The First Kind of Predictability Study for El Niño Prediction in a Multivariate Coupled Data-Driven Model

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2025-4-30

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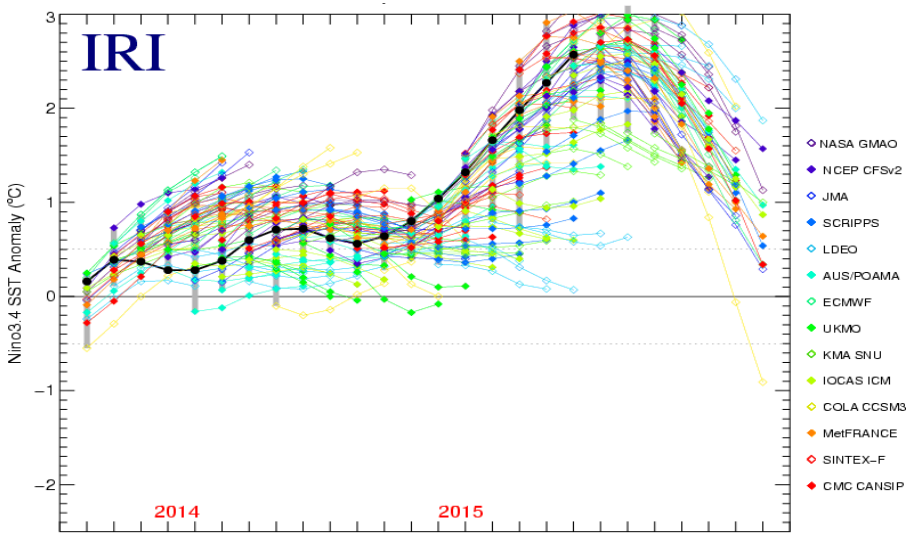
CONTENT

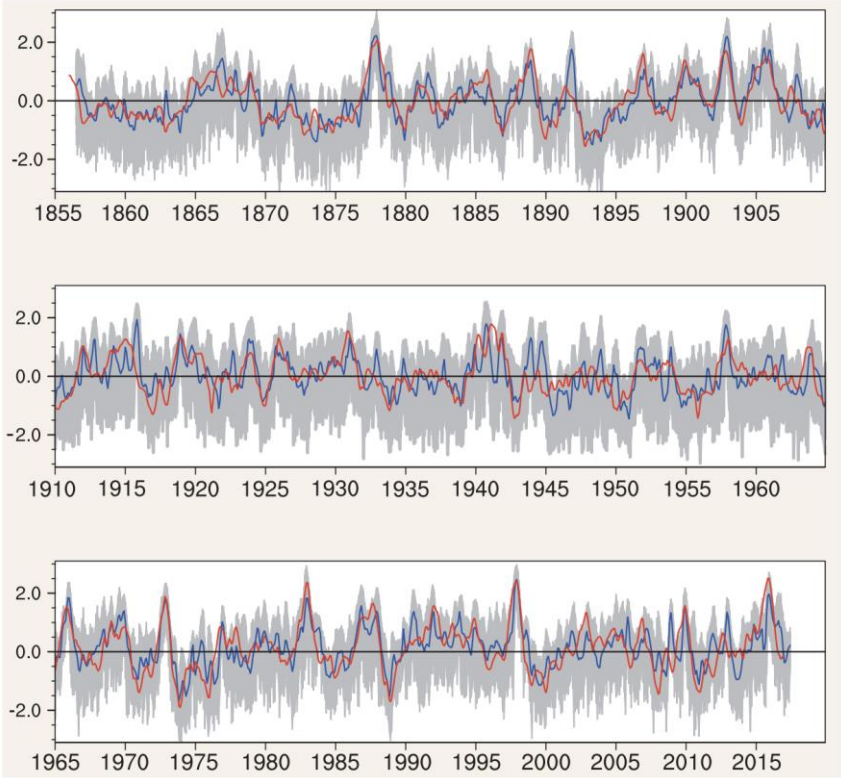
1. Predictability Problem for ENSO

➢ **For decades, ENSO forecasts have been impressively improved via advanced numerical models**



2015/2016 forecasts

International Research Institute



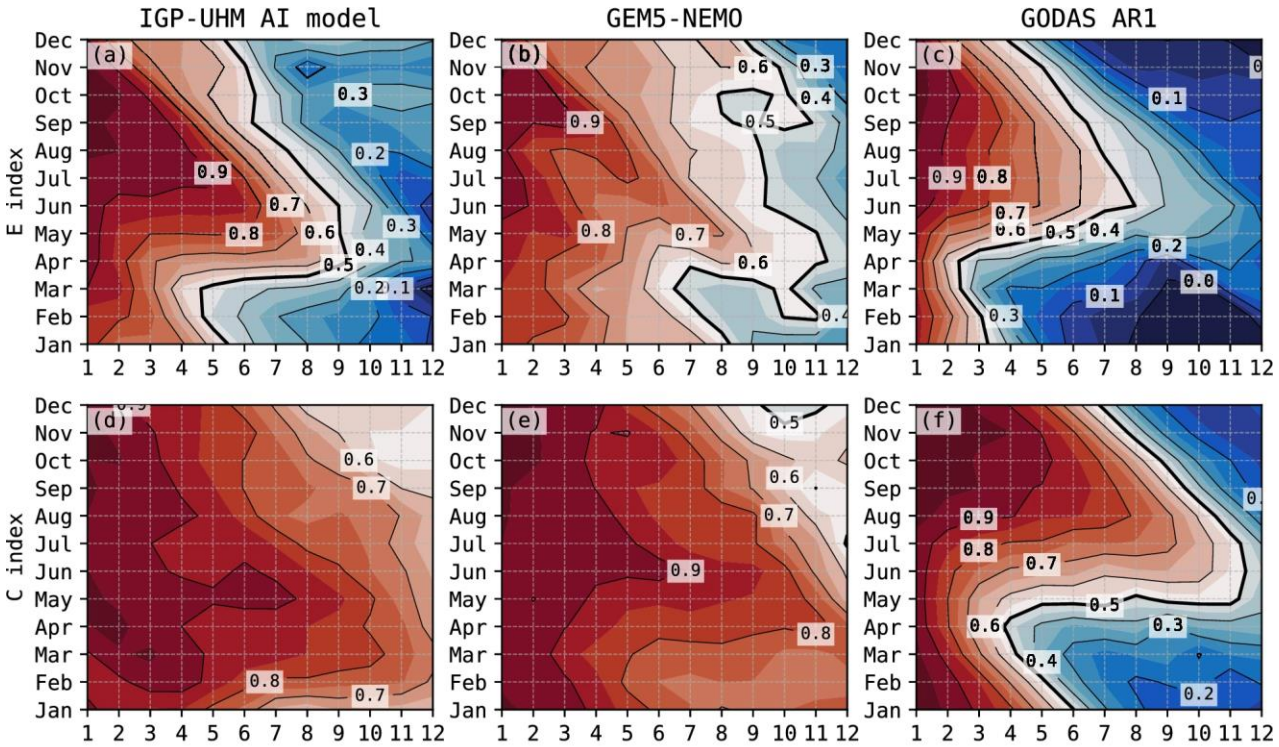
1856-2016 super-ensemble hindcasts

Second Institute of Oceanography, China

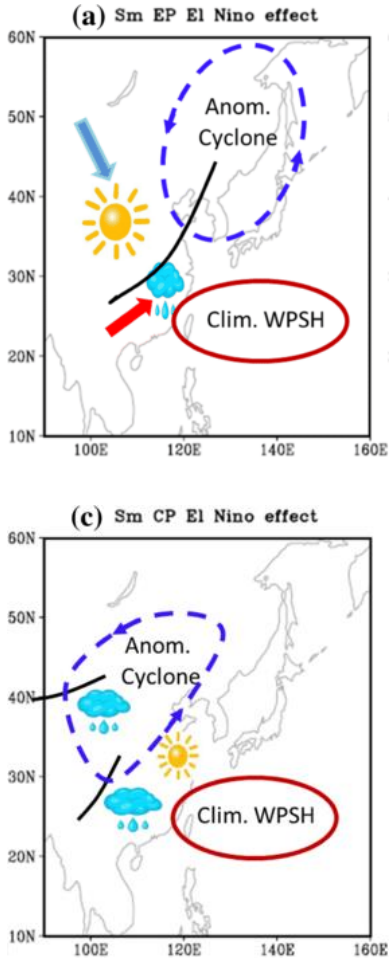
➢ **Numerical models can usually provide effective forecasts within 6~12 lead months**

