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Strengthening of tropical Indian Ocean teleconnection to the Northwest Pacific since the mid-1970s: An atmospheric GCM study and The Simulations in CMIP5 models

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2IPRC, UCSD,SCRIPPS, U.S.A

Part1: Strengthening of tropical Indian Ocean teleconnection to the Northwest Pacific since the mid-1970s: An atmospheric GCM study

1 Shang-ping Xie,Yan Du, Gang Huang,Xiao-tong Zheng,Hiroki Tokinaga,Kaiming Hu,Qinyu Liu,Decadal Shift in El Nin˜o Influences on Indo–Western Pacific and East Asian Climate in the 1970s, Journal of Climate, 2010,vol.23,3352-3368

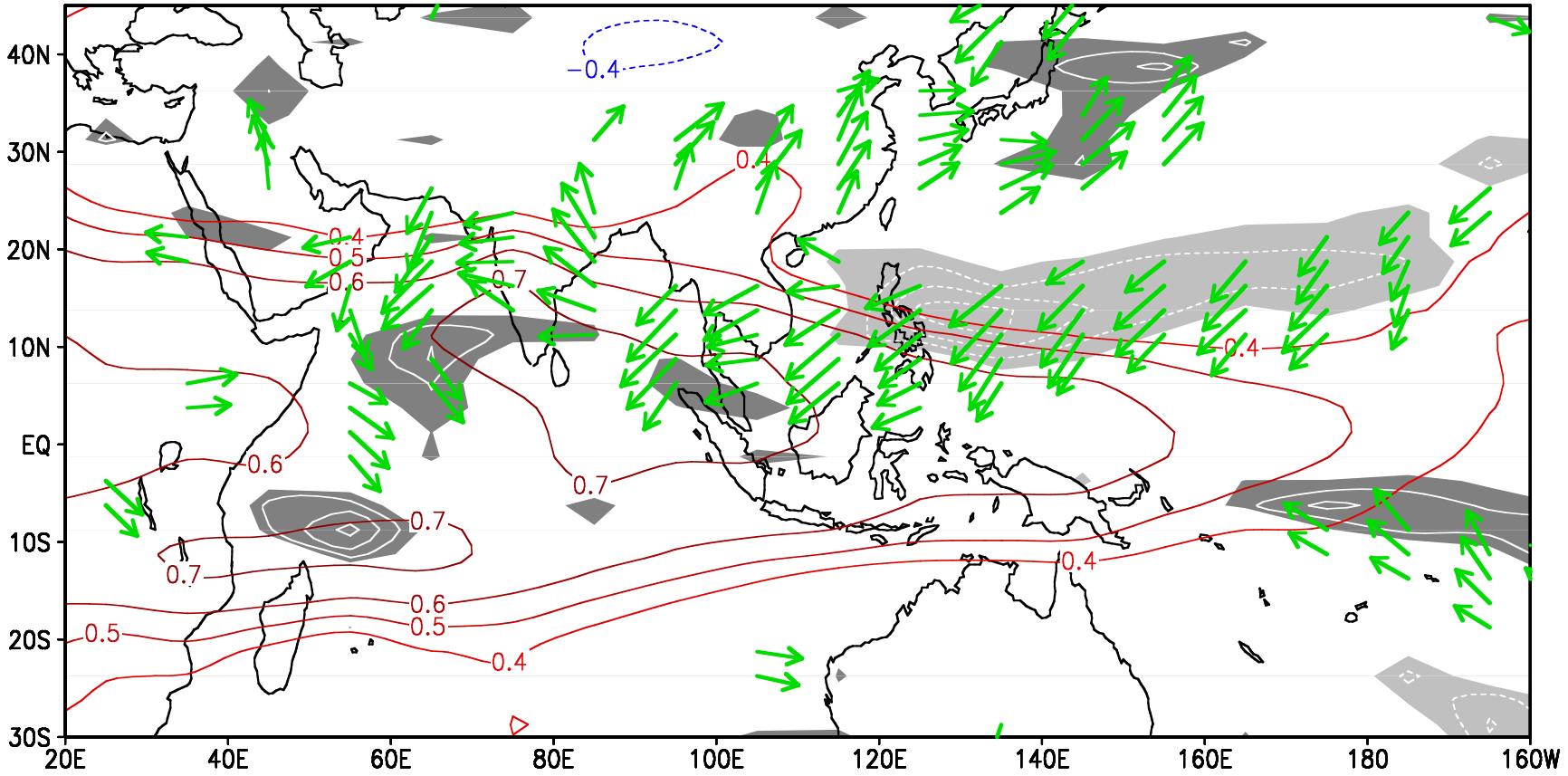
2 Gang Huang,Kaiming Hu,Shang-Ping Xie,Strengthening of tropical Indian Ocean teleconnection to the Northwest Pacific since the mid-1970s: An atmospheric GCM study, Journal of climate, Vol. 23, No. 19, 2010, 5294–5304

3Xie, S.P., K. Hu, J. Hafner, H. Tokinaga, Y. Du, Huang Gang , and T. Sampe, 2009: Indian Ocean Capacitor Effect on Indo–Western Pacific Climate during the Summer following El Nino. J. Climate , 22 , 730–747.

How does IO warming force NW Pacific anticyclone?

IO warming → Warm Kelvin wave into the WP
→ Northeasterly winds to the north under friction
→ Divergence over NW Pacific ←→ Suppressed convection

From（Xie et al 2009）

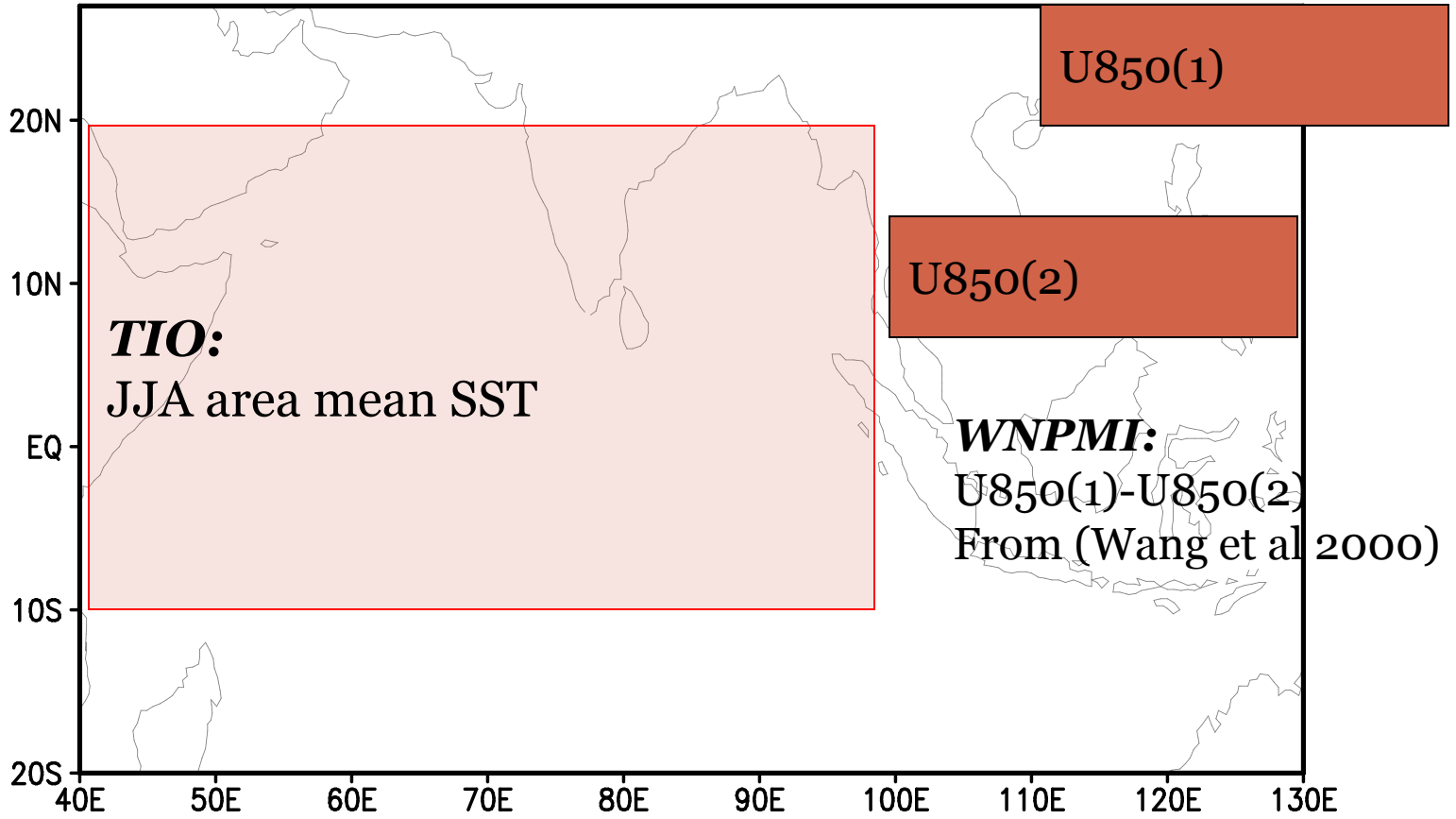


Tropospheric temp,
surface wind & rainfall

−0.4 0.4

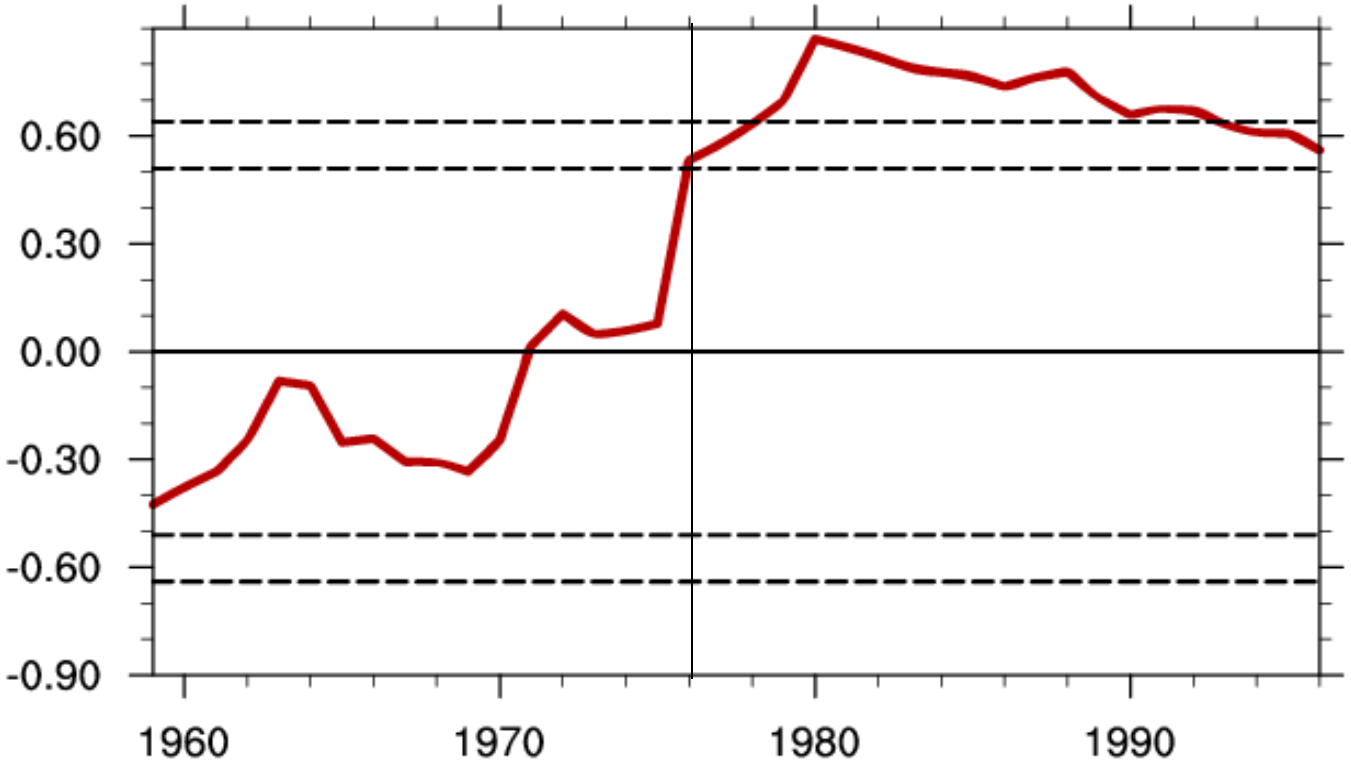
1

Definition



TIO: Tropical Indian Ocean (10S~20N：40~100E）area mean SST in JJA (June to August)
WNPMI: U850(1)-U850(2). (followed Wang et al (2000) but the sign is reverse)

Sliding correlation coefficients between WNPMI and JJA TIO index with a window of 15 years



The relationship between the TIO SST and the WNPSM is strong in recent decades (1977-1996), but weak before 1977 (1958-1976).

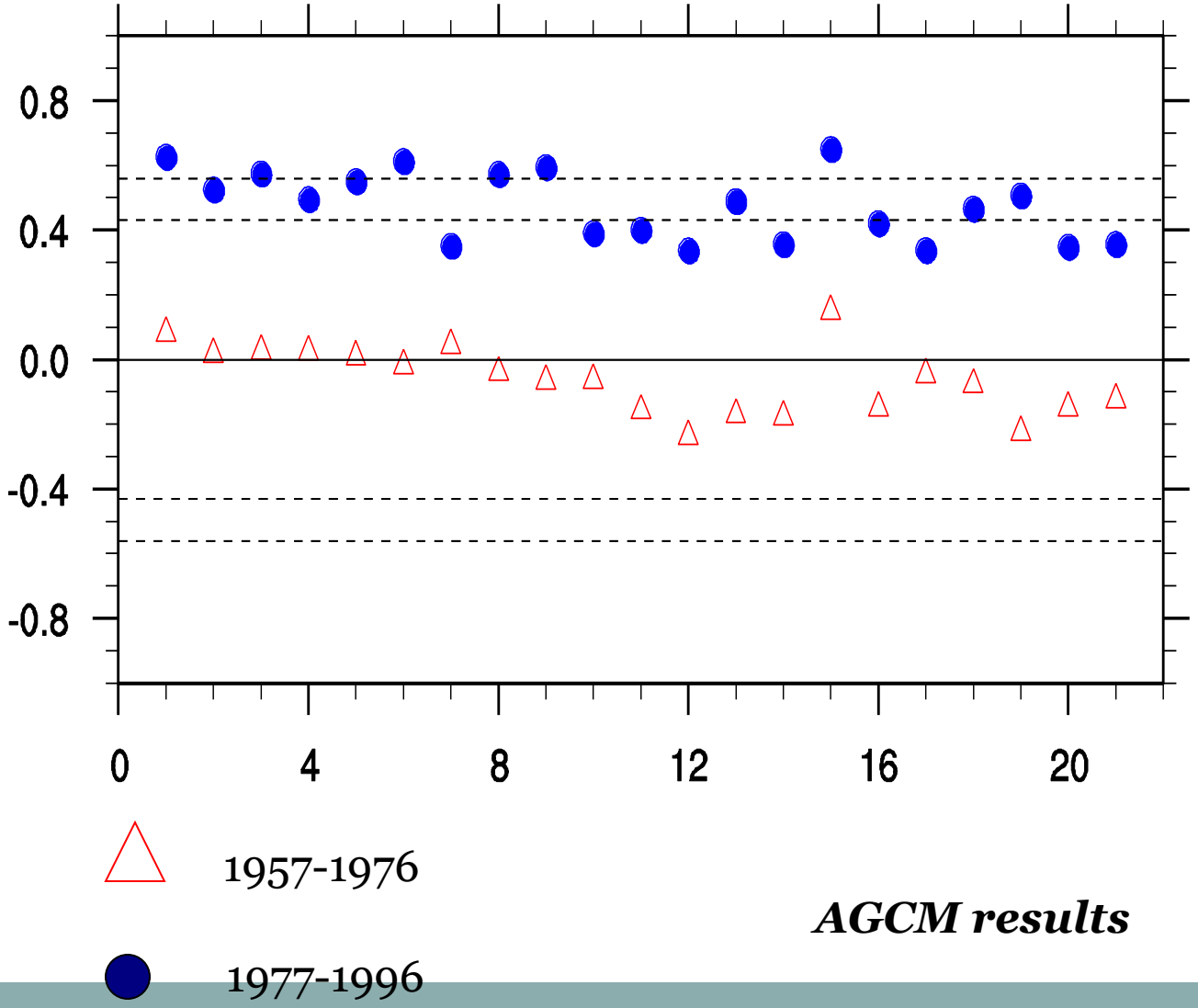
Numerical experiment:

AGCM: Community Atmosphere Model Version 3 (CAM3)

Resolution: T42 resolution (equivalent to 2.8° latitude × 2.8° longitude) in the horizontal and with 23 sigma levels in the vertical.

Experiment: A 21-member ensemble of CAM3 simulations are performed with HadSST observations as surface boundary conditions for a 51-year period of 1950-2000. Each member simulation differs only in the initial conditions.

