State Key Laboratory of Numerical Modelling for Atmospheric Sciences
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Simulation of Inter-annual Variability of East Asian Summer : *Does Air-Sea Coupling Improve the performance*?

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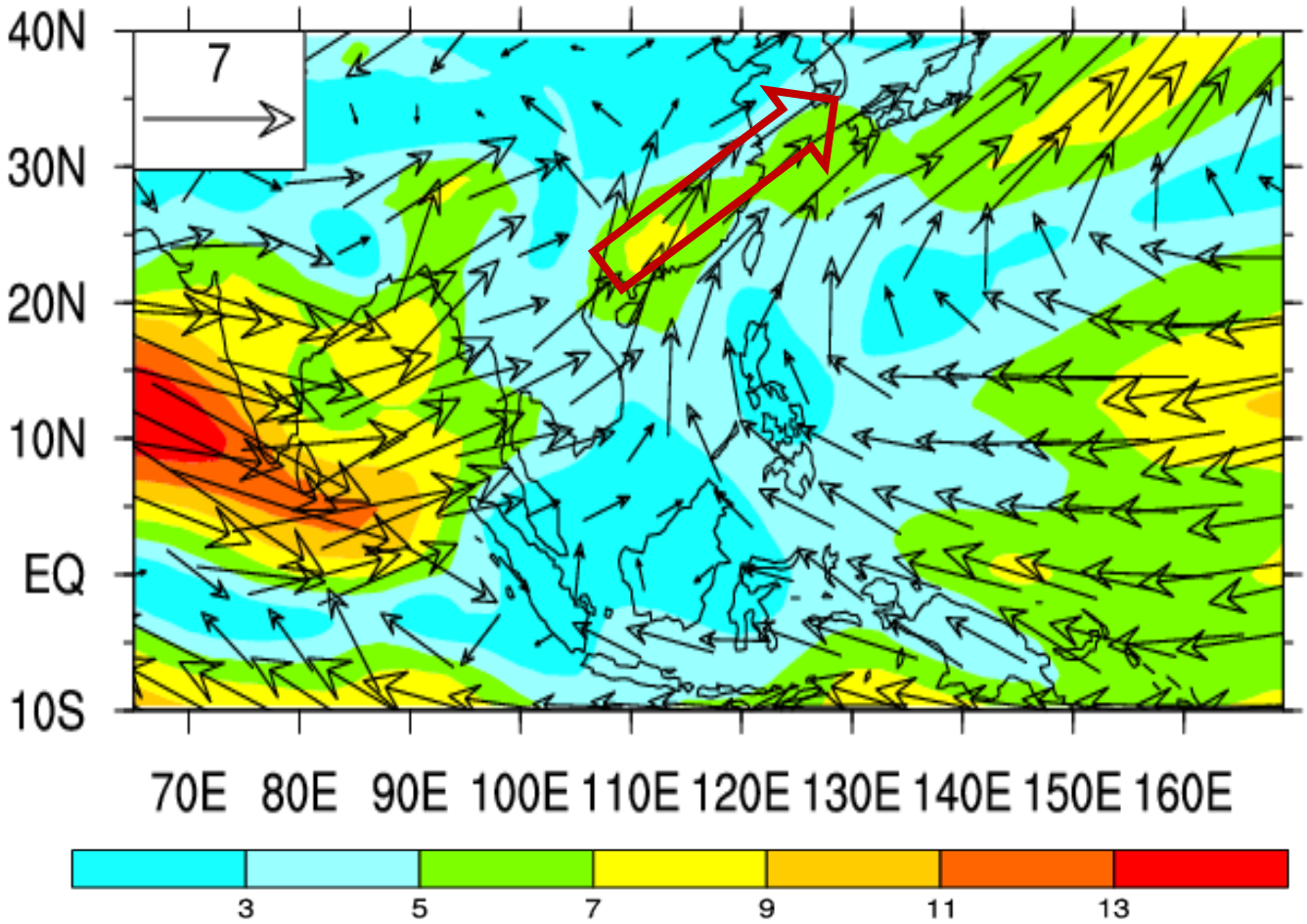
WCRP-JNU Training School on Monsoon Variability in Changing Climate

15-21 Jan 2017, Juju National University

Outline

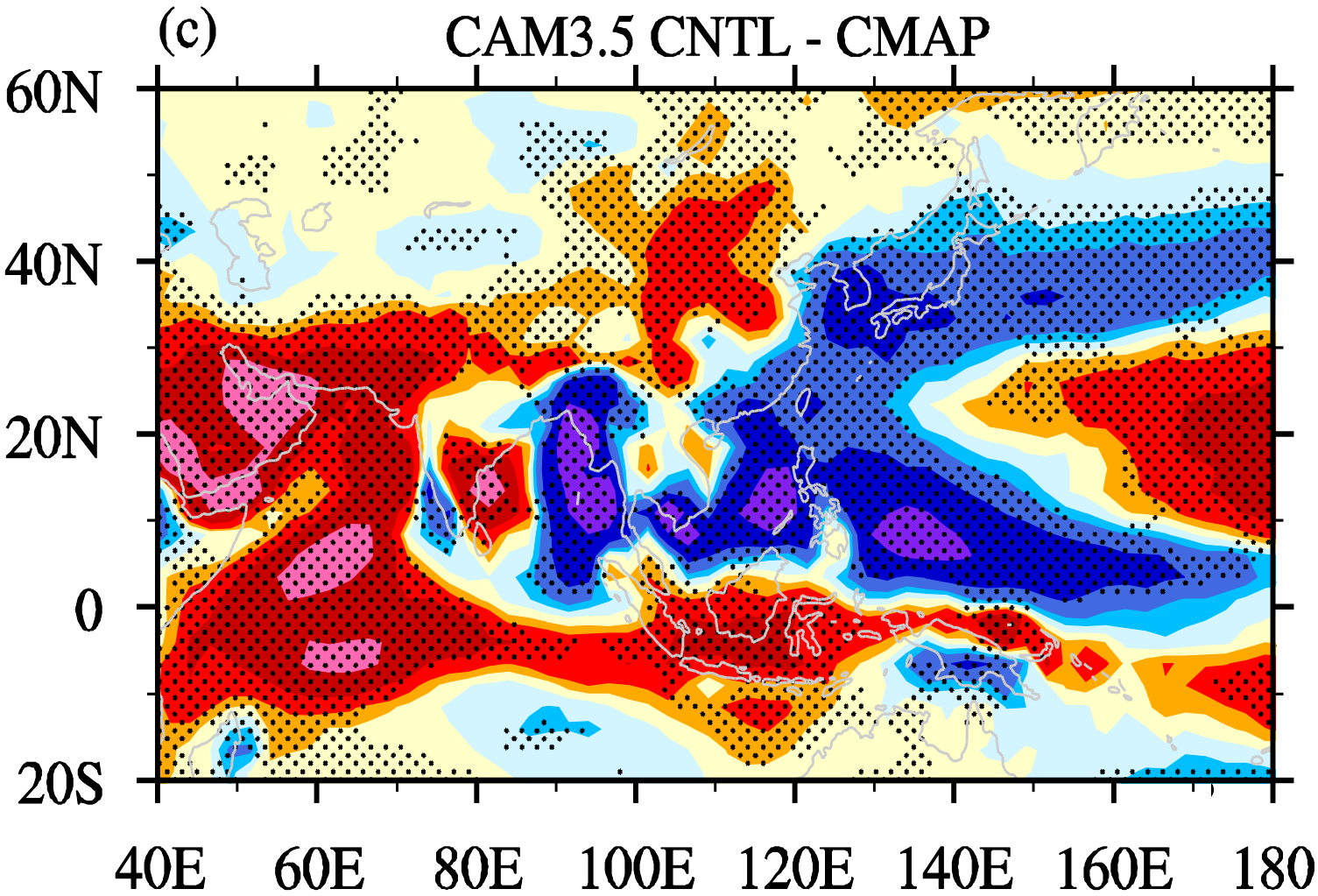
- **Background**
- **CMIP3 & CMIP5 AGCMs**
- **CMIP5 CGCMs**
- **Summary**

JJA UV 850 hPa (vectors) and precipitation (shading)



Summer monsoon circulation and rainband: The simulation of E Asian summer monsoon has been a rigorous test for climate models

Bias of monsoon rainfall in CAM3



Chen, H., **T. Zhou**, R. B. Neale, X. Wu, G. Zhang, 2010: Performance of the New NCAR CAM3.5 in East Asian Summer Monsoon Simulations: Sensitivity to Modifications of the Convection Scheme. ***Journal of Climate***, 23, 3657-3675

Questions: How about the performances of current models?

Motivation: To examine the improvements of E. Asian summer monsoon simulation in CMIP5 models by using the observational metrics of :

- mean state
- Interannual variability

Outline

- Background
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- CMIP5 CGCMs
- Summary

Model and Data

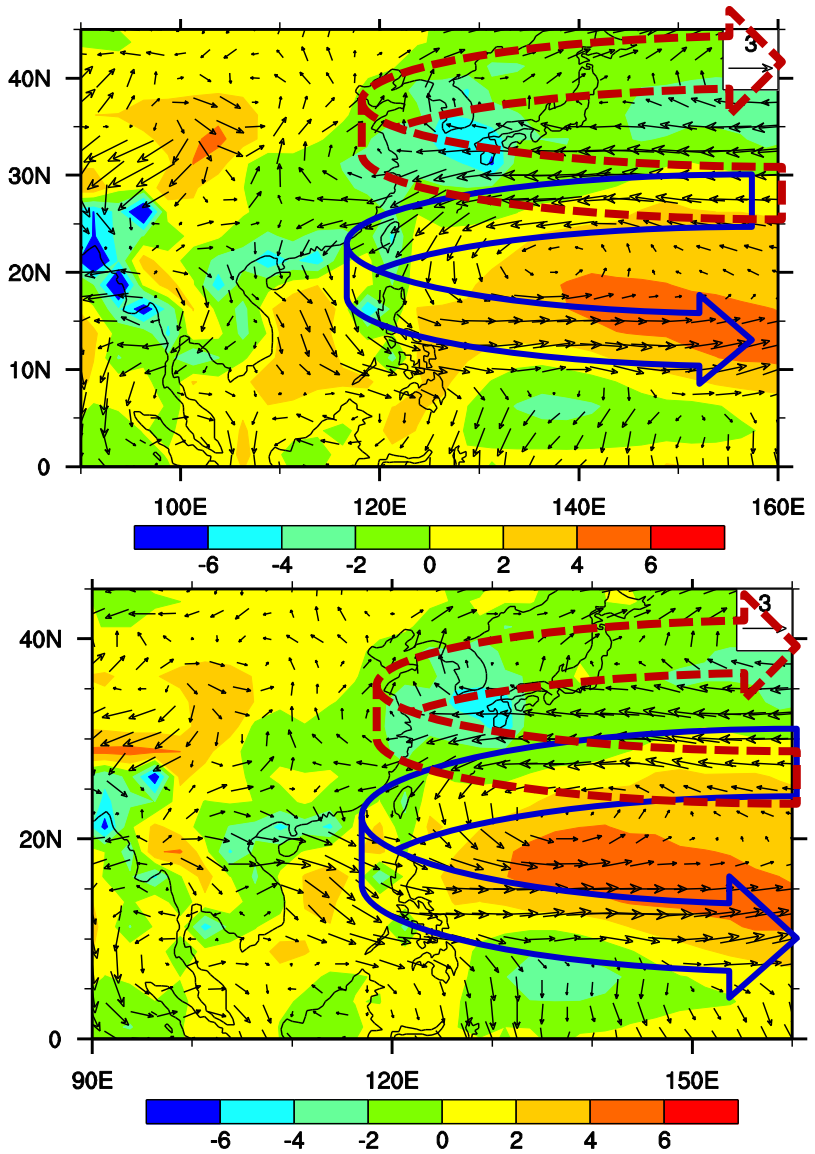
- **13 CMIP3** and **19 CMIP5 AMIP experiments**.
- Observational and reanalysis data:
  - NCEP2: 850 hPa wind, air temperature;
  - GPCP: precipitation;
  - ERSST: SST;
- Period: 1980 to 1997.
- All the datasets are interpolated onto common grid 2.5°x2.5°

Song, F., **T. Zhou,** 2014a: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean-Western Pacific Anticyclone Teleconnection. ***Journal of Climate***, 27, 1679-1697