1. Predictability Problem for ENSO

- **Prediction and predictability of ENSO diversity is one of the most concerned topics**



Comparison of forecast skills



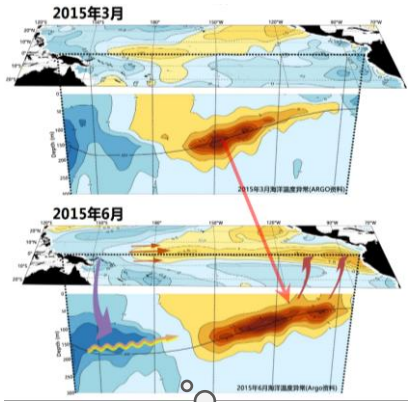
Comparison of climate impacts

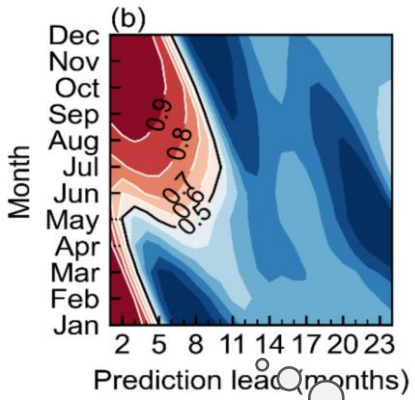
- **Predictability study can reveal the origins of the forecast errors, further improving forecast skills**

1. Predictability Problem for ENSO

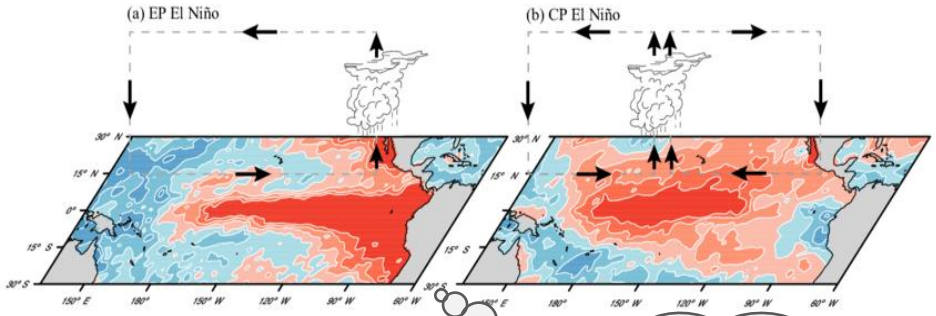
➢ **Conditional Nonlinear Optimal Perturbation (CNOP) is one of the most proven methods**

(The initial perturbation that can cause the maximum error at the forecast time under certain constraints)





Examples for some concerned problems



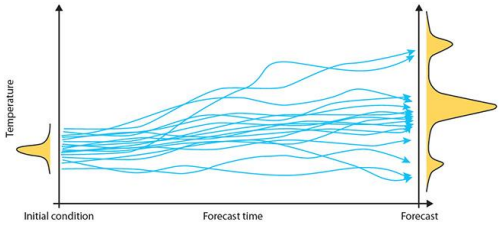
What precursors can result in occurrences of El Niño ?

What factors contribute to Spring persistence barrier?

What errors contribute to forecast El Niño diversity

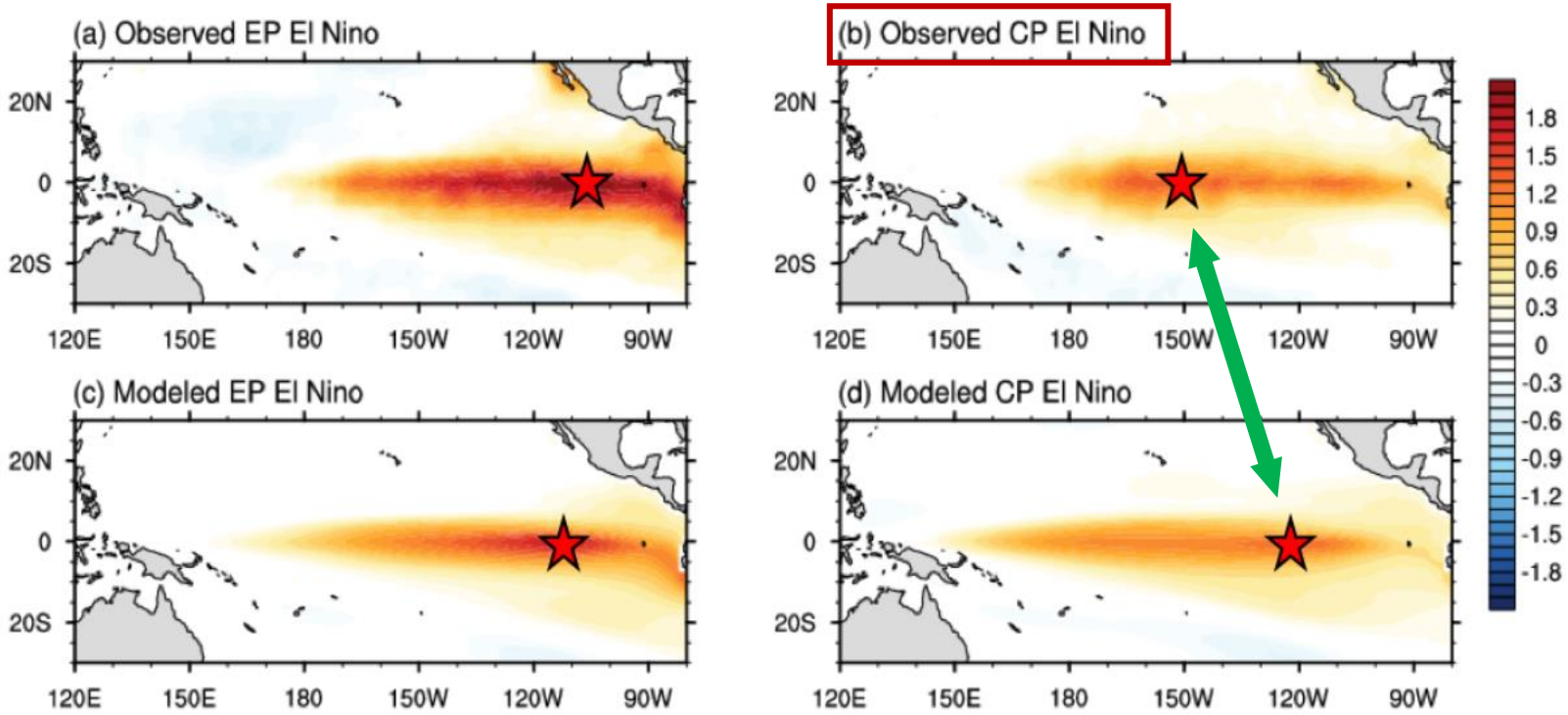
➢ **Such initial error can be reduced by a variety of means, thereby improving forecast skills**

e.g., Data Assimilation Targeted Observation Ensemble Forecast etc.