Correlation coefficients between JJA TIO SST index and WNPSMI in the 21 members CAM3_REAL numerical experiment during 1957-1976 (red triangle) and 1977-1996 (blue dot)



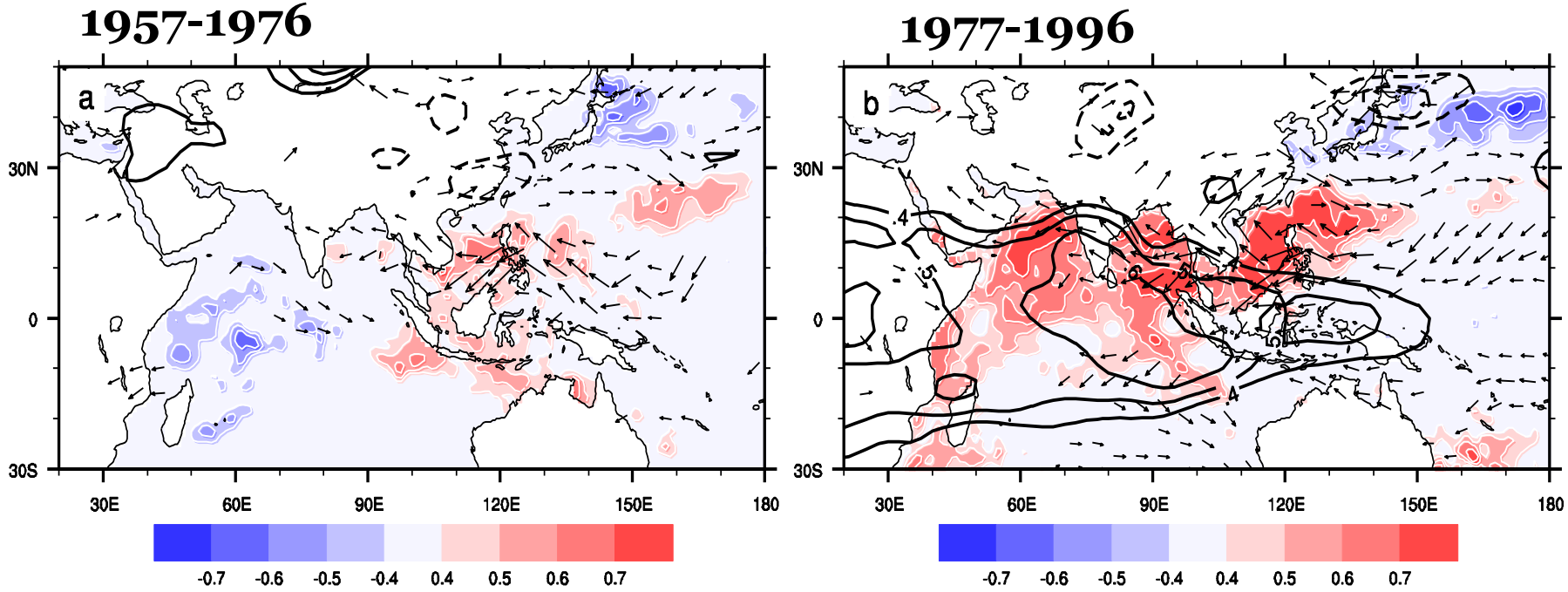
The relationship between TIO and WNPMI have decadal change during the late 1970s in both Observation and model study.

Question ?

Why this climate shift happened in the late 1970s ?

Why the AGCM can simulate this climate shift?

Matsuno-Gill response to TIO Warming during late epoch



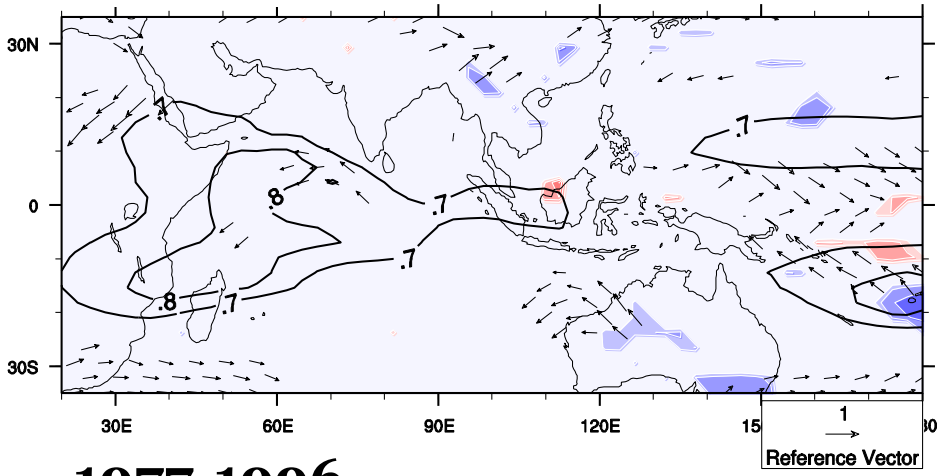
Color shaded: ***WNPMI Cor. SST***

Solid Line: ***WNPMI Cor. Troposphere average temperature (200-850 hPa)***

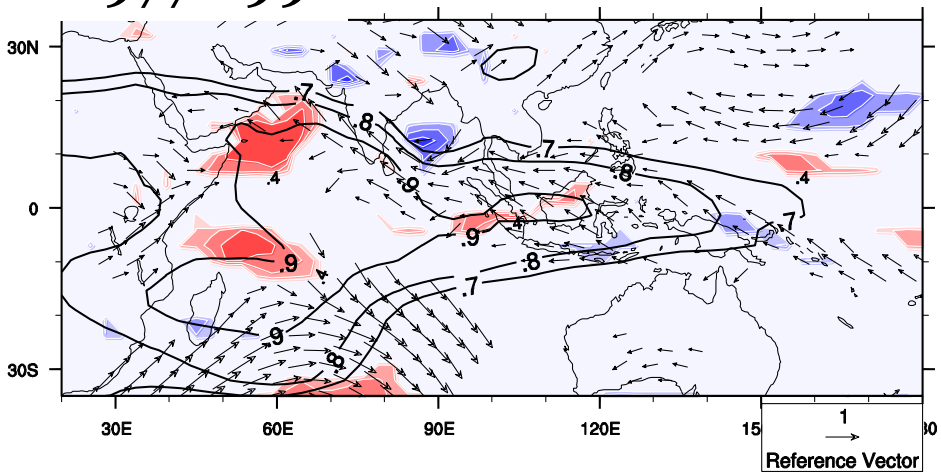
Vector : ***WNPMI Cor. 850 hPa wind***

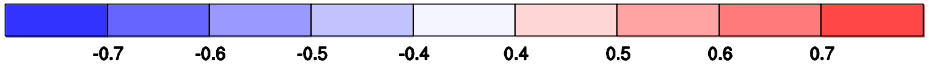
Ensemble mean results

1957-1976



1977-1996





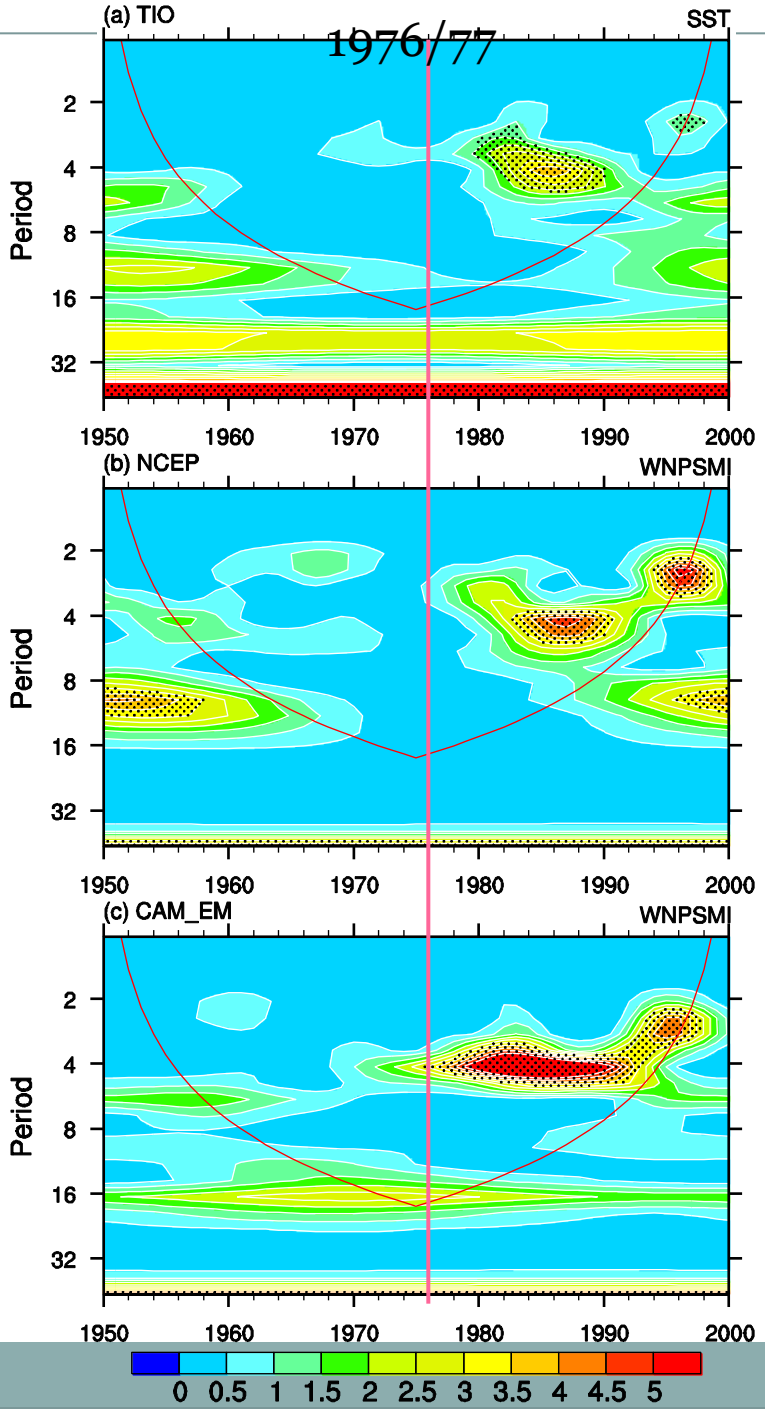
Color shaded: ***TIO Cor. Precipitation***
Solid Line: ***TIO Cor. Troposphere average temperature (200-850 hPa)***
Vector : ***TIO Cor. 850 hPa wind***

The AGCM experiments also reproduce the atmosphere Matsuno-Gill pattern response to Indian Ocean warming during 1977-1996

Tropical Indian Ocean SST

NWP summer monsoon in observation

NWP summer monsoon in simulation

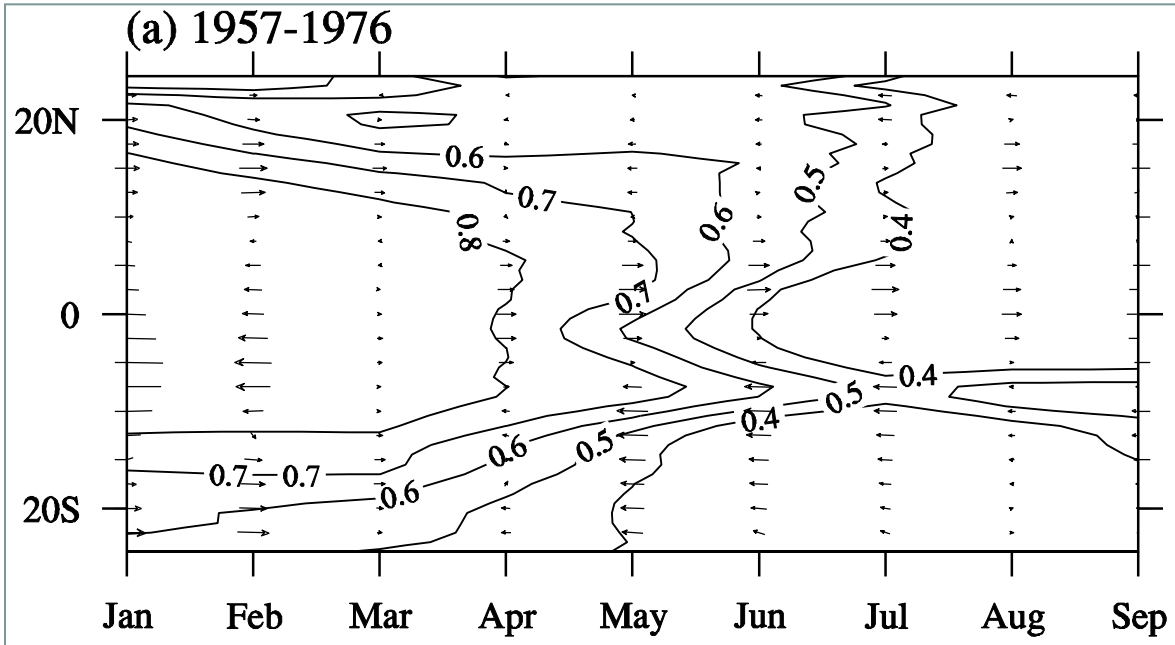


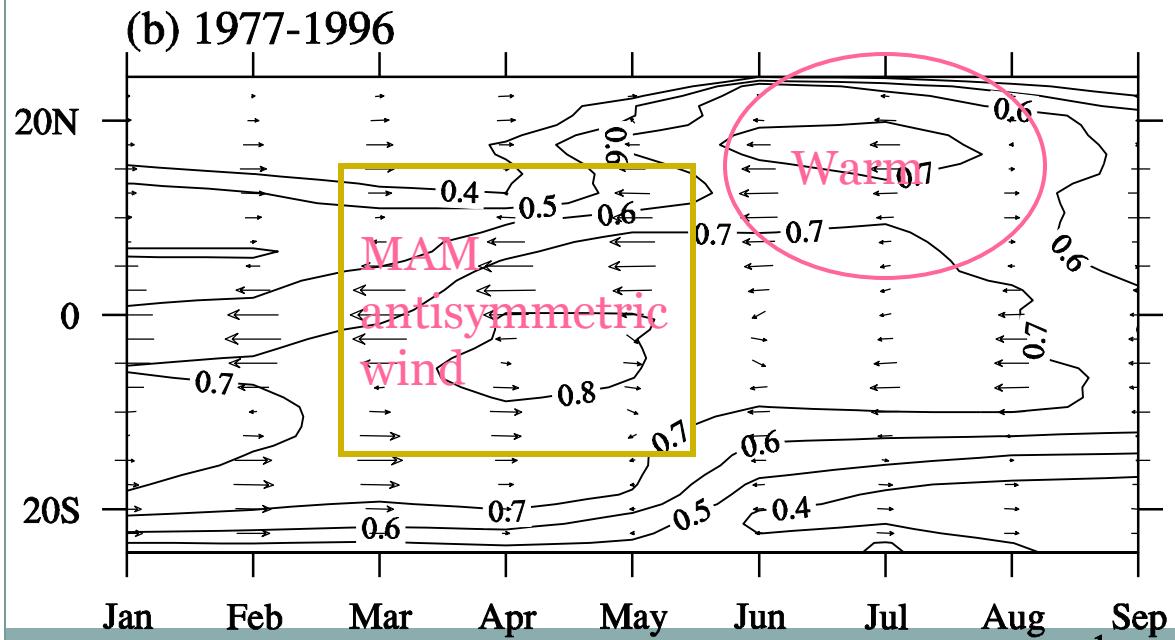
(1) TIO SST variability has experienced a prominent increase in the late 1970s.

(2)There is a concurrent increase in NWP monsoon variability in the same frequency band both for observation and model simulation.

Question:

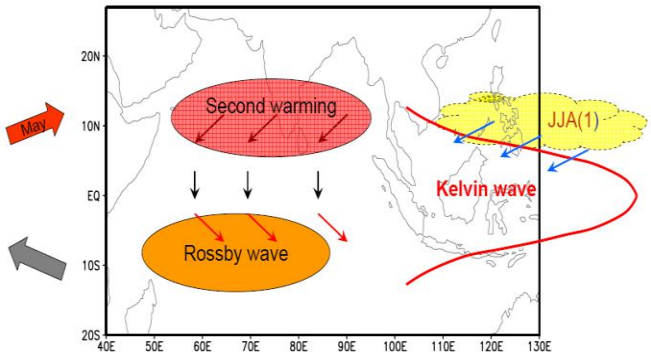
Why the amplitude of TIO SST anomalies in boreal summer are increased after the late 1970s ?



