IBS Center
for Climate Physics

Estimating Predictability of Modes of Variability using the CESM2-based Multi-year Prediction System

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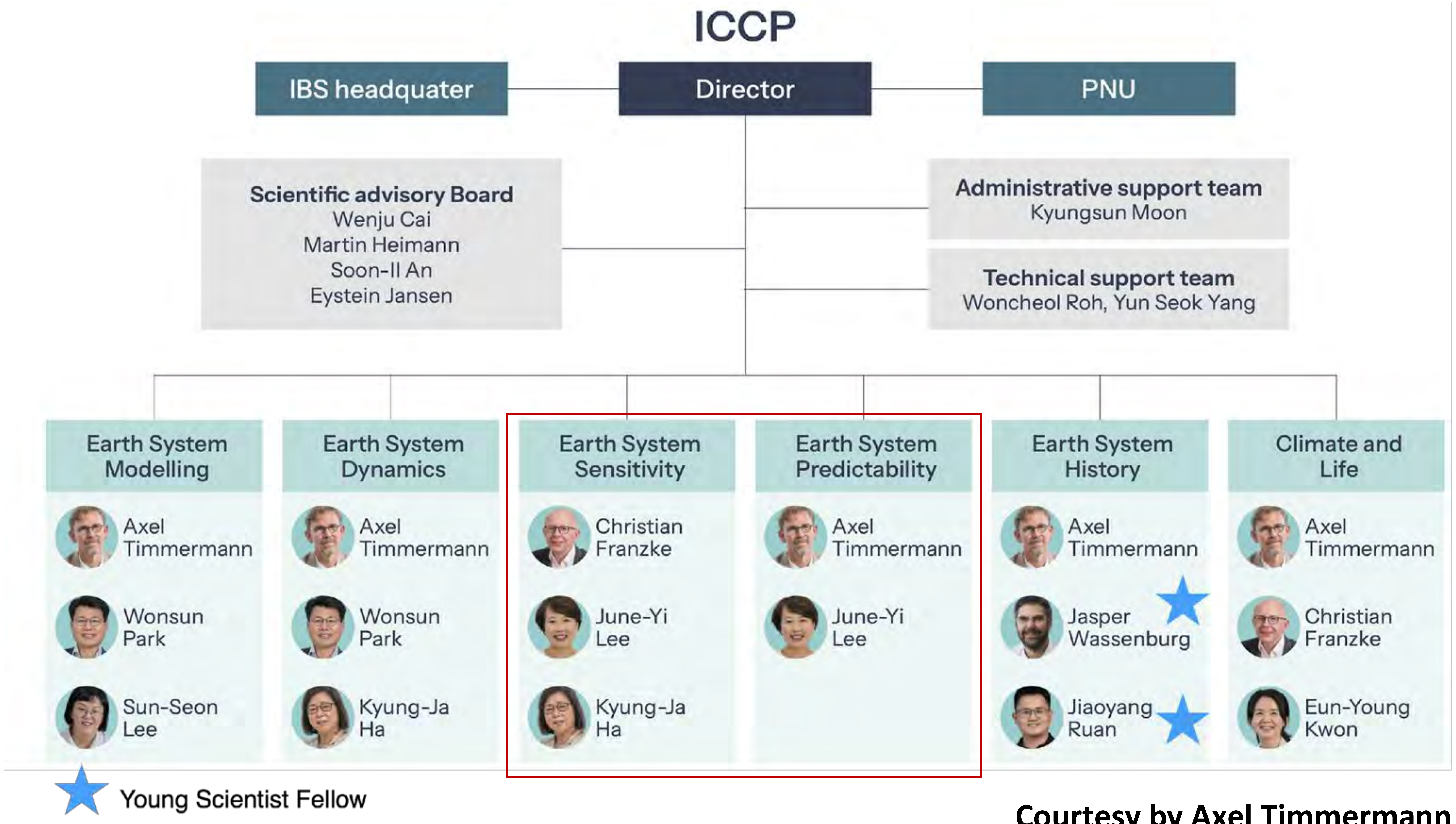
Introduction to IBS Center for Climate Physics (ICCP)



Courtesy by Axel Timmermann

Earth System Predictability Theme in ICCP

Theme Leader: June-Yi Lee

ICCP theme members

Poster No.11

Yong-Yub Kim

Axel Timmermann

Sun-Seon Lee

Poster No.12

Gopi Nadh Konda

Christian Franzke

Oral Session D-2

Won-Sun Park

Abhinav R. V.

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External collaborators

Pusan National Univ.

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Whanhee Lee

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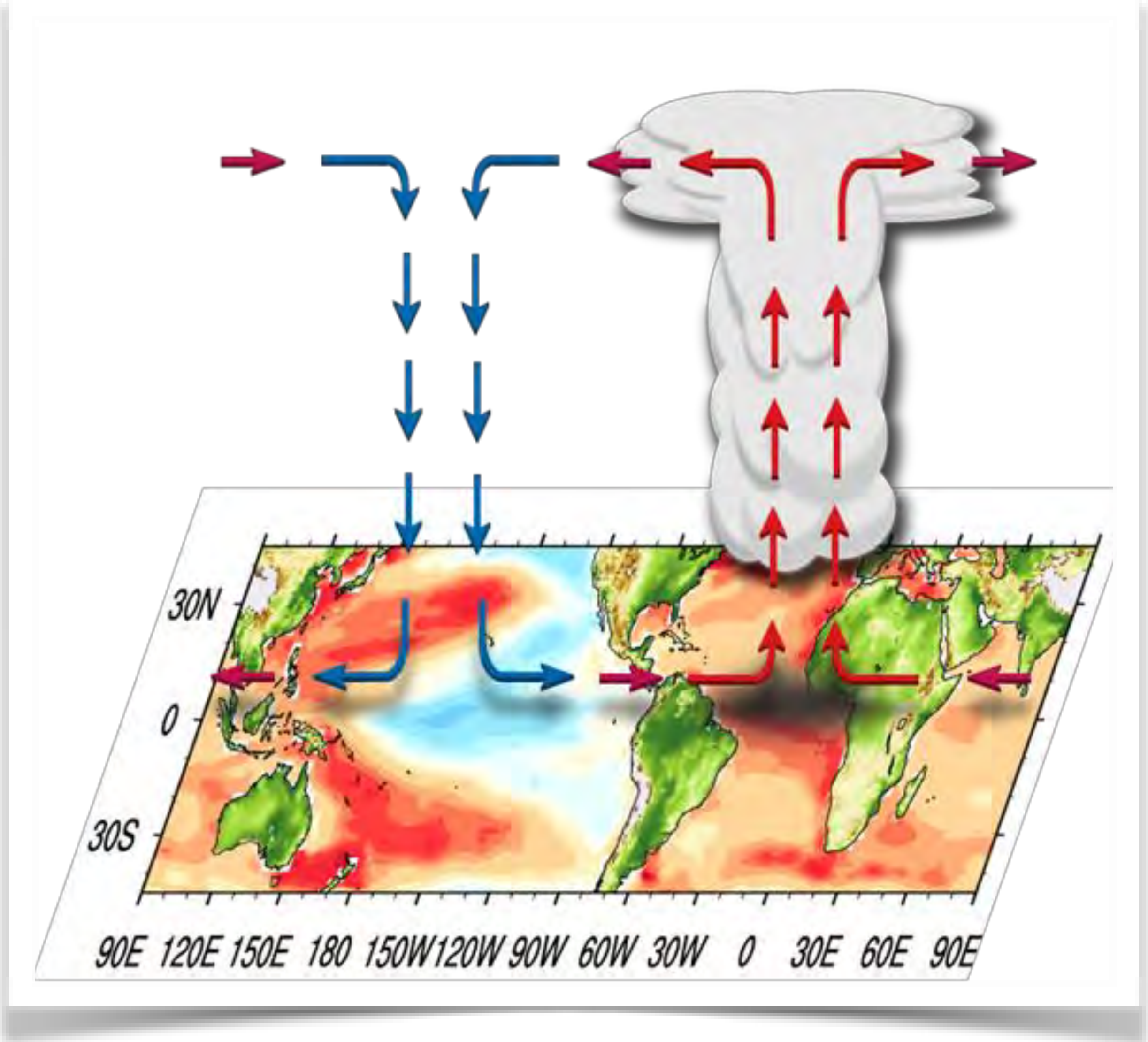


Tropical Trans-basin Variability

Image credit: Yoshi Chikamoto

Contents

Objectives of This Study

- **Enhancing our predictive capability of Earth system components**, not only **physical** but also **ecological** variables, on timescales of **weeks to decades**, using improved comprehensive Earth System models and innovative technologies
- **Improving estimates of predictability** of Earth system components on seasonal to multi-year timescales
- **Better identifying the internal and external components of Modes of Variability**, including ENSO, Trans-Basin Variability, PDO, and AMV
- **Estimating and attributing predictability of Modes of Variability** based on the CESM2-based multi-year prediction system in ICCP

02 Models and Tools for the Earth System Predictability Theme

Predictability of
Sea Level and Ice Sheet

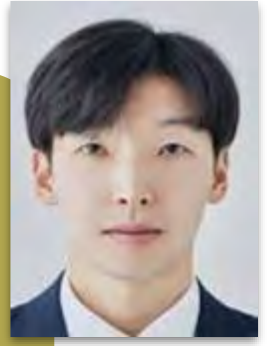
*Climate-Ice-Sheet Coupled Prediction System (CESM1.2.2+PSUISM)

Subseasonal-to-Seasonal S2S Prediction Project

S2S Prediction Models

CESM2 Large Ensemble (LENS2)

**AI Global Climate Prediction Model



Multi-year Prediction System based on CESM2

Predictability from Forcing

Predictability of Extreme Events

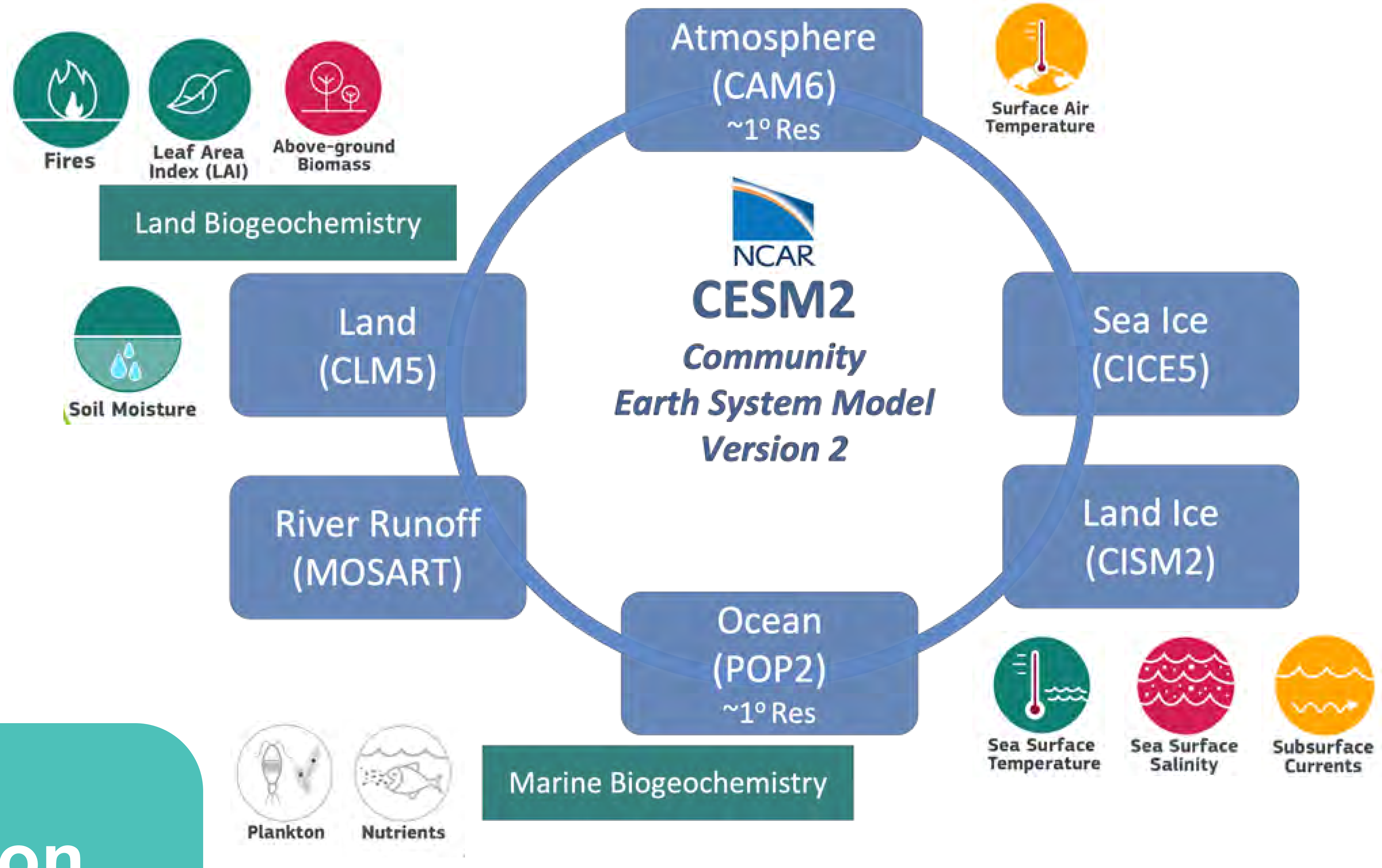
Predictability from Forcing, Ocean Memory, & Internal Variability

