Evaluation of climate model toward CMIP6 protocol

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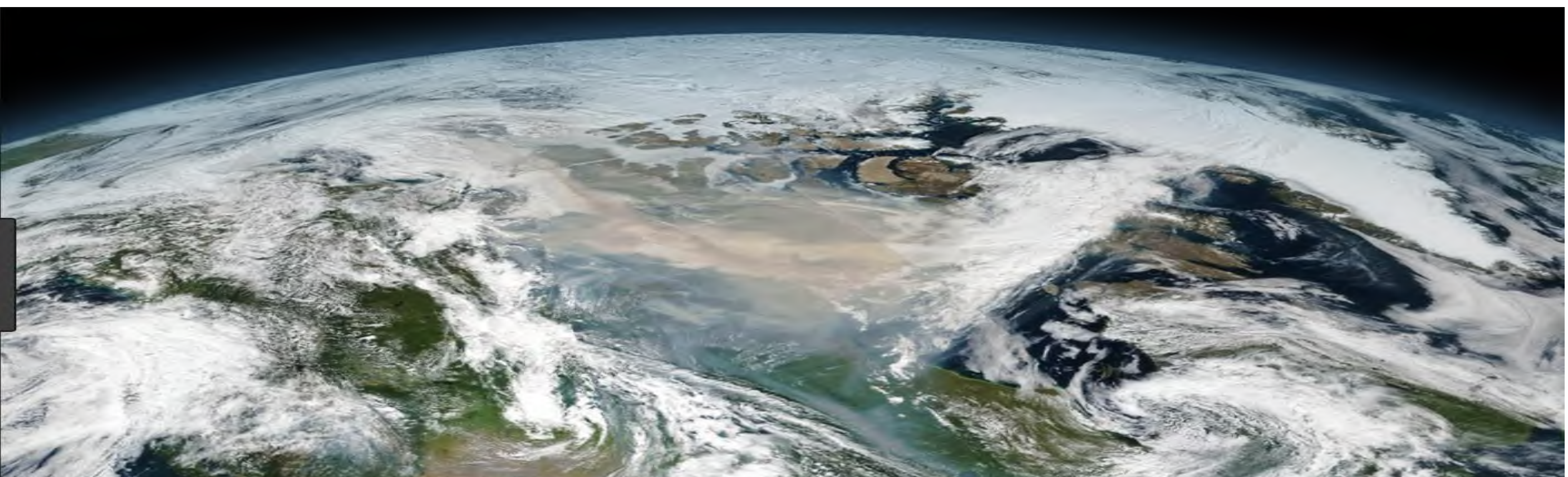
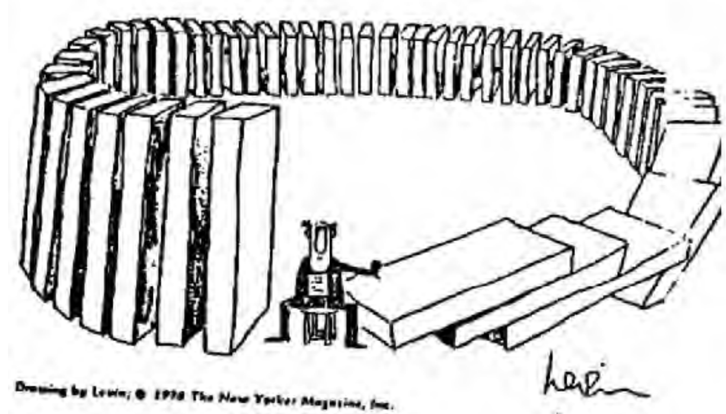


Climate model is …

Very Complex

Internal feedback



An effective evaluation tool is critical for further model improvement.

Introduction

Motivation

- Facilitate routine evaluation of climate model
- Need for standard tool for model evaluation
- Supporting decision about whether this version is improved or not?

Goal

- Develop an evaluation tool for climate model improvement
- Apply an evaluation for examining model performance (e.g. DECK run)

Contents

- Pre-Industrial (PI, fixed external forcing at 1850)
- Historical run (HIS, time evolution external forcing 1850 to 2014)
- Atmosphere, Land, Ocean and Sea ice
- Key variables : Global mean quantities, Climatology and variability

Introduction

Evaluation Index

Pattern correlation coefficient (PCC)
Normalized root-mean-square error (NRMSE)

Observation

HIS: CERES (radiative fluxes)/ CloudSat (cloud water)/CMAP (pr)/CRU (tas, pr) /ERA-40/ERA-Interim / GPCP(pr), HadCRUT (tas), MODIS (clivi, clwvi, clt), NCEP (ta, ua, va, zg, hus, tas), NOAA-PSD (radiation), OAFlux (surface fluxes)

PI : CMIP5 MME

Performance

- Comparison with CMIP5 MME and individual models.
- Good (upper 30% of CMIP5), Average (50% of CMIP5), poor (below 50% CMIP5)

Introduction

Software

Shell script, NCL script and Ferret

Process

1) Preparing model data (NC file format and specific variable names)
2) Copy evaluation tools (Scripts and observed data)
3) Setup key variables – path, period of data and variables to be analyzed
4) Run the tools
5) Post-processing (making summary table for performance)

Variables

- Atmosphere : Global mean quantities, Climatology, ENSO, EASM, EAWM, MJO, Global monsoon and teleconnection (zero or one)

- Land/Ocean/Seaice : Global mean quantities/Climatology

Table of overall performance (e.g NUIST-CSMv3.0)

Model (No. of variables)		Top 30%		Top 50%		Below 50%	
		ens1	ens2	ens1	ens2	ens1	ens2
Atmosphere	**Global mean/trends (33)**	16	16	12	12	5	5
	Climatology (34)	30	29	3	4	1	1
	ENSO (10)	7	9	2	1	1	0
	Global Monsoon (16)	14	15	2	1	0	0
	East Asian Summer Monsoon (44)	25	31	7	7	12	6
	East Asian Winter Monsoon (25)	23	22	2	3	0	0
	MJO (24)	24	24	0	0	0	0
	Teleconnection (6)	4	4	2	2	0	0
Ocean (36)		23	22	8	9	5	5
Land (28)		21	20	5	6	2	2
Seaice (10)		4	4	5	4	1	2
Total (266)		191 (72%)	196 (74%)	48 (18%)	49 (18%)	27 (10%)	21 (8%)

Atmosphere

- Each evaluation method is coherent and relevant?
- They also can classify good & poor model successfully?
- Is the tool provide key information for further improvement?

- Global mean quantities
- Climatology
- ENSO
- EASM/EAWM
- MJO
- Teleconnection

Atmosphere – global mean quantities (33)

- Temperature : ST, SST, Land T2m, precipitation
- Hydrology : freshwater
- Radiation : Net, SW and LW radiation at TOA and the surface

Red : -0.5 std ~ +0.5 std, Green: -1.0 std ~ +1.0 std, Blue : out of the range -1.0 std ~ +1.0 std

global mean	obs (1979-2005)	MME (1979-2005)	**(MME std) (1979-2005)**	**ens1**	**ens2**
ST (^oC)	15.53	15.49	(0.51)	15.28	15.19
land 2m T (^oC)	9.15	9.16	(0.80)	9.06	8.99
precip (mm d^{-1})	2.68	2.99	(0.14)	2.82	2.81
SST (^oC)	18.26	18.16	(0.56)	17.98	17.87
Fresh water flux (E-P, mm d^{-1})		-0.0004	(0.005)	0.001	0.01
TOA energy budget (w m^{-2})		0.77	(0.43)	0.34	0.50
TOA olr (w m^{-2})		238.41	(2.95)	235.45	235.58
TOA srad (w m^{-2})		239.19	(3.03)	235.7	235.88
Surface energy budget (w m^{-2})		1.31	(0.24)	1.10	1.05
surface energy budget (ocean)		1.62	(0.33)	1.45	1.52
surface energy budget (land)		0.62	(0.68)	0.39	0.50