JJA mean UV850 and precipitation in CMIP3&5 models

CMIP3 MME - OBS

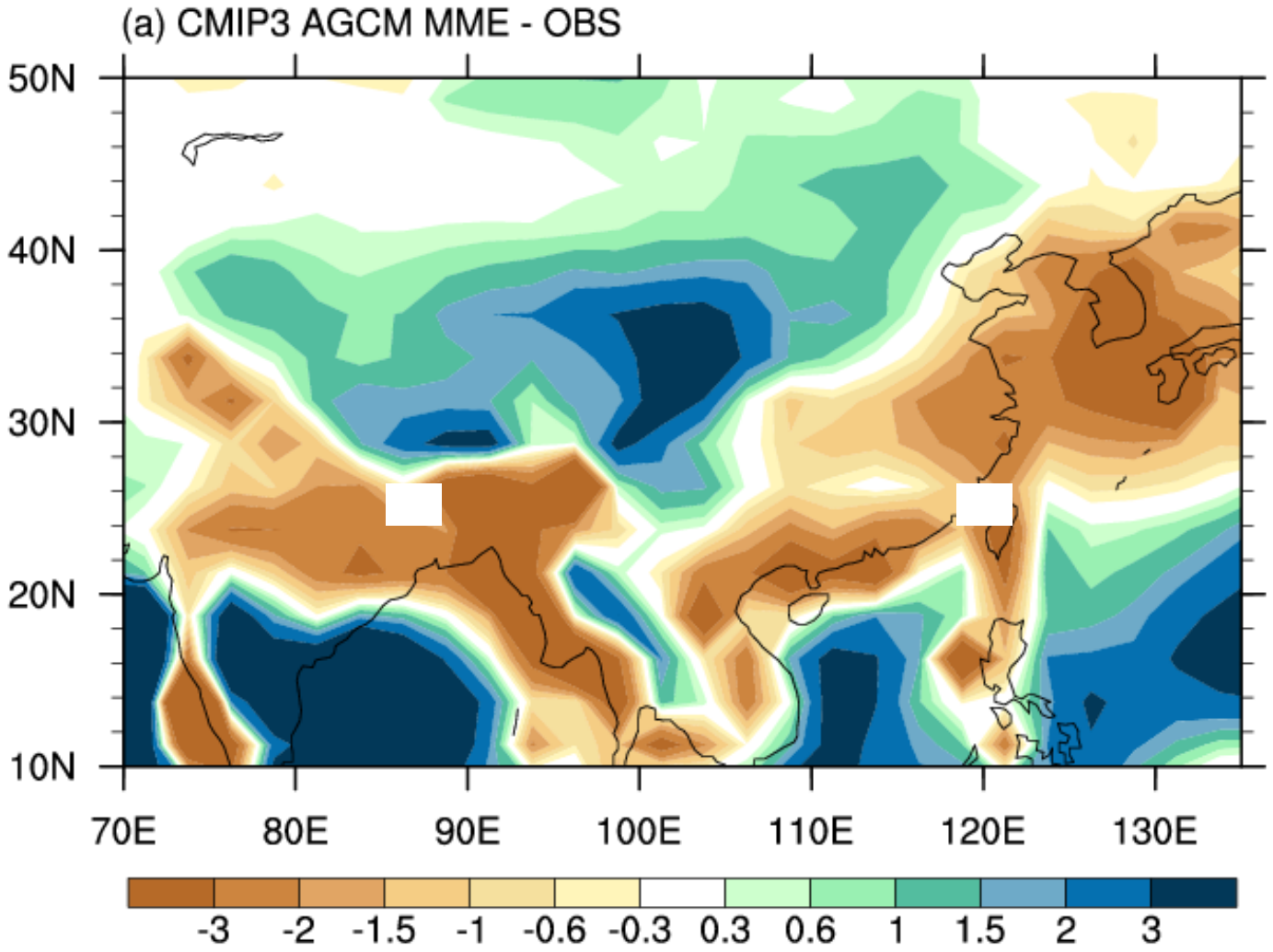
CMIP5 MME - OBS



- Northward shift of subtropical high
- No improvement from CMIP3 to CMIP5

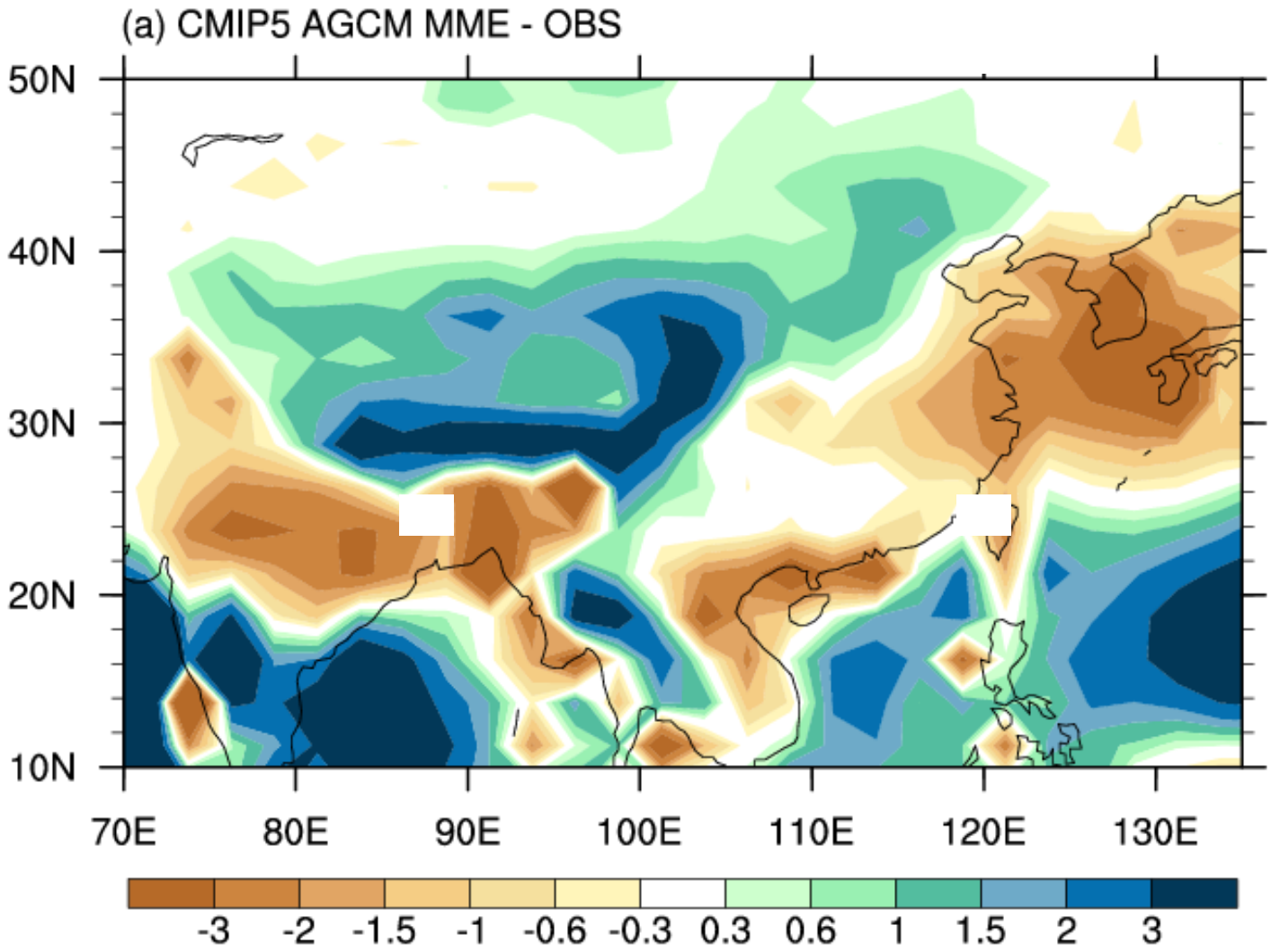
Song, F., **T. Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679-1697.

Large bias of JJA rainfall in CMIP3 AGCM



CMIP3 AGCM MME minus Observation

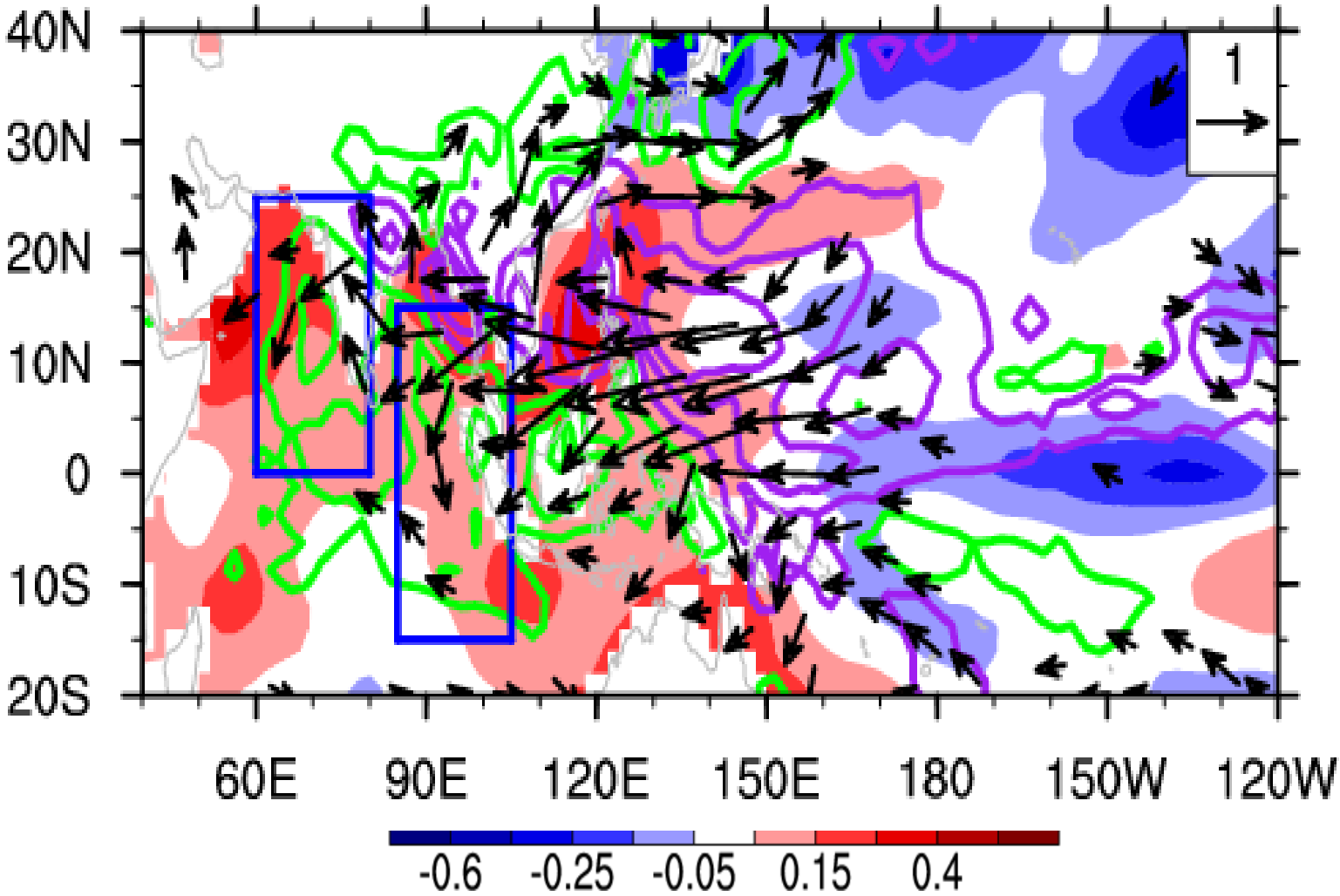
Large bias of JJA rainfall in CMIP5 AGCM



CMIP5 AGCM MME minus Observation

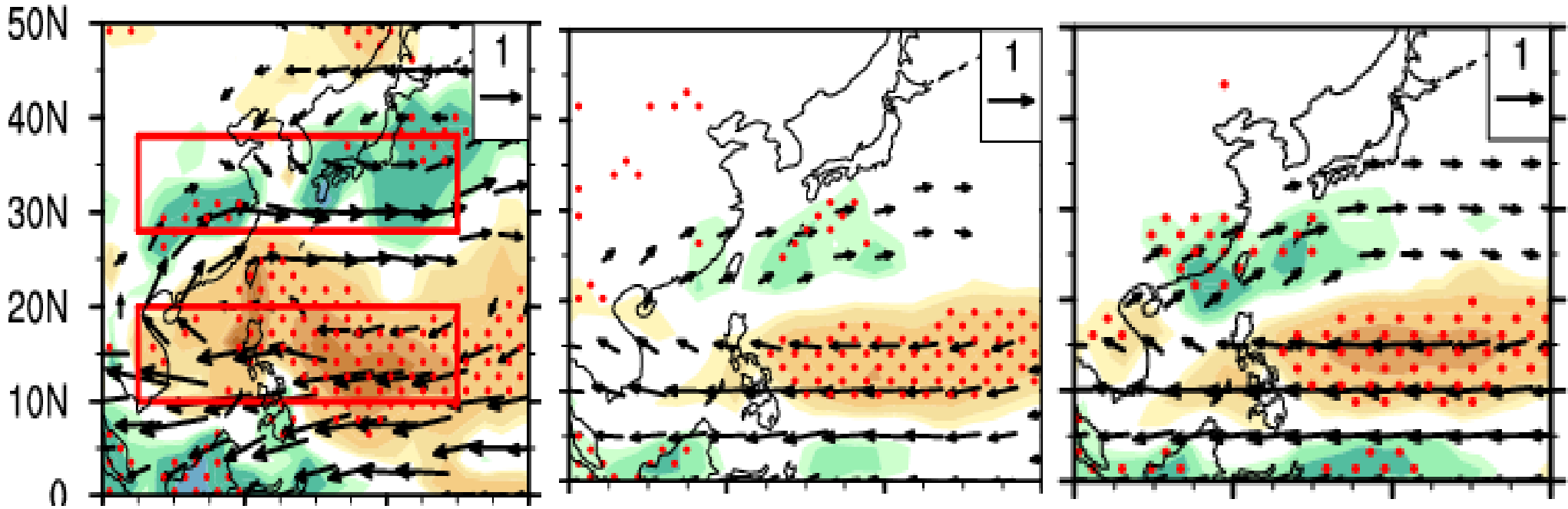
Metric: Observed changes of monsoon in El Nino decaying year summer

SST (shading), UV850 hPa (Vector), precipitation (contour)



Song, F., **T. Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679-1697.

UV850 and precipitation in El Nino decaying year summer



Observation

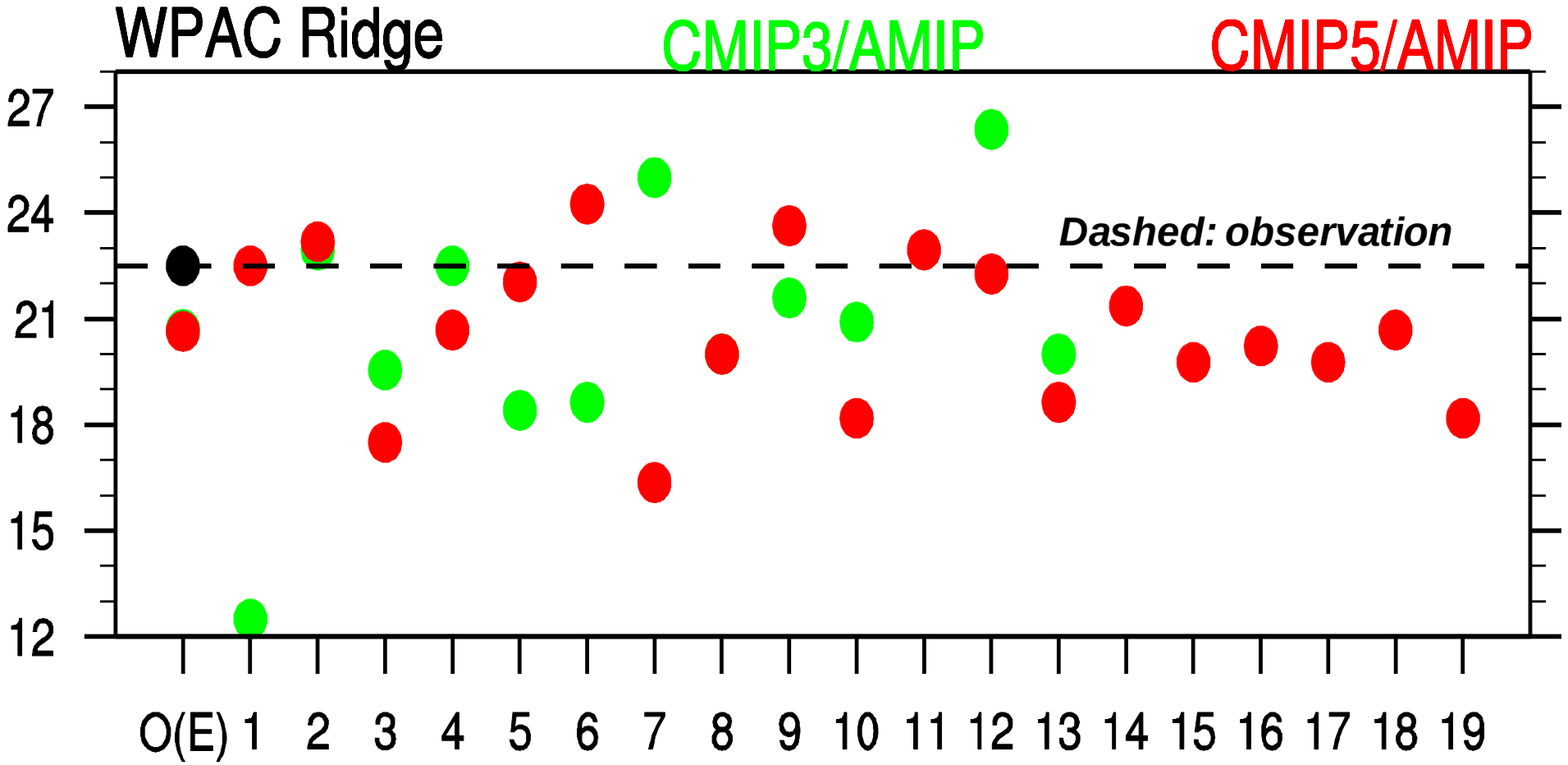
CMIP3 MME

CMIP5 MME

• **Southward shifts of the W. Pacific Anticyclone and the associated rainfall anomalies over EA; Similar bias in CMIP3 & CMIP5 models**

Song, F., **T. Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679-1697.

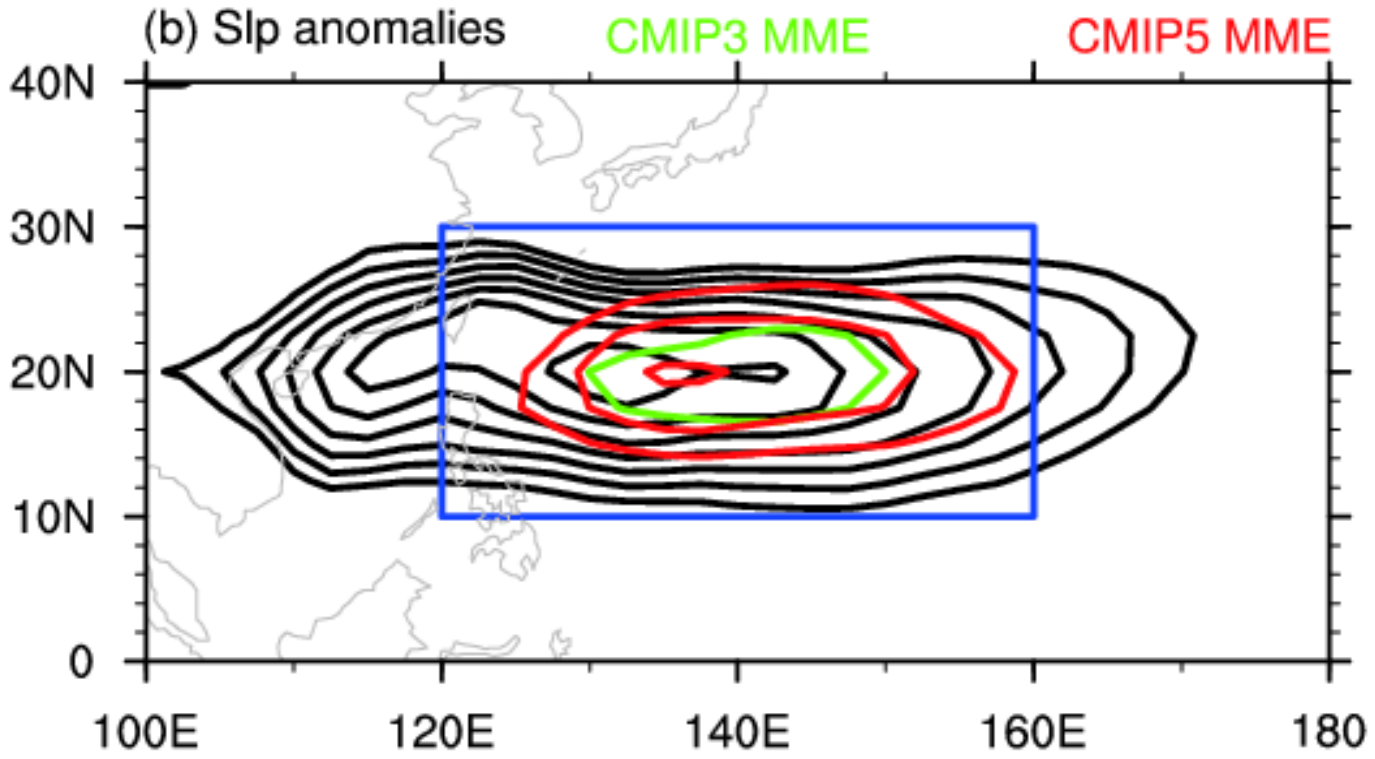
Latitude Position of the western Pacific AC ridge line



- The ridge shifts southward in CMIP3 & CMIP5 models

Song, F., **T. Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679-1697.