Days → Weeks → Months → Seasons → Years → Decades → Centuries

* Development of a climate-ice-sheet coupled prediction system based on CESM1.2.2 and PSUISM is on progress for sea-level and ice-sheet predictability study

** Development of the AI Global Climate Prediction Model is in progress, collaborating with KIST, POSTECH, and Chonnam Univ.

02 Models and Tools for the Earth System Predictability Theme



Multi-year Prediction System based on CESM2

Predictability from Forcing, Ocean Memory, & Internal Variability

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The CESM2-based Multi-year Prediction System



Ocean Reanalyses

- UKMO EN4.2.2 (Good et al., 2013)
- JMA ProjD7.3 (Ishii et al., 2017)
- ECMWF ORAS4 (Balmaseda et al., 2013)

3-Dimensional Ocean Temperature & Salinity

CESM2 Large Ensemble (Uninitialized runs) → Full Forcing Included → **Ocean Anomaly Data Assimilation (Temperature/Salinity)** → Initialized from Jan 1 → **5-year Hindcast (Initialized runs)**

- Total 100 members (Rodger et al., 2021)
- 10 members for assimilation

- 10 members from EN4.2.2 (1950-2021)
- 10 members from ProjD7.3 (1955-2021)
- 10 members from ORAS4 (1958-2016)

- 20 members (EN4.2.2, ProjD7.3)
- 62 years from 1960-2021
- 6200 simulation years (>2 PB)

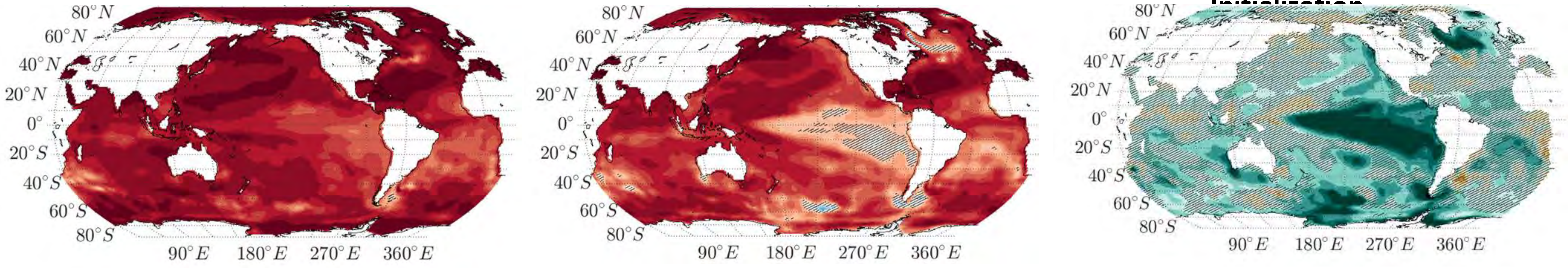
Predictability of the 2nd Kind arising from external forcings

+ Predictability of the 1st Kind arising from ocean memory and modes of variability

Kim et al. under review DOI: 10.21203/rs.3.rs-5748726/v1

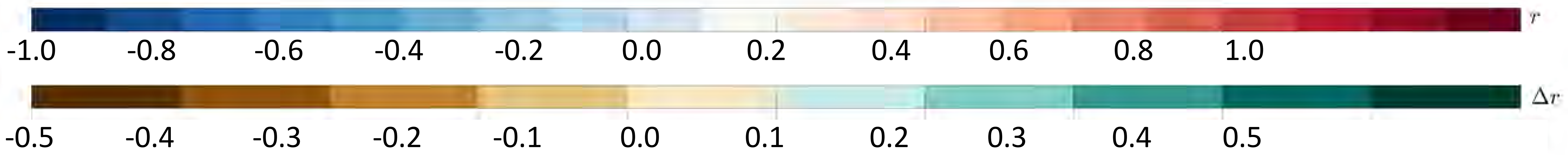
New Estimation of Predictability (ASSM vs HIND): SST

Conventional Method (Ensemble-mean Based, Lead Year 1)/ Assimilation as a reference



- Does ensemble mean represent the most probable predictable state for nonlinear system with non-Gaussian properties?

- **A higher anomaly correlation coefficient skill in the ensemble mean** than individual-member-based metrics by **removing stochastic noise** and **filtering out the less predictable internal variability component**



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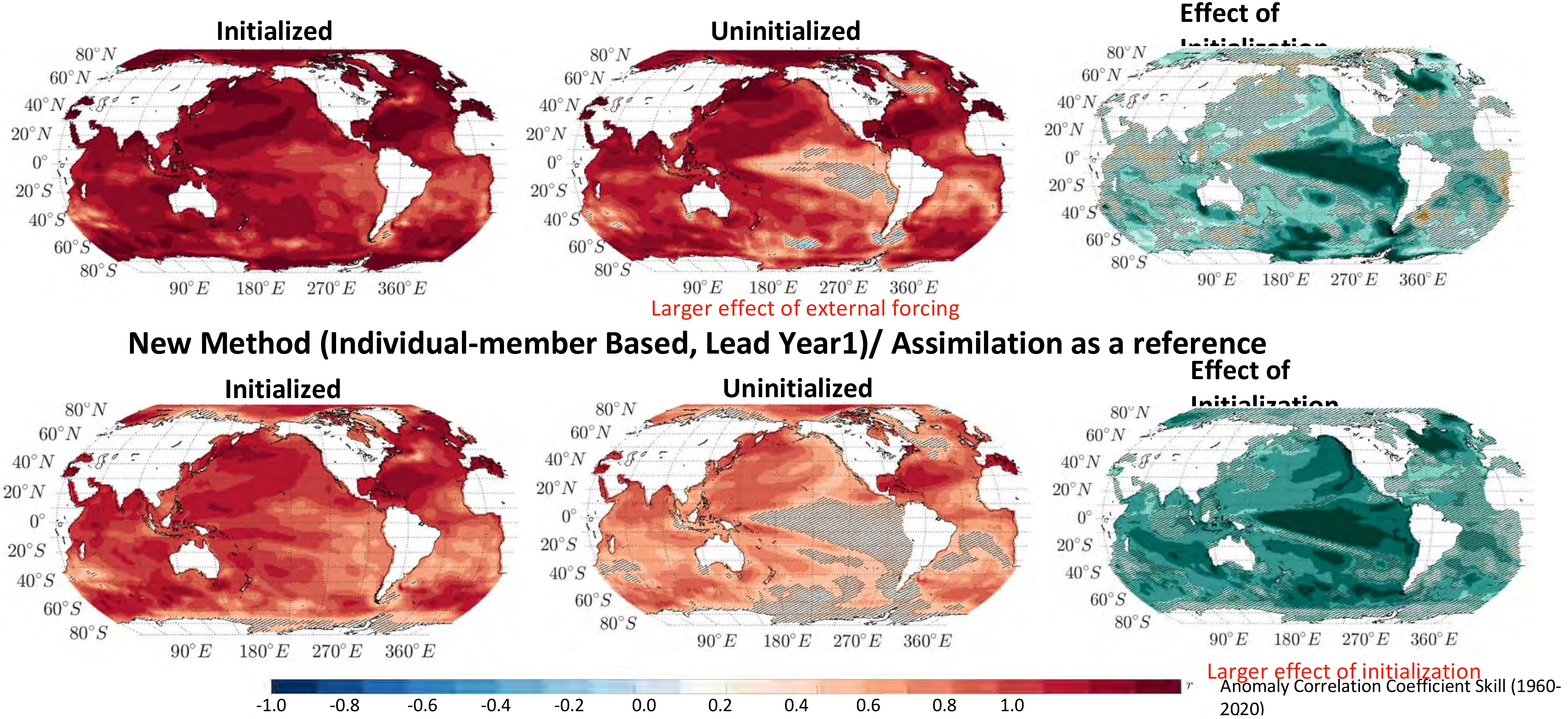
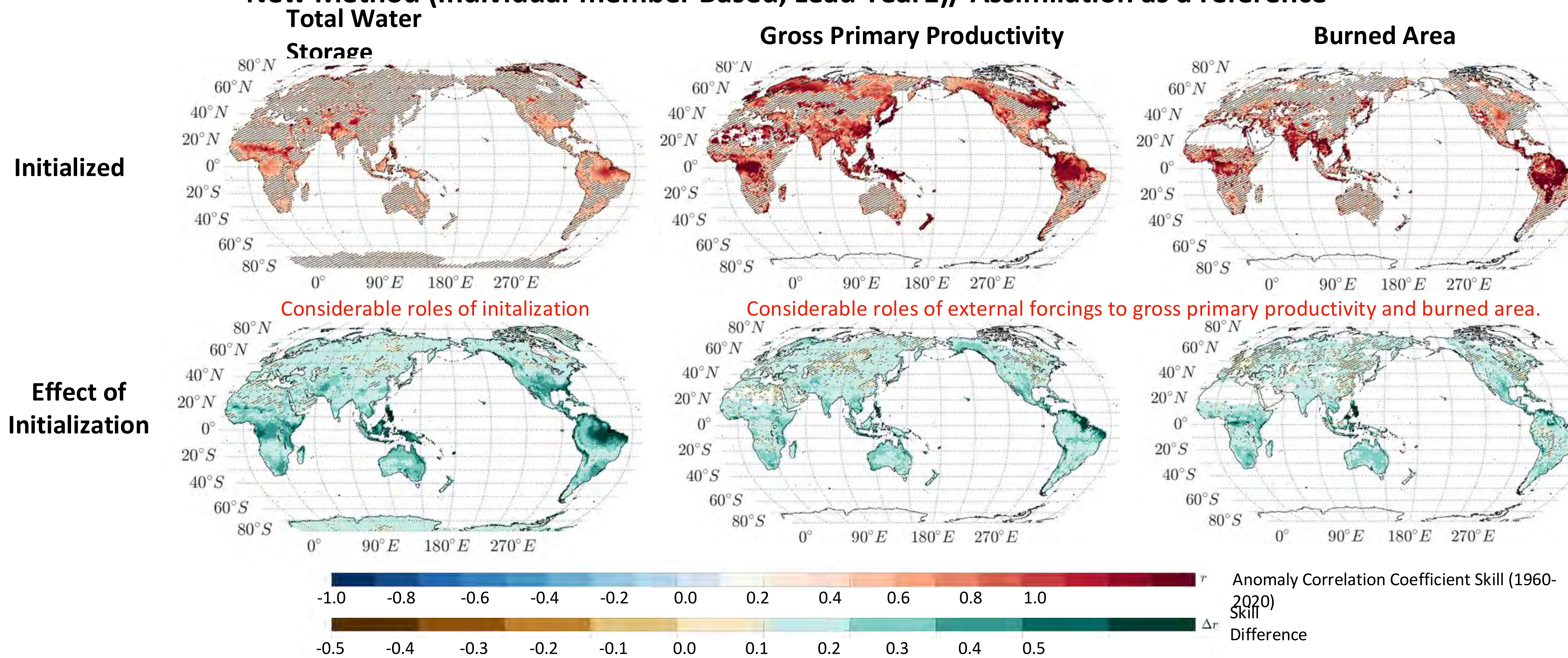


