Interannual variability in East Asian summer rainfall: CMIP5 vs CMIP3

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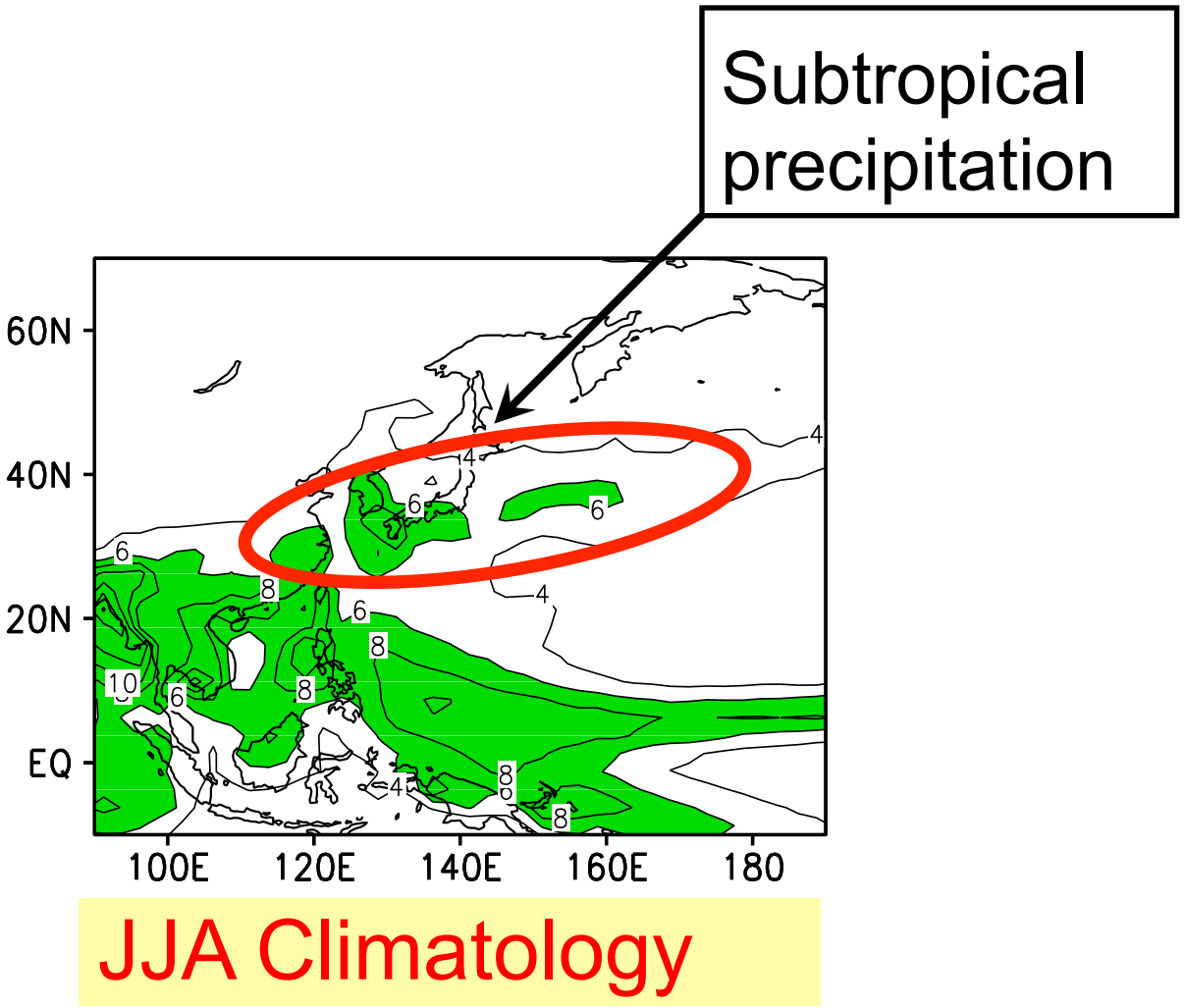
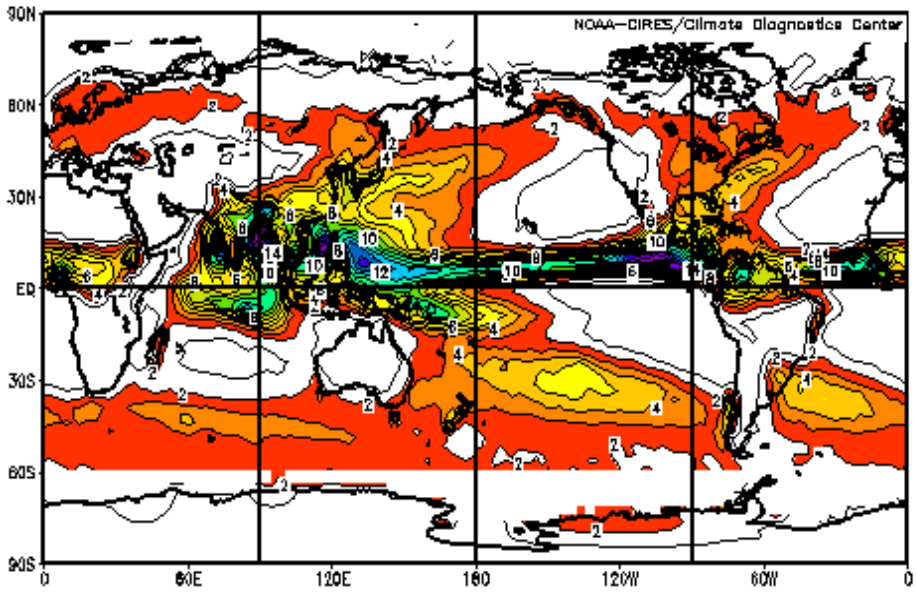
ITCP-Monsoons and Climate Change

Outline

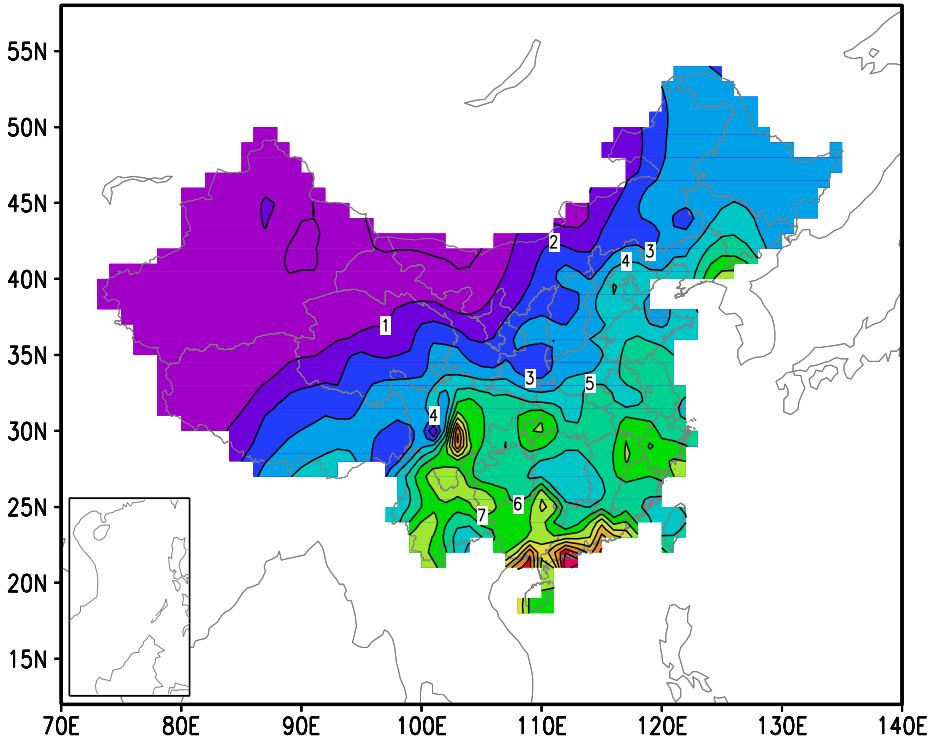
- Introduction
- Relationship to ENSO
- Projected change
- Summary


Subtropical precipitation
60N
40N
20N
EQ
100E
120E
140E
160E
180
JJA Climatology

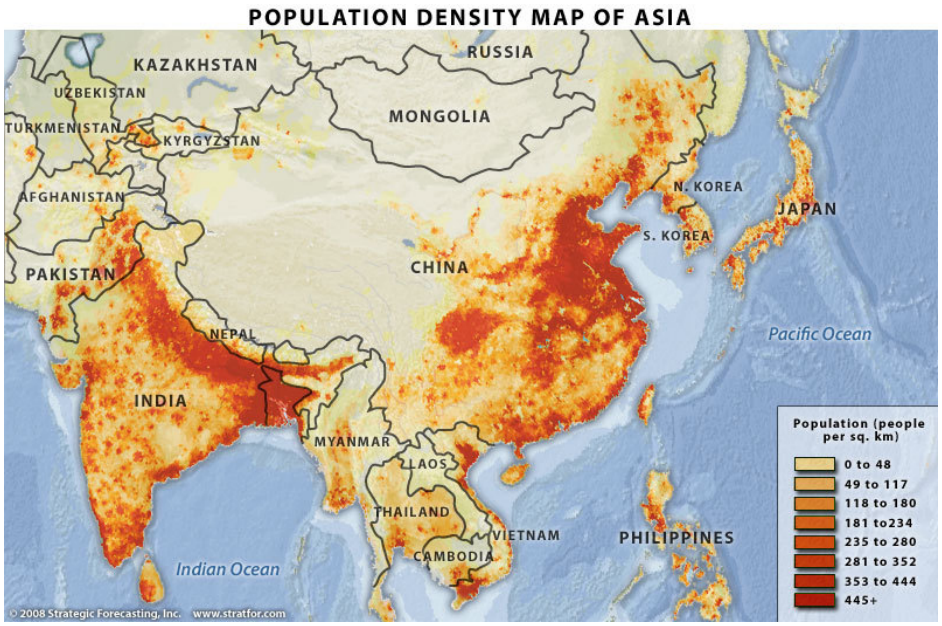
Summer rainfall

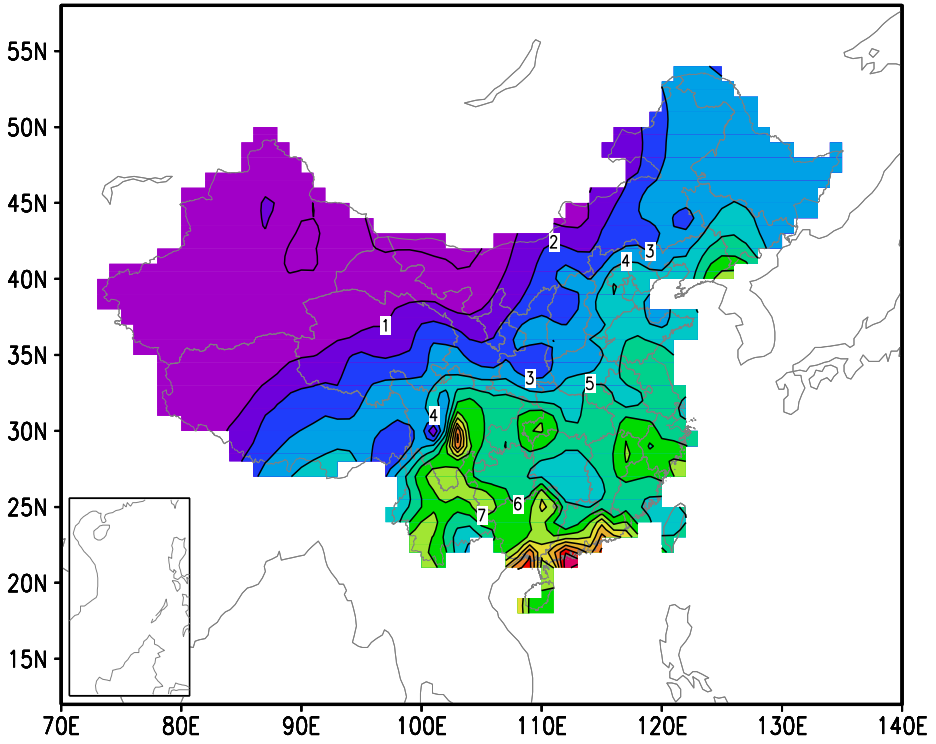


China station rainfall



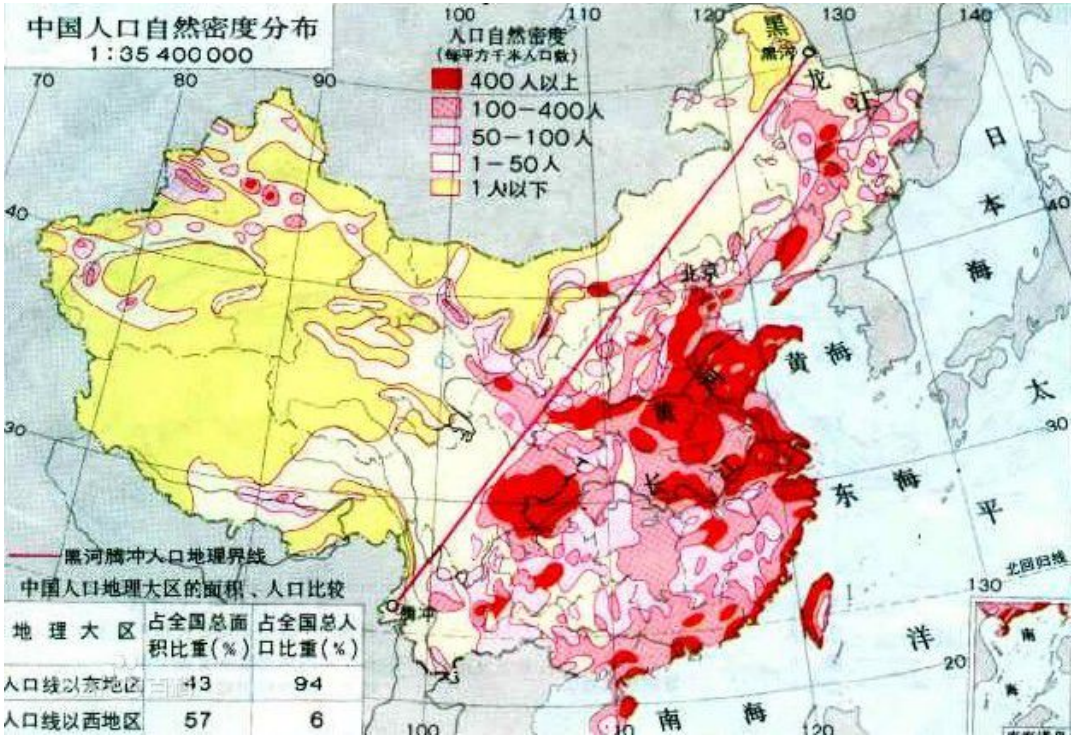
Consistency between population density and rainfall