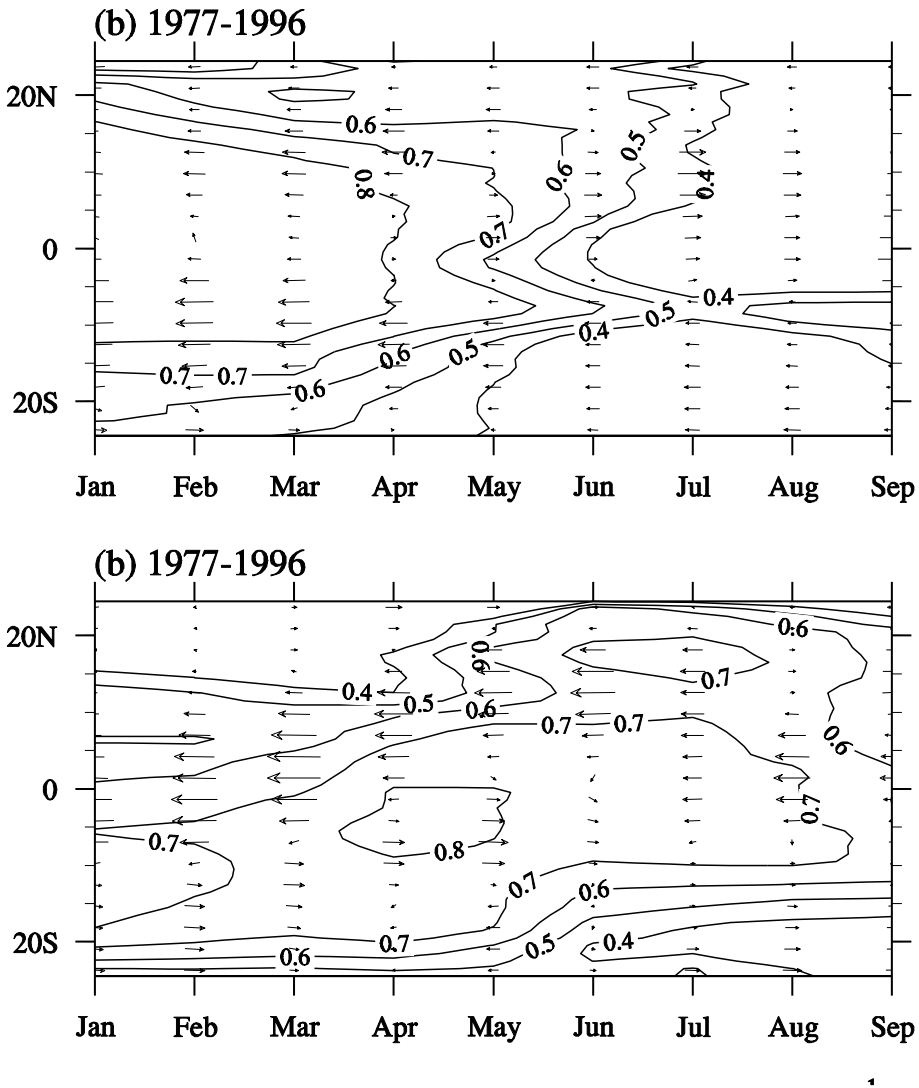


contours:
SST (40-100E average) cor.NINO3.4[DJF(0)]

Vector:
850 hPa wind (40-100E average) cor.NINO3.4[DJF(0)]

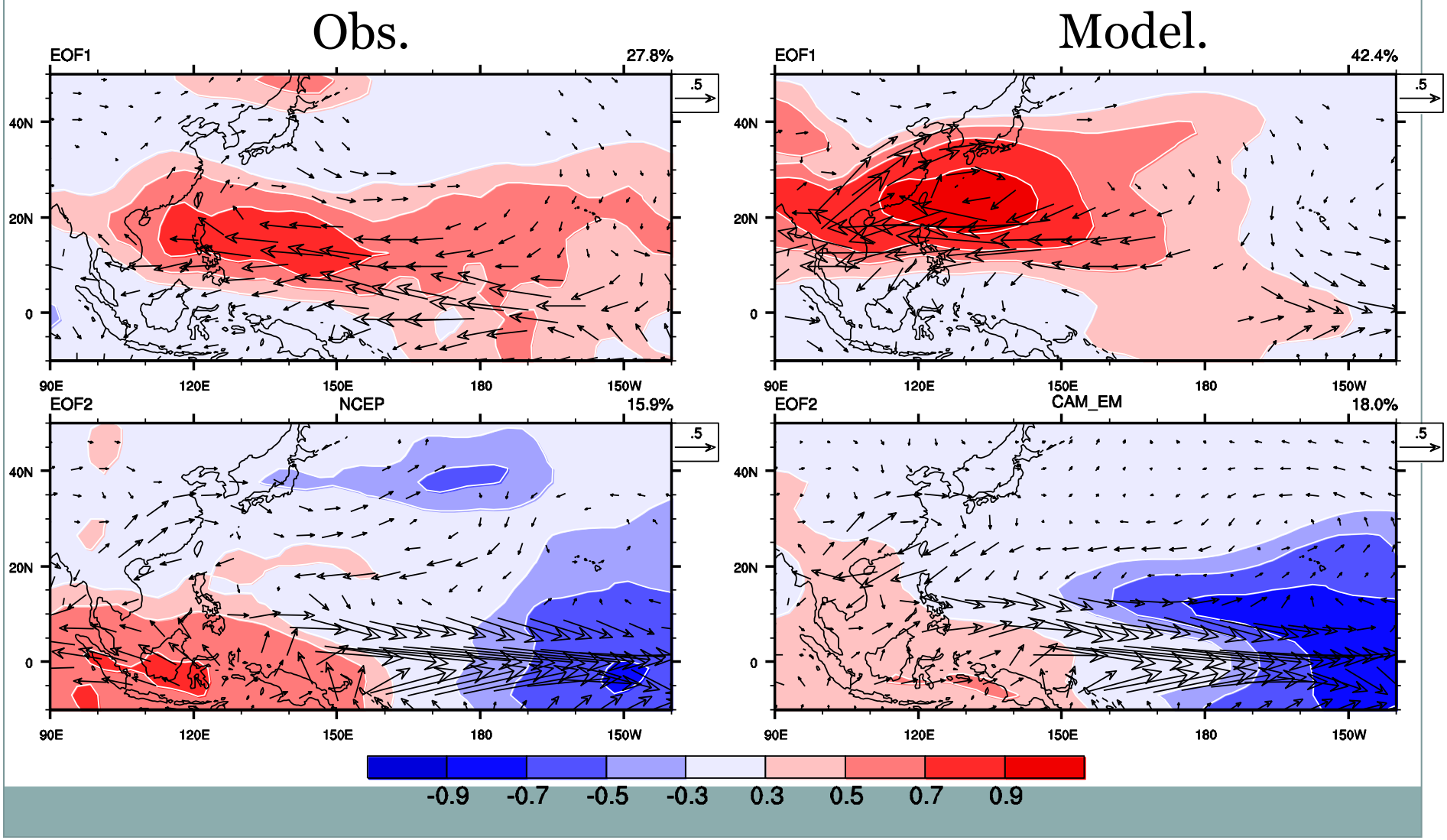


AGCM simulation

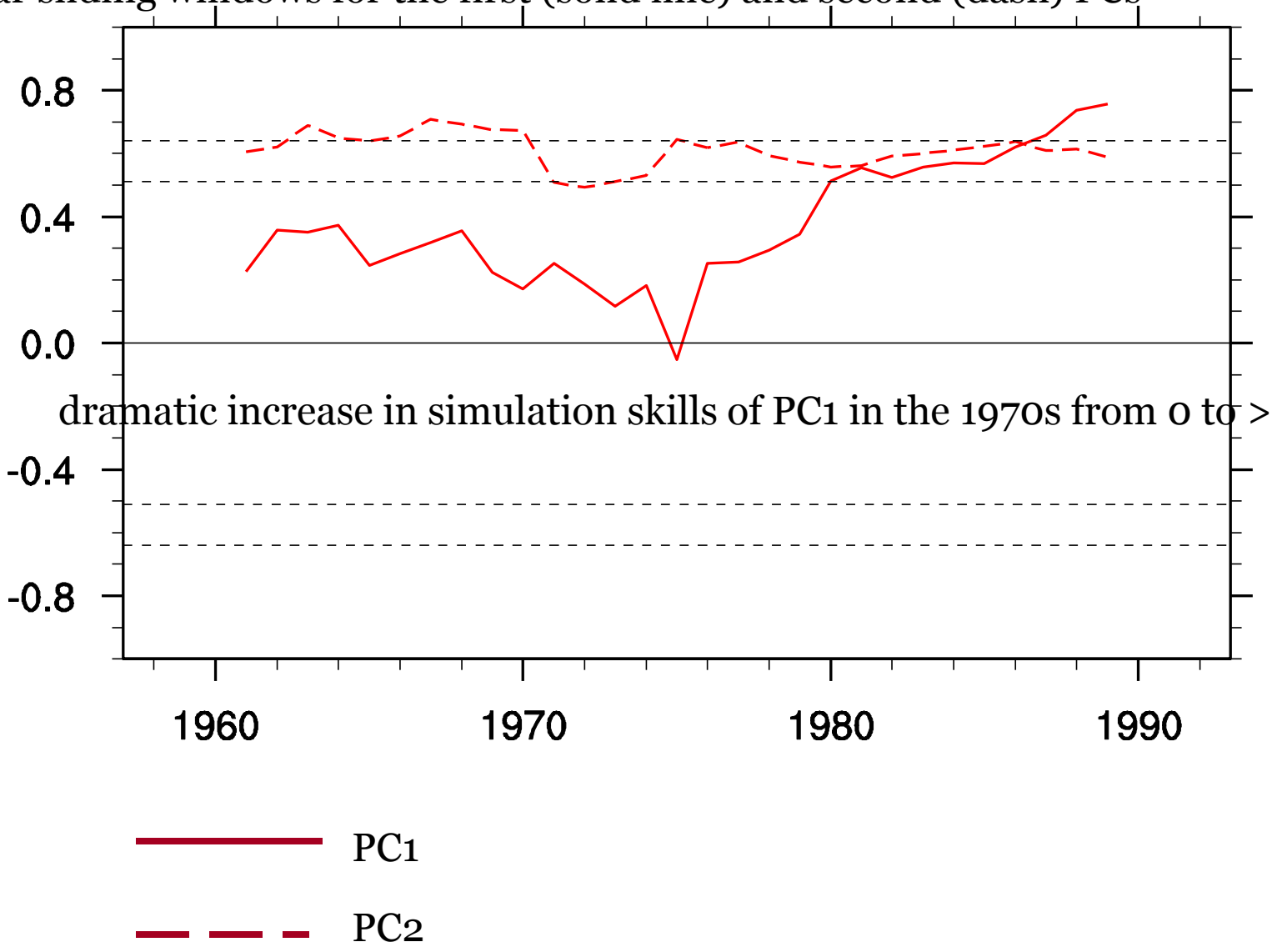


Moreover, this climate shift influence the western North Pacific climate potential predictability.

Correlation of 850 hPa wind vectors and SLP in JJA (June-August) with the leading PCs of 850 hPa wind velocity in (left) observations and (right) the ensemble mean simulation. The domain for EOF analysis covers the Northwest Pacific (90E-180E, 5N-50N).



Correlation between observations and the ensemble mean simulation in 15-year sliding windows for the first (solid line) and second (dash) PCs



dramatic increase in simulation skills of PC1 in the 1970s from 0 to >0.6.

summary

- Observational and model results show that the TIO teleconnection to the NWP strengthens after the mid-1970s, most likely as a result of enhanced variability in summer TIO SST.
- the model's skills in simulating of NWP summer climate displays a pronounced interdecadal change in the late 1970s, low and insignificant before the shift but rising rapidly after 1976/77.

Part2: An interdecadal change in the impact of summer Indian Ocean SST on the western North Pacific summer monsoon in CMIP5 models

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Motivation

The impact of tropical Indian Ocean on the western North Pacific summer monsoon (WNPSM) has experienced interdecadal change in recent decades in observation. (Xie etc,2010 ; Huang etc,2010)

Whether the CMIP5 models can capture the decadal change of tropical Indian Ocean's impact on WNPSM is still unknown.

Data

Historical Run(12 CGCMs)

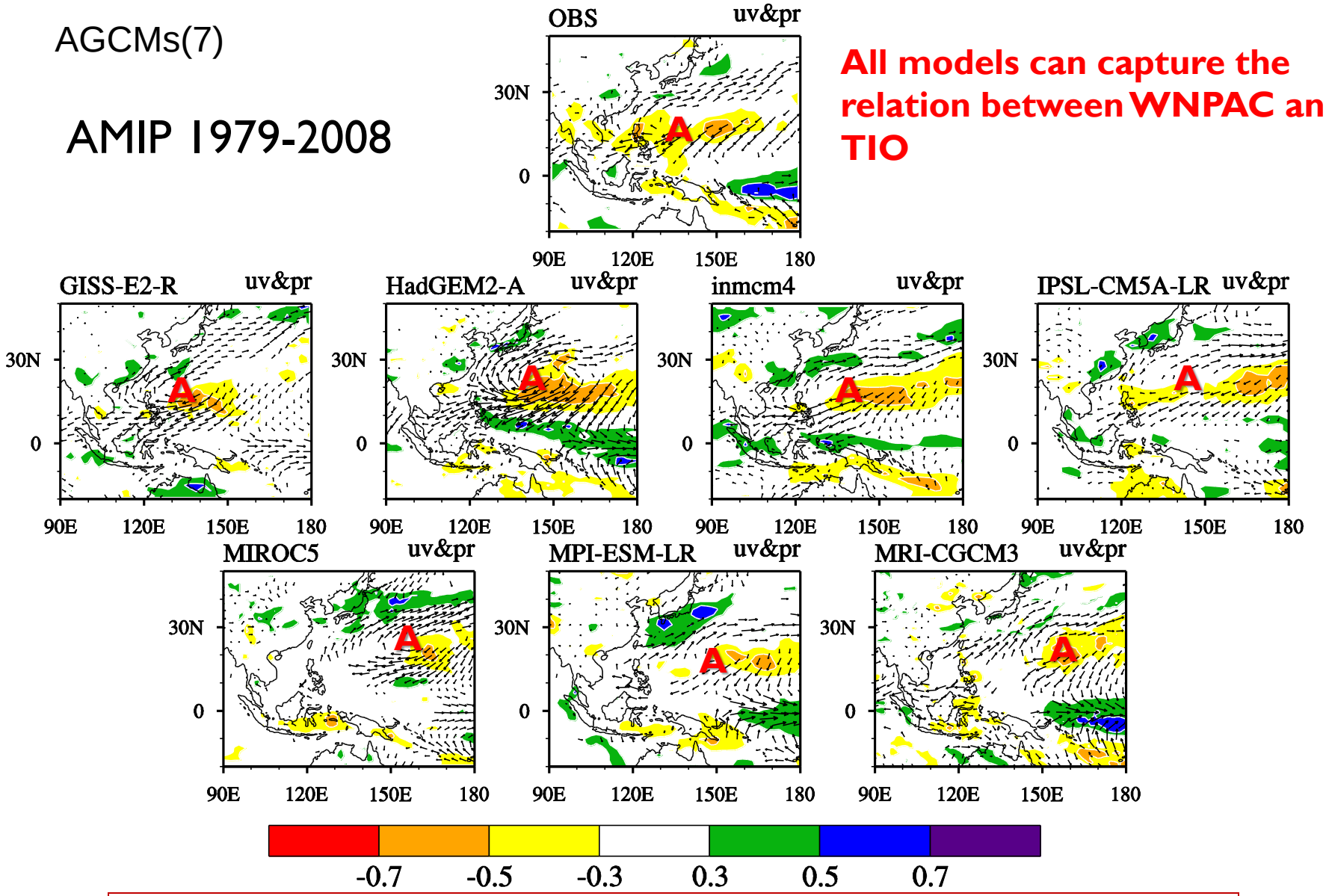
CanESM2	**CSIRO-Mk3-6-0**	**FGOALS-s2**	**GFDL-ESM2M**
GISS-E2-R	**HadCM3**	**HadGEM2-ES**	**inmcm4**
IPSL-CM5A-LR	**MIROC5**	**MRI-CGCM3**	**MPI-ESM-LR**

AMIP Run(7 AGCMs)

GISS-E2-R	**HadGEM2-A**	**inmcm4**	**IPSL-CM5A-LR**
MIROC5	**MPI-ESM-LR**	**MRI-CGCM3**	

AGCMs(7)