- Initialized physical properties and the associated constrains in ocean circulation provide an important source for marine ecosystem predictability. => See Dr. **Yong-Yub Kim's Poster** for details

Kim et al. under review *DOI: 10.21203/rs.3.rs-5748726/v1*

New Estimation of Predictability (ASSM vs HIND): Terrestrial Variables

New Method (Individual-member Based, Lead Year1)/ Assimilation as a reference



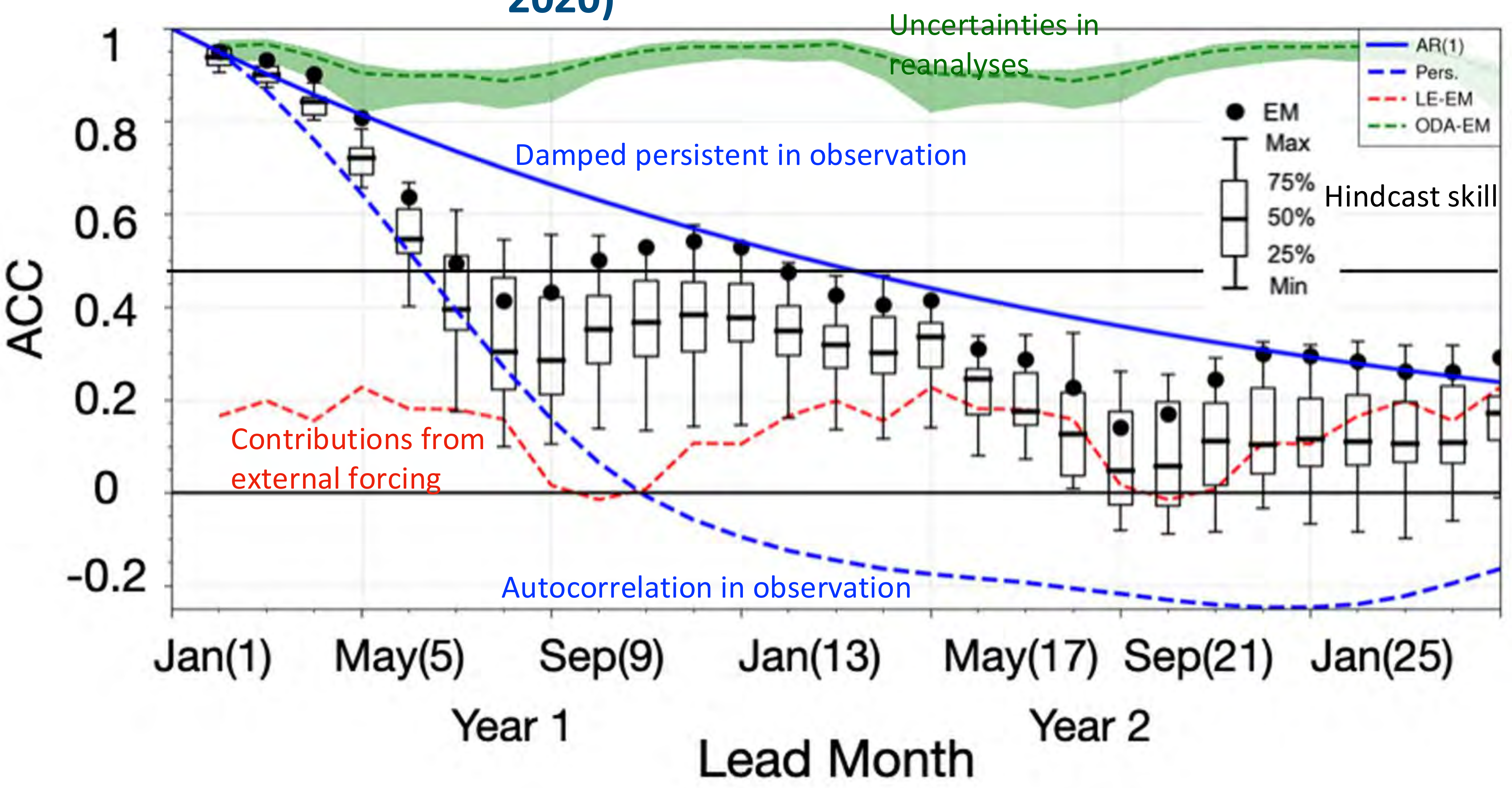
- Predictability for **gross primary productivity** arising from variations in surface temperature, solar radiation, CO_2 levels, and land water storage.
- Predictability for **wildfire** arising from large-scale climate patterns and external forcings.

Kim et al. under review DOI: 10.21203/rs.3.rs-5748726/v1

03

Prediction of Modes of Variability: El Nino-Southern Oscillation

Anomaly Correlation Skills (1960-2020)



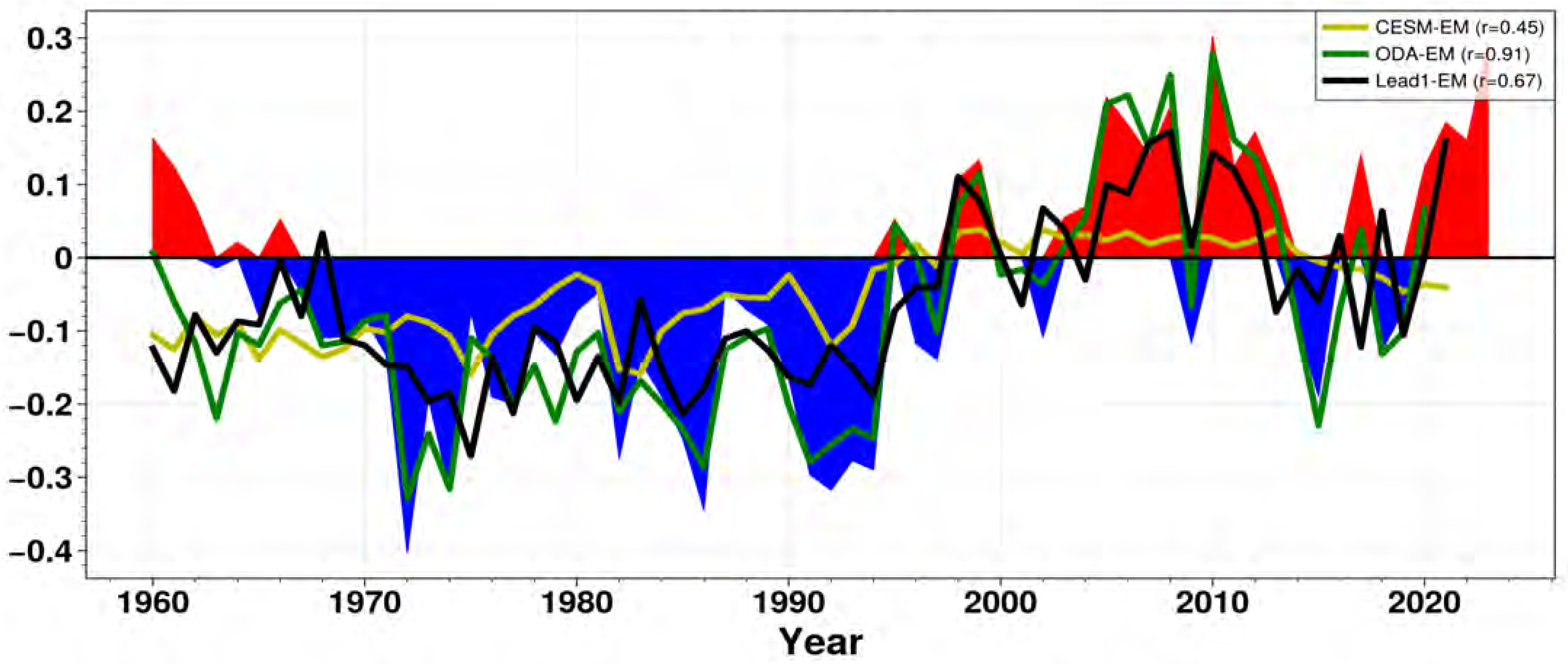
- Major modes of climate variability such as **El Niño-Southern Oscillation (ENSO)** are important sources of earth system predictability.
- Their corresponding predictive skill due to initialization may be translated into other **societally relevent physical and biogeochemical variables**.
- For ENSO, the individual-member based skill is a more robust metics for predictability of the 1st kind since the probability distribution of ENSO is highly skewed with considerable nonlinearities.
- The long-lead predictability of the ENSO is also contributed by its damped persistent characteristics.

* The ENSO index based on Niño 3.4 SST index
* The prediction skill is against observation

03 Prediction of Modes of Variability: Atlantic Multidecadal Variability

Poster No.8

The AMV index

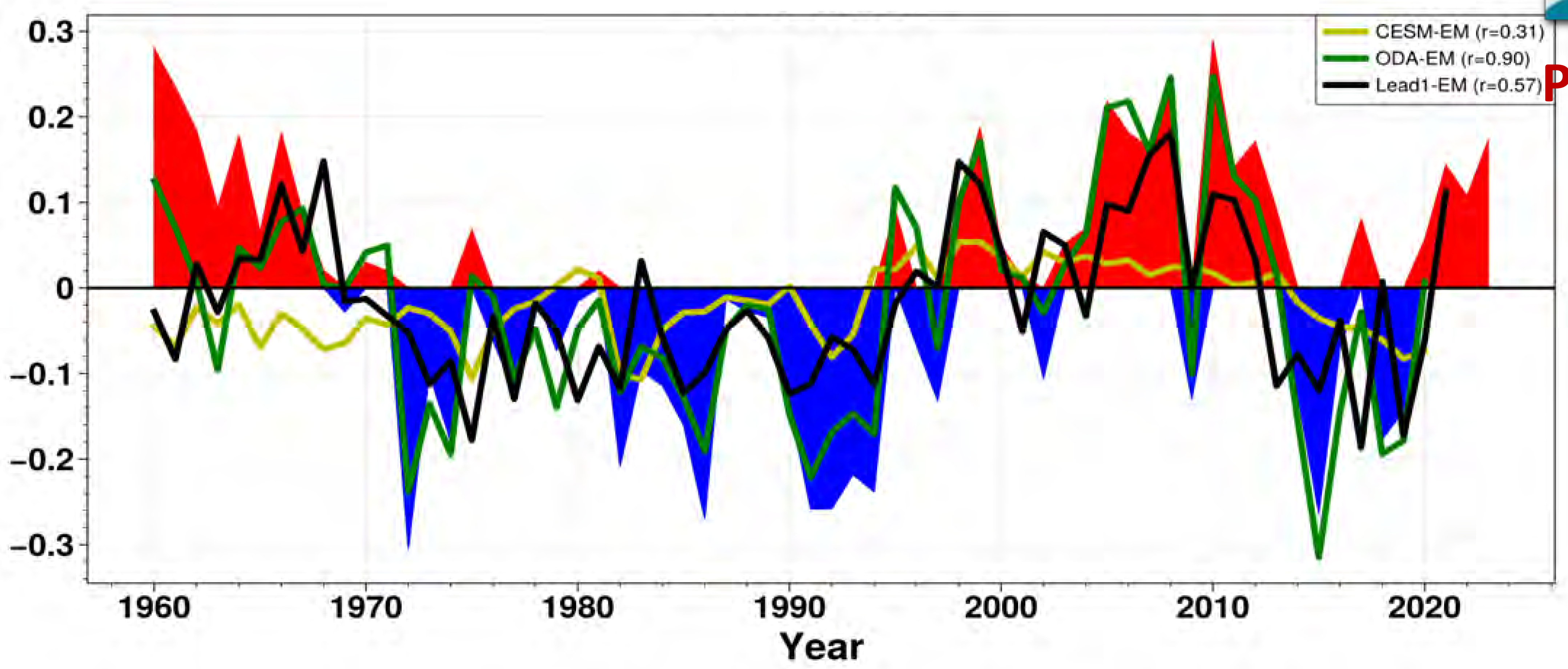


Based on Trenberth and Shea (2006)