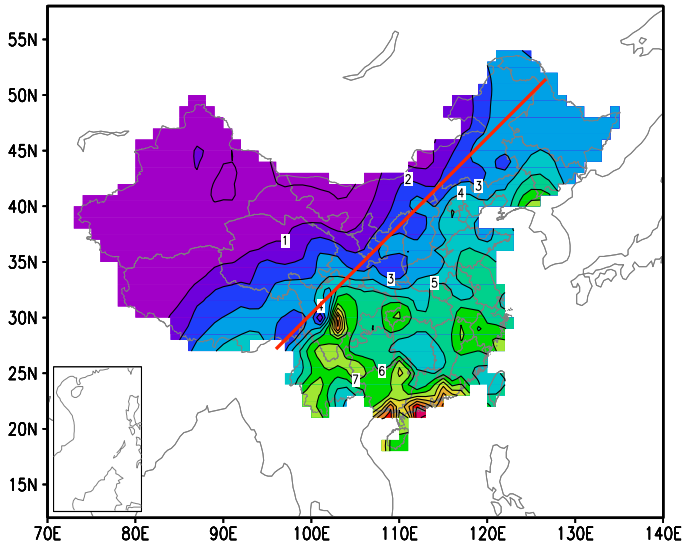


<u>Rainfall is important for human life</u>

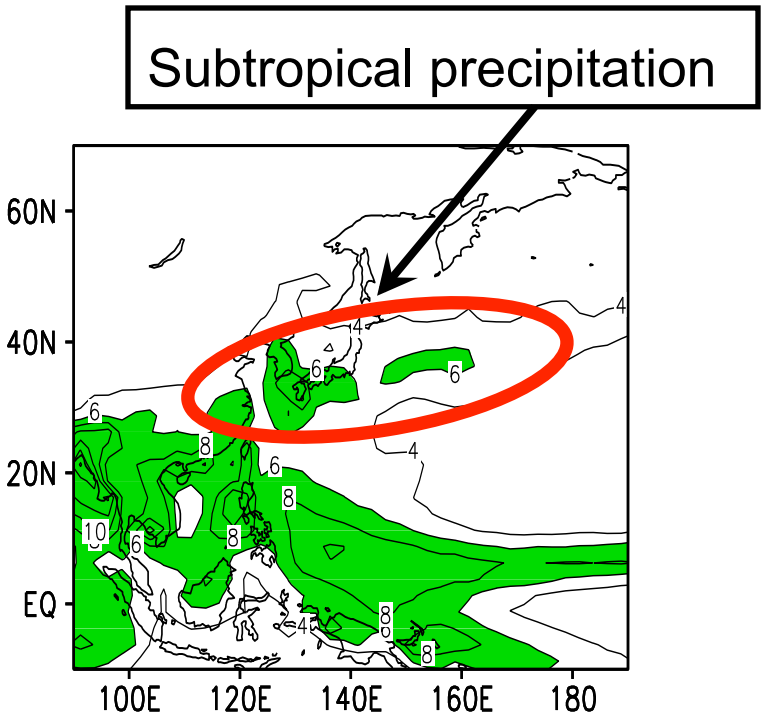
Population in East and West China



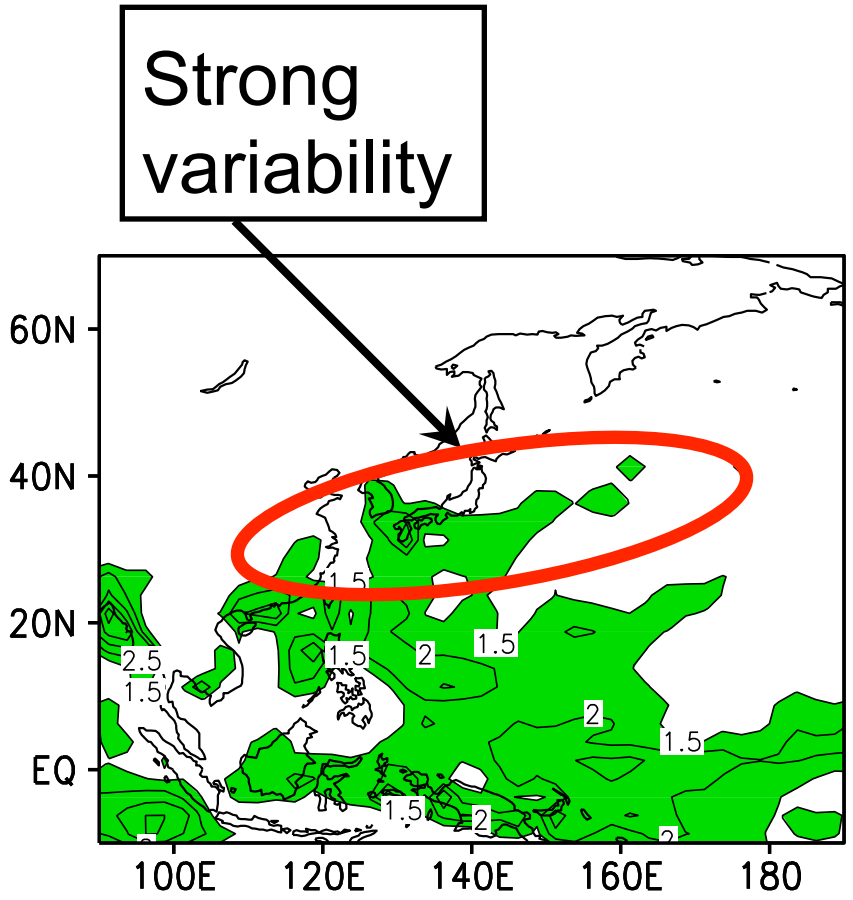
China rainfall



	Area	Population
East	43%	94%
West	57%	6%



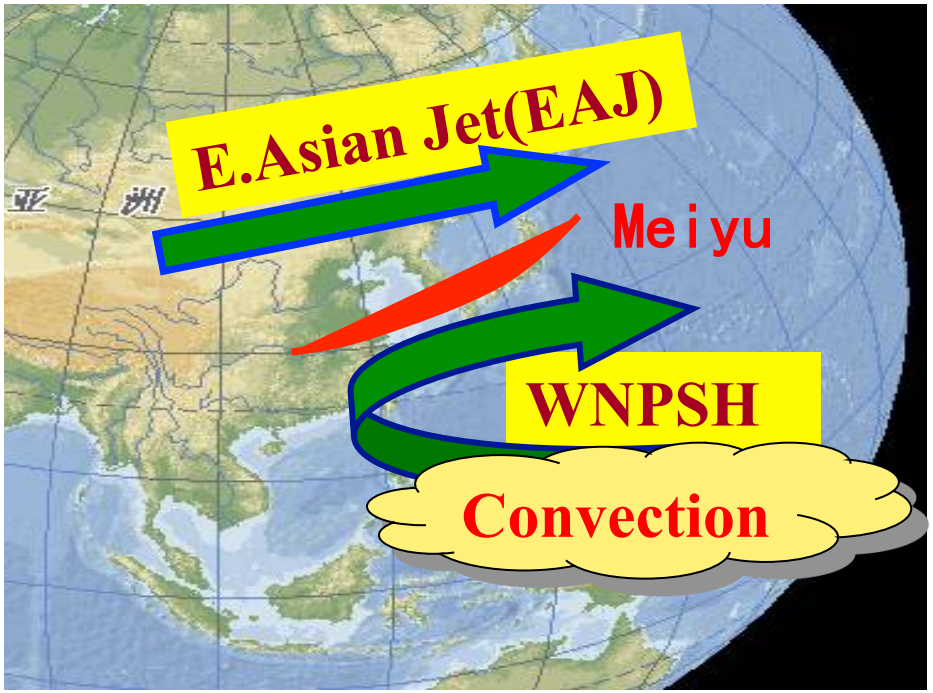
JJA Climatology



Interannual Standard Deviation

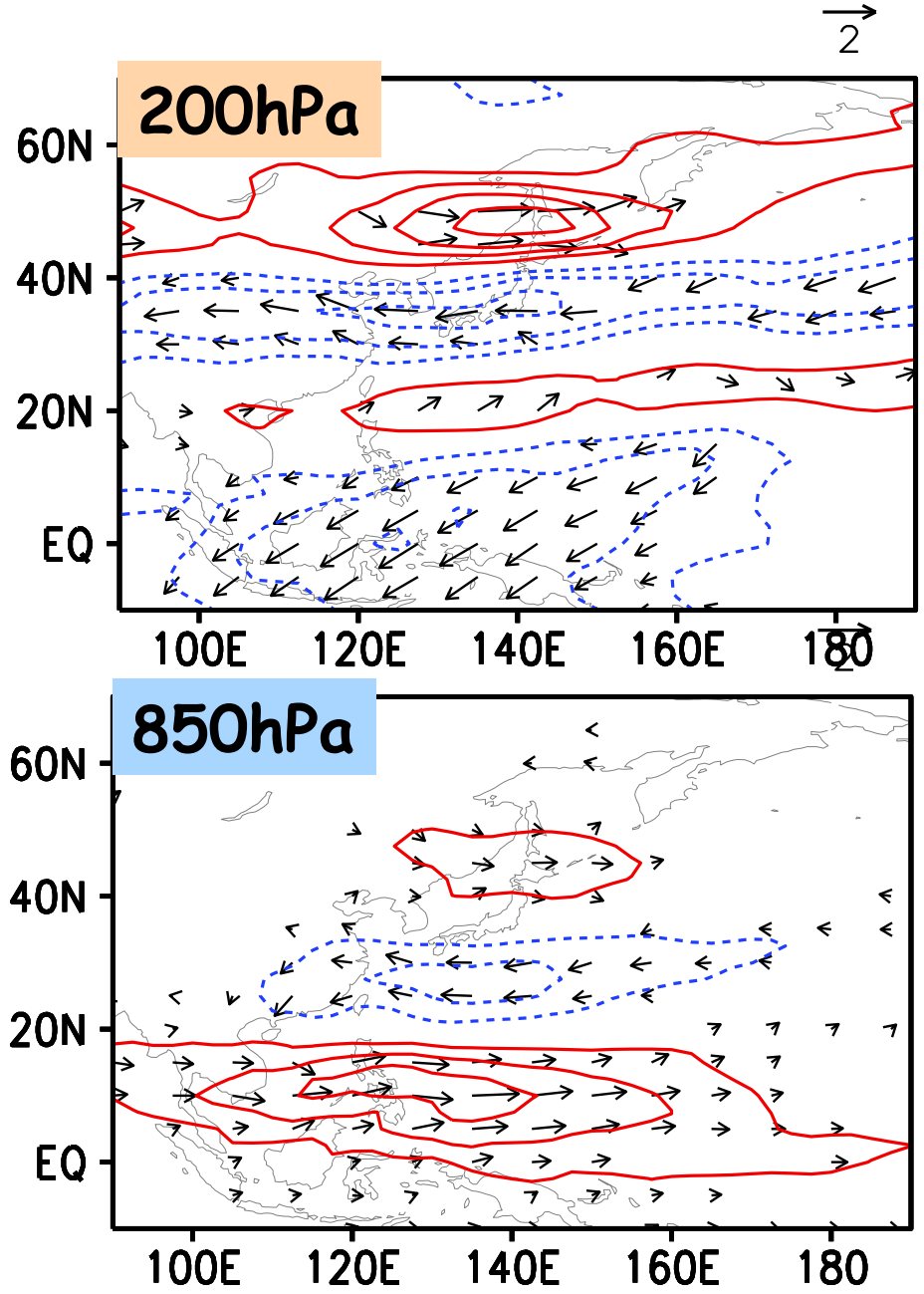
Floods and droughts occur frequently in East Asia

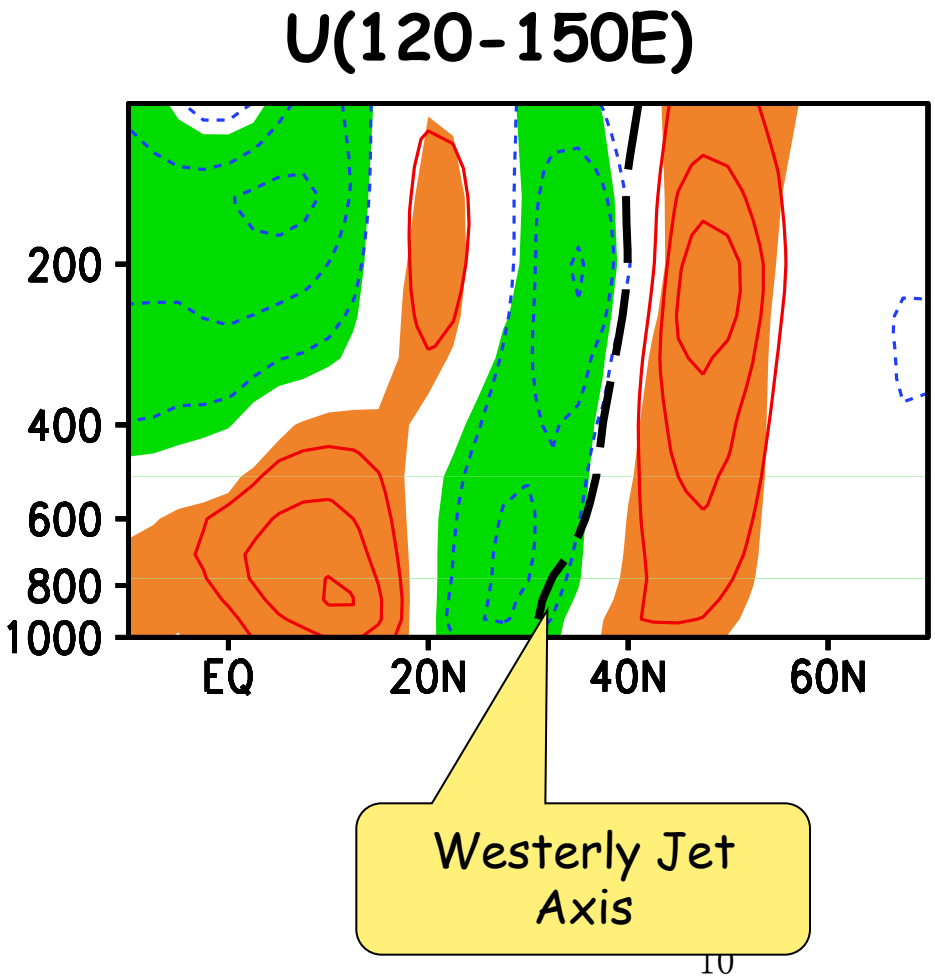
Major components of EASM system



There are meridional teleconnections on the interannual timescale

3-D structure of the Meridional Teleconnection

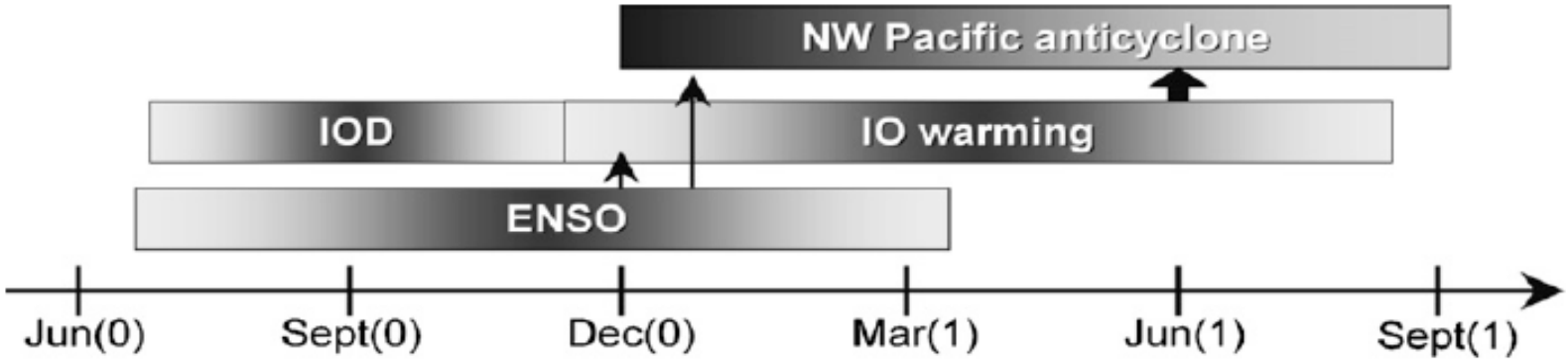




ENSO – Indian Ocean SST – WNP anticyclone – East Asian Summer Rainfall

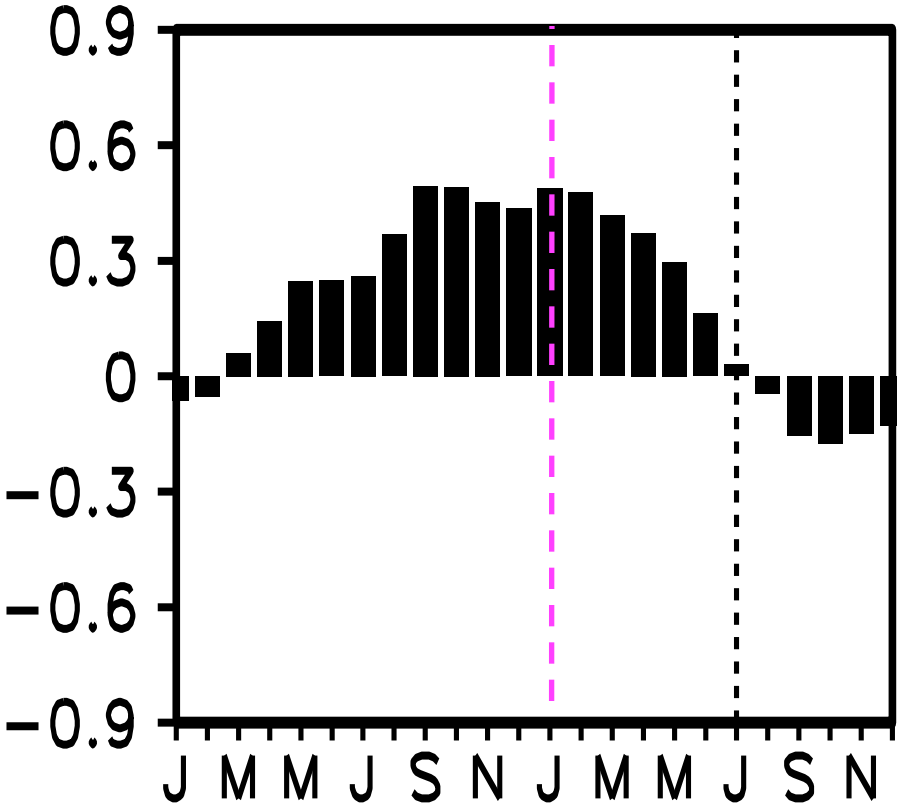
(e.g., Huang and Wu, 1989; Wang et al., 2000; Li et al. 2008; Xie et al. 2009)

Indian Ocean capacitor



Xie et al., 2009, JCL

- ENSO events in winter are used as a predictor by East Asian meteorologists to forecast summer precipitation anomaly.



