Prediction Capabilities: Monsoons (2019-2024)

Yuhei Takaya*, Hongli Ren

*Meteorological Research Institute, Japan Meteorological Agency

With inputs from Monsoons initiative members

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Contents

- Reports on the research progress by members since WGSIP24.
- Summary of the Monsoon Initiative.
- Discussion on the possible renewal of the Monsoon initiative.

Main progresses in the monsoon and its precipitation predictions

From Hong-Li Ren's group in CMA

1) Found the new precursors for the East-Asian monsoon and precipitation variability

2) Evaluated dynamical model predictions of the monsoon and precipitation variability

3) Error corrections of dynamical predictions of the East-Asian monsoon precipitation

15 October, 2024

1) Found the new precursors for the East-Asian monsoon and precipitation variability

- **The soil moisture in the late spring (May) over North Eurasia is negatively correlated with the summer rainfall in the northern East Asia, potentially used as a precursor**

May Soil moisture

JJA precipitation

High Corr of the two Indices

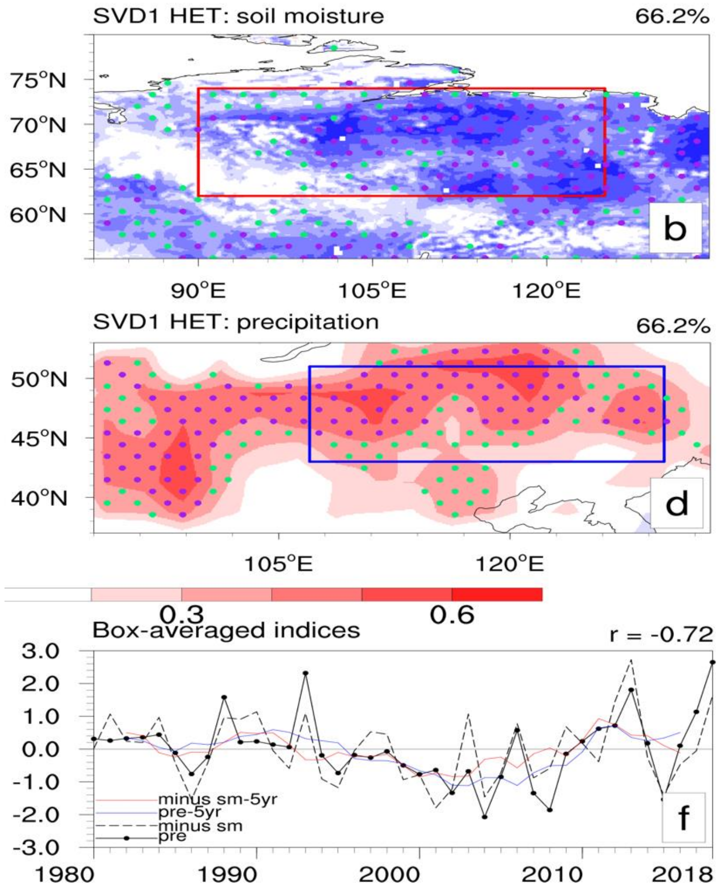
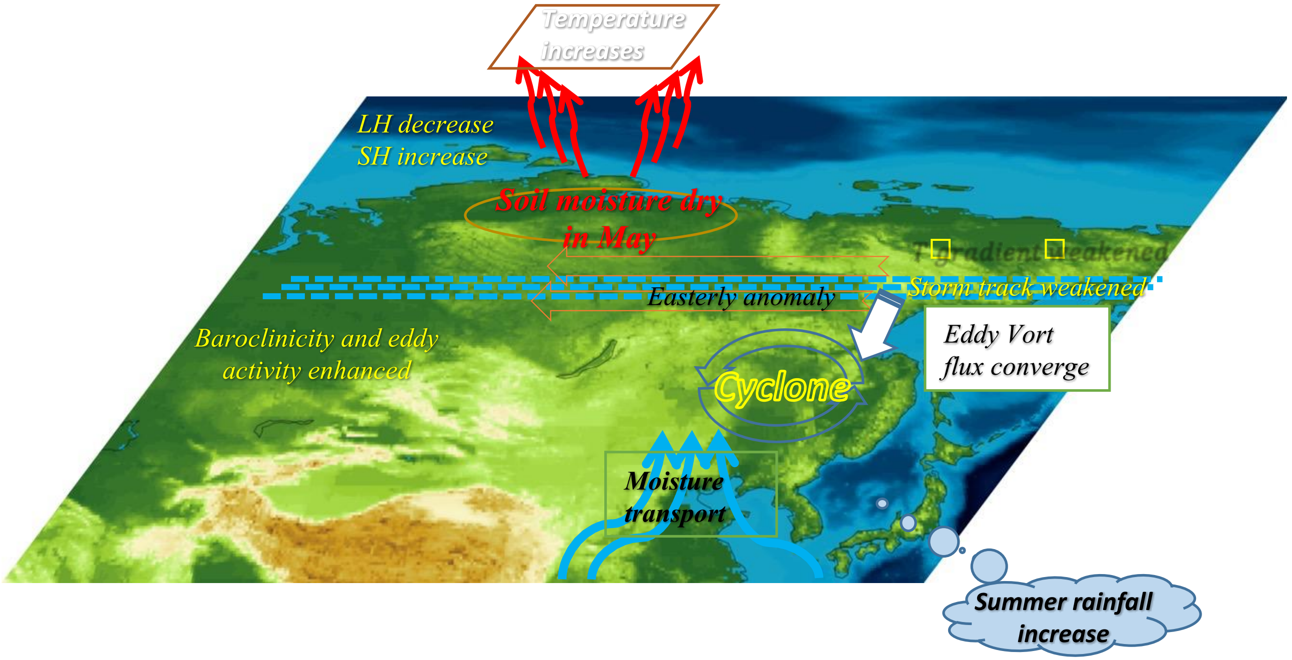


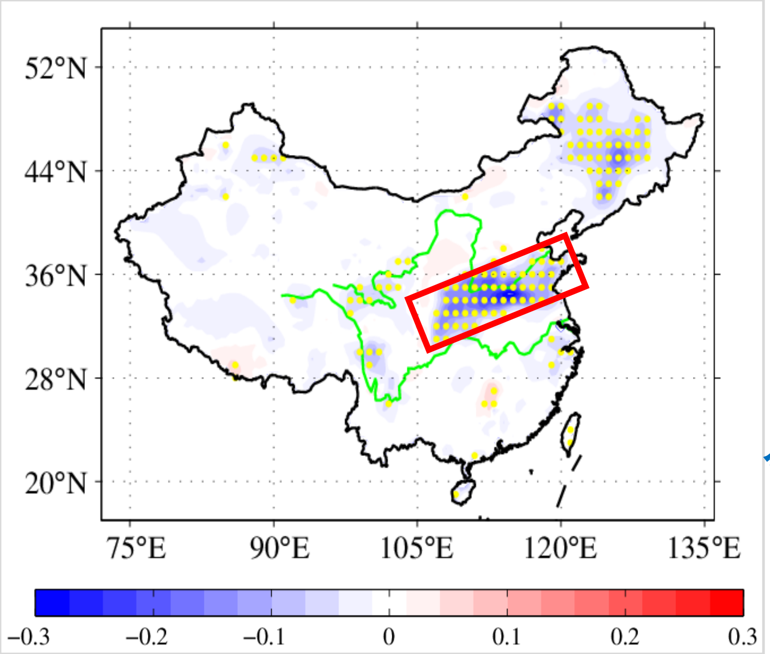
Illustration for the physical mechanism



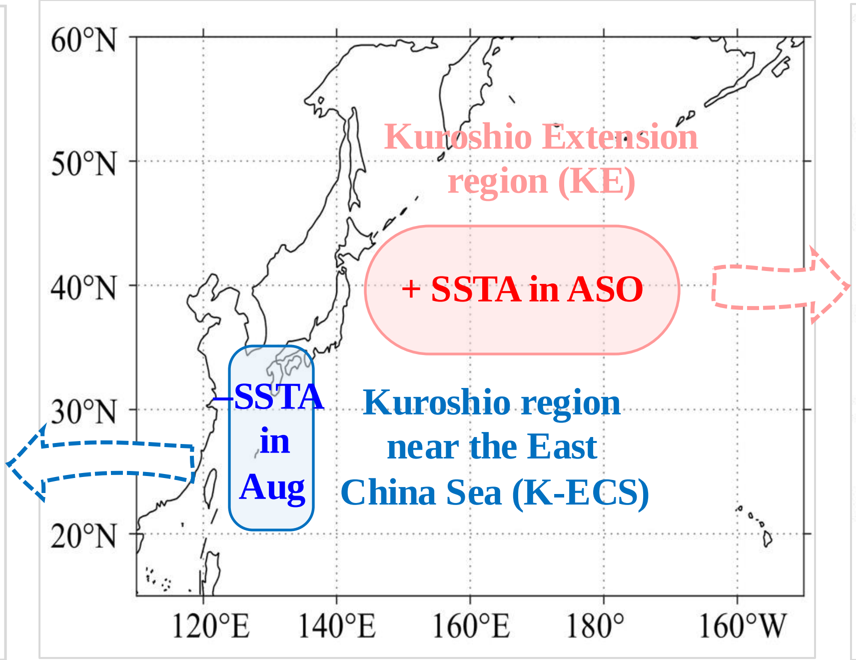
Sang, Ren et al. 2022 CD*

1) Found the new precursors for the East-Asian monsoon and precipitation variability

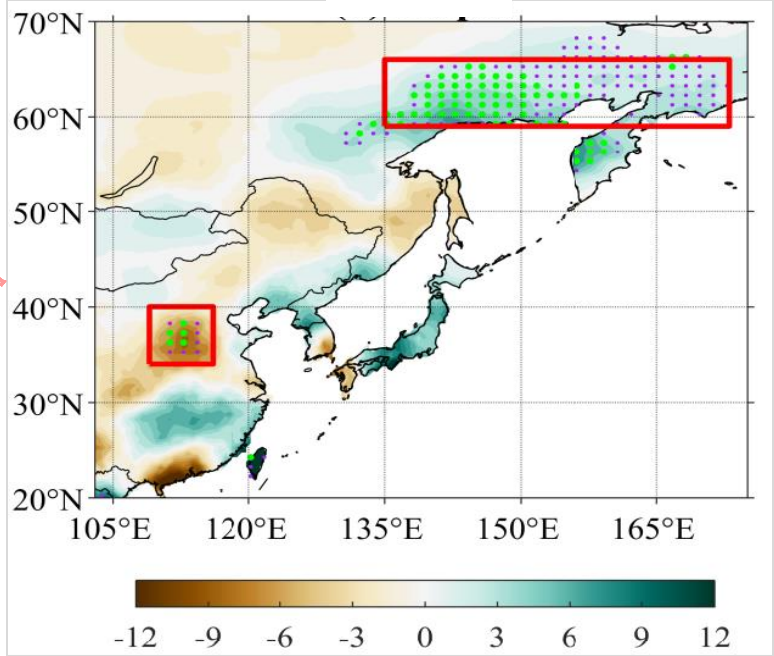
- **There are significant climatic effects of the SST anomalies in the Kuroshio and its extension regions on the East-Asian autumn precipitation anomalies**



Causal relationship between K-ECS SSTA and September precipitation



SSTA in the regions along the Kuroshio System

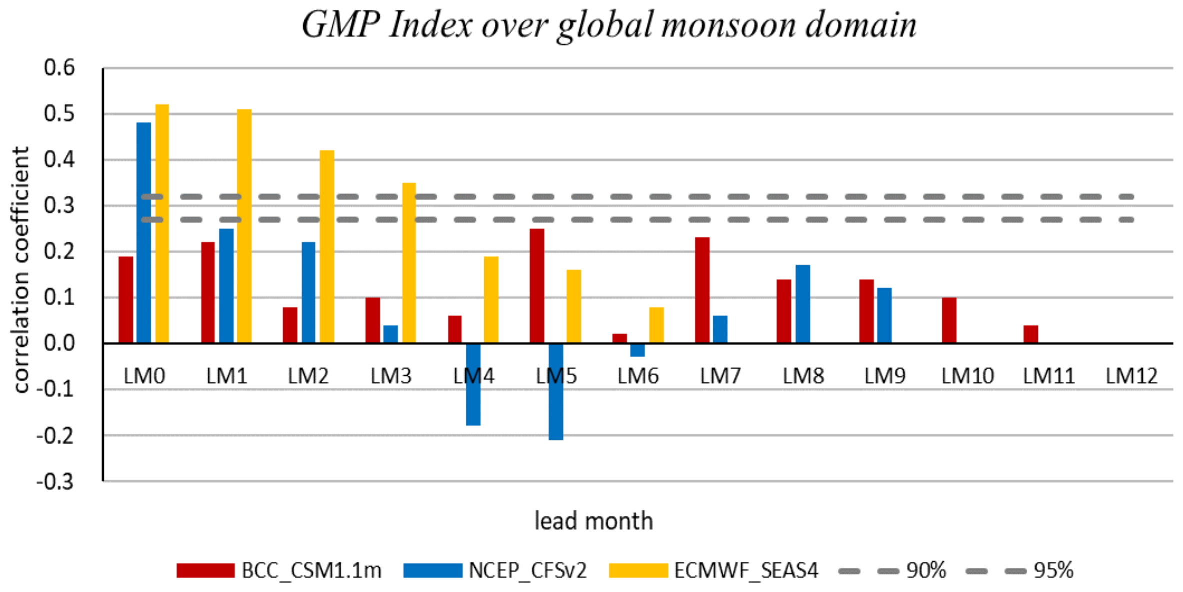


Regressed precipitation onto KE SSTA in autumn (ASO)

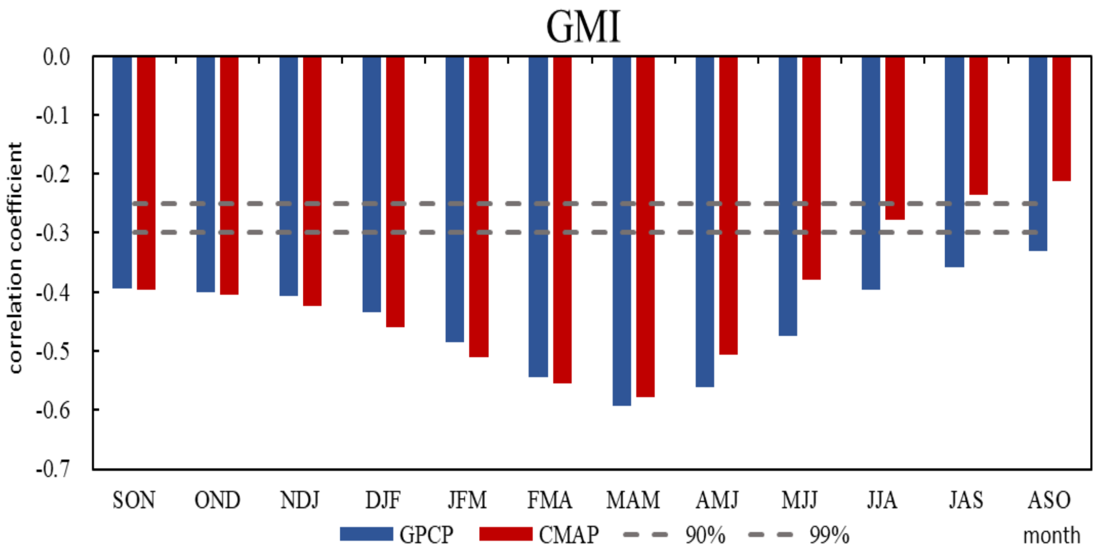
Geng, Ren et al. 2022 JC; 2024 JMSJ*

2) Evaluated dynamical model predictions of the monsoon and precipitation variability

- **The three operational models show different correlation skills for the global monsoon index (GMI)**
- **GMI has a significant relationship with ENSO, particularly during its decaying time (boreal spring)**



