Applications of ocean data assimilation into a coupled climate model to East Asian summer monsoon simulations

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outline

1. Motivation
2. Evaluation
3. Decadal Variations of EASM
4. Interannual variations of EASM
5. Seasonal forecasting

Difficulty in simulating variations of EASM

East Asian Summer Monsoon (EASM) is a complex system in which the **air-sea interaction** shouldn't be neglected (Wang et al. 2005). Its interannual and decadal variations are largely influenced by **SST variations** (e.g. PDO) (Yu et al. 2015)

Two types of simulation for EASM

CMIP-type

Advantages
- Fully coupled model
- **Air-sea interaction**
- Real external forcing: GHGs, aerosols…

Disadvantages
- cannot capture the real internal variability of climate system, **variations of SST**

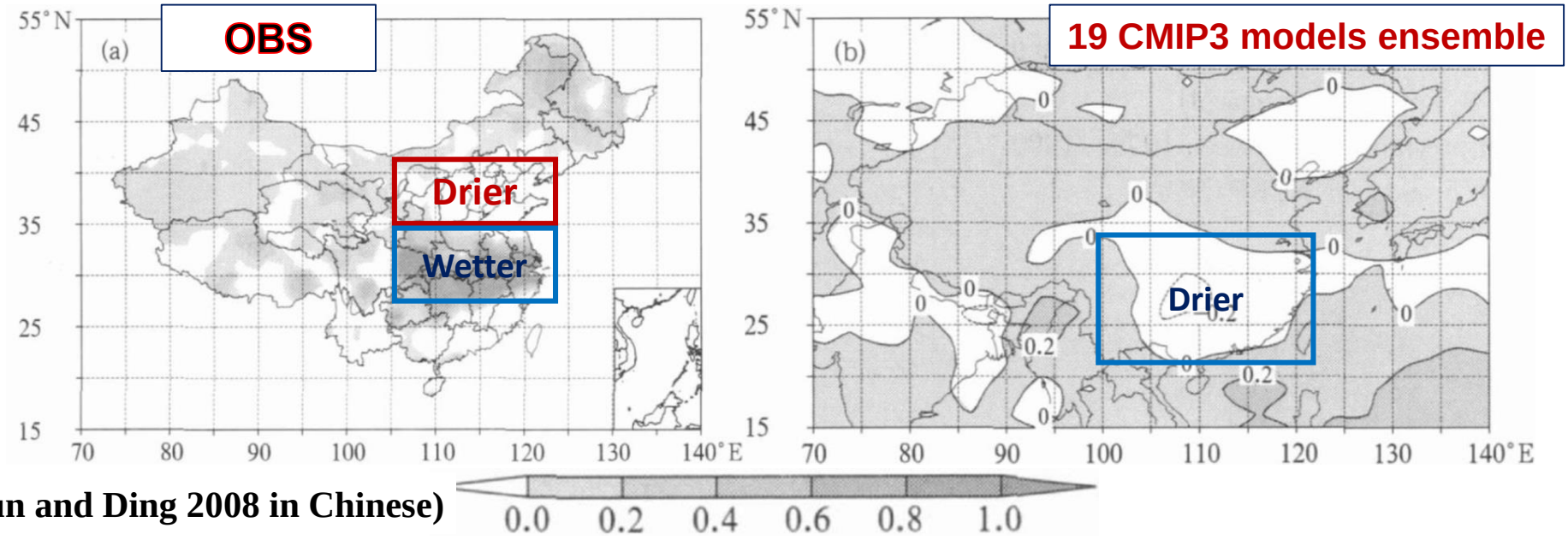
AMIP-type

Advantages
- **Forced by the real SST**

Disadvantages
- **Stand-alone atmospheric model**
- **break air-sea interaction**: lack the atmospheric feedback to the ocean

Difficulty in simulating decadal change of EASM

Decadal change of Prec. 1979-1999 minus 1958-1978



(Sun and Ding 2008 in Chinese)

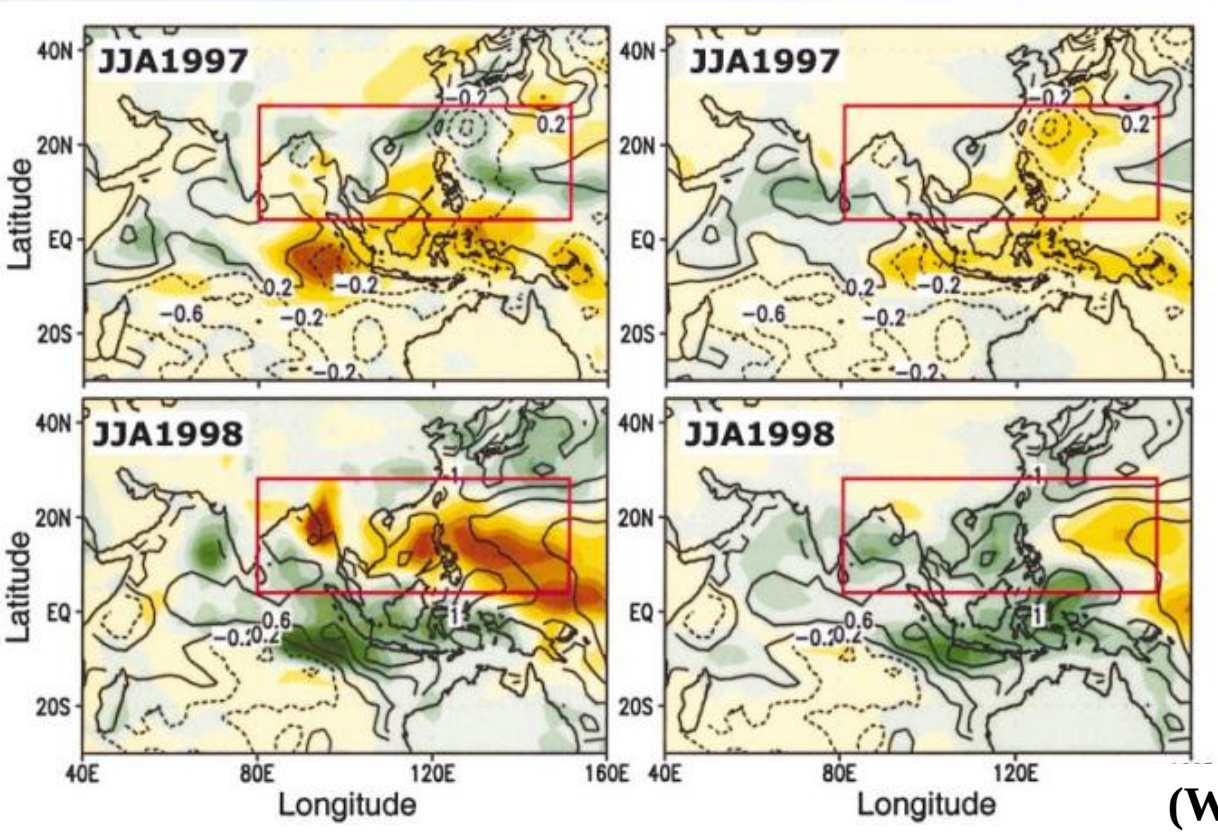
OBS: wetter-south-and-drier-north pattern over the eastern China.

CMIP historical exp. (using real external forcing): low skills (right Figure)

Neither coupled climate model (CGCM) nor stand-alone atmospheric model (AGCM) can reveal the real decadal variation of EASM, even they've used real external forcing or observed SST and sea ice

Difficulty in simulating interannual variability of EASM

OBS



AMIP simulation

(Wang et al. 2004)

This figure compares the observed and model composite precipitation anomalies for JJA1997 and JJA1998.

Atmospheric model performed unsuccessfully in reproducing the rainfall anomalies over west northern Pacific region.

Motivation

Applying ocean data assimilation in a coupled climate model, to capture the oceanic variations without breaking air-sea interaction, and finally improve EASM simulation

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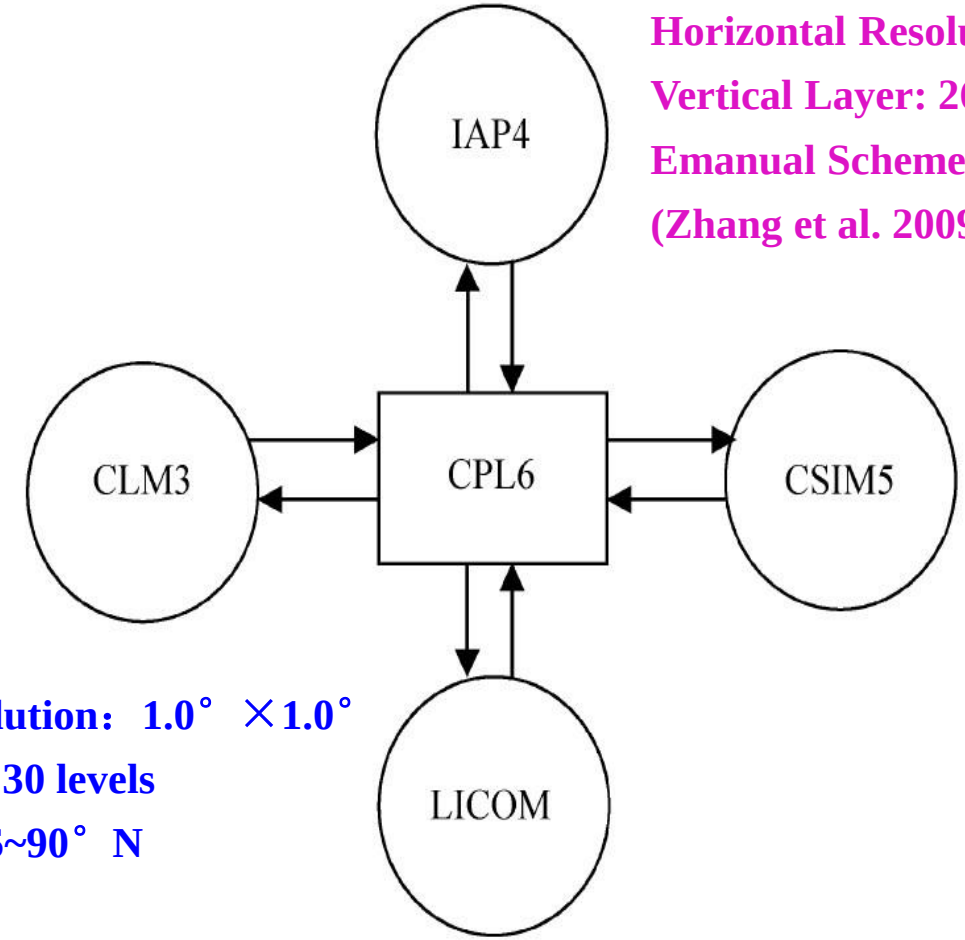
Model Introduction: CAS-ESM-C