Q:*Can models capture this ENSO–EASR relationship?*

Correlation coefficient between East Asian summer rainfall and monthly Nino3.4

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18 models in CMIP3

Model I.D.	Abbreviation	Atmospheric Resolution
BCCR-BCM2.0	*bcm2.0*	128 × 64, L17
CCSM3	*ccsm*	256 × 128, L17
CGCM3.1(T47)	*cgcm47*	96 × 48, L17
CGCM3.1(T63)	*cgcm63*	128 × 64, L17
CNRM-CM3	*cnrm*	128 × 64, L17
CSIRO-MK3.0	*csiro3.0*	192 × 96, L17
CSIRO-MK3.5	*csiro3.5*	192 × 96, L17
ECHAM5/MPI-OM	*echam*	192 × 96, L16
FGOALS-G1.0	*fgoals*	128 × 60, L17
GFDL-CM2.0	*gfdl2.0*	144 × 90, L17
GFDL-CM2.1	*gfdl2.1*	144 × 90, L17
GISS-EH	*giss*	72 × 46/45, L17
UKMO-HadCM3	*hadcm3*	96 × 73/72, L15
UKMO-HadGEM1	*hadgem*	192 × 145, L16
MIROC3.2(hires)	*miroch*	320 × 160, L17
MIROC3.2(medres)	*mirocm*	128 × 64, L17
MRI-CGCM2.3.2	*mricgcm*	128 × 64, L17
PCM	*pcm*	128 × 64, L17

Method and data

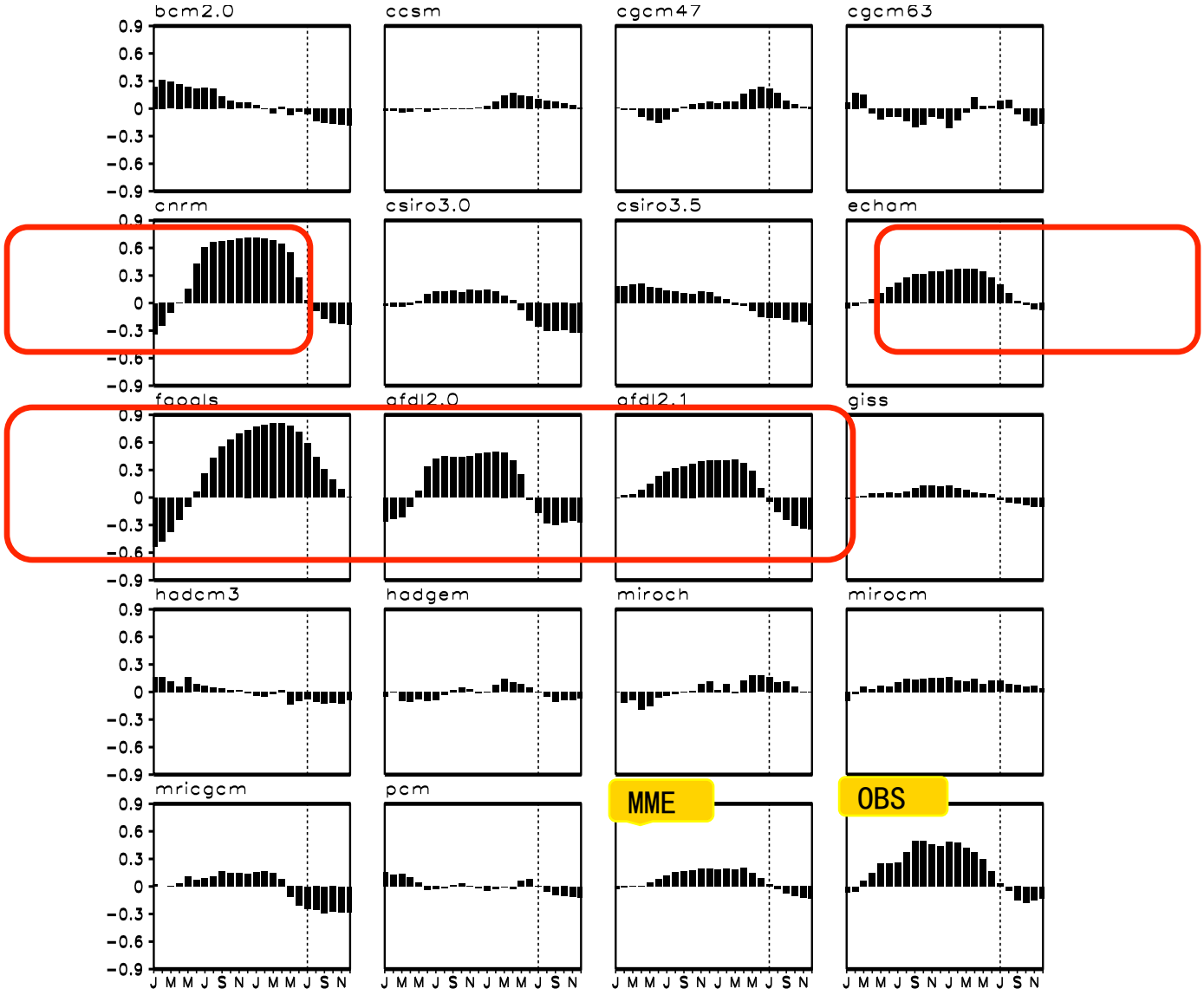
- 9-year gauss filter is used to obtain the component of interannual variability.
- Models:

  20th century (1901-2000), 21st century (2001-2100)

  Observations:

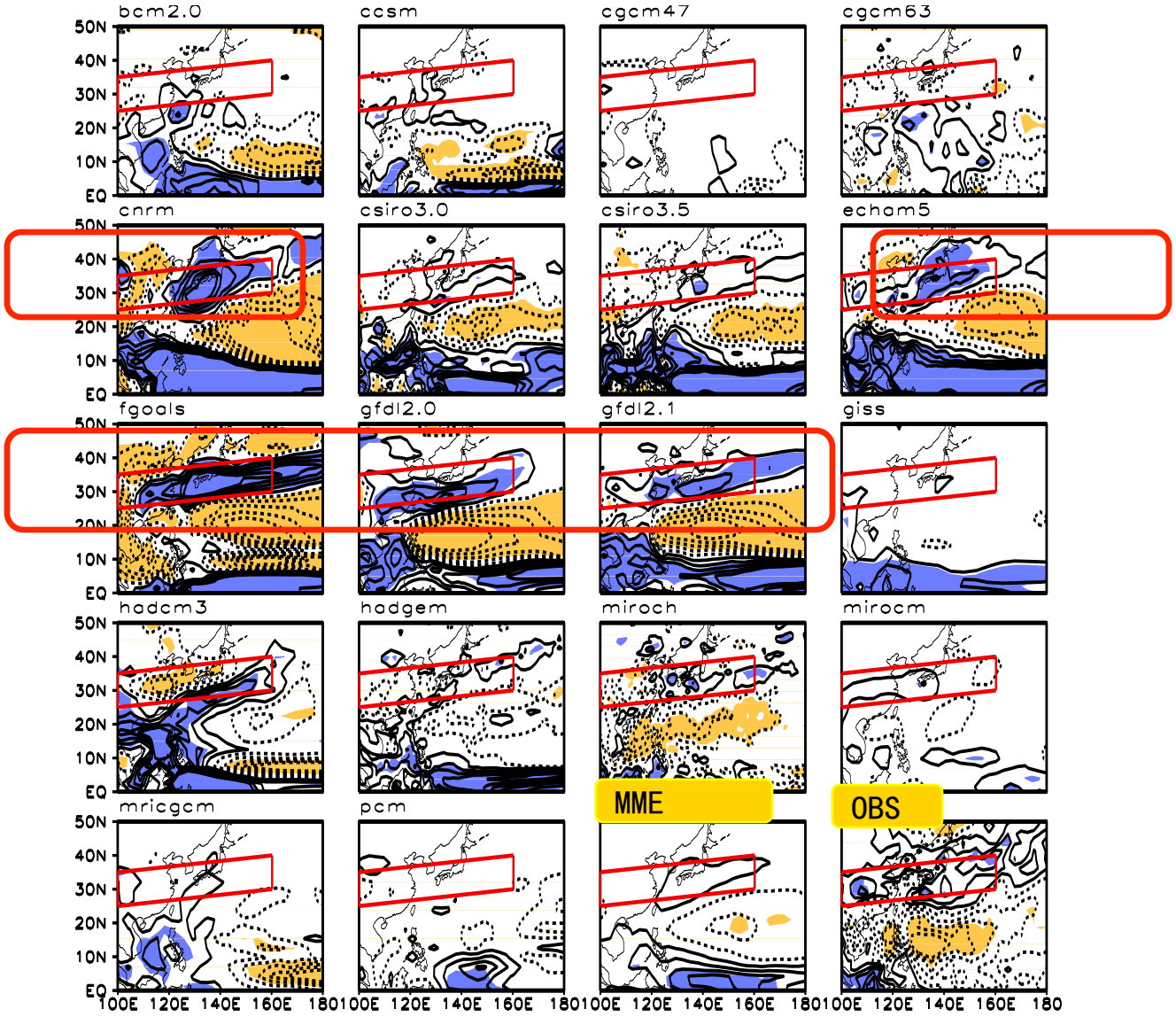
  NCEP-NCAR (1958-2007), GPCP (1979-2007)

CC(EASR, monthly Nino3) in CMIP3



Fu et al., 2013, *J. Geophys. Res. Atmos.*

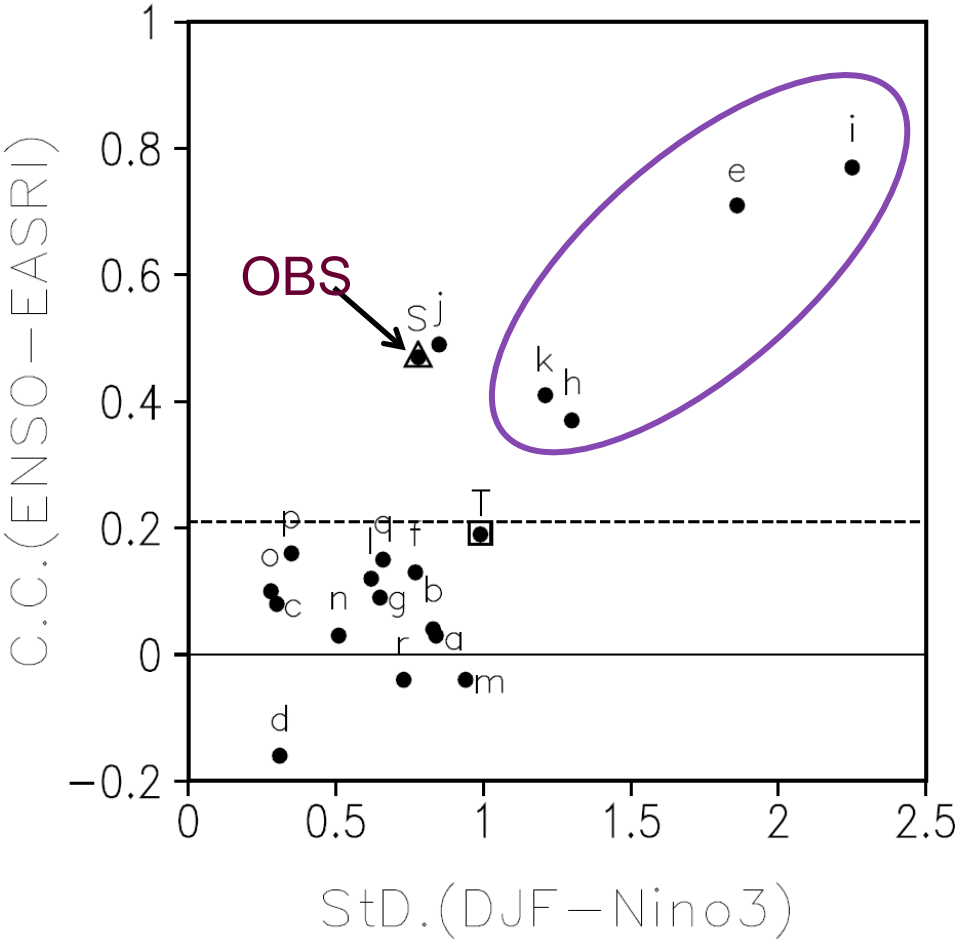
DJF Nino3-regressed summer rainfall in CMIP3



5/18

Fu et al., 2013, *J. Geophys. Res. Atmos.*

In CMIP3, the models capturing ENSO-EASR relationship strongly overestimate ENSO



Fu et al. 2013

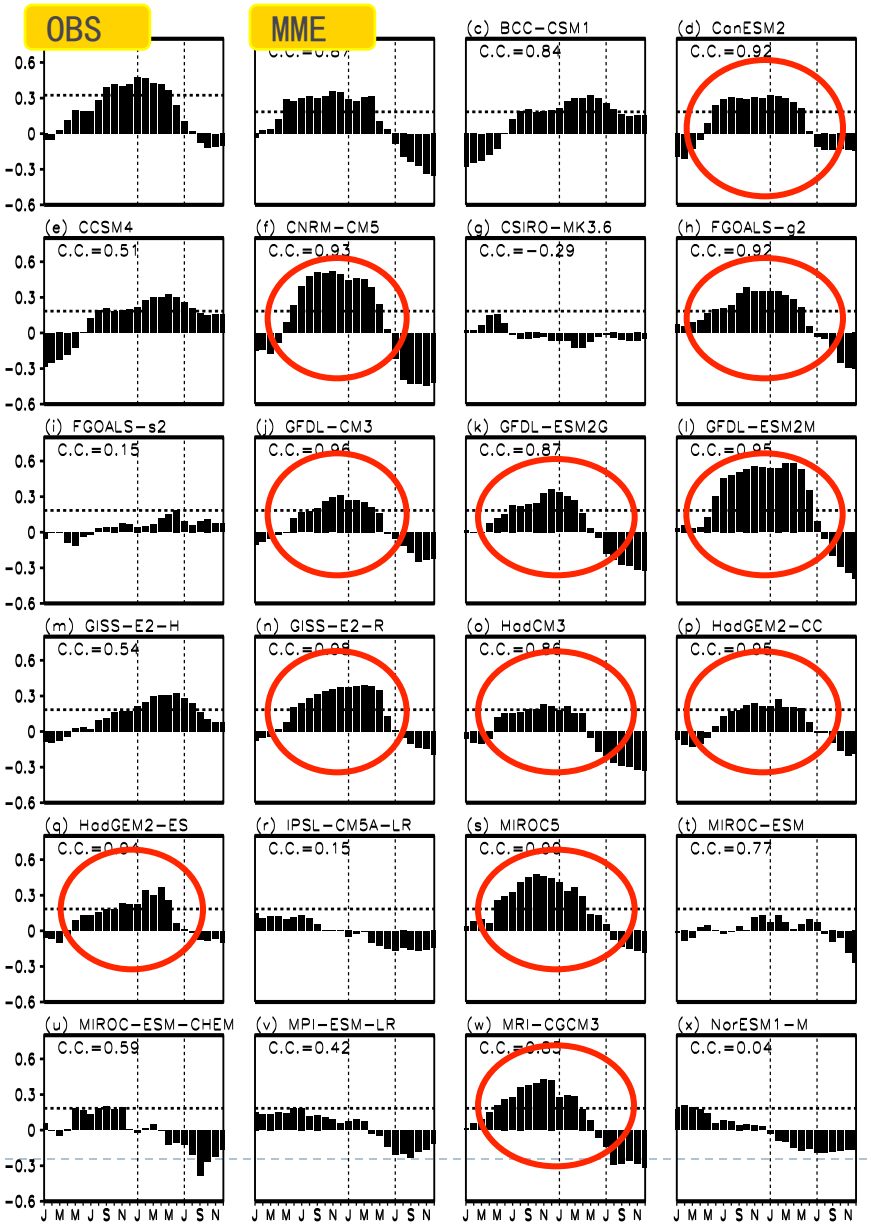
Ques:

Can the CMIP5 models show any improvements in representing the ENSO–EASR relationship?

22 models in CMIP5

	Model I.D.	Atmospheric Resolution
a	BCC-CSM1	128×64, L17
b	CanESM2	128×64, L22
c	CCSM4	288×192, L17
d	CNRM-CM5	256×128, L17
e	CSIRO-MK3.6	192×96, L18
f	FGOALS-g2	128×60, L17
g	FGOALS-s2	128×108, L17
h	GFDL-CM3	144×90, L23
i	GFDL-ESM2G	144×90, L17
j	GFDL-ESM2M	144×90, L17
k	GISS-E2-H	144×89, L17
l	GISS-E2-R	144×89, L17
m	HadCM3	96×73/72, L17
n	HadGEM2-CC	192×145/144, L23
o	HadGEM2-ES	192×145/144, L17
p	IPSL-CM5A-LR	96×96, L17
q	MIROC5	256×128, L17
r	MIROC-ESM	128×64, L35
s	MIROC-ESM-CHEM	128×64, L35
t	MPI-ESM-LR	196×96, L25
u	MRI-CGCM3	320×160, L25
v	NorESM1-M	144×96, L17

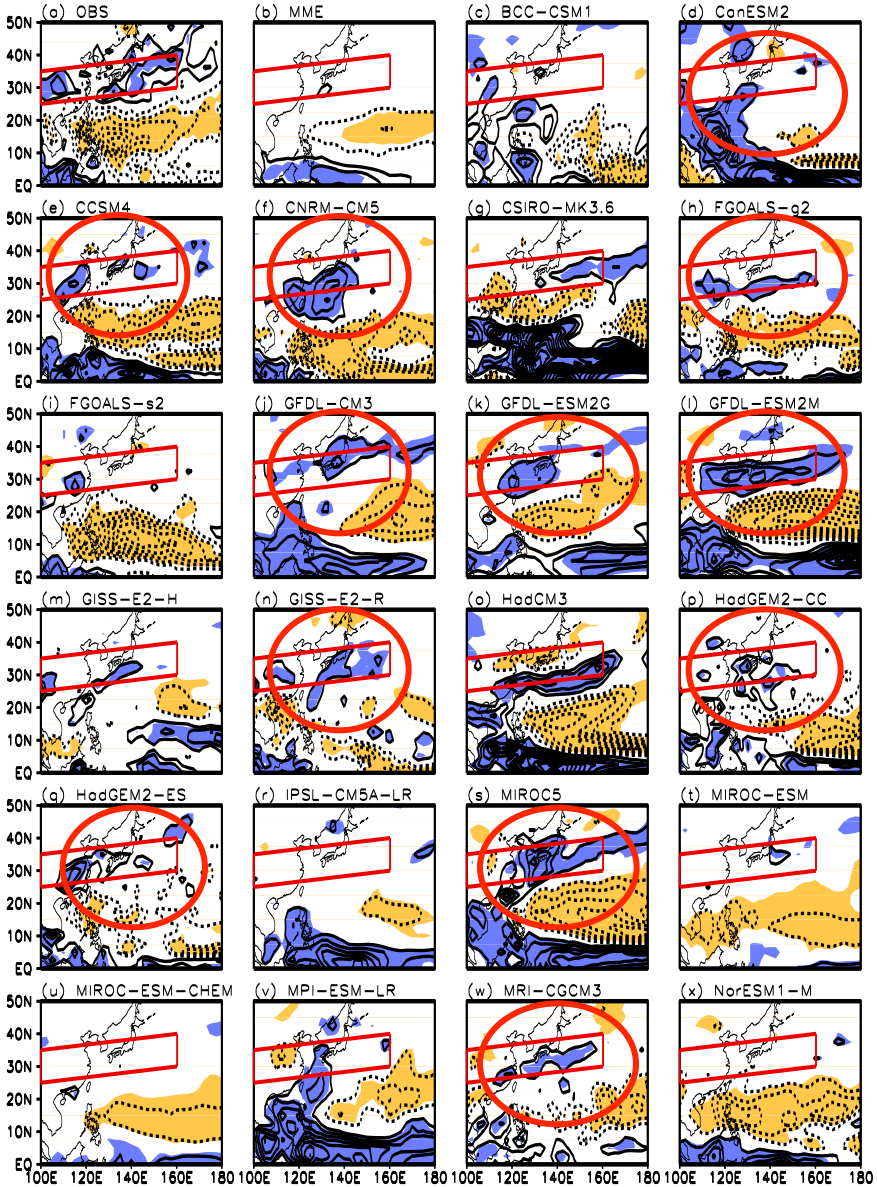
CC(EASR, monthly Nino3) in CMIP5



A large improvement in the CMIP5 models.