1. Predictability Problem for ENSO

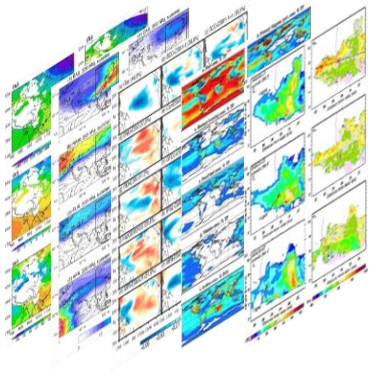
- **However, predictability studies for two types of El Niño events encounter bottlenecks**

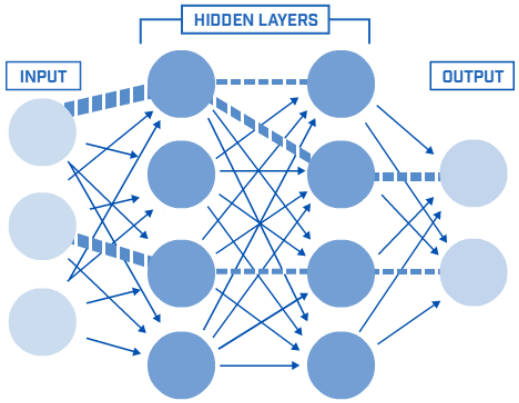


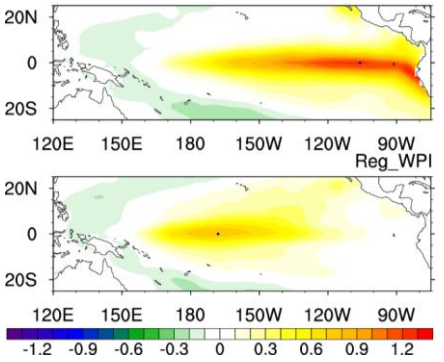
- **Weak simulation capability for CP types**
- **Low efficiency for complex nonlinear optimization in predictability studies**

1. Predictability Problem for ENSO

➢ **Recent years, Artificial Intelligence (AI) have further promoted ENSO forecast skills**

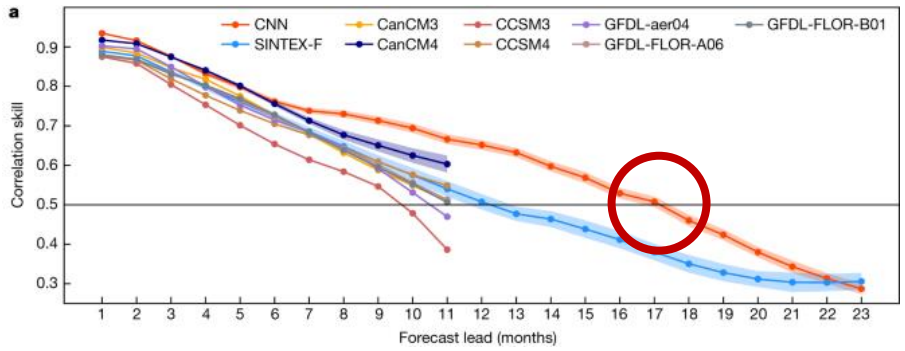




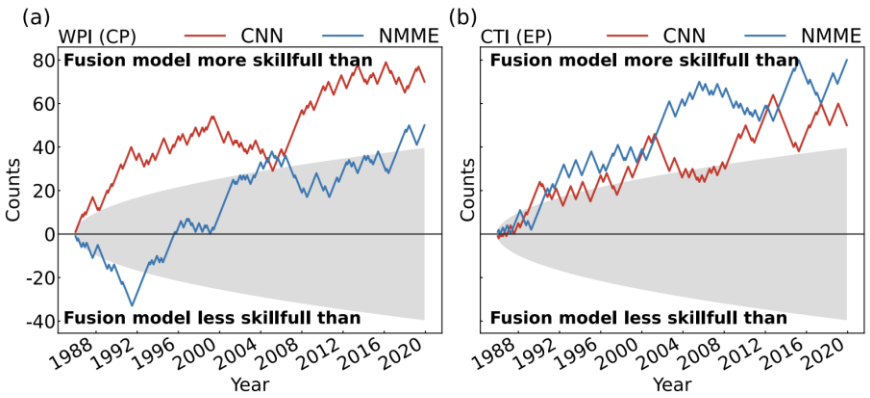


Big Data → **Training** → **Neural Network** → **Forecasting & Simulating** → **Results**

Powered by  **GPU**



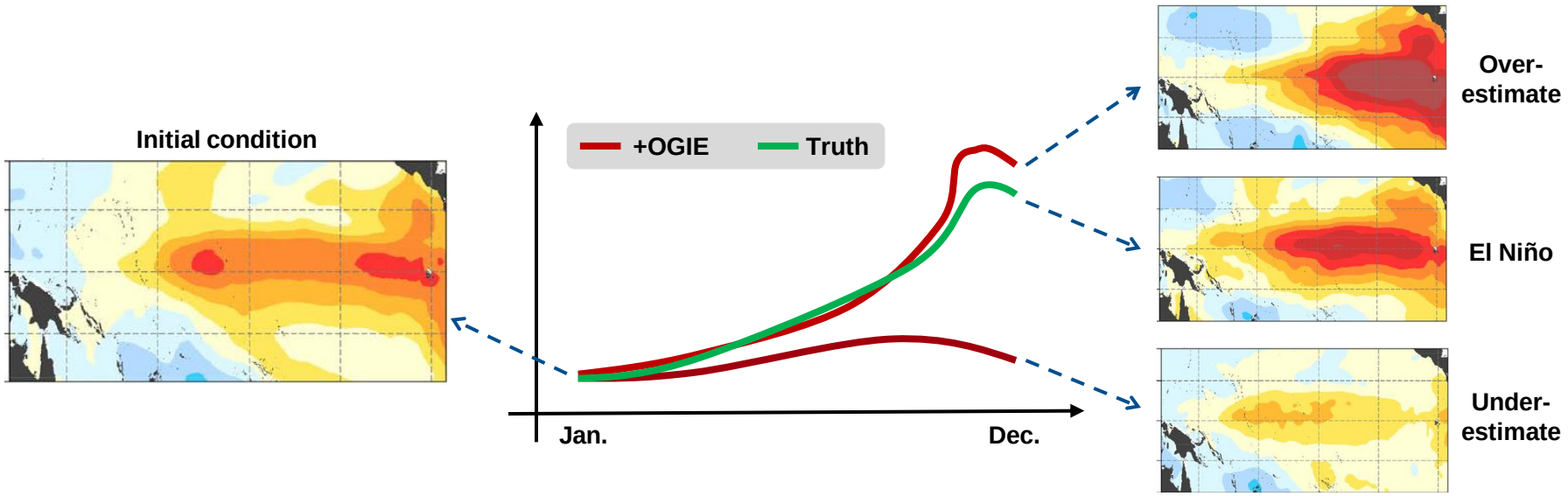
Longer effective forecast month



More discriminative simulation capability

1. Predictability Problem for ENSO

➢ **We focus on revealing optimally growth initial errors for two types of El Niño events**



Experiment Schema

- ➢ **Events:** two types of El Niño (i.e., CP and EP)
- ➢ **Method:** CNOP
- ➢ **Model:** our constructed ENSO deep learning model (ENSO-MC v2.0)
- ➢ **Validation:** GFDL CM2p1

(To increase the creditability of our results)