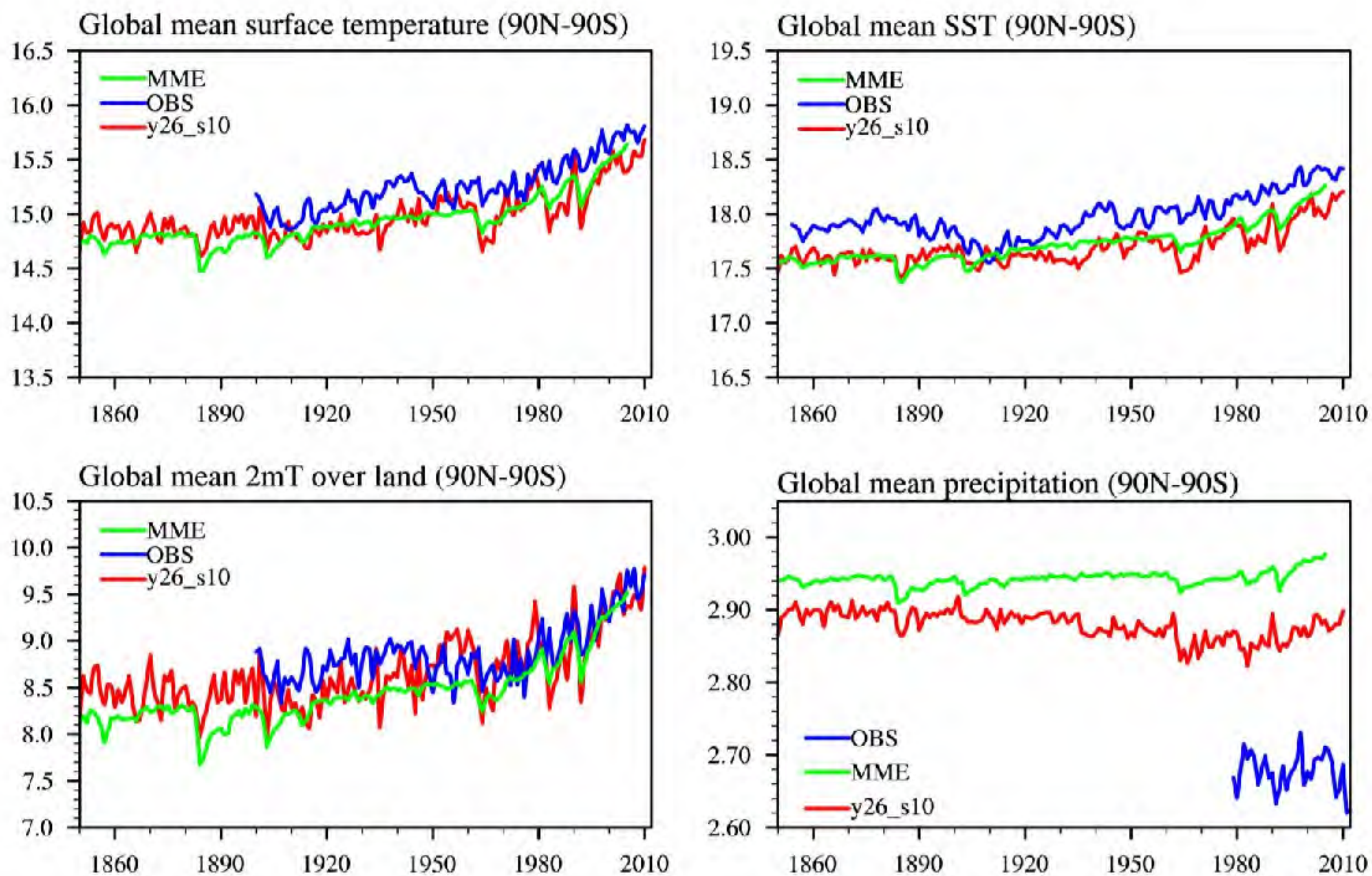
Atmosphere – global mean quantities

Global Mean Trends (1979-2005) (Historical)

global mean trend (*/100yr)	obs (1979-2005)	MME (1979-2005)	(MME std) (1979-2005)	ens1	ens2
ST (^{o}C)	1.53	1.93	(0.53)	1.55	1.53
land 2m T (^{o}C)	2.48	3.10	(0.84)	2.74	2.78
precip (mm d^{-1})	0.05	0.12	(0.05)	0.10	0.10
SST (^{o}C)	1.13	1.43	(0.44)	1.05	1.01
Fresh water flux (E-P, mm d^{-1})		0.0001	(0.003)	0.0005	0.001
TOA energy budget (w m^{-2})		2.45	(0.69)	3.11	3.12
TOA olr (w m^{-2})		-0.81	(1.44)	-1.25	-0.24
TOA srad (w m^{-2})		3.28	(1.71)	4.39	4.42
Surface energy budget (w m^{-2})		2.37	(0.66)	1.75	1.83
surface energy budget (ocean)		3.24	(0.95)	2.32	2.35
surface energy budget (land)		0.29	(0.24)	0.73	0.71

Red : -0.5 std ~ +0.5 std, Green: -1.0 std ~ +1.0 std, Blue : out of the range -1.0 std ~ +1.0 std

Atmosphere – global mean quantities



Atmosphere – Climatology (34)

- Climatology is critical for realistic simulation of ISO, monsoon, - ENSO-monsoon relationship

✓ Precipitation : annual mean/annual cycle mode (solstice/equinox)
✓ SST : annual mean/annual cycle
✓ Circulation : zonal mean wind, Hadley circulation, surface winds, SLP, vertical velocity
✓ Surface fluxes : evaporation

(bracket : PCC)

	Top 30% of CMIP5 models	Top 50% of CMIP5 models	ENS3	ENS4	ENS5	ENS mean
EQ SST AC*	0.64 (0.79)	0.66 (0.75)	0.62 (0.79)	0.60 (0.80)	0.60 (0.80)	
EQ ZWS AC*	1.64 (0.37)	1.73 (0.35)	1.23 (0.47)	1.34 (0.37)	1.34 (0.37)	
PRCP AM	0.58 (0.85)	0.64 (0.81)	0.49 (0.87)	0.49 (0.87)	0.49 (0.88)	
PRCPAC1	0.66 (0.83)	0.69 (0.81)	0.72 (0.86)	0.69 (0.86)	0.69 (0.87)	
PRCP AC2	0.97 (0.69)	0.99 (0.67)	0.99 (0.58)	0.97 (0.58)	0.98 (0.63)	
SST AM	0.10	0.11	0.10	0.10	0.10	
SST AC1	0.24 (0.97)	0.26 (0.96)	0.29 (0.97)	0.29 (0.97)	0.29 (0.97)	
SST AC2	0.34 (0.95)	0.36 (0.94)	0.41 (0.95)	0.41 (0.95)	0.40 (0.96)	

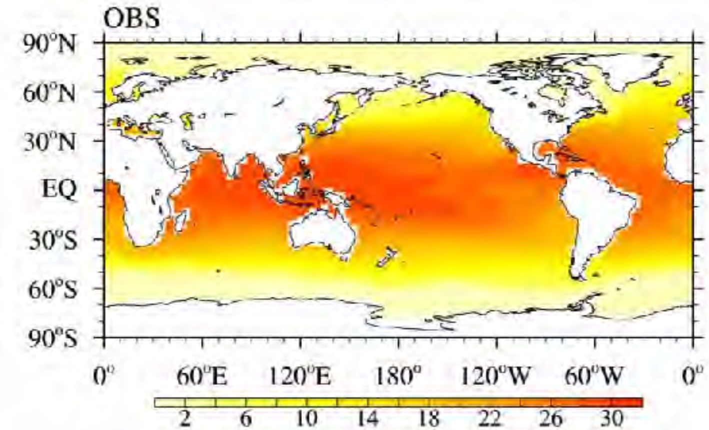
Atmosphere - Climatology

	top 30% of CMIP5 models	top50% of CMIP5 models	ENS1	ENS2	ENS3	ENS4	ENS5	ENS mean
Zonal Mean U	0.23 (0.98)	0.29 (0.97)			0.23 (0.98)	0.23 (0.98)	0.23 (0.98)	
Evap (land)	0.57 (0.85)	0.58 (0.84)			0.46 (0.88)	0.46 (0.88)	0.46 (0.88)	
Evap (ocean)	0.43 (0.95)	0.45 (0.94)			0.31 (0.95)	0.30 (0.95)	0.31 (0.95)	
V (Hadley circulation)	0.42 (0.92)	0.46 (0.91)			0.34 (0.94)	0.34 (0.94)	0.34 (0.94)	
W (Hadley circulation)	0.55 (0.85)	0.59 (0.84)			0.49 (0.93)	0.49 (0.93)	0.49 (0.92)	
Surface U	0.31 (0.97)	0.33 (0.96)			0.23 (0.97)	0.23 (0.97)	0.23 (0.97)	
Surface V	0.46 (0.92)	0.48 (0.91)			0.40 (0.92)	0.40 (0.92)	0.40 (0.92)	
JJA SLP	0.012	0.013			0.010	0.010	0.011	
DJF SLP	0.008	0.010			0.006	0.006	0.006	
Omega	0.77 (0.72)	0.86 (0.69)						
SST STD	1.03 (0.67)	1.18 (0.65)						
Land T2m STD	0.95 (0.40)	1.02 (0.36)						
precip STD	0.56 (0.87)	0.62 (0.83)						
SLP STD	0.60 (0.85)	0.63 (0.83)						