AMIP 1979-2008



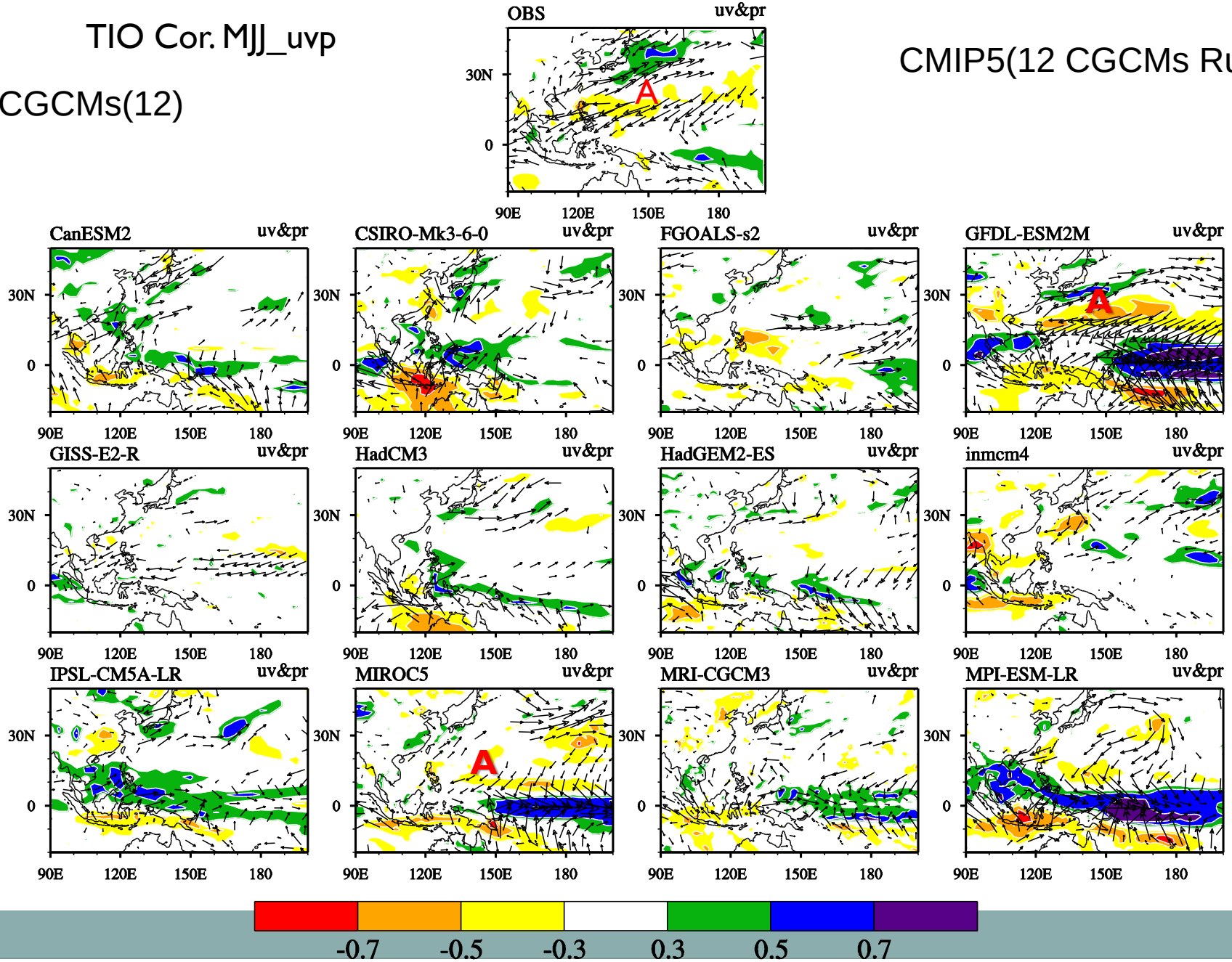
All models can capture the relation between WNPAC and TIO

Colors: MJJ TIO Index correlated with simultaneous precipitation
Vectors: The regression of surface wind on TIO index

TIO Cor. MJJ_uvp

CGCMs(12)

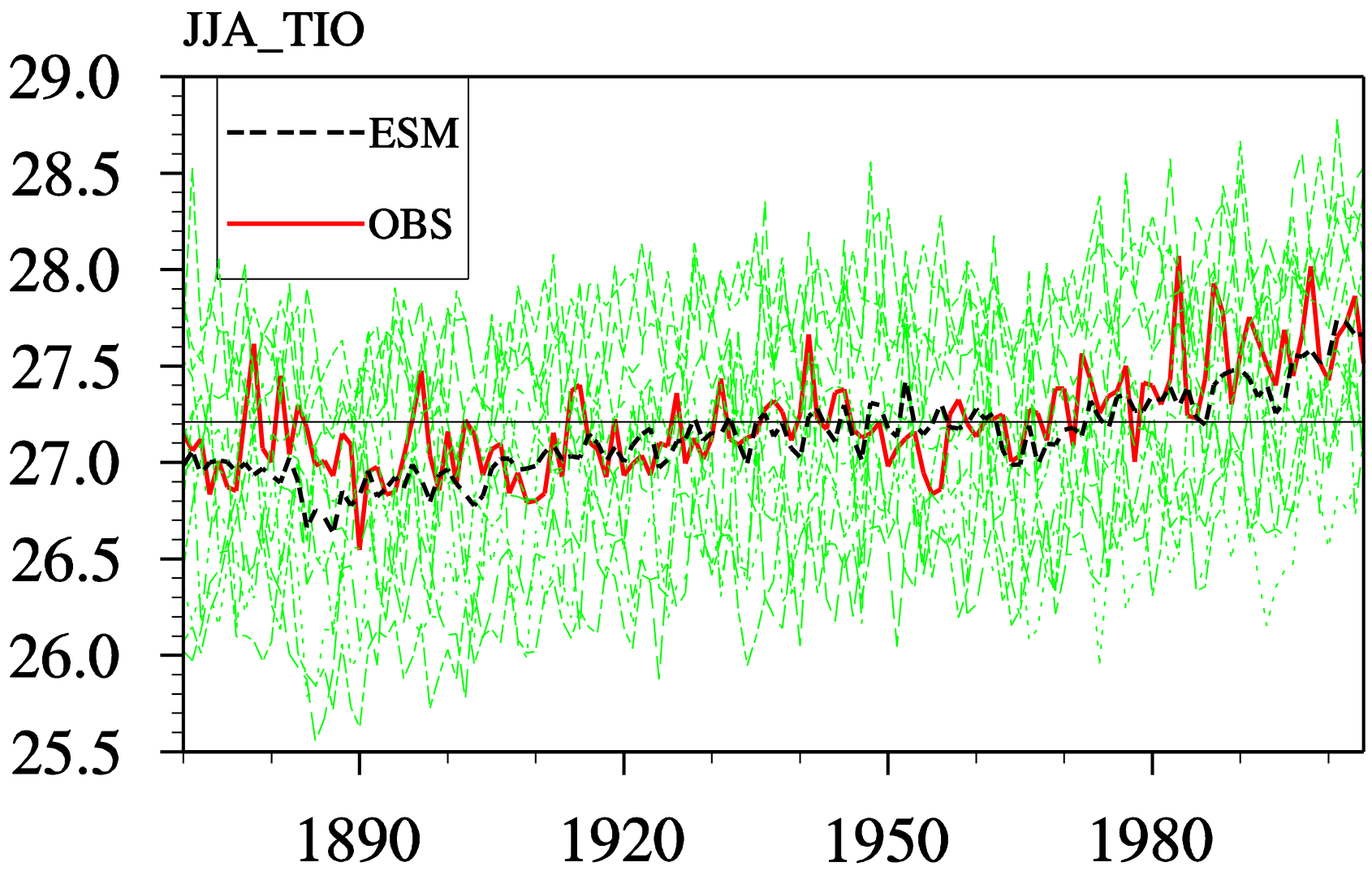
CMIP5(12 CGCMs Run)



But Why AGCMs can capture the WNP anticyclone?

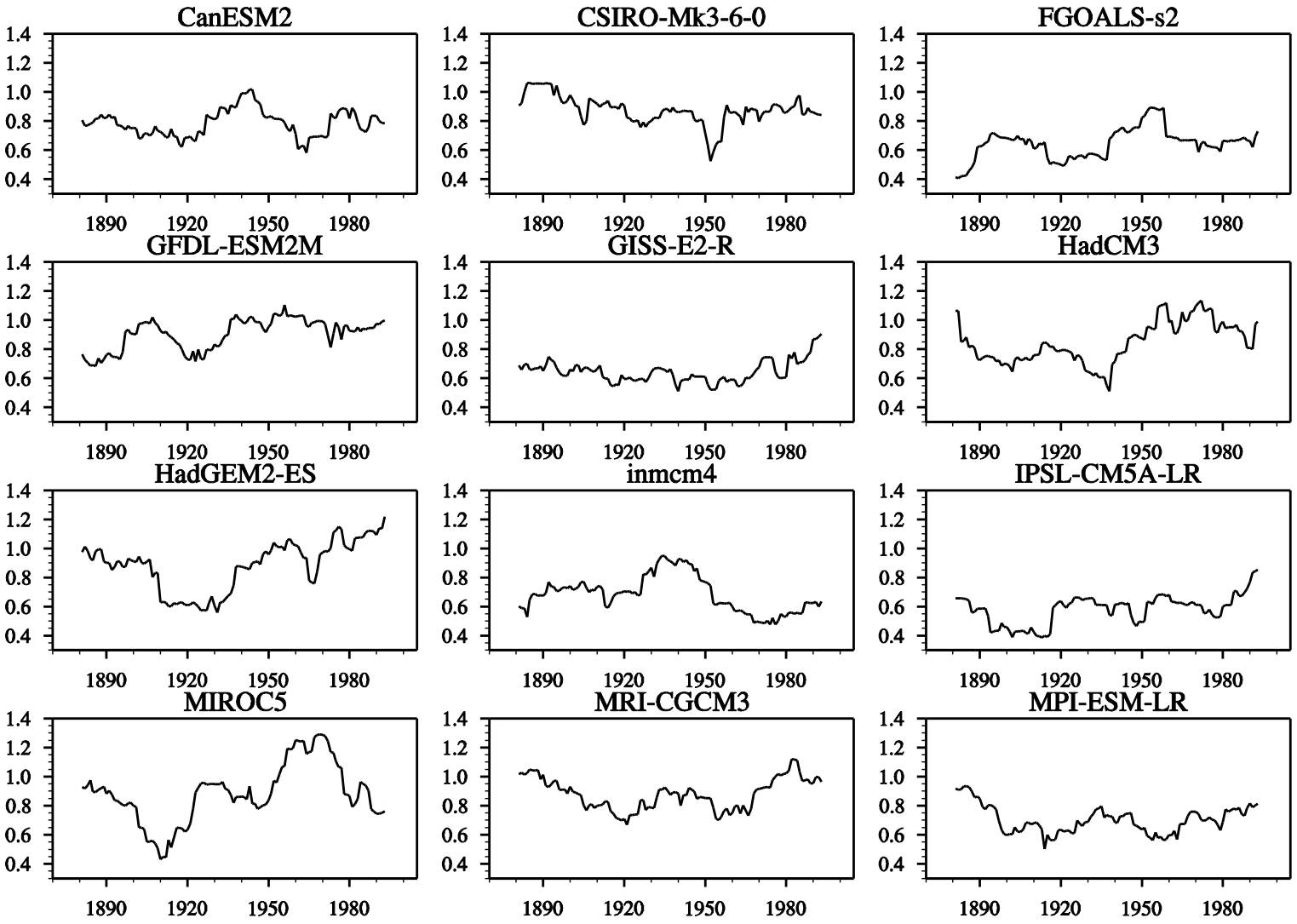
CGCMs difficult to capture the WNP anticyclone ?

Both the observation and the ensemble mean show significant warming trend of TIO in recent decades

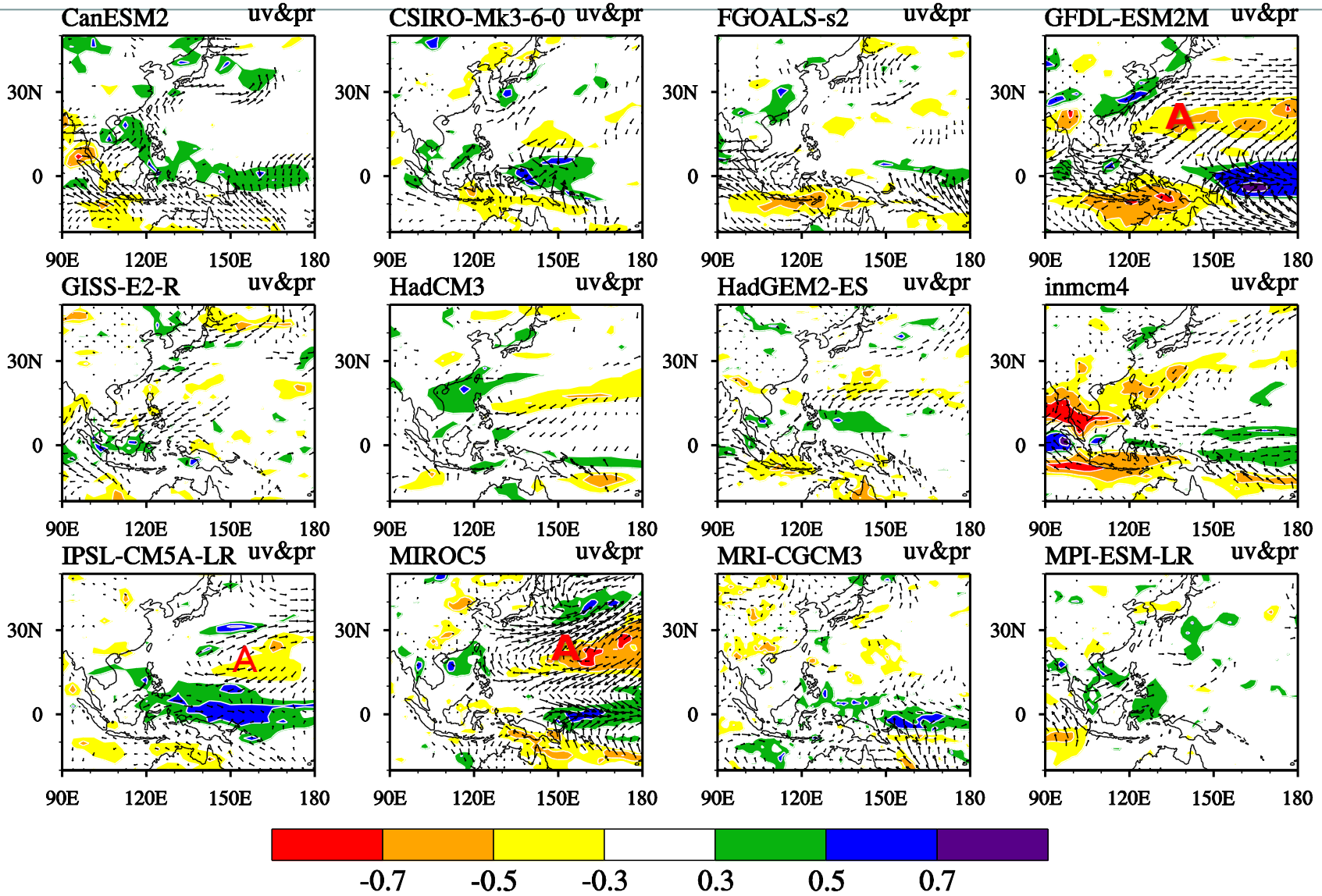


The time series of MJJ TIO index from 1870-2004

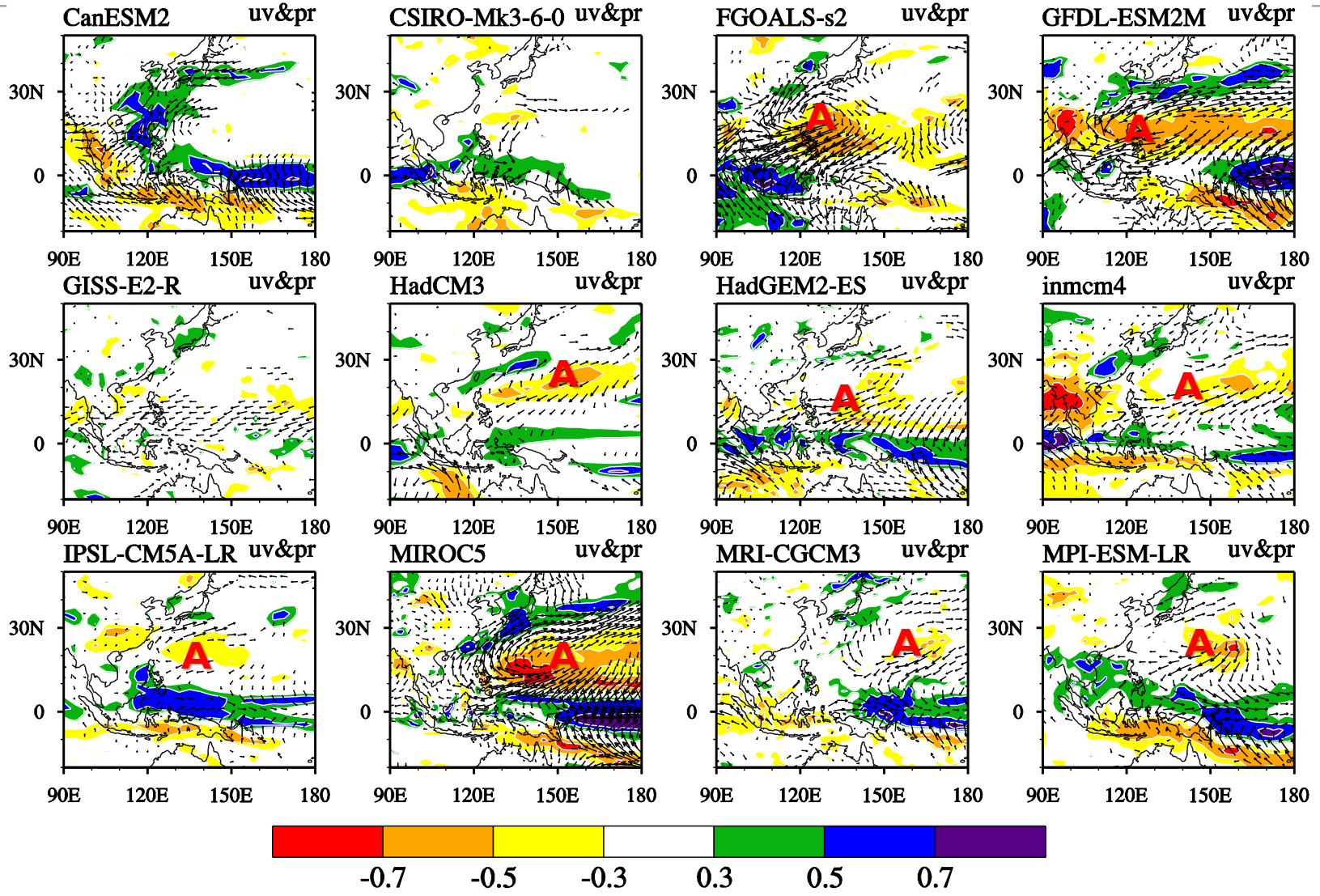
The standard deviation of MJJ TIO index has experienced significant decadal change in each model .