Horizontal Resolution：1.4°×1.4°
Vertical Layer: 26 levels
Emanual Scheme
(Zhang et al. 2009; 2011)

Horizontal Resolution：1.0°×1.0°
Vertical Layer：30 levels
Domain： 79°S~90°N
(Liu et al. 2004)

fully coupled climate system model developed by Institute of Atmospheric Physics (IAP)

Data assimilation method

Ensemble Optimal Interpolation **(EnOI)**

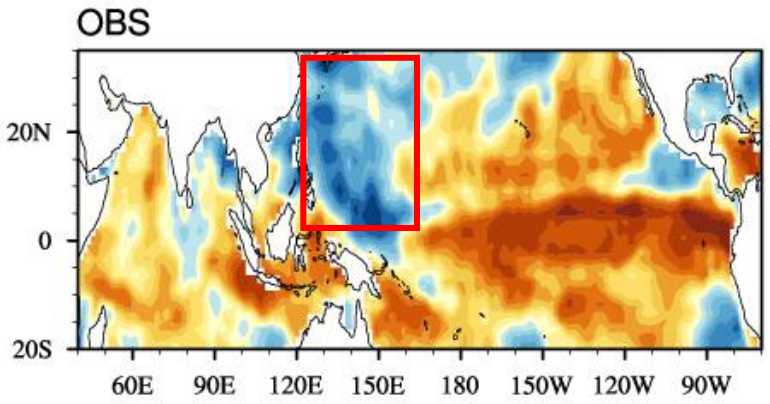
- The EnOI uses a stationary ensemble of model states taken from a long-term model simulations to estimate the background error covariance (Evensen 2003).
- The ensembles used in the assimilation are dependent on different months, in order to adequately describe the distinct characteristics of the oceanic current in different months (Xie et al. 2010)

Two types of Experiment

Name	Model	Experiment	Time Period
SST_Assim	CAS-ESM-C	assimilate SST	1981-2014
AMIP	IAP AGCM4	historical SST forcing	1979-2014

Although only SST field is assimilated, the oceanic fields, i.e. SSH, T, S, U and V current, will adjust dynamically based on background error covariance

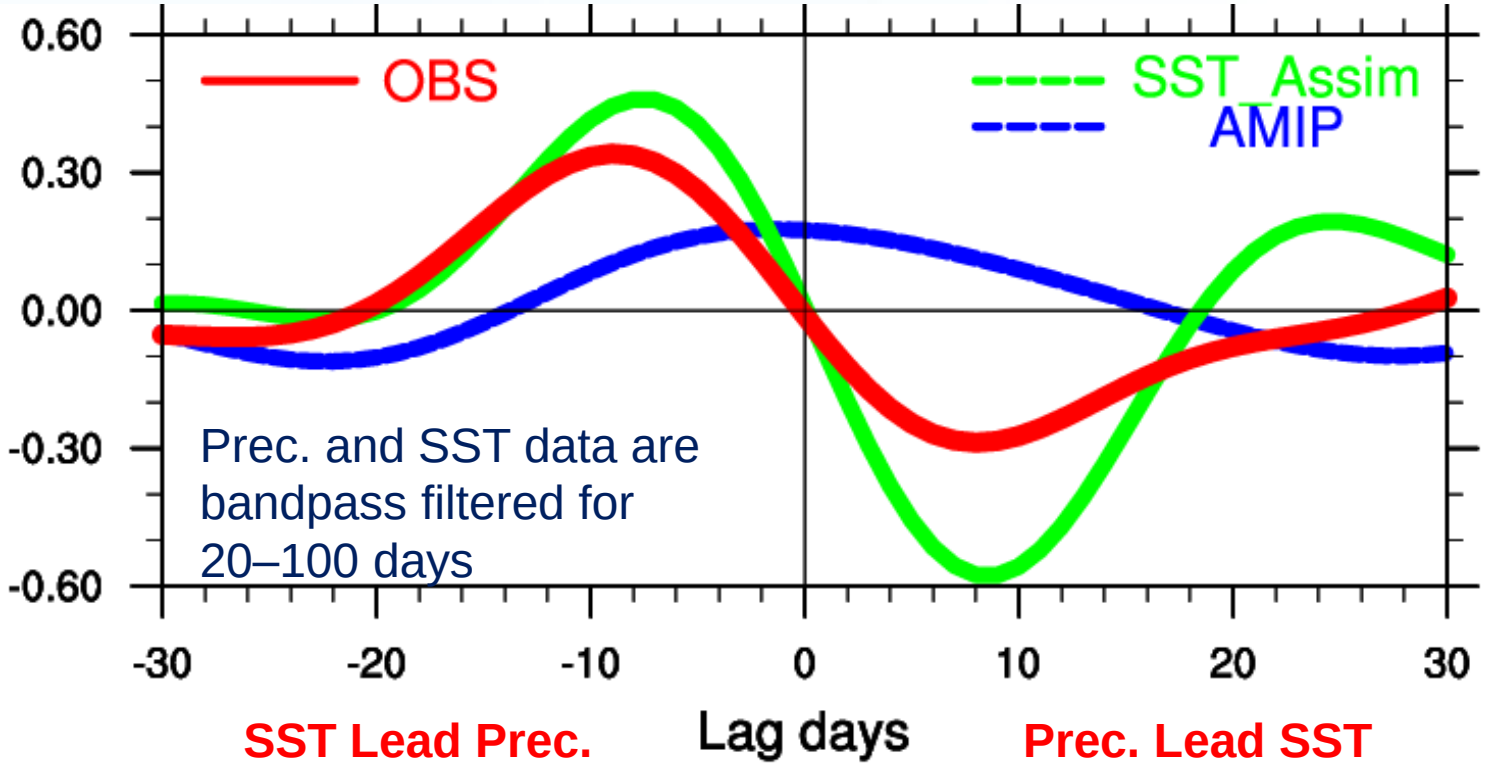
Correlation between SST and Prec. in JJA



The local SST and Prec. anomalies are positively correlated in most tropical area. While negatively correlated in the western North Pacific (WNP) region.

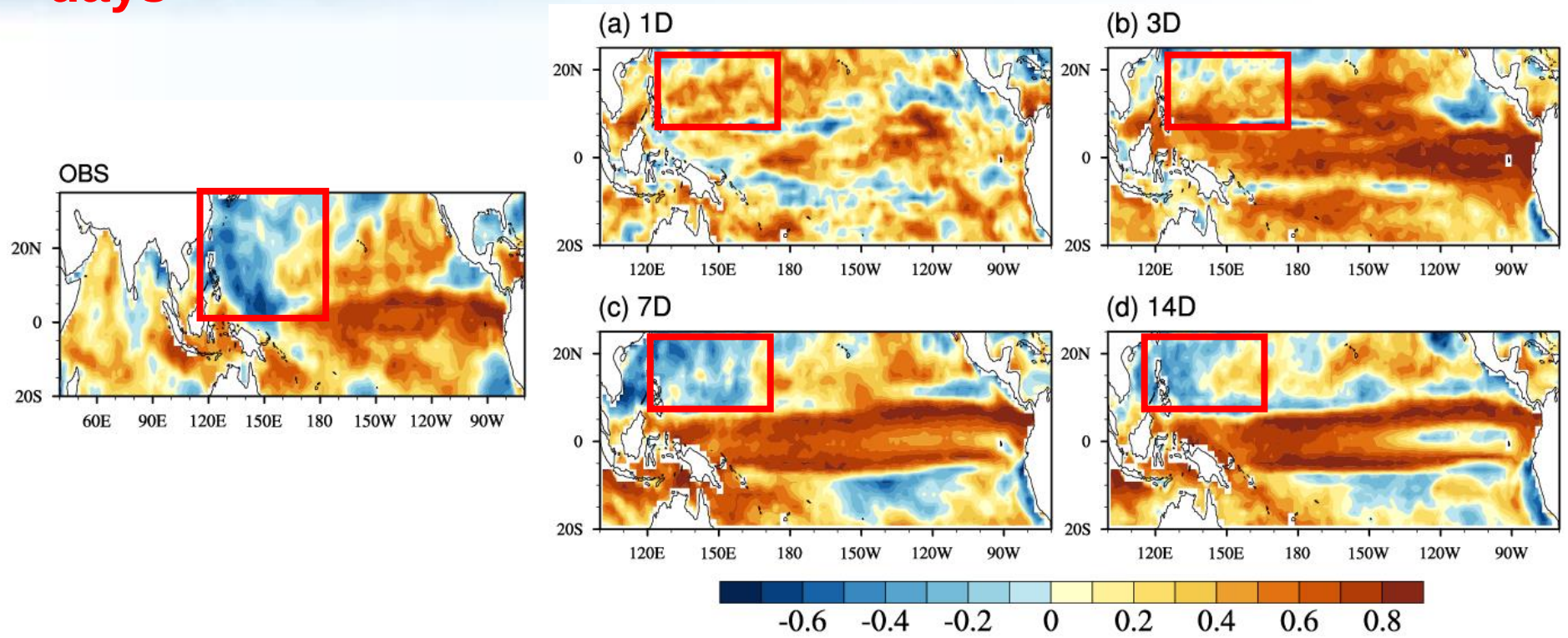
- Positive correlation means the ocean plays a major role in determining atmospheric response
- Negative correlation means the atmosphere affects SST more than SST affects the atmosphere
- In the WNP and East Asian monsoon regions, The atmospheric feedback play a major role in determining local SST