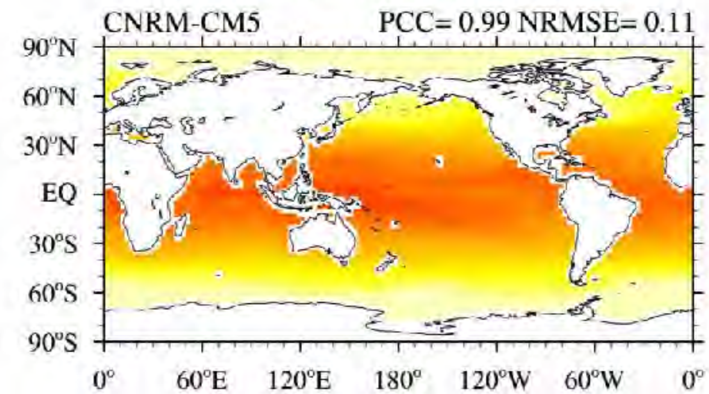
Red : reach the top 30% Green: reach the top 50% Blue : not reach the top 50%

Annual mean SST

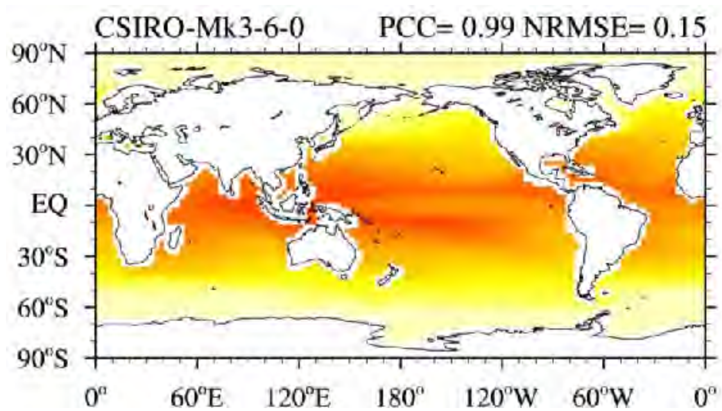
OBS

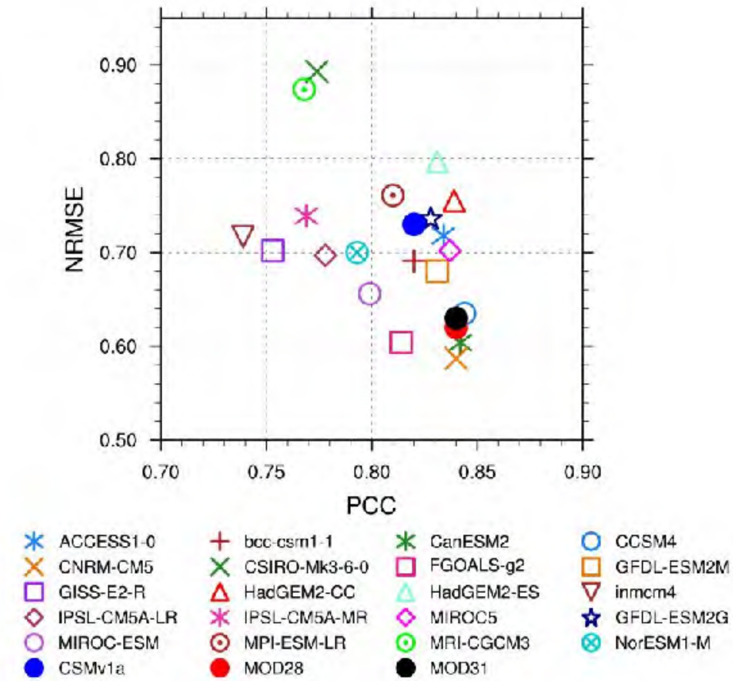


Good



Poor



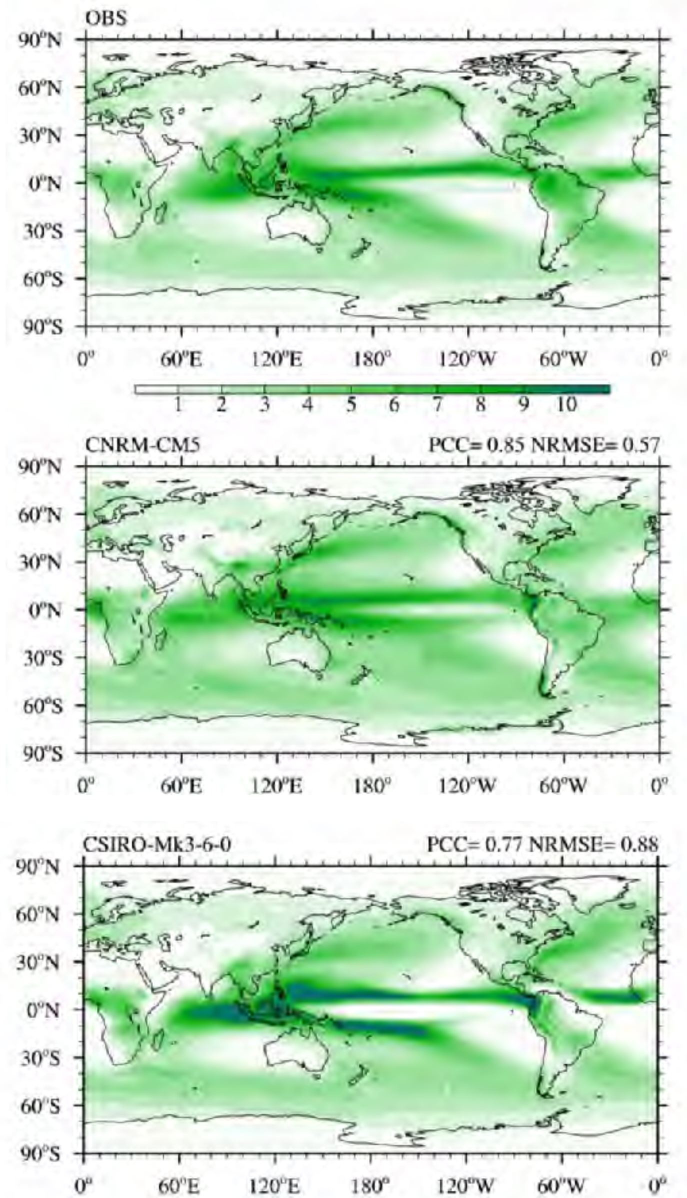


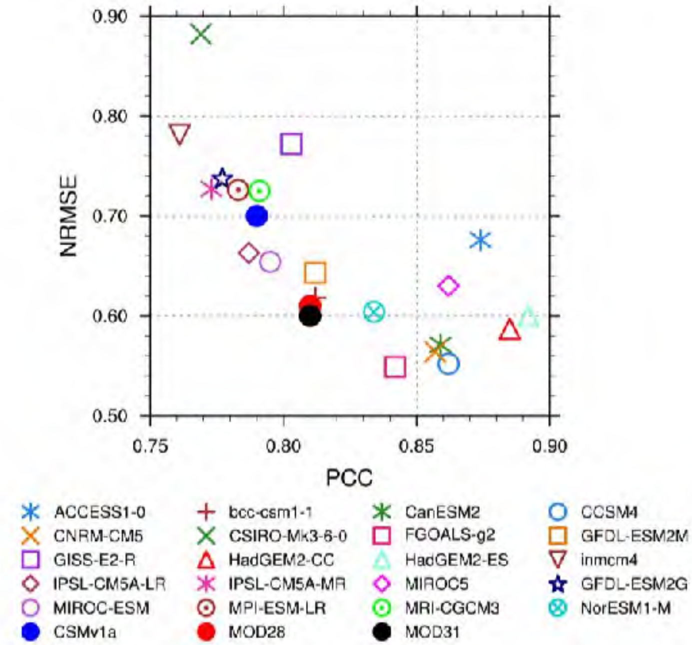
Annual mean precipitation