Intensity of the WPAC



- **Weaker than the reanalysis**
- **No improvement from CMIP3 to CMIP5**

Song, F., **T. Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679-1697.

Outline

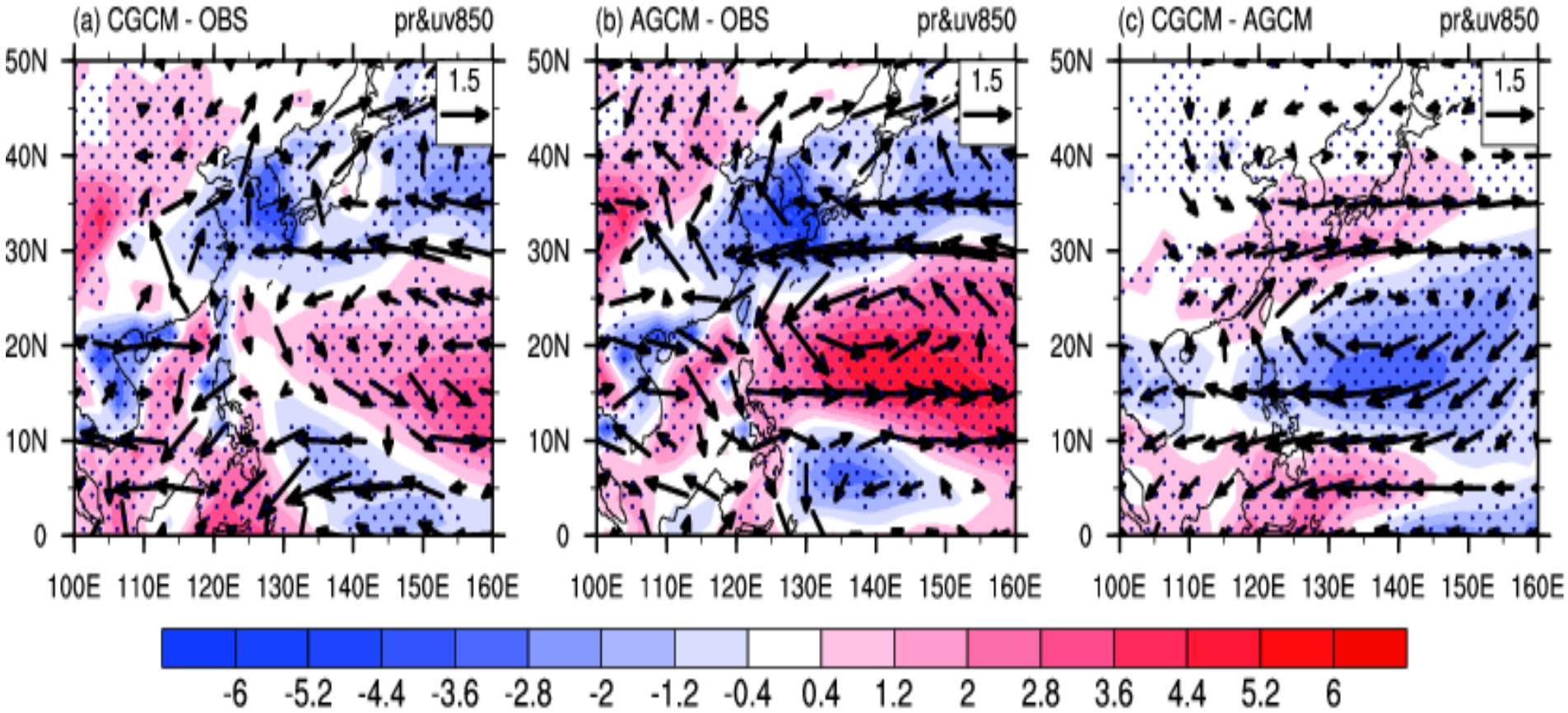
- Background
- CMIP3 & CMIP5 AGCMs
- CMIP5 CGCMs
- Summary

Model and Data

- **17 CMIP5 AGCMs and corresponding CGCMs are analyzed**
- **Observational and reanalysis data:**
  - **NCEP2&ERA40; GPCP&CMAP; ERSST**
- **the period for the comparison between AGCMs and CGCMs is 1979-2005**
- **All the datasets are interpolated into common grid 2.5°x2.5°**

Song F., **T. Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

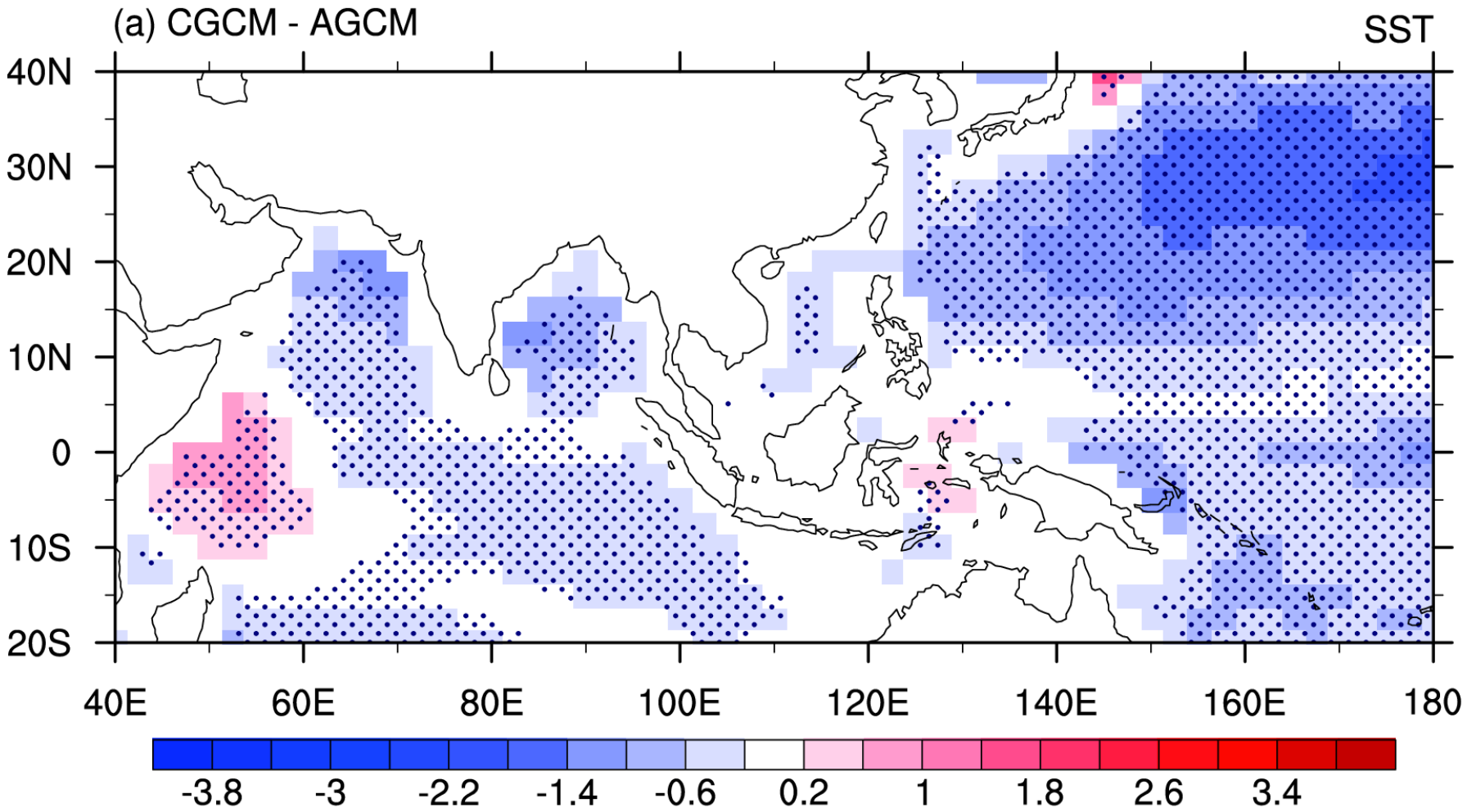
Improvement in climatology



- Bias of CGCM resembles that of AGCM: cyclonic bias over WNP and less rainfall along 30N
- Improvement from AGCMs to CGCMs: enhanced WNPSH; better monsoon rainband

Song F., **T. Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

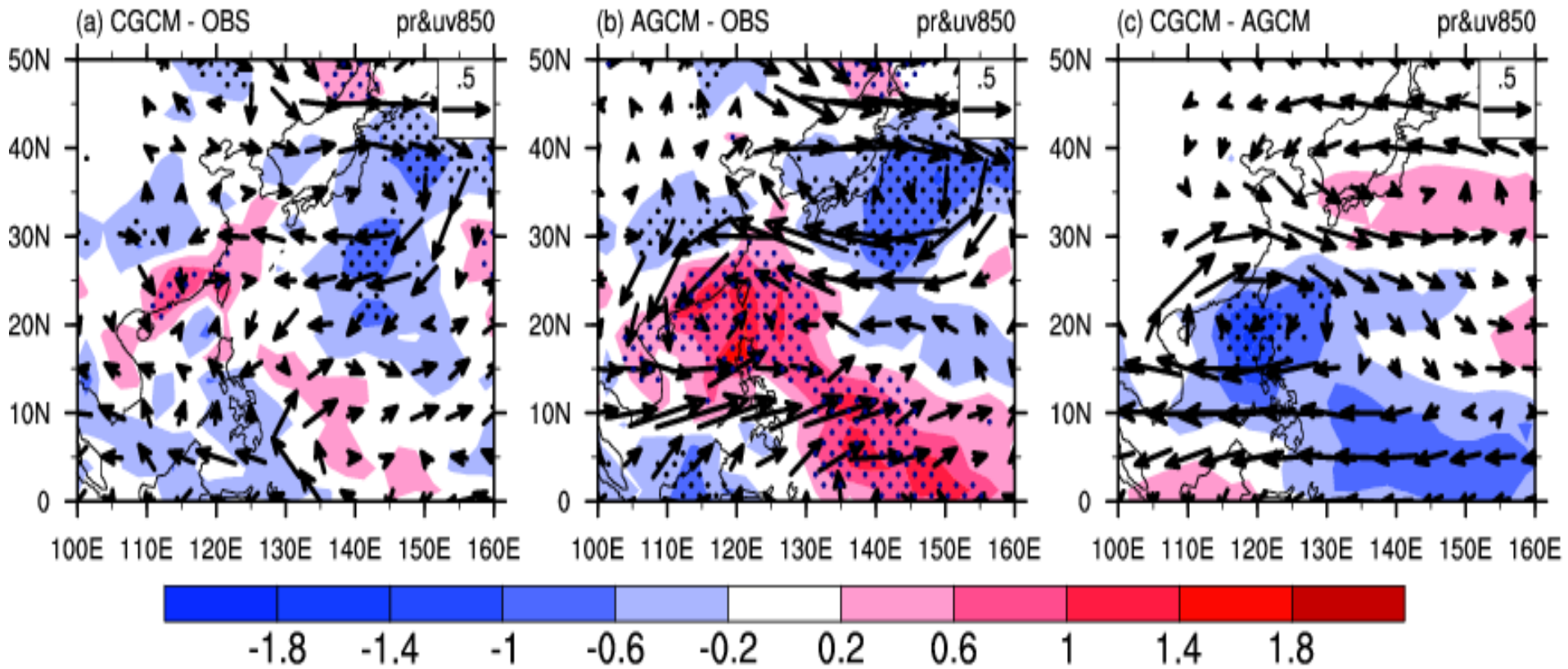
Improvement at a cost of SST bias in the W. Pacific



- Colder SST bias -> enhanced WPSH

Song F., **T. Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

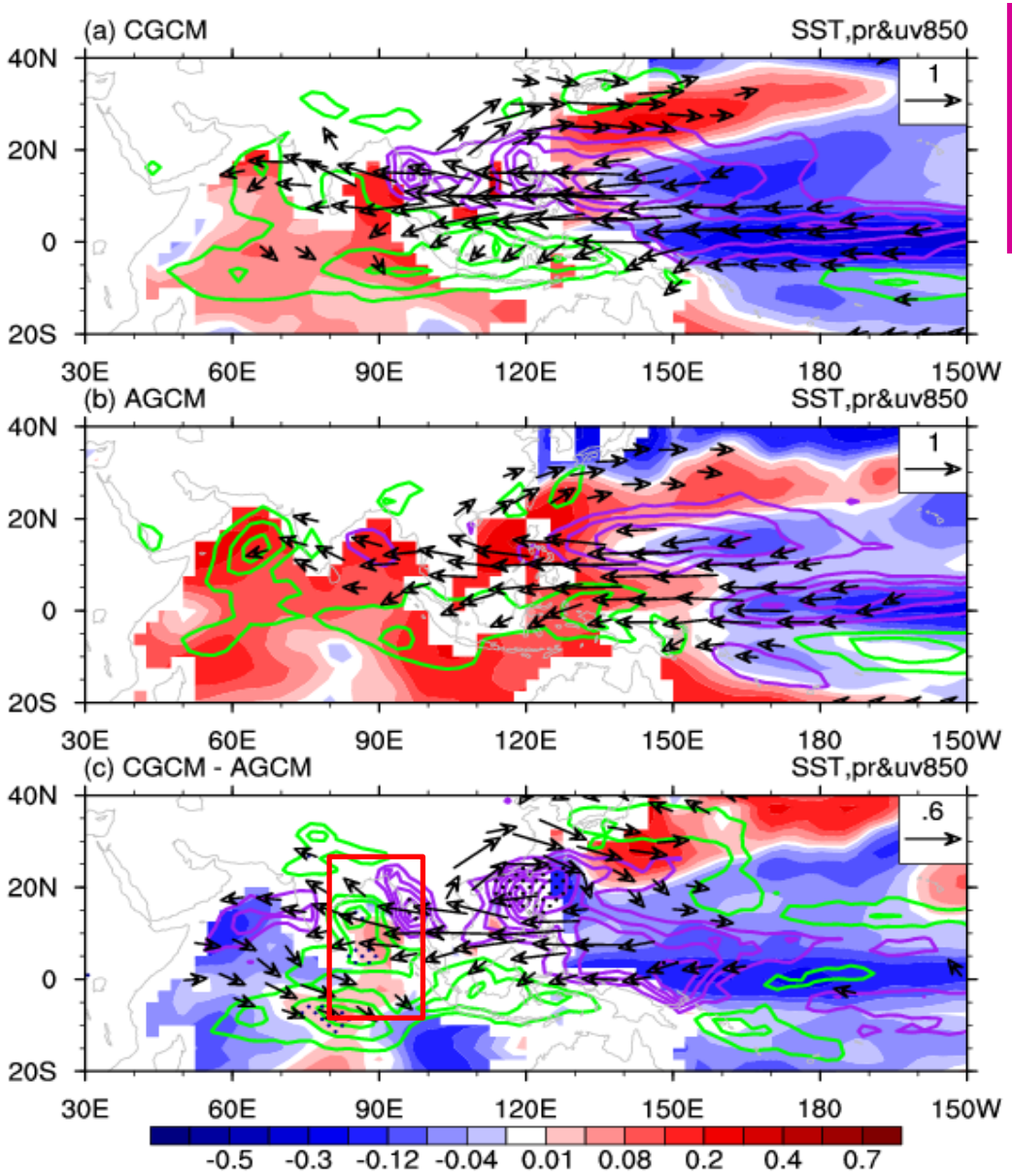
Bias in El Nino decaying year summer: CGCM vs AGCM



- **CGCM:** **less bias in precipitation and wind**
- **AGCM:** **positive bias over the western Pacific**
- **From AGCM to CGCM: better precipitation in the western Pacific**