➢ Data for training the deep learning model

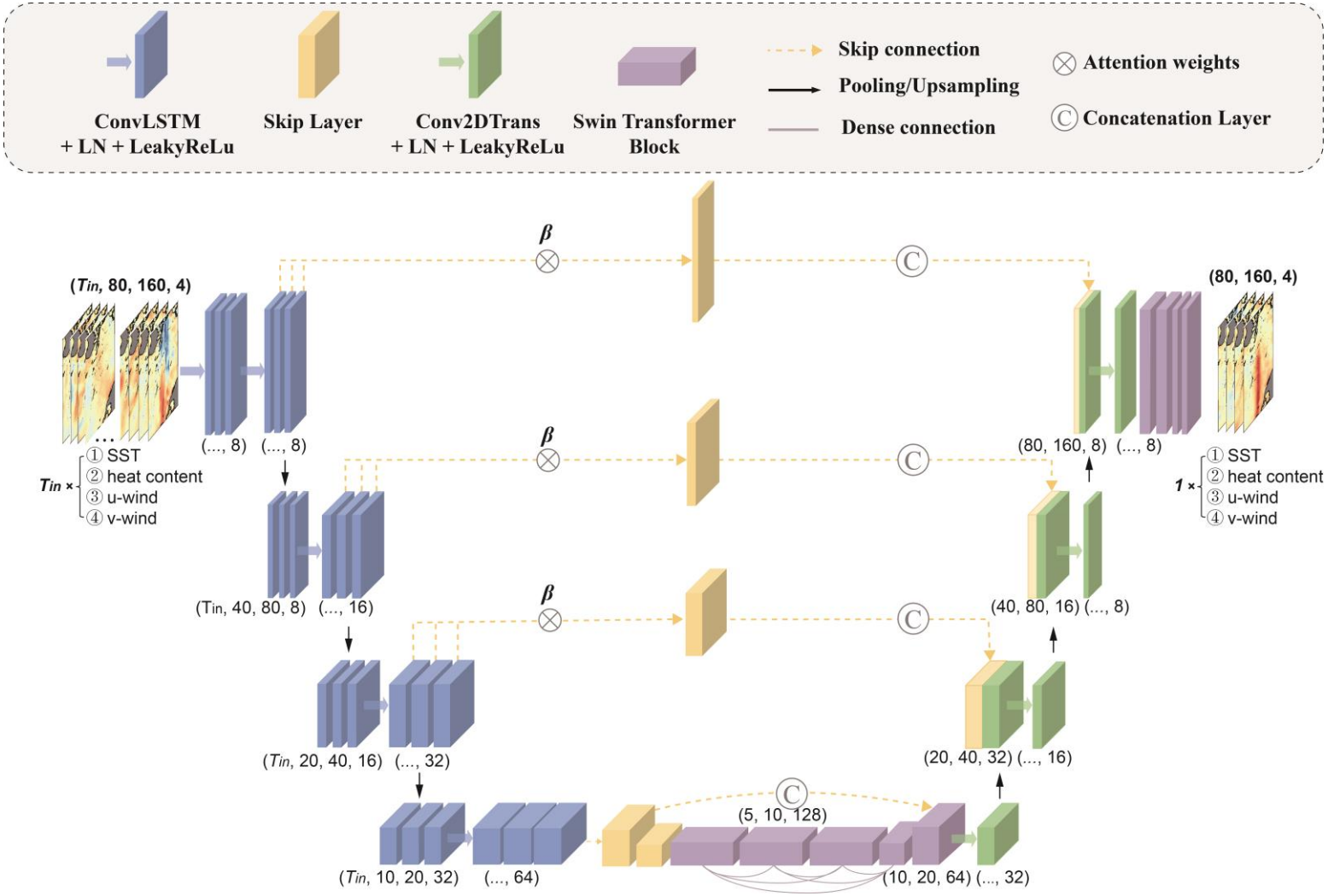
No	CMIP6 Model Source	Modeling Group	Period
1	ACCESS-CM2	CSIRO-ARCCSS	Jan. 1850-Dec.2014
2	CAMS-CSM1-0	CAMS	
3	CESM2	NCAR	
4	CESM2-WACCM	NCAR	
5	E3SM-1-1	E3SM-Project RUBISCO	
6	FGOALS-g3	CAS	
7	FIO-ESM-2-0	FIO-QLNM	
8	GFDL-CM4	NOAA-GFDL	
9	NESM3	NUIST	
10	NorESM2-MM	NCC	
No	**Reanalysis Data**	**Institution**	**Period**
1	SODA	University of Maryland	Jan. 1871-Dec. 1979
2	GODAS	NCEP	Jan. 1980-Dec. 2022
3	ERA5	ECMWF	Jan. 1980-Dec. 2022

Training & Validating

Testing & Experiment

2. Data, Model and Method

➢ ENSO-MC v2.0: our upgraded deep learning ENSO forecasting model



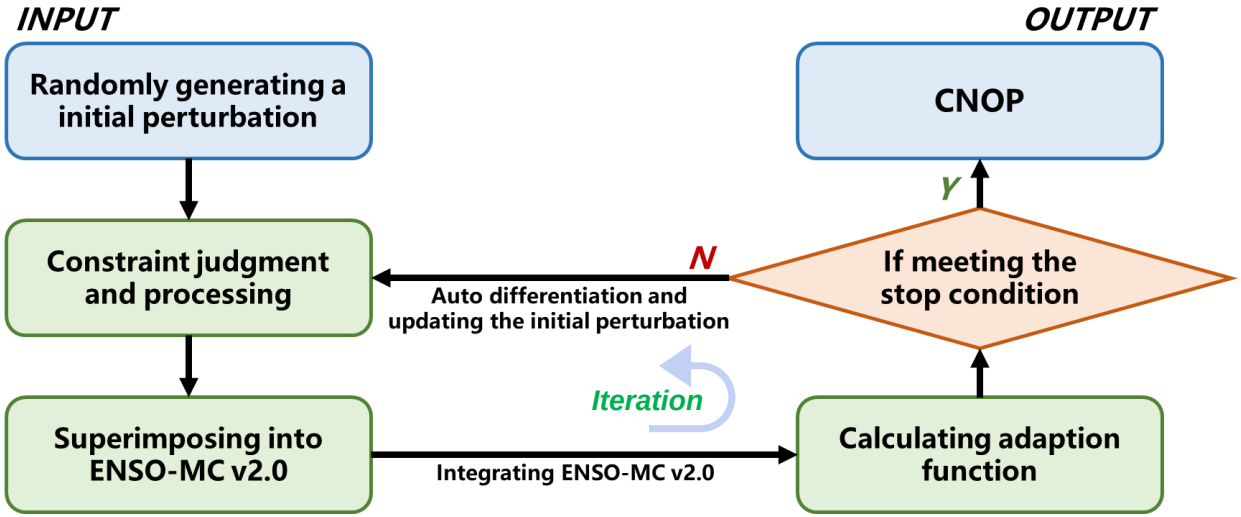
2. Data, Model and Method

➢ Solving CNOPs in ENSO-MC v2.0

$$\max J(\Delta) = \|M_\tau(x+\Delta) - M_\tau(x)\|_\ell$$

Optimally Growth Initial Errors (OGIEs) | **Nonlinear System** | **Simulation Period**

Constraints $\text{s.t.} \quad \|\Delta\|_\ell \le \delta$



Selected events

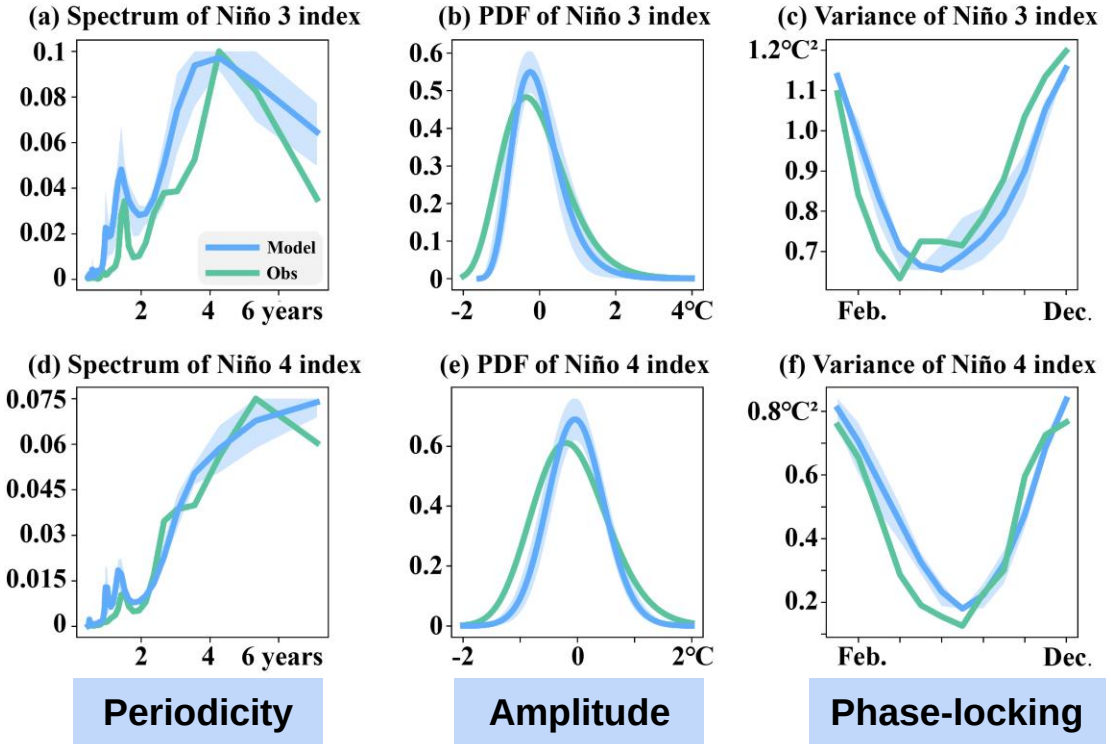
- EP: 1982, 1986, 1991, 1997, 2006, and 2014
- CP: 1994, 2002, 2004, and 2009
- The obtained OGIE are the averaged patterns

