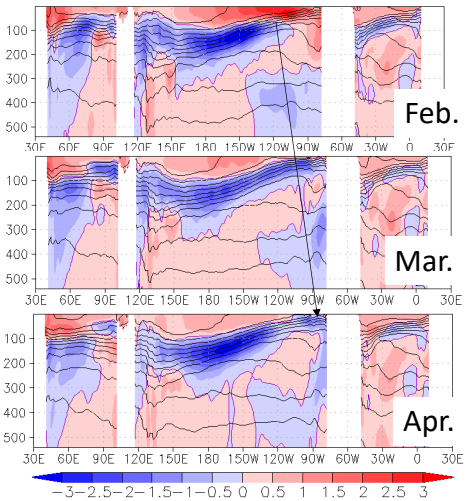
El Nino, which peaked in this early winter, will gradually decay into boreal summer as cold water volume in the western equatorial Pacific moves eastward.

39

Sub-surface water temperature and anomaly along the Equator (Depth - Longitude)

FMA



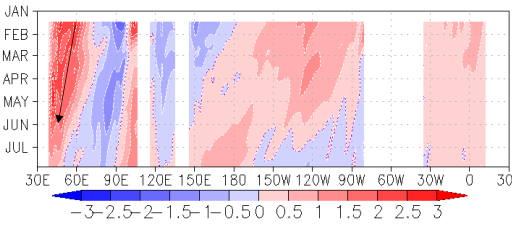


The El Niño, which peaked this early winter, will gradually decay over the summer as the cold water in the western equatorial Pacific moves eastwards.

40

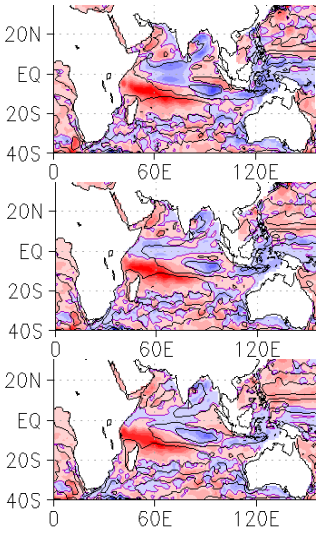
OHC anomaly along 6S

Time-longitude cross section of OHC anomaly along 6S



A strong warm Rossby wave, which was forced by surface wind associated with positive IOD and El Nino, will continue to propagate westward off the equator in the southern Indian Ocean.

OHC anomaly



Feb.

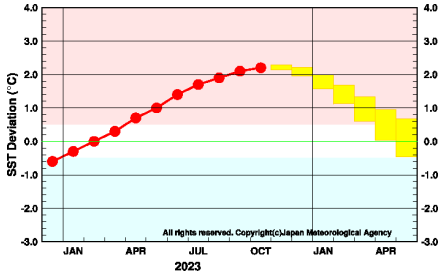
Mar.

Apr.

41

Five-month running mean of the SST deviation for NINO.3

Red dots indicate observed values, and boxes indicate predictions. Each box denotes the range where the value will be included with the probability of 70%.



The El Niño event, which has persisted since last spring and is in its mature phase in the fist half of the winter, will gradually decay. It is more likely to transition to ENSO-neutral conditions (60%) by the end of boreal spring than the event will persist (40%).

ENSO forecast probabilities

Red, yellow, and blue bars indicate probabilities that the five-month running mean of NINO.3 SST deviation from the latest sliding 30-year mean is +0.5° C or above (El Niño), between +0.4° C and -0.4° C (ENSO Neutral), and -0.5° C or below (La Niña), respectively. Labels in lightface indicate the past months, and ones in bold face indicate the current and future months.