AMV Index = AVG (NASST – Gt)

* Forced Response for AVG(NASST) ~ 45%

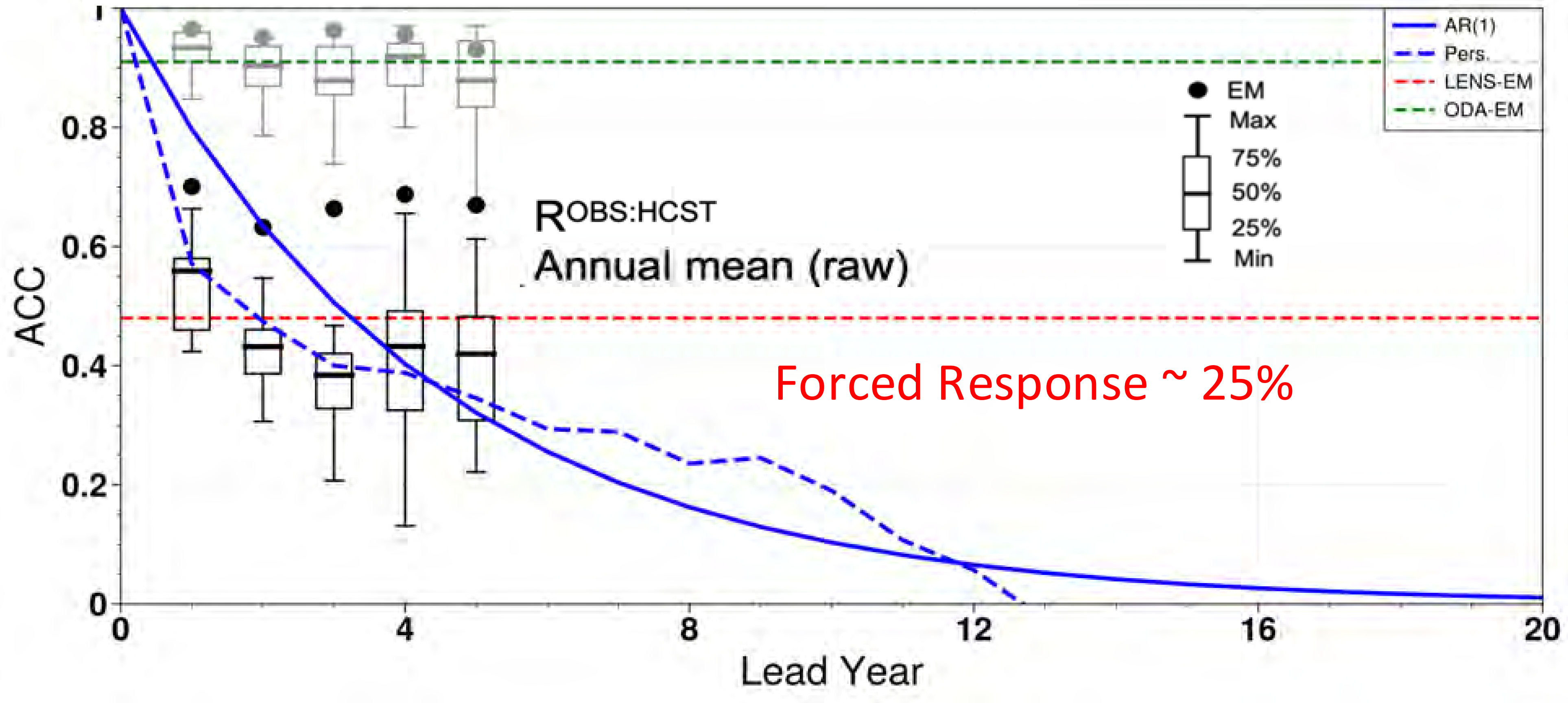
The internal AMV (iAMV) index



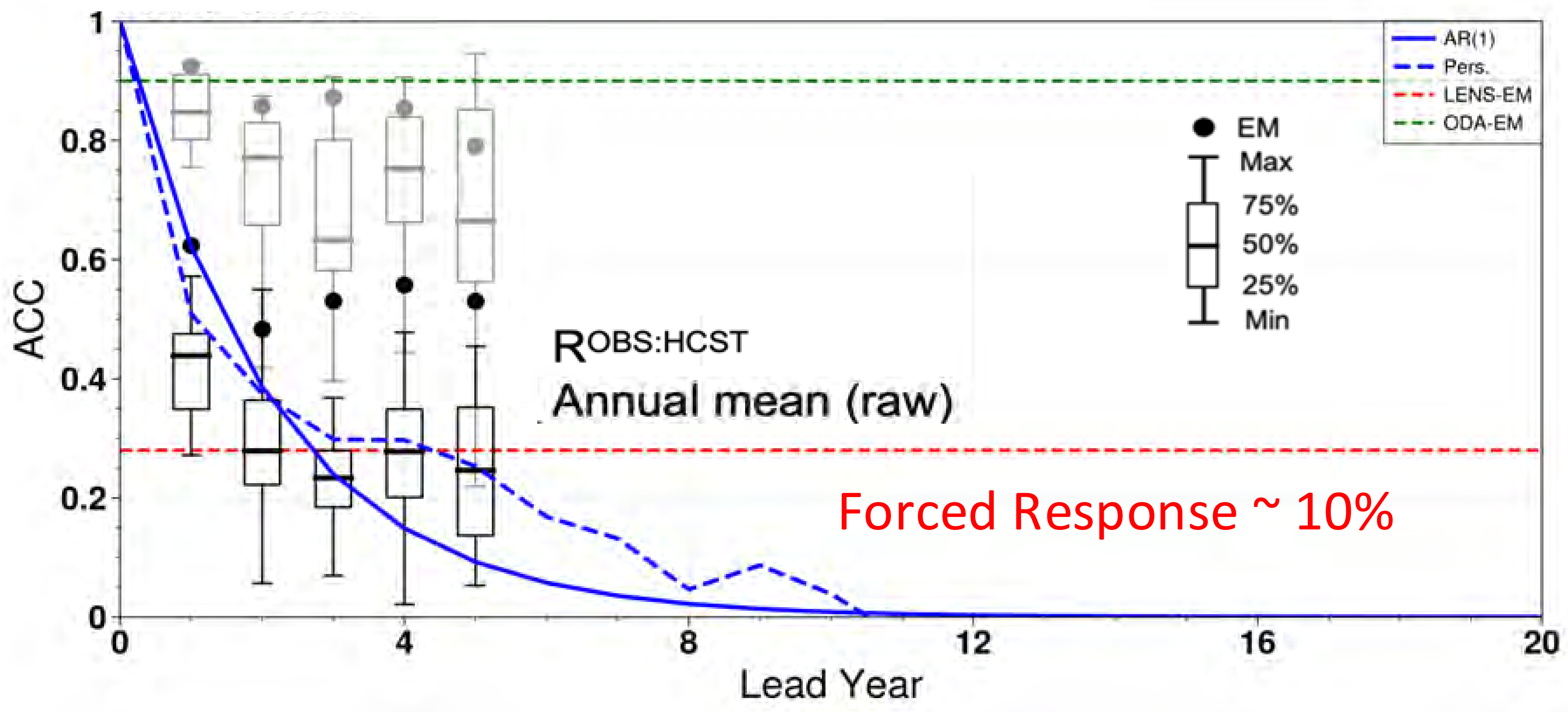
Based on Global Residual Method (Deser and Phillip, 2021)

iAMV Index = AVG (NASST-GT*GSSTreg)