Intra-seasonal Lead or Lag correlations between SST and Prec. in WNP region



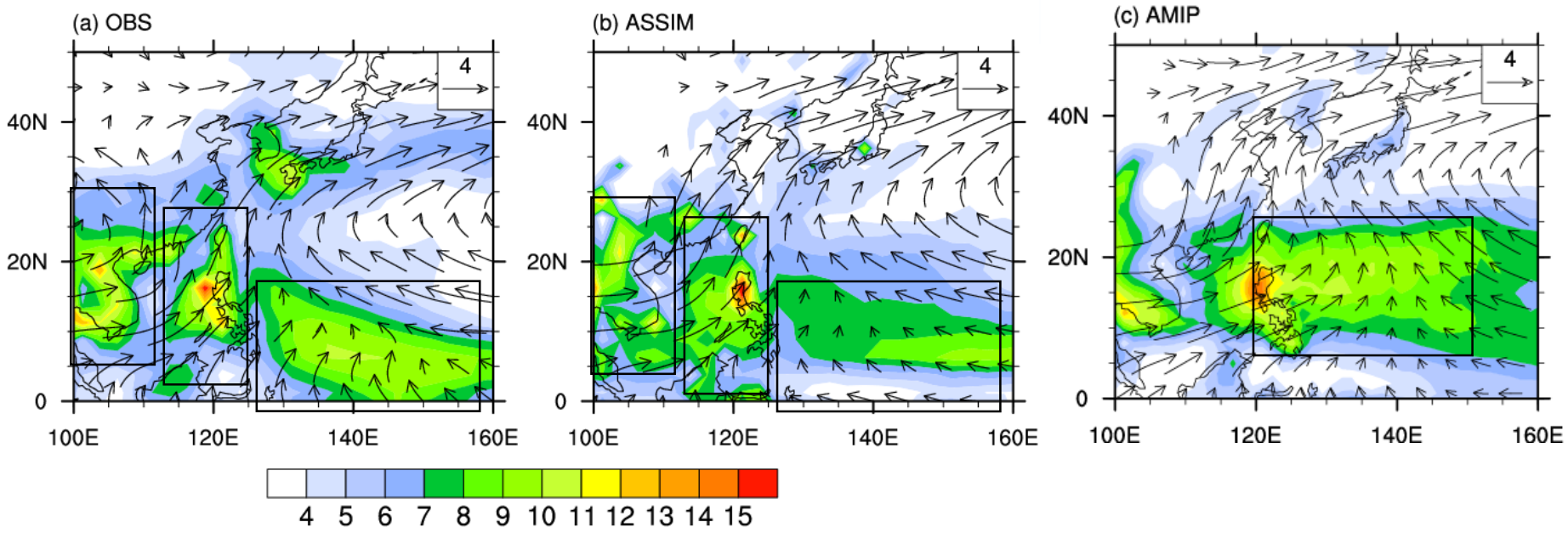
- obs. and SST_Assim: positive (negative) SST leads (lags) prec. by 10 days
- AMIP: positive SST is almost in phase with rainfall
- On intraseasonal scale, AMIP reveal wrong air-sea relationship

Worth noting: in our exp., The SST is assimilated every 7 days



- The 1-day and 3-day exp. cannot reproduce the observed negative SST-rainfall correlation.
- The **7-day** and longer intervals reproduce the observed negative correlation.

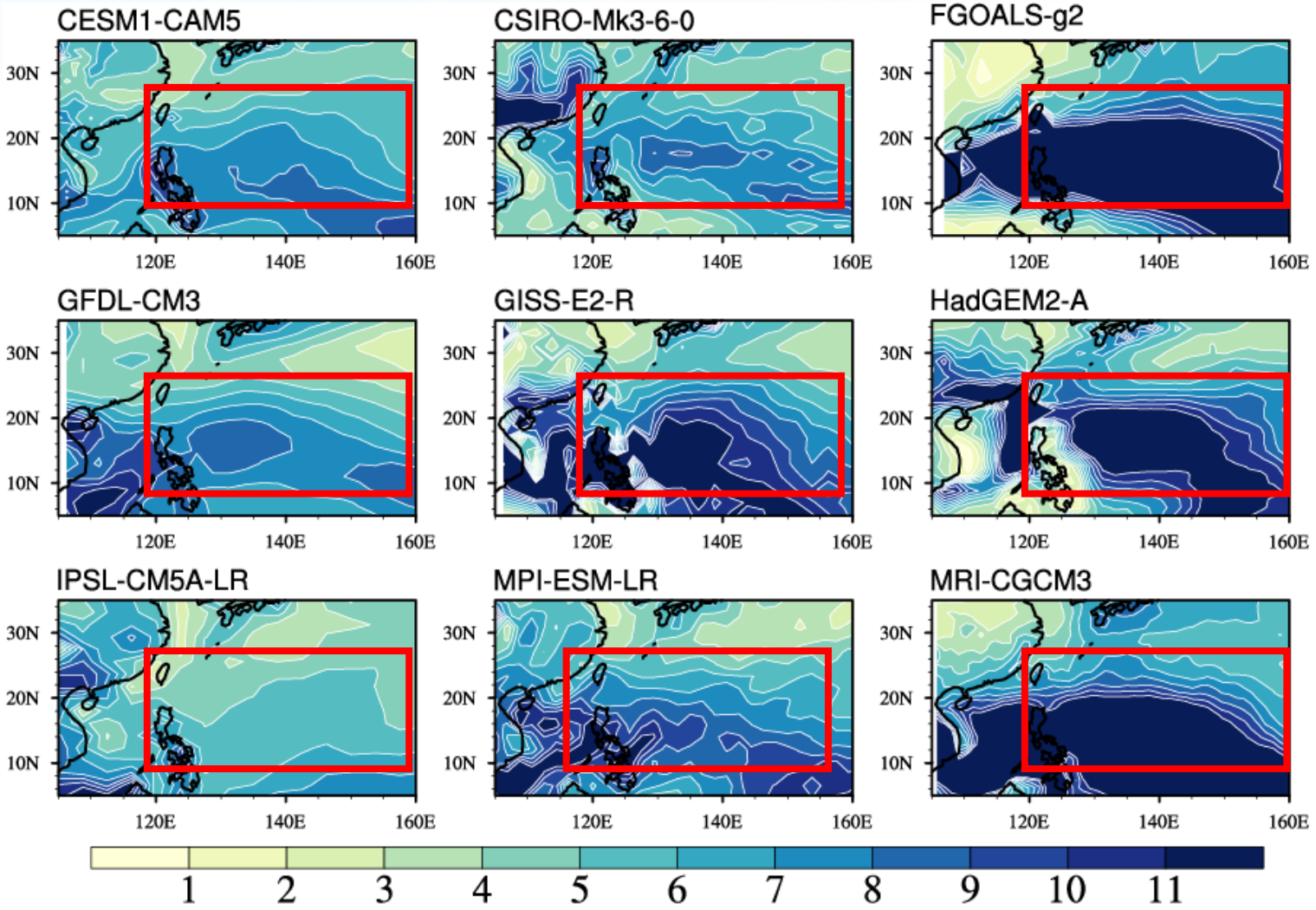
The Climatology of JJA Prec. and UV850



SST_Assim can reasonably reproduce the three precipitation centers in low latitude.

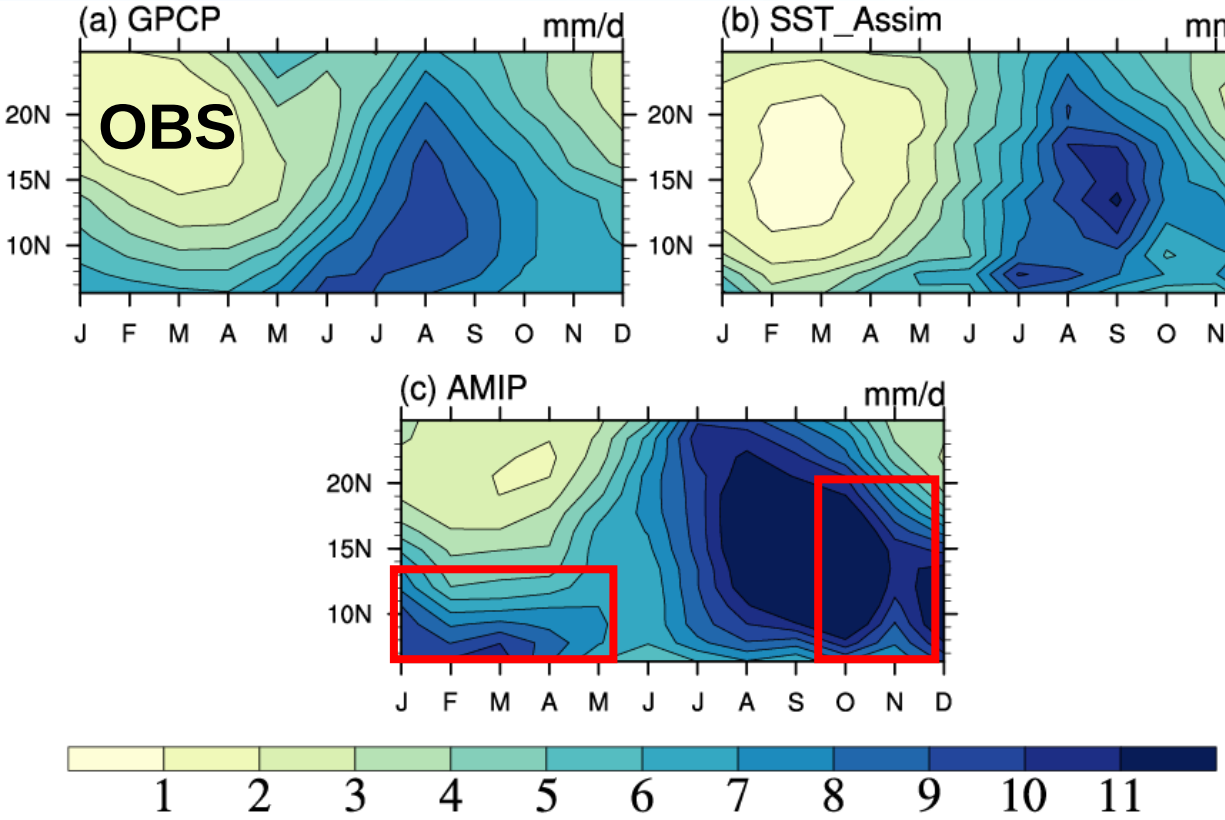
The AMIP underestimate the precipitation along the monsoon rain-band and overestimate precipitation over the South China Sea.