21-year sliding standard deviation of MJJ (May-to-July) TIO index (area mean on the region of 15S-15N, 40-100E) for each model



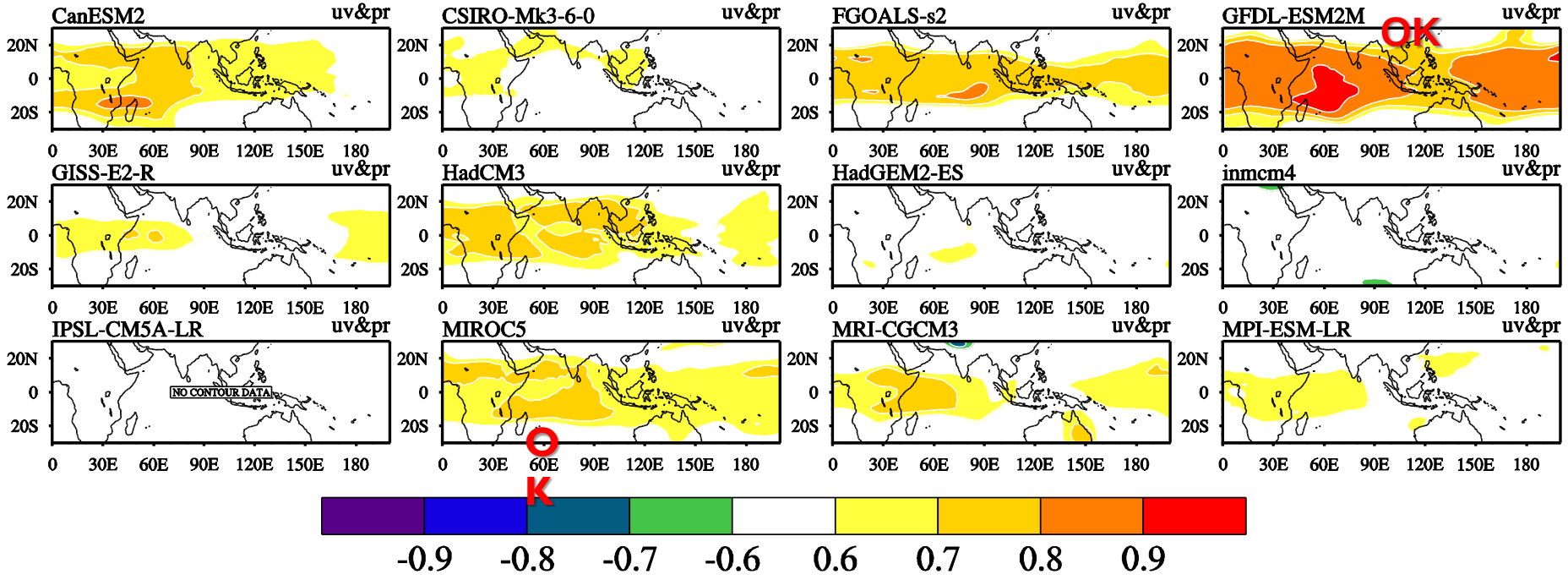
The regression of MJJ surface wind field (vectors, above 90% confidence level) on MJJ TIO index and the correlation of MJJ precipitation (colors) with MJJ TIO index for each model during the period of 21 years with min standard deviation of MJJ TIO



The regression of MJJ surface wind field (vectors, above 90% confidence level) on MJJ TIO index and the correlation of MJJ precipitation (colors) with MJJ TIO index for each model during the period of 21 years with max standard deviation of MJJ TIO

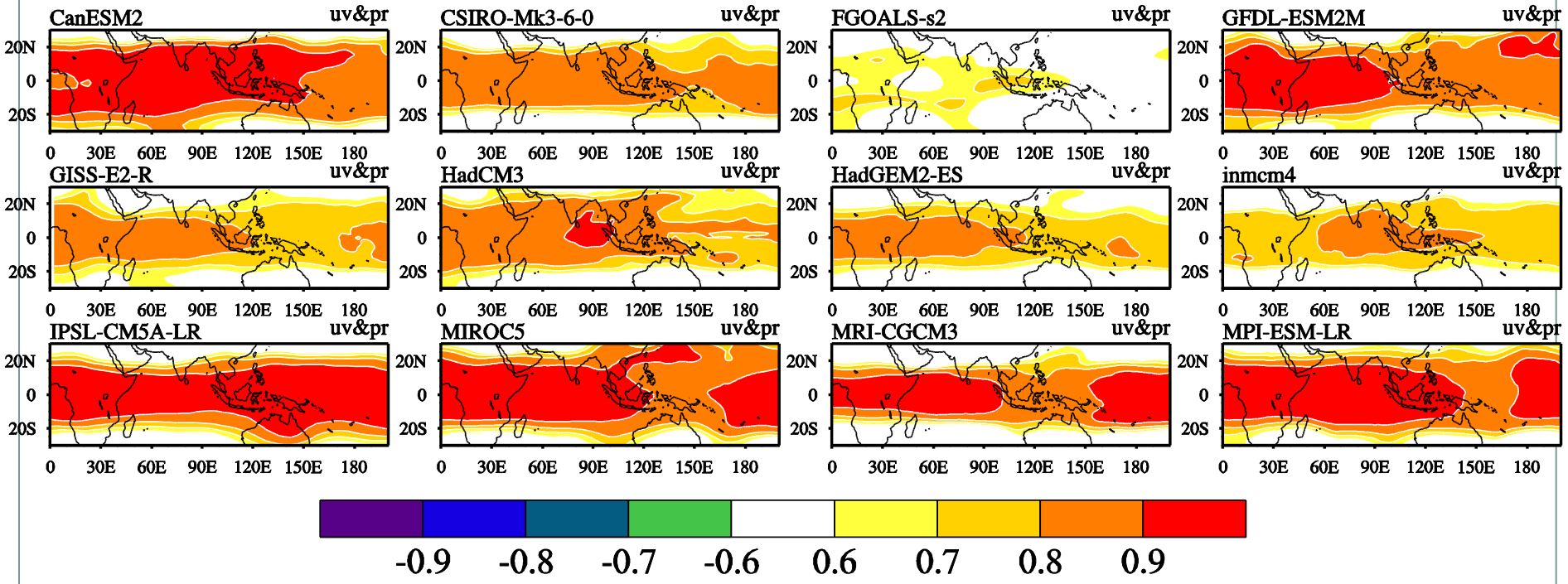
period	The Number of models which capture TIO -related WNPAC
21 years with max standard deviation of MJJ TIO	9
21 years with min standard deviation of MJJ TIO	3

The results suggest that the impact of tropical Indian Ocean on WNP is more significant when the SST standard deviation is large, which are consistent with our previous observation analyses.



The correlation map between MJJ 200 hPa geopotentia height and simultaneous TIO index for each model during the period of 21 years with min standard deviation of MJJ TIO .

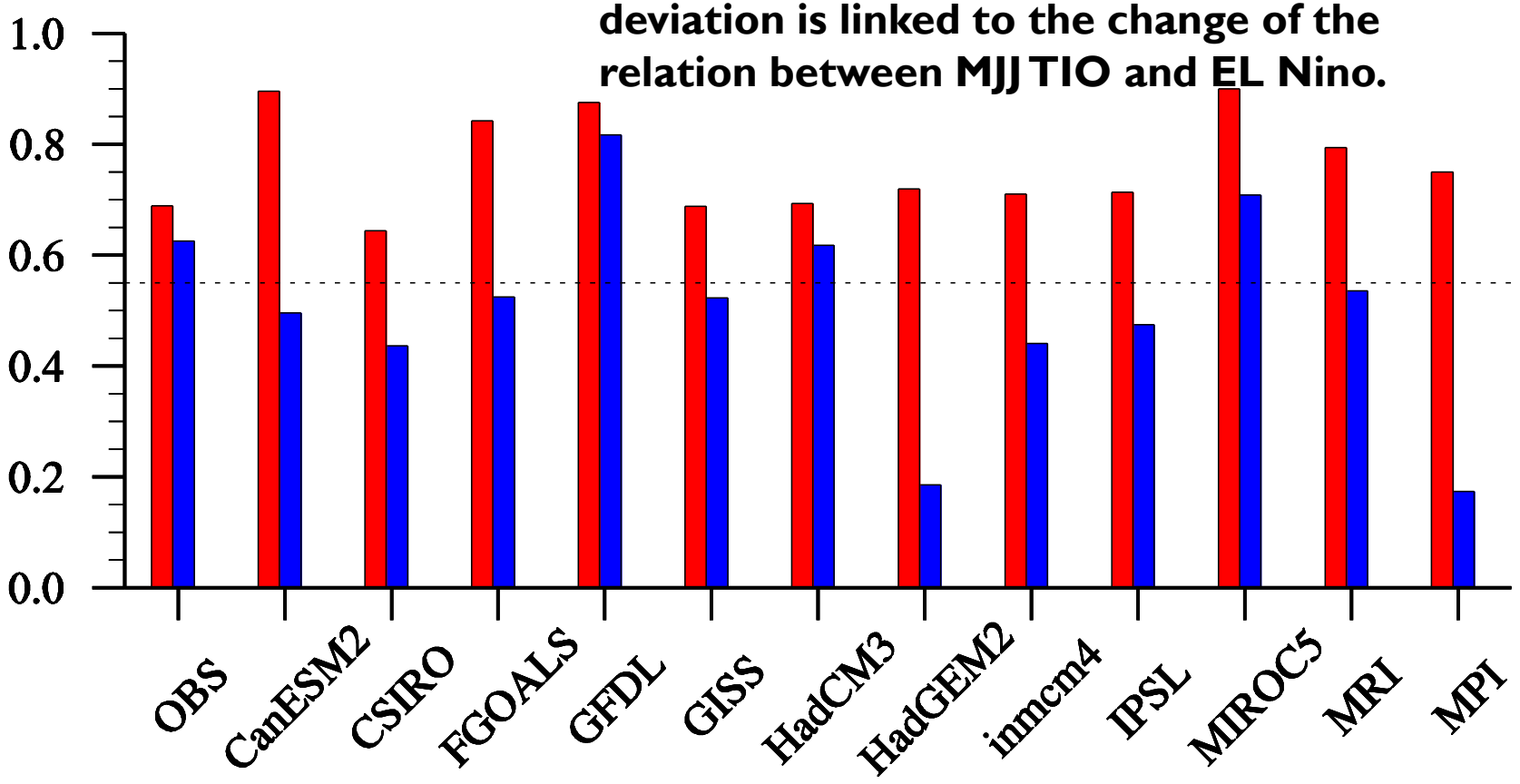
Obviously, the relation between 200hPa geopotential height and TIO are close when TIO have large standard deviation



The correlation map between MJJ 200 hPa geopotentia height and simultaneous TIO index for each model during the period of 21 years with max standard deviation of MJJ TIO .

Red: the period of 21 years with max standard deviation of MJJ TIO
Blue: the period of 21 years with min standard deviation of MJJ TIO

The decadal change of TIO standard deviation is linked to the change of the relation between MJJ TIO and EL Nino.



The correlation between MJJ TIO index and DJF NINO3.4 index in the observation and all models, the dash line denote the 99% confidence level

Summary

- The AMIP simulations can capture the impact of TIO on WNPAC during 1979-2008.
- The standard deviation of MJJ TIO have experience significant decadal change in most models of historical simulation.
- The impact of TIO on MJJ WNPAC are more significant when TIO have large standard deviation.
- The decadal change of TIO standard deviation is linked to the change of the relation between MJJ TIO and EL Nino.

- The above results suggest that the relation between ENSO and summer tropical Indian SST have experienced decadal change in most couple models. And the response of tropical Indian Ocean SST to ENSO can modulate the connection from ENSO to summertime WNP climate.

Acknowledgments. This work was supported in part by National Basic Research Program of China 2011CB309704, 2012CB955604 and Chinese Academy of Sciences， Grant No. XDA05090101

全球变化研究国家重大科学研究计划
太平洋印度洋对全球变暖的响应及其对气候变化的调控作用
The response of the Ind-Pacifec Oceans to global warming and their role in climate change
项目编号：2012CB955600

Part3: Coupled ocean-atmosphere dynamics of global warming

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Institute of Atmospheric Physics, CAS

Flood and Drought are major climatic Disaster.

Ocean-atmosphere dynamics plays a significant role in understanding precipitation change under global warming.

Outline

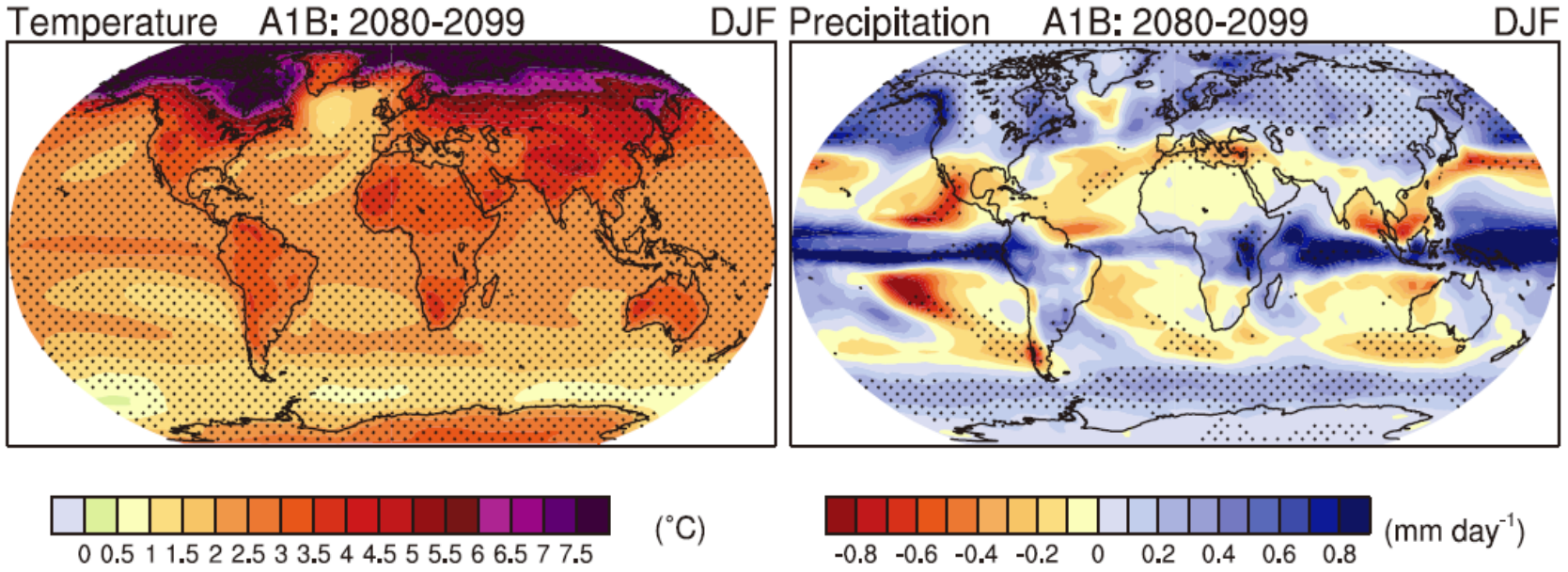
- Patterns of The Seasonal Tropical Rainfall to Global Warming
- Response of the Indian Ocean mode to global warming
- summary

In a warmer world, extreme precipitation events over wet tropical regions will are very likely to be intensified and more frequent by the end of this century (IPCC-AR5). But what determines the pattern of tropical precipitation change?

Temperature warming is not uniform, and precipitation change is to first order spatially variable.