Fu and Lu, J. Climate, in press.

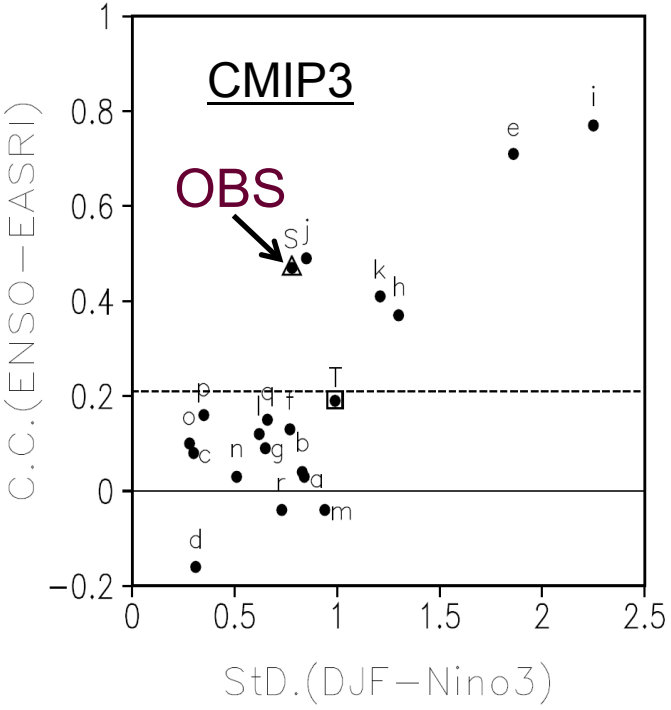
DJF Nino3-regressed summer rainfall in CMIP5

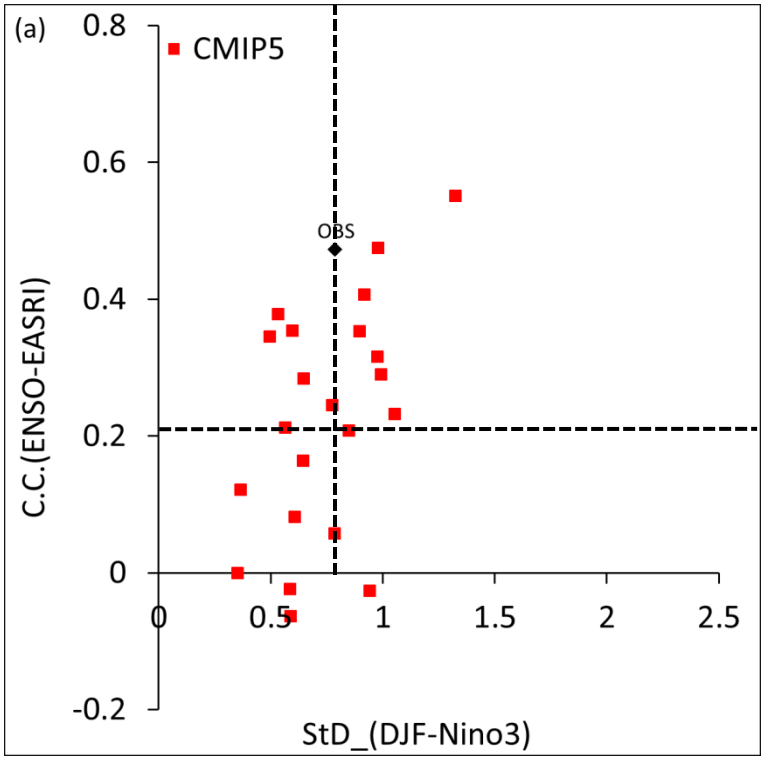


More than half CMIP5 models VS only five CMIP3 models reasonably replicate the positive EASR anomaly.

MME simulates a very weak precipitation anomaly.

In CMIP5, the models better capturing ENSO-EASR relationship and do not overestimate ENSO



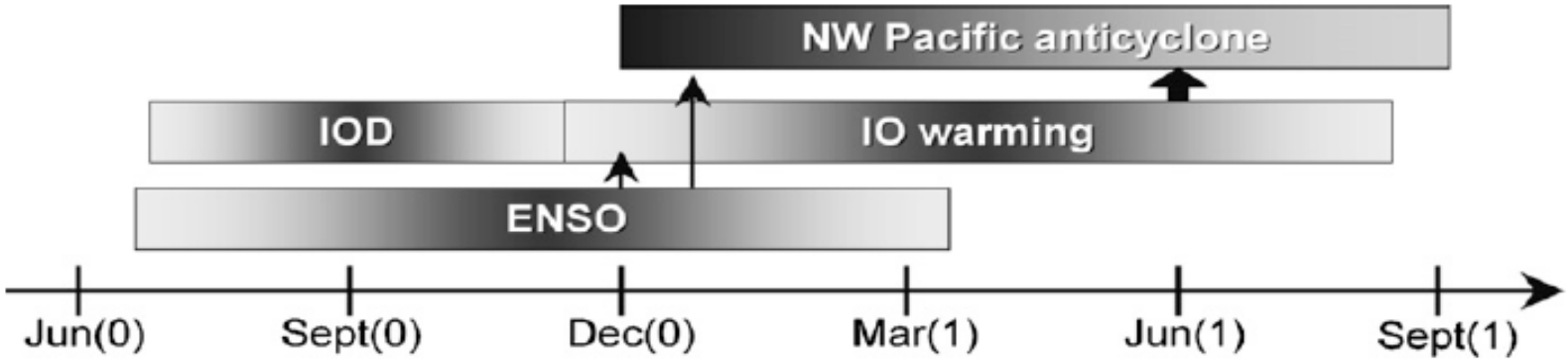


Possible processes:

ENSO – Indian Ocean SST – WNP anticyclone – East Asian Summer Rainfall

(e.g., Huang and Wu, 1989; Wang et al., 2000; Li et al. 2008; Xie et al. 2009)

Indian Ocean capacitor

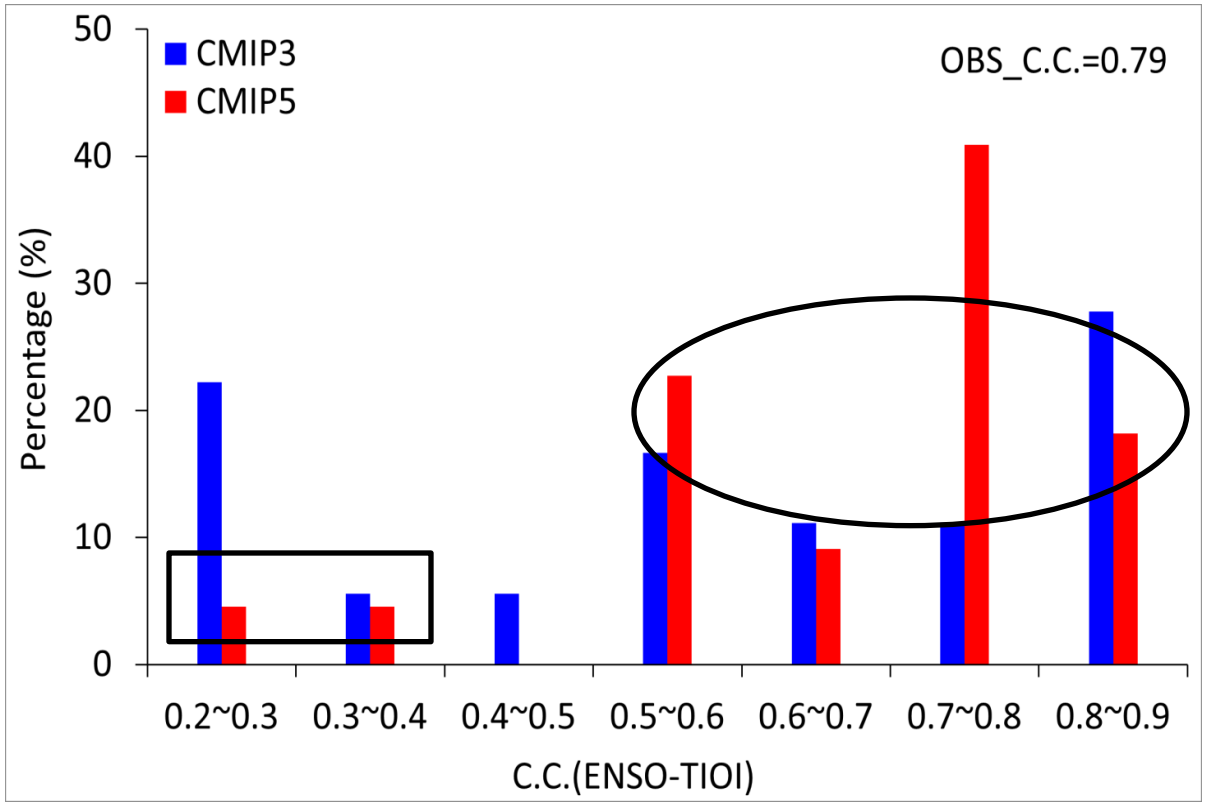


Xie et al., 2009, JCL

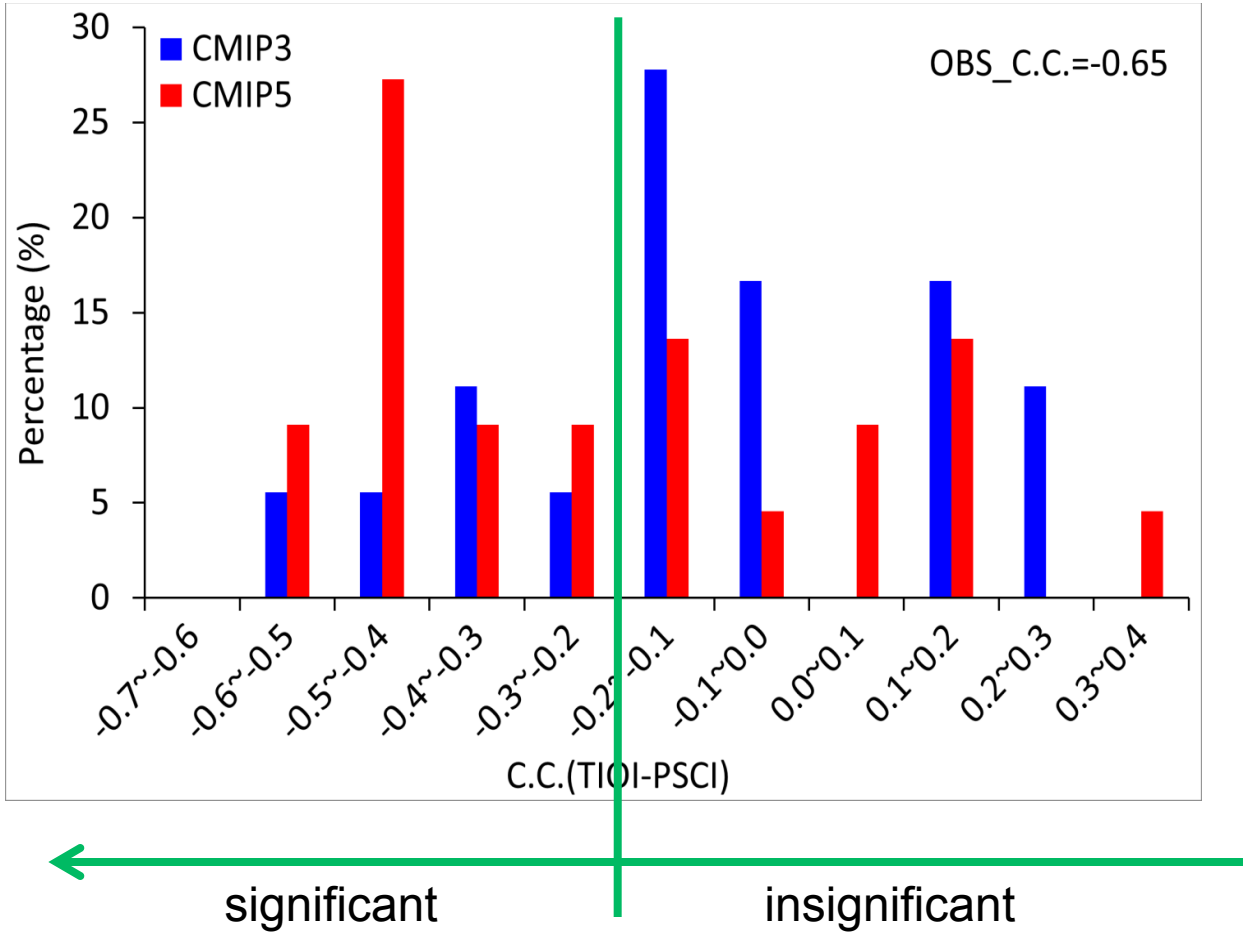
Four indices:

- EASRI: Precip$_{[\ (100^{o}E,\ 25^{o}N),\ (100^{o}E,\ 35^{o}N),\ (160^{o}E,\ 30^{o}N),\ (160^{o}E,\ 40^{o}N)\ ]}$
- Niño3: SST $_{[5^{o}S–5^{o}N,\ 150^{o}–90^{o}W\ ]}$
- TIOI: SST $_{[20^{o}S–20^{o}N,\ 40^{o}–110^{o}E]}$
- PSCI: Precip $_{[110^{o}–160^{o}E,\ 10^{o}–20^{o}N]}$

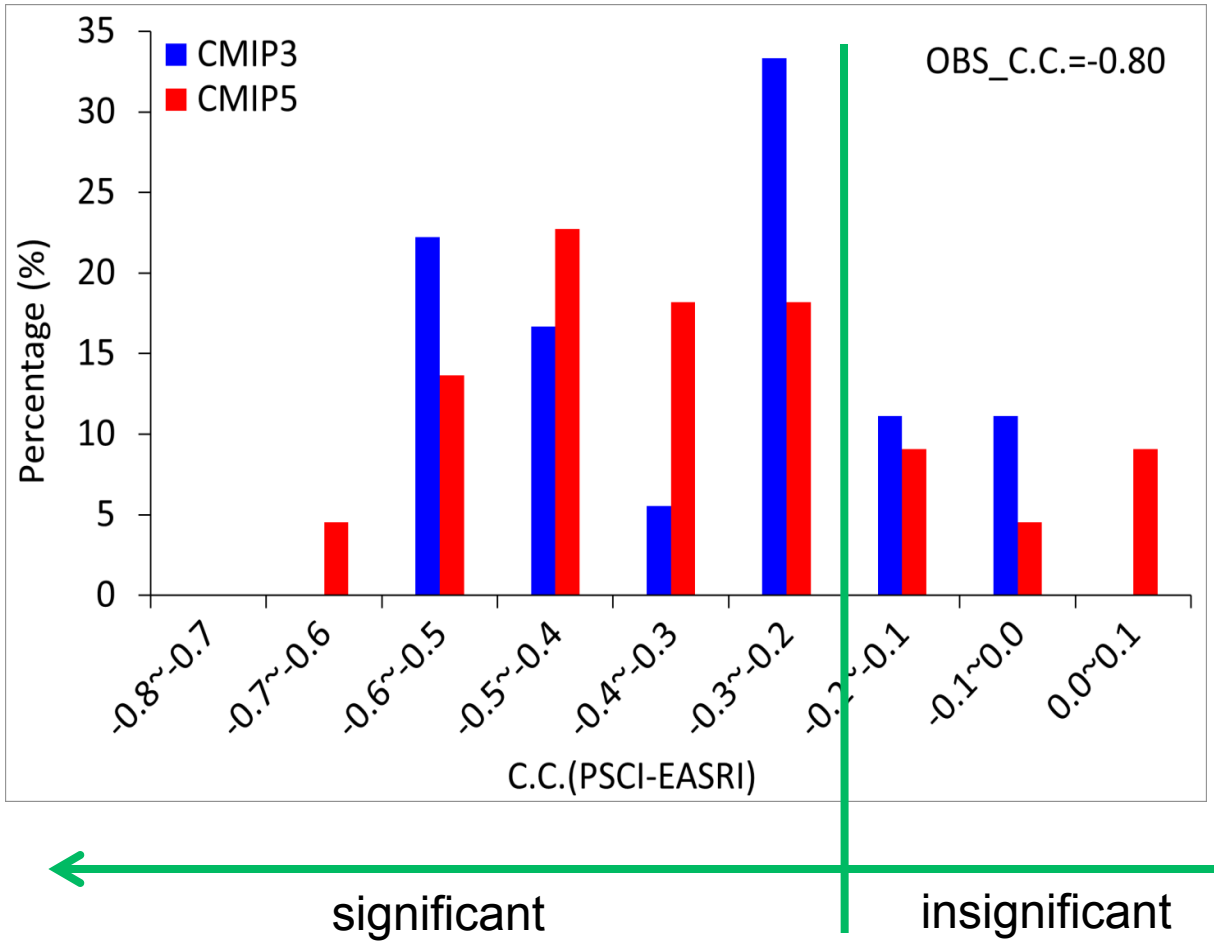
Physical Processes-1: ENSO-TIO



Physical Processes-2: TIO-PSC



Physical Processes-3: PSC-EASR



- ✓ No appreciable improvement

  CMIP5: 77% significant
  CMIP3: 78% significant

- ✓ Large uncertainty
- ✓ All underestimate the relationship

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Motivation

- Great interannual variability in East Asian summer monsoon leads to frequent occurrence of floods and droughts