(To eliminate optimization uncertainties)

3. Evaluations for ENSO Deep Learning Model

➢ Evaluations on simulation capability

- ➢ Selecting every month from 2010-2019 as the initial states
- ➢ Integrating ENSO-MC v2.0 for 100 years with each initial states
- ➢ Obtaining a 12,000-year long-term simulation



➢ ENSO-MC v2.0 can skillfully simulate statistically robust features of observed El Niño diversity

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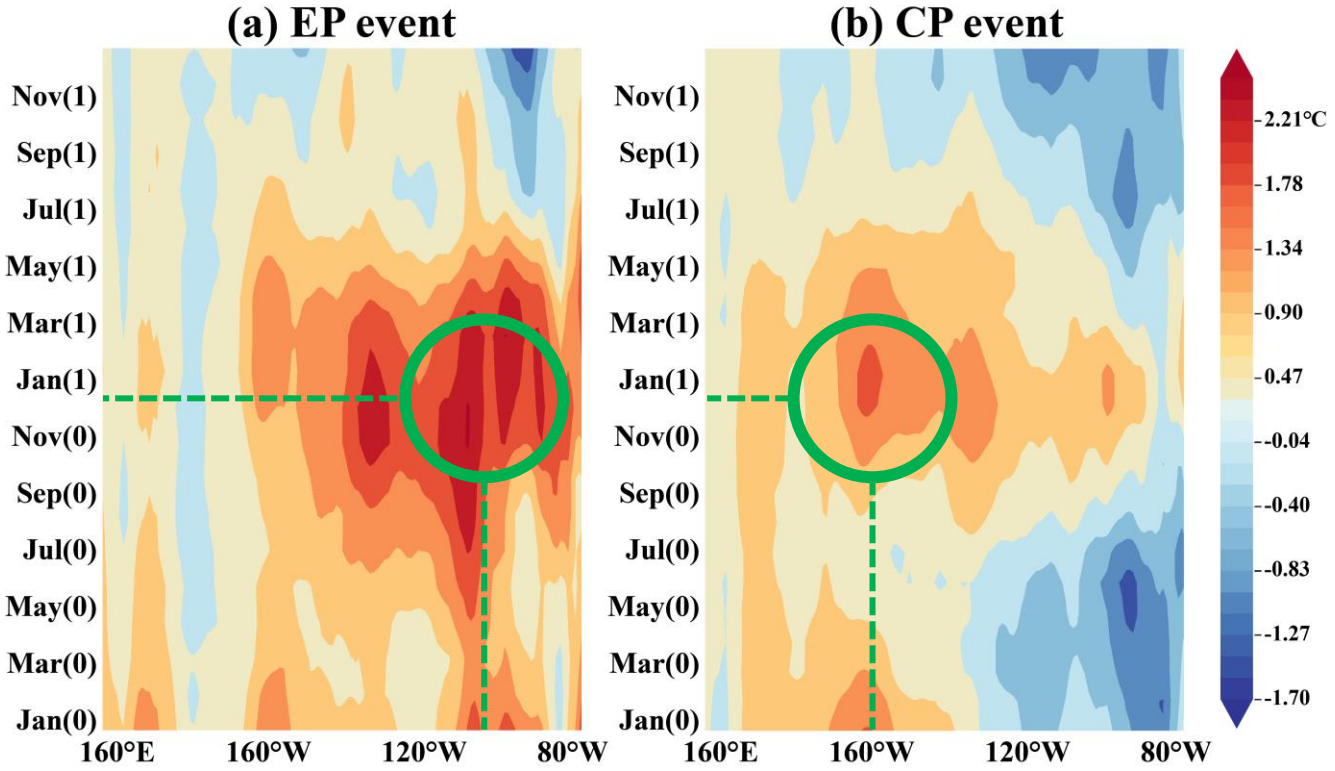
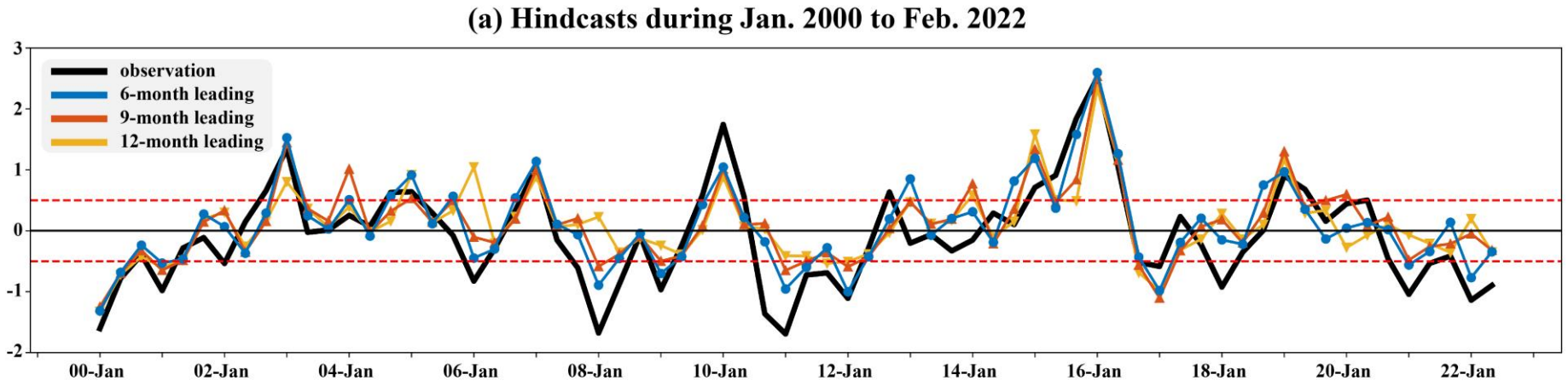


➢ ENSO-MC v2.0 can skillfully simulate statistically robust features of observed El Niño diversity

3. Evaluations for ENSO Deep Learning Model

➢ Evaluations on forecast skill

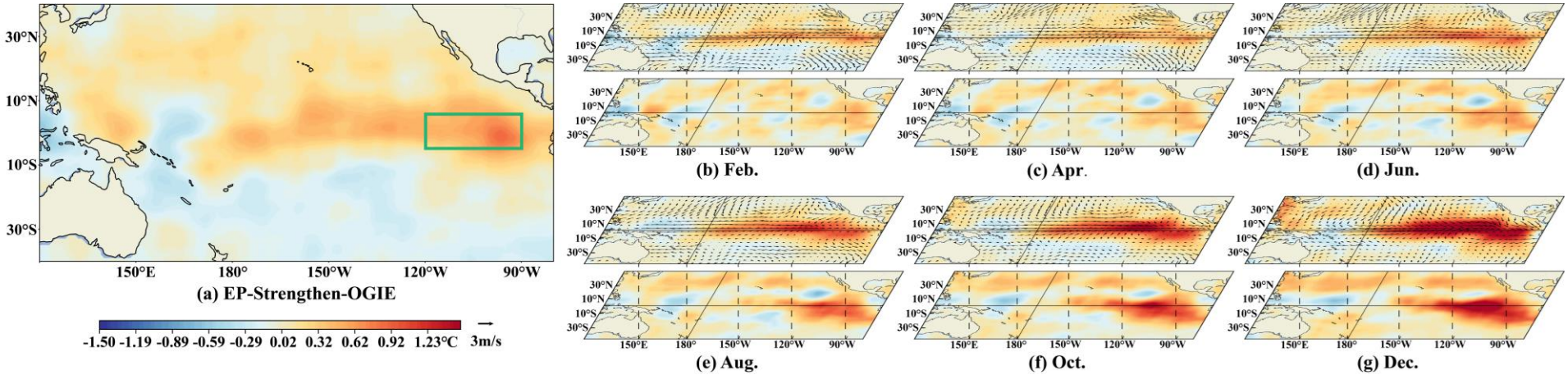
➢ Performing Hindcasts in testing set



➢ ENSO-MC v2.0 can skillfully simulate statistically robust features of observed El Niño diversity