The ACC Skill for the AMV index

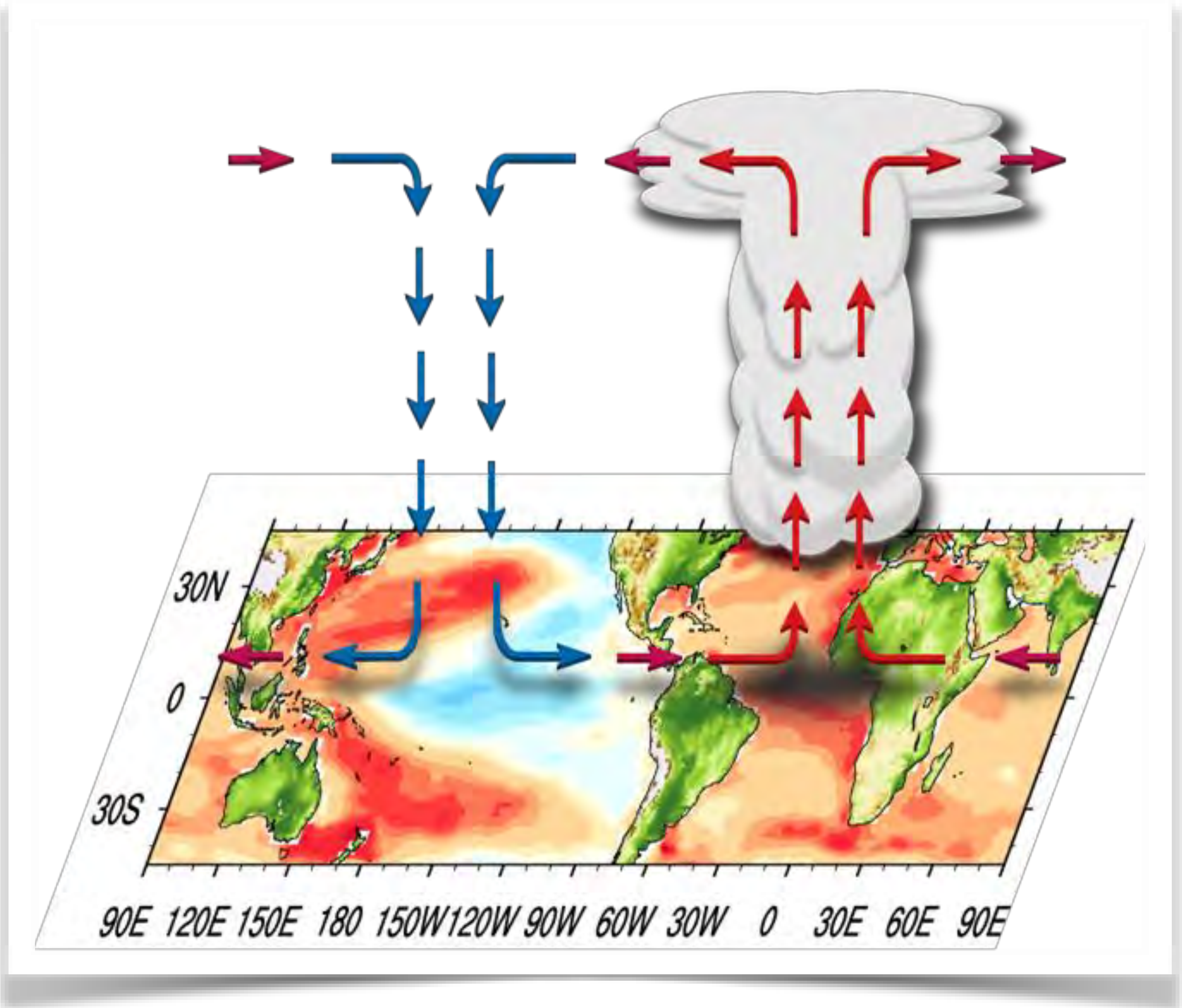


The ACC Skill for the iAMV index

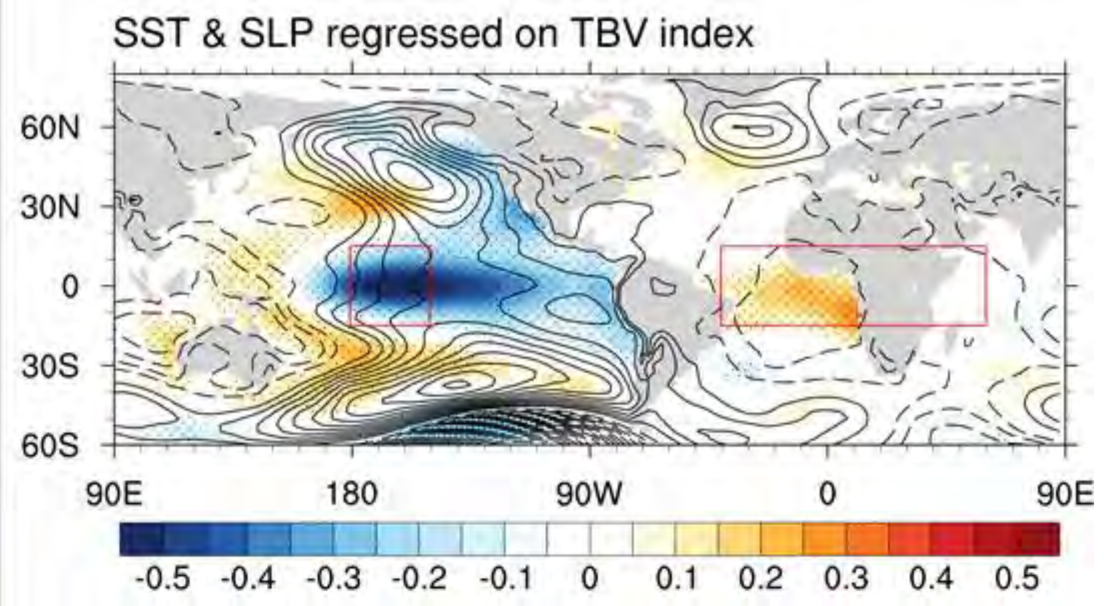


03

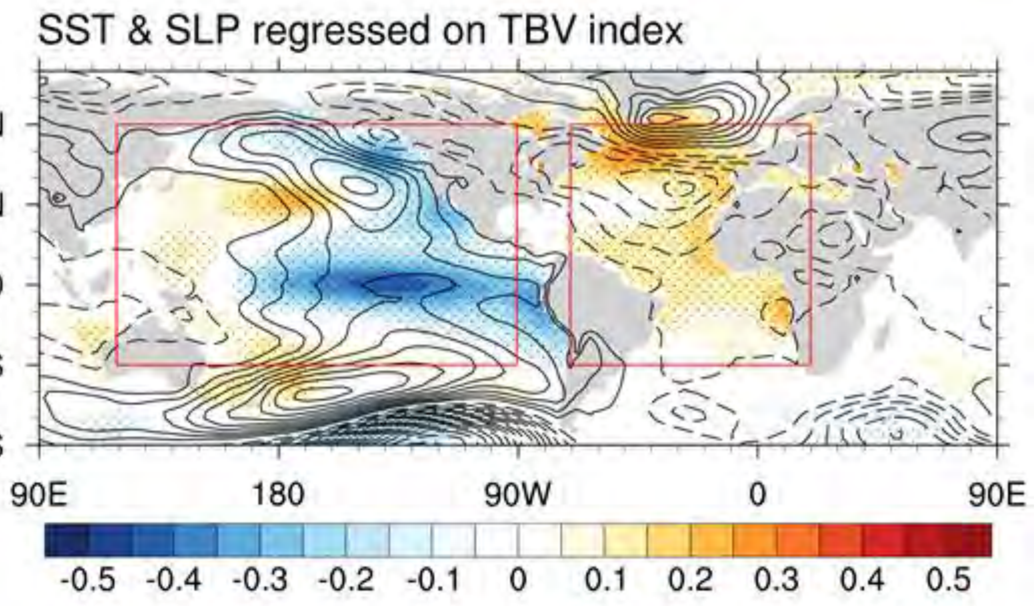
Prediction of Modes of Variability: Trans-basin Variability



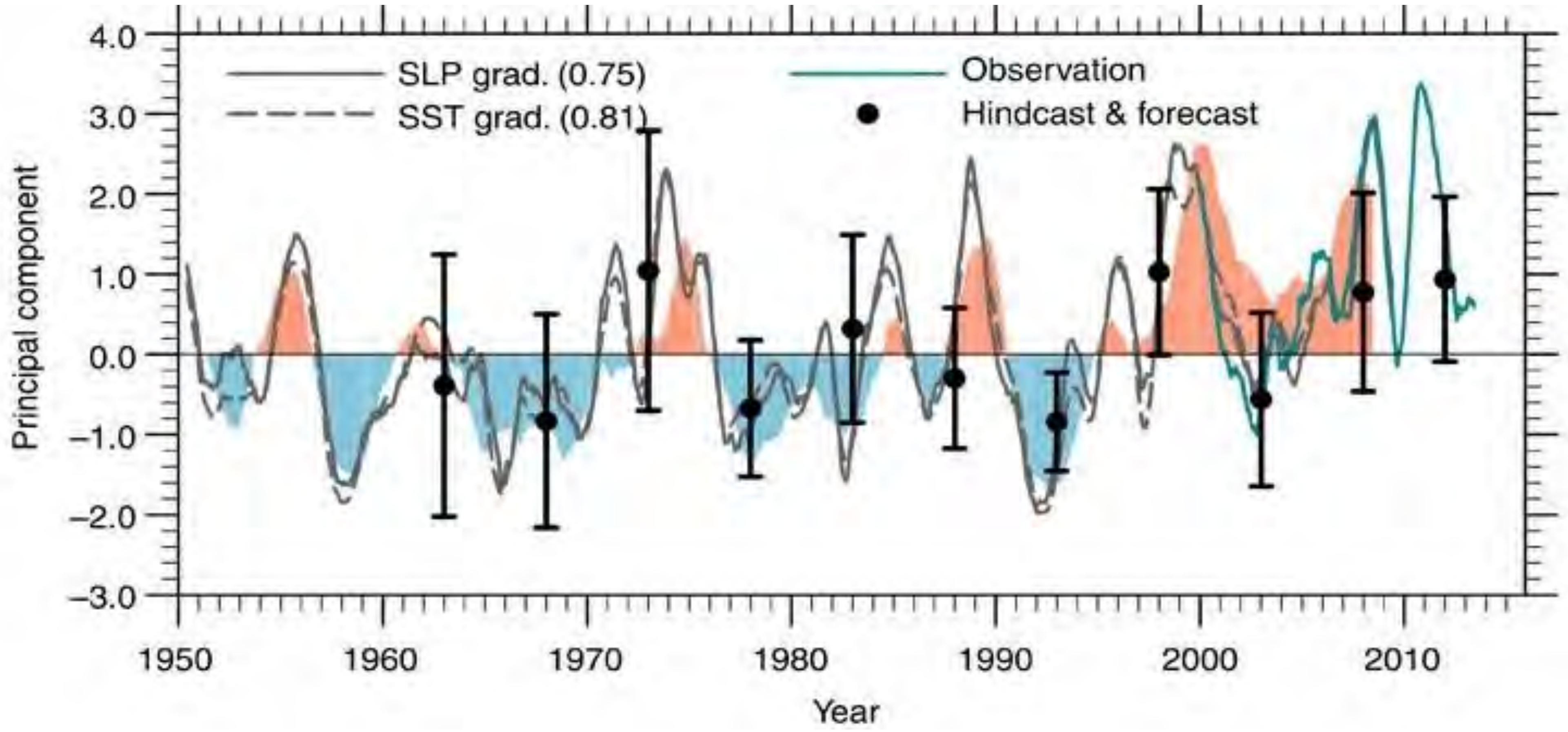
SST-based index (Chikamoto et al. 2015)

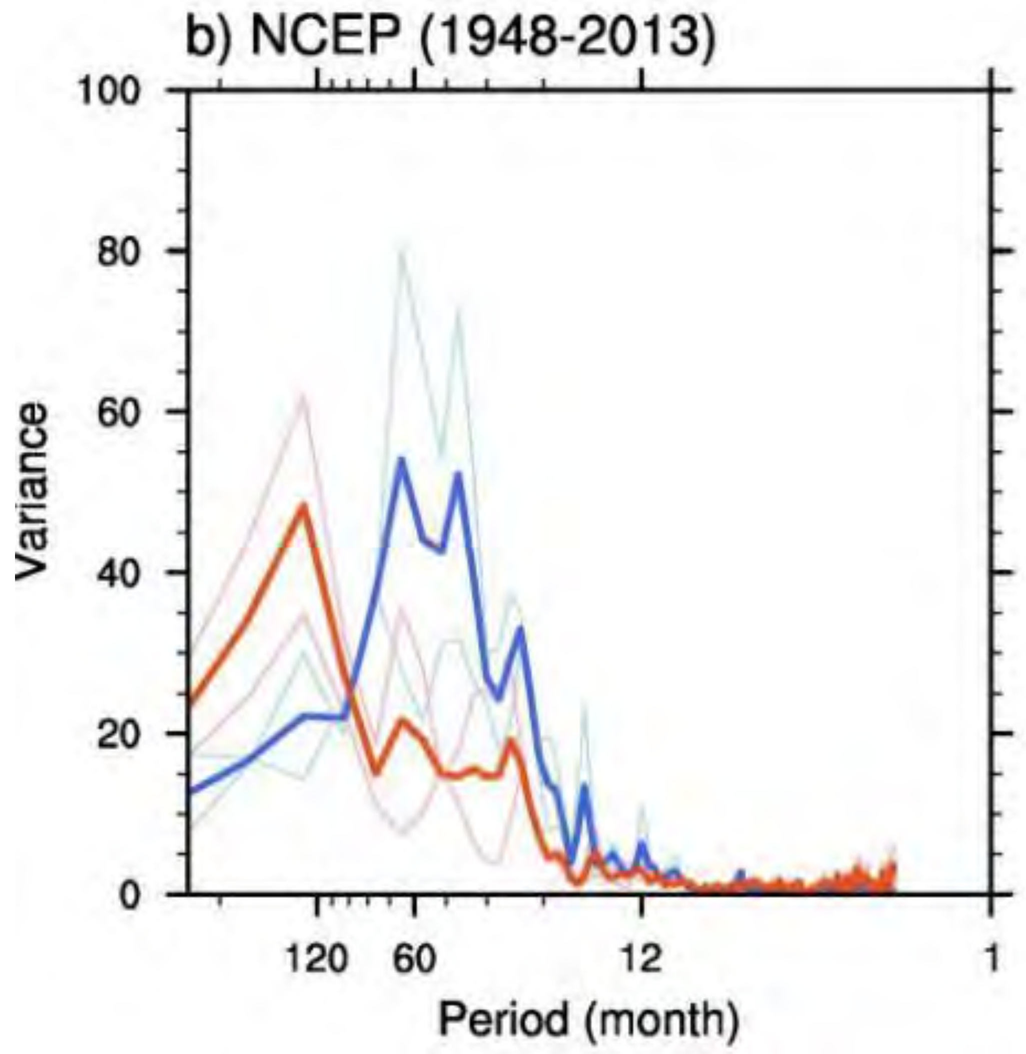


SST-based index (McGregor et al. 2014)