Song F., **T. Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

Anomalies of SST, precipitation, and 850 hPa winds in El Nino decaying year summer

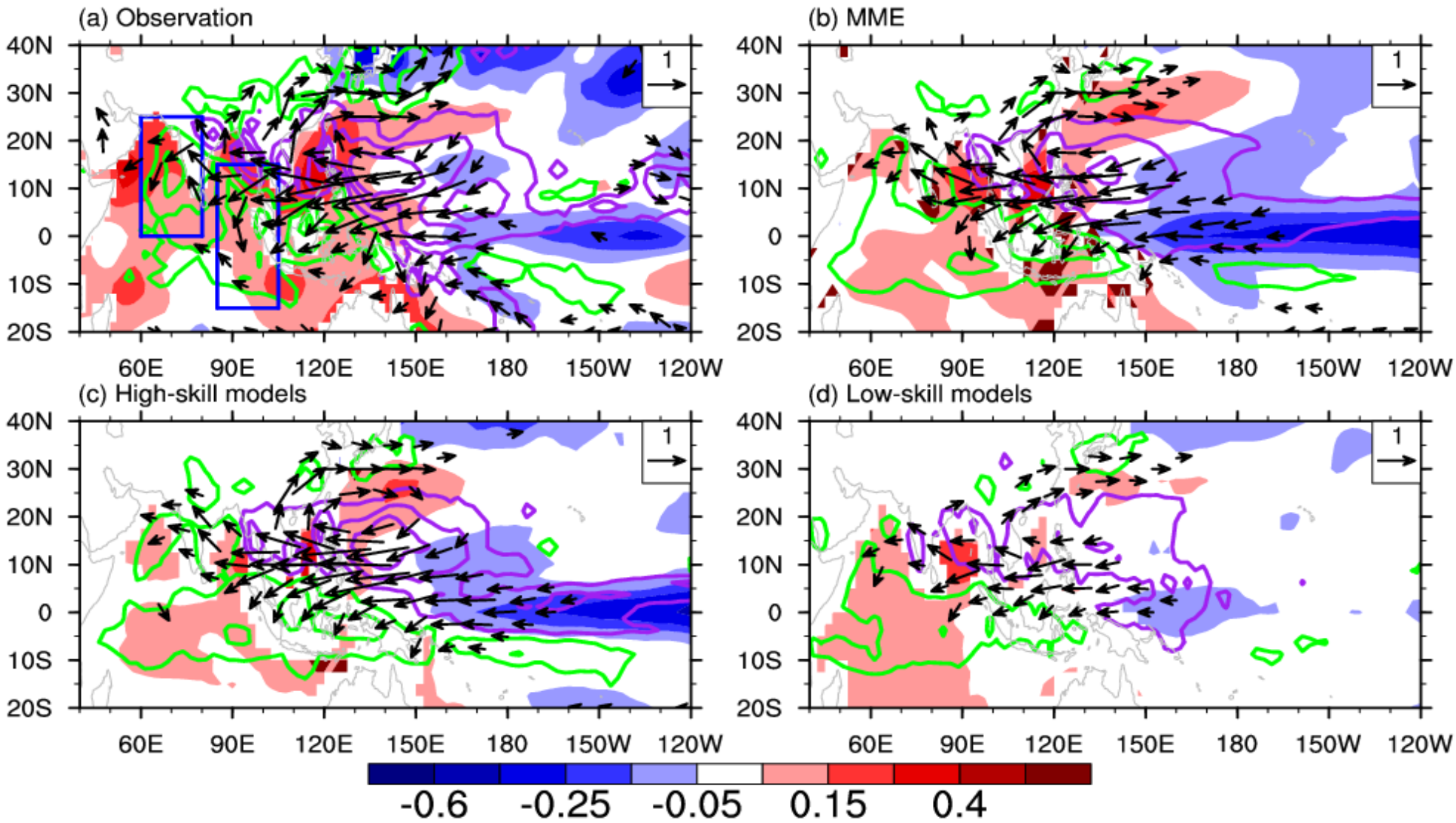


Shading: SST
Green contour: positive precipitation
Purple contour: negative precipitation
Vector: 850 hPa winds

- CGCM: SSTA over TEIO is warmer than the OBS.
- Warmer TEIO SSTA -> more precipitation -> stronger Kelvin wave response as W. Pac AC -> enhanced EASM simulation.
- Local colder SST over the W. Pac also enhances the W. Pac AC

Song, F., **T. Zhou,** 2014b, ***Journal of Climate***

SST (shading), wind and rainfall (contour) composite fields in 35 CMIP5 CGCMs



Summary

- **Biases of AGCM:**

  Northward shift of the WP subtropical high in mean state;

  Southward shift of the WP AC in interannual variability.

- Improvements of CGCM

  Mean state: Better WPSH at a cost of colder local SST.

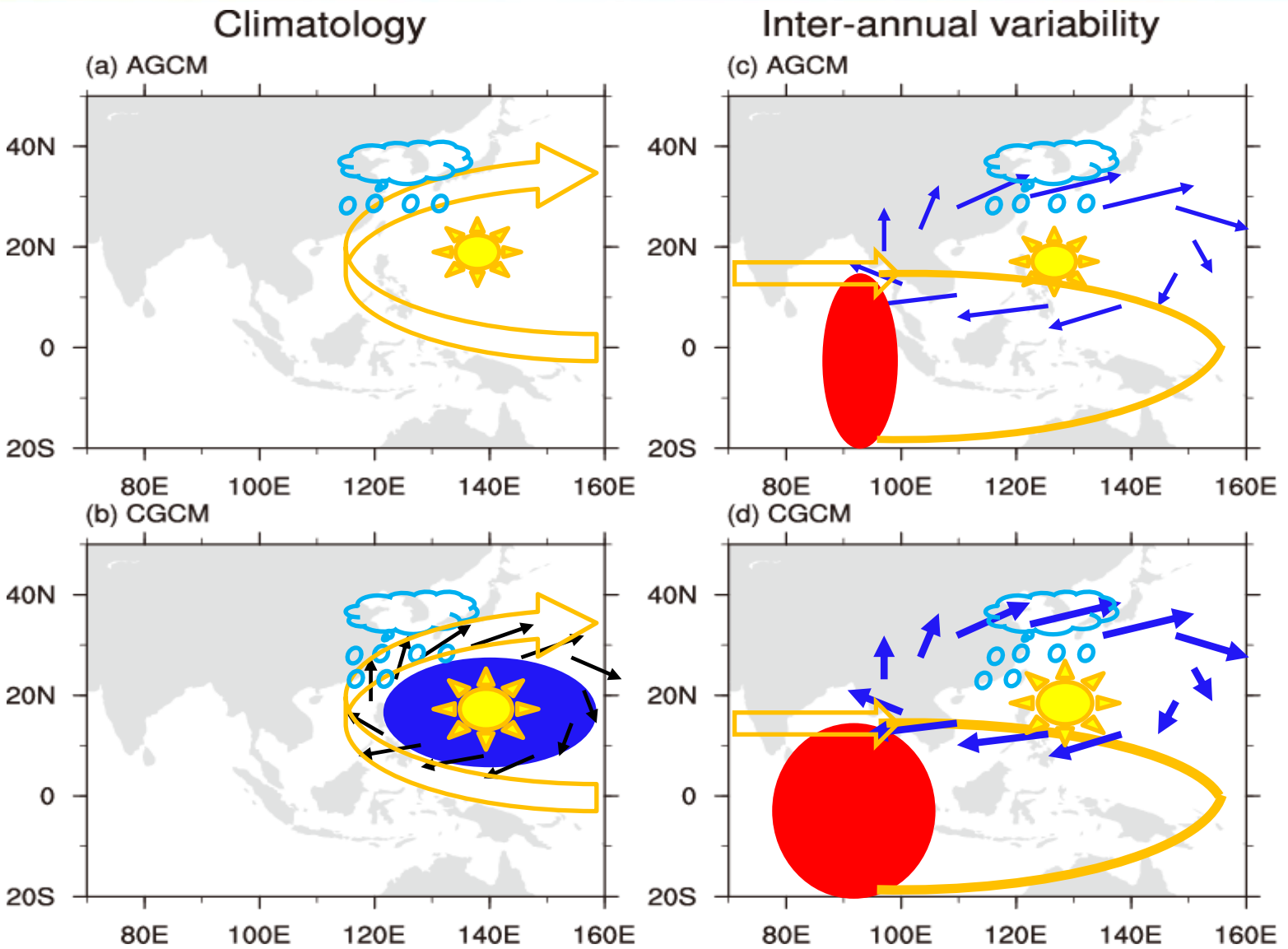
  Interannual variability: Improvements in WP AC location and intensity of monsoon rainfall anomaly, due to the enhanced IO-WPAC tele-connection through the air-sea coupling.

- Dynamics:

  More rainfall over the Indian Ocean associated with a warmer SST, and a stronger equatorial Kelvin wave response in the W. Pac.

Song F., **T. Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

Summary


Climatology
Inter-annual variability
(a) AGCM
(c) AGCM
(b) CGCM
(d) CGCM
40N
20N
0
20S
80E
100E
120E
140E
160E

References

- Song, F., **T. Zhou** (corresponding author), 2014a: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean-Western Pacific Anticyclone Teleconnection. ***Journal of Climate***, 27, 1679-1697
- Song, F., **T. Zhou** (corresponding author), 2014b: The mean state and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations? ***Journal of Climate***, 27, 8761-8777
- Chen, H., **T. Zhou**, R. B. Neale, X. Wu, G. Zhang, 2010: Performance of the New NCAR CAM3.5 in East Asian Summer Monsoon Simulations: Sensitivity to Modifications of the Convection Scheme. ***Journal of Climate***, 23, 3657-3675
- **Zhou T.**, Z. Li, 2002, Simulation of the east Asian summer monsoon by using a variable resolution atmospheric GCM, **Climate Dynamics,**19:167-180
- **Zhou T.**, WU Bo, Bin WANG, 2009, How Well Do Atmospheric General Circulation Models Capture the Leading Modes of the Interannual Variability of the Asian-Australian Monsoon?, **Journal of Climate**, 22, 1159-1173
- Sperber K. R., H. Annamalai, I.-S. Kang, A. Kitoh, A. Moise, A. Turner, B. Wang, **T. Zhou**,2012: The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century,***Clim Dyn***, *DOI 10.1007/s00382-012-1607-6*

Thanks

www.lasg.ac.cn/staff/ztj

CMIP3 AGCMs

No.	CMIP3 Models	Horizontal Resolution
1	cnrm_cm3	2.8*2.8
2	gfdl_cm2_1	2.0*2.5
3	giss_model_e_r	4.0*5.0
4	iap_fgoals1_0_g	3.0*2.8
5	inmcm3_0	4.0*5.0
6	ipsl_cm4	2.5*3.8
7	miroc3_2_hires	1.1*1.1
8	miroc3_2_medres	2.8*2.8
9	mpi_echam5	1.9*1.9
10	mri_cgcm2_3_2a	2.8*2.8
11	ncar_ccsm3_0	1.4*1.4
12	ncar_pcm1	2.8*2.8
13	ukmo_hadgem1	1.3*1.9

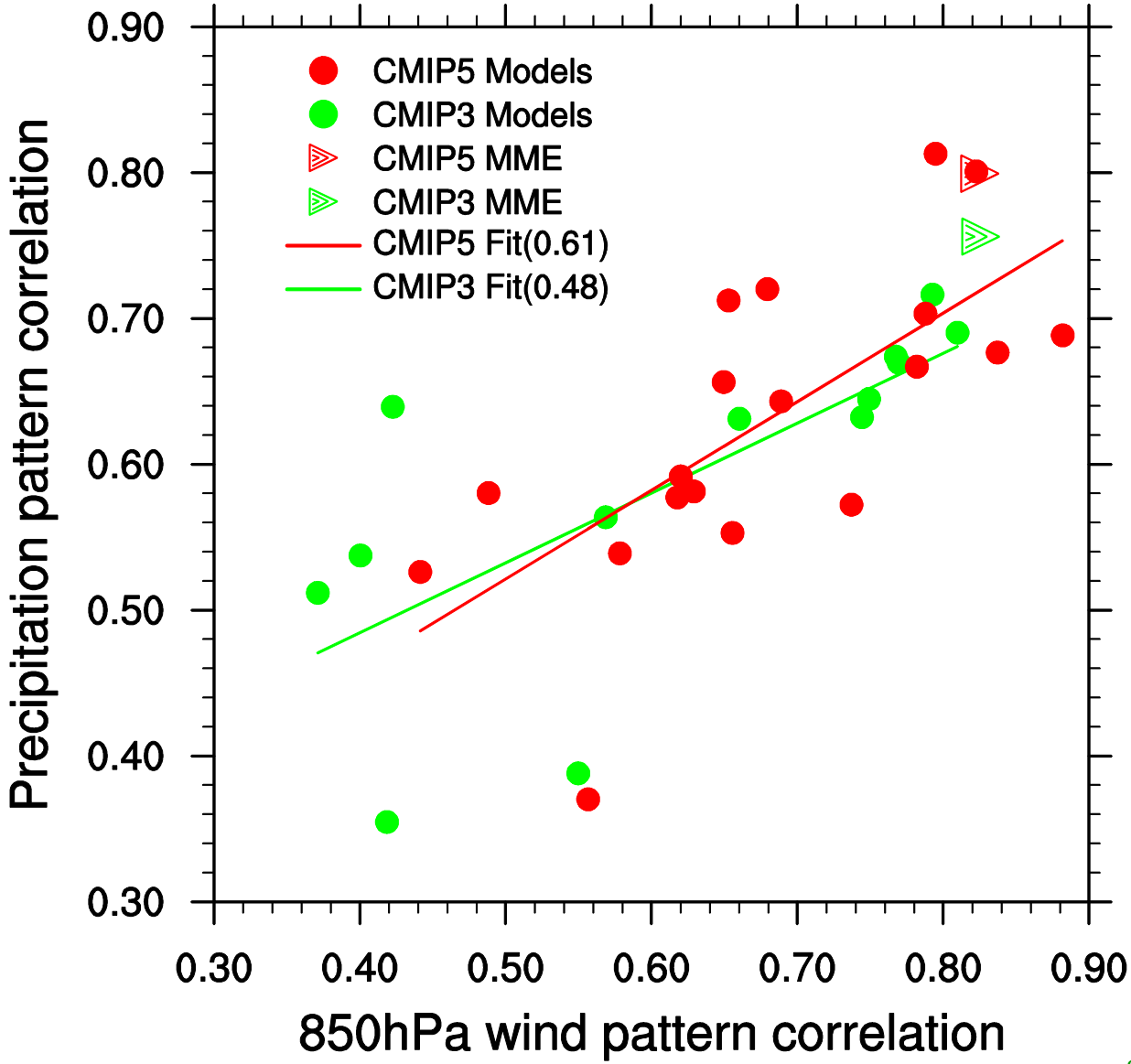
(Song, F., **T. Zhou,** 2014a: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean-Western Pacific Anticyclone Teleconnection. ***Journal of Climate***, 27, 1679-1697)

CMIP5 AGCMs

No.	CMIP5 Models	Horizontal Resolution	No.	CMIP5 Models	Horizontal Resolution
1	ACCESS1-0	1.3*1.9	11	HadGEM2-A	1.3*1.9
2	bcc-csm1-1	2.8*2.8	12	inmcm4	1.5*2.0
3	BNU-ESM	2.8*2.8	13	IPSL-CM5A-LR	1.9*3.8
4	CanAM4	2.8*2.8	14	MIROC5	1.4*1.4
5	CCSM4	0.9*1.3	15	MPI-ESM-LR	1.9*1.9
6	CESM1-CAM5	0.9*1.3	16	MPI-ESM-MR	1.9*1.9
7	CNRM-CM5	1.4*1.4	17	MRI-AGCM3-2H	0.6*0.6
8	FGOALS-g2	3.0*2.8	18	MRI-AGCM3-2S	0.2*0.2
9	FGOALS-s2	1.7*2.8	19	NorESM1-M	1.9*2.5
10	GISS-E2-R	2.0*2.5			

(Song, F., **T. Zhou,** 2014a: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean-Western Pacific Anticyclone Teleconnection. ***Journal of Climate***, 27, 1679-1697)