OBS

Good

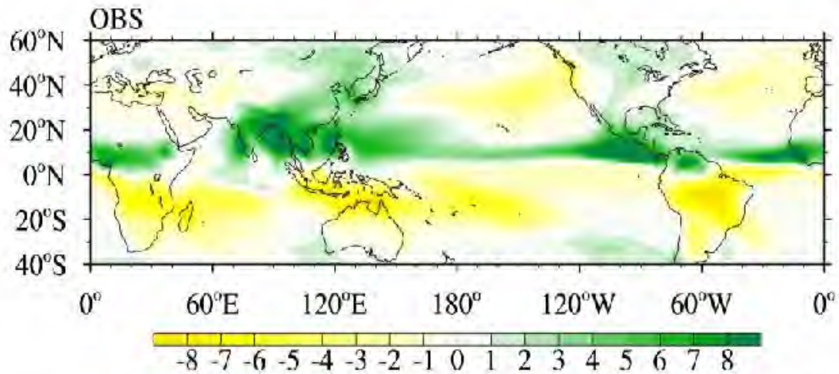
Poor





First annual cycle mode : precipitation

OBS



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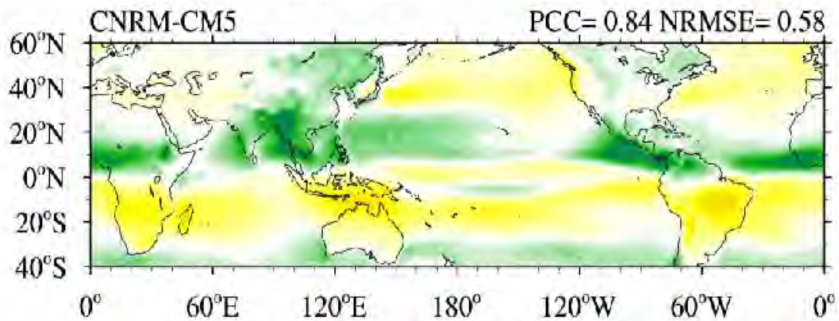

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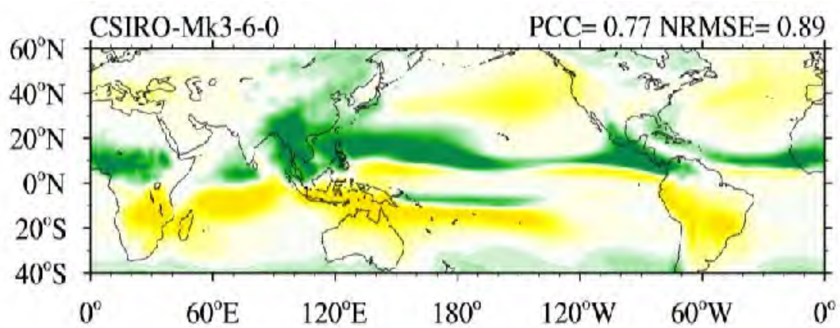
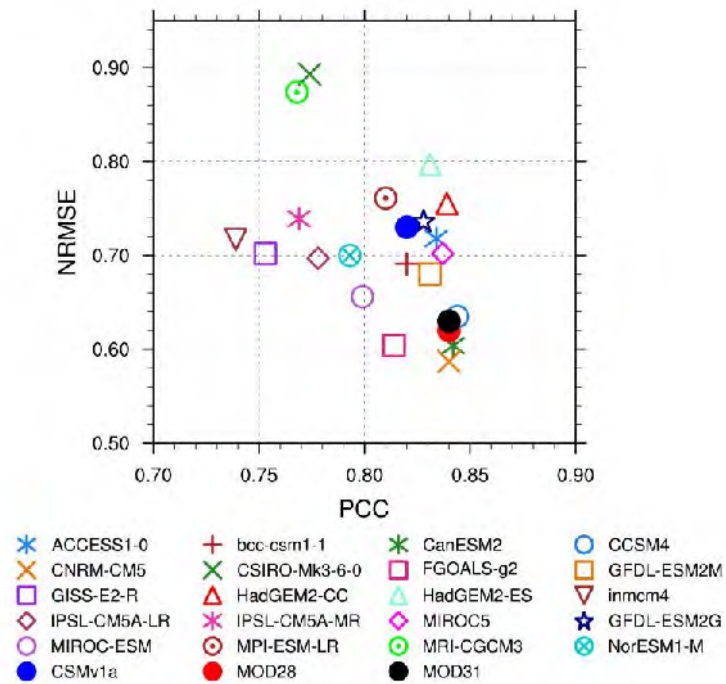