Other AMIP results from CMIP5 models



Similar biases are also evident in other CMIP5 models

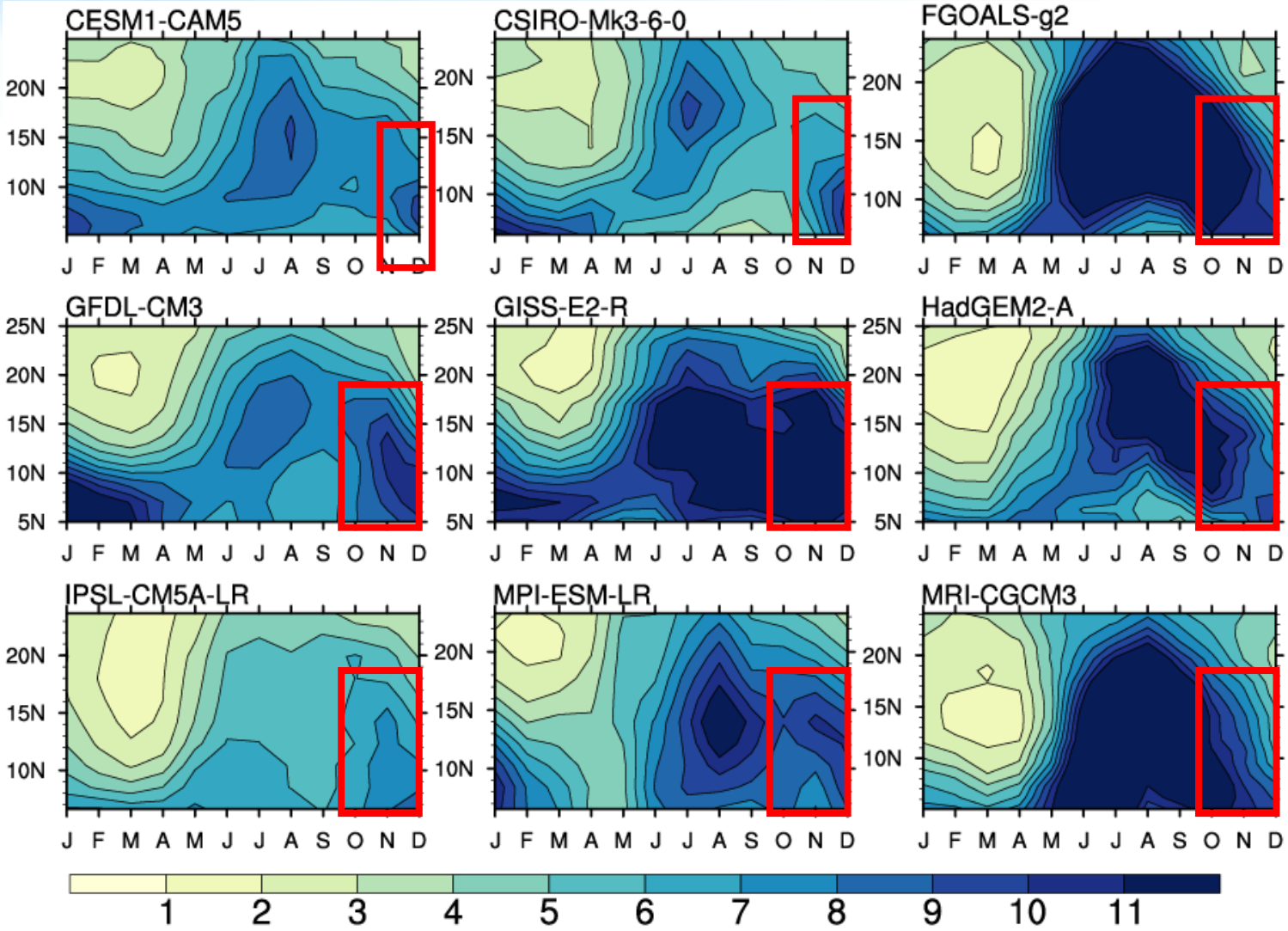
Annual cycle of Prec. Over WNP



SST_Assim reasonably reproduce the annual cycle of prec. over WNP region.

AMIP overestimate the precipitation in boreal winter and spring.

Other AMIP results from CMIP5 models



Similar overestimation of boreal winter precipitation is evident in other CMIP5 models

Conclusion (1)

- We developed a weakly-coupled data assimilation system in which SST are employed to constrain ocean fields of CAS-ESM-C through EnOI method.
- The basic behavior of the data assimilation system has been evaluated on the SST-rainfall relationship and climatology.

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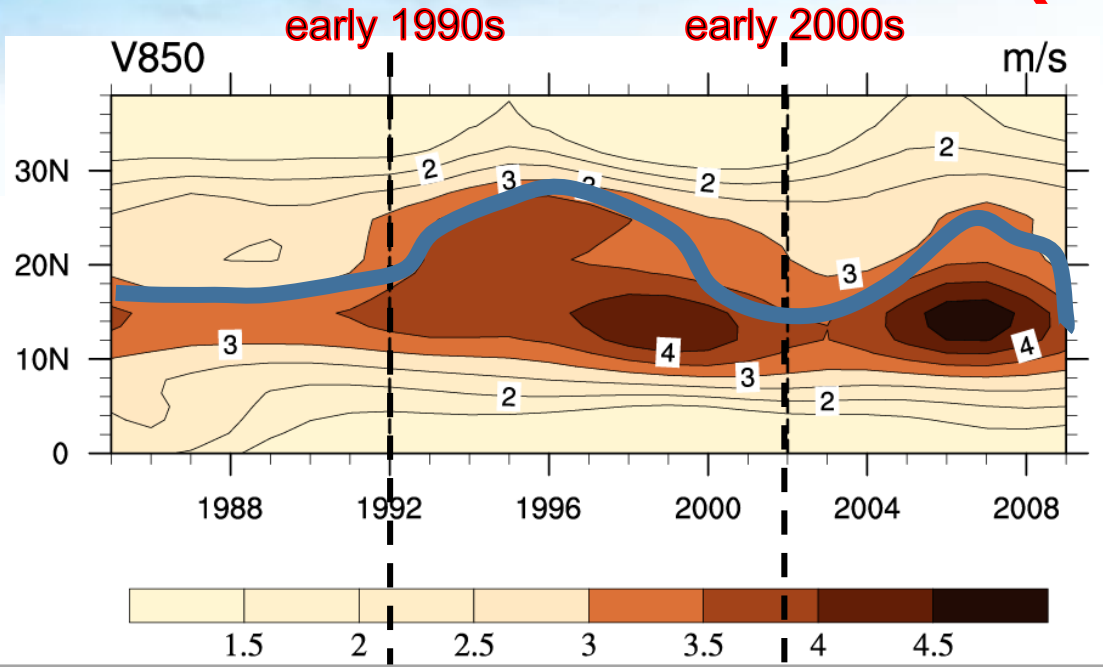
Decadal variations of EASM (OBS)

JJA south wind



East China
$110°E \sim 120°E$

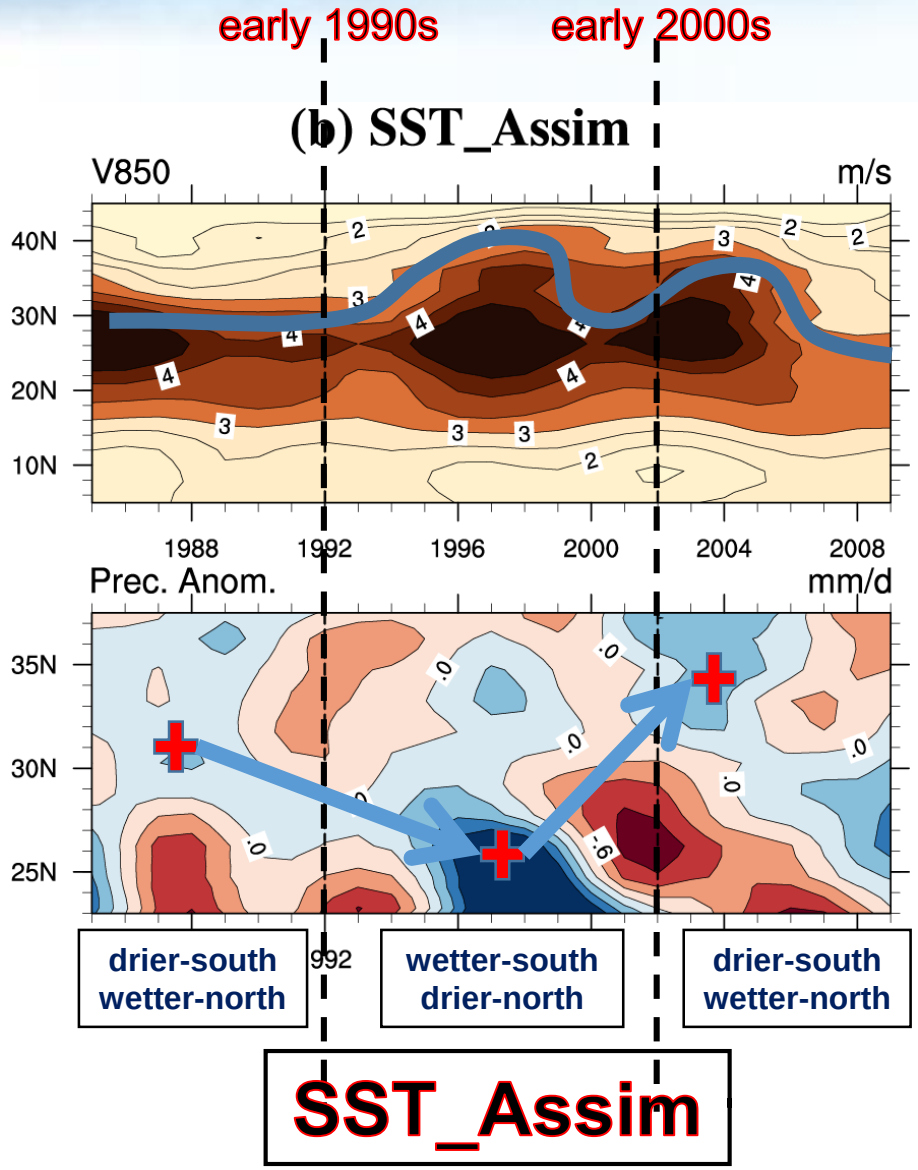
The 7-year low-pass filter is applied to suppress the interannual variability

- Evolution of JJA mean wind-850hPa; X Axis is time; Y Axis is latitude
- It reflects the evolution of EASM
- There are two marked decadal changes.