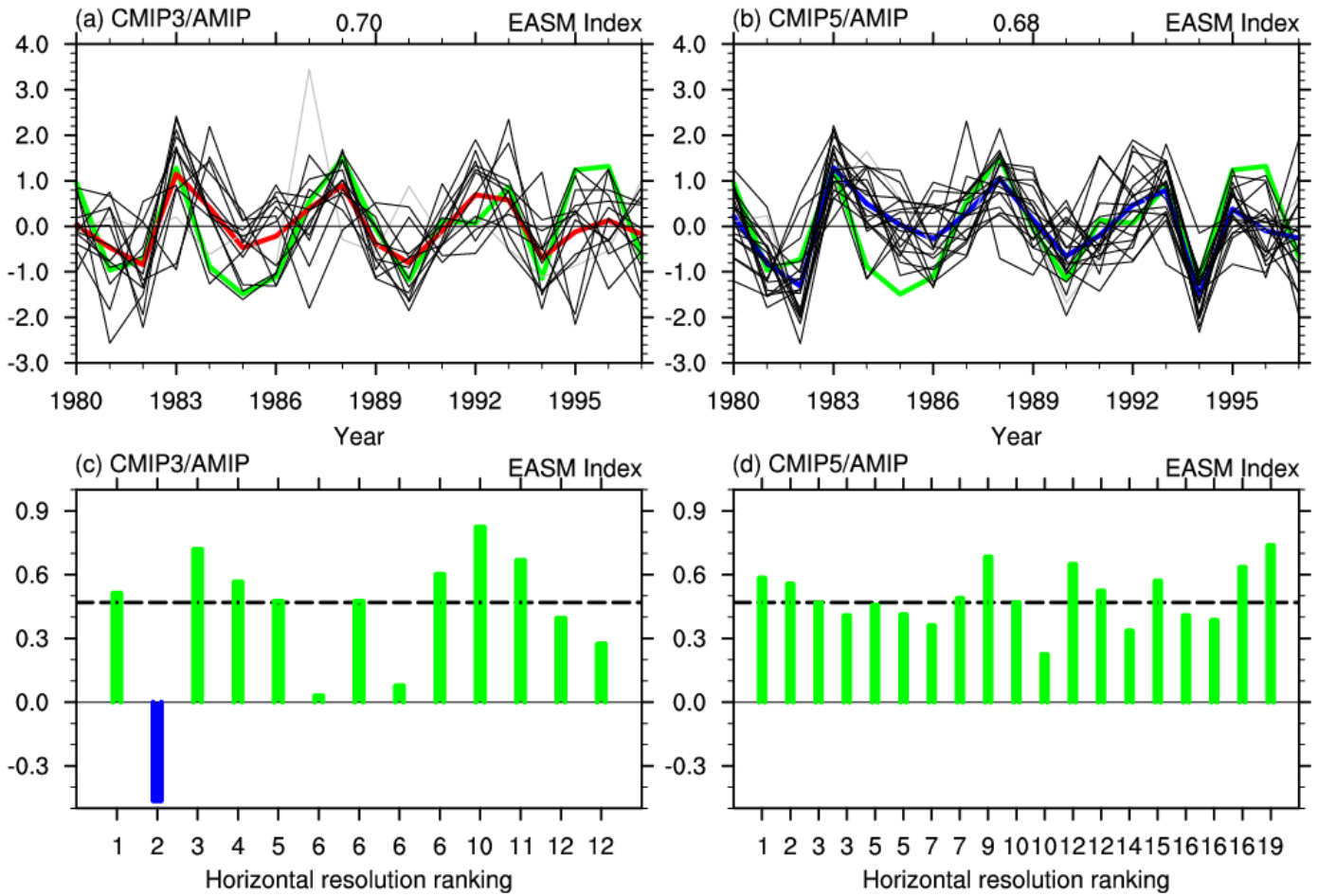
Pattern correlation coefficients: precipitation vs. 850 hPa wind



- Surface wind better simulated than precipitation;
- Better simulation of monsoon circulation leads to a better simulation of precipitation
- monsoon rainfall simulation: CMIP5 better than CMIP3

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

Time series of the EASM index



green line: NCEP2

red line: CMIP3 AGCM MME

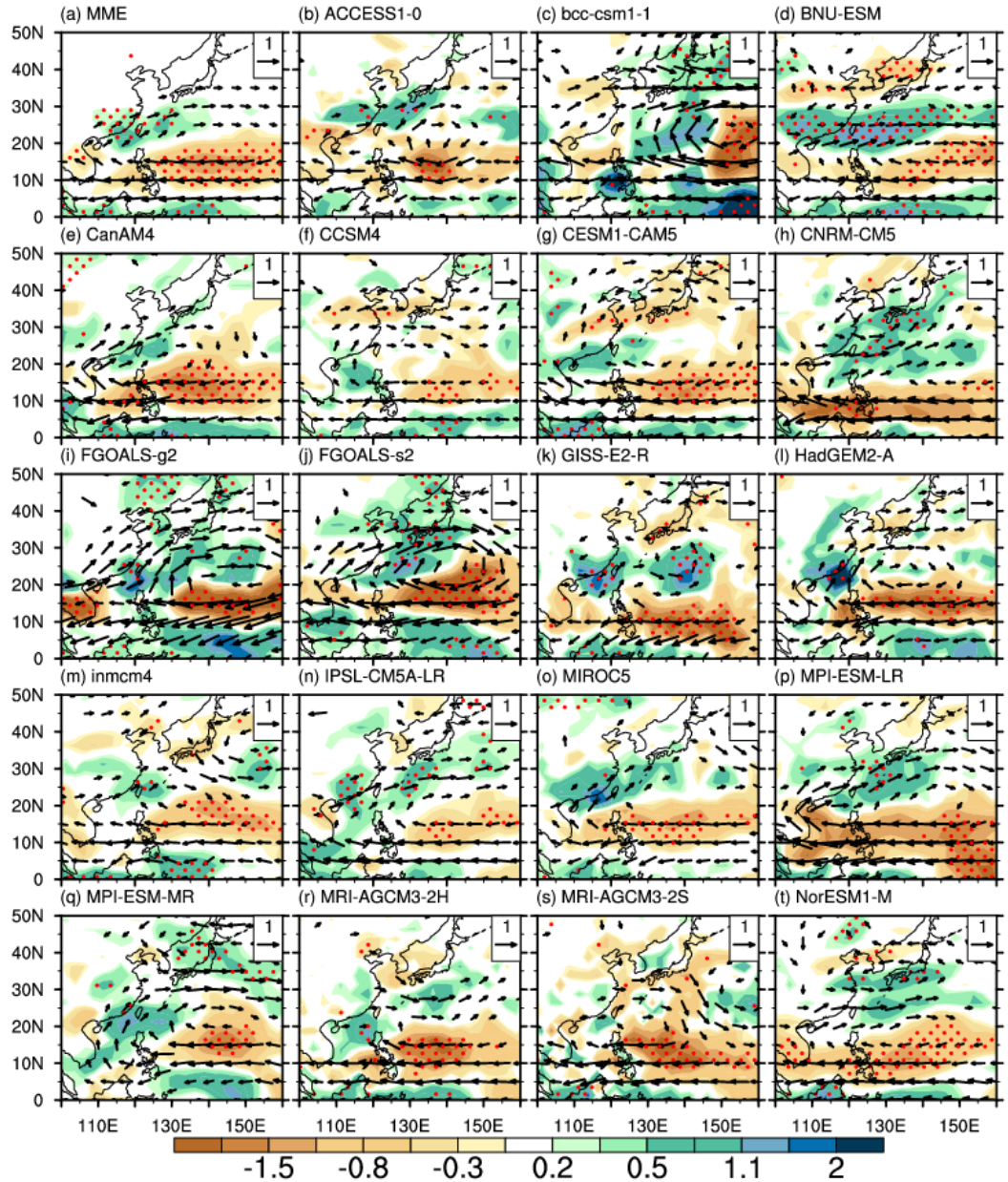
Blue line: CMIP5 AGCM MME

- The temporal phase of the EASM is reasonably reproduced in CMIP3 (0.70) and CMIP5 MME (0.68)

- The temporal correlation is also independent of horizontal resolution.

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

Inter-annual variability mode of EASM in CMIP5 AGCMs

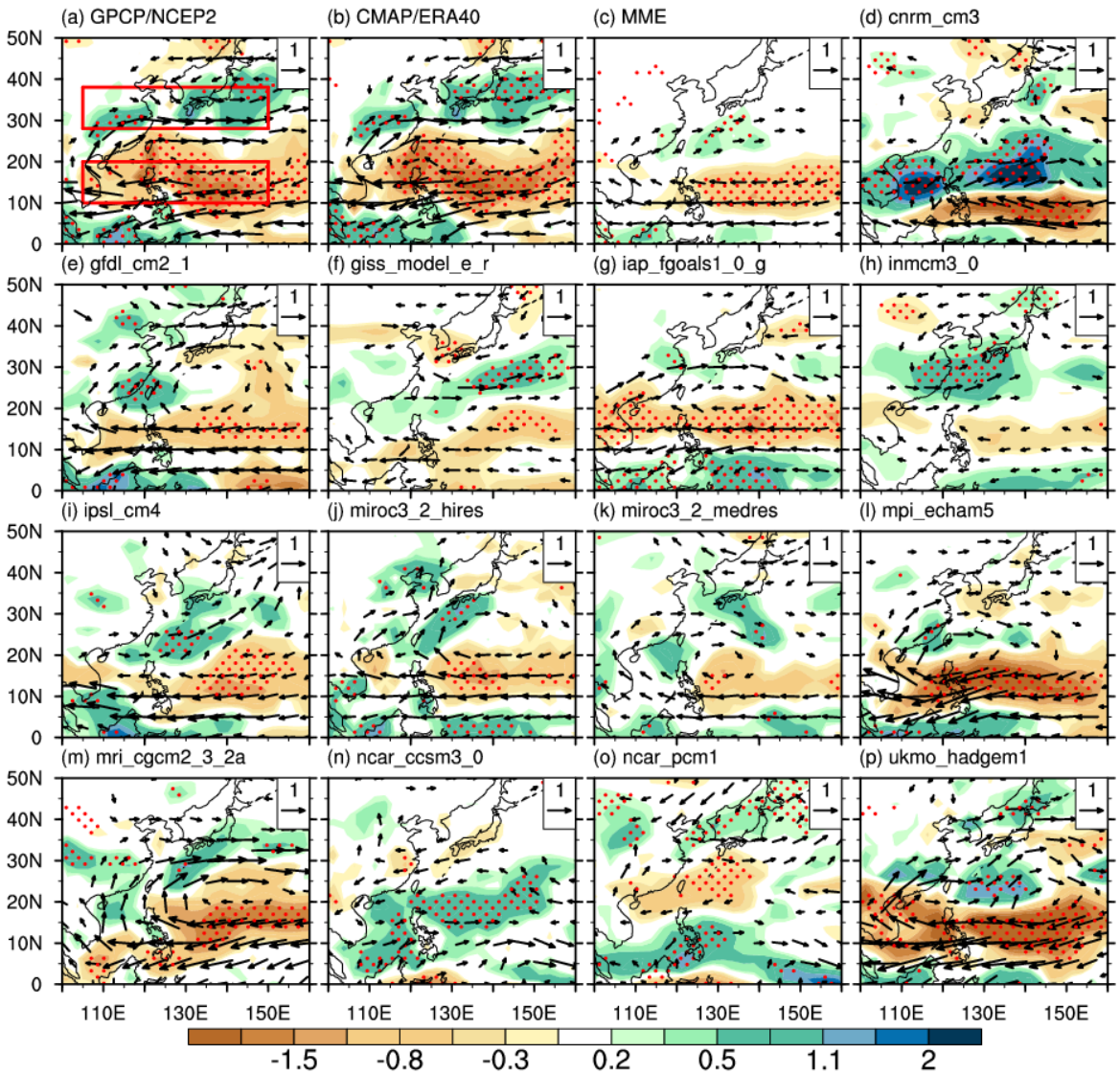


850 hPa wind and precipitation regressed on the observed EASM index

- **Two main deficiencies of rainfall pattern simulation also exist: weaker magnitude and more southward shift;**
- **The magnitude in rainfall pattern is improved from CMIP3 to CMIP5.**

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

Inter-annual variability mode of EASM in CMIP3 AGCMs

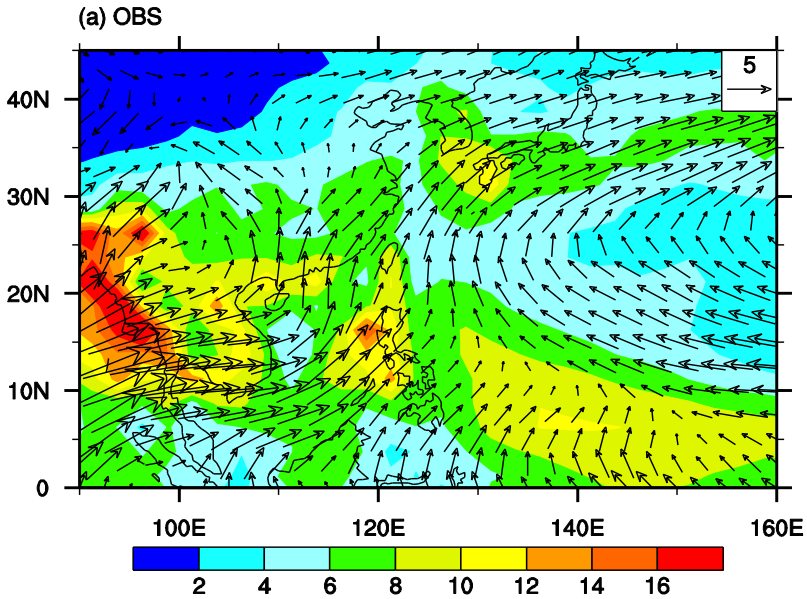


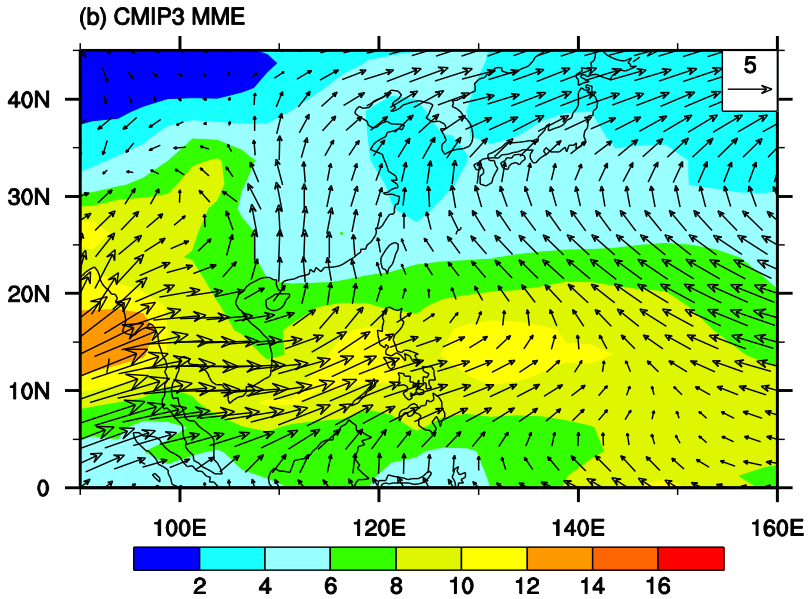
850 hPa wind and precipitation regressed on the observed EASM index

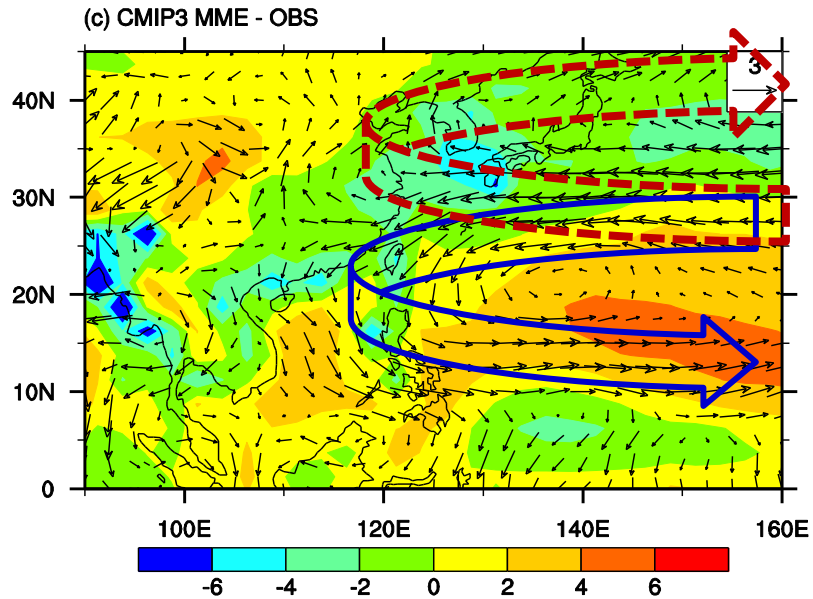
- **Two evident features: western Pacific anti-cyclone (WPAC) and dipole rainfall pattern;**
- **The WPAC is better reproduced than the dipole rainfall pattern;**
- **Two deficiencies: the weaker and southward shift of the dipole rainfall pattern.**