Question：

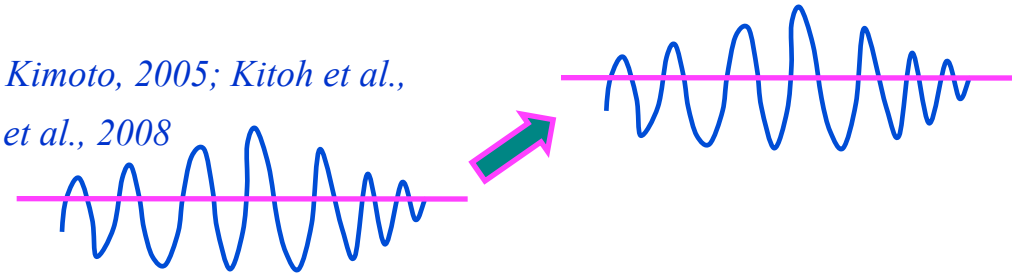
What will the interannual variability be like under global warming?

Previous results

under global warming:

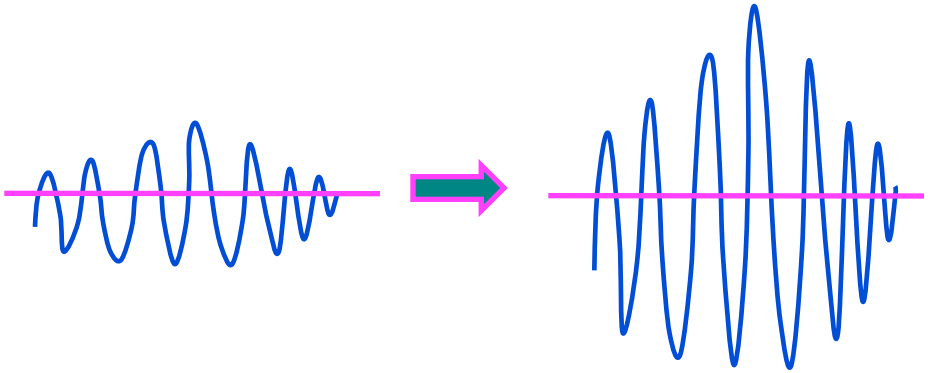
- **East Asian summer rainfall will be enhanced**

Hu et al., 2000; Bueh et al., 2003; Min et al., 2004; Kimoto, 2005; Kitoh et al., 2005; Kripalani et al., 2007; Lu et al., 2007; Lee et al., 2008



- **Interannual variability of East Asian summer rainfall may be enhanced**

Kripalani et al. (2007)

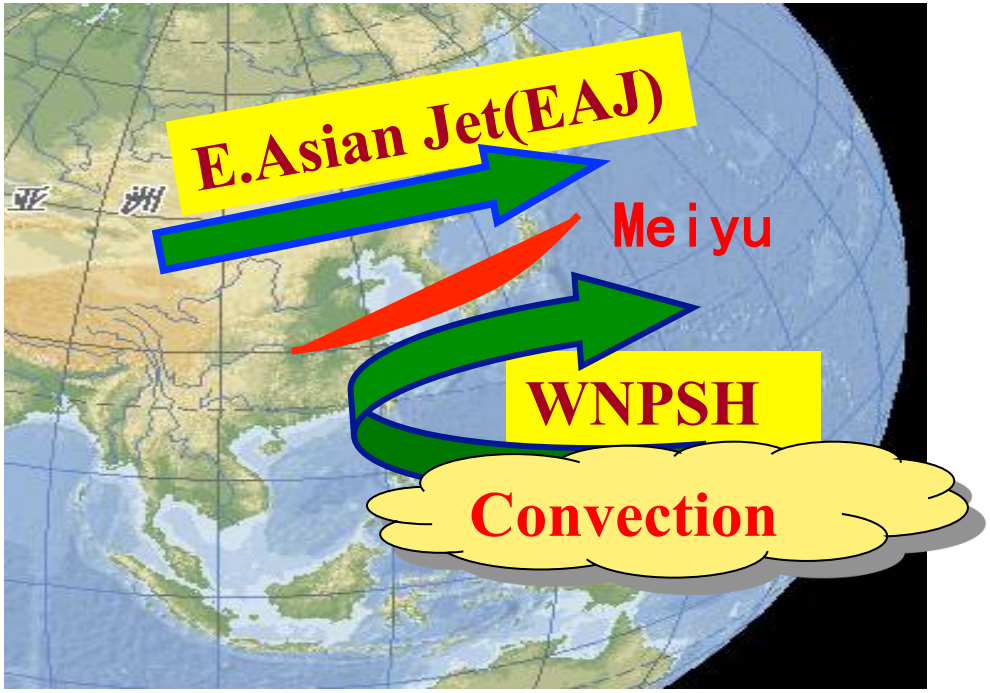


In this study

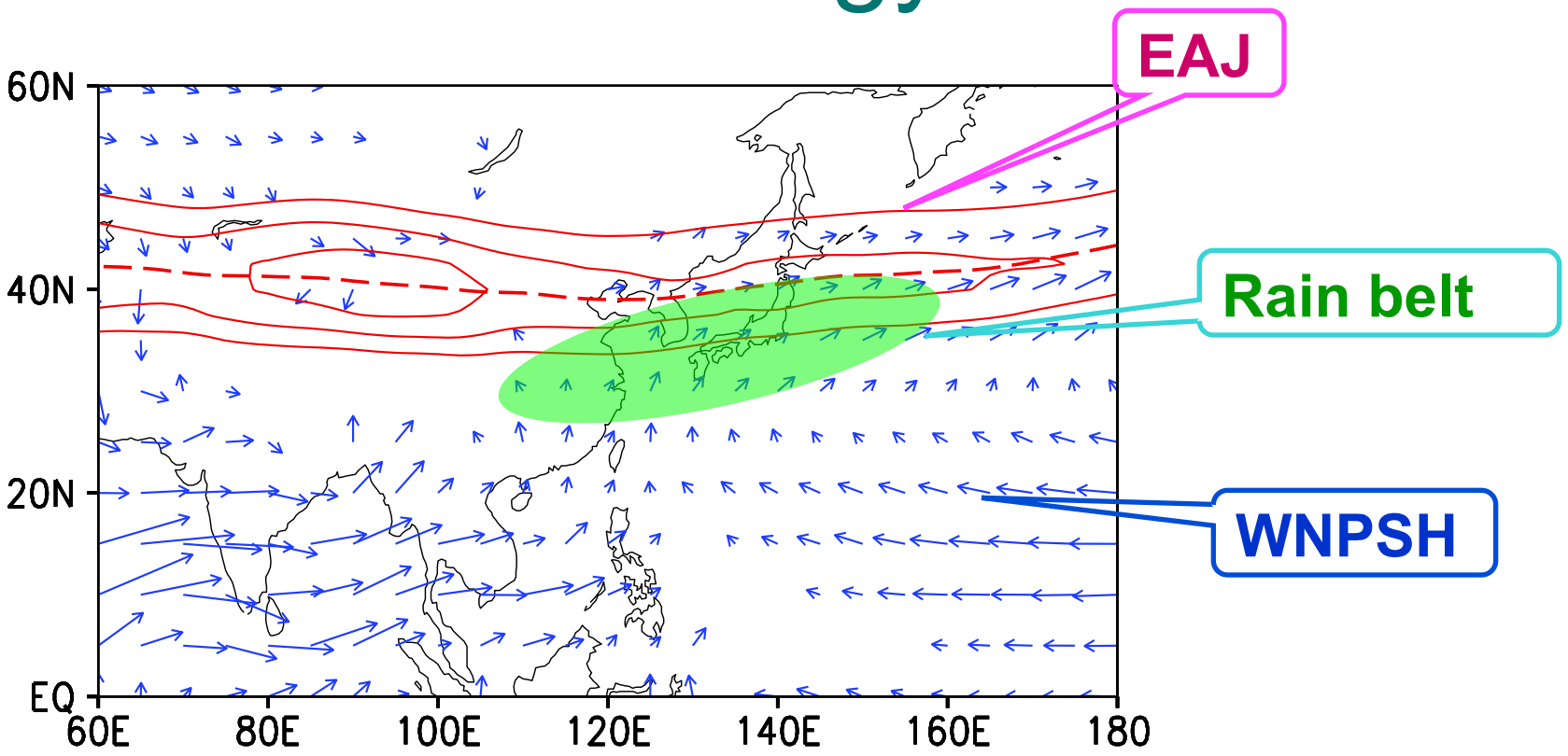
- We focus on the simulated changes in rainfall variability along the East Asian summer rain belt

- Dynamical components of East Asian monsoon are also investigated
  - Circulation can be more reliably simulated than rainfall

Major components of EASM system



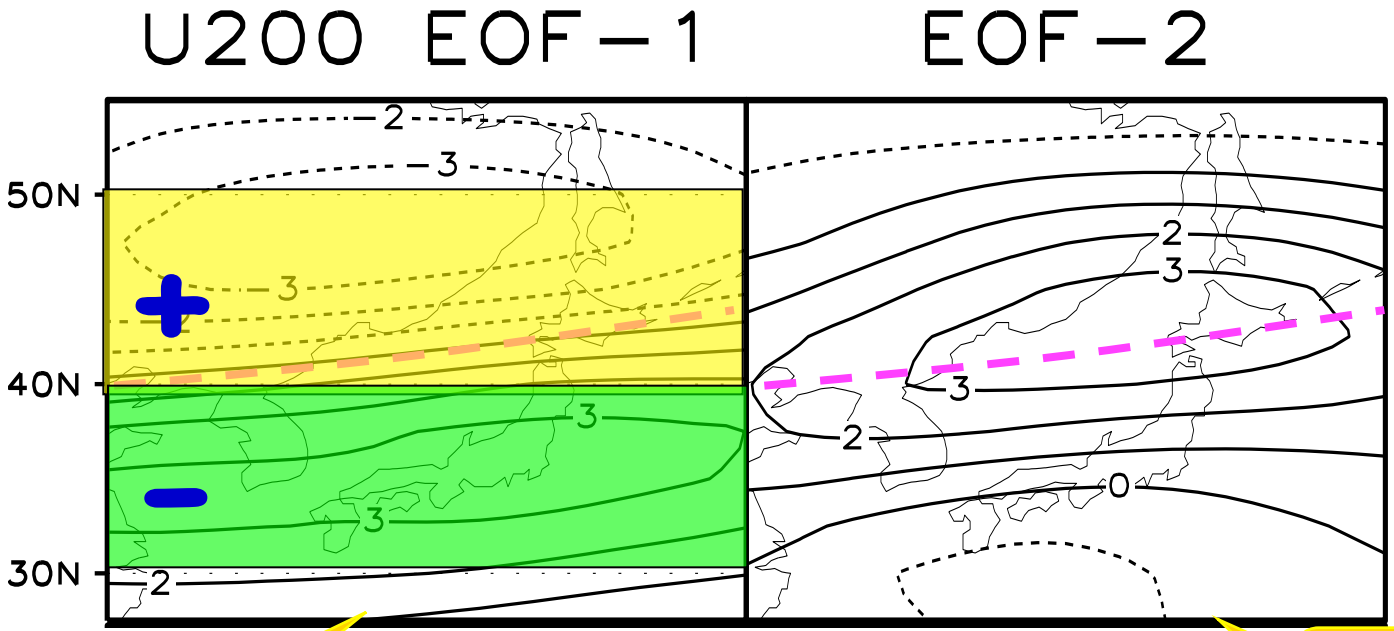
JJA Climatology



EAJ: East Asian up-level Jet

WNPSH: Western North Pacific Subtropical High

EOF analysis on 200hPa zonal wind



~50%

~25%

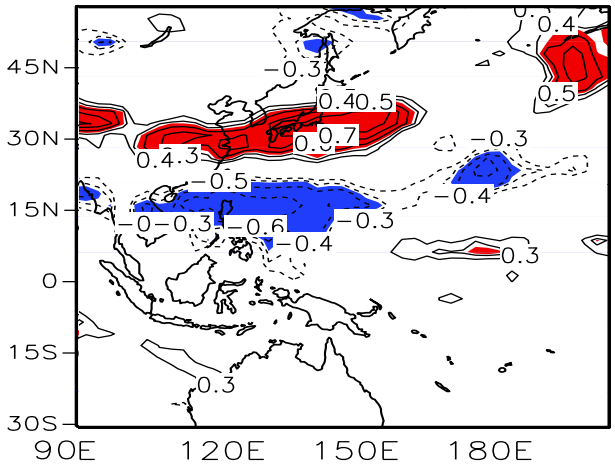
Meridional displacement

Intensity change

EAJI=U200[120-150E,40-50N]-U200[120-150E,30-40N]

Lin and Lu, 2005, *Adv. Atmos. Sci.*
Lu, 2004, *J. Meteor. Soc. Japan*

Corr. (EAJI & OLR)



Lu, 2004, JMSJ

Models

Information of the 12 models

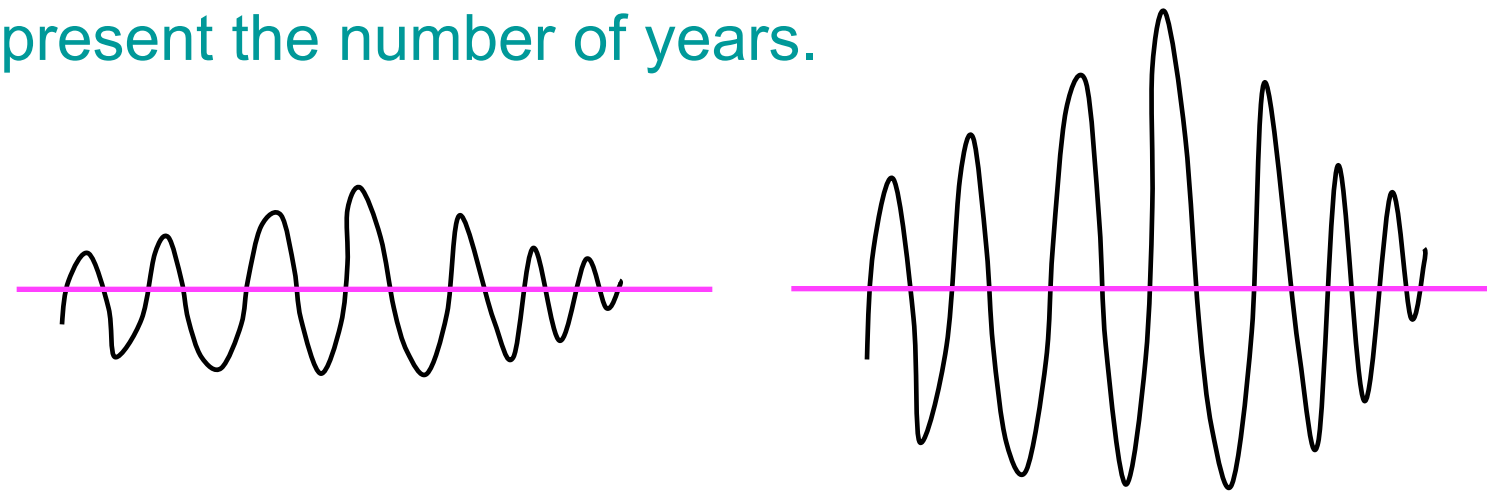
Modeling group	IPCC I.D.	Country	Resolution		Ensemble members		
			Atmosphere	Ocean	20C3M	A1B	A2
Canadian Centre for Climate Modeling and Analysis	CGCM3.1(T63)	Canada	T42L17	0.9° × 1.4° L29	1	1	×
Météo-France/Centre National de Recherches Météorologiques	CNRM-CM3	France	T42L17 128*64	0.5–2° × 2° L31	1	1	1
Commonwealth Scientific and Industrial Research Organization	CSIRO-Mk3.0	Australia	T63L17	0.8° x 1.9° L31	2	1	1
Atmospheric Research	CSIRO-Mk3.5	Australia	192*96		1	1	1
Max Planck Institute for Meteorology	ECHAM5/MPI-OM	Germany	T63L16	1.5° x 1.5° L40	4	4	3
U.S. Dept. of Commerce/NOAA/Geophysical Fluid	GFDL-CM2.0	USA	2.0°*2.5°L17	0.3–1° x 1°	3	1	1
Dynamics Laboratory	GFDL-CM2.1	USA	144*90		3	1	1
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	MIROC3.2(medres)	Japan	T42L17	0.5–1.4° x 1.4° L43	3	3	3
Meteorological Research Institute	MRI-CGCM2.3.2	Japan	T42L17	0.5–2.0° x 2.5° L23	5	5	5
National Center for Atmospheric Research	NCAR-PCM	USA	T42L17	0.5–0.7° x 1.1° L40	4	4	4
Hadley Centre for Climate Prediction and Research, Met Office	UKMO-HadCM3	UK	~2.5°*3.8°L15	1.5° x 1.5° L20	2	1	1
	UKMO-HadGEM1	UK	~1.3°*1.9°L16	0.3–1.0° x 1.0° L40	2	1	1

Method

Standard deviation is used to depict the intensity of interannual variability.