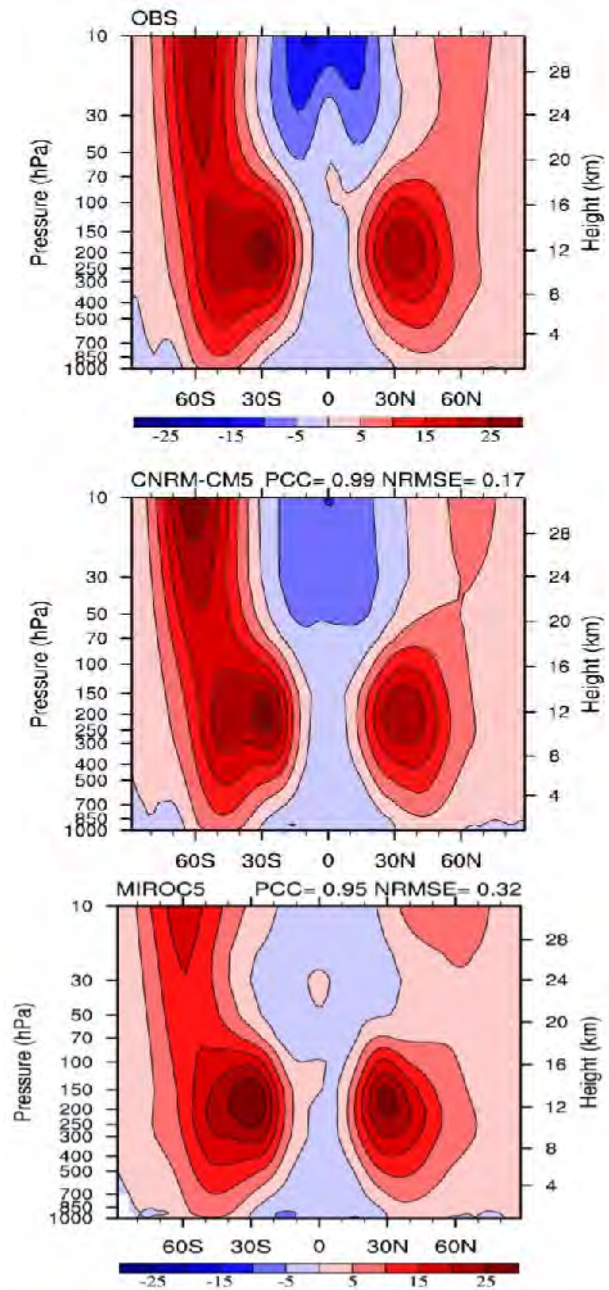


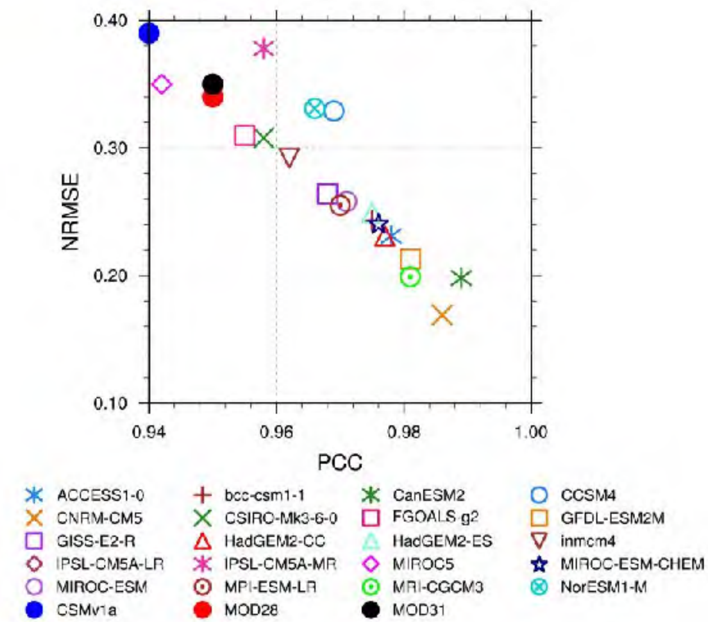
Zonal mean wind

OBS

Good

Poor





Global Monsoon

1) GMPI (Global Monsoon Precipitation domain & Intensity, Wang et al. 2011)

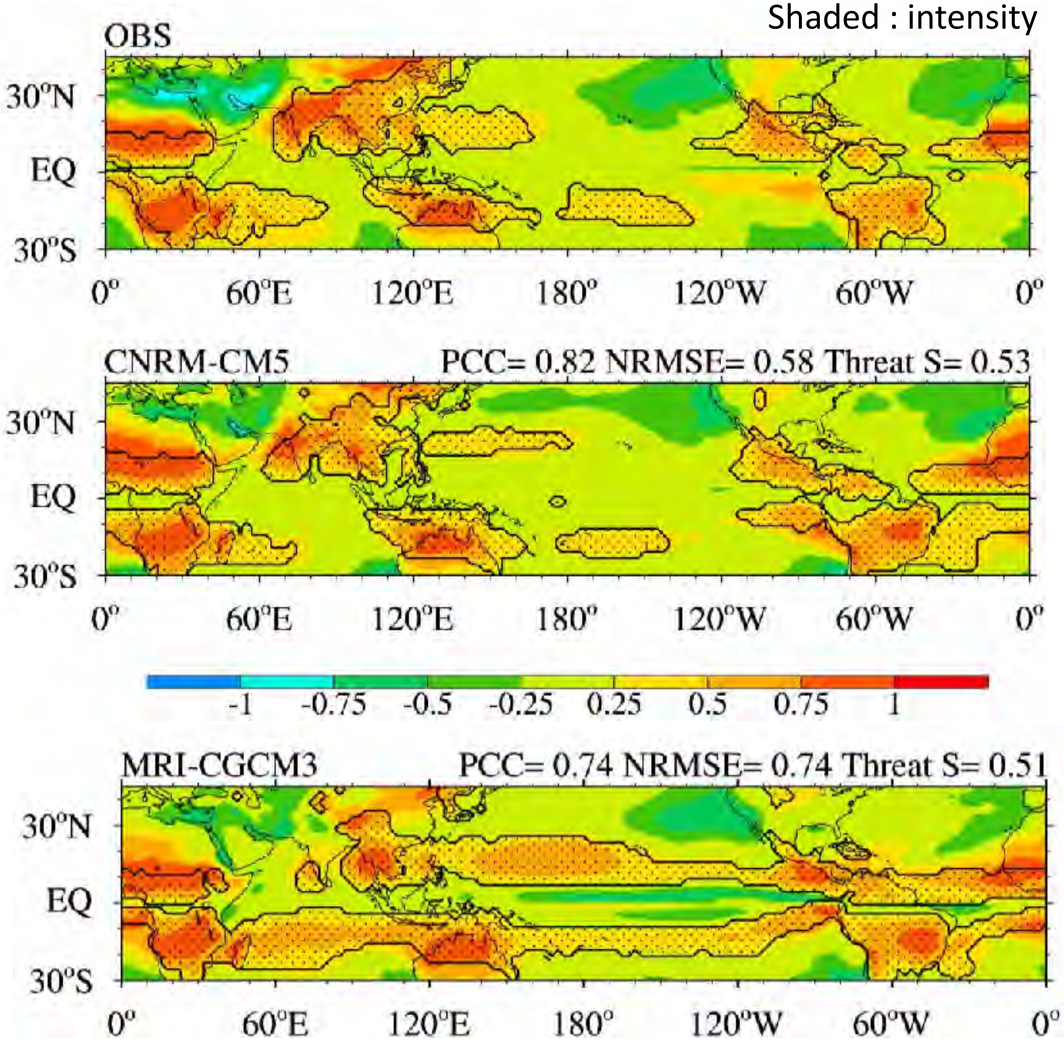
- Domain : local summer minus winter PRCP exceeding 2 mm/day and local summer PRCP exceeding 55% of annual total PRCP
- Intensity : ratio of local summer-minus-winter PRCP over annual mean PRCP.

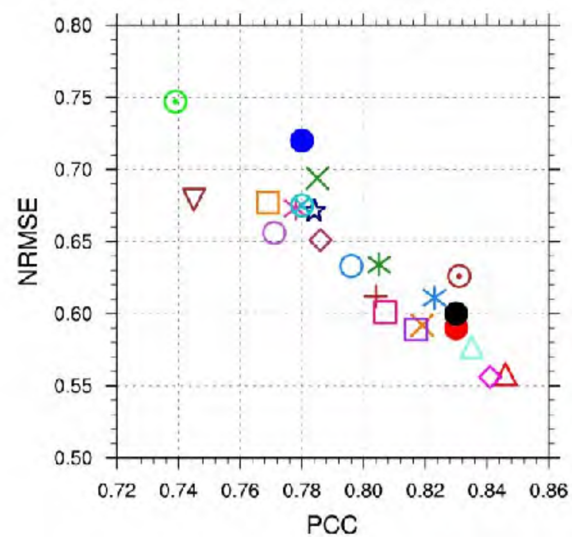
2) Seasonal mean & variance

3) Seasonal-reliant EOF (AAM precipitation variability)