Correlation skills of GM index predicted in three models



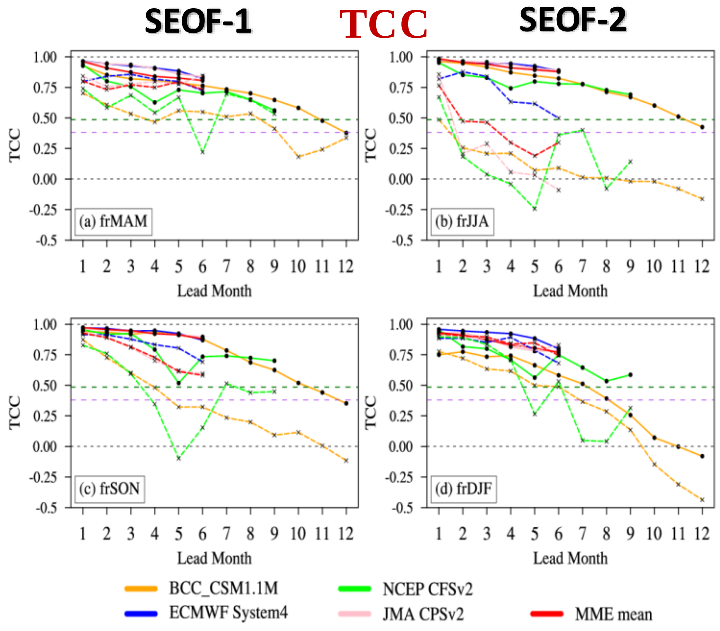
Correlations between GM indices and Nino3.4 index

Wang N, Ren et al. 2024 in preparation*

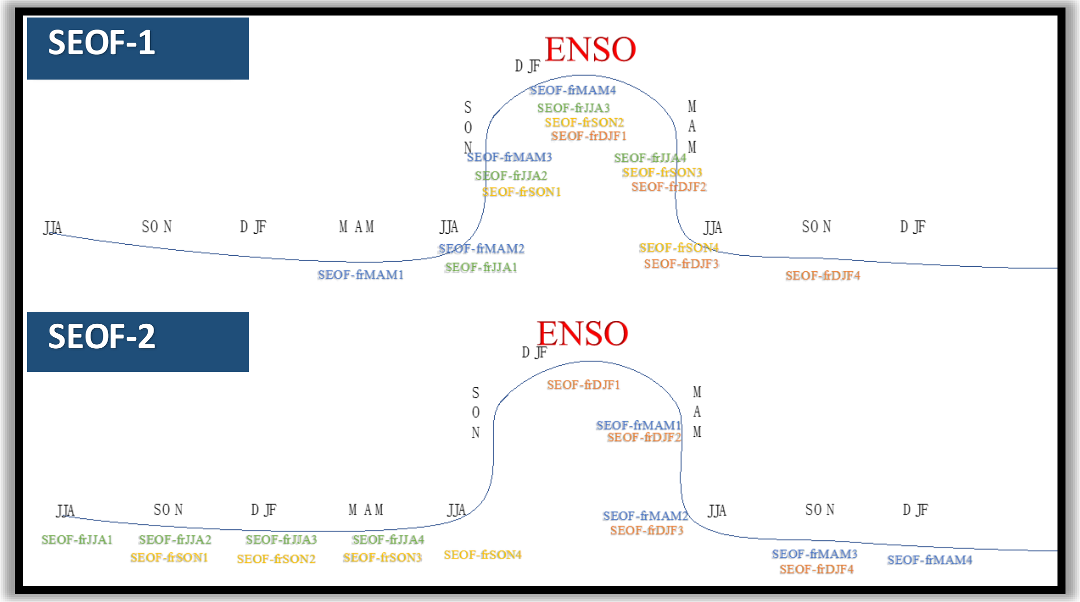
2) Evaluated dynamical model predictions of the monsoon and precipitation variability

- The Asian-Australian Monsoon (AAM) SEOF-based indices can be well predicted by the four operational climate models and their MME mean, with higher skills in SEOF-1 than SEOF-2
- ENSO is the primary seasonal-interannual predictability source of such two AAM indices

SEOF-frMAM :
MAM (0) to DJF(0/1)
SEOF-frJJA :
JJA (0) to MAM(1)
SEOF-frSON :
SON (0) to JJA(1)
SEOF-frDJF :
DJF(0/1) to SON(1)



Correlation skills of the AAM indices predicted in the models

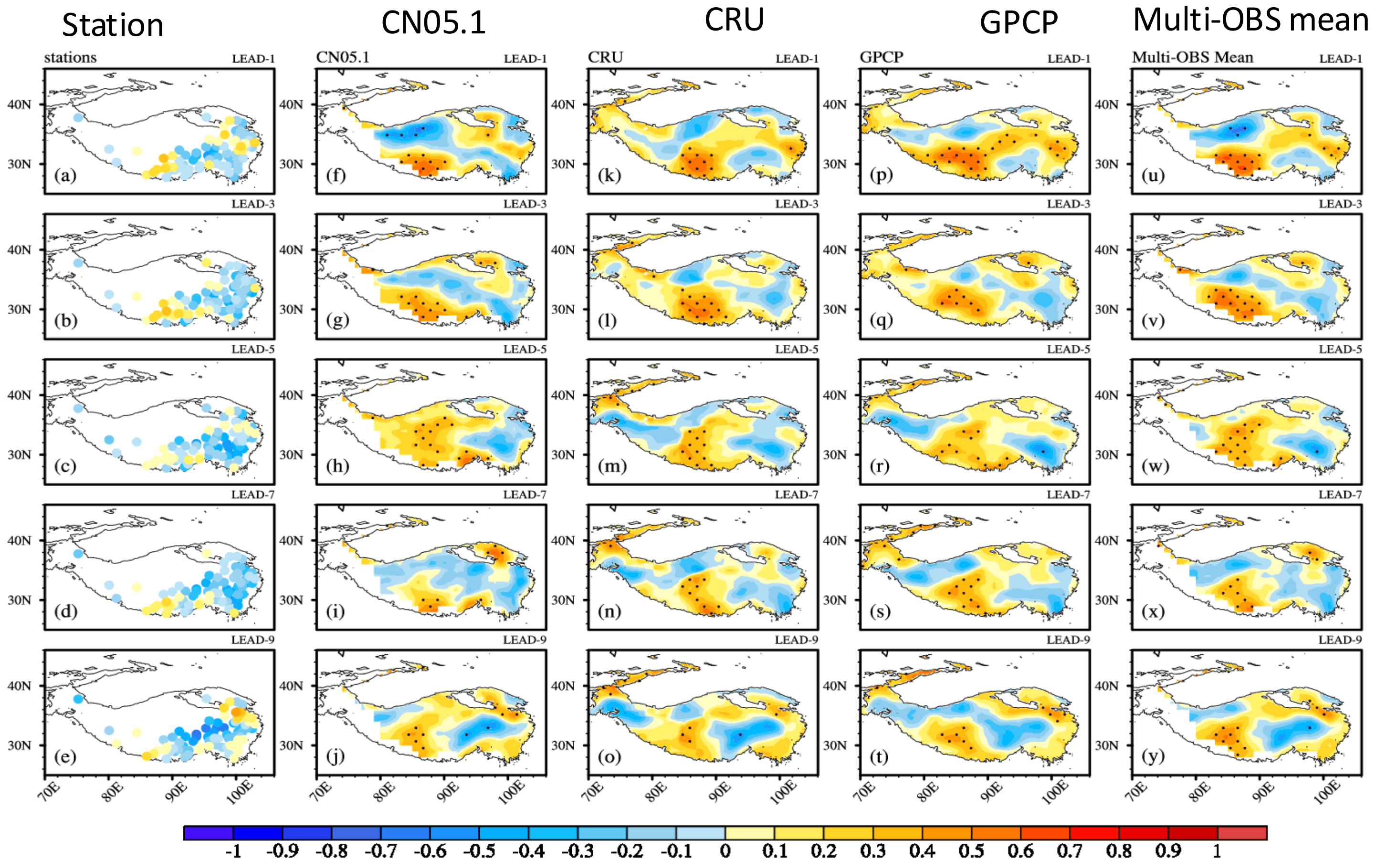


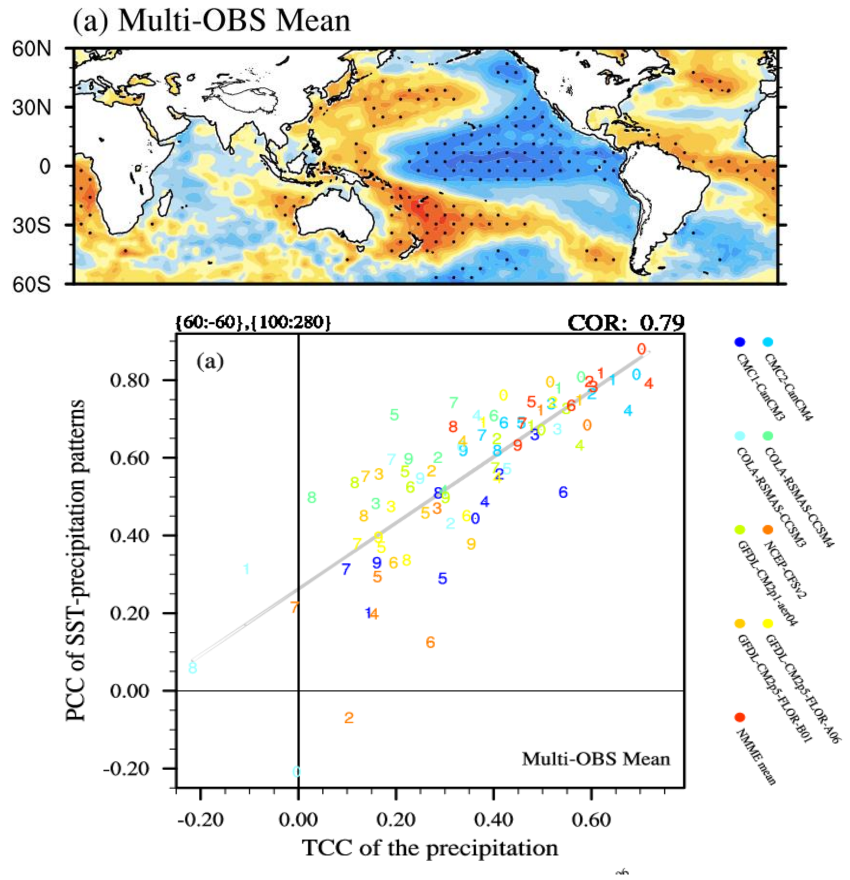
ENSO modulations on the AAM predictions

Wang L, Ren et al. 2023 AAS*

2) Evaluated dynamical model predictions of the monsoon and precipitation variability

- **Dynamical prediction skills of the summer precipitation over TP are regionally dependent in the NMME, with higher skill in the southwestern TP**
- **Ability of the models in reproducing the Pacific SST-precipitation relation is highly responsible for it**



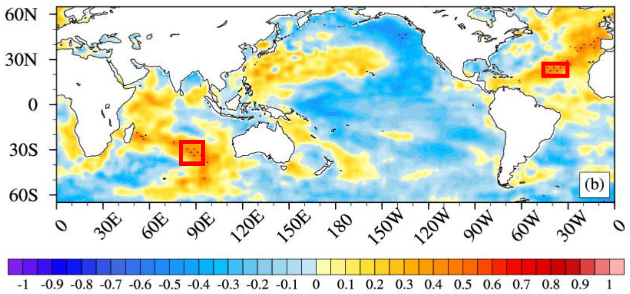


Wang L, Ren et al. 2022 GRL*

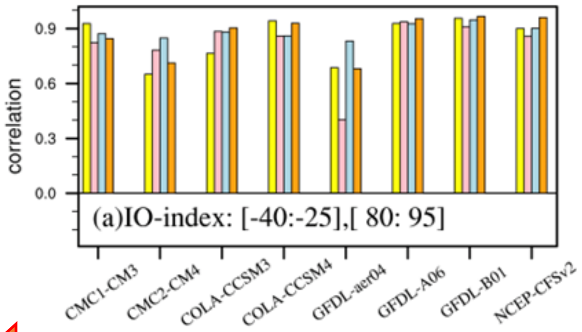
3) Error corrections of dynamical predictions of the East-Asian monsoon precipitation

- **Prediction errors for the TP summer precipitation are significantly correlated with previous February SST anomalies in key tropical Ocean regions (ATL and IO)**
- **The new SST analog-based correction method, with the ATL and IO SSTs serving as effective predictors, has notably improved the prediction skill for the TP summer precipitation**

Correlation between TPSP and previous February SST anomalies



High consistency in TPSP prediction errors across climate models

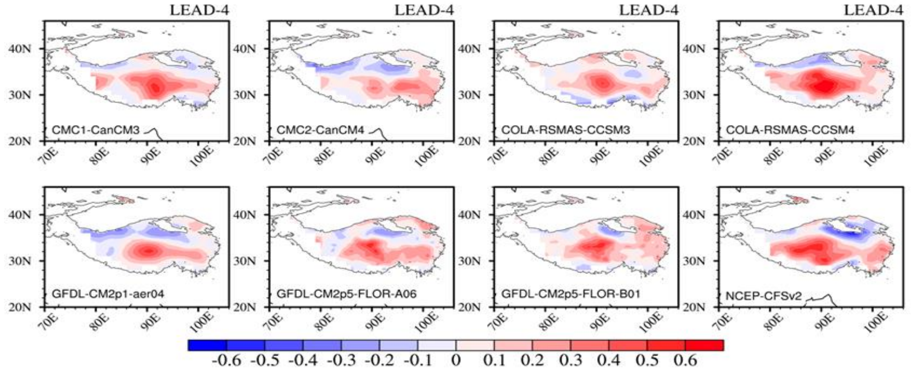


$$\widehat{Pred}(\psi_0) = Pred(\psi_0) + \sum_{i=1}^{n} w_i[Obs(\tilde{\psi}_i)\text{-}Pred(\tilde{\psi}_i)].$$

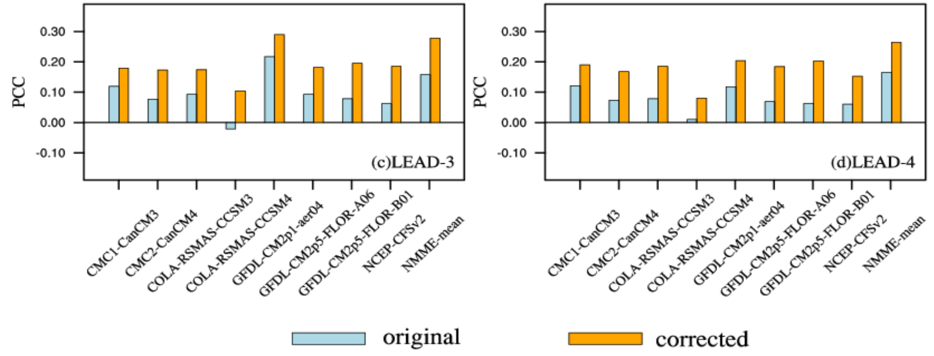
historical analog prediction errors

Skill Improvement

TCC improvement



Long-term averaged PCC

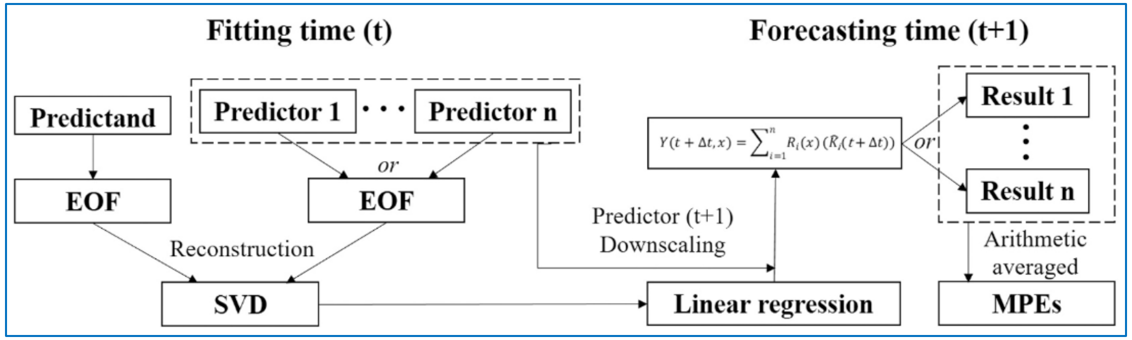


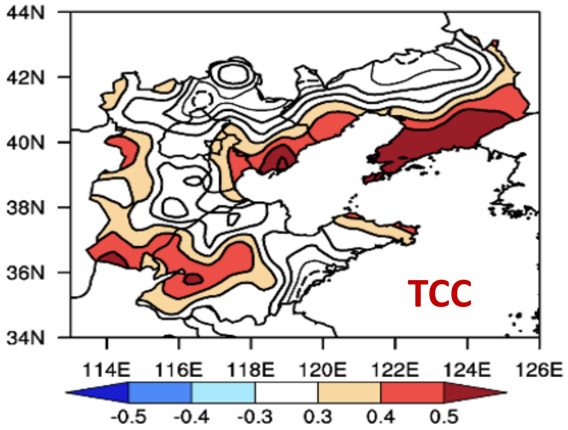
Wang L, Ren et al. 2023 RS*

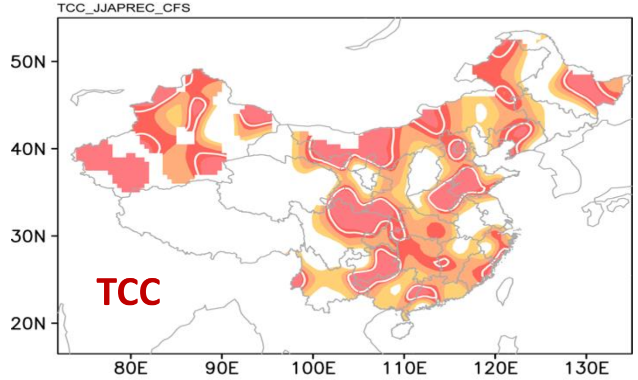
3) Error corrections of dynamical predictions of the East-Asian monsoon precipitation