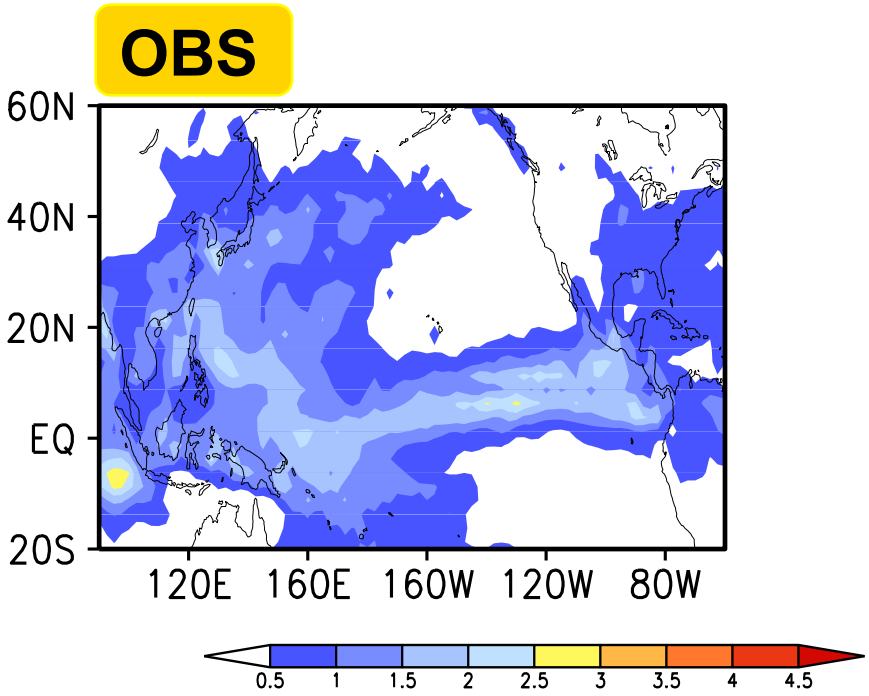
$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Here, *i* represent the number of years.