4. OGIEs for Two Types of El Niño Events

➢ **Error evolutions (SST, T300, and U/V-Wind) for EP-Strengthen-OGIE**

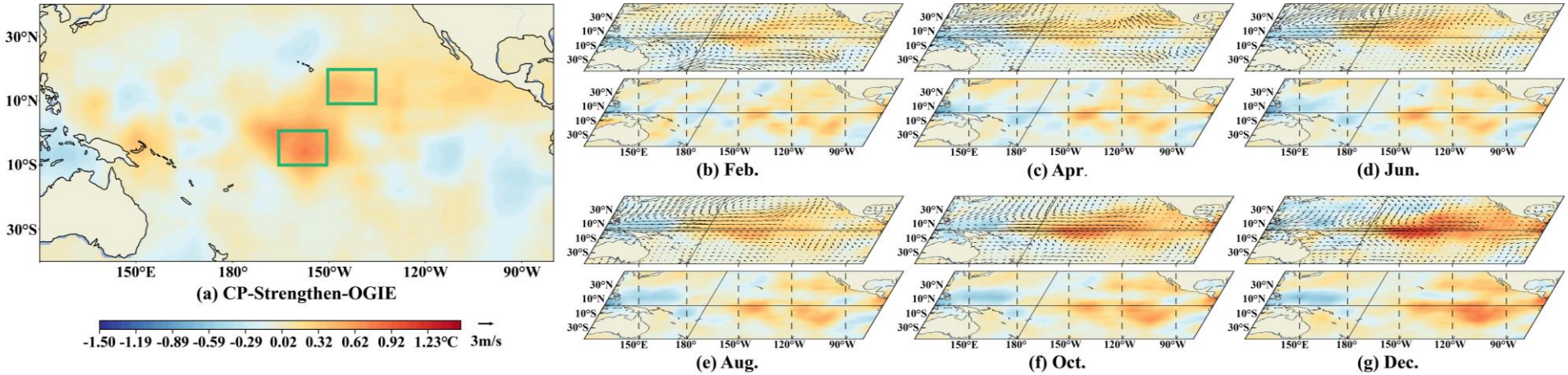


Possible Growth Mechanism form AI

- **Significant Area: positive SST errors over the equatorial eastern Pacific**
- **Bjerknes Mechanism: weakening the east-west SST gradient in the equatorial Pacific, exciting the westerly wind errors, inducing eastward Kelvin waves.**

4. OGIEs for Two Types of El Niño Events

- Error evolutions (SST, T300, and U/V-Wind) for CP-Strengthen-OGIE
- **NEW FINDING:** This type of OGIE is rarely investigated in numerical models



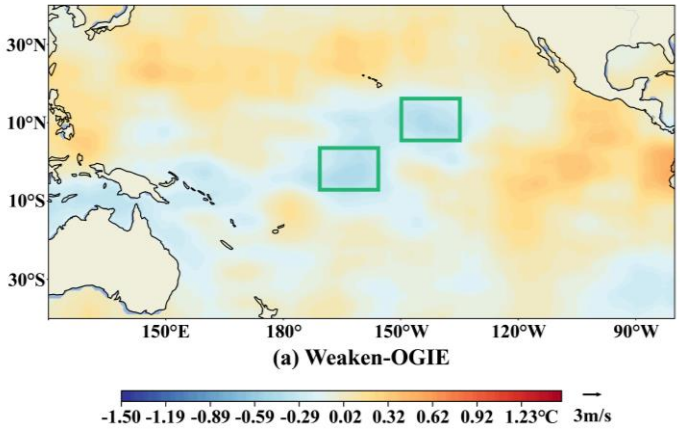
Possible Growth Mechanism form AI

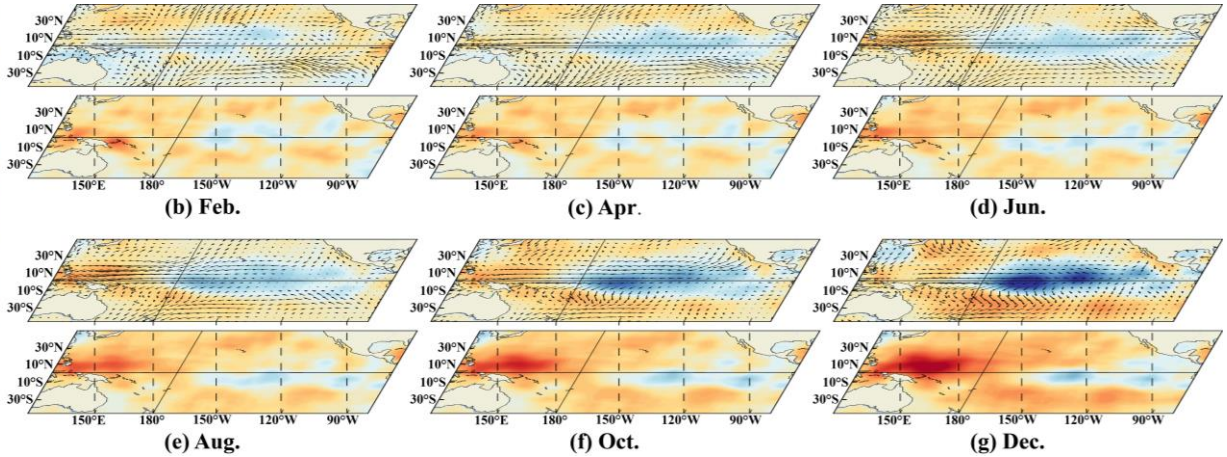
- Significant Area: positive SST errors over ① the equatorial central Pacific and ② the off-equatorial northern Pacific
- Bjerknes Mechanism ① : exciting the local westerly wind errors, inducing eastward Kelvin waves.
- WES Mechanism ② : exciting local southwesterly wind errors, weakening the local trade winds and evaporation, propagating toward the equatorial central Pacific

(Need to be verified)

4. OGIEs for Two Types of El Niño Events

- Error evolutions (SST, T300, and U/V-Wind) for Weaken-OGIE
- The OGIEs that weaken the two types of El Niño events are very similar
- This type of OGIE is almost opposite to CP-Strengthen-OGIE