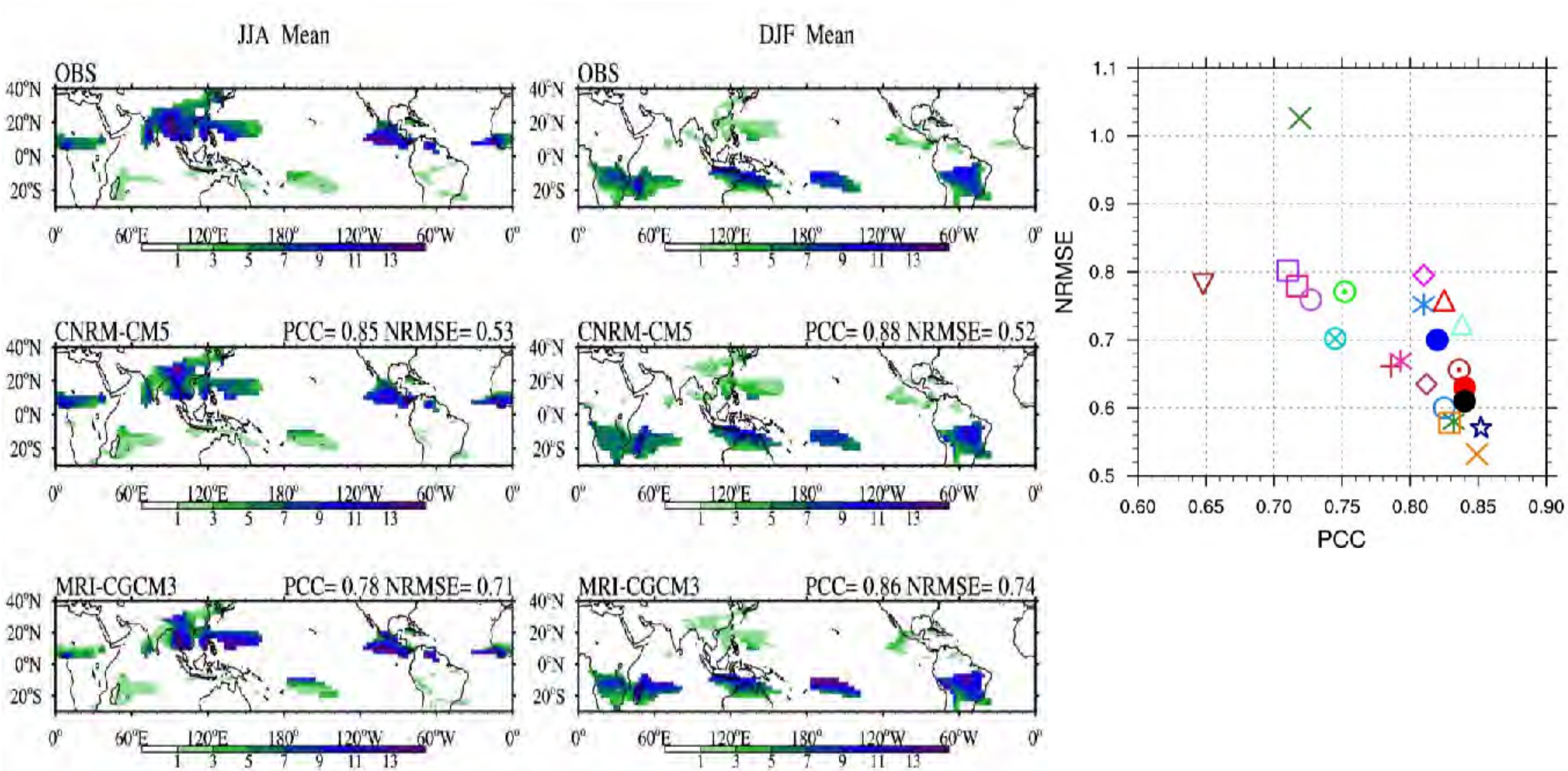
Global Monsoon – domain & intensity

Dotted : domain
Shaded : intensity

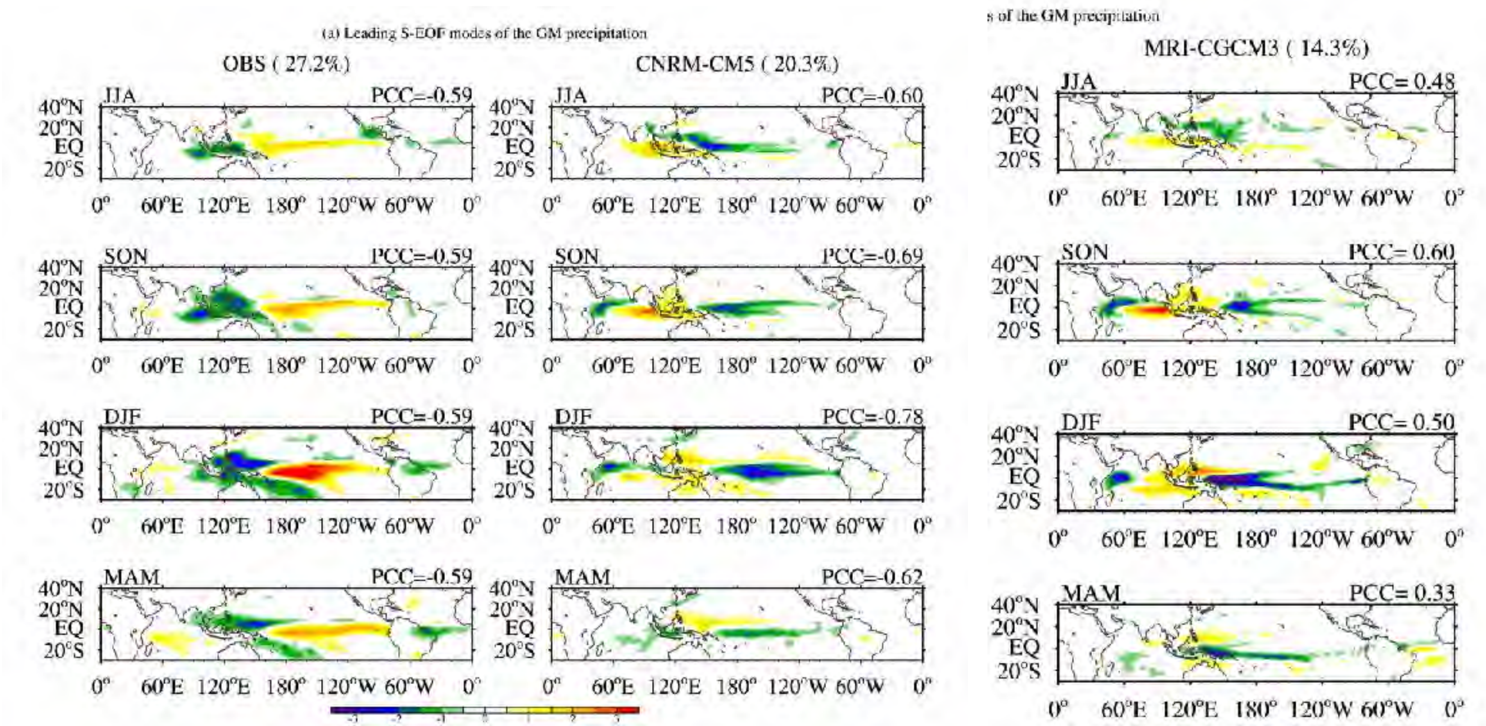


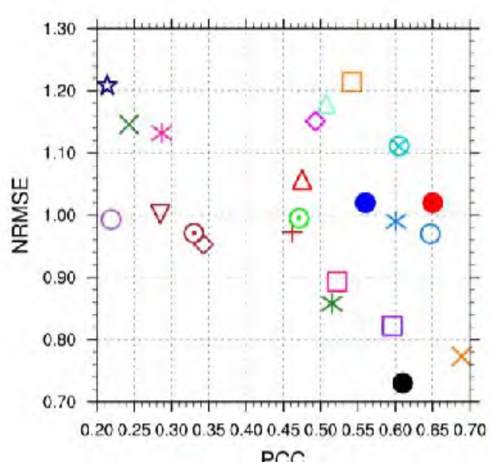


Global Monsoon – seasonal mean&variance



Global Monsoon – AAM; seasonal EOF

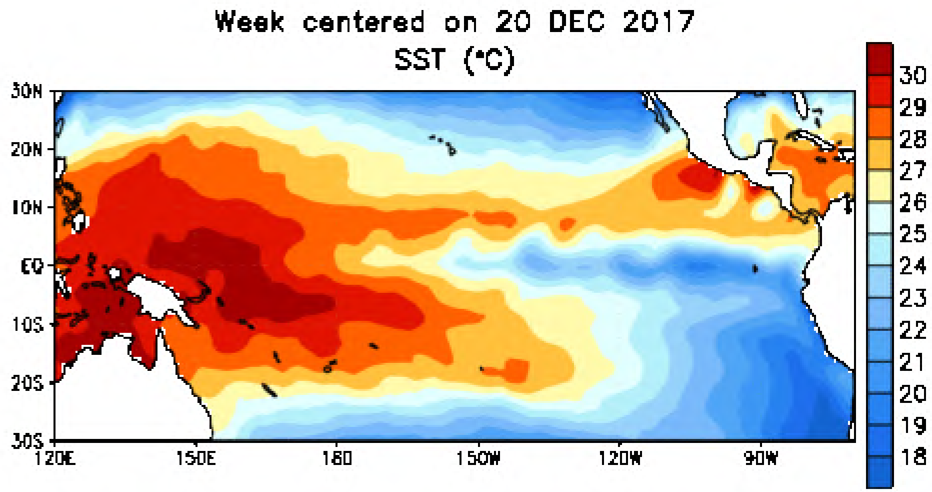




ENSO

- Amplitude – interannual variability & Phase-locking (Wang and Fang, 2000)
- Spatial-temporal variation (Wang and An, 2005)
  - EOF1&2 (multi-time scales)
  - LF (low frequency) & QB (Quasi-biennial) : S-EOF
- Two ENSO type – CP/EP ENSO
- Periodicity - Power spectrum analysis