Tropical Trans-Basin Variability Indices





Dominant Periods

Blue line for ENSO: 2~7 years

Red line for TBV: 10~20 years

Prediction of Modes of Variability: Trans-basin Variability

Definition

Tropical Central Pacific — Tropical Atlantic-Indian Ocean

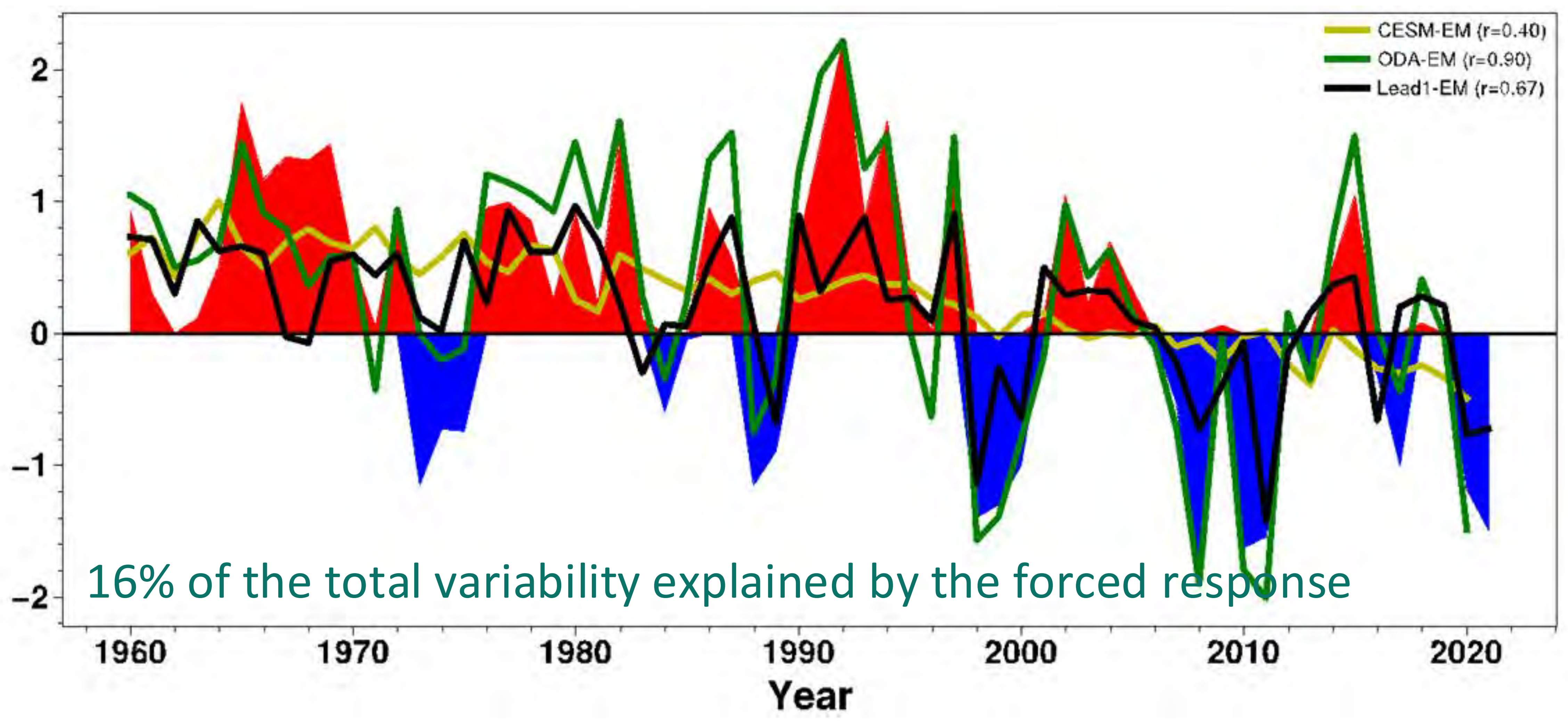
The TBV index: SST_{norm} (15°S-15°N, 180°W-150°W) - SST_{norm} (15°S-15°N, 40°W-60°W)

SST_{norm} = SST anomaly normalized by standard deviation at each grid
(based on Chikamoto et al. (2015)

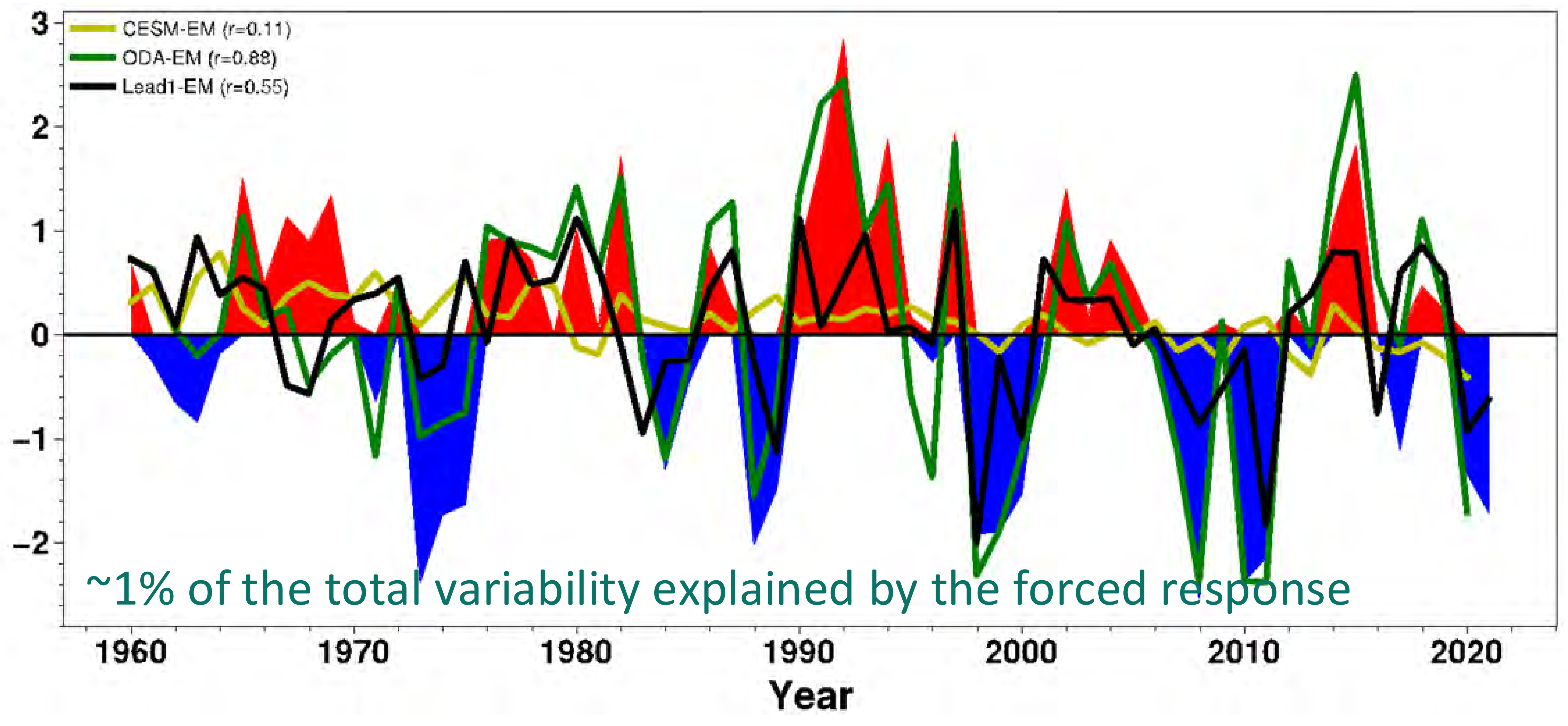
The iTBV index: $iSST_{norm}$ (15°S-15°N, 180°W-150°W) - $iSST_{norm}$ (15°S-15°N, 40°W-60°W)

iSST anomaly = SST anomaly (i,j) – GM Regression (I,j) (based on Deser and Phillips (2021)