-Since early-1990s: an increasing and northward shift of low-level south wind over East China ⟶ a decadal strengthening of EASM

-another decadal variation take place in the early-2000s

Decadal variation of EASM (SST_Assim& AMIP)

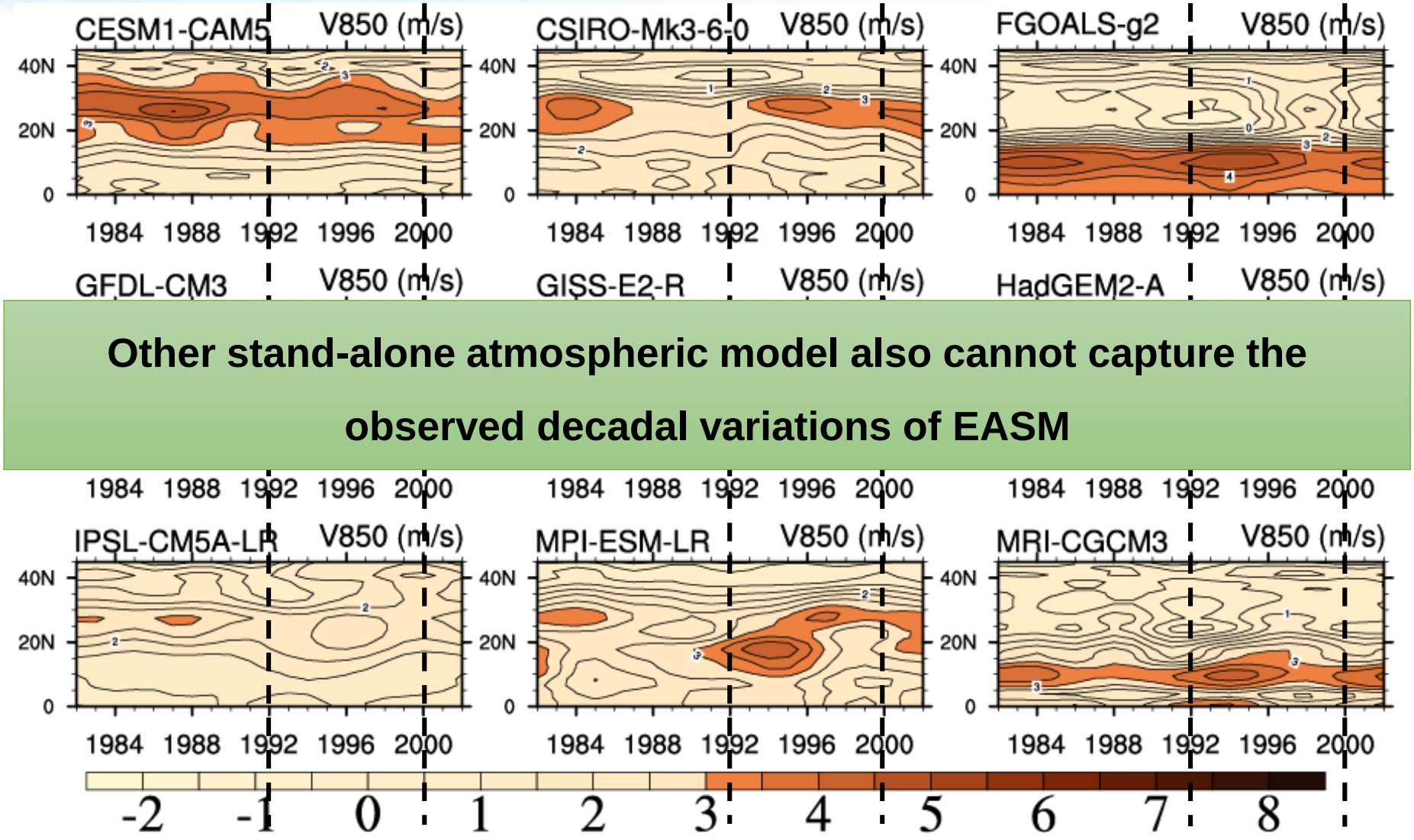


The results of SST_Assim (good simulation!)

Main substantial features in the obs. are well captured

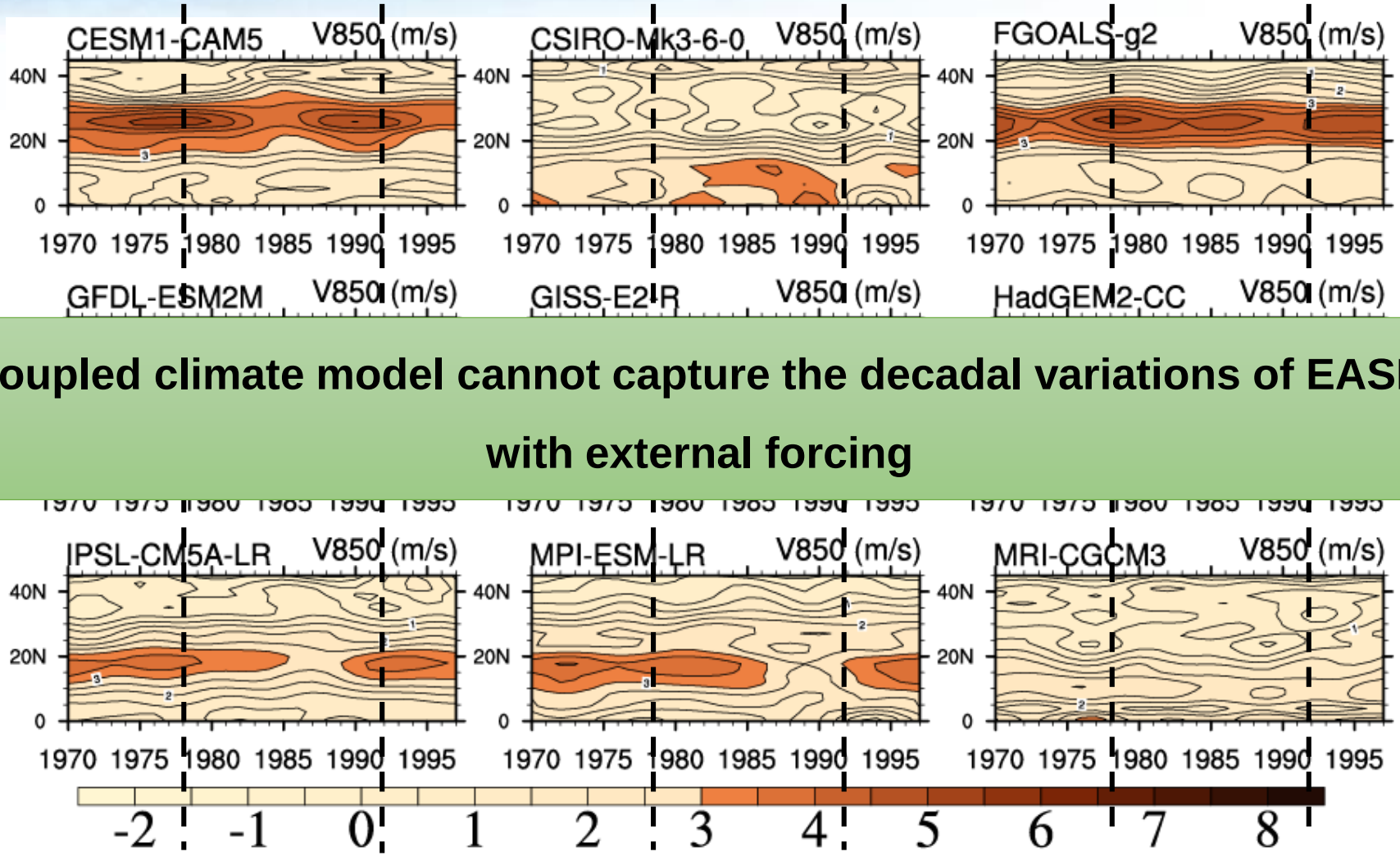
- the enhancing and northward shift of low-level southerly wind since the early 1990s
- the southward shift of the East Asian rain belt since the early 1990s
- The positive prec. anomalies over southeastern China in the 2nd decadal period is evident.