- Reference : 20 CMIP5 models data
- OBS : ERSST



NOAA

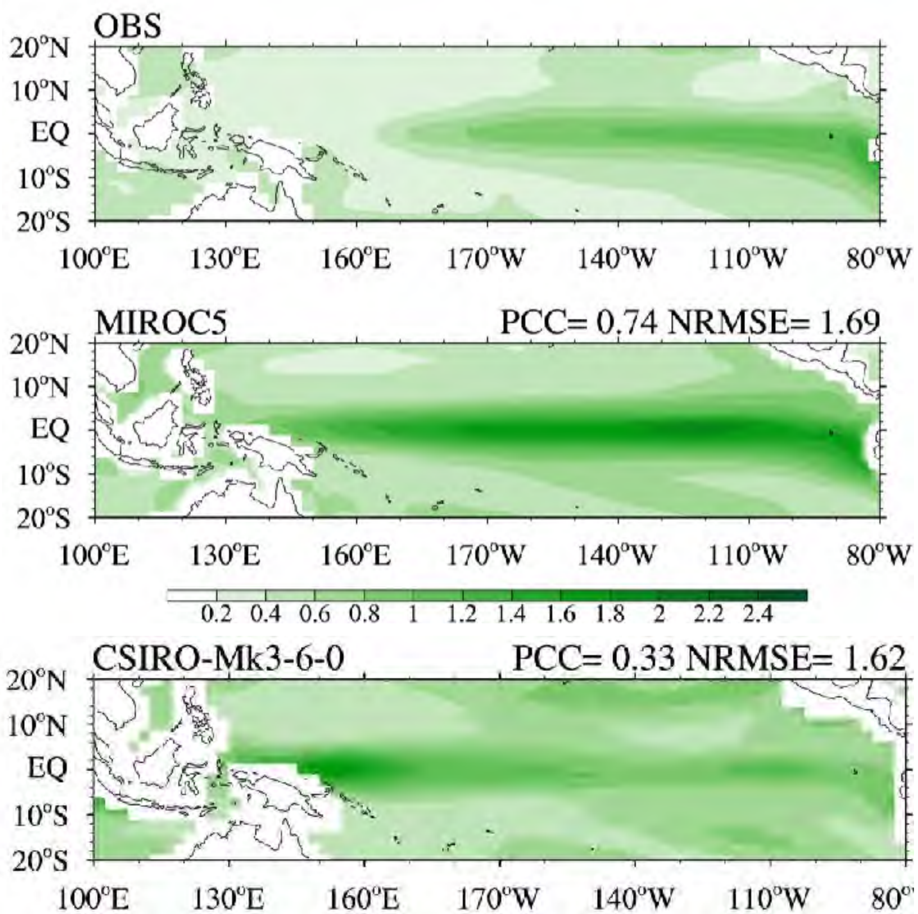
ENSO diagnostics (10)

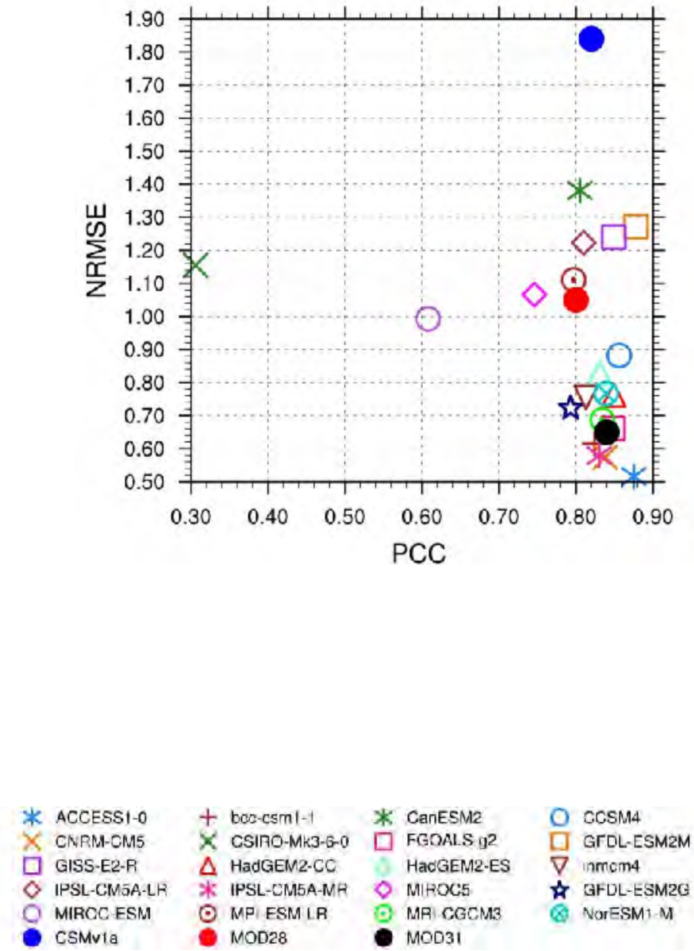
		Top 30% of CMIP5 models	Top 50% of CMIP5 models	Y27	Y30
ENSO	**SSTV**	0.68 (0.84)	0.72 (0.83)	0.60 (0.84)	0.54 (0.89)
	EOF1	(0.93)	(0.92)	(0.94)	(0.94)
	EOF2	(0.39)	(0.26)	(0.33)	(0.45)
	CP-ENSO	(0.85)	(0.83)	(0.90)	(0.85)
	EP-ENSO	(0.93)	(0.91)	(0.93)	(0.93)
	Spectrum	(0.48)	(0.32)	(0.33)	(0.48)
	Phase-locking	(0.86)	(0.83)	(0.87)	(0.74)
	LF-ENSO**	(0.75)	(0.69)	(0.75)	(0.82)
	QB-ENSO**	(0.70)	(0.62)	(0.62)	(0.73)