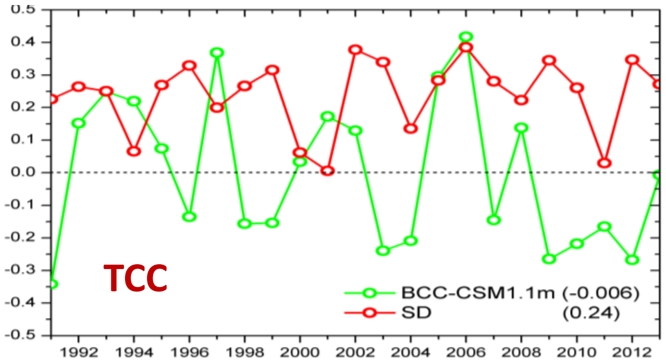
- A statistical downscaling and correction method has been developed to improve the seasonal-interannual predictions of summer precipitation over China based on the CMA climate model
- The new method is eligible to improvement in the northern China where skills are low as usual

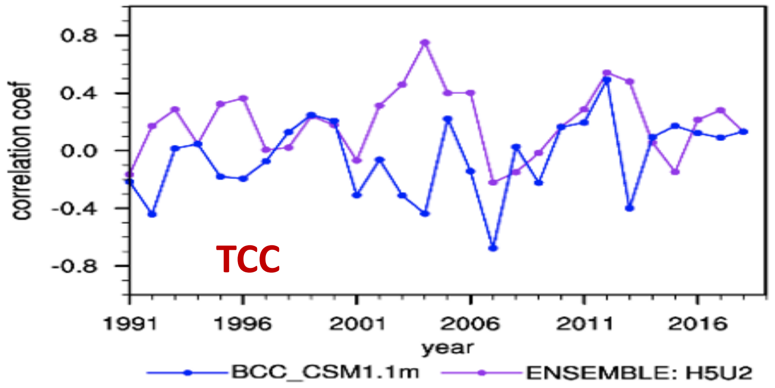
Schematic Diagram











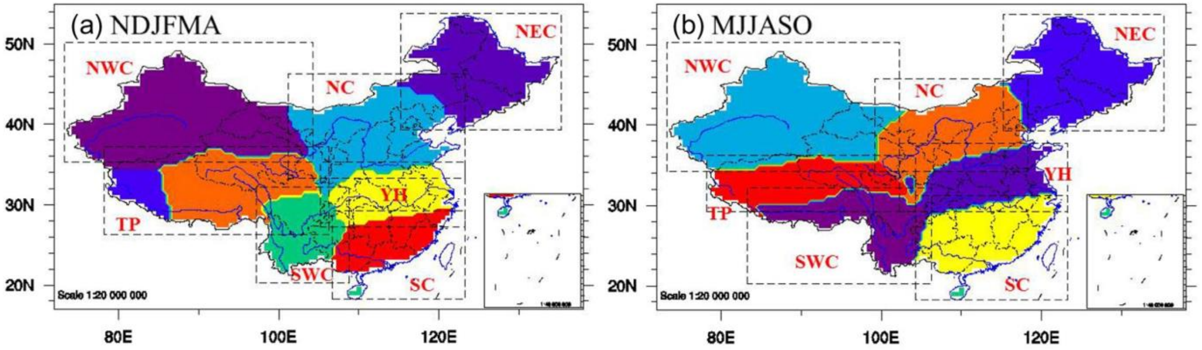
Liu, Ren et al. 2021 DAO*

Wang N, Ren et al. 2022 AR*

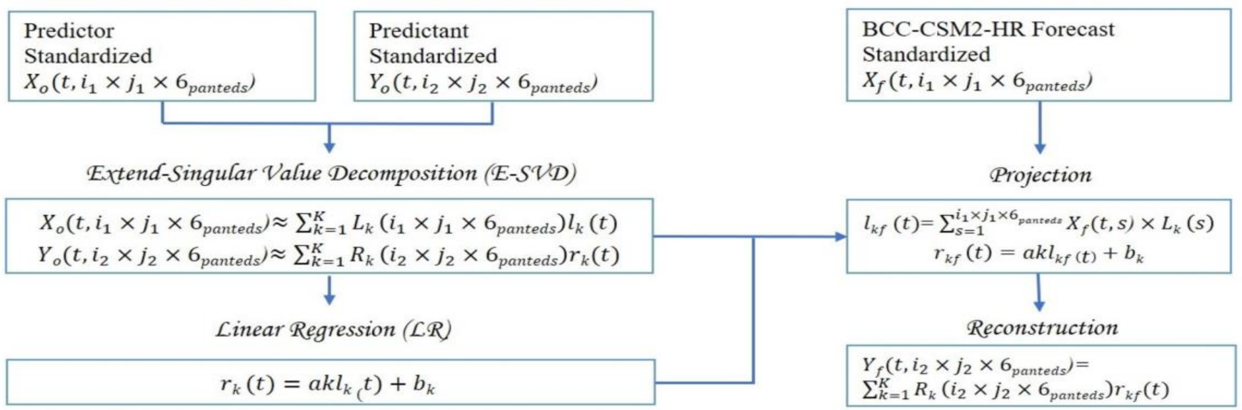
3) Error corrections of dynamical predictions of the East-Asian monsoon precipitation

- **Through developing a statistical-dynamical method, we have improved the pentad-mean subseasonal prediction skill for China precipitation in the boreal winter and summer**

Divisions

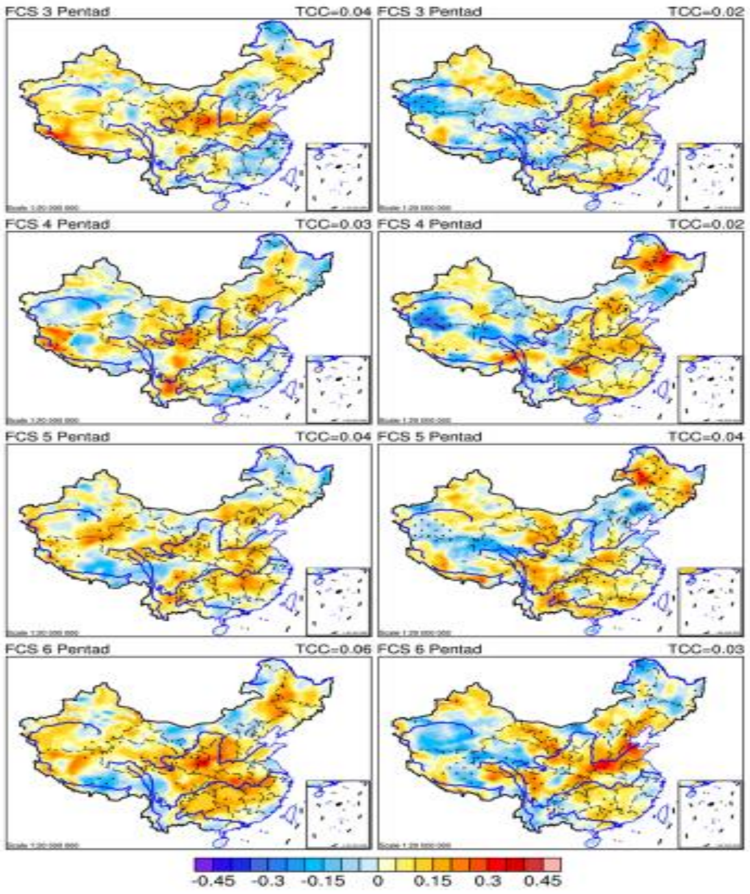


Training Period **Schematic Diagram** **Prediction Period**



Predictors: OLR/SH0700; SLP/U850/U200; Z850/Z500/Z200

TCC Skill improvement



Wu, Ren et al. 2022 CD*

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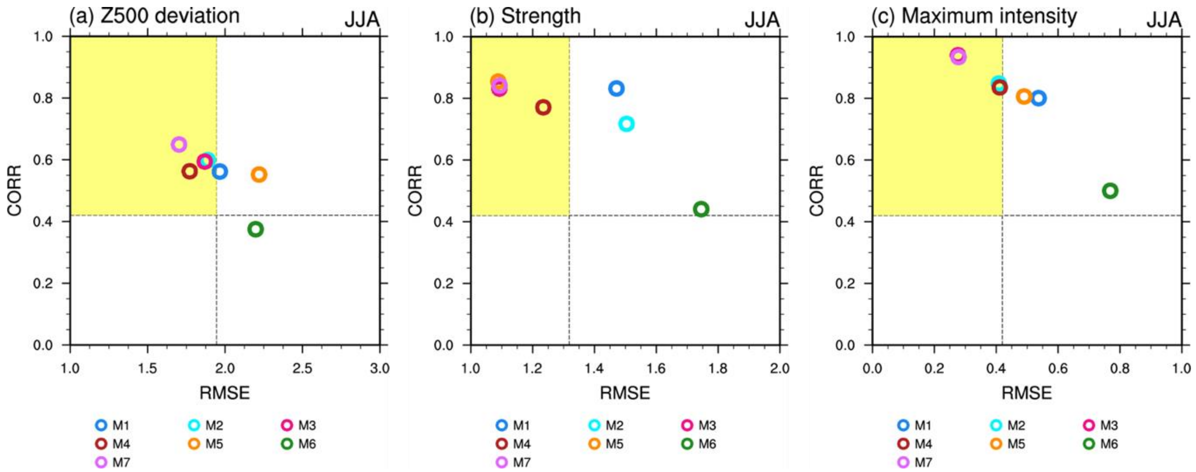
Predictability of the Western North Pacific Subtropical High and Associated East Asian Monsoon Rainfall in APCC Multi-Models

O. Y. Kim and C.-M. Lim (JGR, 2023)

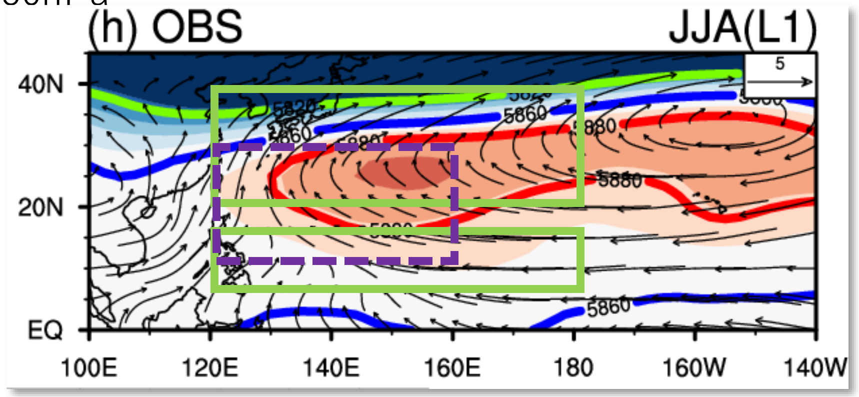
Indices for WNPSH characteristics

- **Z500 deviation**: the areal mean (5N-40N, 110E-180) of the departure of Z500 from its zonal mean (0-45)
- **Strength**: the differences of zonal mean at 850hPa between north (20N-40N, 120E-180) and south (5N-15N, 120E-180)
- **Maximum intensity**: the averaged MSLP over the local maximum center of the WNPSH (10N-30N, 120E-160E) → EASM

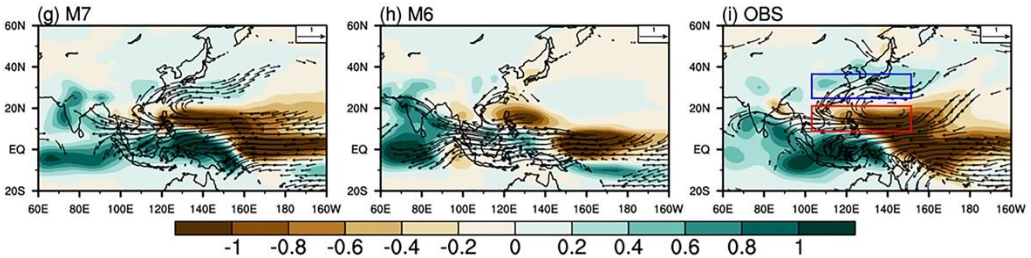


Model selected : Good: M7, Poor : M6

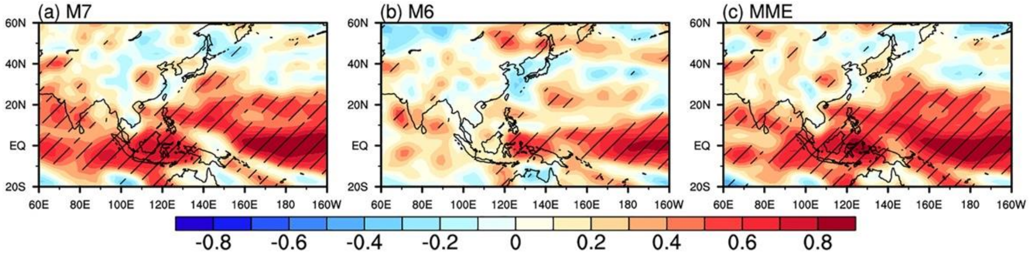
Summer mean geopotential height at 500hPa (contour), its departure from zonal mean over 0-45N (shading) wind fields at 850hPa



Precipitation, 850hPa wind regressed onto the observed WNPSH index **Strength**

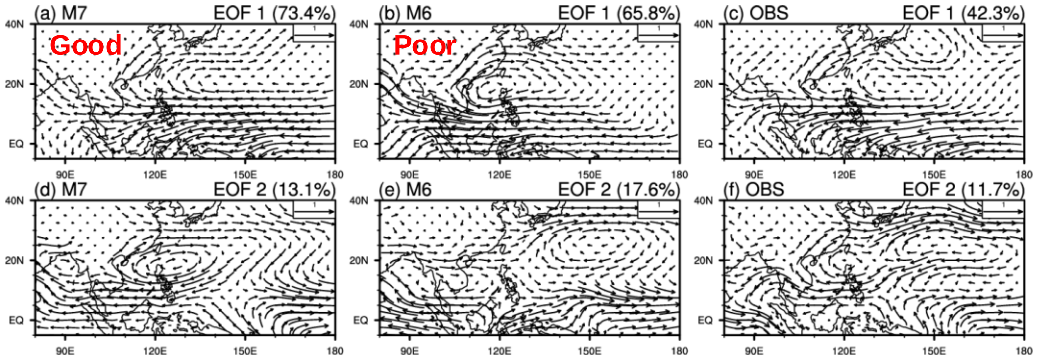


Summer mean rainfall skill (ACC)