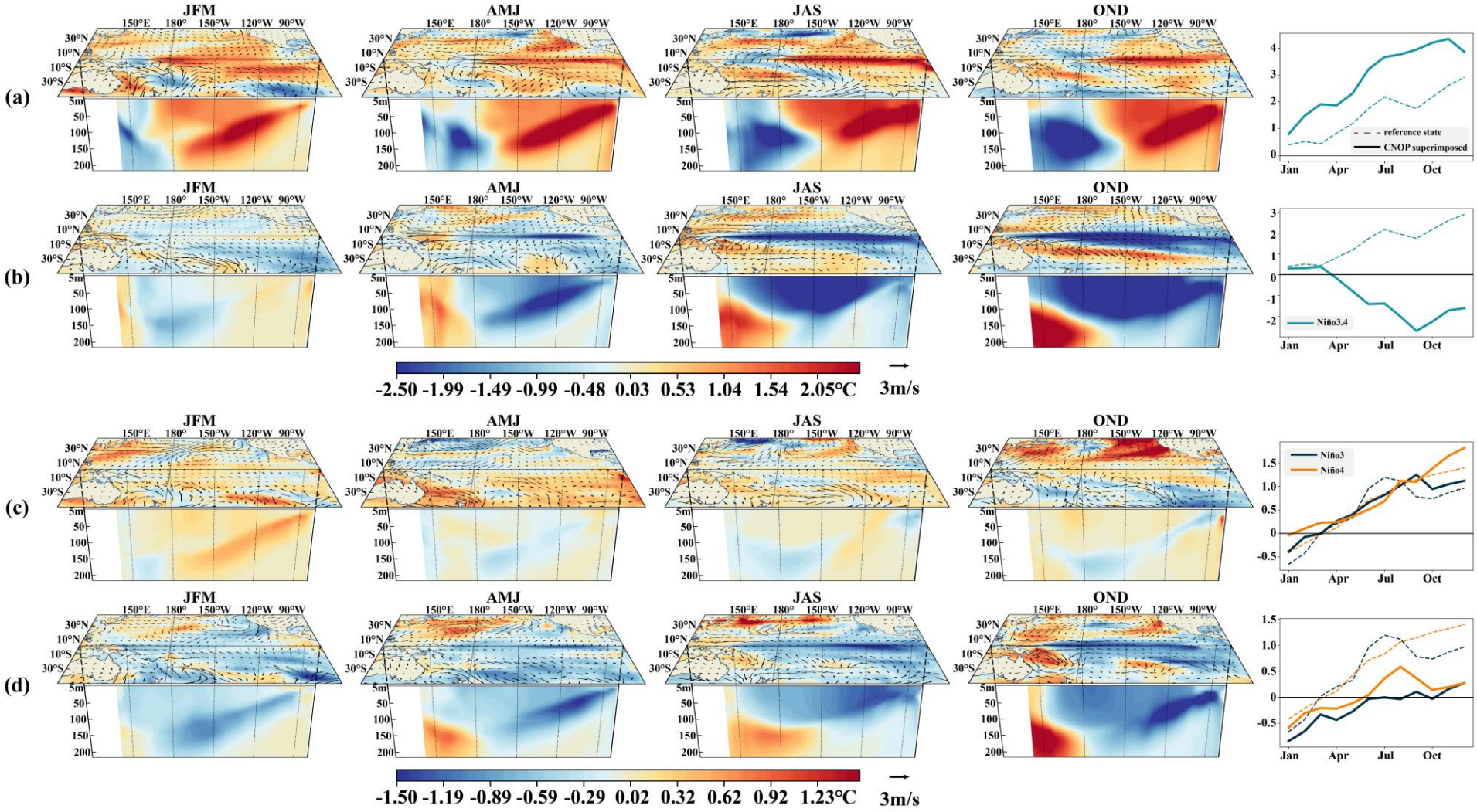


Possible Growth Mechanism form AI

- Significant Area: negative SST errors over ① the equatorial central Pacific and ② the off-equatorial northern Pacific
- Bjerknes Mechanism ① and WES Mechanism ②

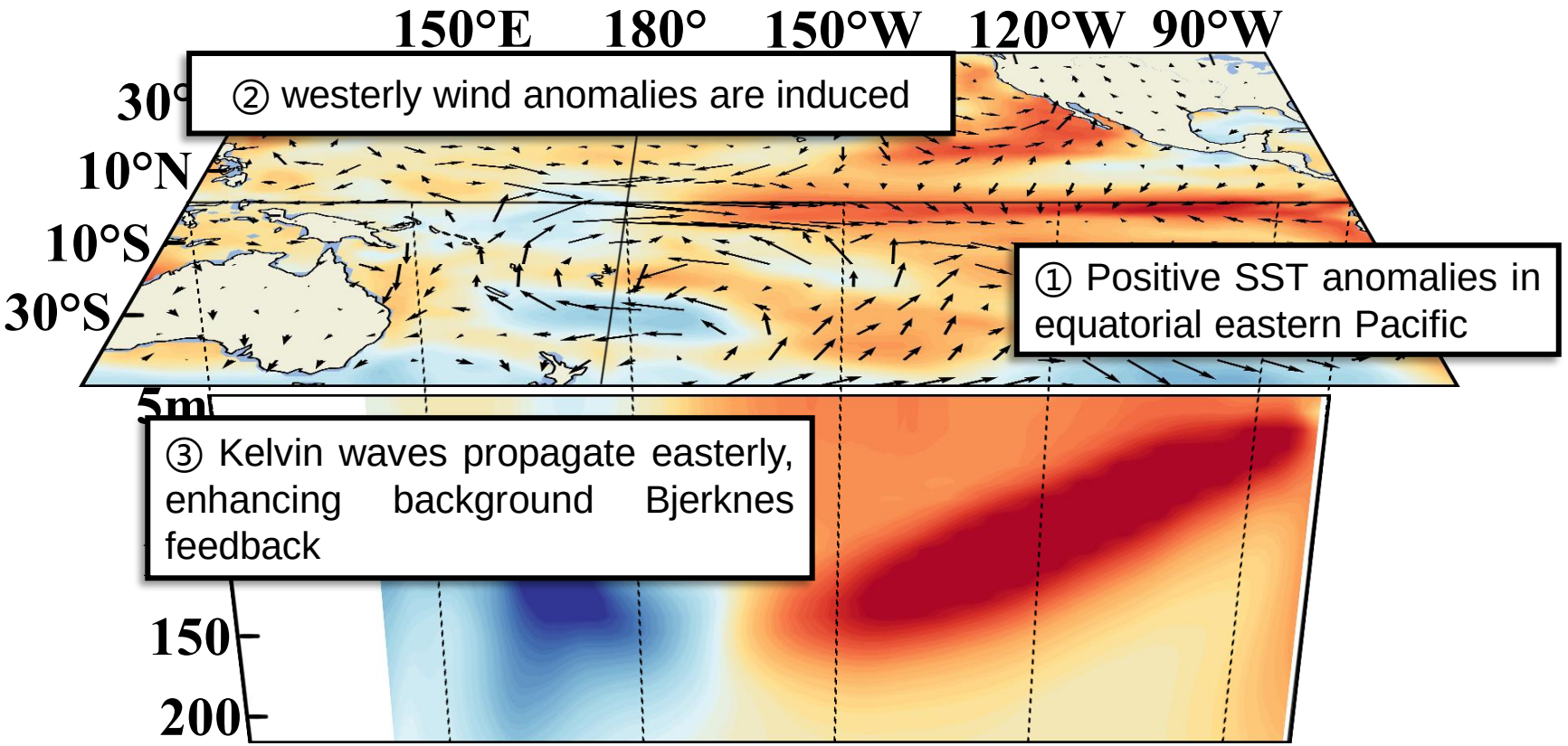
4. OGIEs for Two Types of El Niño Events