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

JJA mean UV850 and precipitation in CMIP3 models





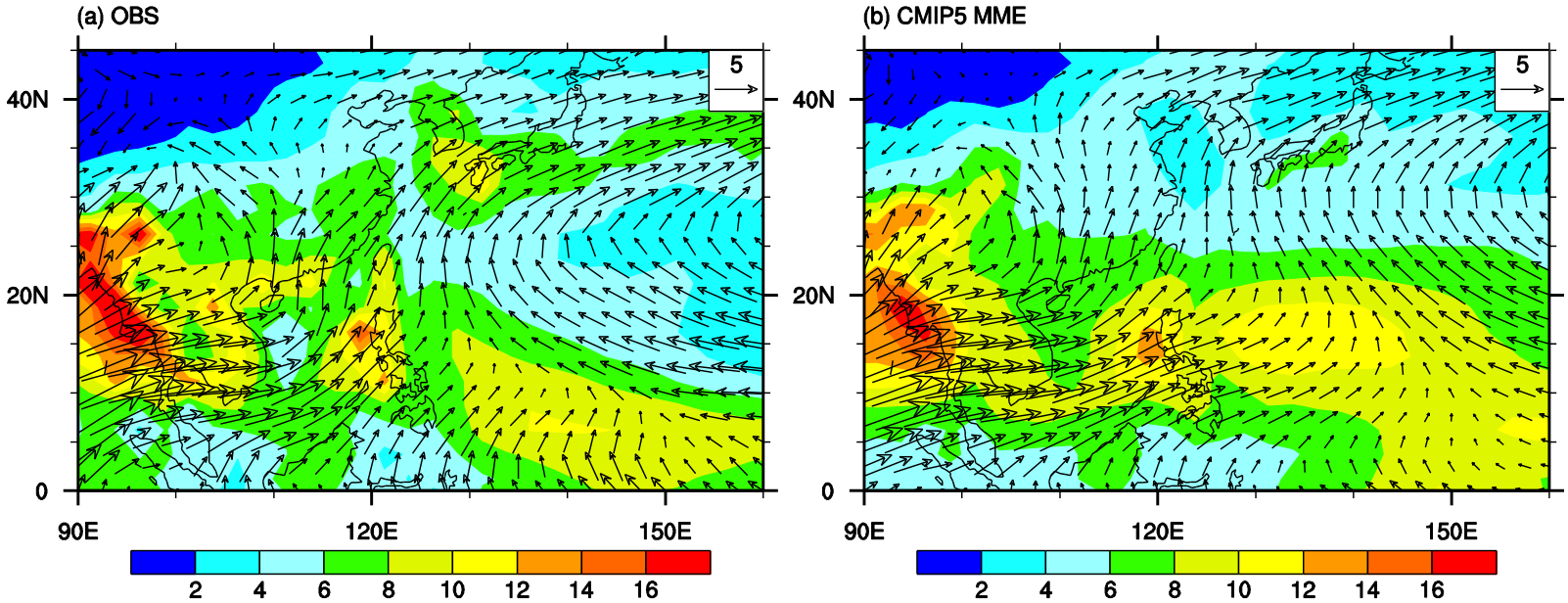


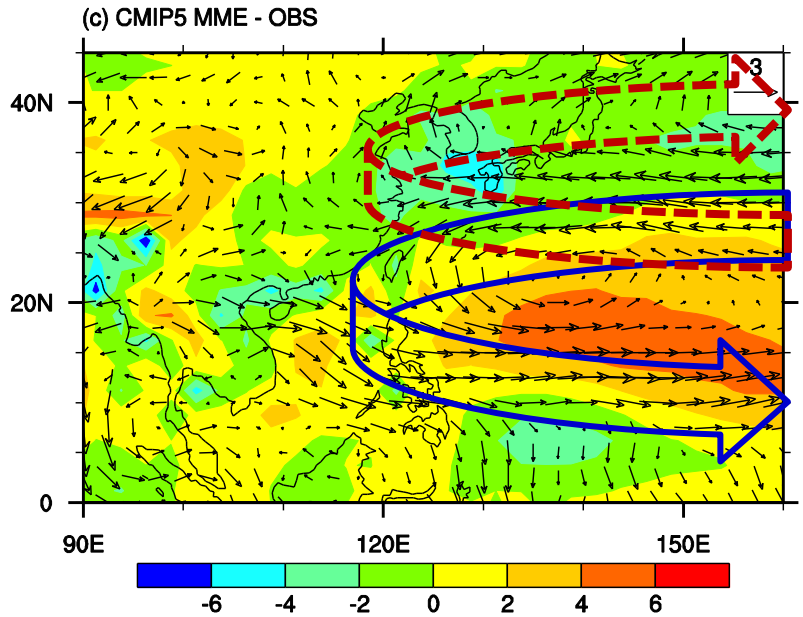
MME - OBS

- monsoon rainband poorly simulated
- Bias in subtropical high

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

JJA mean UV850 and precipitation in CMIP5 models





MME - OBS

- **Similar bias as CMIP3**

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

The skill score formula for inter-annual variability pattern

A measure of both spatial similarity and magnitude of rainfall pattern

$$\text{Skill Score} = \frac{(1+R)^2}{(SDR + \frac{1}{SDR})^2}$$

- **R: the pattern correlation between the observation and models;**
- **SDR: the ratio of spatial standard deviations of models against the observation.**

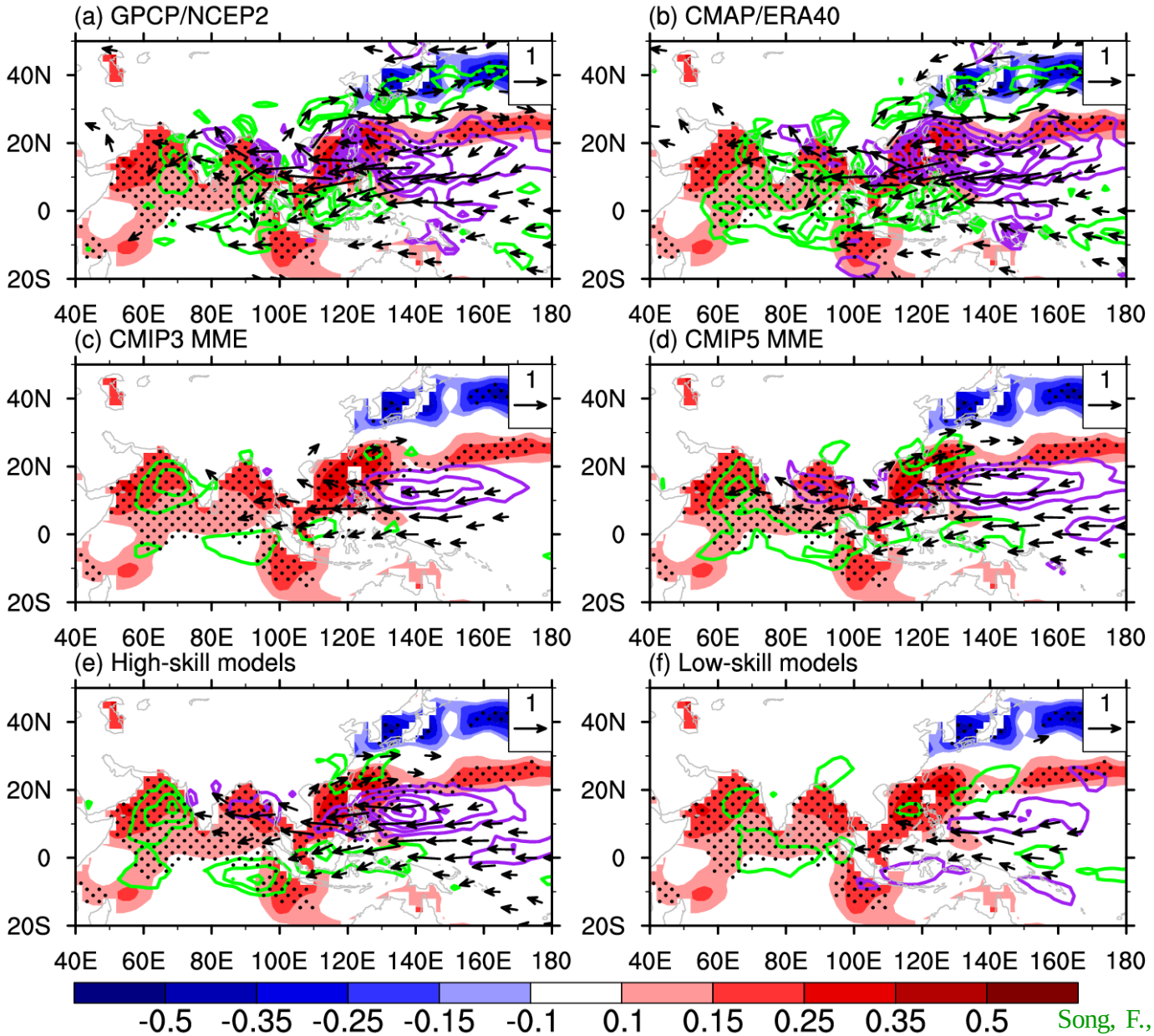
(Hirota et al., 2011)

The composite models based on precipitation skill

	High-skill models	Low-skill models
CMIP3	ipsl_cm4; mpi_echam5; mri_cgcm2_3_2a	cnrm_cm3; giss_model_e_r; inmcm3_0; ncar_ccsm3_0; ncar_pcm1
CMIP5	ACCESS1-0; CanAM4; MIROC5; MRI-AGCM3-2H; MRI-AGCM3-2S; NorESM1-M	bcc-csm1-1; CCSM4; CNRM-CM5

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

SST (shading), wind and rainfall (contour) in El Nino decaying year summers

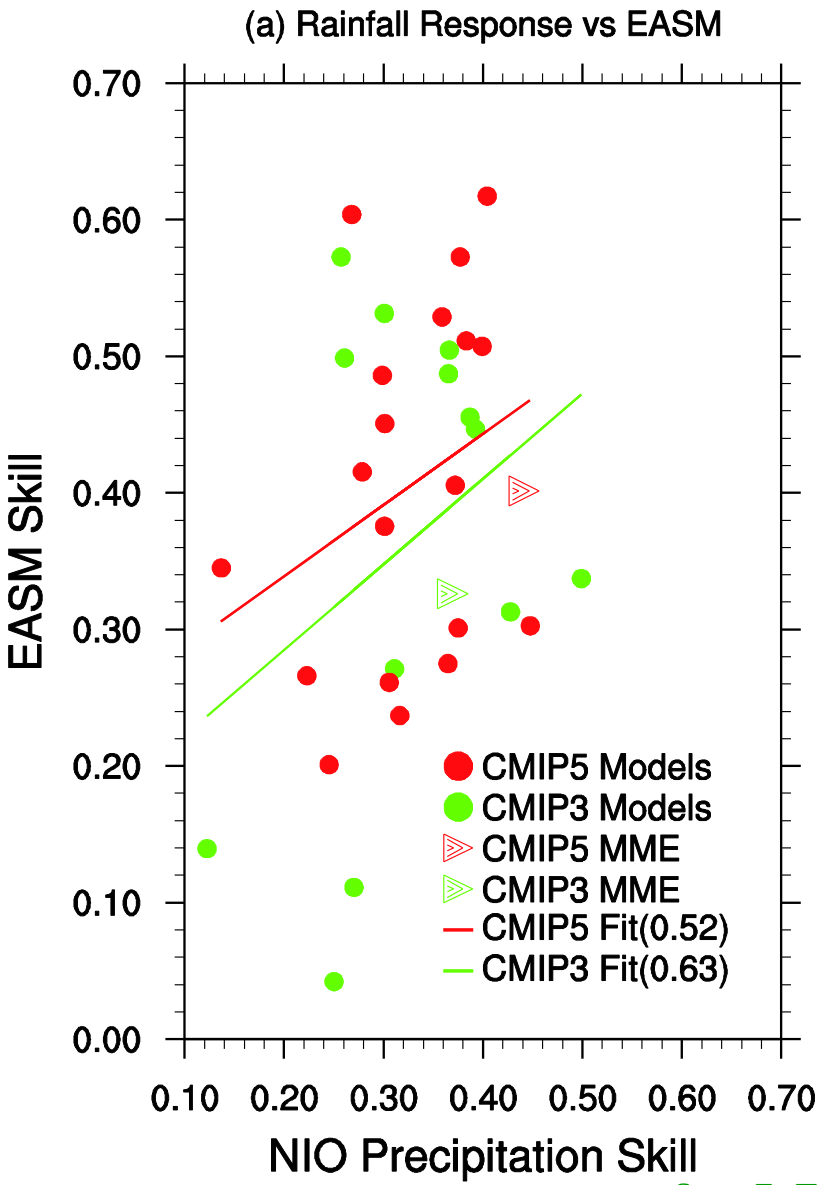


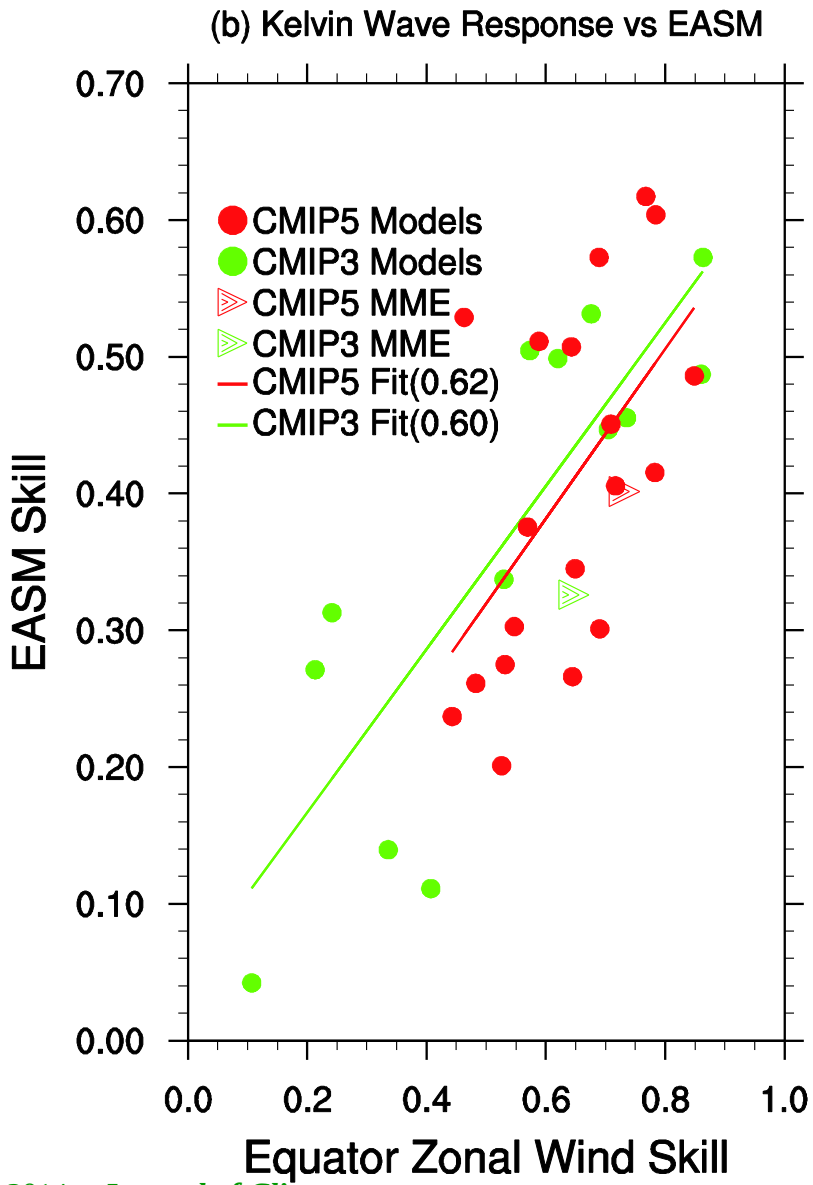
Contours: rainfall (green: positive; purple: negative)

- warmer IO
- more rainfall
- Kelvin wave response in the east, viz. WNPAC
- Improvement from CMIP3 to CMIP5 models

Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

North Indian Ocean (NIO) rainfall skill and equator zonal wind skill vs. EASM skill