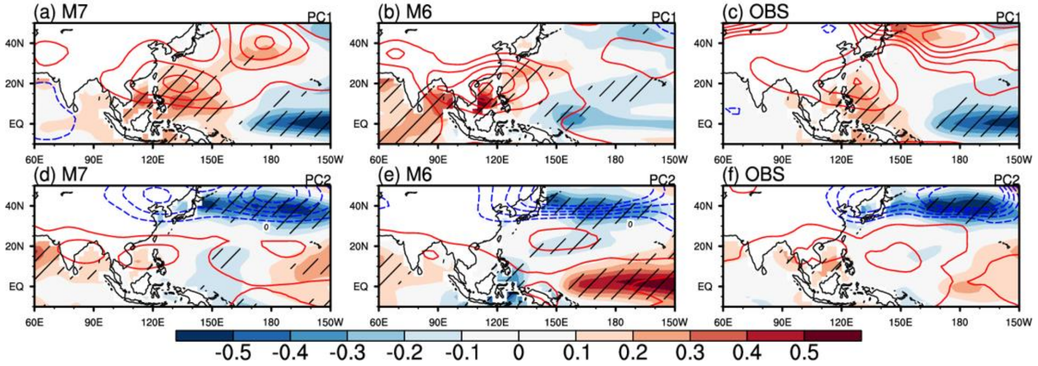


Reproducibility of WNPSH modes and influence of ENSO

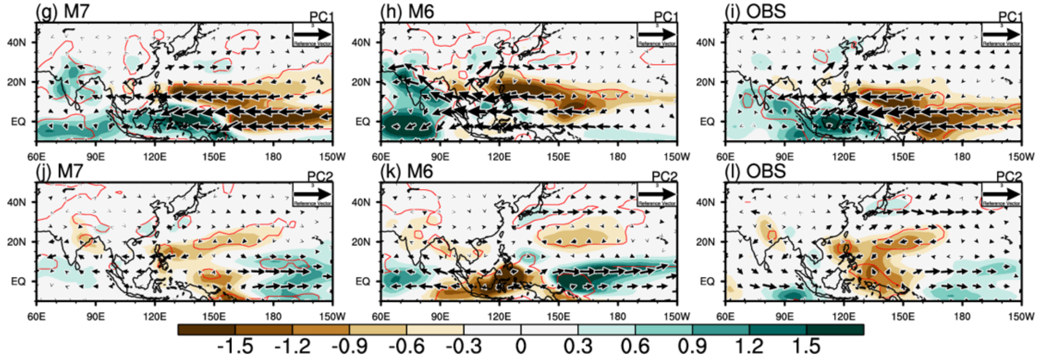
Leading modes of 850 winds (JJA)

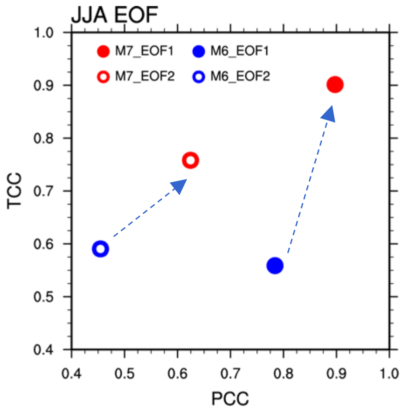


SST, 500hPa geopotential height regressed onto two PCs



Precipitation, 850hPa wind regressed onto two PCs





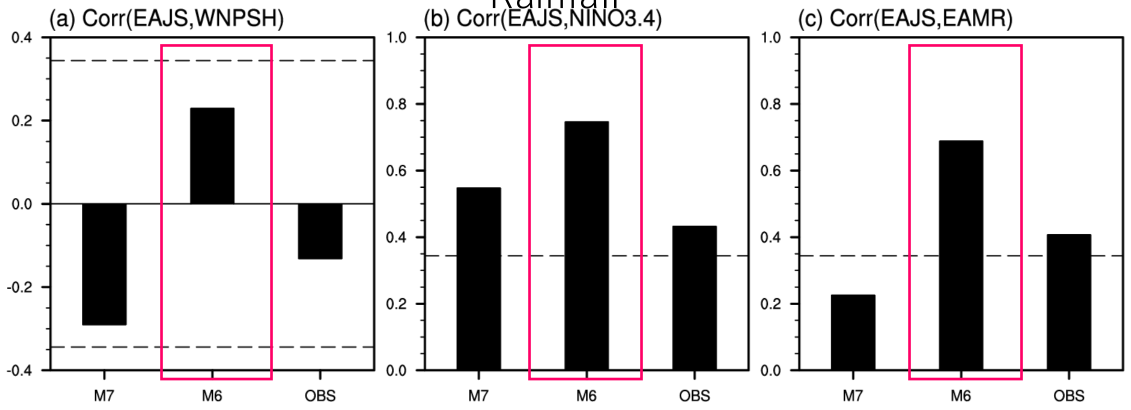
1st mode: Transition mode

- (M6) Not capturing the anticyclonic circulation in the northern central Pacific, Stronger delaying influence of ENSO on EASM through the IO capacitor effect → more (less) precipitation in IO (WNP) in M6

2nd mode: Persistent mode

- (M6) Stronger El Nino persistent SSTA patterns in the central-eastern Pacific until JJA → more bias in the WNP

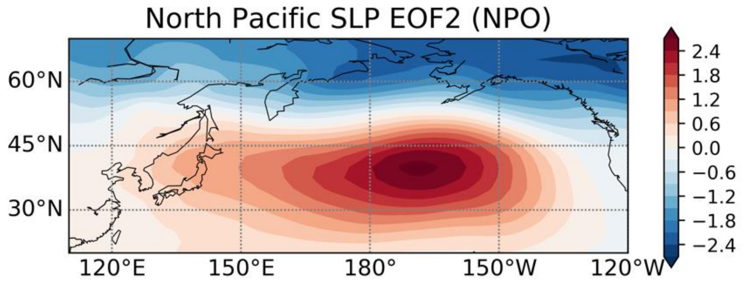
Correlation between East Asian Jet, WNPSH, Nino, EA Rainfall



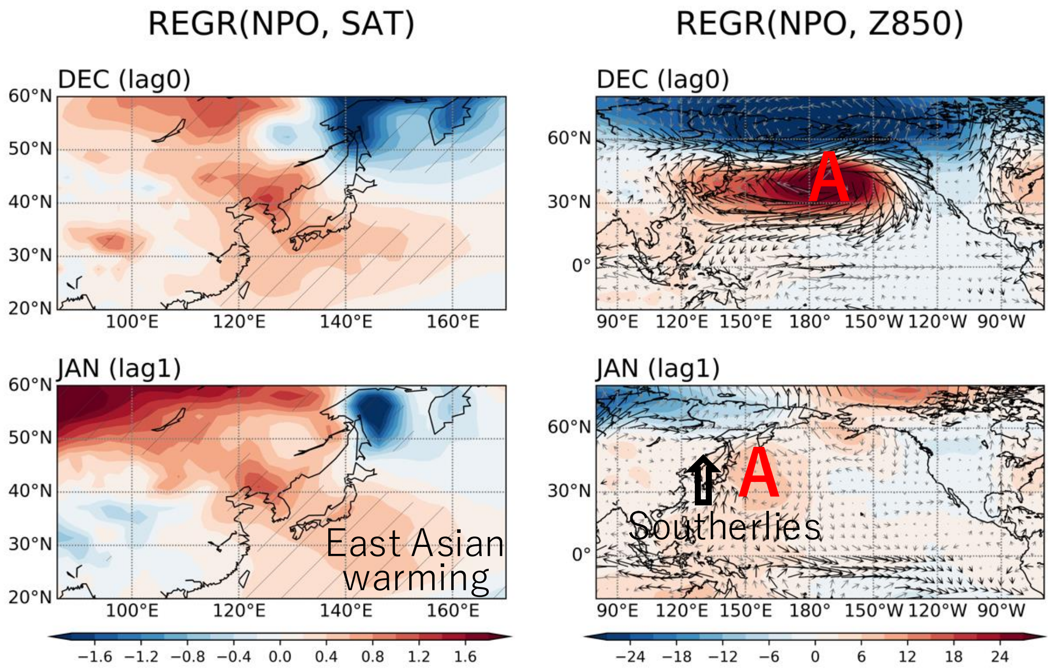
Poor model exaggerates ENSO (IO) response over EA region

Delayed impacts of North Pacific Oscillation (NPO) on wintertime surface air temperature in East Asia

Sunyong Kim and Jin Ho Yoo (2024)



- Atmospheric internal variability over the North Pacific (Walker and Bliss, 1932) – meridional dipole structure
- EOF second mode of North Pacific SLP

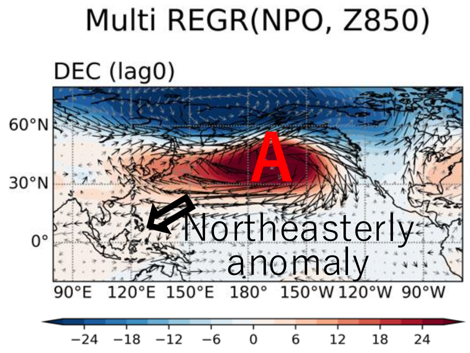


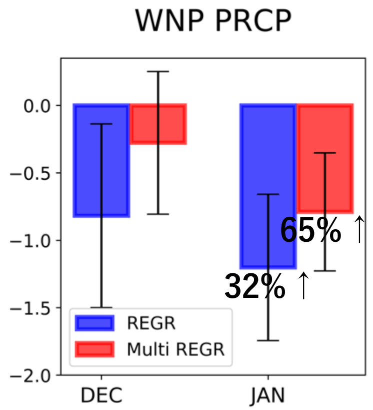
- December NPO-related anticyclonic anomalies responsible for the surface warming in East Asia of the following January, a 1-month lag
- **How December NPO impact on the surface temperature variability in East Asia take a month to manifest?**

Observational Results

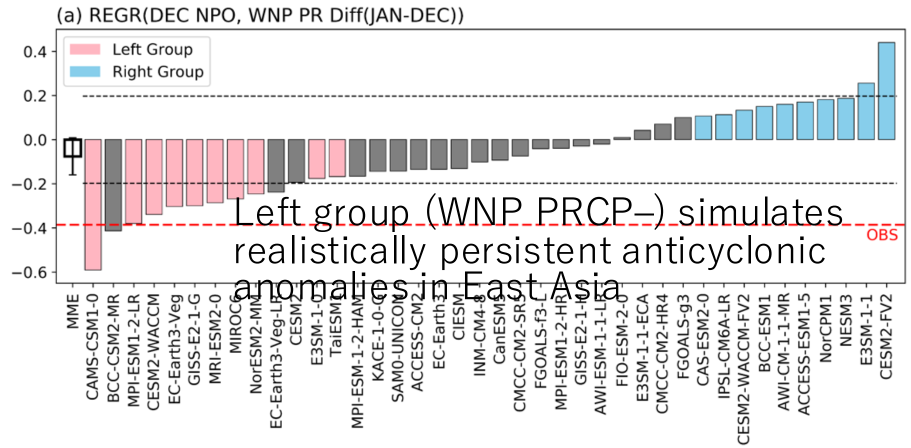
CMIP6 Results

Tropics-Extratropics Teleconnection



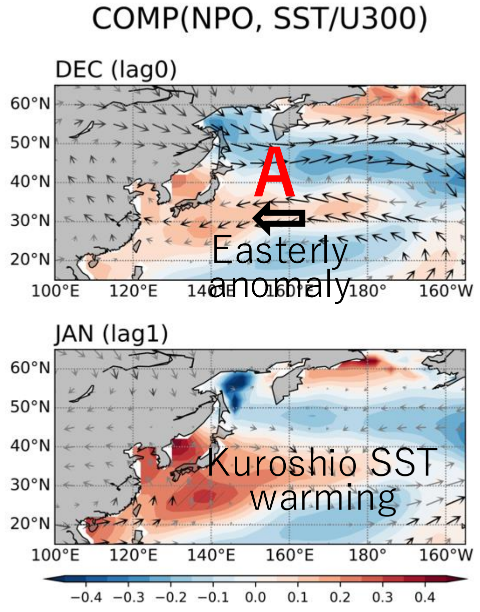


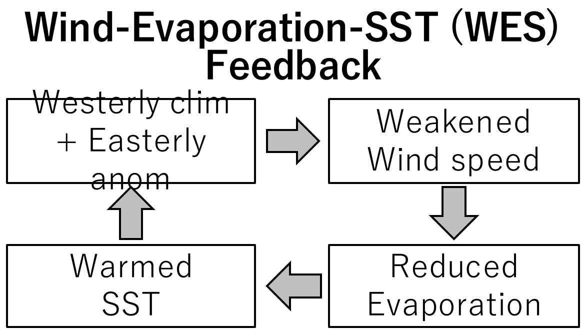
Intensified WNP PRCP– in January contributes to East Asian surface warming



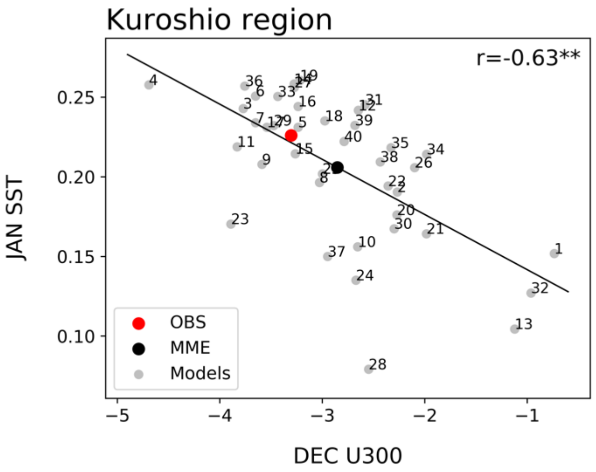
Left group (WNP PRCP–) simulates realistically persistent anticyclonic anomalies in East Asia

Local Air-Sea Interaction



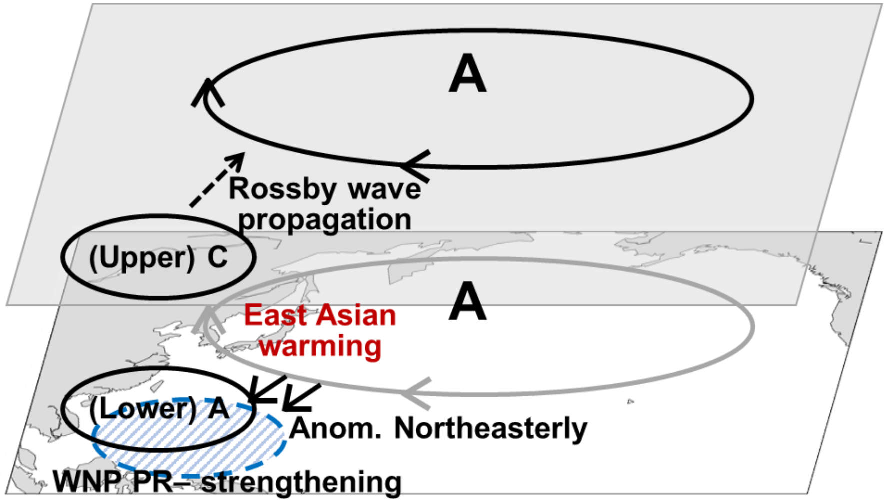


SST warming in January over the Kuroshio region is favorable conditions for East Asian surface warming

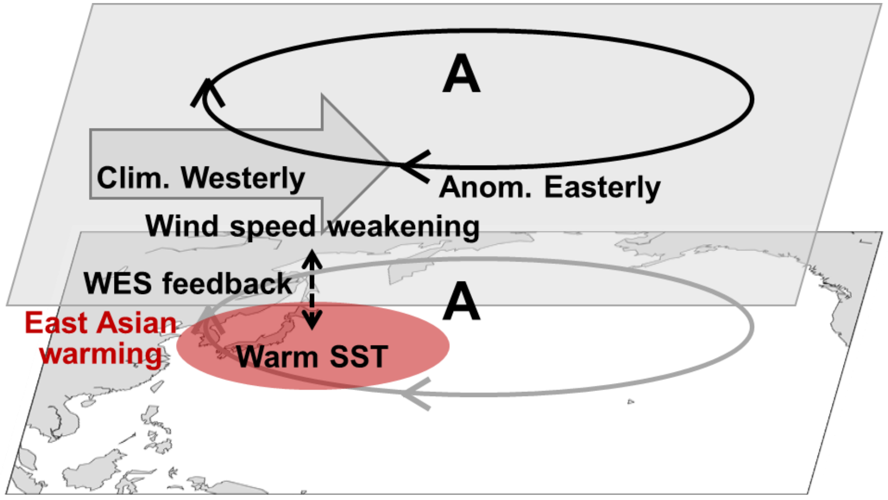


Result from the intermodel comparison reasonably agrees with observational analysis -> NPO-induced weakened westerlies in December lead SST warming in January over the Kuroshio region

Tropics-Extratropics Teleconnection



Local Air-Sea Interaction



- Delayed impacts of NPO on the East Asian winter climate and its dynamics are investigated
- December NPO significantly affects the persistence of anticyclonic anomalies and resultant East Asian warming into January with two possible pathways

Tropics-Extratropics Teleconnection and Local Air-Sea Interaction

- CMIP6 models reasonably simulate the overall delayed impacts of NPO in East Asia supporting the observational hypothesis