The TBV index



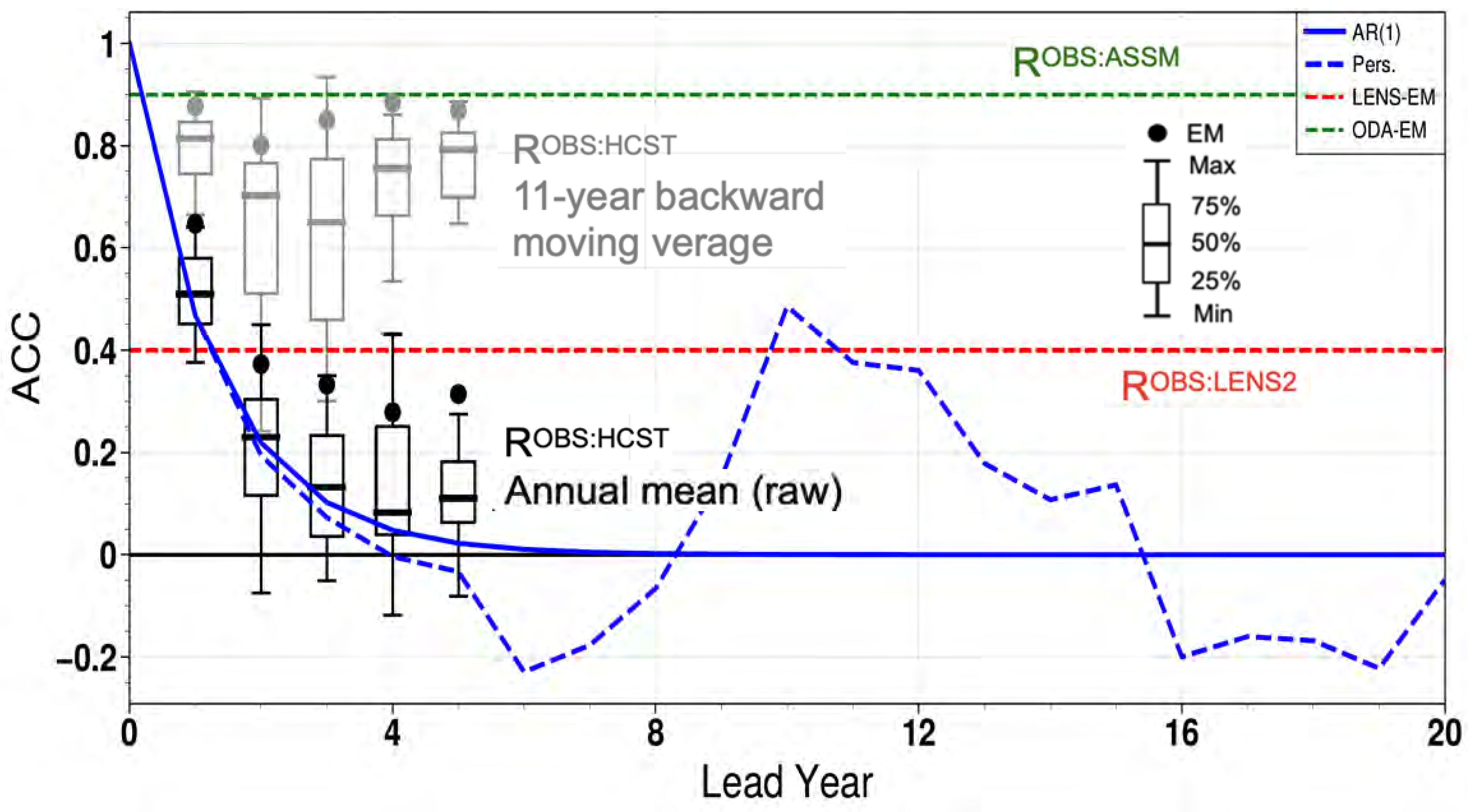
The iTBV index



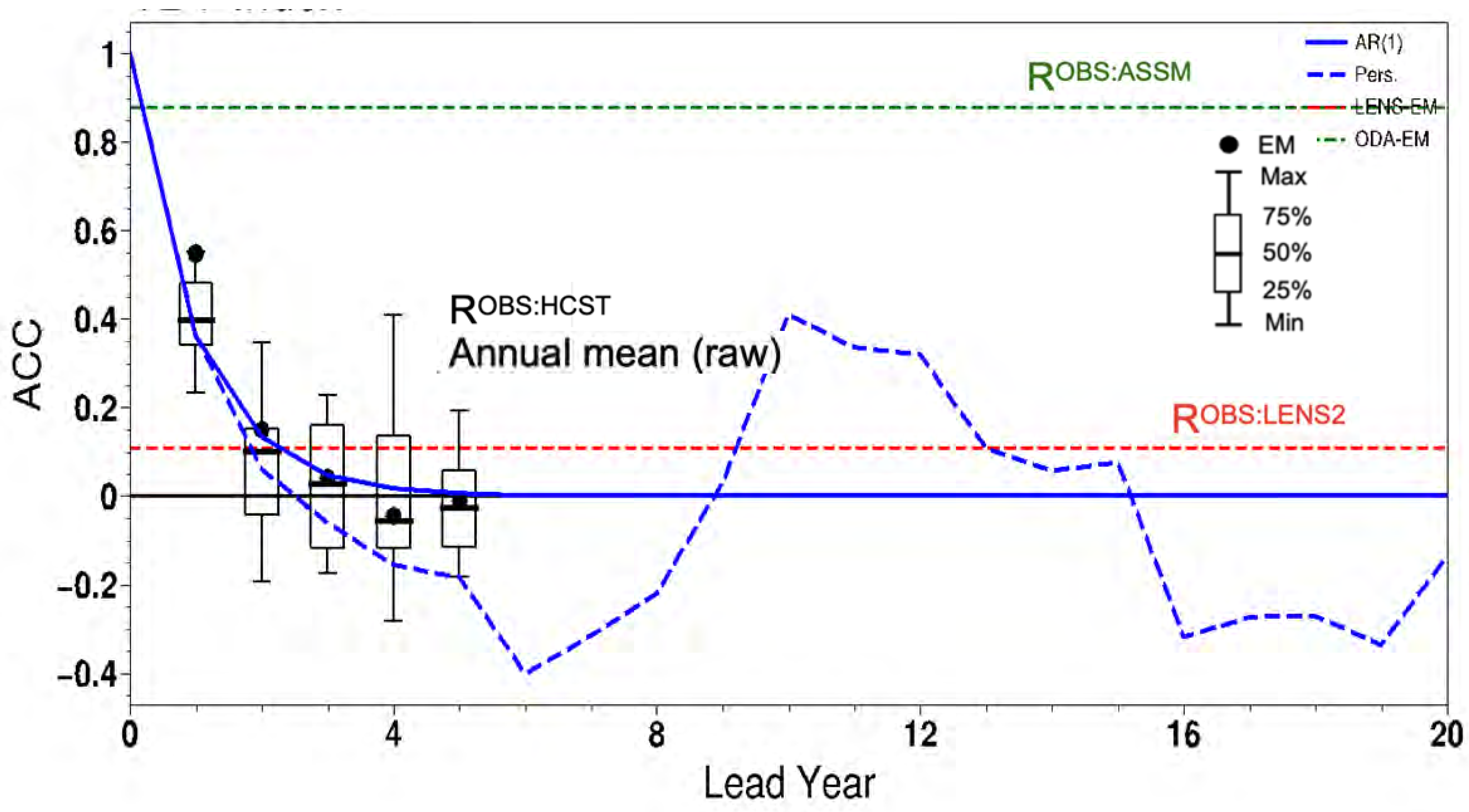
03

Prediction of Modes of Variability: Trans-basin Variability

The TBV index



The iTBV index



- The long-term predictability mainly comes from the externally forced response
- The CESM2 hindcast has a useful skill for the internal component of the TBV only at 1-year forecast lead

Analysis Period: 1960-2020, Hindcast: 20 members, LENS: 50 members

ICCP

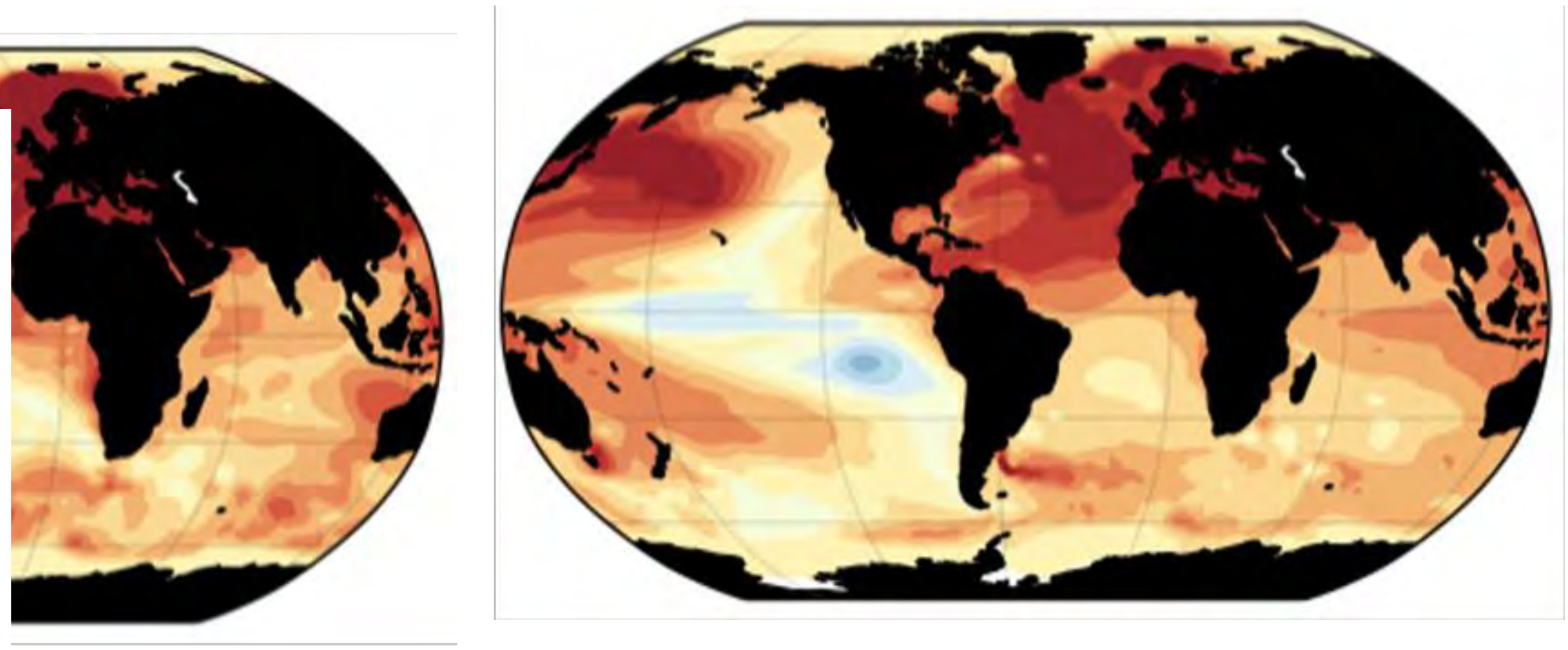
04

Modes of Variability as Important Sources for Climate Predictability

The AMV and iAMV Teleconnection: Sea Surface Temperature

OBS Only 1 sample | **LENS2** Average of 50 samples | **ODA** Average of 20 samples | **1-yr HCST** Average of 20 samples

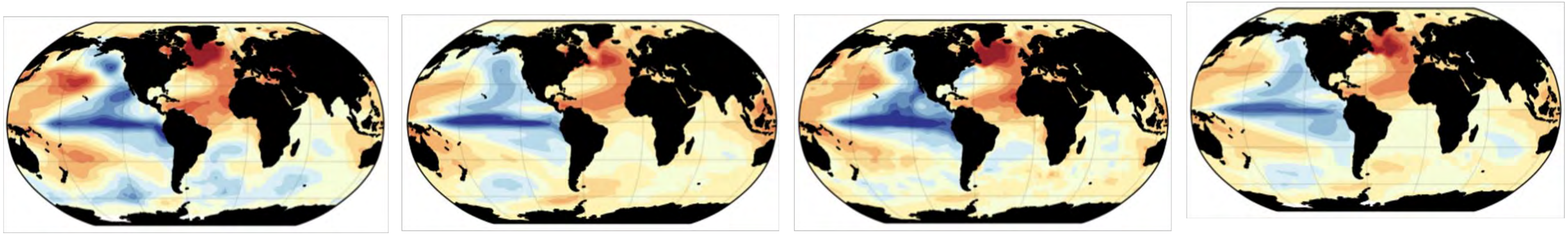
The AMV Index



In many cases, the externally forced responses tend to reinforce the teleconnection of internal components of modes of variability.

The model's systematic biases in the modes of variability and their teleconnection still hinder our prediction capability.