YEAR	MONTH	mean period	El Niño	ENSO neutral	La Niña
2023	NOV	SEP2023–JAN2024	100		
	DEC	OCT2023–FEB2024	100		
2024	**JAN**	**NOV2023–MAR2024**	100		
	FEB	**DEC2023–APR2024**	90	10	
	MAR	**JAN2024–MAY2024**	80	20	
	APR	**FEB2024–JUN2024**	50	50	
	MAY	**MAR2024–JUL2024**	40	60	

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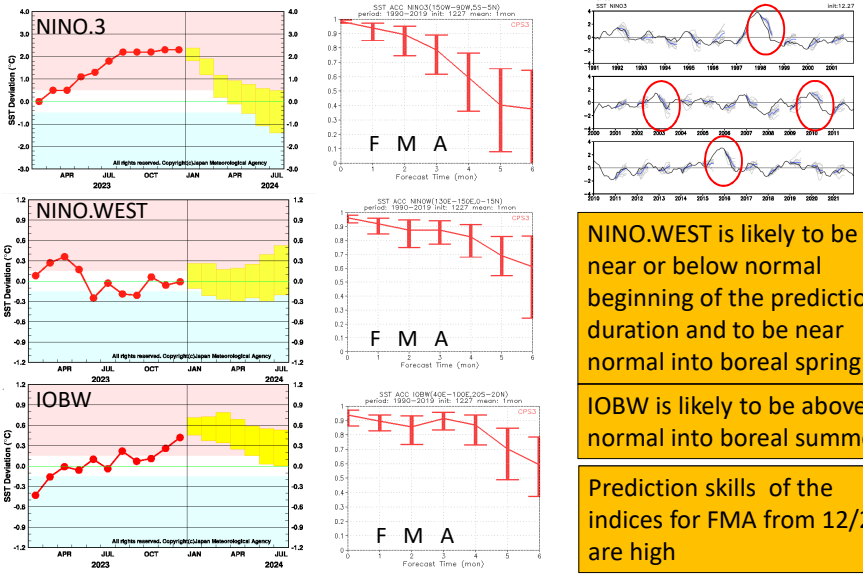
Monthly values El Nino monitoring indices

Prediction skill init.:1227

Nino.3 Prediction cases init.:1227



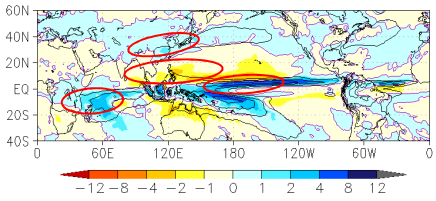
NINO.WEST is likely to be near or below normal beginning of the prediction duration and to be near normal into boreal spring

IOBW is likely to be above normal into boreal summer

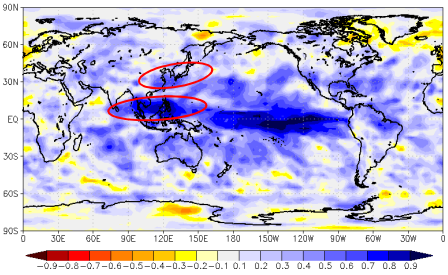
Prediction skills of the indices for FMA from 12/27 are high

Precipitation

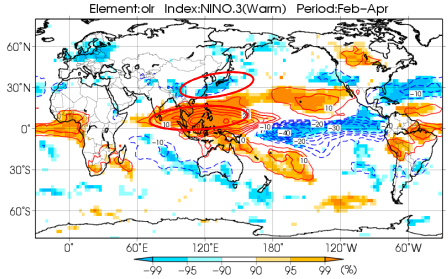
Precipitation and anomaly in FMA



Prediction skill init:1227



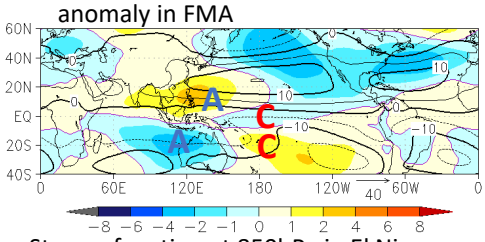
OLR in El Nino years



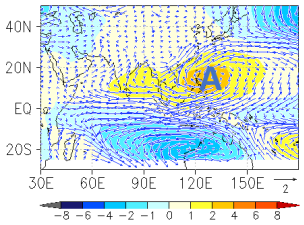
Above-normal precipitation over the southwestern Indian Ocean, western and central equatorial Pacific, and southeastern East Asia
Below-normal precipitation over and around the Philippines