Two views concerning tropical rainfall change:

- Wet gets wetter (IPCC); (SST uniform increase)
- Warmer gets wetter (CLIVAR). (sst nonuniform increase)

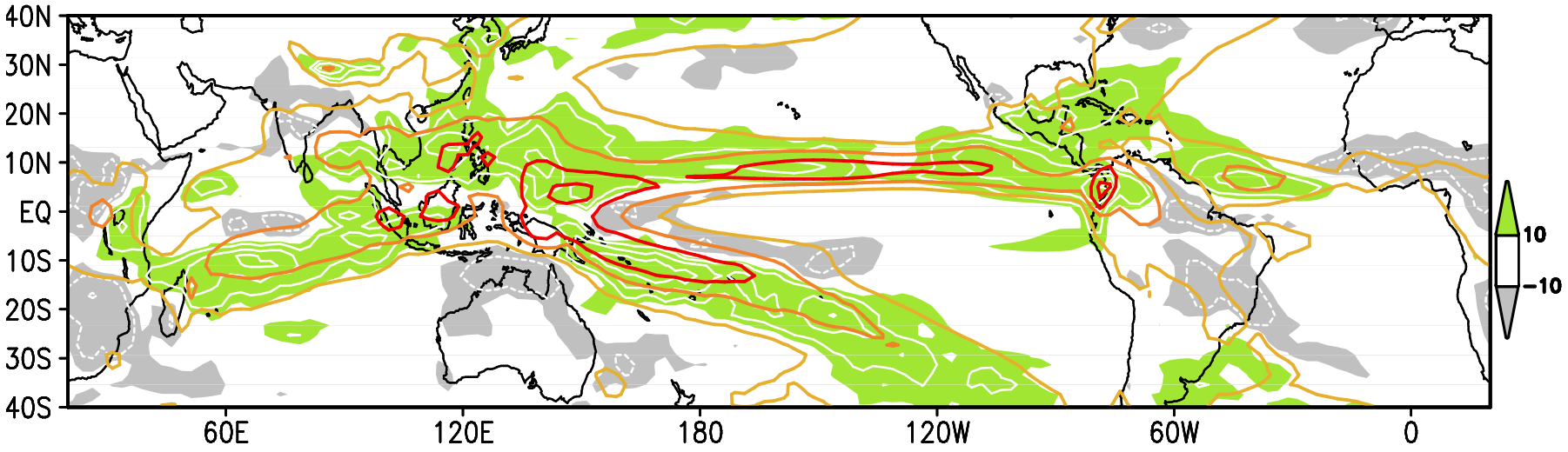


A1B multi-model ensemble mean (IPCC AR4, 2007)

The wet-get-wetter pattern (e.g., Neelin et al. 2003; Held & Soden 2006) if SST warming is uniform.

But what about in coupled simulations with patterned warming?

Xie, S.-P., C. Deser, G.A. Vecchi, J. Ma, H. Teng, and A.T. Wittenberg, 2010: Global warming pattern formation: Sea surface temperature and rainfall. *J. Climate*, 23, 966-986.



2K uniform SST warming: mean (contour) and change of precipitation

→ Wet-get-wetter pattern

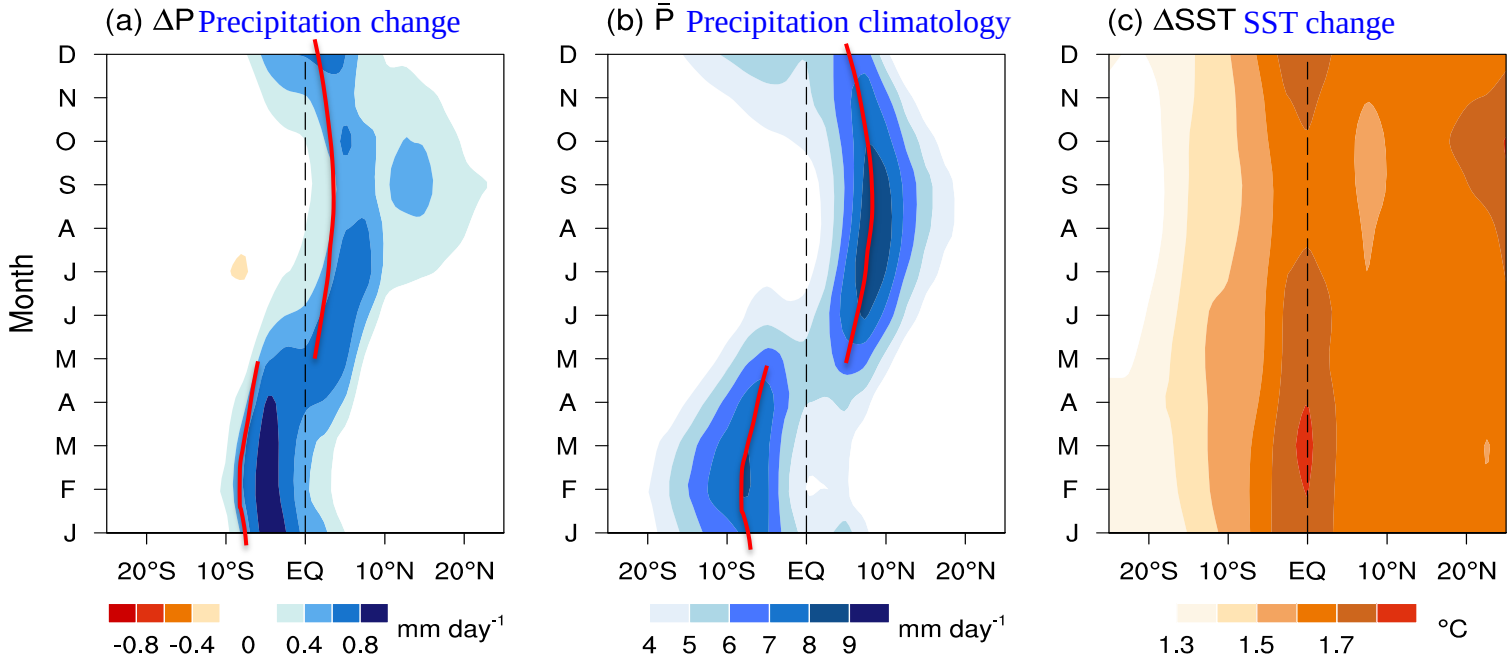
Patterns of the seasonal response of tropical rainfall to global warming

nature geoscience

Ping Huang[1]*, Shang-Ping Xie[2,3,4]*, Kaiming Hu[1], Gang Huang[5] and Ronghui Huang[1]

The seasonal precipitation response: hybrid of WeGW & WaGW

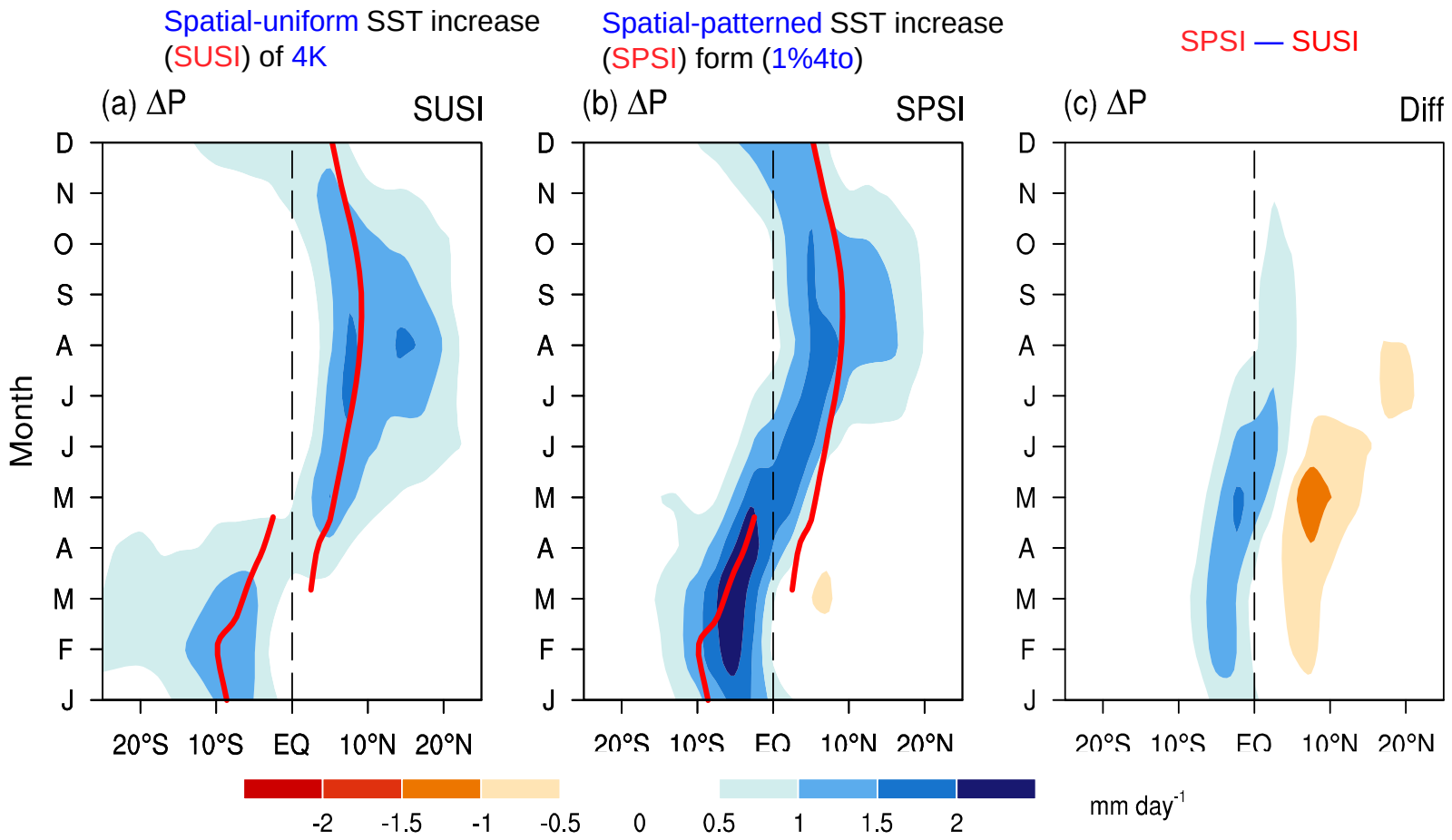
- The anomalous rain band moves back and forth across Equator. (unlike ΔSST);
- The peak of SST warming anchors a band of anomalous ascent and rainfall increase near the Equator.



Seasonal cycle of precipitation and SST change. The red curve marks the latitude of the maximum in mean precipitation

To isolate SST change effect , analyzing a pair of atmospheric experiments in CMIP5 (prescribed A1B ΔSST).

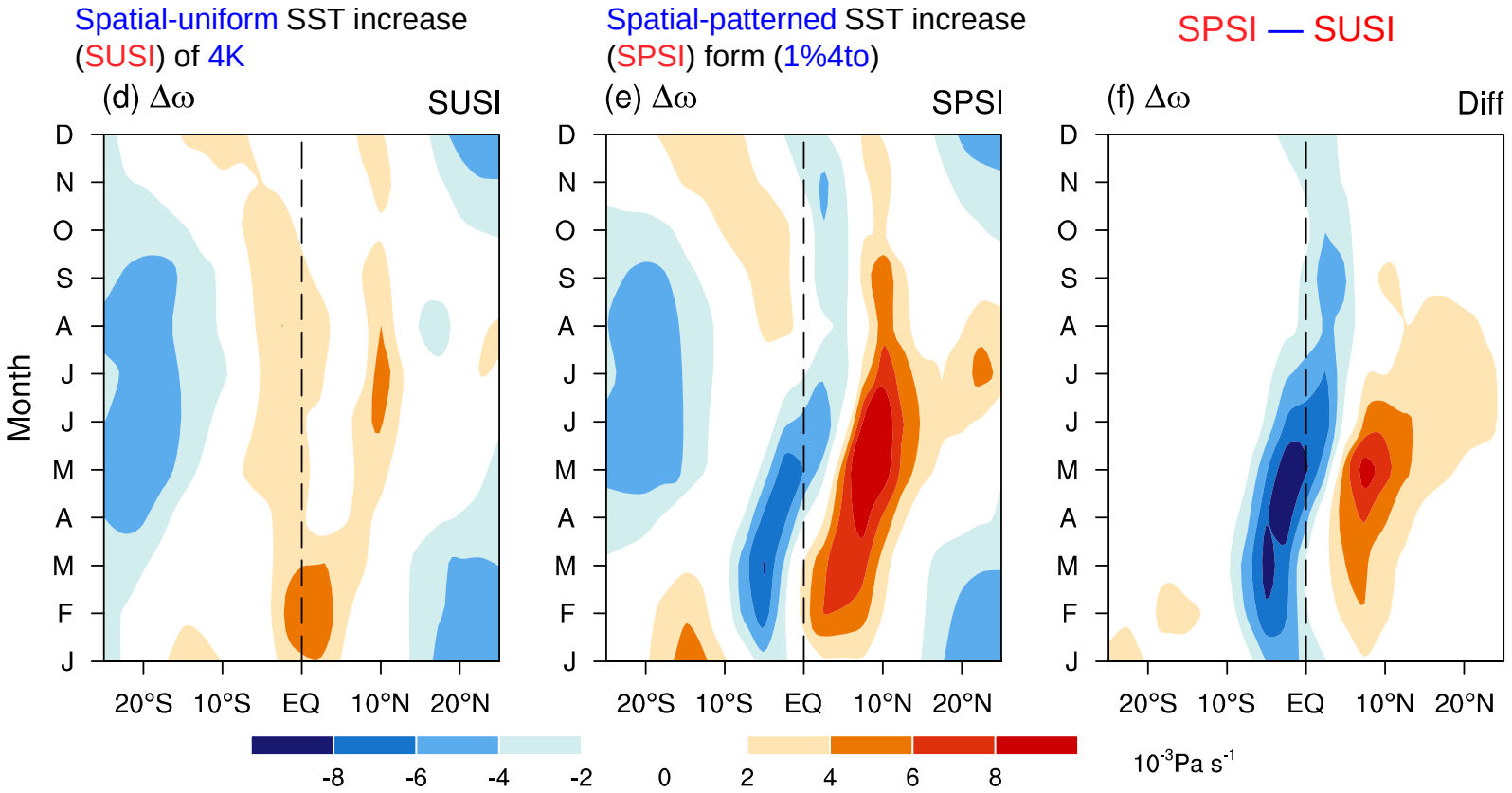
- WeGW (SUSI):a band of increased precipitation marches across the Equator following precipitation climatology, and the peak of precipitation change coincides with that of precipitation climatology.
- The SST warming pattern used in the SPSI run with an equatorial peak due to ΔSST effect.



Seasonal cycle of precipitation change in SUSI and SPSI runs. The Red line marks the latitude of the Climatological precipitation maximum in the control.

Atmospheric GCM experiments (prescribed SST)

- $\Delta\omega$ broadly represents a weakening of tropical circulation in SUSI as required by a muted response of global precipitation;
- $\Delta\omega$ is greatly enhanced near the Equator owing largely to the SST pattern in SPSI.



Seasonal of cycle of circulation change in SUSI and SPSI. $\Delta\omega$ denotes pressure velocity at 500hpa.

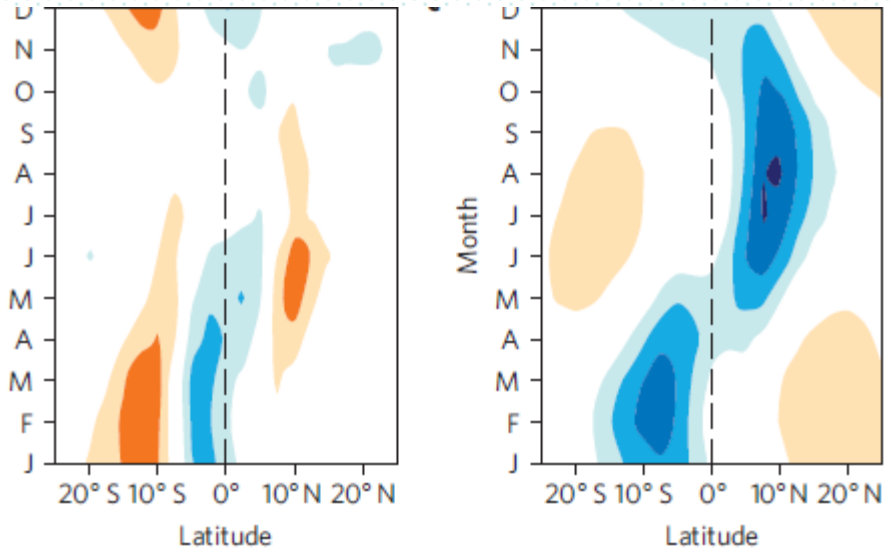
Warmer-get-wetter

Wet-get-wetter

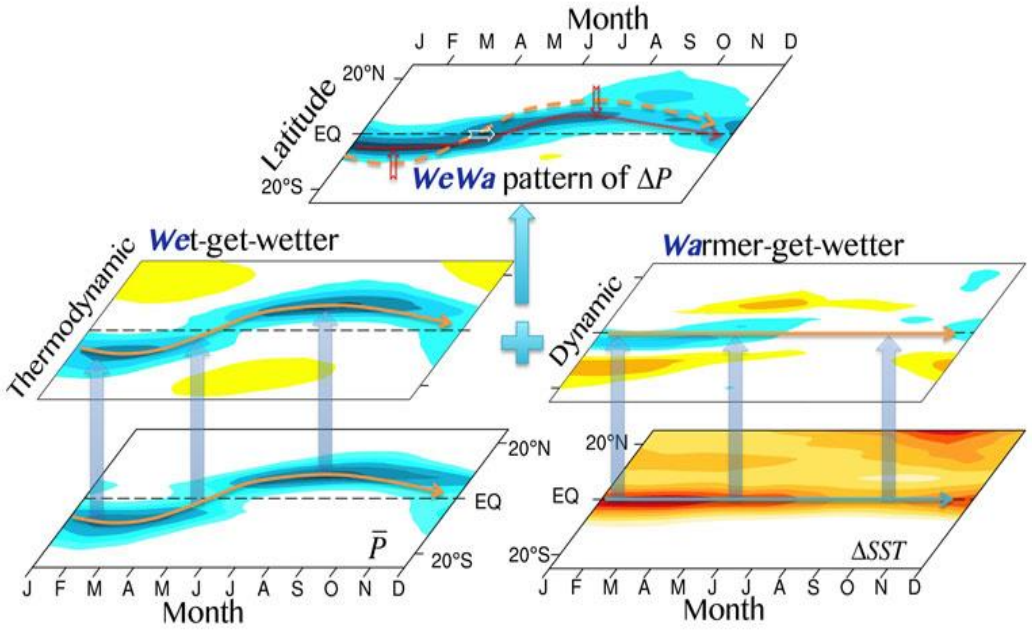
Dynamic component

Thermodynamic component

$$\Delta P \sim \Delta\omega \cdot \bar{q} + \bar{\omega} \cdot \Delta q$$



Decomposition of precipitation change.