Other AMIP results from CMIP5 model



Other stand-alone atmospheric model also cannot capture the observed decadal variations of EASM

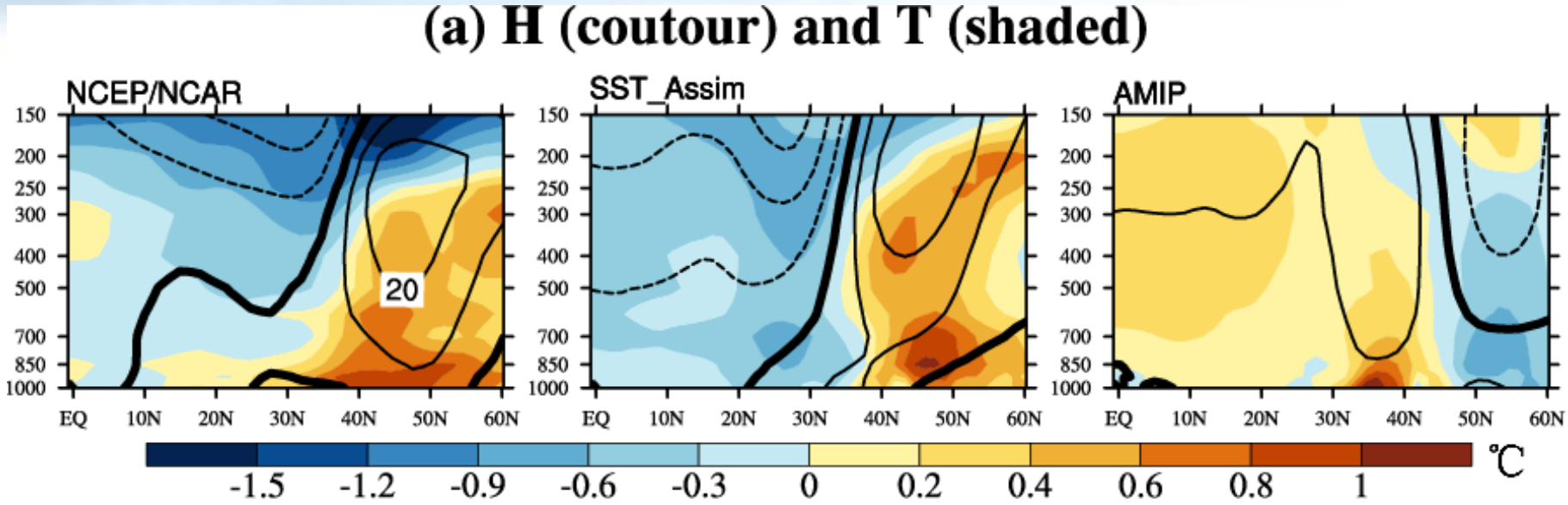
Other Coupled model results from CMIP5



Coupled climate model cannot capture the decadal variations of EASM with external forcing

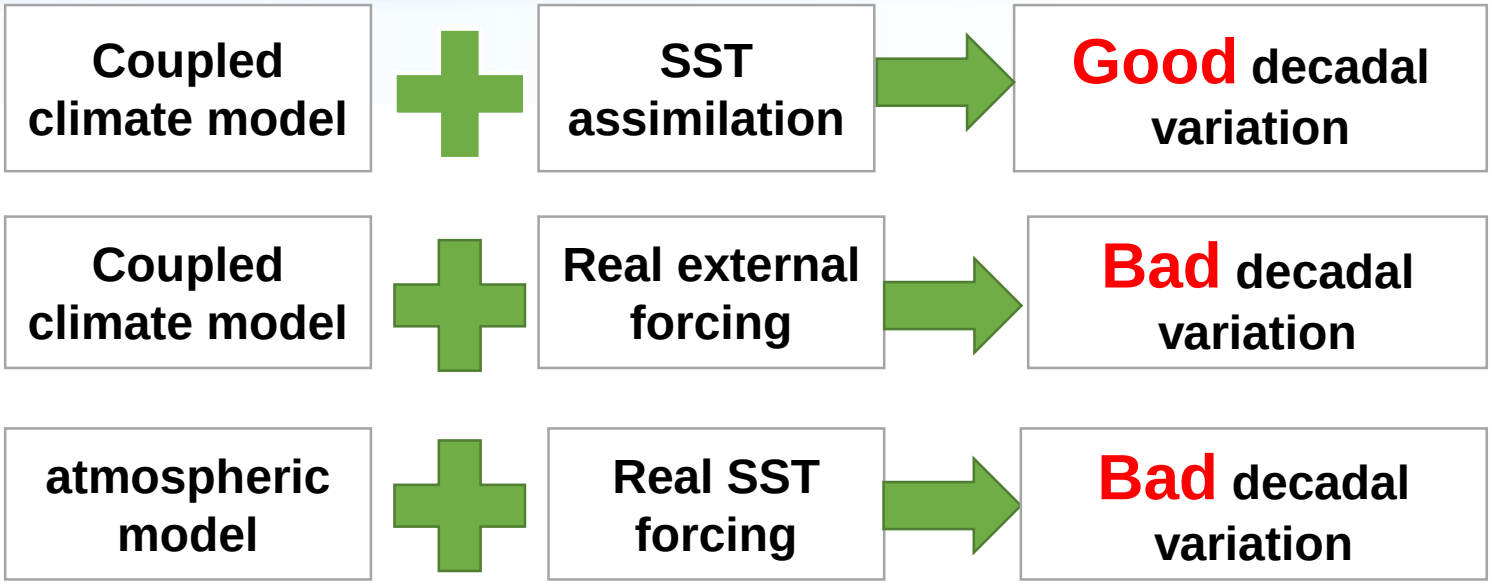
All-forcing run are forced by both natural (solar variability and volcanic aerosols) and anthropogenic forcings (GHG and anthropogenic aerosols)

Decadal variation of the three-dimensional structure of EASM



- zonal–height cross sections in the geopotential height (contour, units: gpm) and temperature (shaded, units: ° C);
- X Axis is latitude; Y Axis is level.
- The “south-cool-north-warm” pattern of the upper-level tropospheric temperature is well captured by SST_Assim.

Conclusion (2)



- Failure of AMIP_type is the lacking of air-sea interaction
- Failure of CMIP_type is that using only external forcing cannot capture the decadal variations of oceanic field.
- Applying ocean data assimilation to a coupled climate model
  - input the real SST variations
  - Not break air-sea interaction

→ **Right decadal variation**

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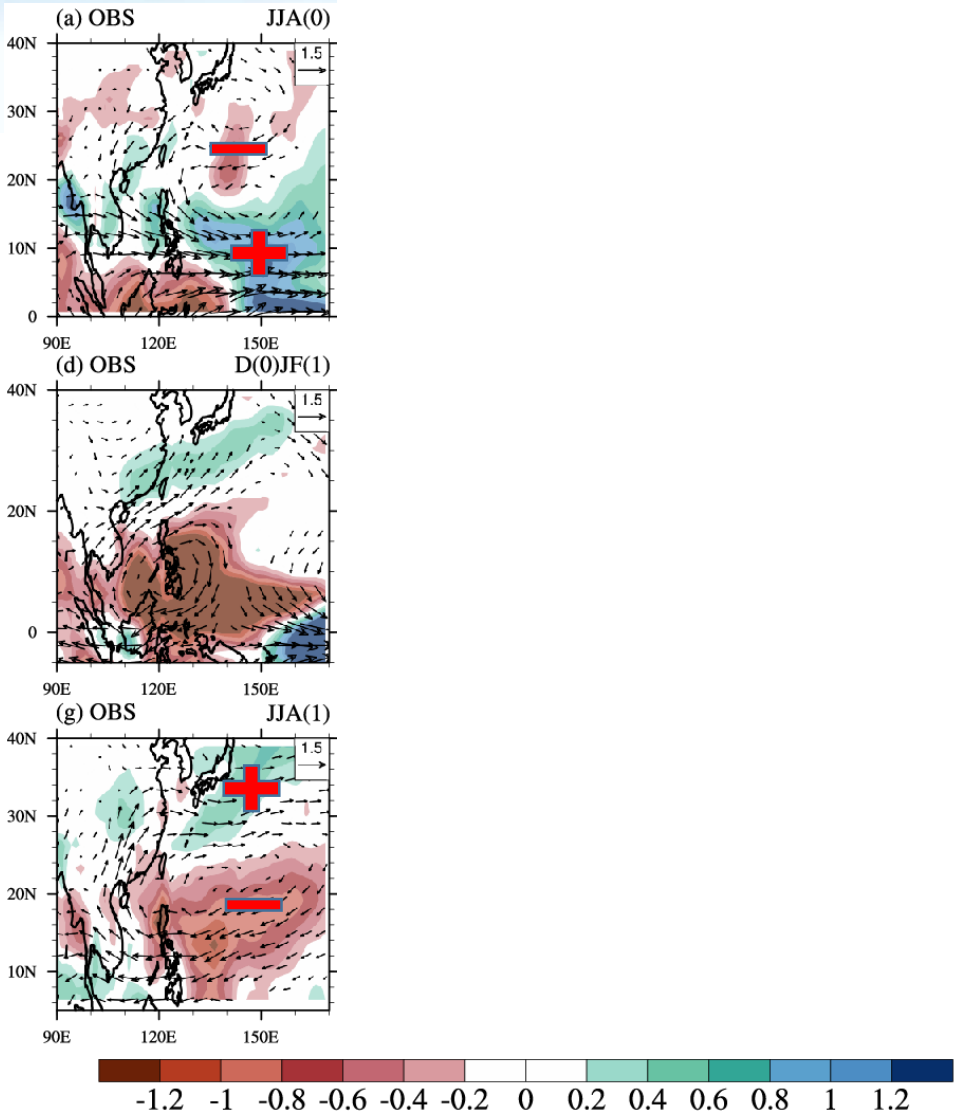
Regressions of Prec. and UV850 anomaly on observed Nino3.4 index