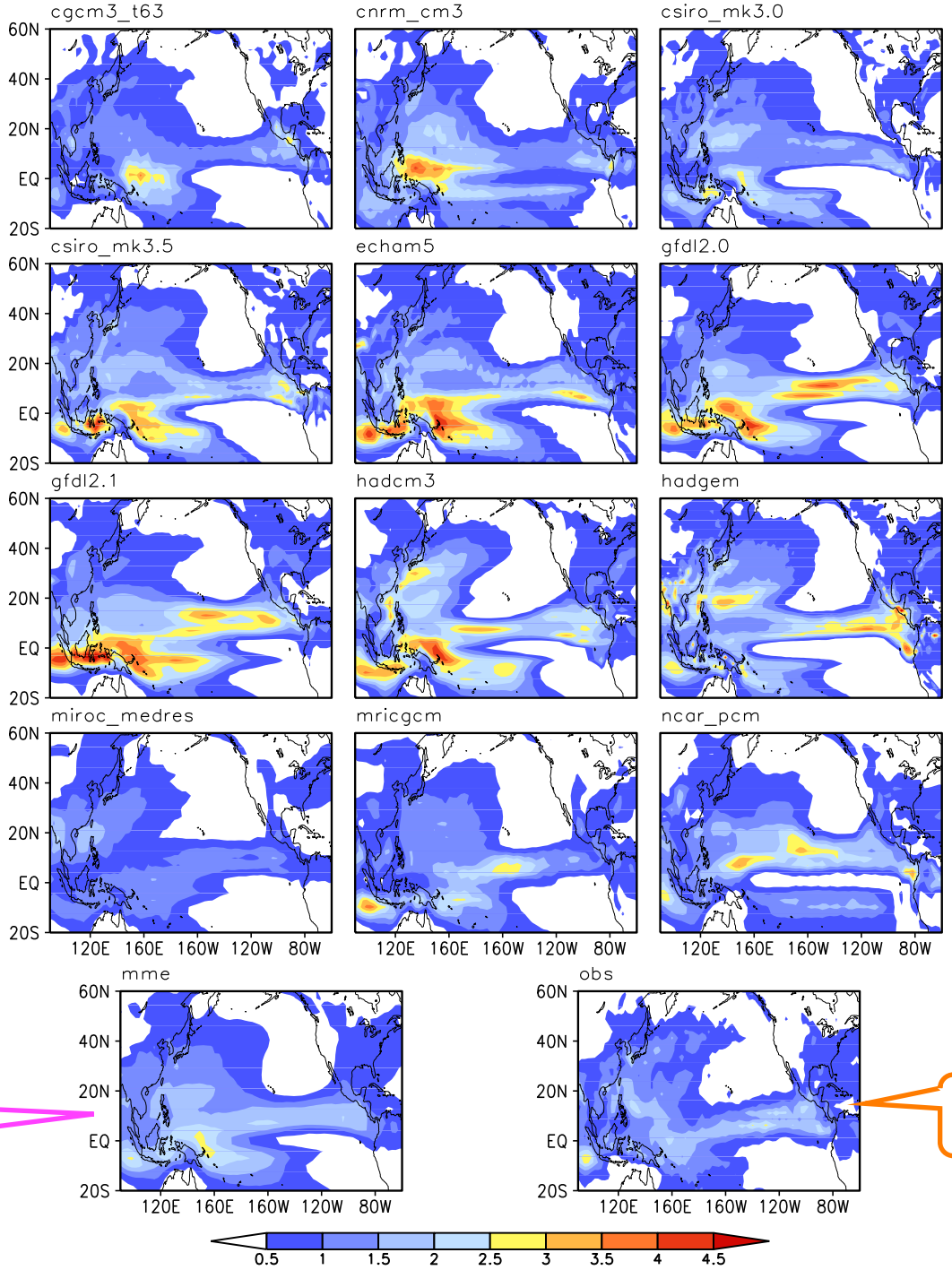


Evaluation of models capacity in simulating interannual variability

Standard Deviation of JJA Precipitation



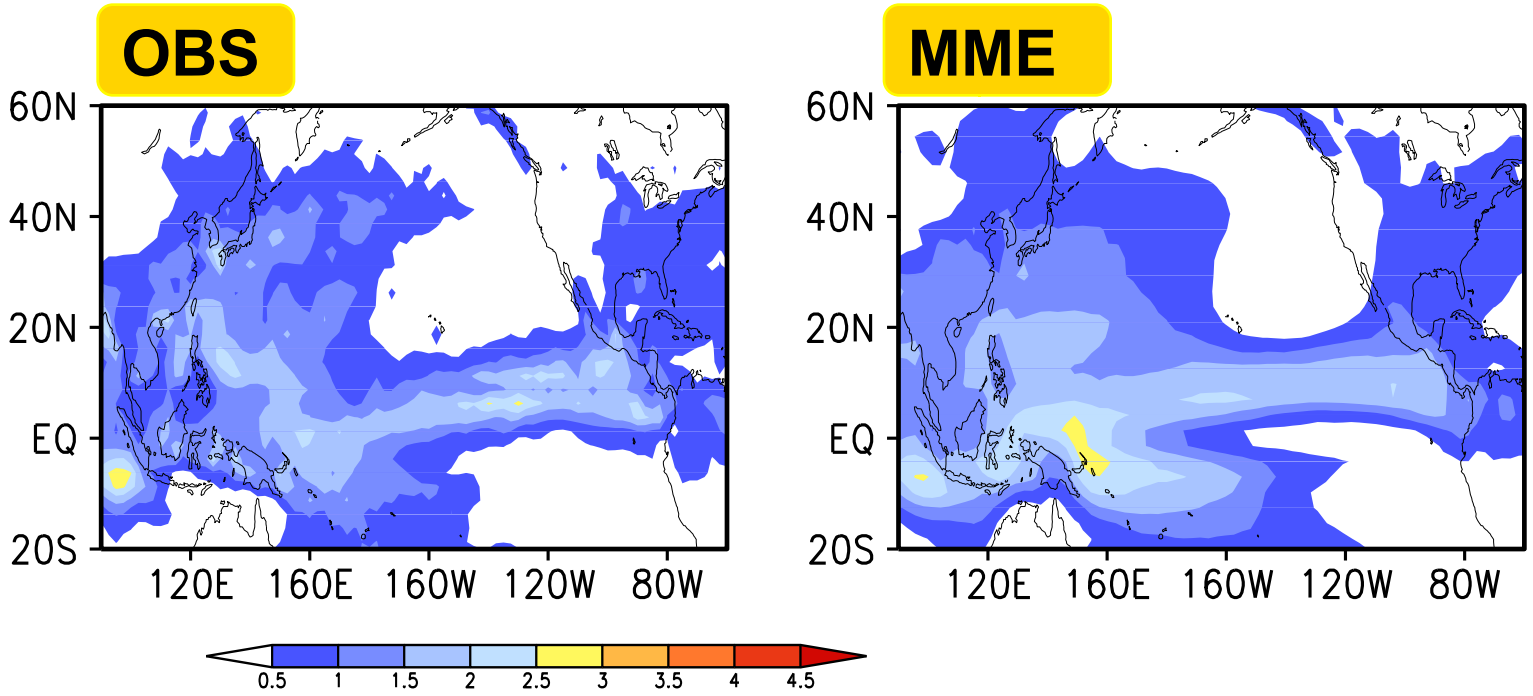
Standard Deviation of JJA Precipitation



MME

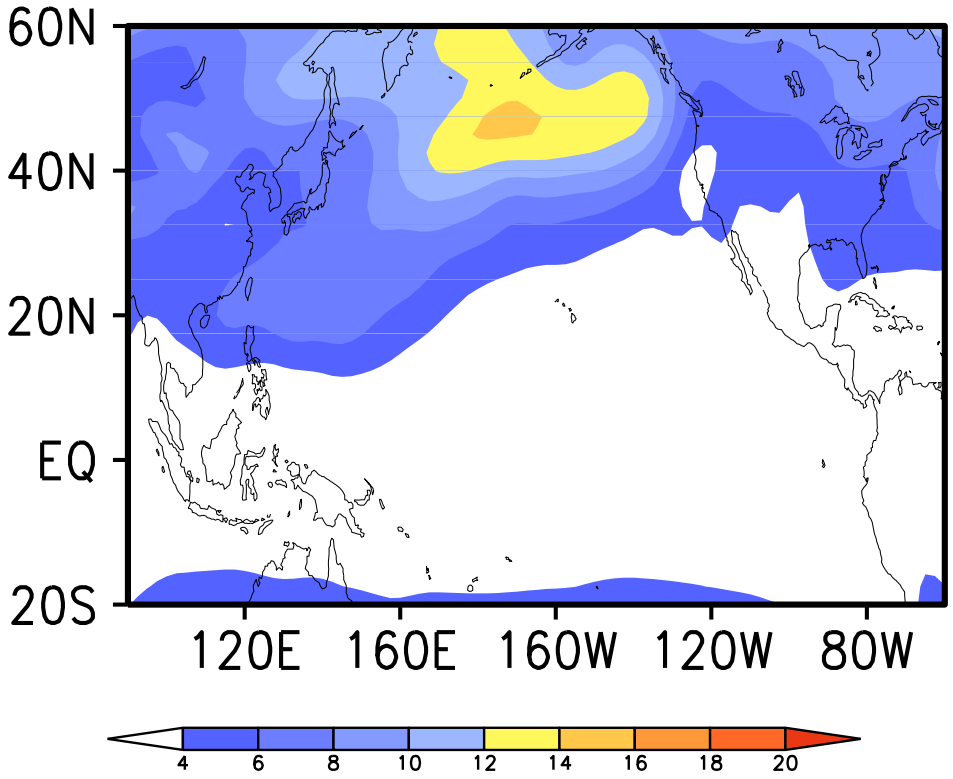
OBS

Standard Deviation of JJA Precipitation

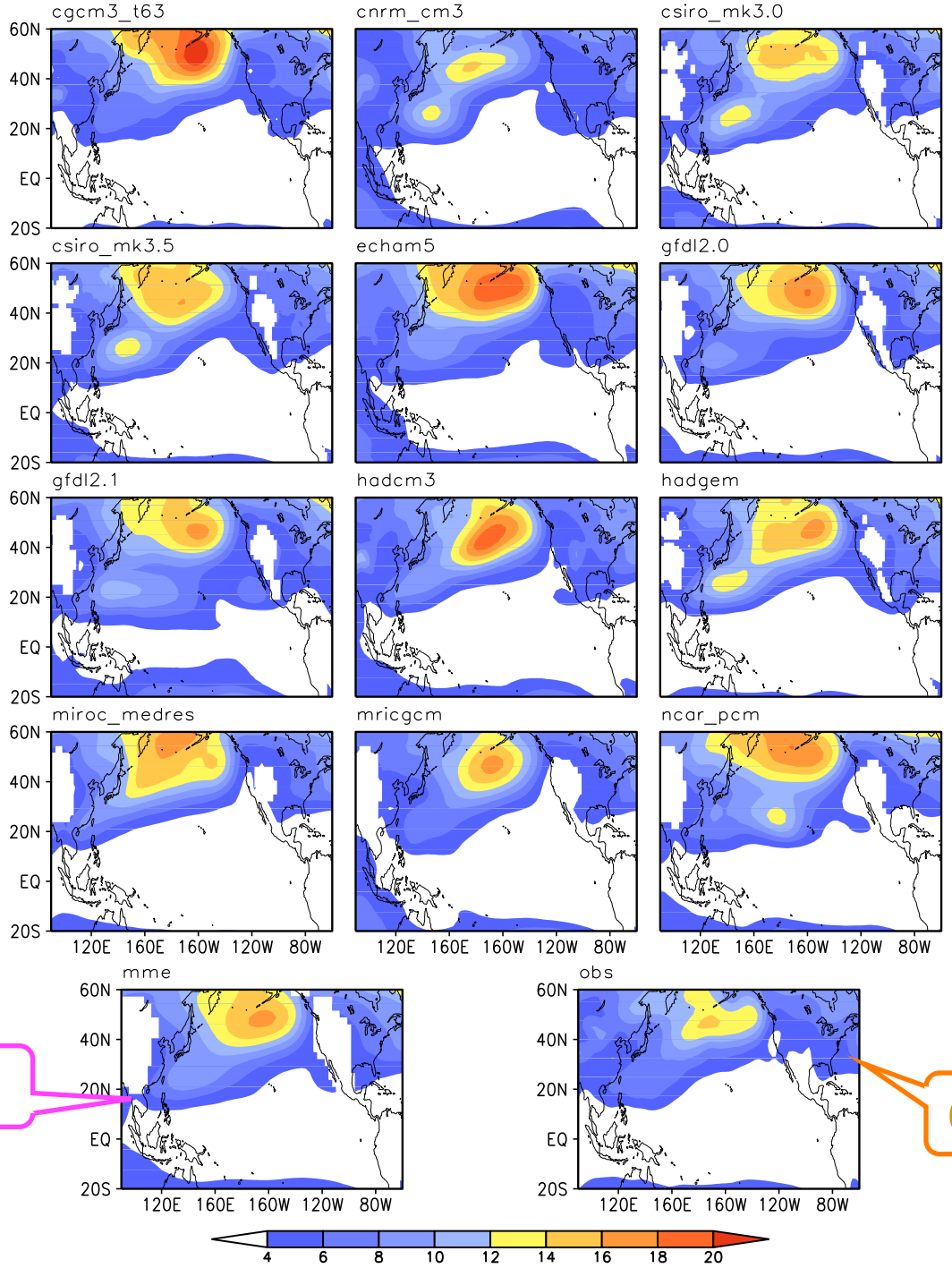


Standard Deviation of 850-hPa height

OBS



Standard Deviation of 850-hPa height



MME

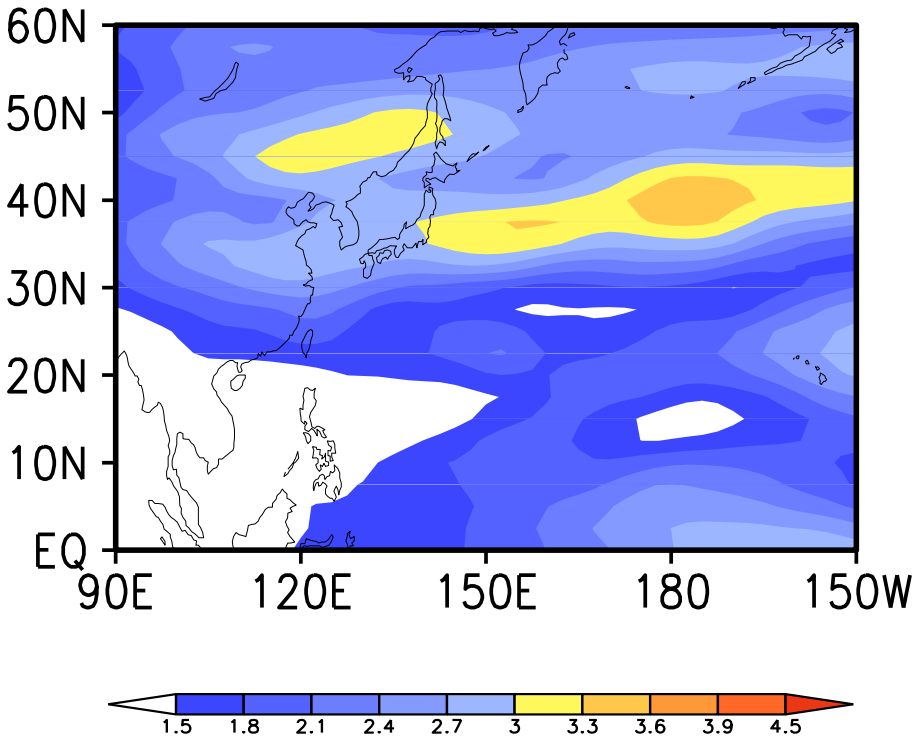
OBS

Standard deviations of EASRI and WNPSHI

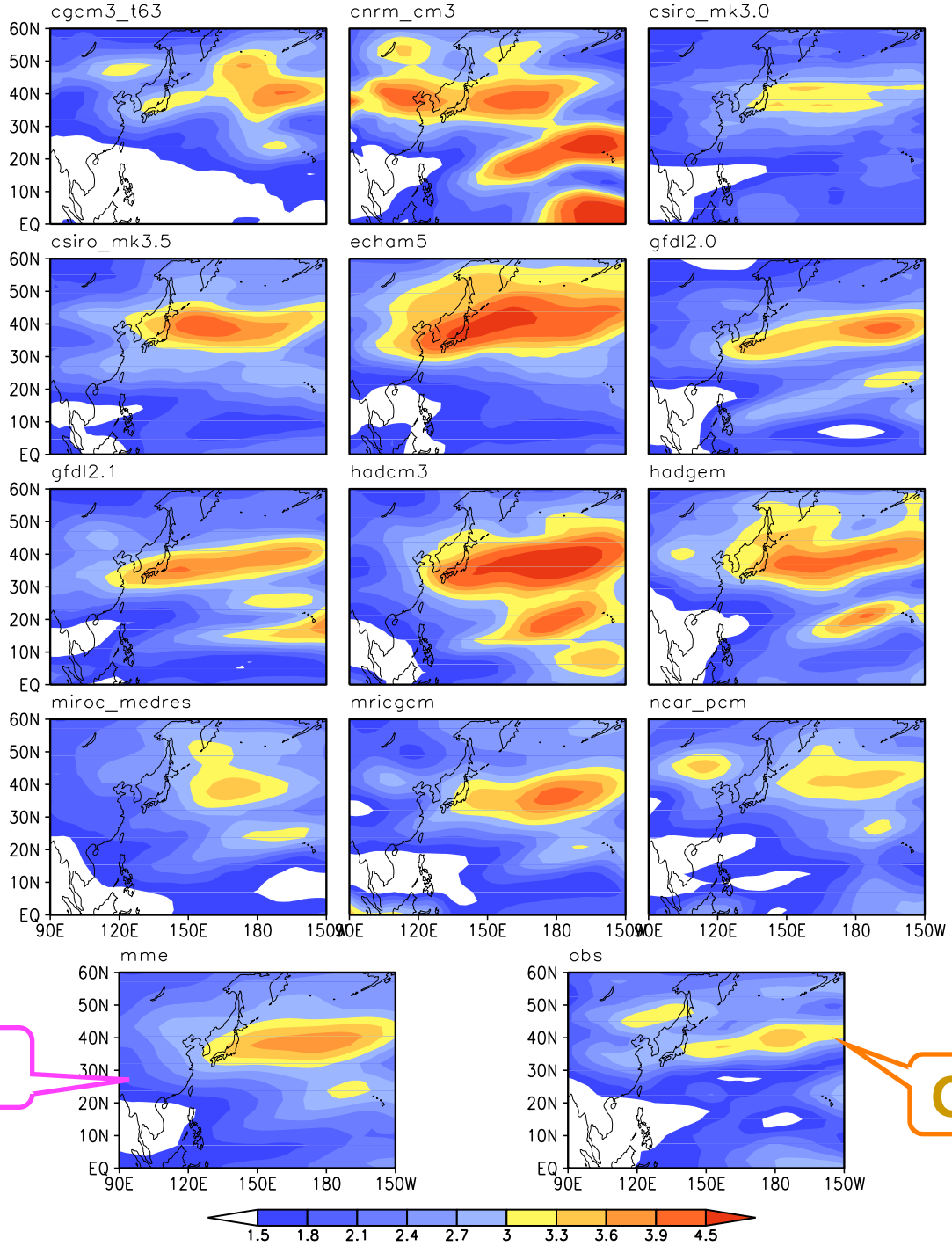
	EASRI	WNPSHI
CGCM3.1(T63)	0.32	4.4
CNRM-CM3	0.37	5.3
CSIRO-Mk3.0	0.36	7.0
CSIRO-Mk3.5	0.42	6.3
ECHAM5/MPI	0.42	5.1
GFDL-CM2.0	0.45	5.8
GFDL-CM2.1	0.45	7.1
MIROC3.2(m)	0.35	4.9
MRI-CGCM2.3.2	0.38	4.5
NCAR-PCM	0.27	5.0
UKMO-HadCM3	0.62	5.2
UKMO-HadGEM1	0.45	7.1
ENSEMBLE	0.41	5.6
OBSERVATION	0.56	5.0

Standard Deviation of 200-hPa zonal wind

OBS



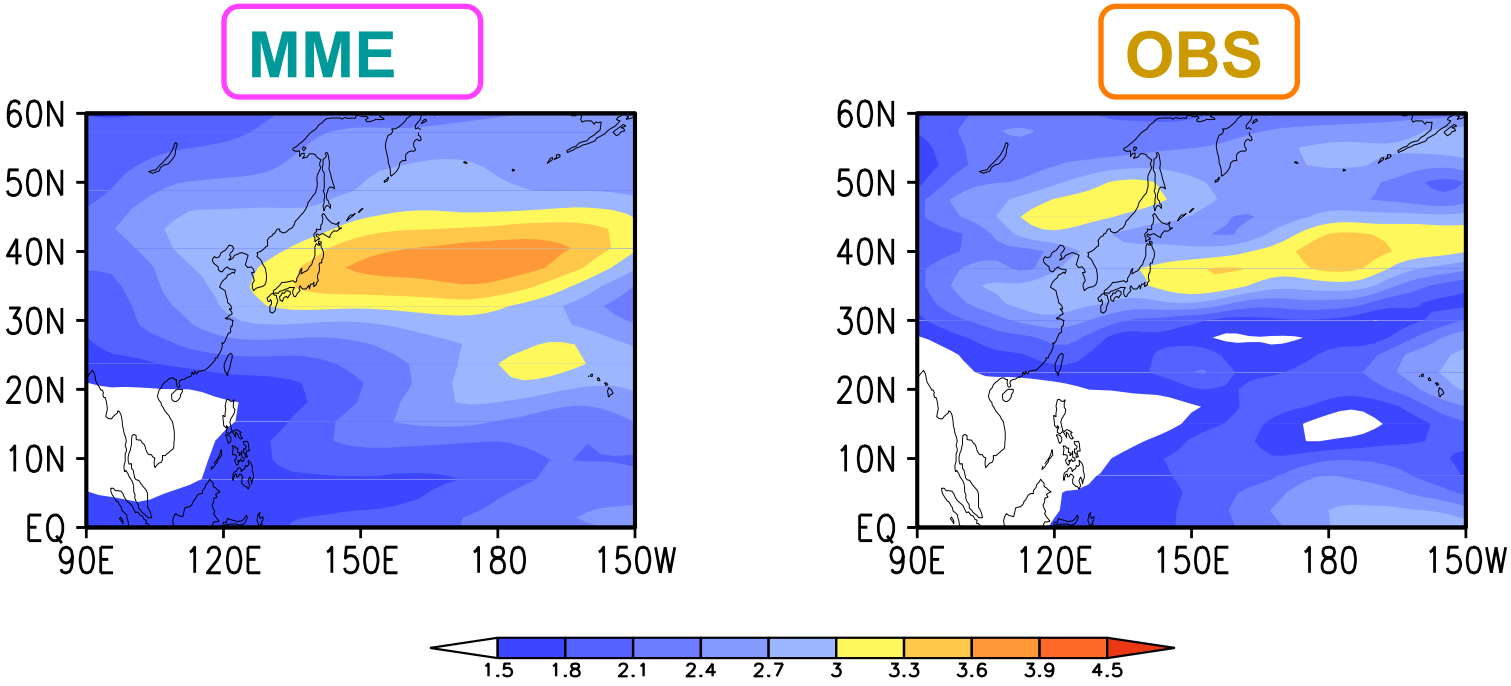
Standard Deviation of 200-hPa zonal wind



MME

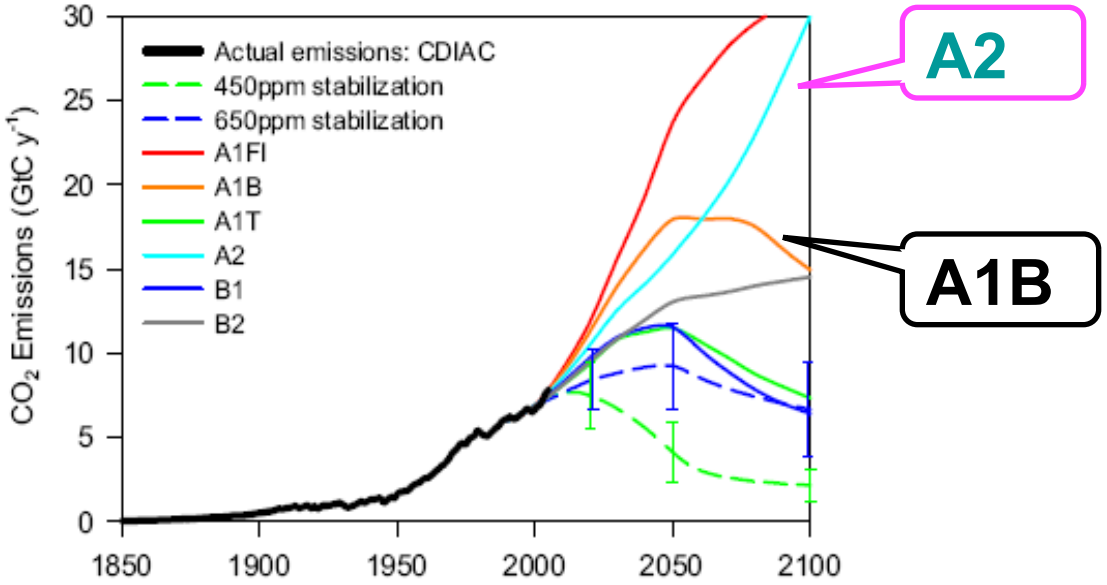
OBS

Standard Deviation of 200-hPa zonal wind



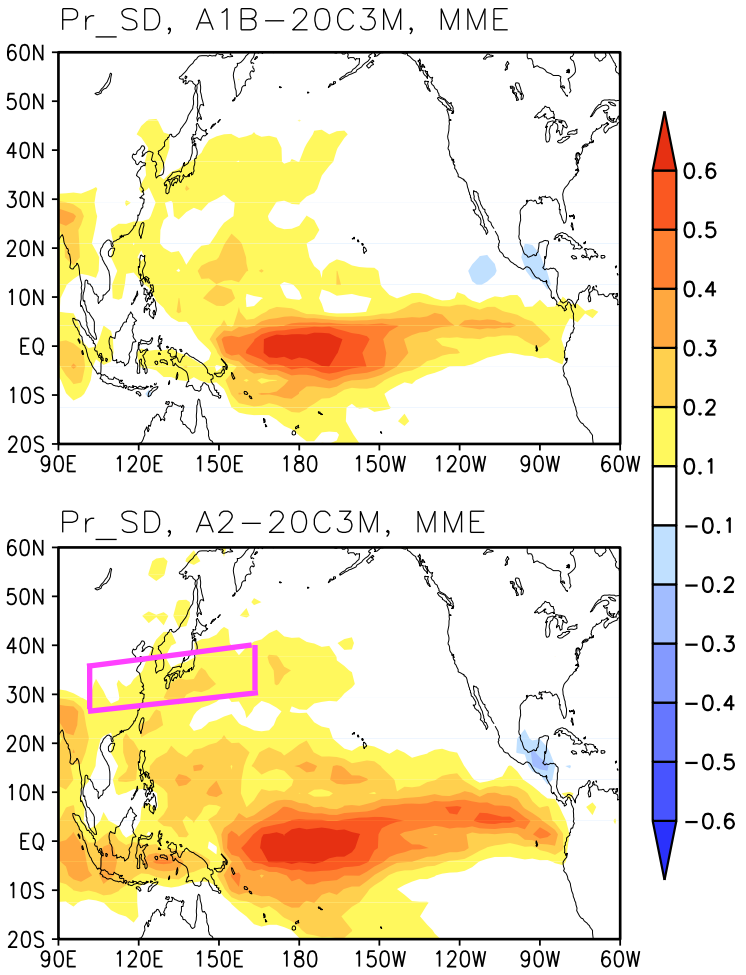
Projected changes in the 21st century

Scenarios：A1B, A2



Including Climate of twentieth century (20c3m)

Precipitation



SD difference between 21st and 20th century

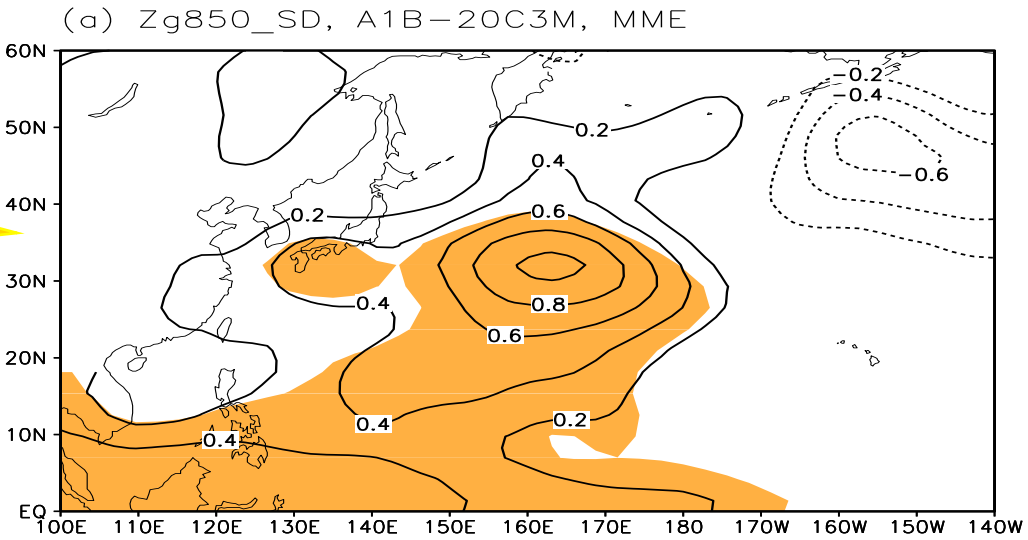
Standard deviations of East Asian precipitation

Model	EASRI_SD		
	20C3M	SRESA1B	SERSA2
ccsm	0.30	**0.39****	**0.44****
cgcm	0.32	**0.38****	×
cnrm	0.37	0.36	**0.42**
csiro3.5	0.43	**0.53****	**0.51****
echam5	0.43	**0.46***	**0.52****
gfdl2.0	0.45	0.39	**0.48****
gfdl2.1	0.46	**0.51**	**0.54****
mirocm	0.35	**0.50****	**0.49****
miroch	0.38	**0.50****	×
mricgcm	0.38	**0.45****	**0.43****
hadcm3	0.62	**0.65**	0.61
hadgem	0.45	**0.51***	**0.64****
mme	0.42(0.43)	**0.47**(12%)**	**0.51**(19%)**