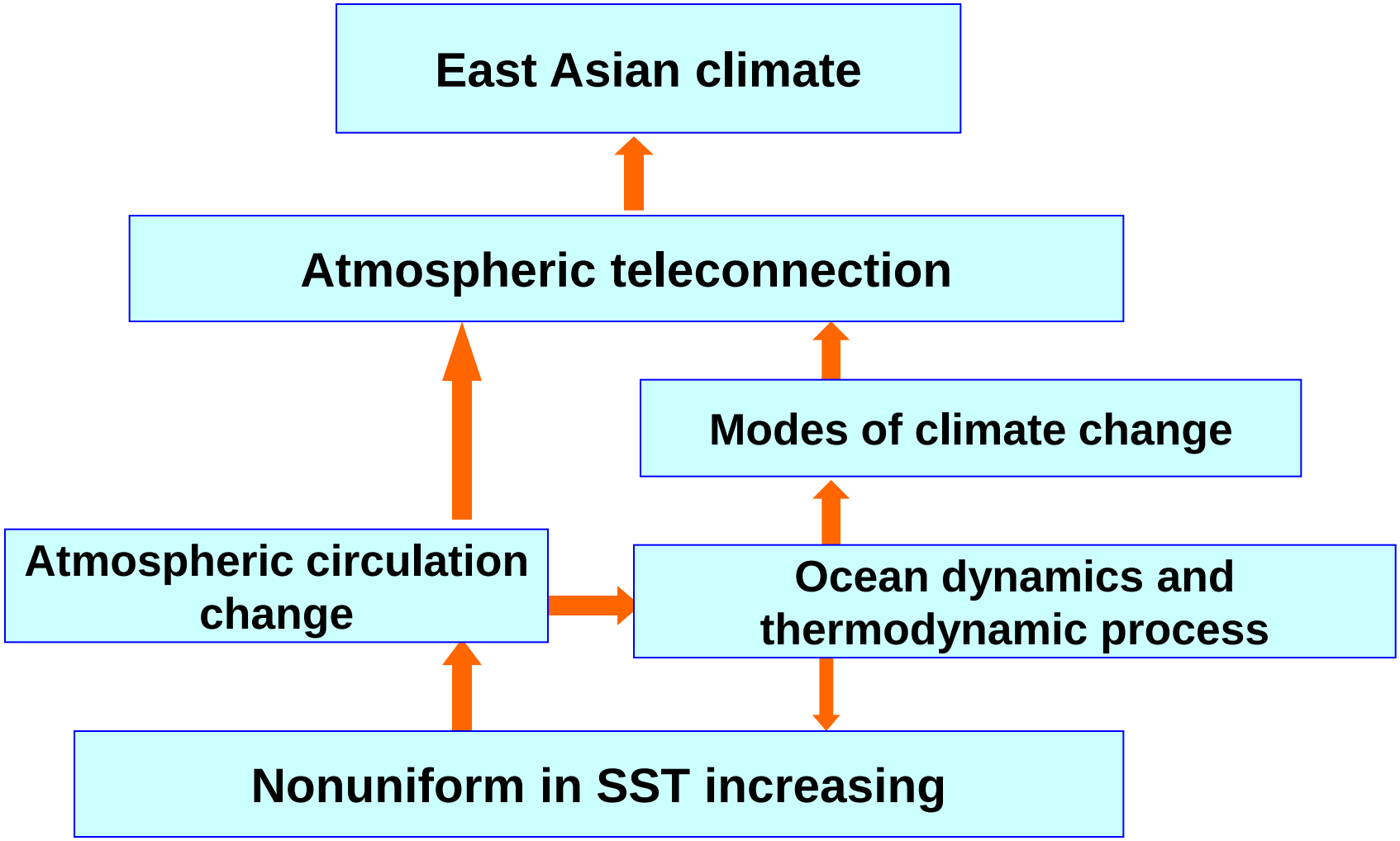


Schematic of tropical precipitation change response to global warming.

The two effects are not mutually exclusive but complementary and the combined WeWa view best explains the seasonal precipitation change in the tropic.

Annual mean precipitation follows WaGW but the WeGW mechanism dominates in seasonal mean.

Scientific Rationale

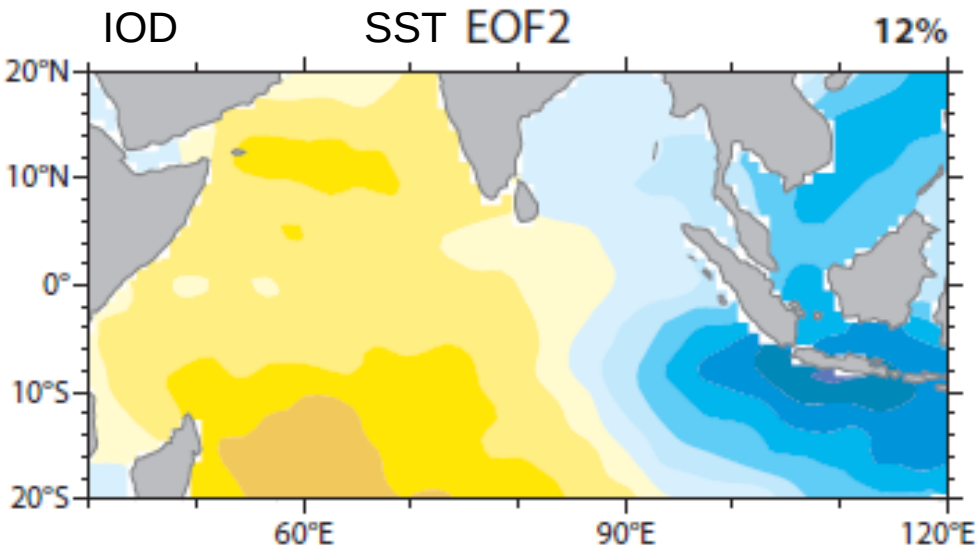


What will IOD mode experience under global warming?

Response of the Indian Ocean Dipole mode to global warming

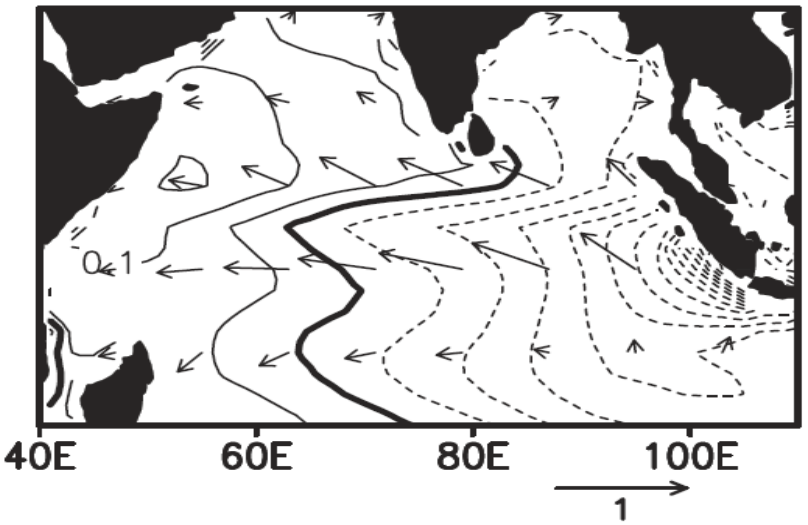
Zheng, X.-T., S.-P. Xie, Y. Du, L. Liu, **G. Huang**, Q. Liu, 2013: *Journal of Climate*

The spatial pattern of the IOD mode is also comparable with observations in modes, exhibiting an east-west dipole pattern associated with easterly wind anomalies along the equator.



Observations: IOD mode of SST anomalies

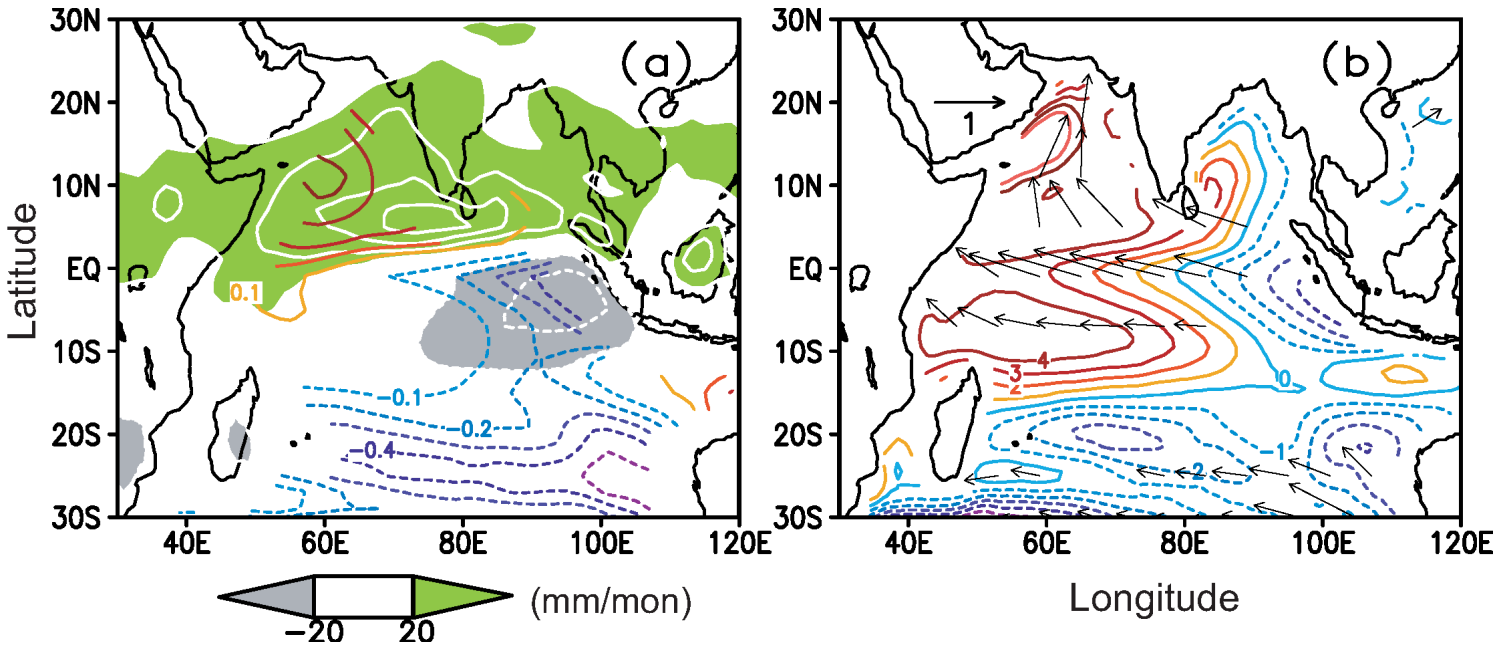
CMIP5 multi-model ensemble

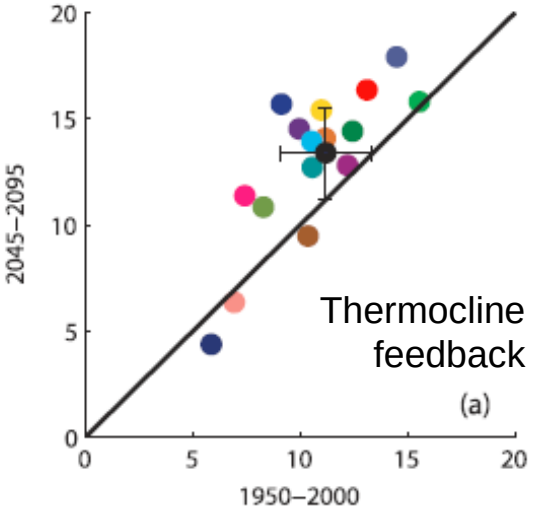


Simulations: regressions of SST and surface wind anomalies(vectors) upon the IOD PC

SST & Precipitation change

Sea surface height & wind





Scatterplots of thermocline feedback between 1950-2000 and 2045-95.The black dot denotes the ensemble mean.

IOD-like mean state change

↓

Enhanced thermocline feedback

The IOD-like mean state changes modulate interannual modes and the recent changes in IOD mode are likely due to natural variations.

IOD-like mean state change

Enhanced thermocline feedback

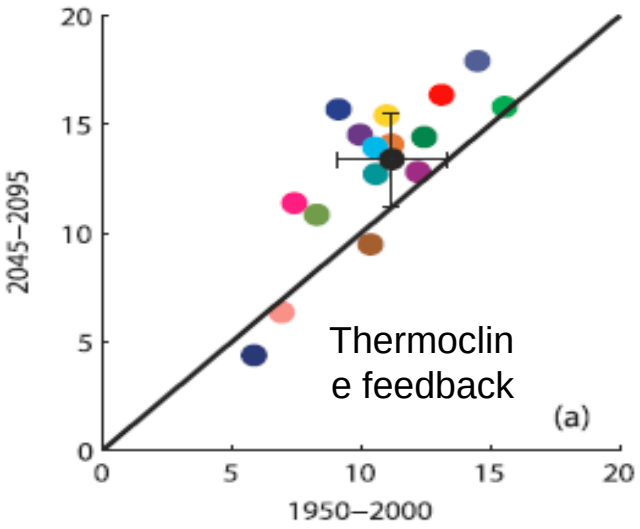
Enhanced atmospheric stability

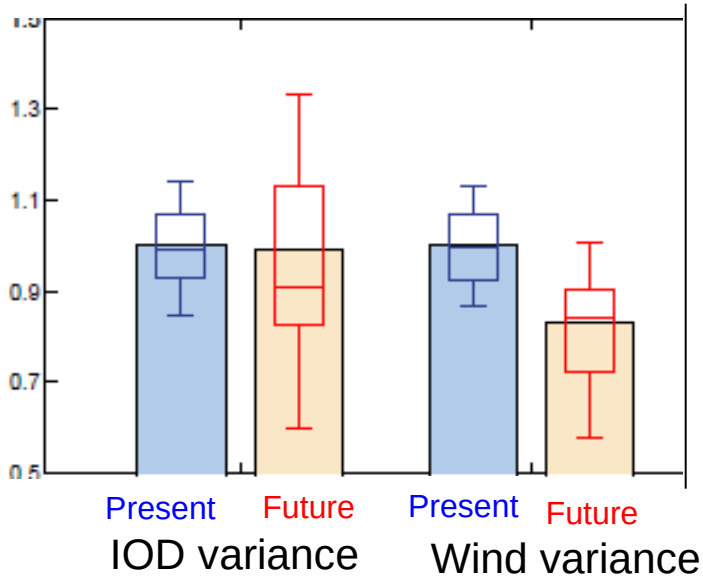
Reduced wind feedback

?

IOD variance in SST remains unchanged

The shoaling thermocline in the eastern EIO leads to a strengthened thermocline feedback, enabling subsurface temperature anomalies to affect SST more effectively. The atmospheric response weakens, counteracting the stronger thermocline feedback due to a shoaling thermocline.