Developing summer

Mature phase

Decaying summer



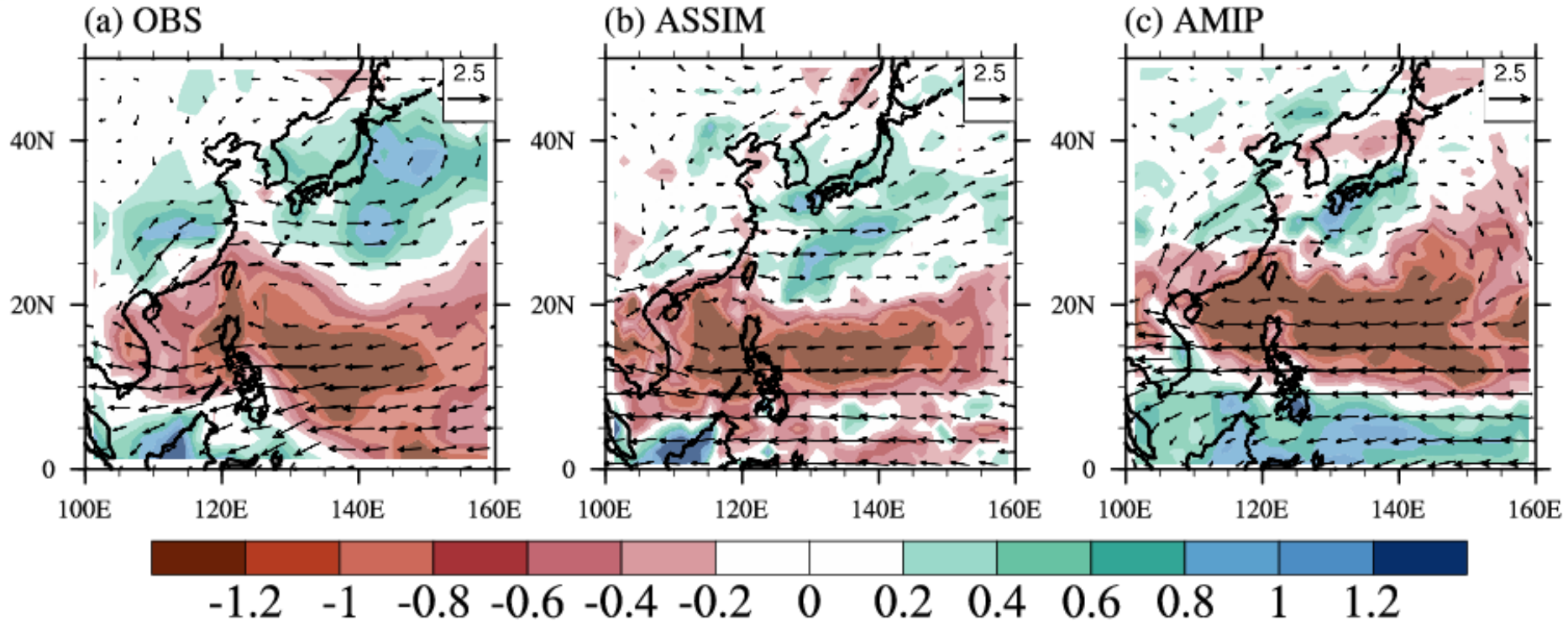
JJA(0)

D(0)JF(1)

JJA(1)

The anomalous pattern of circulation and rainfall are contrary in developing and decaying summer, implying a substantial interannual variation of EASM climate.

Regressions of Prec. and UV850 anomaly on observed EASM index



- In the observation, the EASM-related precipitation shows a north-south dipole pattern and an anti-cyclonic circulation anomaly exists in low level.
- Compare to AMIP simulation, SST_Assim shows better performance in reflecting the location and magnitude of the EASM-related climate.

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Motivation

- Rainfall forecasting in the wet season (JJA) has been a problem of great concern for China's climate prediction community. Developing well-performed operational seasonal-to-interannual short-term prediction systems is an essential issue.

Develop a "one-tiered" seasonal forecasting system based on CAS-ESM-C to improve summer rainfall prediction in China.

Method description

Model	CAS-ESM-C
Ensemble number	9 ensemble members, the prediction results were the nine-member ensemble means
Initial conditions	Derived from SST_Assim
Period	1982-2016, 6 months into the future from 1st of March
Analysis	June to August (JJA)

Skill score definitions

- The temporal correlation coefficient (**TCC**)
- Anomaly pattern correlation coefficient (**ACC**)

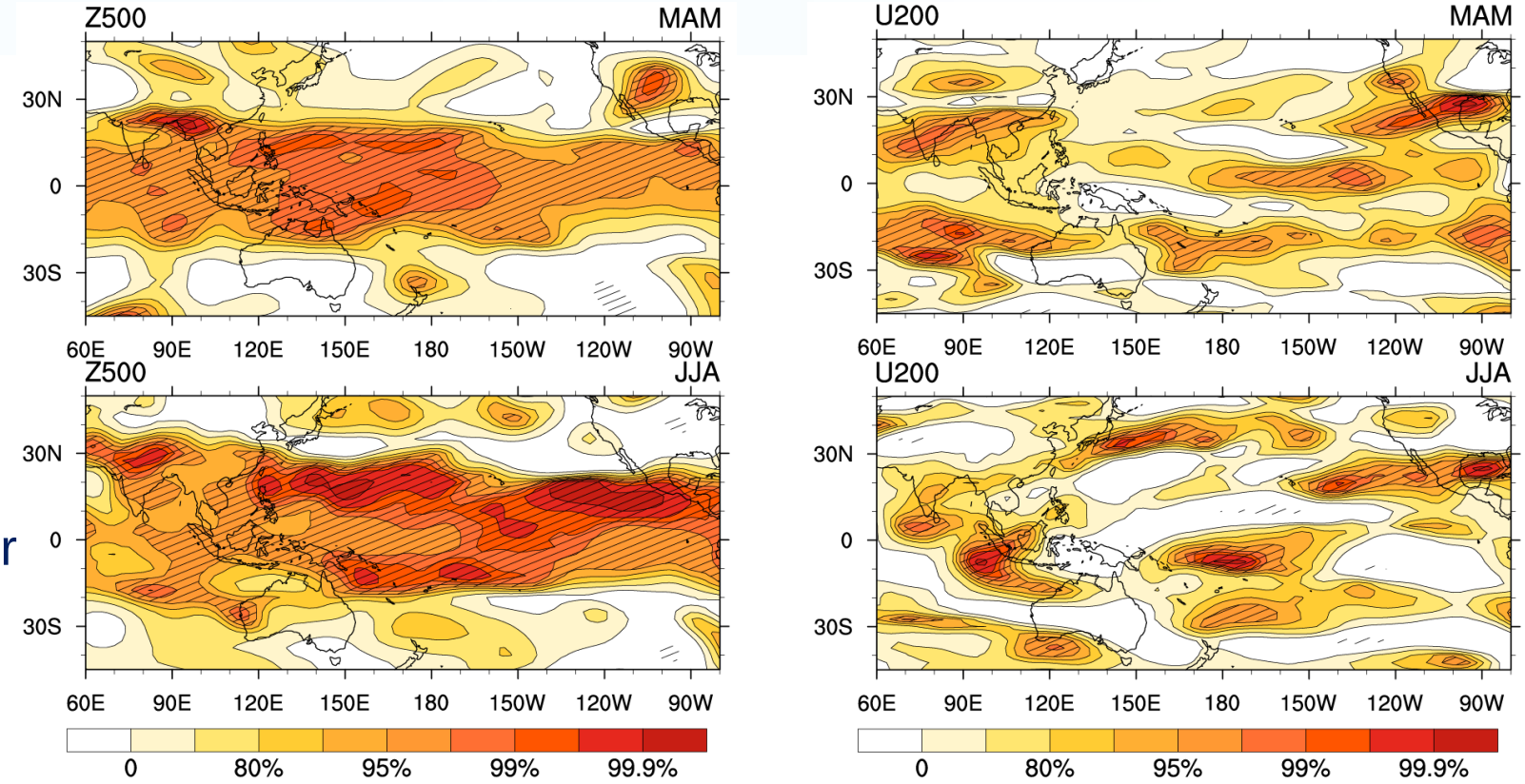
Prediction skills for large-scale circulation