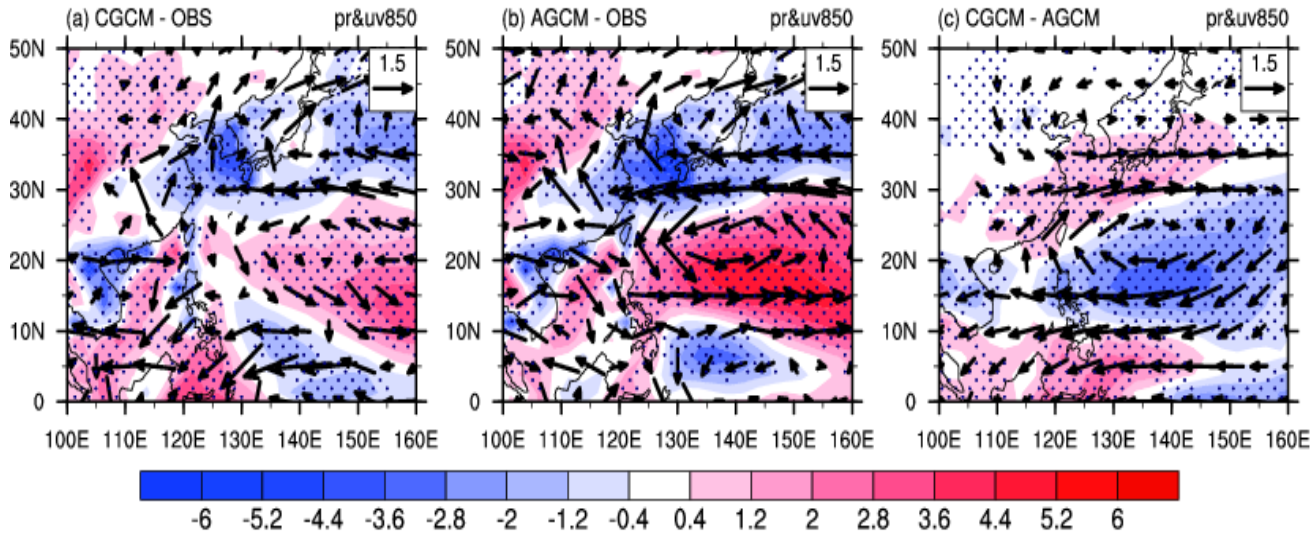
Song, F., **T. Zhou,** 2014a, ***Journal of Climate***

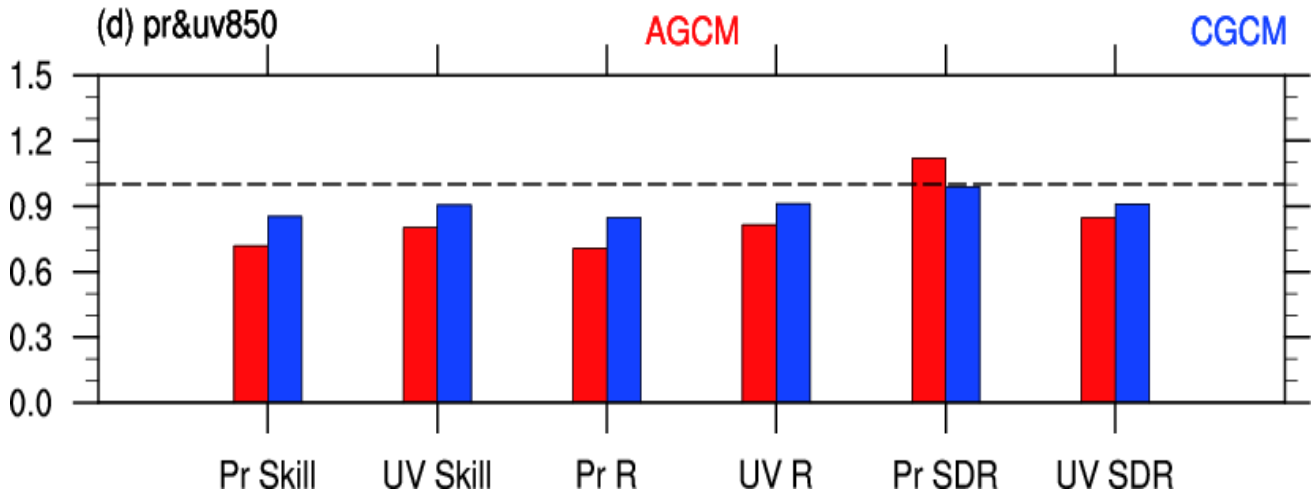
Model Details

Red: Both the AMIP and CGCM historical run in these models are used.

No.(HR ranking)	Institute	Model name	HR (lat*lon)	Category
1(8)	CSIRO-BOM	ACCESS1-0	144*192	L
2(8)	CSIRO-BOM	ACCESS1-3	144*192	L
3(29)	BCC	bcc-csm1-1	64*128	-
4(29)	BNU	BNU-ESM	64*128	H
5(29)	CCCma	CanESM2	64*128	-
6(2)	NCAR	CCSM4	192*288	H
7(2)	NSF-DOE-NCAR	CESM1-BGC	192*288	H
8(18)	NSF-DOE-NCAR	CESM1-CAM5-1-FV2	96*144	H
9(2)	NSF-DOE-NCAR	CESM1-CAM5	192*288	-
10(1)	CMCC	CMCC-CM	240*480	-
11(6)	CNRM-CERFACS	CNRM-CM5	128*256	-
12(15)	CSIRO-QCCCE	CSIRO-Mk3-6-0	96*192	L
13(34)	LASG-CESS	FGOALS-g2	60*128	H
14(21)	LASG-IAP	FGOALS-s2	108*128	-
15(22)	NOAA GFDL	GFDL-CM3	90*144	-
16(22)	NOAA GFDL	GFDL-ESM2G	90*144	L
17(22)	NOAA GFDL	GFDL-ESM2M	90*144	-
18(22)	NASA-GISS	GISS-E2-R	90*144	-
19(22)	NASA-GISS	GISS-E2-H	90*144	-
20(8)	NIMR-KMA	HadGEM2-AO	144*192	-
21(8)	MOHC	HadGEM2-CC	144*192	L
22(8)	MOHC	HadGEM2-ES	144*192	-
23(13)	INM	inmcm4	120*180	L
24(27)	IPSL	IPSL-CM5A-LR	96*96	-
25(14)	IPSL	IPSL-CM5A-MR	143*144	-
26(27)	IPSL	IPSL-CM5B-LR	96*96	-
27(6)	MIROC	MIROC5	128*256	-
28(29)	MIROC	MIROC-ESM	64*128	-
29(29)	MIROC	MIROC-ESM-CHEM	64*128	-
30(15)	MPI-M	MPI-ESM-LR	96*192	L
31(15)	MPI-M	MPI-ESM-MR	96*192	L
32(5)	MRI	MRI-CGCM3	160*320	H
33(18)	NCC	NorESM1-M	96*144	H
34(18)	NCC	NorESM1-ME	96*144	H

Improvement in climatology

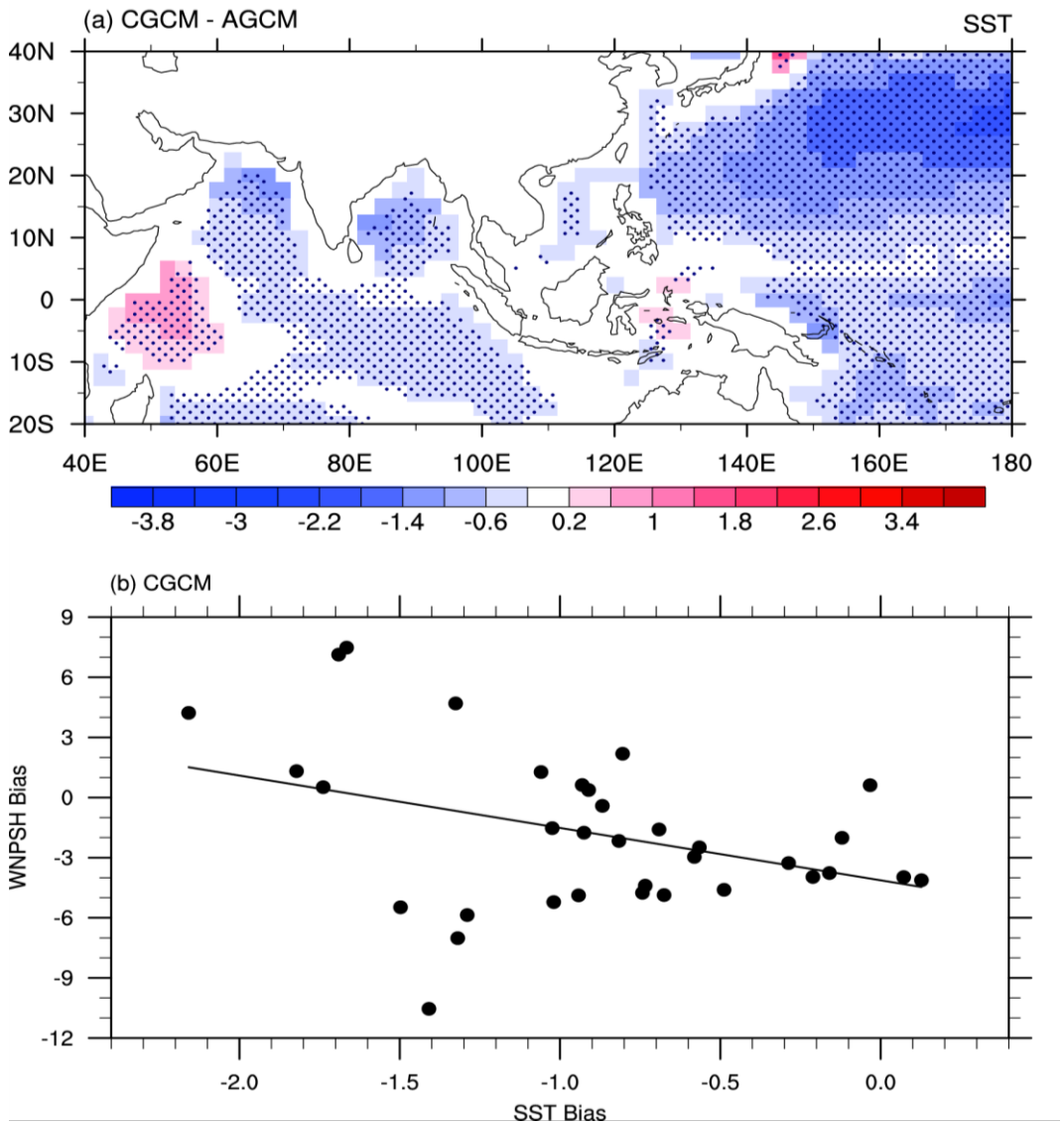




- Bias of CGCM resembles that of AGCM: cyclone bias over WNP and negative (positive) rainfall biases over monsoon rain band (WNP).
- Improvement from AGCMs to CGCMs: enhanced WNPSH; better monsoon rainband and WNP precipitation.
- Pattern Correlation is improved from 0.71 to 0.85 from AGCMs to CGCMs for precipitation, from 0.81 to 0.91 for 850 wind.

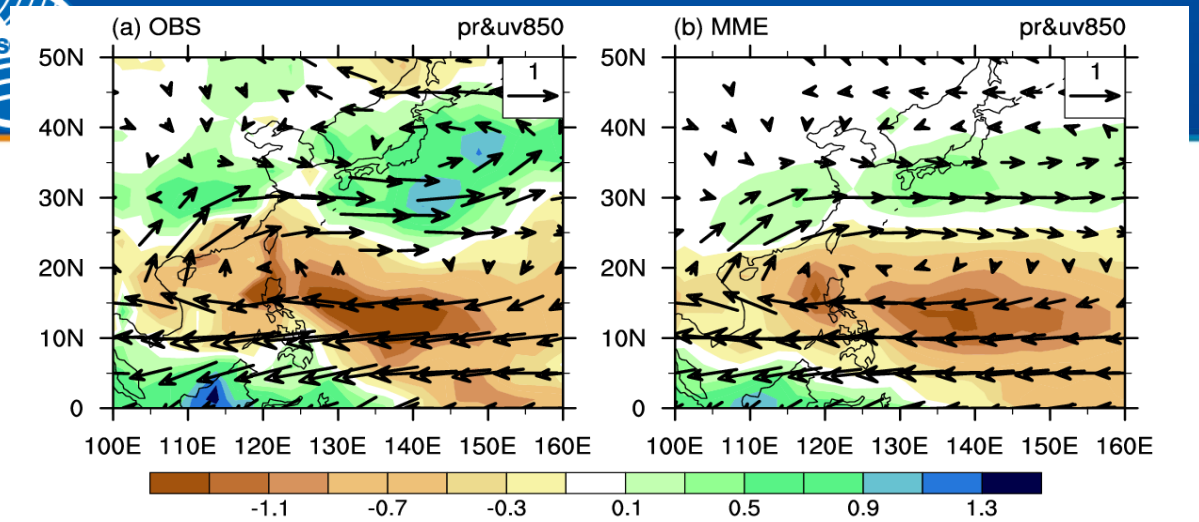
Song Fengfei, **Tianjun Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? **Journal of Climate**, 27, 8761-8777

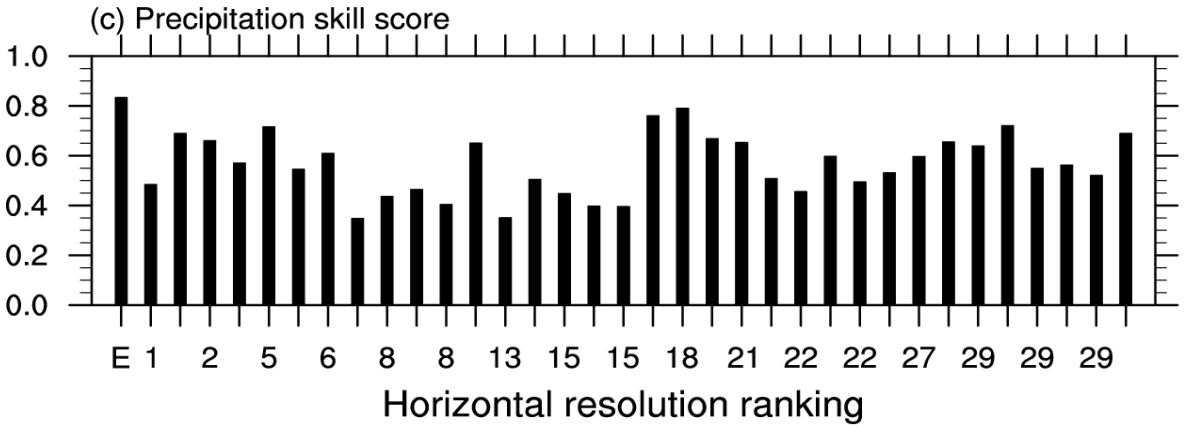
Climatology is improved at a cost of SST bias in the W. Pacific

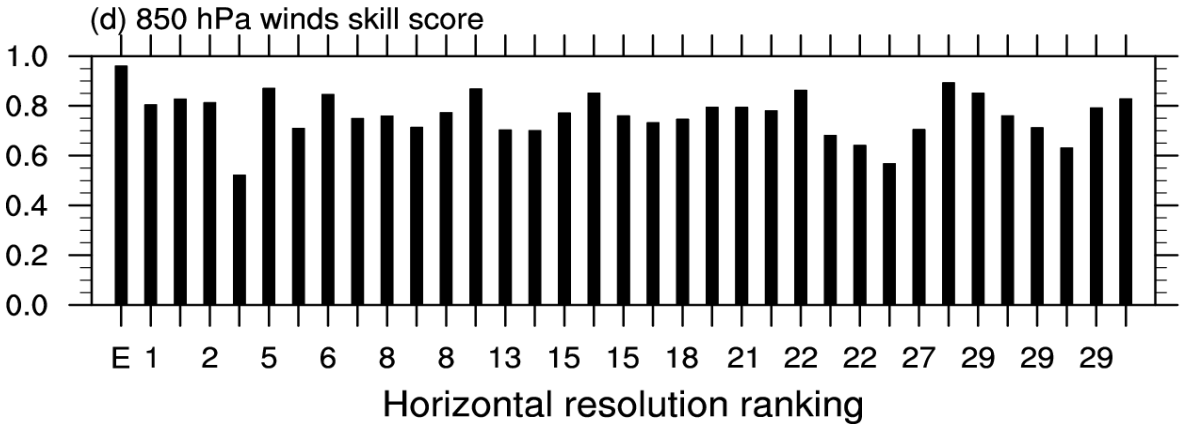


- Colder SST bias
- enhanced WPSH
- Local convection suppressed
- Enhanced water vapor transport
- Better monsoon rainband

Song Fengfei, **Tianjun Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? **Journal of Climate**, 27, 8761-8777