Lower tropospheric circulation

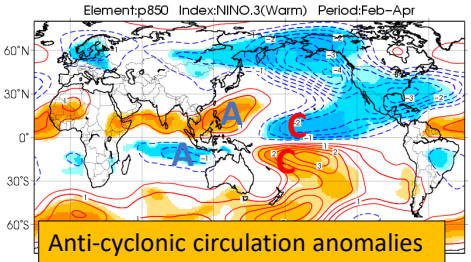
Stream function at 850hPa and anomaly in FMA



Stream function and wind vector anomaly at 850hPa

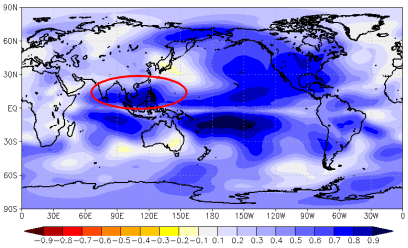


Stream function at 850hPa in El Nino years



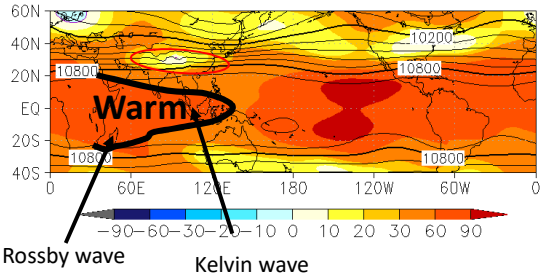
Anti-cyclonic circulation anomalies from the Bay of Bengal to east of the Philippines

Prediction skill init:1227



Tropospheric temperature

Thickness anomaly between 200hPa and 850h in FMA

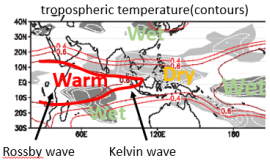


Rossby wave

Kelvin wave

MAM(1) correlation with the NDI(0) Nino3.4

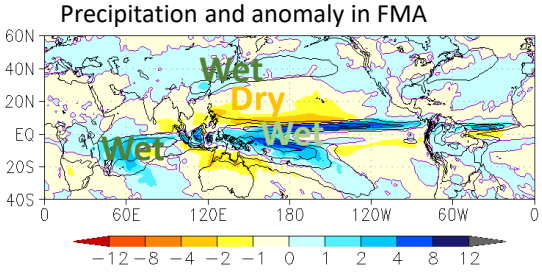
Precipitation (gray shade at intervals 0.1), tropospheric temperature(contours)



Rossby wave Kelvin wave

Xie et al. (2010)

Precipitation and anomaly in FMA

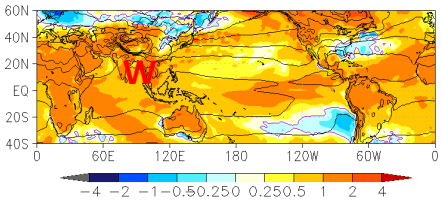


Warm tropospheric temperature in the whole tropics, with Matsuno-Gill pattern like shape in the Indian Ocean

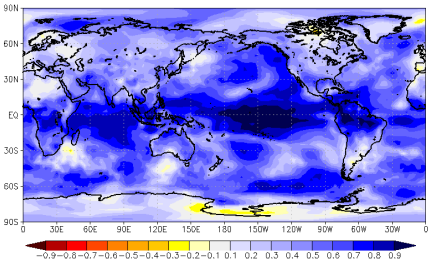
Relatively low from Tibet to East China sea