Z500

U200

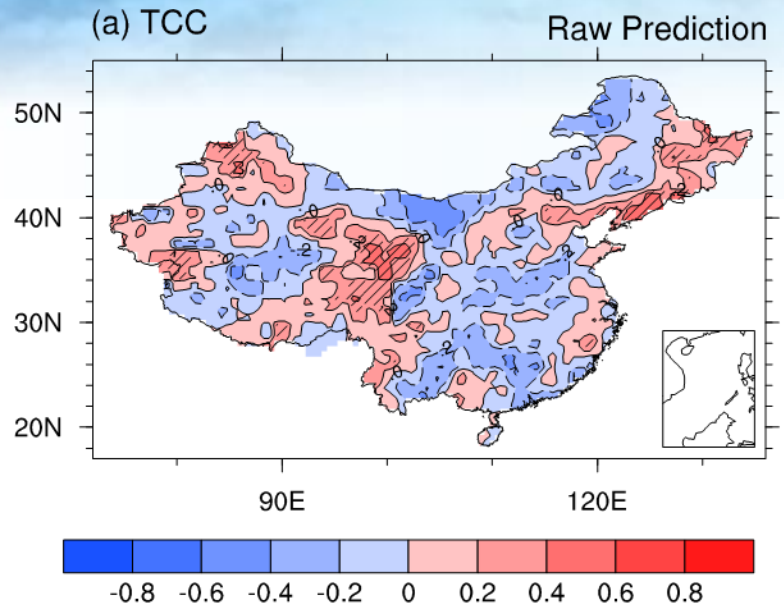
Spring

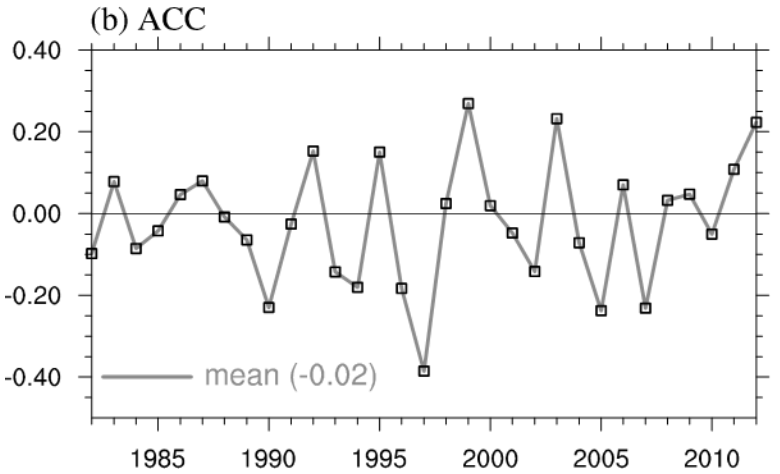
summer



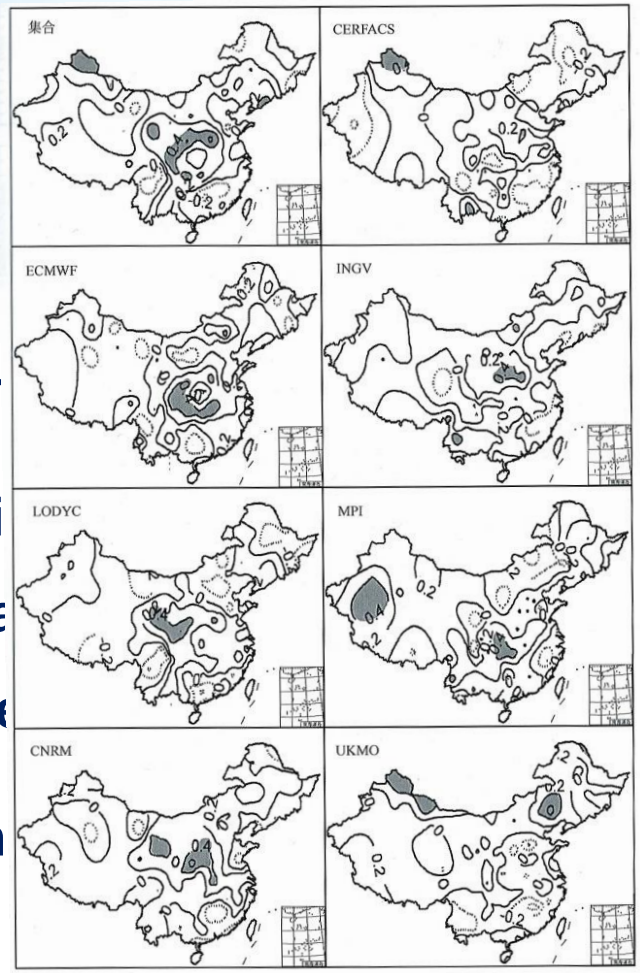
- The background circulation are well predicted by the ensemble seasonal forecasting.

Prediction skill for anomalous JJA rainfall in China





The skill is very limited



- Al … are well
  pr… ll show
  lar…
- It i… e model
  bia… ds after
  pre…
- Th… almost
  all … odels

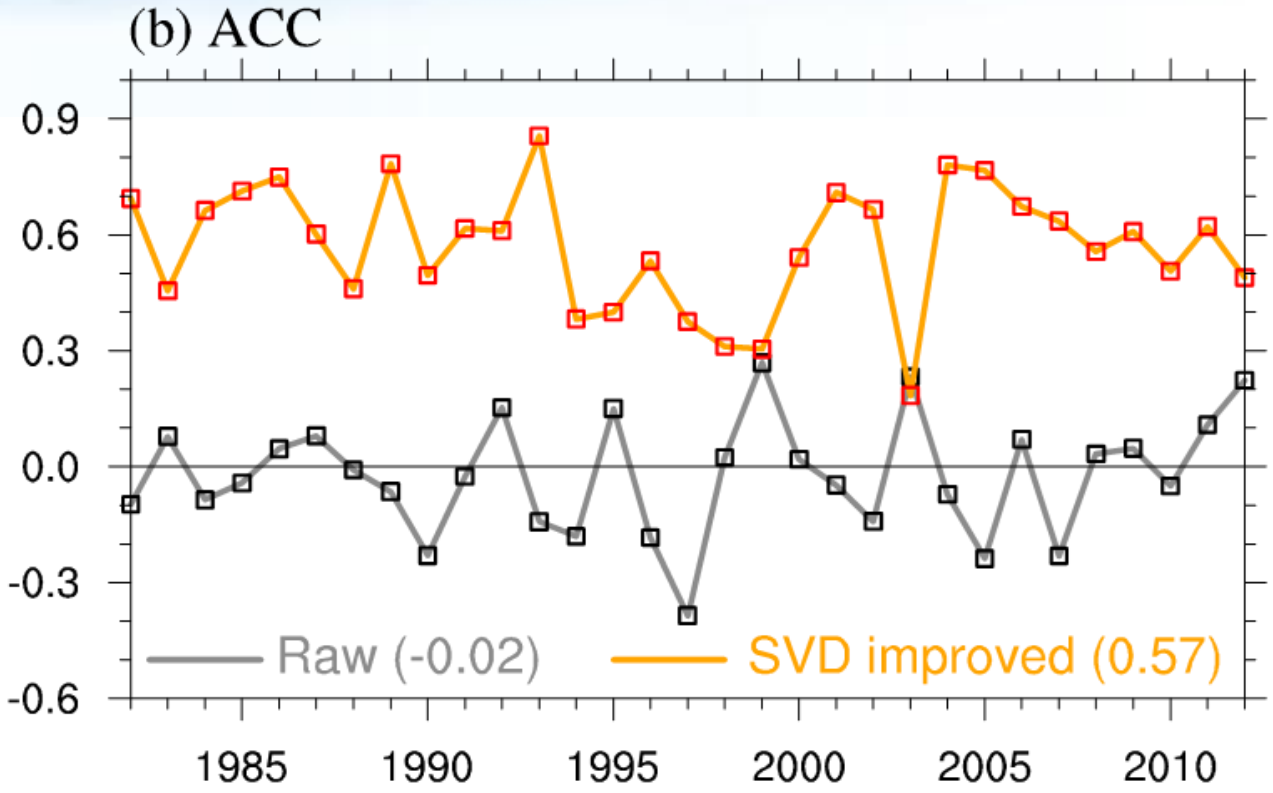
The models that participated in the DEMETER project also had much bias in their prediction (Wang et al. 2012)

Several methods have usually been adopted to correct the model bias after prediction

- The mean bias correction method (systematical bias correction) (Chen and Lin, 2006; Lang et al., 2003; Zhao et al., 1999)
- The year-to-year incremental approach (Fan and Wang, 2010; Wang et al., 2000)
- The Empirical Orthogonal Function (EOF)/Singular Value Decomposition **(SVD) based bias correction method** (Feddersen et al., 1999; Kharin and Zwiers, 2001; Qin et al., 2011)
- Statistical or dynamical downscaling (Chen et al., 2012; Paul et al., 2008).

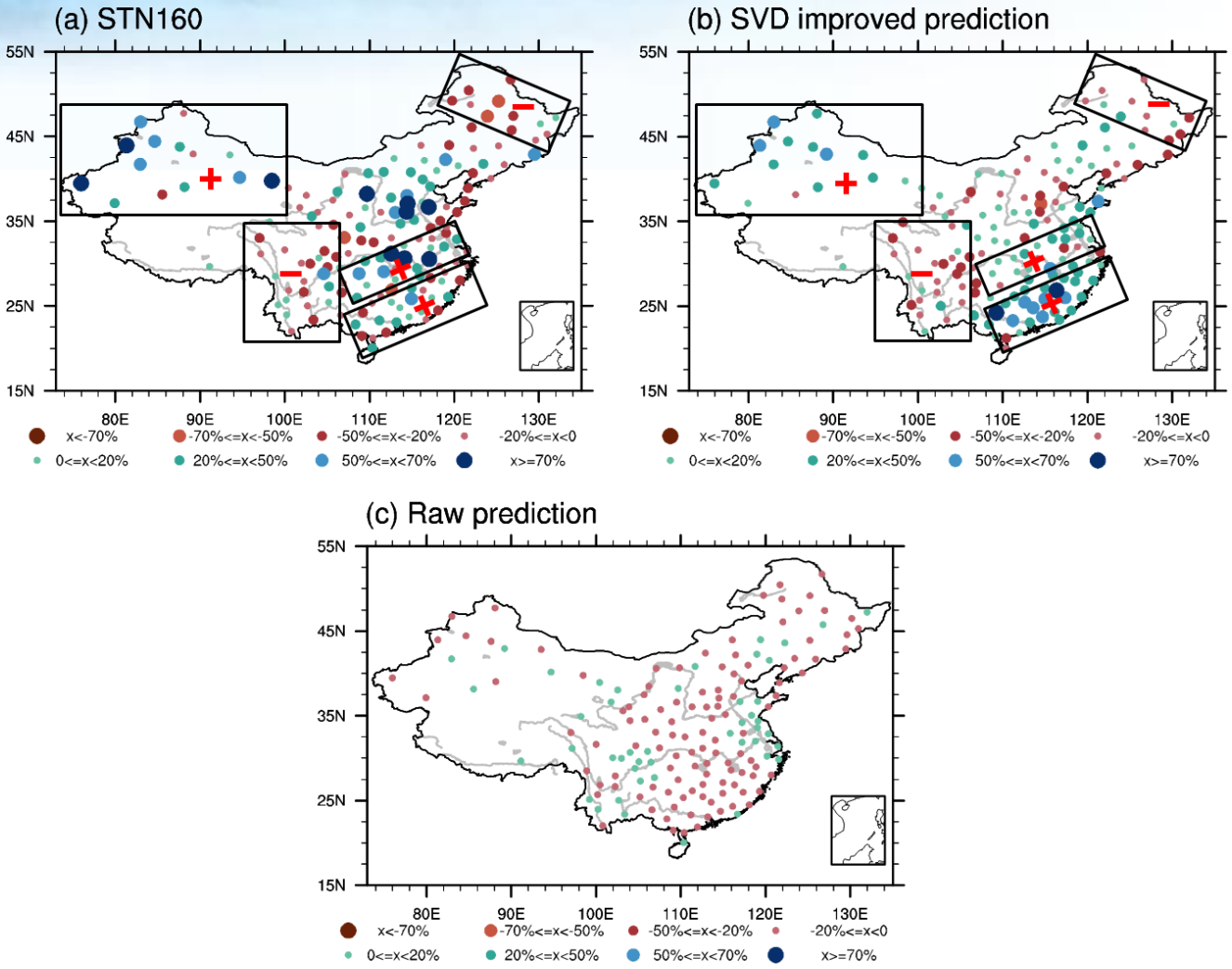
The SVD-based correction method was used in this study

SVD-improved prediction



The yearly pattern correlations for rainfall anomaly with observations are largely improved after SVD-based correction.

Forecast anomalous rainfall in 2016



the main positive or negative anomalies are well predicted by SVD improved prediction

Conclusion (3)

- The large-scale circulation are well predicted by the ensemble seasonal forecasting.
- Without bias correction, the skills is very limit in predicting rainfall anomaly in China.
- After SVD-based bias correction, the skill substantially increased. SVD improved prediction have been used to operational seasonal prediction.

Thank you!

Thanks for your attention