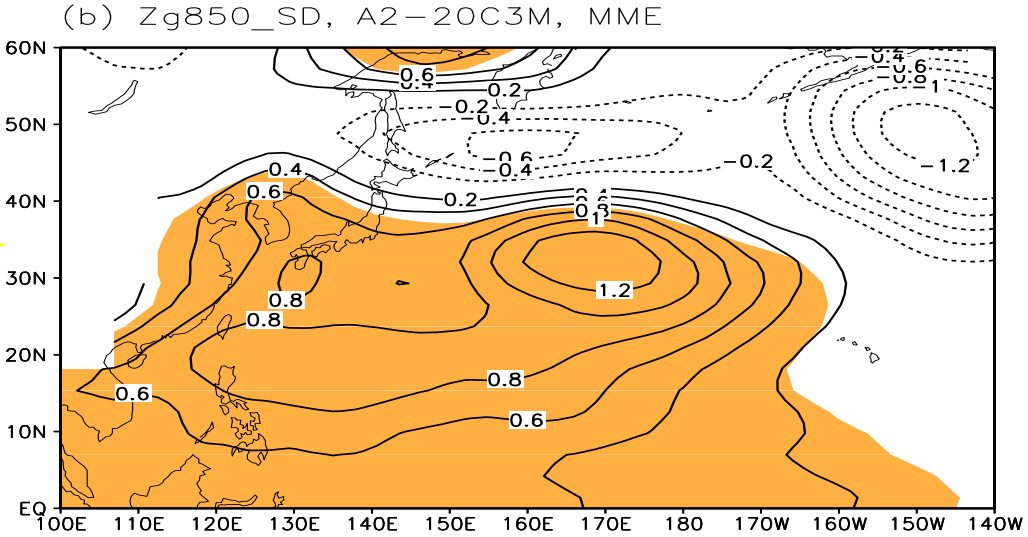
* 10% significant level ** 5% significant level

Changes of 850hPa Height SD (21st-20th)

A1B-20C3M



A2-20C3M



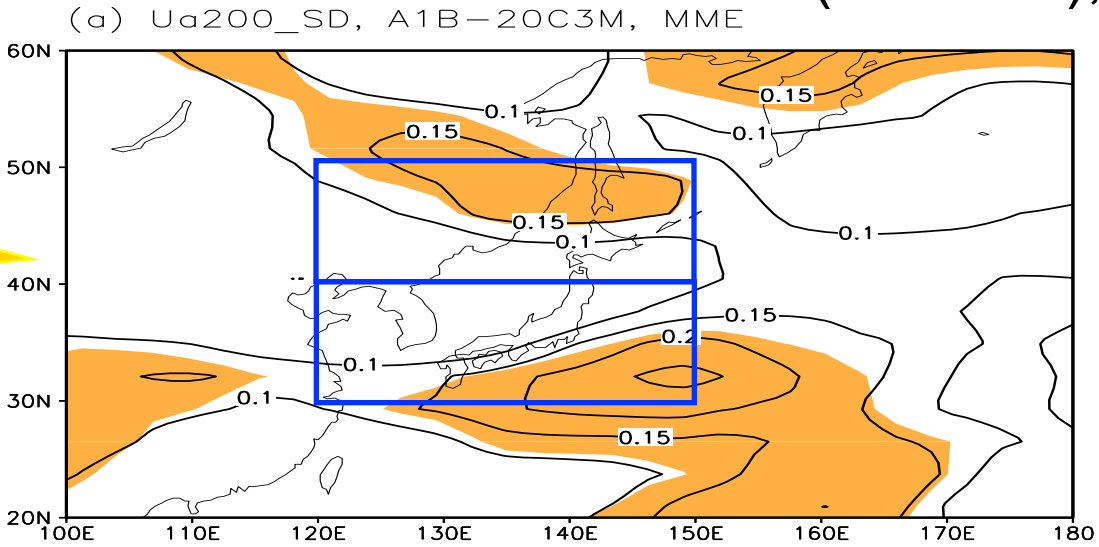
Standard deviations of WNPSHI

Model	WNPSHI_SD		
	20C3M	SRESA1B	SERSA2
ccsm	3.9	**4.0**	3.6
cgcm	4.4	3.9	×
cnrm	5.3	**6.4****	**7.6****
csiro3.5	6.3	**6.5**	**6.7**
echam5	5.1	**6.3****	**7.0****
gfdl2.0	5.8	**6.8****	**6.6***
gfdl2.1	7.1	6.7	**7.2**
mirocm	4.9	**5.0**	**5.4****
miroch	4.2	**4.3**	×
mricgcm	4.5	**5.4****	**5.0****
hadcm3	5.2	**6.2****	**6.5****
hadgem	7.1	6.7	**8.1***
mme	5.4(5.6)	**5.8**(7%)**	**6.5**(16%)**

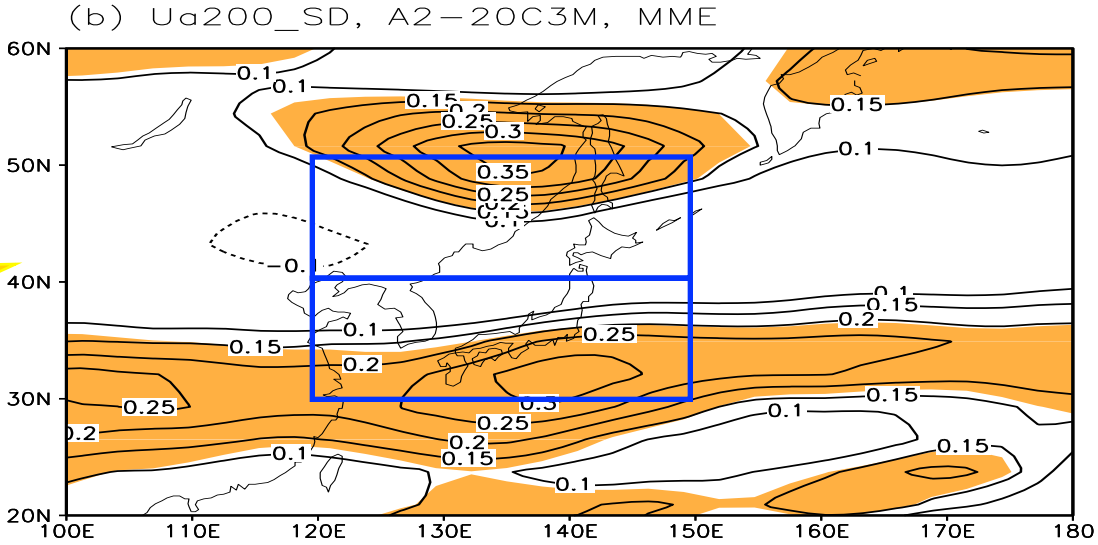
* 10% significant level ** 5% significant level

Changes of 200hPa Zonal Wind SD (21st-20th), m/s

A1B-20C3M



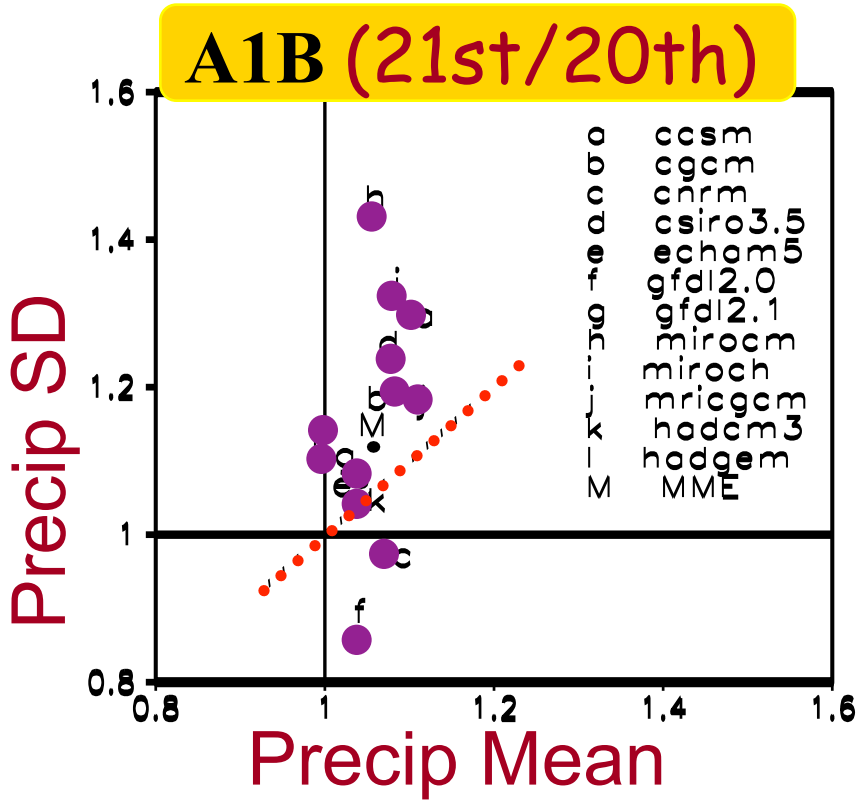
A2-20C3M

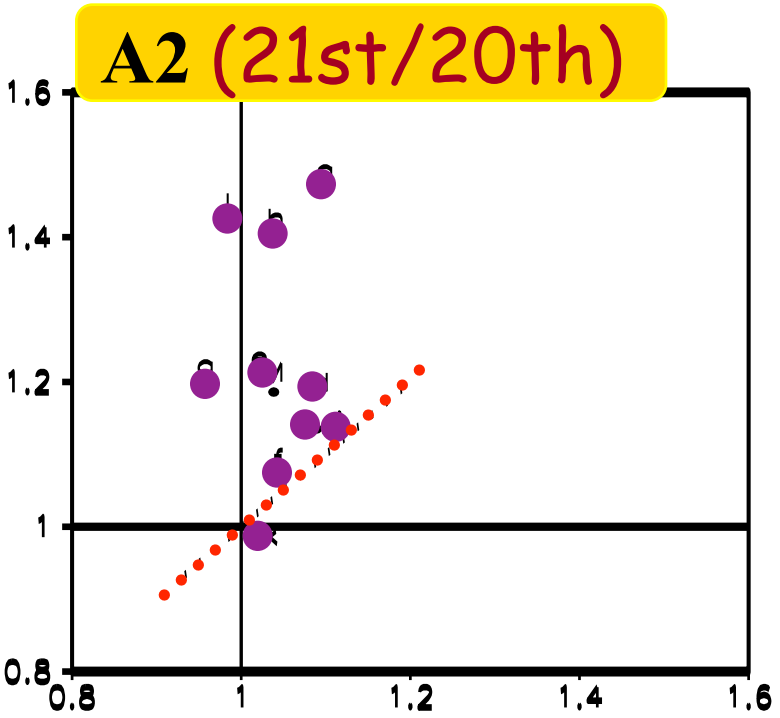


Standard deviations of EAJI

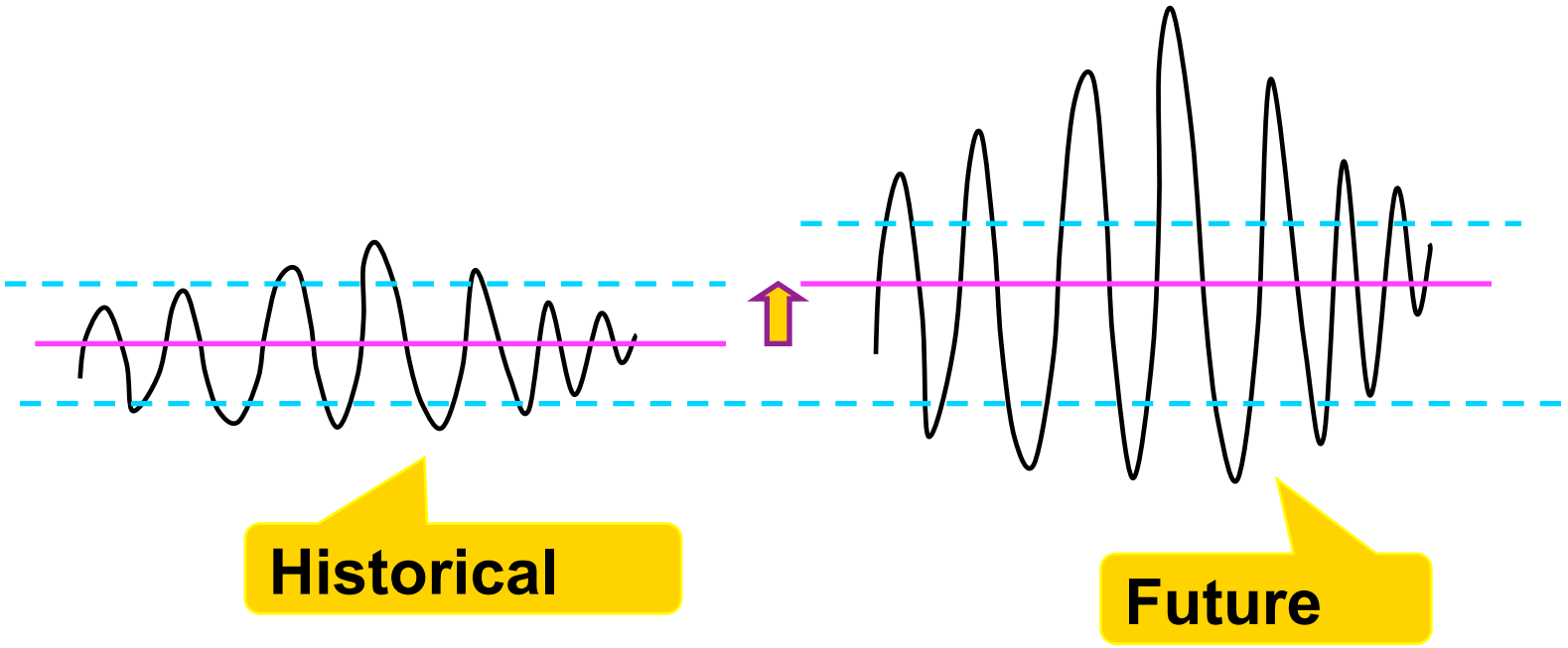
MODEL I.D.	EAJI _SD		
	20C3M	SRESA1B	SERSA2
ccsm	4.4	4.6	4.8**
cgcm	3.4	3.5	×
cnrm	3.6	4.6**	4.3**
mk3.5	3.3	3.1	3.5
echam	4.4	4.9**	4.8*
gfdl2.0	3.8	4.3*	4.1
gfdl2.1	3.6	3.9	4.2**
mirocm	2.9	3.3**	3.3**
miroch	3.6	3.6	×
mricgcm	3.0	3.3**	3.3**
hadcm3	4.5	4.7	5.3**
hadgem	4.0	4.1	3.9
mme	3.8(3.8)	4.0**(5.3%)	4.2**(10.5%)

* 10% significant level ** 5% significant level





Increase in precipitation SD is stronger than that in precipitation mean



Stronger variability and more occurrence of floods in the 21st century

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Interannual variability of western North Pacific subtropical high, East Asian jet and East Asian summer precipitation: CMIP5 simulation and projection

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Table 1
Information of the 19 CMIP5 models used in the present analysis.

Name	Modeling group	Atm. Resolution (lon × lat)
ACCESS1-0	Common wealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	192 × 145
ACCESS1-3	Common wealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	192 × 145
BCC-CSM1-1-m	Beijing Climate Center, China Meteorological Administration, China	320 × 160
BNU-ESM	Beijing Normal University/China	128 × 64
CanESM2	Canadian Centre for Climate Modeling and Analysis, Canada	128 × 64
CCSM4	National Center for Atmosphere Research, United States	288 × 192
CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy	192 × 96
CNRM-CM5	Centre National de Recherches Meteorologiques and Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique, France	256 × 128
FGOALS-g2	State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, China	128 × 60
FIO-ESM	First Institute of Oceanography, China	128 × 64
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory, United States	144 × 90
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory, United States	144 × 90
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory, United States	144 × 90
HadGEM2-AO	Met Office Hadley Centre, United Kingdom	192 × 144
HadGEM2-CC	Met Office Hadley Centre, United Kingdom	192 × 144
HadGEM2-ES	Met Office Hadley Centre, United Kingdom	192 × 144
IPSL-CM5A-MR	Institute Pierre-Simon Laplace, France	144 × 143
MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	128 × 64
NorESM1-M	Norwegian Climate Centre/Norway	144 × 96

Ren et al., 2017

Interannual standard deviations of EASRI.

Model	EASRI (mm/d)		
	Historical	RCP4.5	RCP8.5
ACCESS1-0	1.64	1.88	1.84
ACCESS1-3	1.53	1.67	1.75
BCC-CSM1-1-m	1.01	1.11	1.18
BNU-ESM	1.12	1.31	1.37
CanESM2	0.91	1.00	1.20
CCSM4	1.16	1.35	1.40
CMCC-CMS	1.23	1.36	1.43
CNRM-CM5	1.07	1.16	1.14
FGOALS-g2	0.93	0.95	0.92
FIO-ESM	1.16	1.21	1.30
GFDL-CM3	0.96	1.05	1.06
GFDL-ESM2G	0.97	1.13	1.16
GFDL-ESM2M	1.07	1.19	1.24
HadGEM2-AO	1.56	1.77	1.83
HadGEM2-CC	1.48	1.64	1.77
HadGEM2-ES	1.56	1.74	1.83
IPSL-CM5A-MR	0.98	1.05	1.12
MIROC-ESM	1.03	1.15	1.16
NorESM1-M	1.22	1.36	1.38
MME	1.19	1.32	1.37
OBS	1.22		

Summary

The CMIP5 models capture the ENSO–EASR relationship more realistically than the CMIP3 models.

The Philippine Sea Atmospheric Convection (PSC)–EASR relationship may be the most crucial physical process for current models to reproduce the ENSO–EASR relationship.

In the 21st century, East Asia will experience greater variability in summer rainfall, shown by both the CMIP3 and CMIP5 models.


THANKS