Surface Temperature

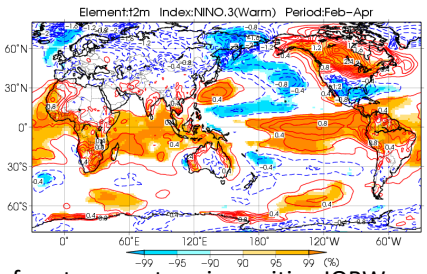
Surface temperature and anomaly in FMA



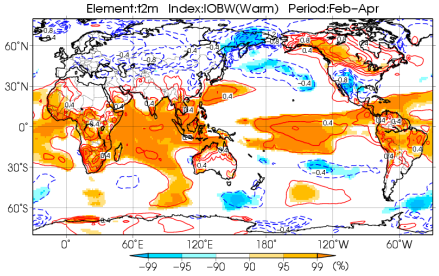
Prediction skill init:1227



Surface temperature in El Nino years



Surface temperature in positive IOBW years



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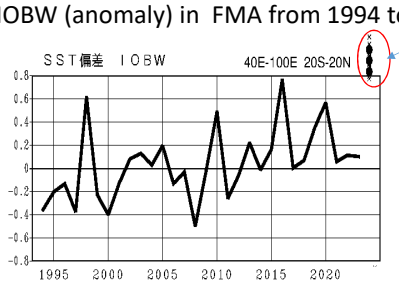
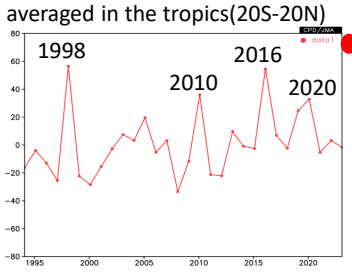
Extreme warm IOBW years

IOBW (anomaly) in FMA from 1994 to 2023



Prediction of 2024

Thickness anomaly between 200hPa and 850h in FMA from 1994 to 2023 averaged in the tropics(20S-20N)



Prediction of 2024

Extreme warm IOBW is predicted.

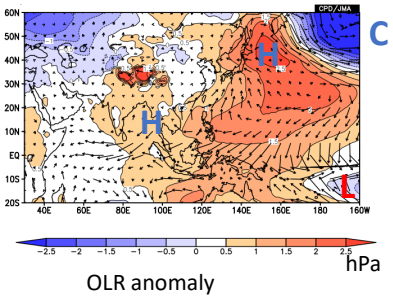
Past extreme warm IOBW years were also extreme warm tropospheric temperature years in the tropics

48

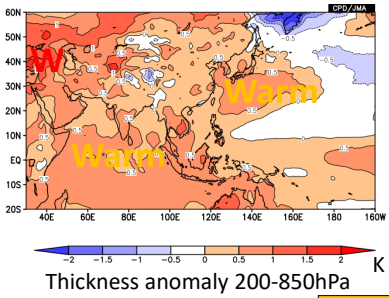
Composite in extreme warm IOBW years

FMA 1998, 2010, 2016, 2020

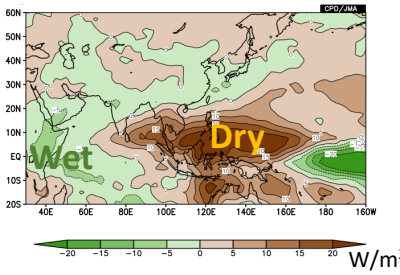
SLP and surface wind anomaly



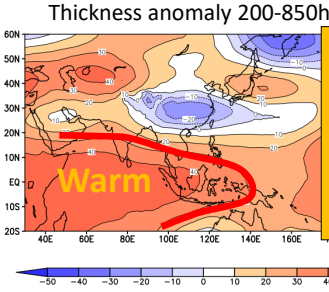
Surface temperature anomaly



OLR anomaly



Thickness anomaly 200-850hPa

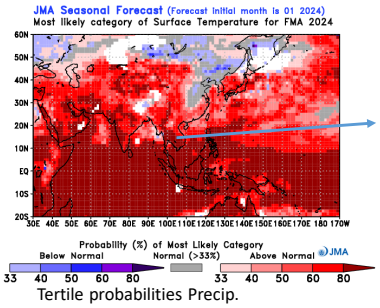


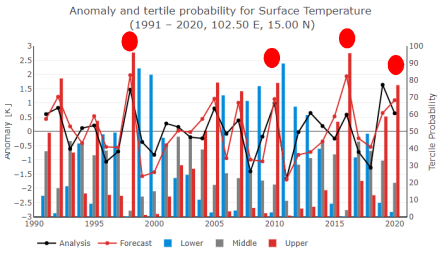
Anomaly patterns of composite maps in extreme warm IOBW years are similar to those of predicted anomaly patterns.