Kim and Yoo: Delayed impacts of NPO on wintertime surface air temperature in East Asia *(submitted)*

References

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Kim. S. and J. H. Yoo. 2024, Delayed impacts of NPO on wintertime surface air temperature in East Asia *(submitted)*

Summary of Monsoons initiative

Concept note

https://www.wcrp-climate.org/images/modelling/WGSIP/documents/WGSIP_Monsoon_Concept_Note_FINAL.pdf

Main goals

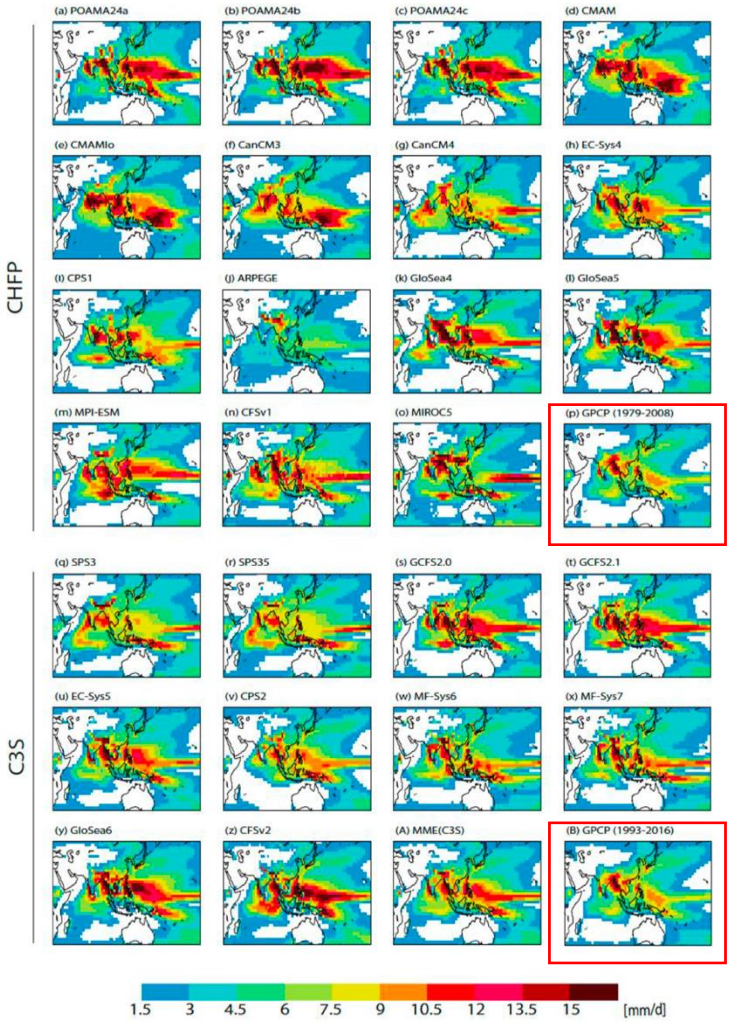
The WGSIP Initiative "Long-Range Forecasts of Monsoons" (LRFM) aims to **systematically evaluate and compare long-range monsoon forecasts across models.**

It includes two themes: "**Asian Monsoon**," focusing on the significant regional monsoon, and "**Global Monsoons**," addressing a wider perspective. The initiative uses publicly available hindcast datasets, such as CHFP, C3S, ENSEMBLES, and DEMETER.

Evaluation of monsoon forecasts across models (1)

Progress of Asian monsoon seasonal prediction

Precipitation climatology in models



CHFP

C3S

Data archive	Institution	Model/ system name	Model/system short name	Hindcast period	Ensemble size	Reference
CHFP	CAWCR	POAMA Version 2.4a	POAMA2a	1980-2009	10	Cottrill *et al*. (2013)
CHFP	CAWCR	POAMA Version 2.4b	POAMA2b	1980-2009	10	Cottrill *et al*. (2013)
CHFP	CAWCR	POAMA Version 2.4c	POAMA2c	1980-2009	10	Cottrill *et al*. (2013)
CHFP	CCCma	CMAM	CMAM	1979-2008	10	Scinocca *et al*. (2008)
CHFP	CCCma	CMAMlo	CMAMlo	1979-2008	10	Sigmond *et al*. (2008)
CHFP	CCCma	CCCma-CanCM3	CanCM3	1979-2008	10	Merryfield *et al*. (2013)
CHFP	CCCma	CCCma-CanCM4	CanCM4	1979-2008	10	von Salzen *et al*. (2013)
CHFP	ECMWF	ECMWF System 4	EC-Sys4	1981-2009	15	Molteni *et al*. (2011)
CHFP	JMA	JMA/MRI-CPS1	CPS1	1979-2009	10	Takaya *et al*. (2017)
CHFP	JMA	JMA/MRI-CPS2	CPS2	1981-2009	10	Takaya *et al*. (2018)
CHFP	Meteo France	ARPAGE	ARPAGE	1979-2007	10	
CHFP	Met Office	GloSea4L85	GloSea4	1989-2009	9	Fereday *et al*. (2012)
CHFP	Met Office	GloSea5	GloSea5	1996-2009	24	MacLachlan *et al*. (2015)
CHFP	MPI	MPI-ESM-LR	MPI-ESM	1982-2009	9	Baehr *et al*. (2015)
CHFP	NOAA	CFSv1	CFSv1	1981-2007	7	Saha *et al*. (2006)
CHFP	Univ. Tokyo, JAMSTEC, NIES	MIROC5	MIROC5	1979-2009	8	Watanabe *et al*. (2010)
C3S	CMCC	SPS3	SPS3	1993-2016	40	Sanna *et al*. (2017)
C3S	CMCC	SPS3.5	SPS3.5	1993-2016	40	Gualdi *et al*. (2020)
C3S	DWD	GCFS2.0	GCFS2.0	1993-2016	30	Fröhlich *et al*. (2021)
C3S	DWD	GCFS2.1	GCFS2.1	1993-2016	30	
C3S	ECMWF	System 5	EC-Sys5	1993-2016	25	Johnson *et al*. (2019)
C3S	JMA	JMA/MRI-CPS2	CPS2	1993-2016	10	Takaya *et al*. (2018)
C3S	Météo France	System 6	MF-Sys6	1993-2016	25	Dorel *et al*. (2017)
C3S	Météo France	System 7	MF-Sys7	1993-2016	25	Batté *et al*. (2019)
C3S	Met Office	GloSea6	GloSea6	1993-2016	28	Williams *et al*. (2017)
C3S	NOAA	CFSv2	CFSv2	1993-2016	24	Saha *et al*. (2014)

Presented at IWM-7, Takaya et al. (2021) *Mausam*

https://doi.org/10.54302/mausam.v74i2.5925

Evaluation of monsoon forecasts across models (2)

Progress of Asian monsoon seasonal prediction

Averaged ACC for precipitation over AMS region

A decade of progress

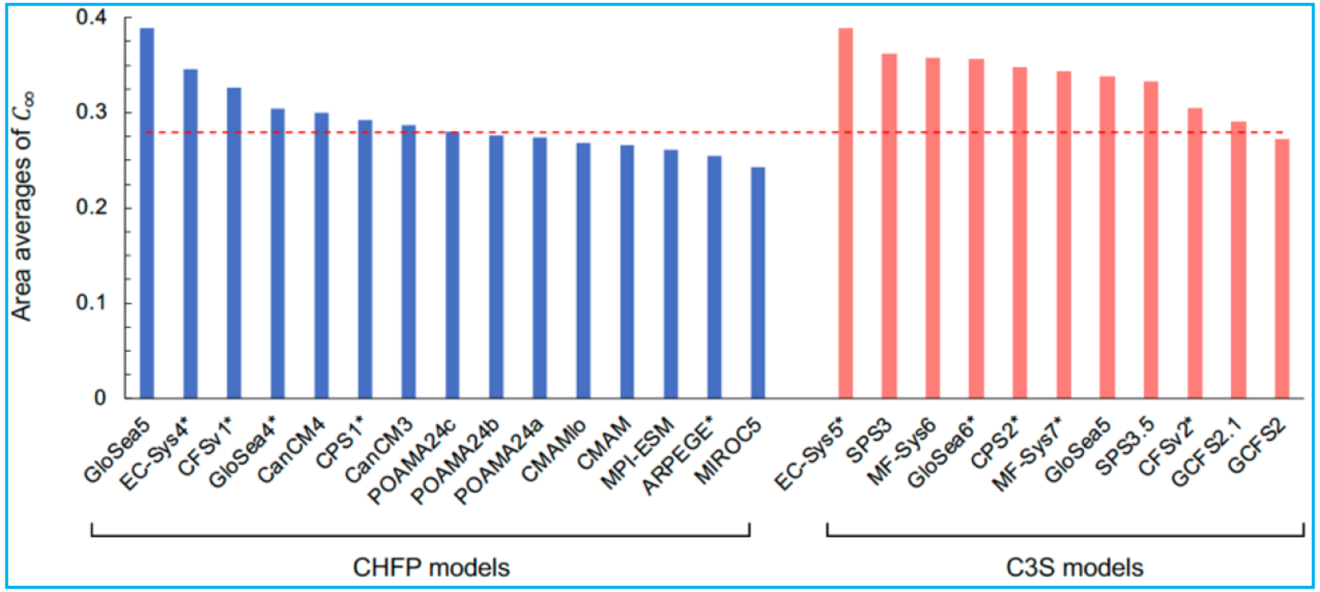


Fig. 6. Comparison of the estimated maximum prediction skill of the ASM precipitation during summer (June-August). The area average of temporal correlations (the estimated skill with infinite members) for June-August precipitation over the ASM region (40° N-10° S, 40° E-180°). The red dashed line indicates the median of the correlations of the CHFP models. The asterisks indicate the selected models for the comparison of the same operational centers

Identifying high predictability regions (majority decision using multi-model approach)

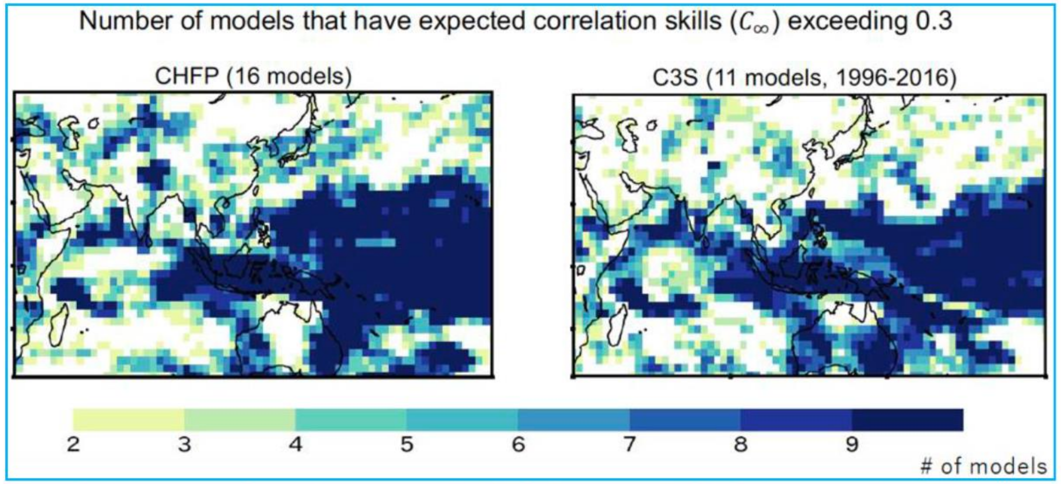


Fig. 5. Predictable regions of seasonal precipitation of the ASM. The number of models that have expected correlation skills (C_∞) exceeding 0.3

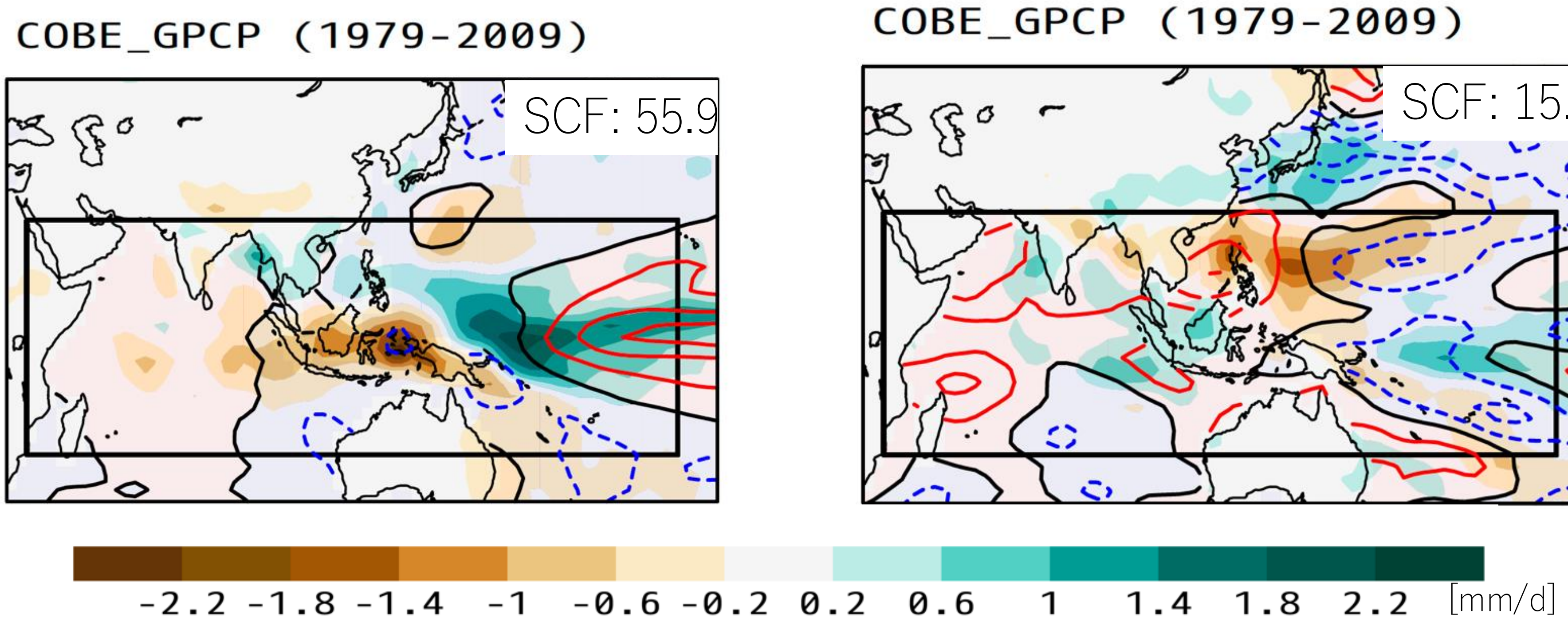
Presented at IWM-7, Takaya, Ren, et al. (2021) *Mausam*
https://doi.org/10.54302/mausam.v74i2.5925

Evaluation of monsoon forecasts across models (2)

Evaluation of dominant climate modes that drive ASM variabiltiy

ENSO mode

IPOC mode



color : precipitation
contour: SST (CI:0.2 [K])

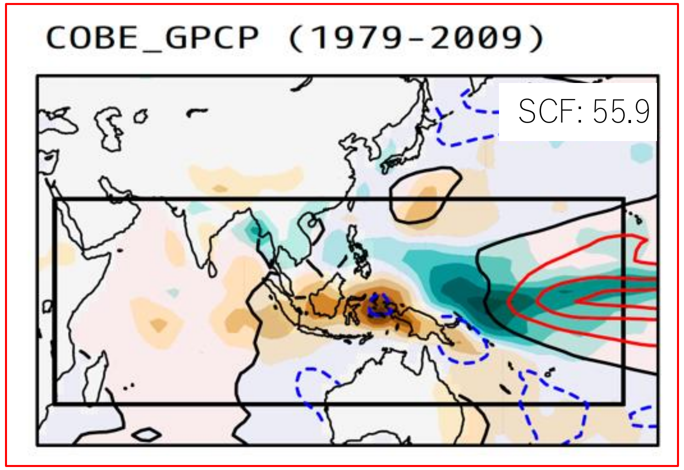
Heterogeneous regression maps of SVD analysis for SST and precipitation in JJA

Both modes seem to have relatively high predictability, being a key for Asian summer rainfall prediction. How well do models represent these mode? How does it relates to the skill?