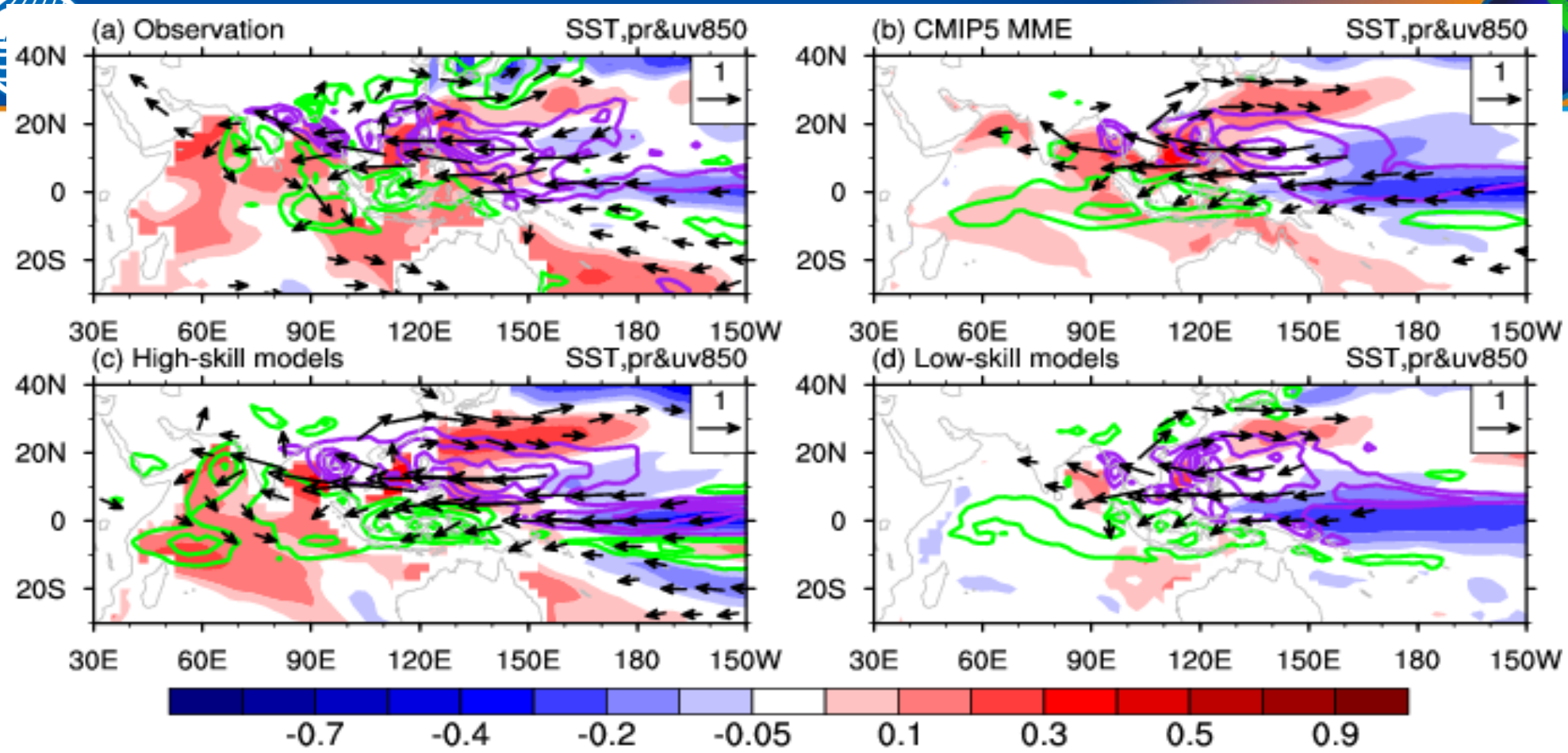
- The western Pacific anticylone (WPAC) is well simulated;
- The southern lobe of the dipole rainfall pattern is better simulated than the northern lobe.
- The 850 wind is better simulated than the precipitation.

High-skill models (8):

BNU-ESM, CCSM4, CESM1-BGC, CESM1-CAM5-1-FV2, FGOALS-g2, MRI-CGCM3, NorESM1-M, NorESM1-ME.

Low-skill models (8):

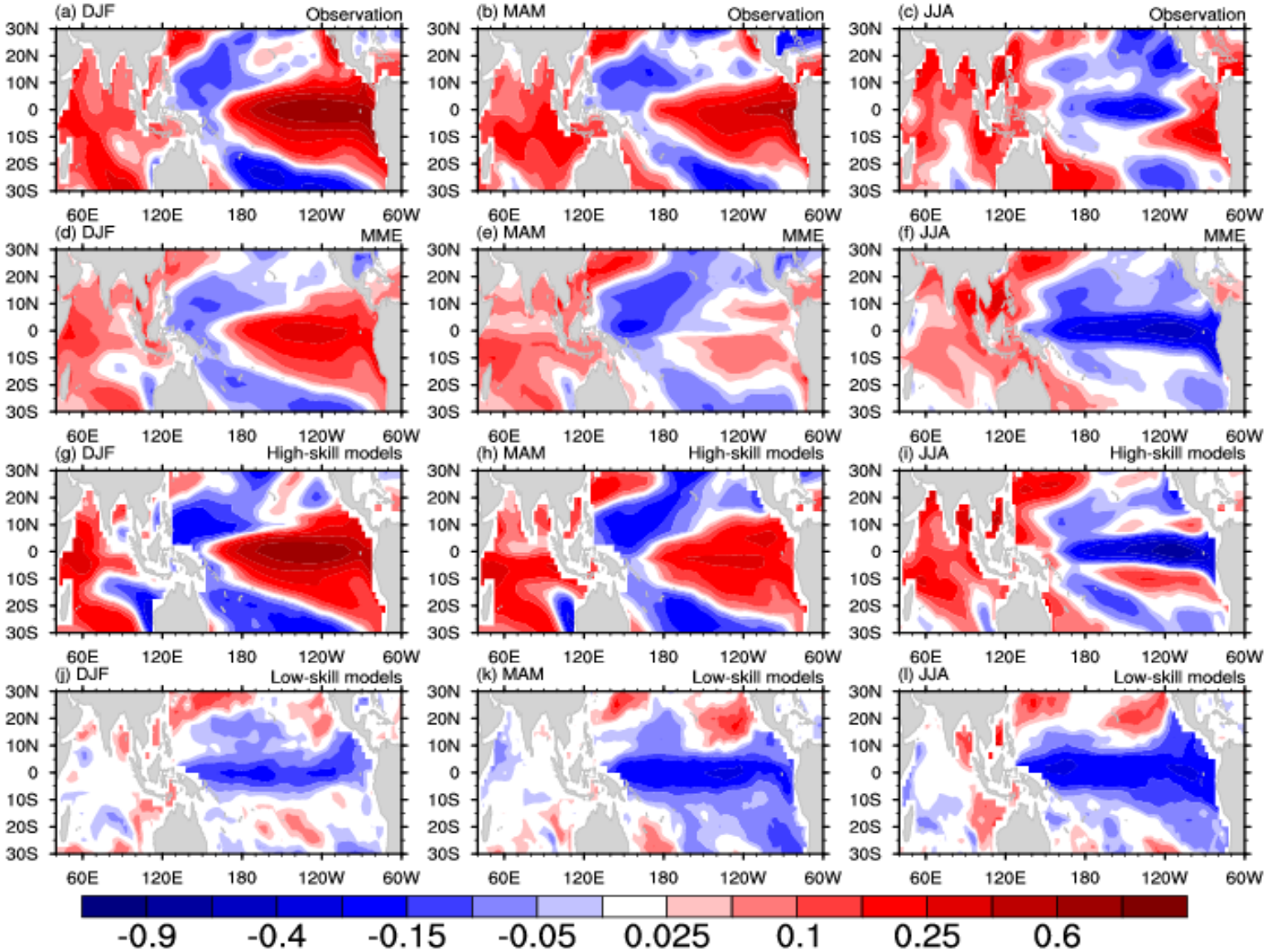
ACCESS1-0, ACCESS1-3, CSIRO-Mk3-6-0, GFDL-ESM2G, HadGEM2-CC, inmcm4, MPI-ESM-LR, MPI-ESM-MR.



• In the observation, the stronger EASM is related to the warmer TIO SST and cooler CP SST. However, in the CMIP5 MME, The TIO warming is weaker but CP cooling is stronger.

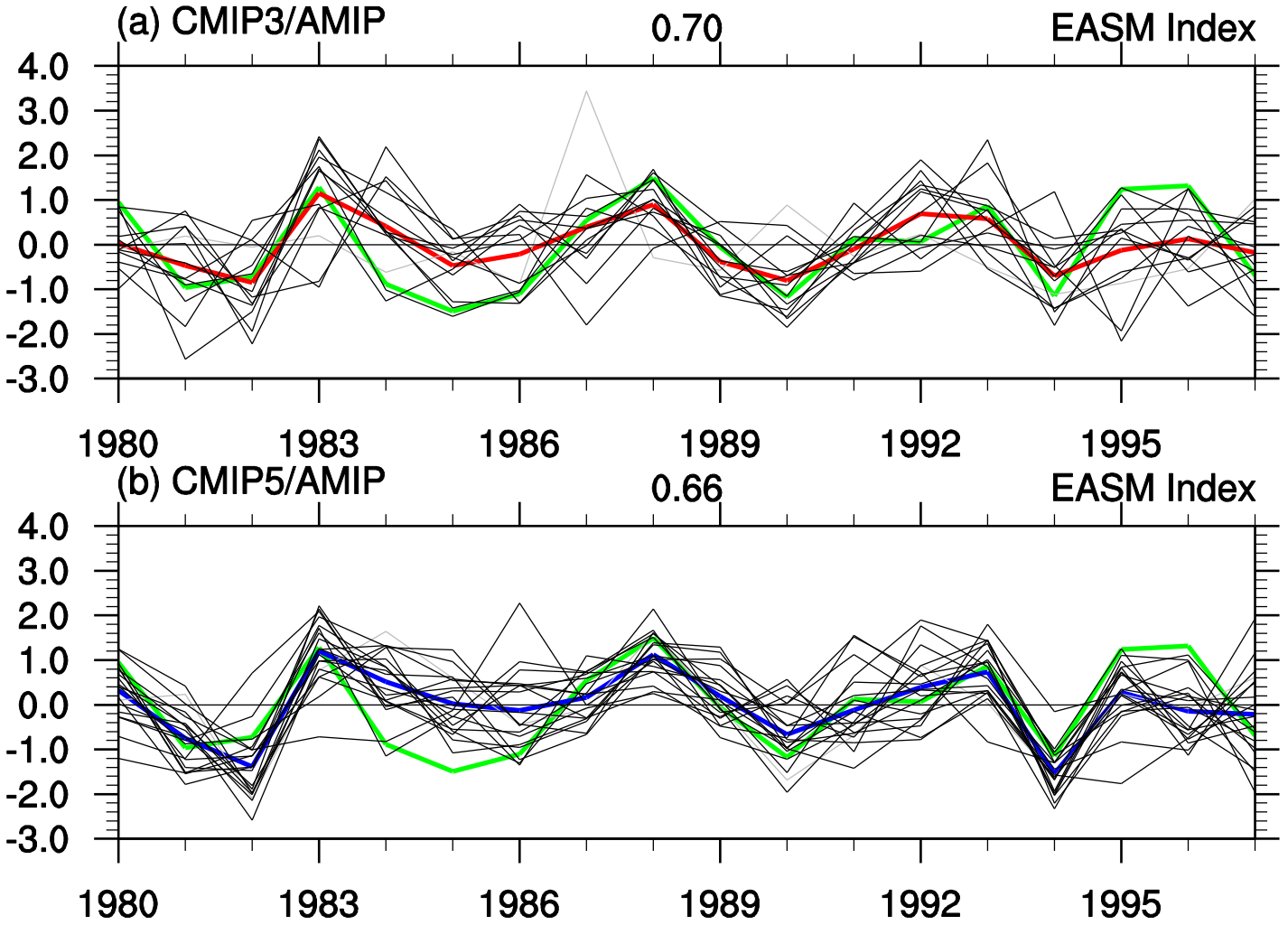
•In the HSMs, the TIO warming and related precipitation are stronger than LSMs. suggesting that the TIO warming and related precipitation are important for EASM simulation.

Song, F., **T. Zhou,** 2014b, ***Journal of Climate***



• In the high-skill models, the observed magnitude and evolution of ENSO is well captured, while the SST in the preceding winter in the low-skill models is not corresponding to ENSO. (CSIRO-Mk3-6-0, inmcm4, MPI-ESM-LR, MPI-ESM-MR)

EA summer monsoon index defined as wind shear along WPSH



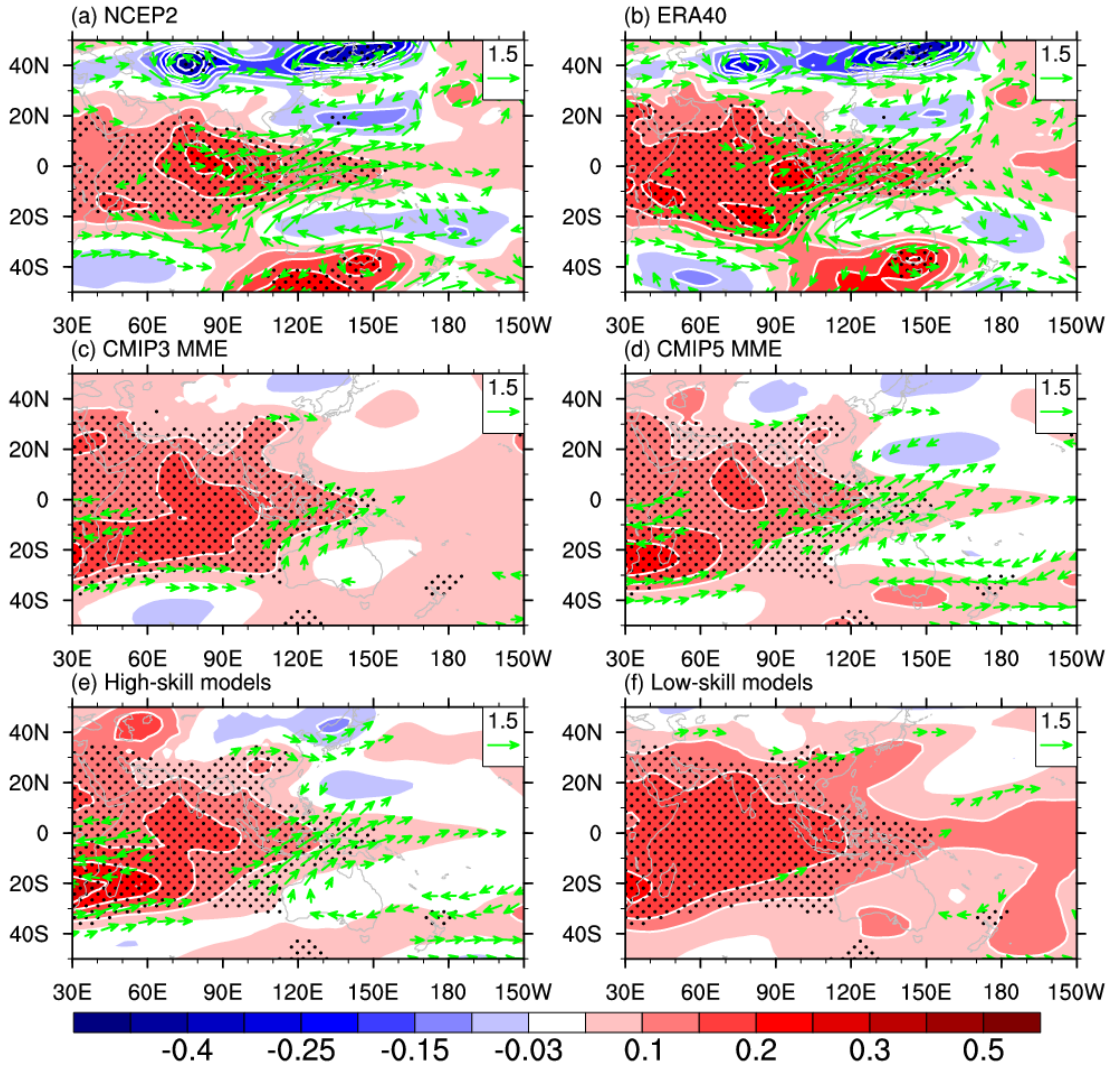
green line: NCEP2

red line: CMIP3 MME

Blue line: CMIP5 MME

- Correlation coefficients for **CMIP3 (0.70)** and **CMIP5 MME (0.66).**
- **Comparable**

Tropospheric temperature and 200 hPa wind regressed on the observed EASM index



- In the observation, Indian Ocean (IO) appears as the heat source for Gill pattern, with Rossby wave to the west and Kelvin wave to the east;
- The Gill-pattern shape and high-level Kelvin wave response is better capture in high-skill models.