The iAMV Index



Analysis Period: 1961-2020

04

Modes of Variability as Important Sources for Climate Predictability

The AMV and iAMV Teleconnection: Sea Level Pressure

OBS — Only 1 sample

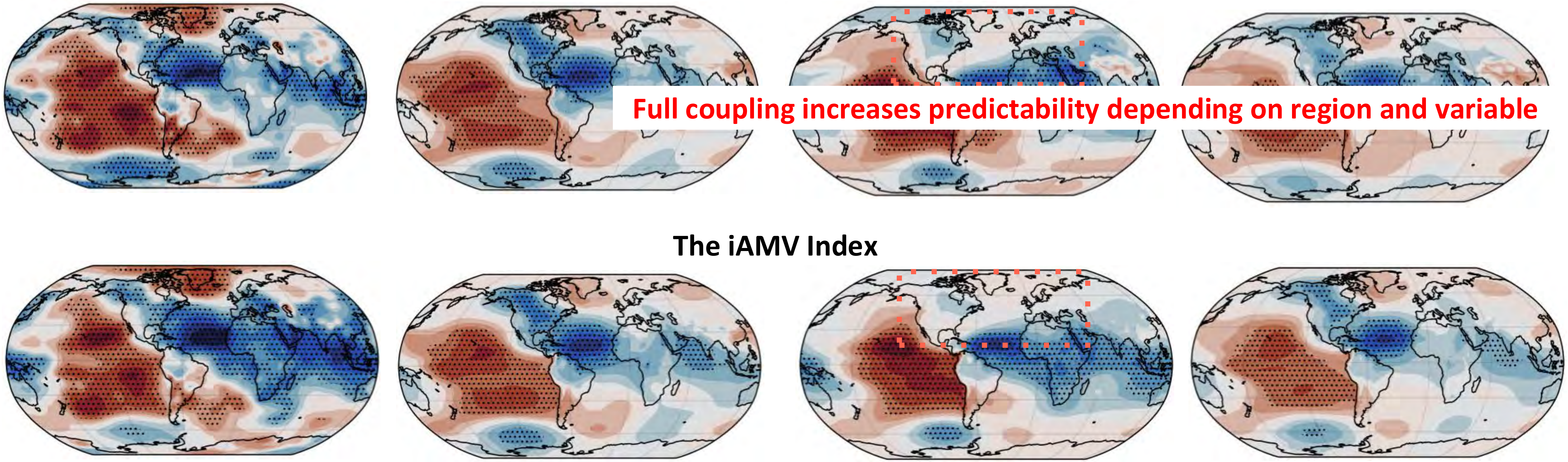
LENS2 — Average of 50 samples

ODA — Average of 20 samples

1-yr HCST — Average of 20 samples

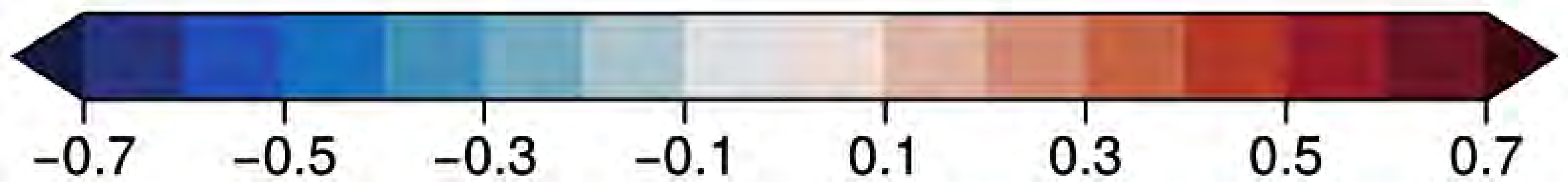
The AMV Index

The iAMV Index



Full coupling increases predictability depending on region and variable

Analysis Period: 1961-2020



Correlation Coefficient

Abhinav et al. in preparation

04

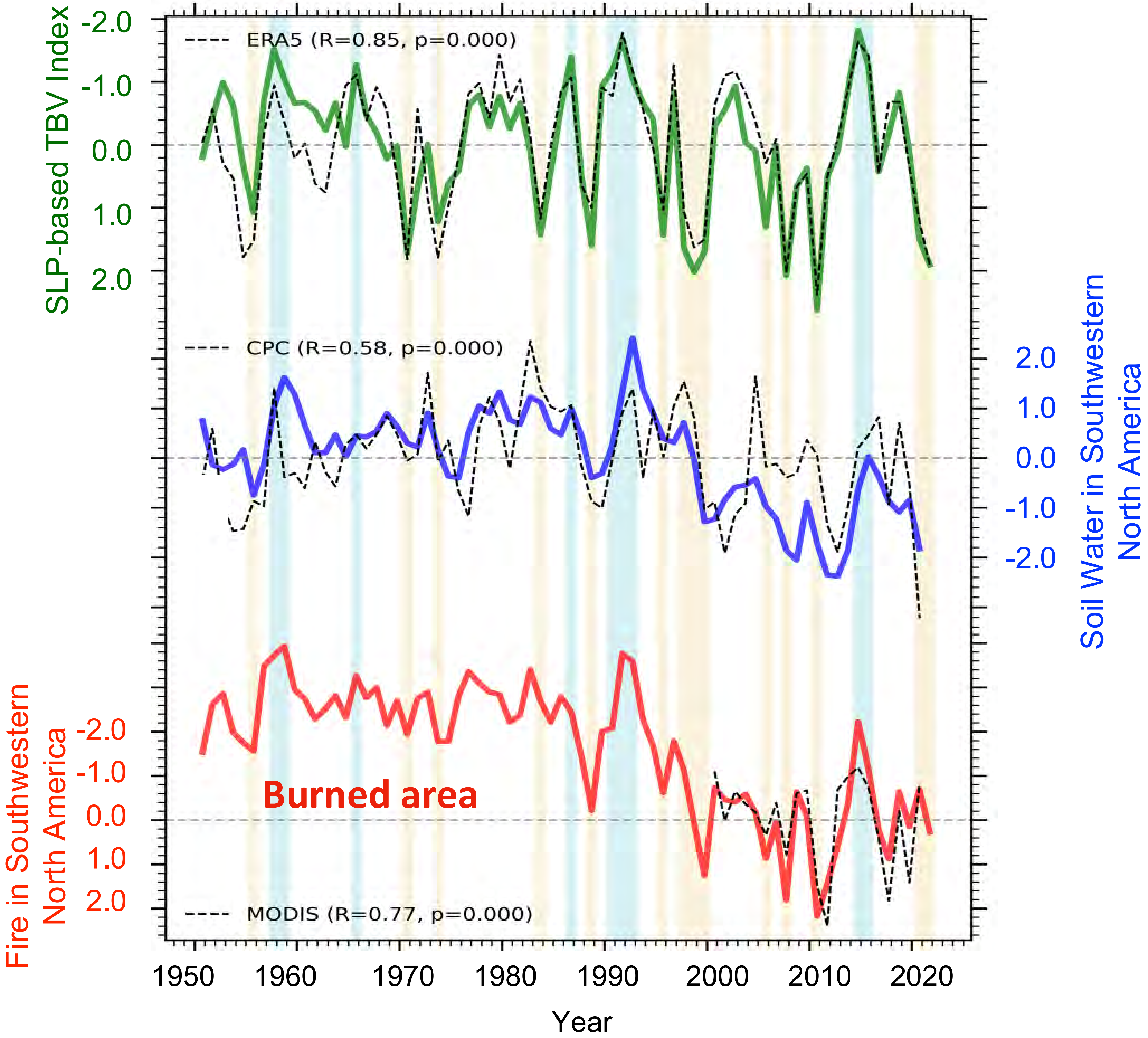
Modes of Variability as Important Sources for Wildfire Occurrences

Trans-basin variability (TBV) between the Pacific and Atlantic sea surface temperature as one of key sources for multi-year predictability of drought and wildfire in Southwestern North America.

Maxar shortwave infrared closer satellite image of burning buildings in Altadena, California, on Jan. 8, 2025. Credit: Satellite image (c) 2025 Maxar Technologies via Getty Images

Maxar shortwave infrared closer satellite image of burning buildings in Altadea, California, on Jan. 8, 2025
(Credit: Satellite image (c) 2025 Maxar Technologies via Getty Images)

CESM2-based prediction system



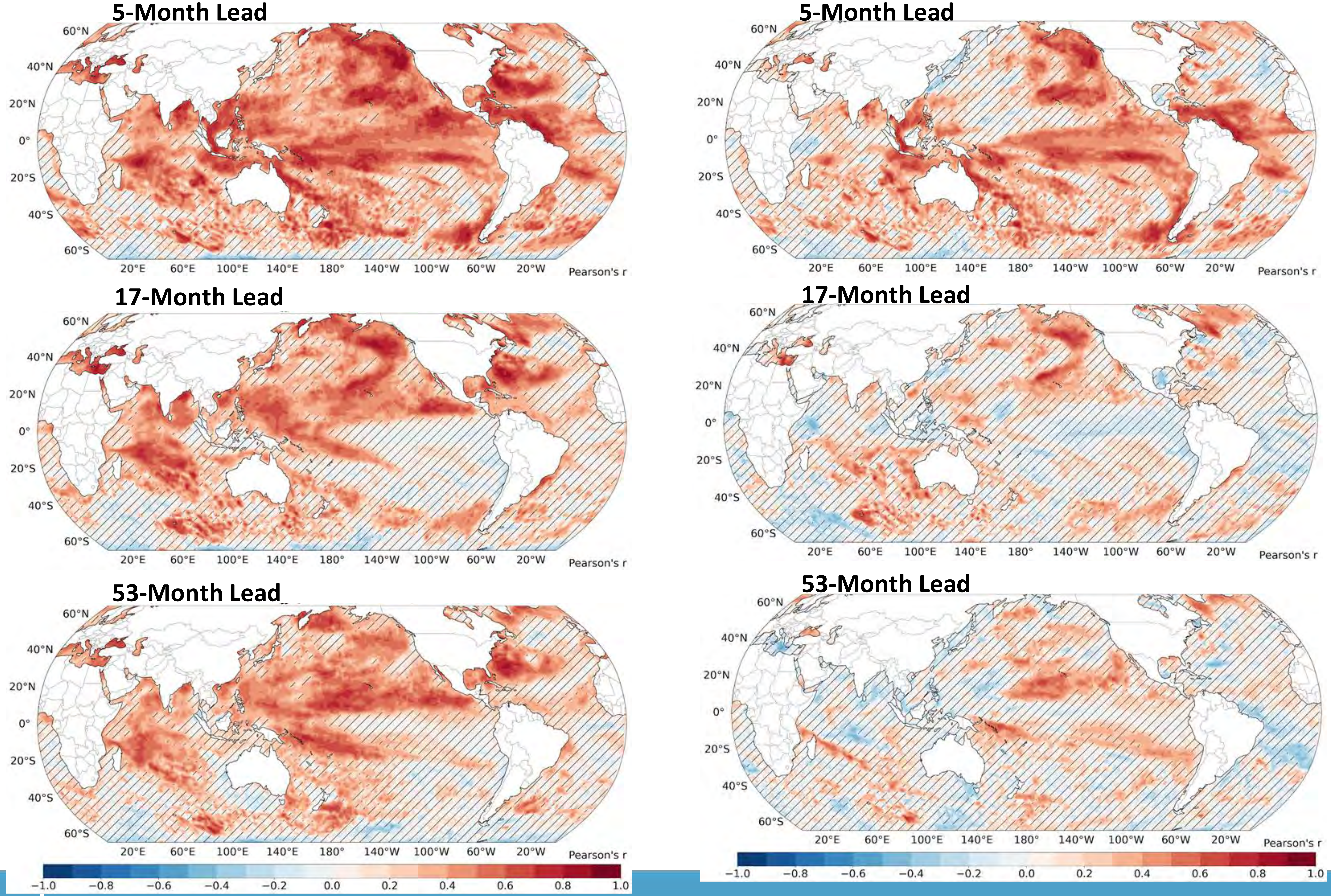
Oral Session A-2

Modes of Variability as Important Sources for Marine Heat Wave Predictability

Prediction of Marine Heat Wave Days during JJA/ 1981-2020

Total ACC Skill

ACC Skill Removing External Forced Response



Oral
Session B-4
for terrestrial heat wave predictability

Summary and Discussion

- A new seasonal-to-multiyear Earth prediction system has been developed based on the Community Earth System Model version 2 (CESM2). A 20-member ensemble which assimilates ocean temperature and salinity anomalies provides the initial conditions for 5-year prediction from 1960 to 2020.
- The CESM2-based Multi-year Prediction System has a useful skill for ENSO up to 1 year, for TBV up to several years, and AMV for more than 5 years.
- Modes of variability, including ENSO, TBV, PDO and AMV, are essential sources of climate variability and predictability, including statistics of extremes, over many parts of the globe. The model's systematic biases in the modes of variability and their teleconnection still hinder our prediction capability.
- The anomaly ocean data assimilation is an effective way to calibrate the pattern of modes of variability in the climate model.
- In many cases, the externally forced responses tend to reinforce the teleconnection of internal components of modes of variability.
- Full coupling of ocean, atmosphere, and land tends to increase predictability depending on region and variables.

Thank You!