Takaya et al. in prep., (sorry little progress…)

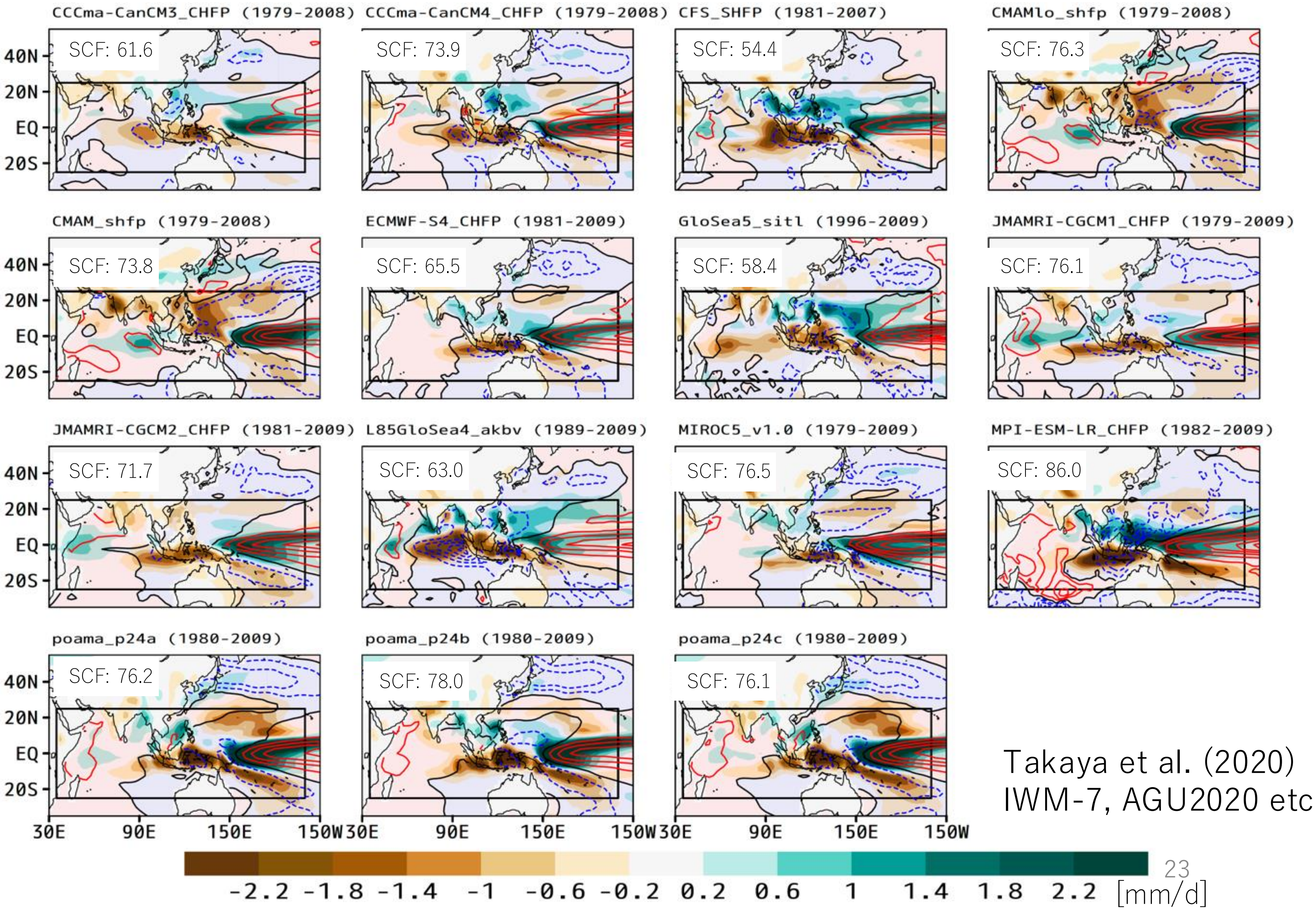
Evaluation of monsoon forecasts across models (3)

ENSO mode (obs)



color： precipitation
contour: SST (CI:0.2 [K])

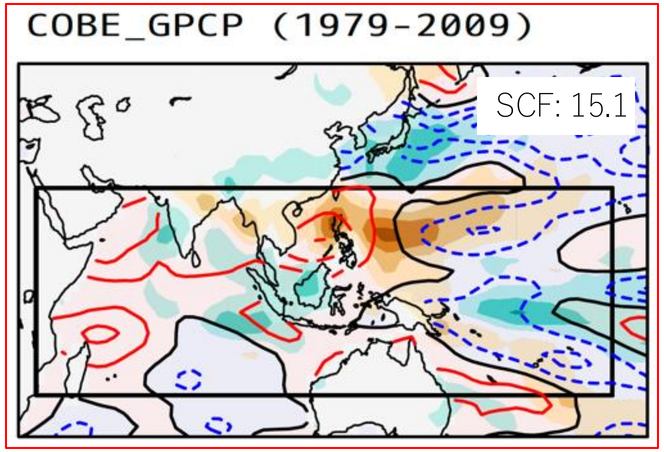
Results of SVD analysis for SST and precipitation in black box.
heterogeneous regression maps



Takaya et al. (2020)
IWM-7, AGU2020 etc.

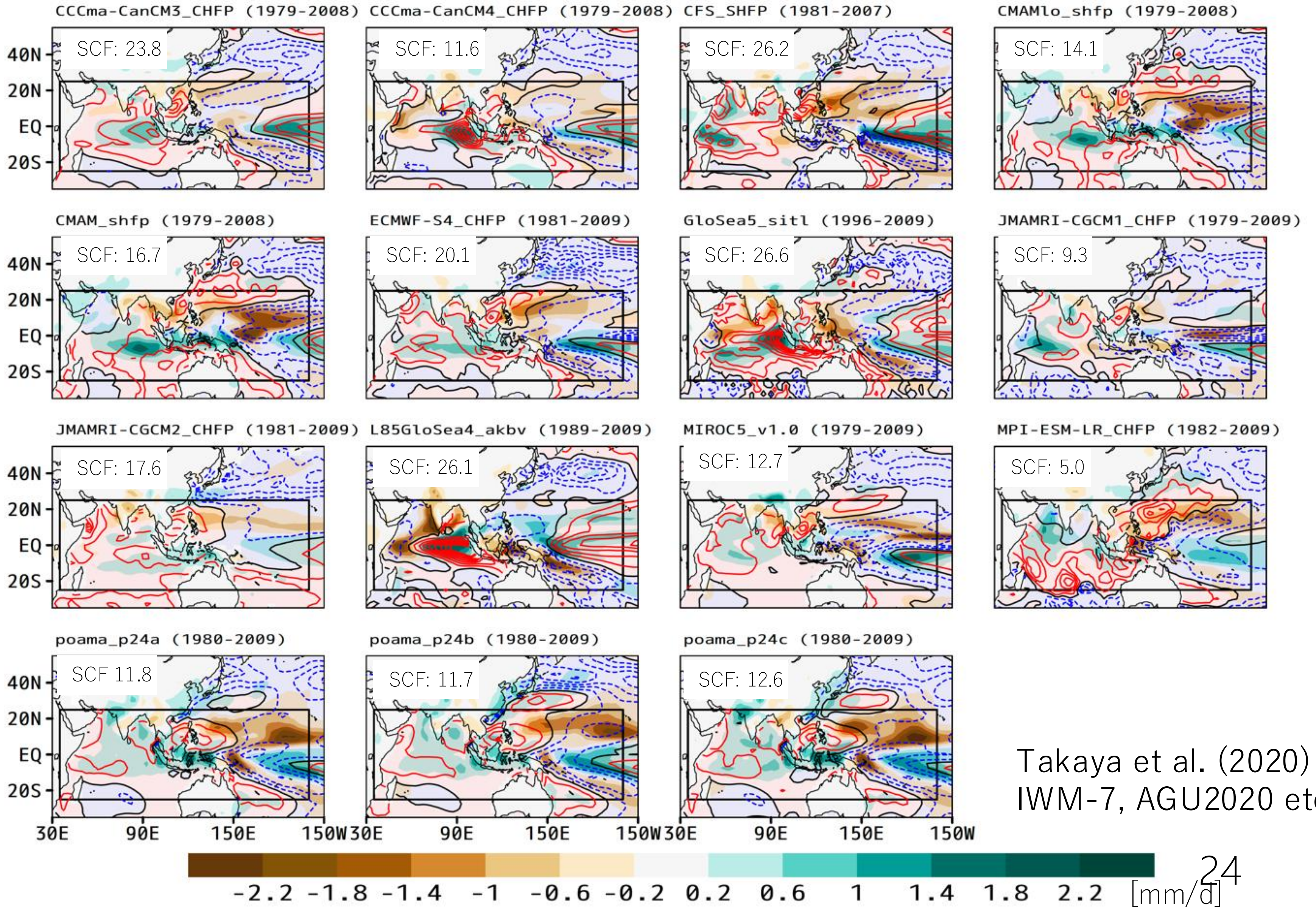
Evaluation of monsoon forecasts across models (4)

IPOC mode (obs)



color : precipitation
contour: SST (CI:0.2 [K])

Results of SVD analysis for SST and precipitation in black box. heterogeneous regression maps



Takaya et al. (2020)
IWM-7, AGU2020 etc.

Evaluation of monsoon forecasts across models (5)

Dynamical Predictability of Leading Modes of Asian–Australian monsoon (AAM) in four operational climate prediction models

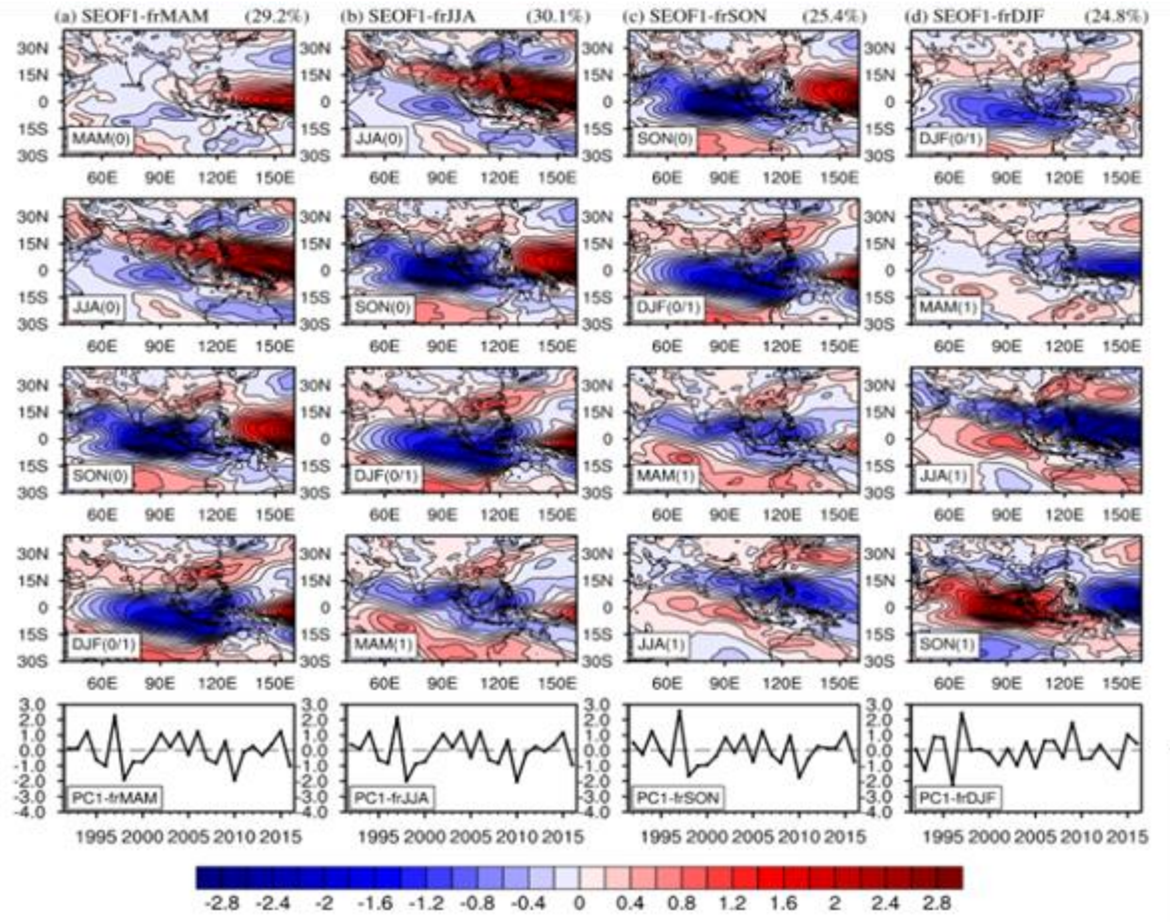


Fig. 1. The first SEOF spatial patterns (from the first to the fourth row) and principal components (the bottom row) of AAM U850 anomalies (units: m s^{-1}) as derived from different initial seasons in ERA reanalysis data: (a) SEOF1-frMAM; (b) SEOF1-frJJA; (c) SEOF1-frSON; (d) SEOF1-frDJF.

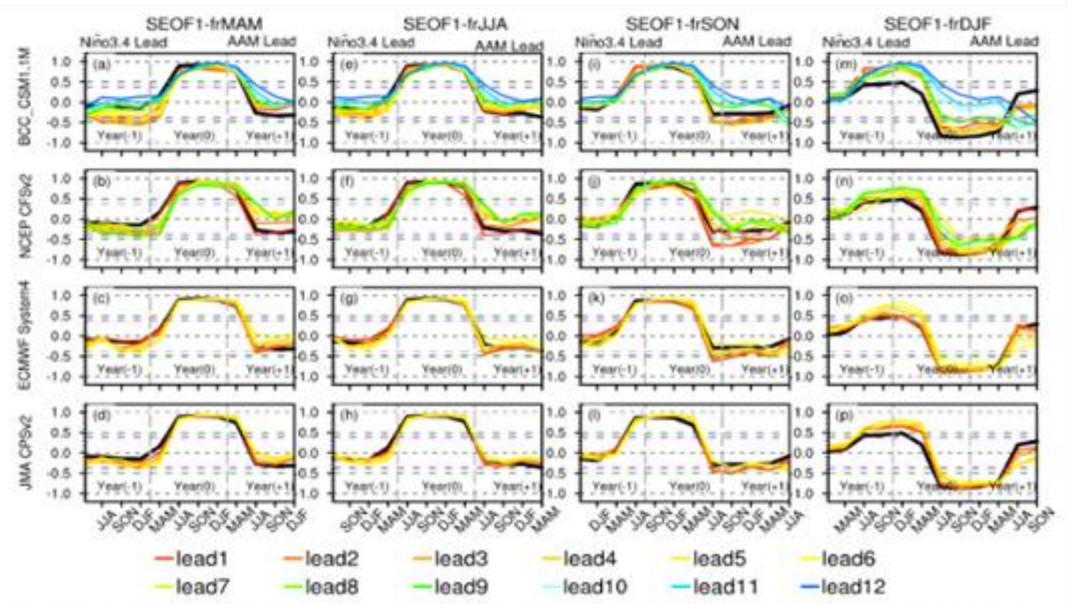


Fig. 6. Lead-lag correlation coefficients of the monthly Niño-3.4 index relative to the SEOF-frMAM (the first column), the SEOF-frJJA (the second column), SEOF-frSON, (the third column), and the SEOF-frDJF (the fourth column) in observation (solid black line) and the models, where the first, second, third, and fourth rows represent the BCC_CSM1.1M, NCEP CFSv2, EMCWF System 4, and JMA CPSv2 models, respectively. Colors are for different lead months. The dashed light green (purple) line denotes statistical significance at the 99% (95%) confidence level based on a Student's *t*-test.

Seasonal-reliant EOF (S-EOF) analysis (Wang and An 2005) identified dominant variability modes of AAM

From Wang Ren* et al. 2023 AAS

Dynamical Predictability of Leading Modes of Asian–Australian monsoon (AAM) in four operational climate prediction models

- Model predictability of the leading AAM modes is much higher for the first mode than the second mode, due to better performance of models in reproducing the first mode.
- ENSO, as an early signal, is conducive to better performance of model predictions in capturing the spatiotemporal variations of the leading AAM modes.