➢ **Superimposing OGIEs on corresponding types of events in GFDL CM2p1**



4. OGIEs for Two Types of El Niño Events

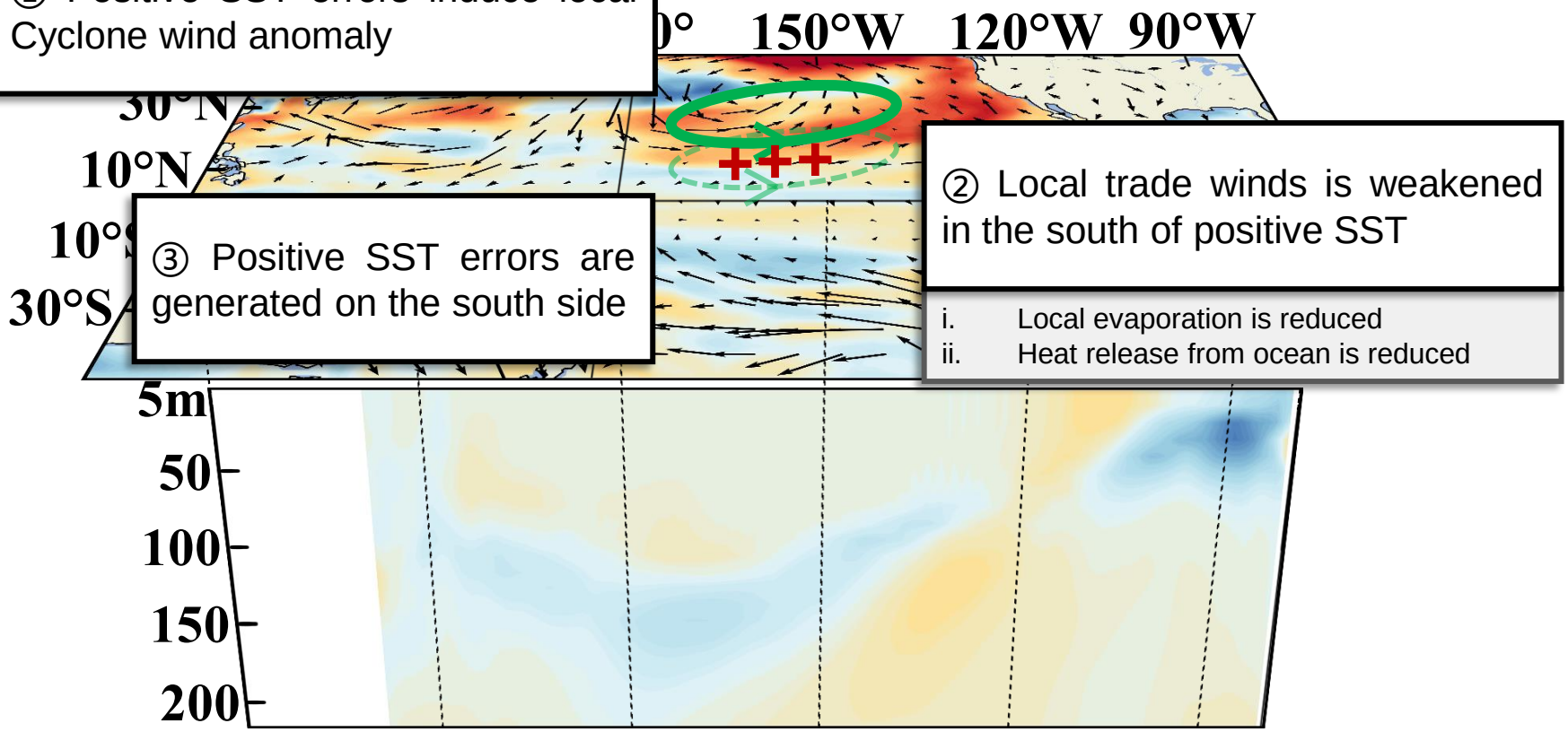
➢ Equatorial error propagation mechanisms



4. OGIEs for Two Types of El Niño Events

➢ Off-equatorial error propagation mechanisms

① Positive SST errors induce local Cyclone wind anomaly



② Local trade winds is weakened in the south of positive SST

i. Local evaporation is reduced
ii. Heat release from ocean is reduced

③ Positive SST errors are generated on the south side

5. Final Remarks

➢ Contributions

- **Constructing a purely data-driven multivariate coupled ENSO forecasting model with skillful simulating for El Niño diversity**
- **Revealing several new types of initial errors that significantly affect predictions of El Niño diversity in this model, especially including one type for strengthening CP events, which is rarely investigated before**
- **Providing theoretical basis for subsequent targeted observation, data assimilation, and ensemble forecasting of two types of El Niño events, further improving forecast skills**
- **The overall research process can be migrated to other weather and climate events to take full advantage of AI**

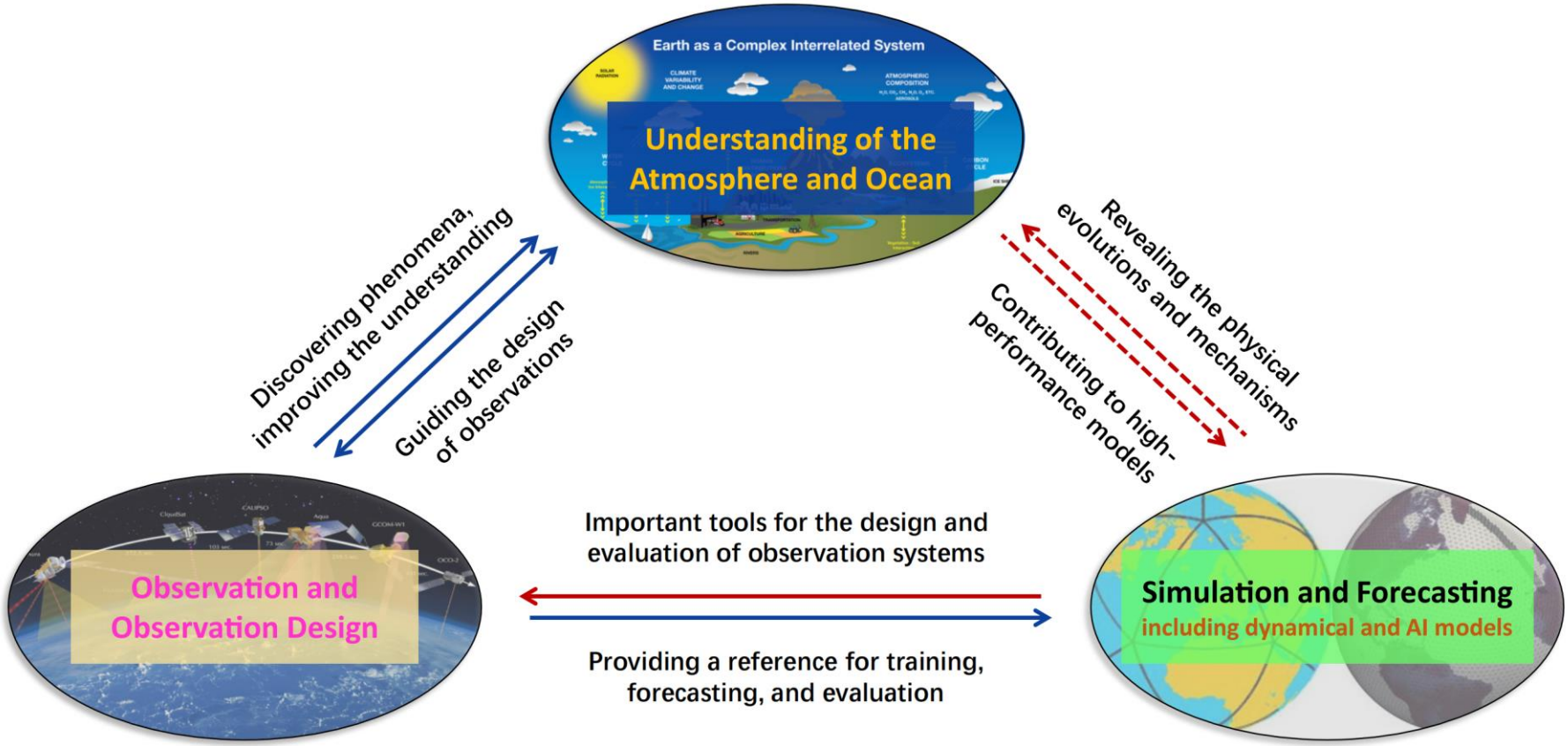
Qin, B. (秦博), Yang, Z. (杨泽芸), **Mu, M.*** (穆穆), Wei, Y. (魏云涛), Cui, Y. (崔悦涵), Fang, X. (方向辉), Dai, G. (戴国锟), Yuan, S (袁时金).

The first kind of predictability problem of El Niño predictions in a multivariate coupled data-driven model. (2024)

Quarterly Journal of the Royal Meteorological Society, 1–20. doi.org/10.1002/qj.4882

5. Final Remarks

➢ Discussions



Mu, M. (穆穆), **Qin, B.*** (秦博), Dai, G. (戴国锟).

The Predictability Study of Weather and Climate Events Related to Artificial Intelligence Models. (2025)

Advances in Atmospheric Sciences. 10.1007/s00376-024-4372-7

Thanks for your attention

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