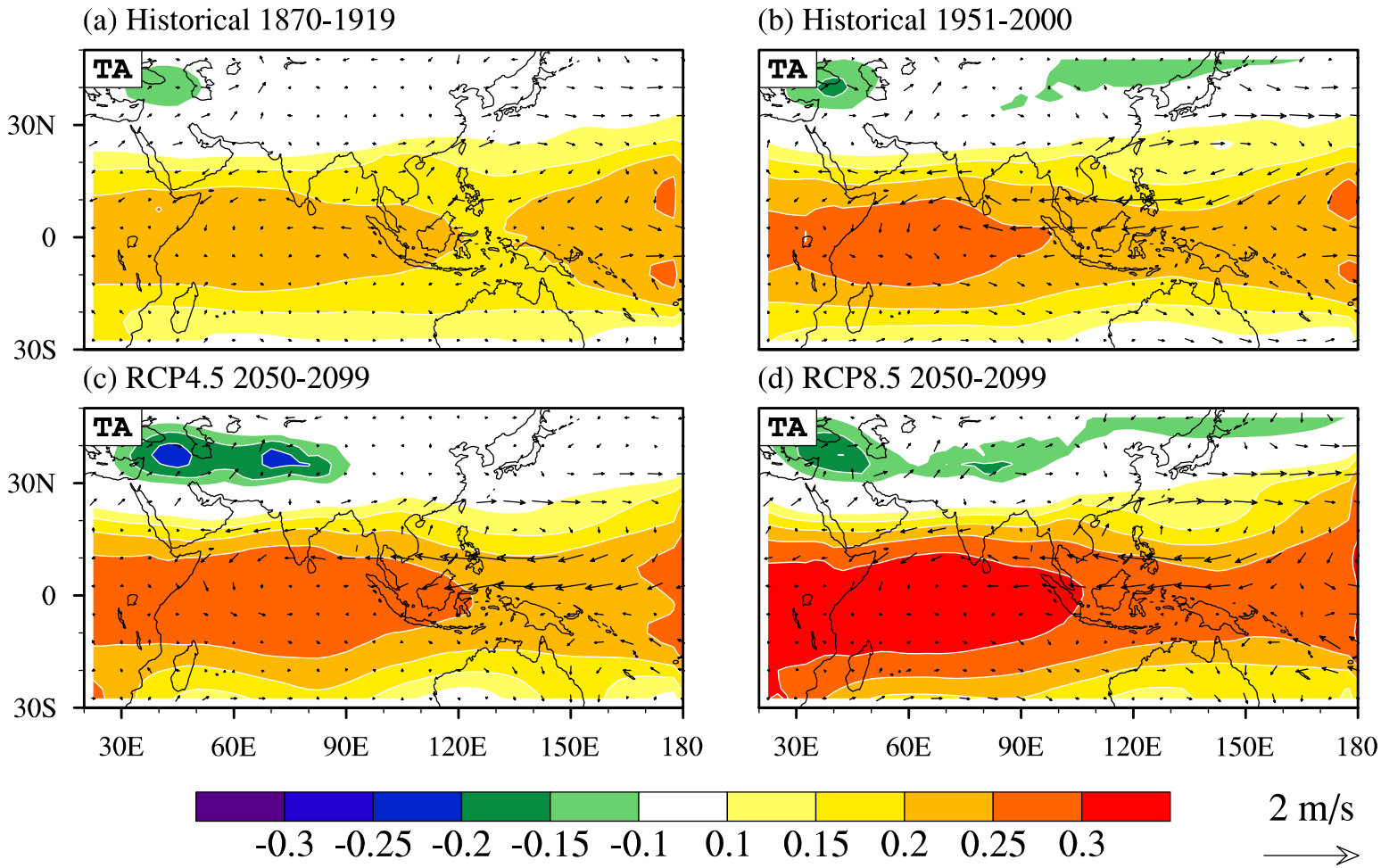


What is the response of Indian Ocean capacitor to global warming? (IOBM)

The change of Indian Ocean capacitor in global warming

(Kaiming Hu, Gang Huang*, Xiao-Tong Zheng, Shang-ping Xie, Xia Qu, Yan Du, and Lin Liu, JC 2013)

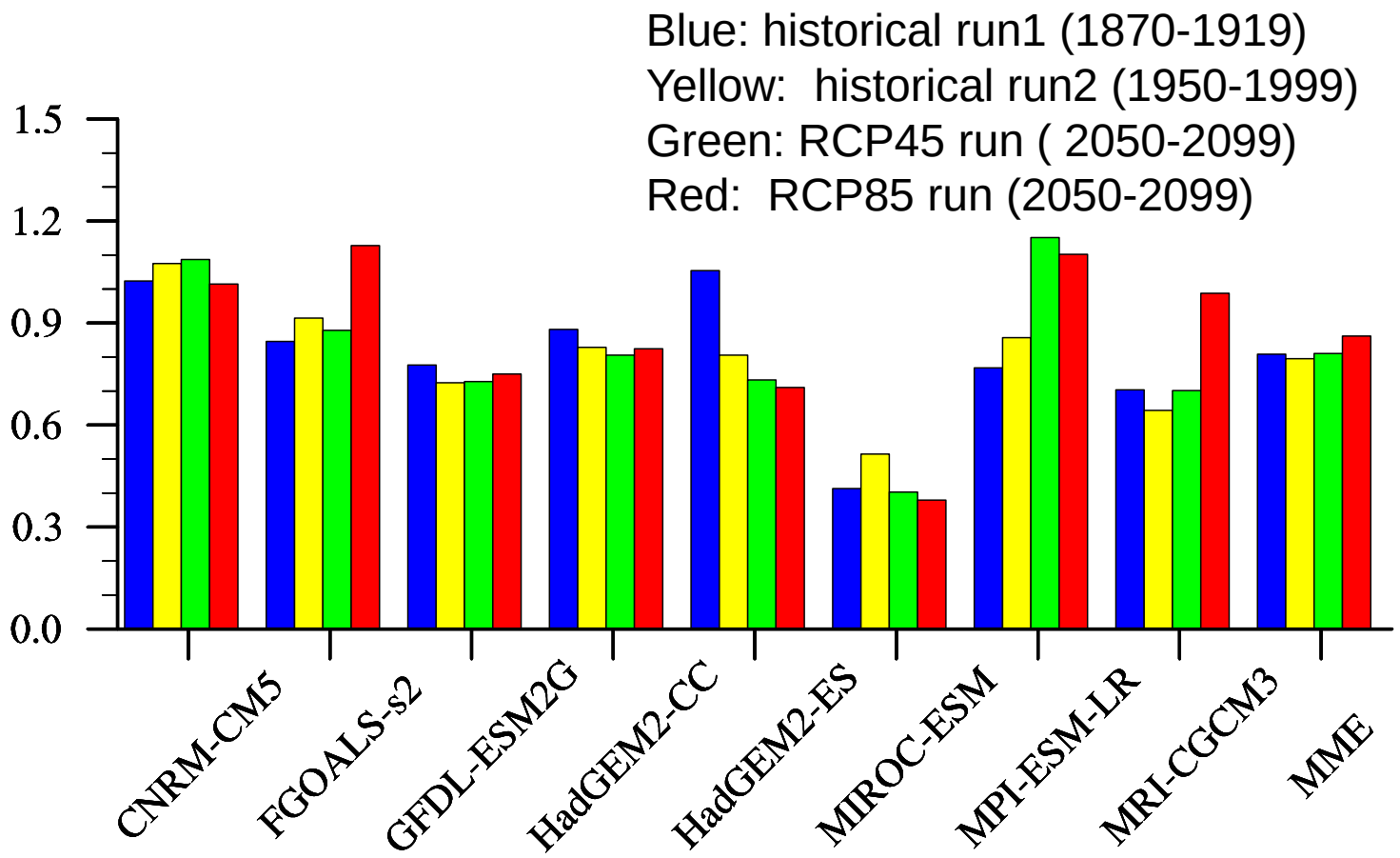
We find that the Indian Ocean capacitor effect strengthens under global warming



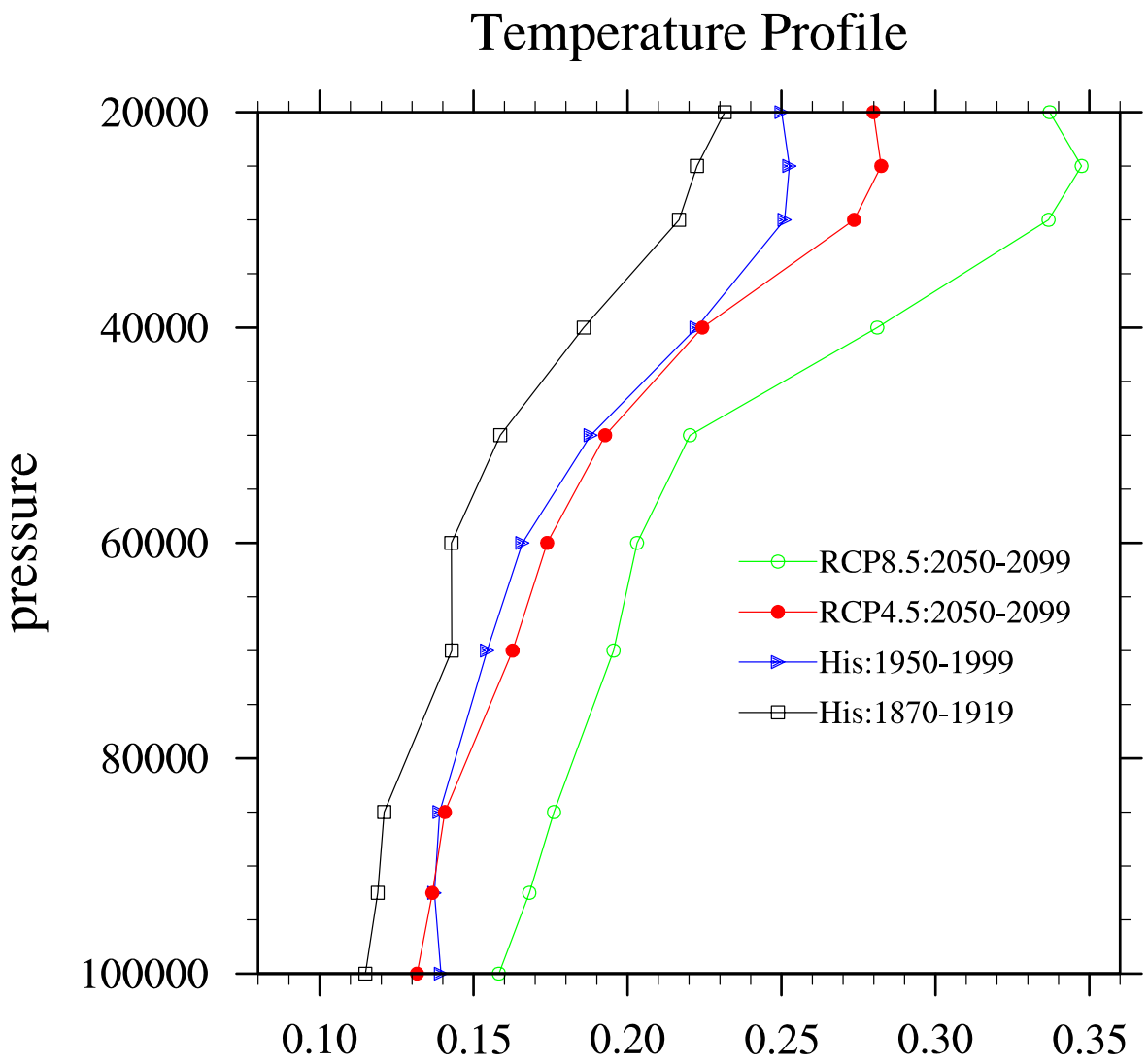
The regression of MJJ TT (vertical average of 850-200hPa) and 850hPa UV on normalized DJF Nino3.4 index.

Colors: TT (unit k); Vectors: 850hPa UV

ENSO magnitude is lack of change in global warming



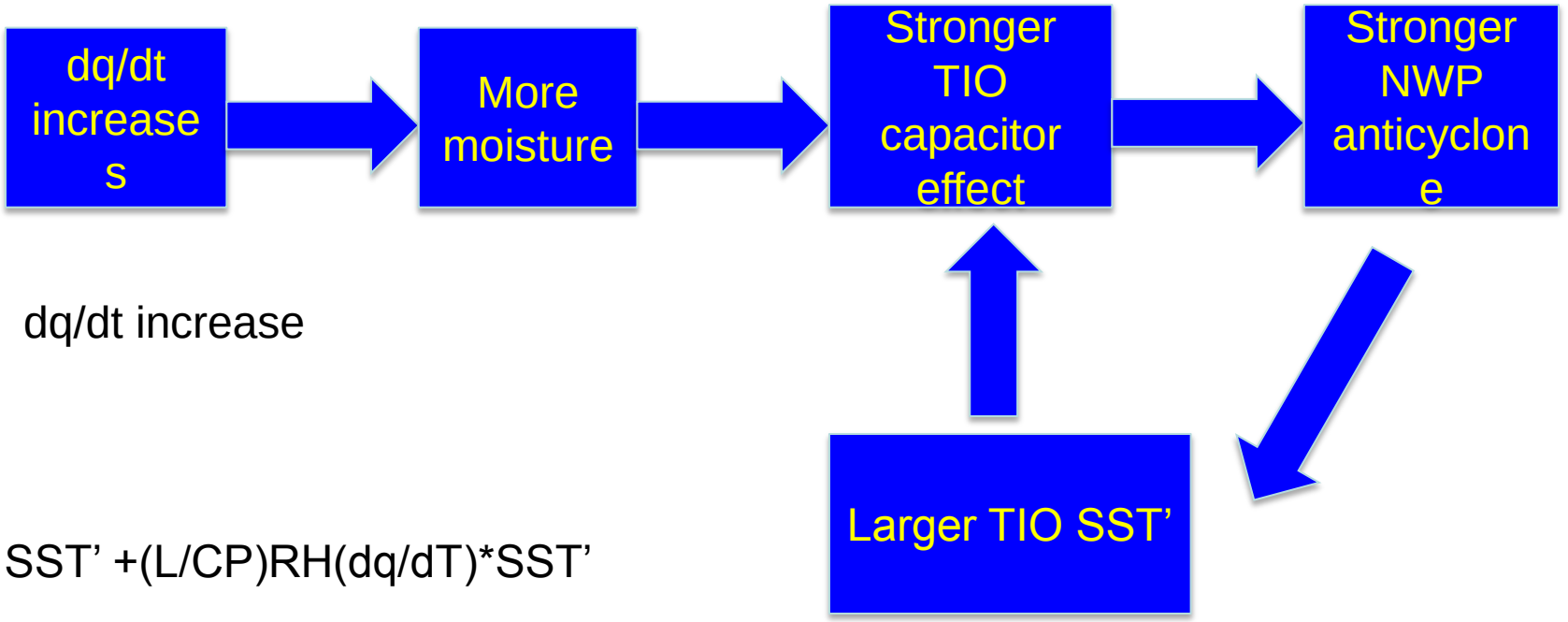
Standard variance of DJF Nino3.4 index in different period: historical run1 (1870-1919), historical run2 (1950-1999), RCP45 run (2050-2099) and RCP85 run (2050-2099)



The MJJ TIO air temperature anomalies profile obtained by on normalized DJF(0) Nino3.4 index.

The temperature range is small in the low level but large in the upper level.

Possible feedback of the NWP anticyclone and TIO SST under global warming



dq/dt increase

T' ~ SST' +(L/CP)RH(dq/dT)*SST'

dq/dT ~ 0.06q

q is the saturation specific humidity

Summary

•The warmer-get-wetter effect is more obvious in the annual mean precipitation change whereas the wet-get-wetter effect is more dominant for the seasonal mean.

•IOD-like mean state change intensifies thermocline feedback. With reduced atmospheric feedback, on balance, IOD variance remains unchanged under global warming.

•Increased moisture intensifies tropospheric temperature response to Indian Ocean warming, enhancing the capacitor effect on the NW Pacific and East Asia.

全球变化研究国家重大科学研究计划
太平洋印度洋对全球变暖的响应及其对气候变化的调控作用
The response of the Ind-Pacifec Oceans to global warning and their role in climate change
项目编号：2012CB955600

Our works about Indian Ocean –East Asian Summer Climate (http://hg.iap.ac.cn/mypaper.html)

- 1Huang, G.*,K. Hu, 2008: Impact of North Indian Ocean SSTA on Northwest Pacific Lower Layer Anomalous Anticyclone in Summer. Journal of Nanjing Institute of Meteorology, 31(6):749-757 (in Chinese)
- 2 Li, S., J. Lu, G. Huang, and K. Hu, 2008: Tropical Indian Ocean basin warming and East Asian Summer Monsoon: a multriple AGCM study. Journal of Climate, 21(22):6080-6088. **(SCI)**
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- * means Corresponding author

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- **17** Qu, X. and Huang, G*. (2012), Impacts of tropical Indian Ocean SST on the meridional displacement of East Asian jet in boreal summer. International Journal of Climatology, 32: 2073-2080. **(SCI)**
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- **28**Weichen Tao,Gang Huang*,Kaiming Hu etc, The response of Indian Ocean Basin Mode to ENSO under global warming in CMIP5 models,acceptede by IJC,2013**(SCI)**
- * means Corresponding author


Thank you!
Photo in Reglan2013