Models : BCC_CSM1.1M CFS_v2 ECMWF_S4 JMA_CPSv2

TCC scores

SEOF-frMAM :

MAM (0) to DJF(0/1)

SEOF-frJJA :

JJA (0) to MAM(1)

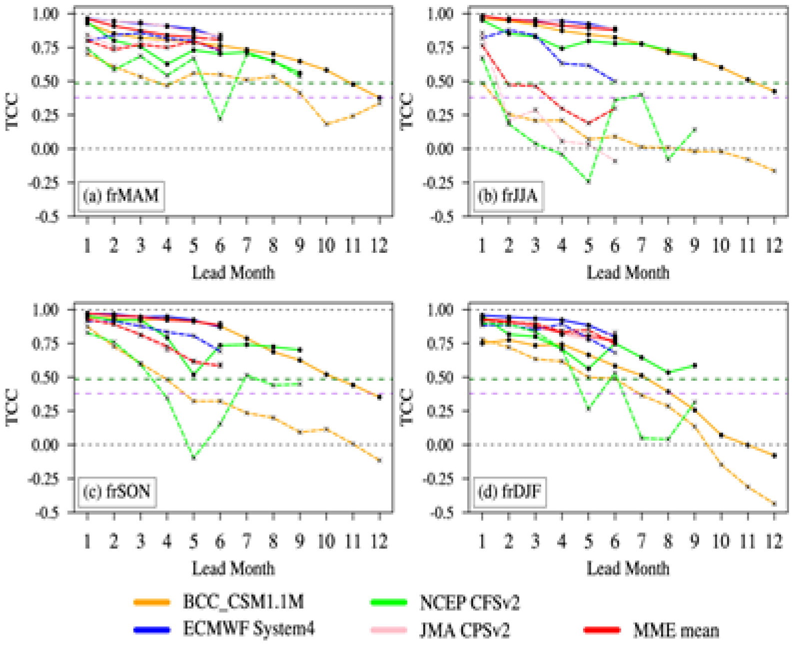
SEOF-frSON :

SON (0) to JJA(1)

SEOF-frDJF :

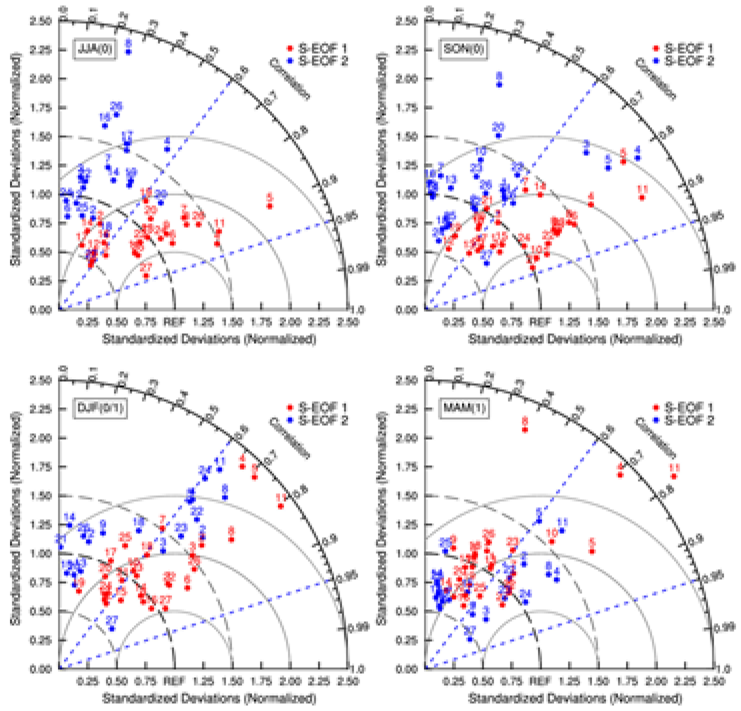
DJF(0/1) to SON(1)

SEOF-1 **SEOF-2**



From Wang Ren* et al. 2023 AAS

Scores of AAM patterns by CMIP5 models



From Zhou Ren* et al. 2021 IJOC

Asian monsoon predictability (1)

Delayed ENSO influence enhance the longer lead predictability through the ”Indian-western Pacific Ocean Capacitor” (IPOC).

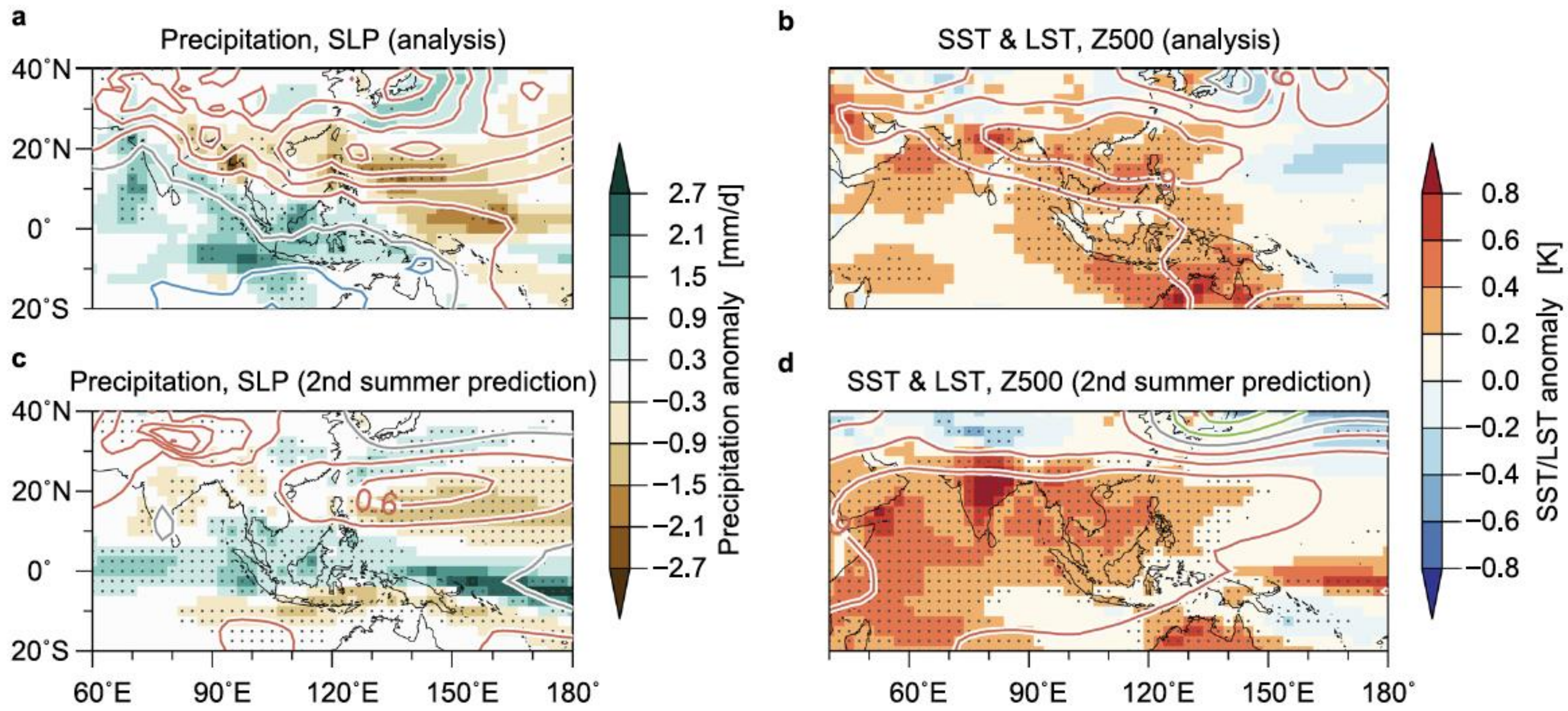


Fig. 3 The IPOC mode and its second summer prediction. Composite anomalies of the (**a**, **b**) observations and (**c**, **d**) JMA/MRI-CPS2 13-month-lead prediction for summers following major El Niño events (1983, 1992, 1998, 2003, 2010 and 2016; see text for definition). **a**, **c** Precipitation (colours) and sea level pressure (SLP; contours with an interval of 0.3 hPa; red for positive, grey for zero and blue for negative). **b**, **d** SST over the ocean and land surface (2 m air) temperature (LST) over land (colours) and 500 hPa geopotential height (Z500; contours with an interval of 3 m; red for positive, grey for zero and green for negative). Stippled regions are statistically significant at the 5% level based on a bootstrap method (10,000 resamplings).

Takaya et al. (2021)
Nature Comms.

Asian monsoon predictability (2)

Developing and delayed ENSO (IO SST) exert influence on WNP monsoon and associated WNP TC activity

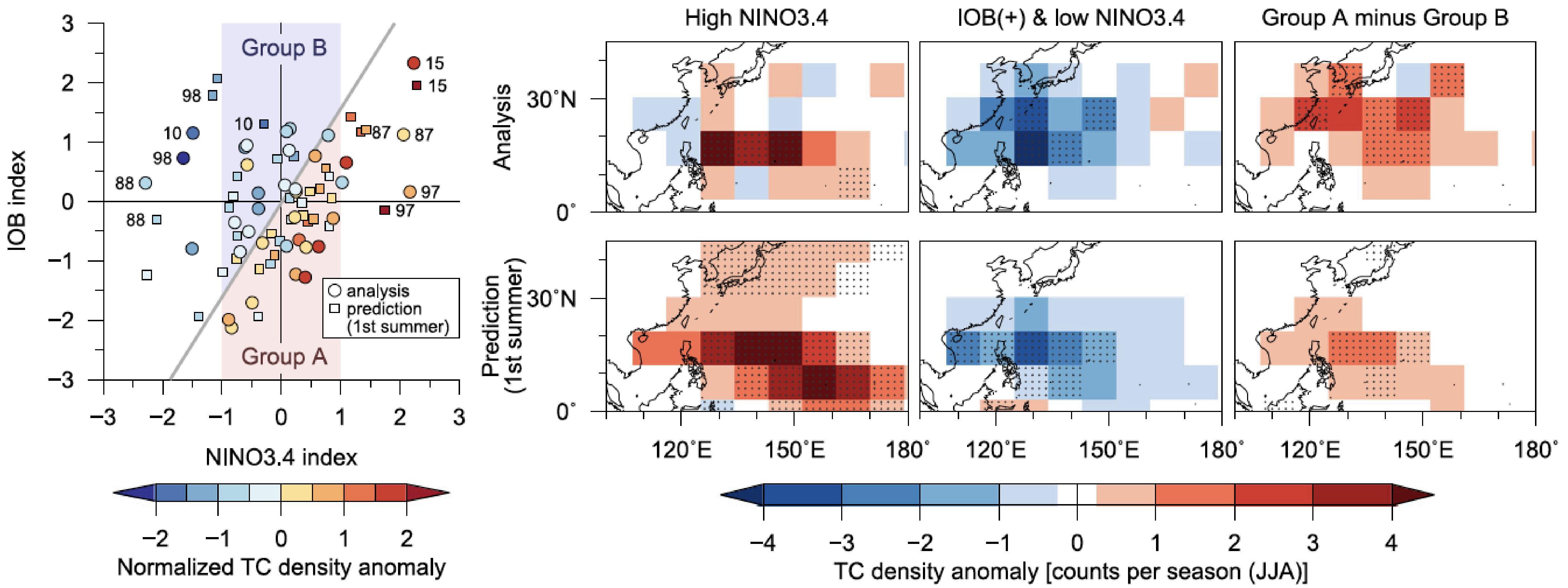


Fig. 5 TC prediction skill and influence from ENSO and IOB SST. Same as Fig. 1 but for the **a** first and **b** second summer predictions of the tropical cyclone (TC) density and monsoon trough (MT) index. **c** Scatterplot of the analysed (circles) and predicted (squares) TC densities with respect to their own Indian Ocean Basin (IOB) and NINO3.4 SST indices. Colours indicate the TC density accumulated in the western North Pacific (WNP) region normalised by the climatological mean and standard deviation. Two-digit numbers shown alongside circles or squares indicate years. **d** Composites of observed and predicted TC density anomalies for summers with (left) the NINO3.4 index >+1.5 std. dev., (middle) the IOB index >0 and NINO3.4 index <−1 std. dev., and (right) Group A minus Group B (groups shown in Fig. 5c). Stippled regions are statistically significant at the 5% level according to a bootstrap method (10,000 resamplings).

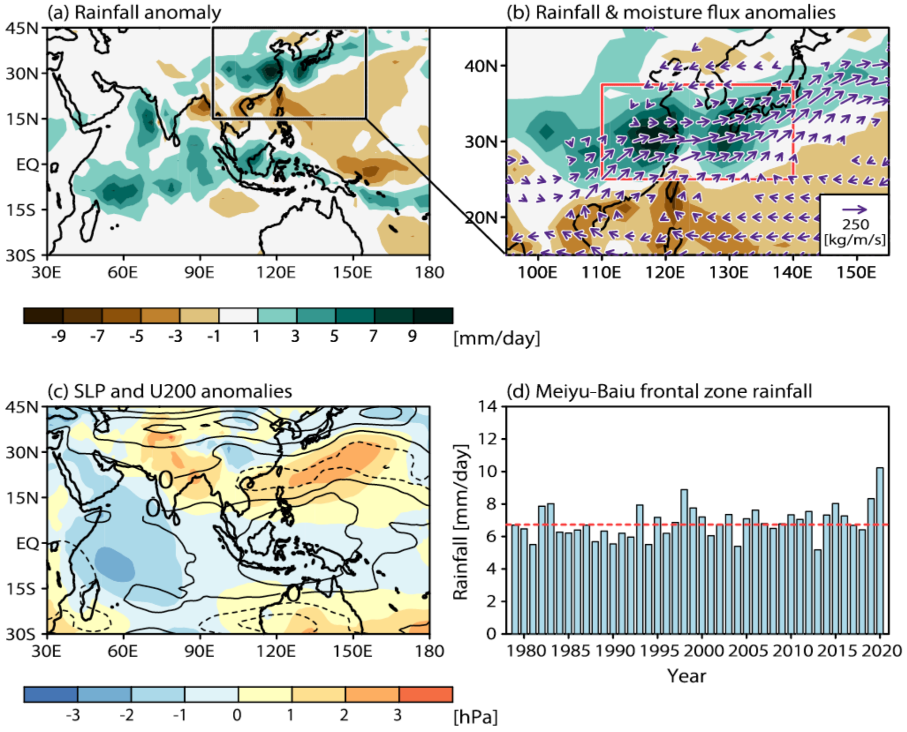
Takaya et al. (2021)
Nature Comms.

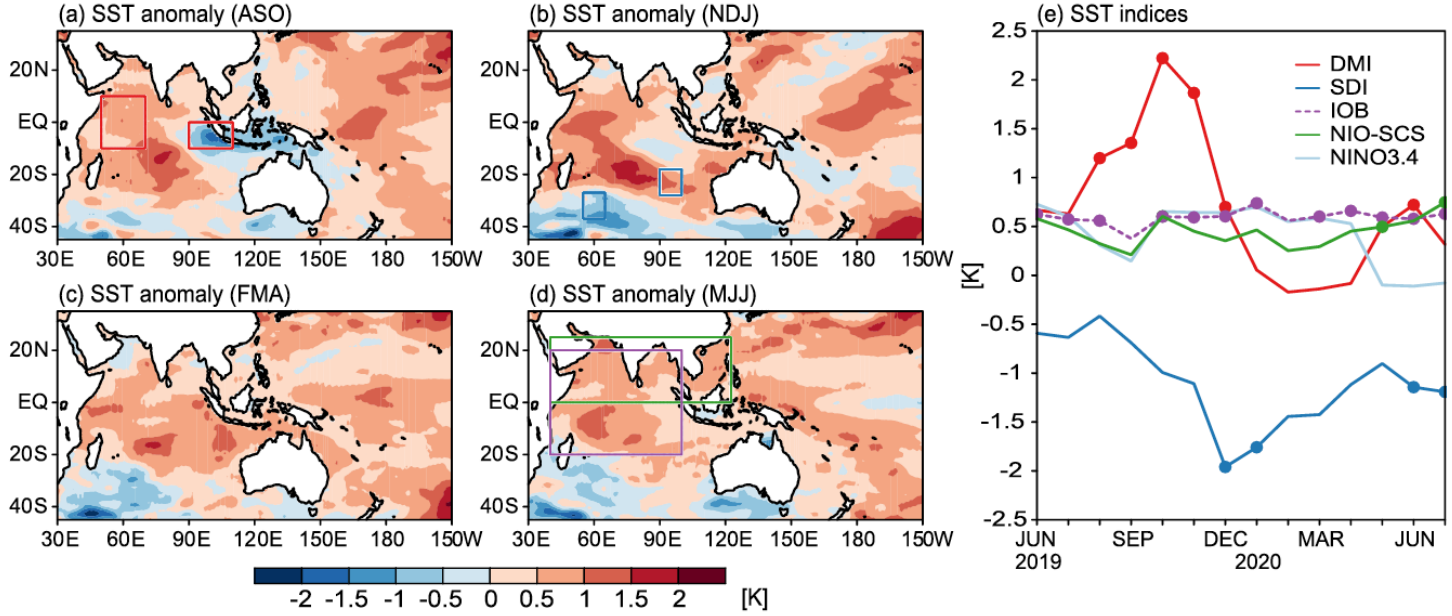
Asian monsoon predictability (3)

Indian Ocean Dipole (IOD), along with El Nino, reinforces the IPOC.