Example of TCC Probabilistic Forecast

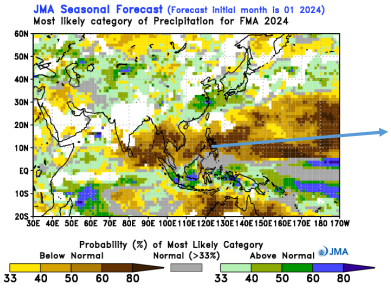
1998,2010,2016,2020

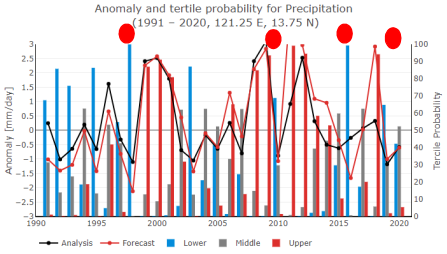
Tertile probabilities Temp.





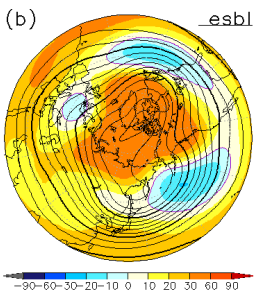
Tertile probabilities Precip.



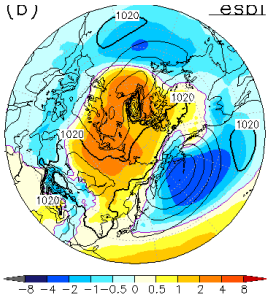


Circulation in mid and high latitudes

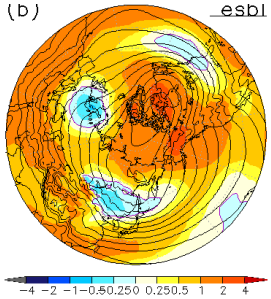
Geopotential height and anomaly at 500hPa in FMA



Sea level pressure and anomaly in FMA

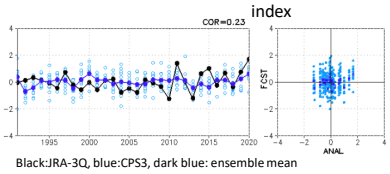


Temperature and anomaly at 850hPa in FMA



Negative AO is predicted, and resultant negative or near normal T850 anomalies are predicted near Mongolia. However, prediction skill of AO is low.

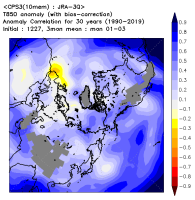
FMA (initial dates: 27th Dec. from 1991 to 2020)



Black:JRA-3Q, blue:CPS3, dark blue: ensemble mean

Time series/scatter diagram of predicted and observed AO index

Prediction skill of T850 init:1227



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Prediction of principal modes and related variation in climate system in FMA 2024

- The El Niño event, which has persisted since last spring and is in its mature phase in the fist half of the winter, will gradually decay. It is more likely to transition to ENSO-neutral conditions (60%) by the end of boreal spring than the event will persist (40%).
- A strong positive IOD event occurred during summer and fall in 2023 forced a strong warm Rossby wave which is propagating westward off the equator in the southern Indian Ocean. The propagation will persist until summer in 2024.
- In FMA 2024, a significant above normal IOBW event is expected. The event is associated with the decaying El Niño event and the strong positive IOD event in last summer and fall: the remnants of El Niño and IOD.
- The decaying El Niño and the positive IOBW warms the tropospheric atmosphere in the tropics, and the positive IOBW forces a warm Kelvin wave which propagates eastward to the western Pacific along the equator, and a Rossby wave which propagates westward off the equator. The decaying El Niño also forces anti-cyclonic circulation anomalies, a Rossby wave, in the western North Pacific.
- The warmed atmosphere in the tropics and circulation anomalies related to the waves are main factors of CPS3's prediction of local climate in Indo-Pacific region for FMA 2024.

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