Enhanced Meiyu-Baiu rainfall in early summer 2020 can be traced back to preceding extreme IOD in 2019

Strong IOD can cause IPOC without El Nino. (Takaya et al. 2020, GRL, Zhou et al. 2021, PNAS)





Takaya et al. 2020, *GRL*

* Lu and Ren (2020, GRL) discussed the cause of extreme IOD in 2019

Summary of Asian monsoon predictability

~~Expected~~ Achieved outcomes:

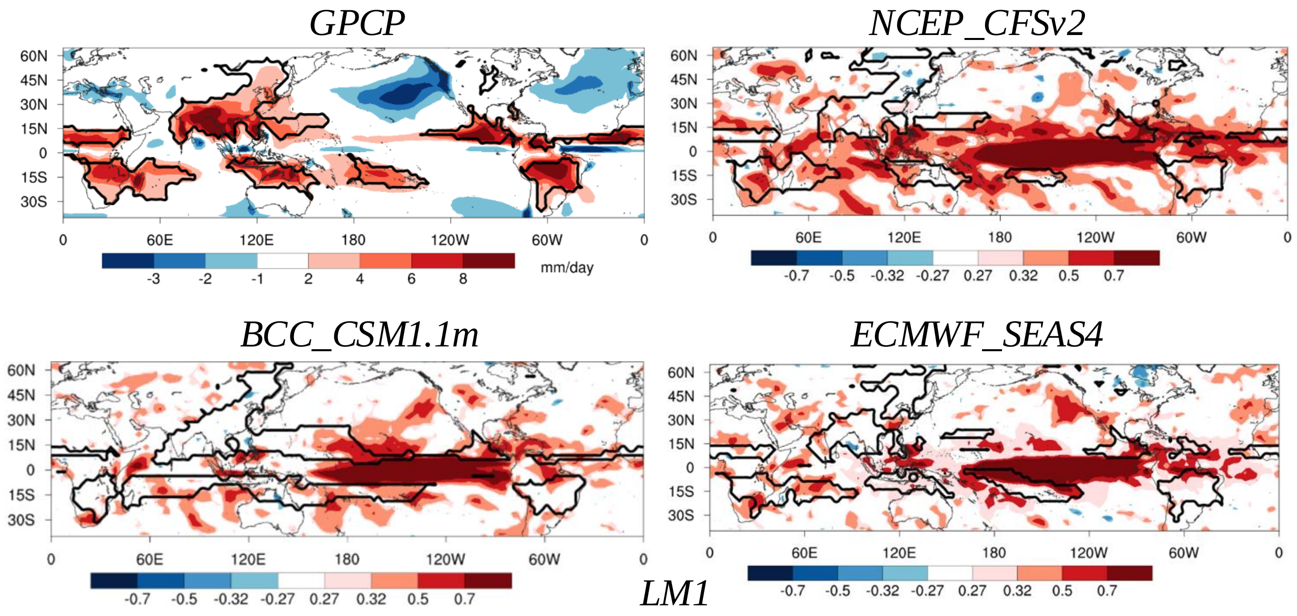
- ✓ Better understanding of processes and mechanisms responsible for the seasonal predictability of the Asian monsoon → IPOC, IOD, ENSO
- ✓ New diagnostic ways to describe the model performance of seasonal predictions of the Asian monsoon → analysis of climate modes using SEOF, CEOF
- ✓ Identification of key aspects to further improve the seasonal prediction skill of the Asian monsoon to facilitate the model development at modeling centers
- ✓ Provision of the systematic assessment of the prediction skill in latest and past seasonal prediction systems, to infer progress and prospects of the Asian monsoon seasonal predictions

* A lot of research has been done across time scales and processes, including monsoon variability, land-atmosphere interactions, model evaluation,… to name a few!

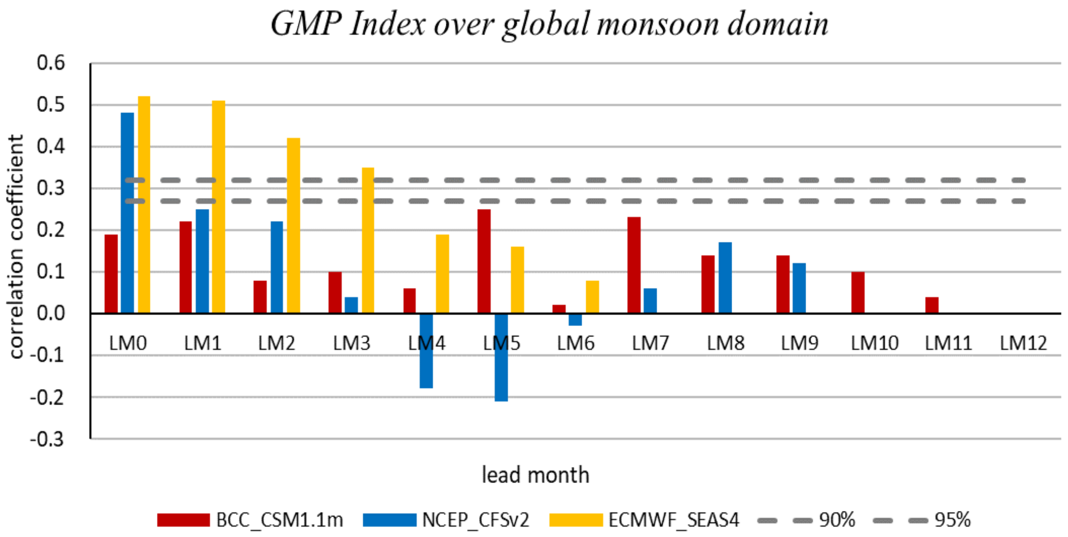
Global monsoon predictability (1)

✓ **Evaluation of the seasonal-forecasting model performance in predicting the GM index.**

Annual range patterns of precipitation between GPCP and models



Correlation skills of GM index predicted in three models



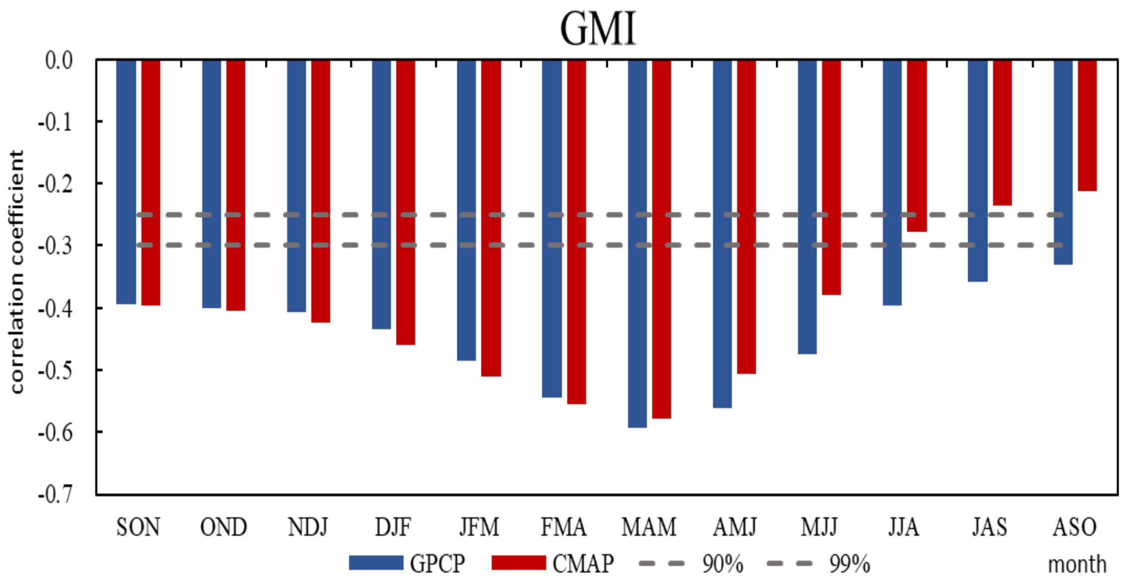
- The three operational models show different correlation skills for the global monsoon index (GMI)

Wang N, Ren et al. 2024 in prep.*

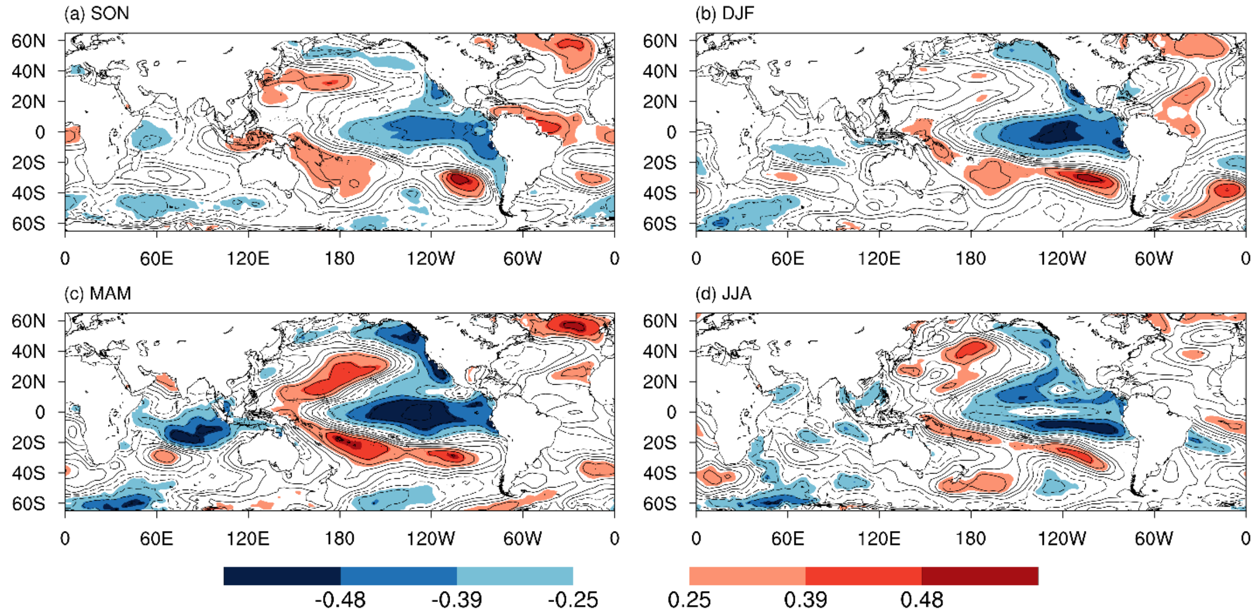
Global monsoon predictability (2)

✓ **Exploring the main factors of ocean forcing on the GM and precipitation, such as ENSO.**

Correlations between GM indices and Nino3.4 index



Impact patterns of ENSO on the GM



- GMI has a significant relationship with ENSO, particularly during its decaying time (boreal spring)

Model-based diagnosis going slowly …

Global monsoon predictability (3)

✓ As a key part of GM, the Asian-Australian Monsoon (AAM) can harvest the primary seasonal-interannual predictability from ENSO through distinct mechanisms for impacting the two modes.

Correlation skills of the AAM indices predicted in the models

SEOF-frMAM :

MAM (0) to DJF(0/1)

SEOF-frJJA :

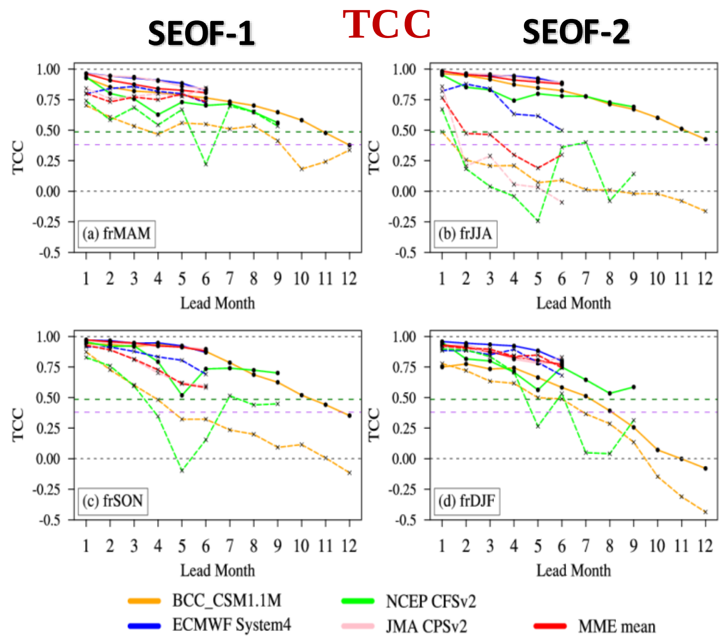
JJA (0) to MAM(1)

SEOF-frSON :

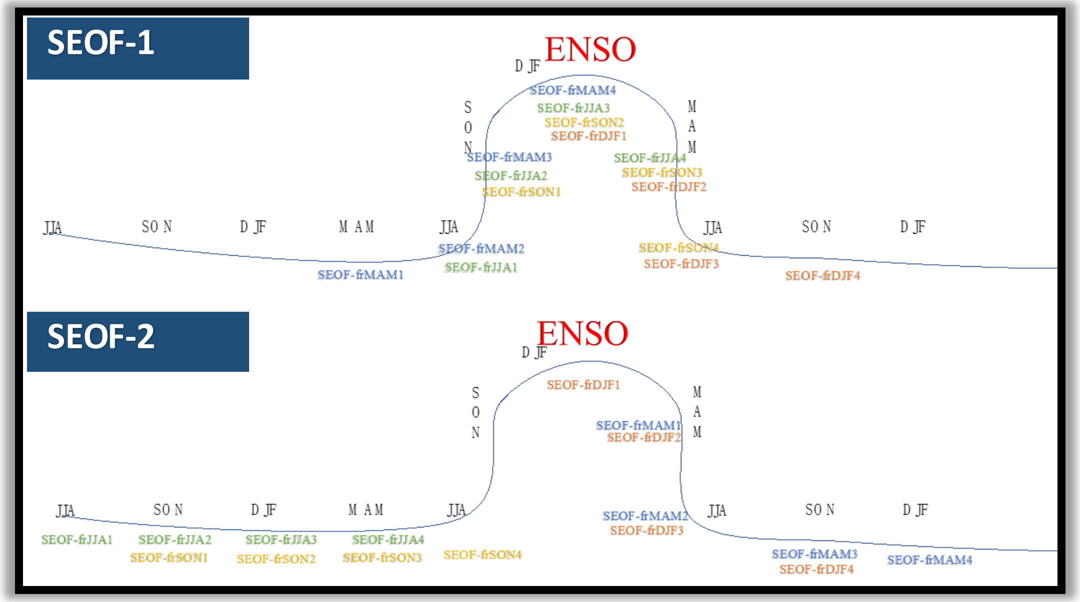
SON (0) to JJA(1)

SEOF-frDJF :

DJF(0/1) to SON(1)



ENSO modulations on the AAM predictions



● **The SEOF-based AAM indices can be well predicted by the four operational climate models**

Wang L, Ren et al. 2023 AAS*

Summary of Global monsoon predictability

~~Expected~~ Achieved outcomes

- ✓ Evaluation of the performance of dynamical models in the seasonal prediction of the GM index and GM precipitation patterns.
- ✓ Evaluation of the performance of dynamical prediction models in representing the impact patterns of the main factors of ocean forcing on the GM and precipitation.
- ✓ Understanding of main mechanism aspects responsible for the seasonal predictability of the GM index or GM precipitation.

A possible renewal of the Monsoons initiative?

In the 5-year Monsoon initiative (2019-2024), main foci were put on the Asian monsoon, with some aspects of the global monsoon.

Concept note:
https://www.wcrp-climate.org/images/modelling/WGSIP/documents/WGSIP_Monsoon_Concept_Note_FINAL.pdf

Should/could we extend the scope of the Monsoon initiative, for instance, including other regional monsoons, South/North American, Australian, western African monsoons.

Any comments and suggestions?
Willingness to serve as leads?