**Average of four seasons

Red : reach the top 30% Green: reach the top 50% Blue : not reach the top 50%

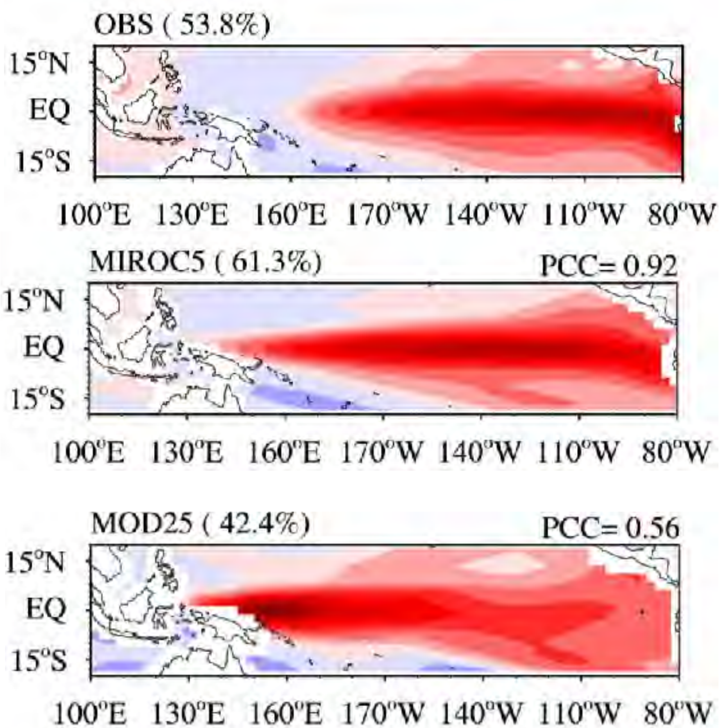
ENSO-Interannual variability



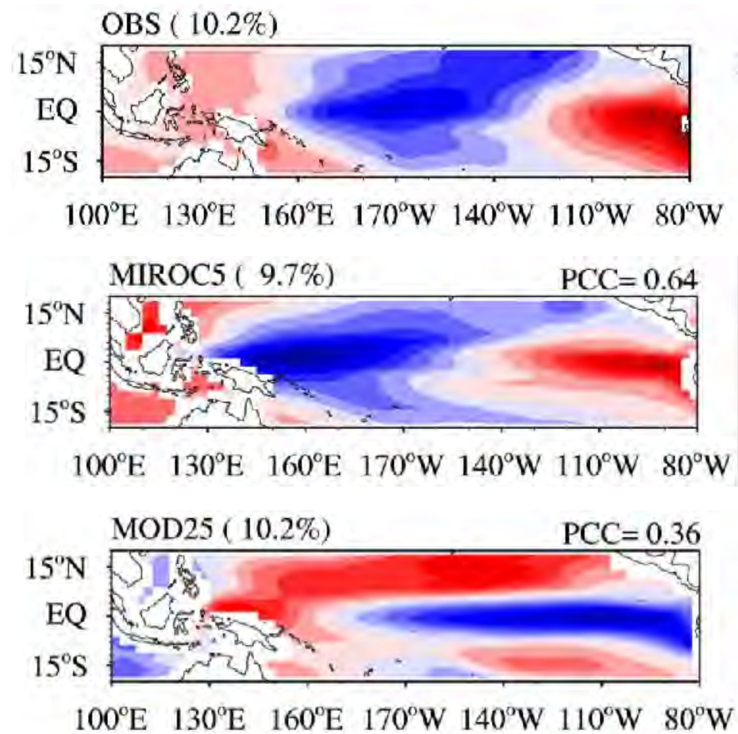


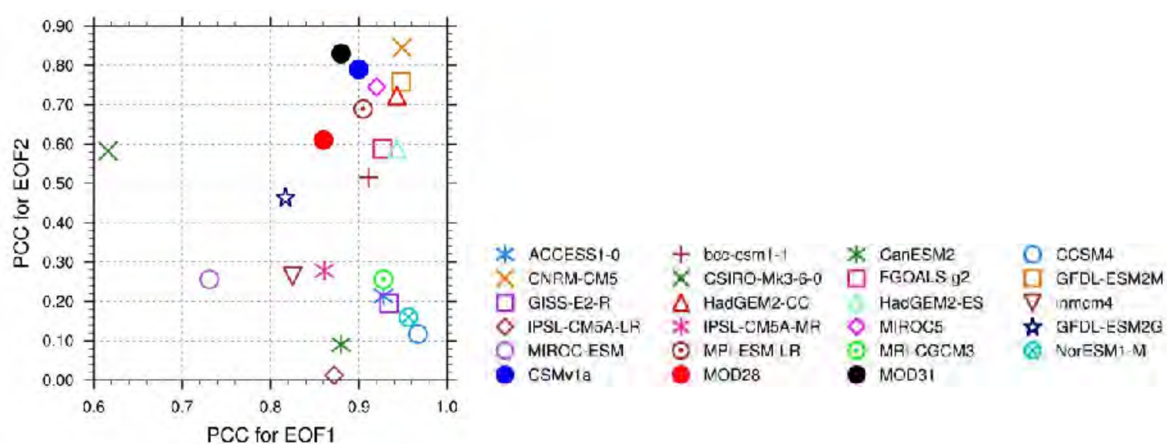
ENSO- EOF analysis

EOF1



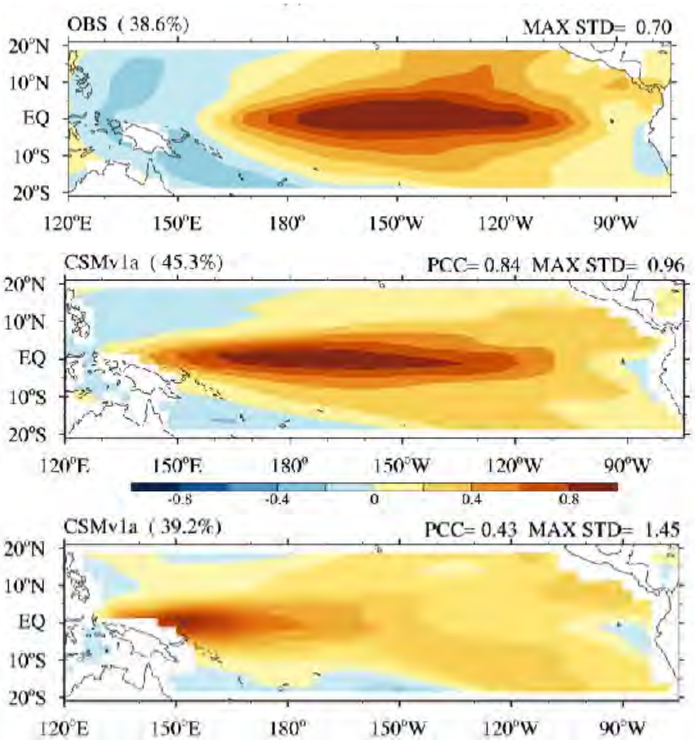
EOF2



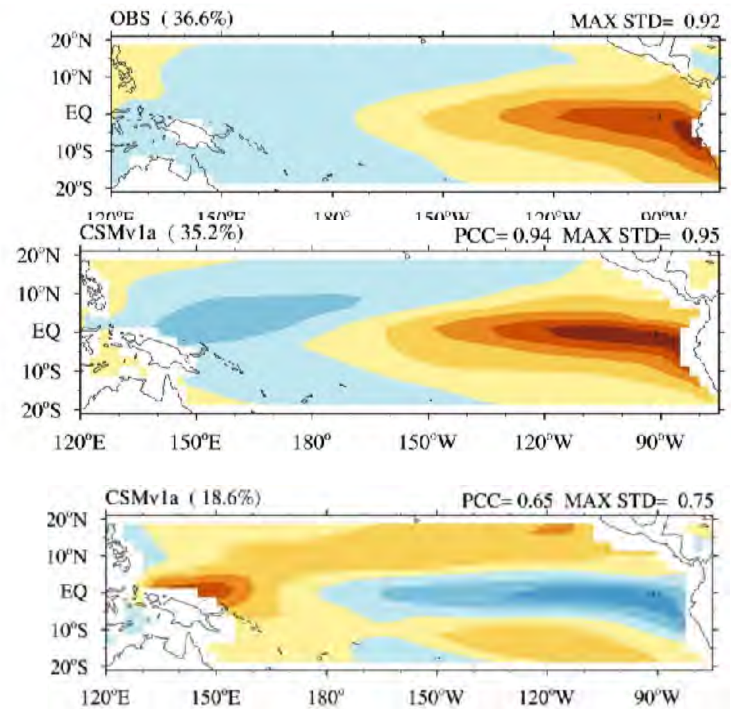


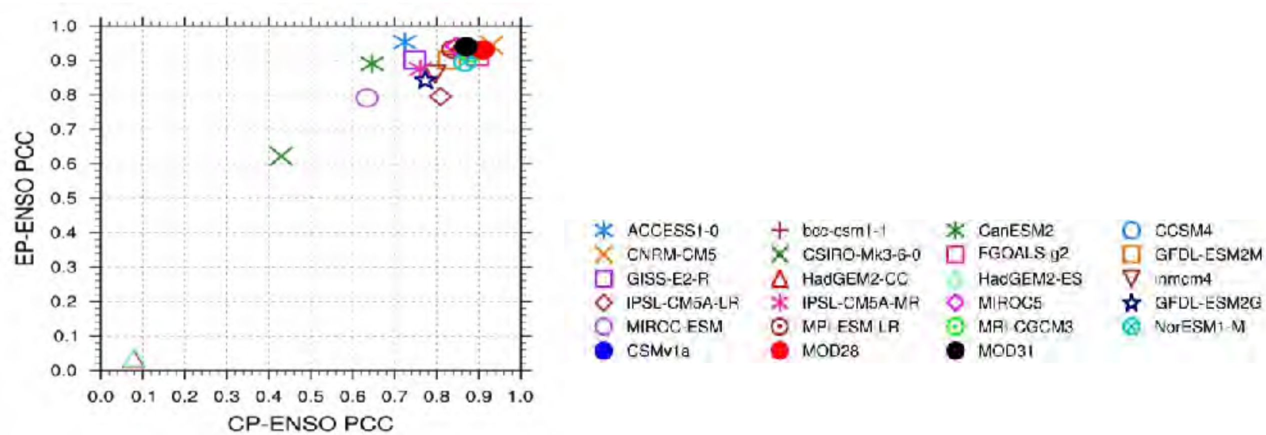
CP/EP ENSO

CP ENSO



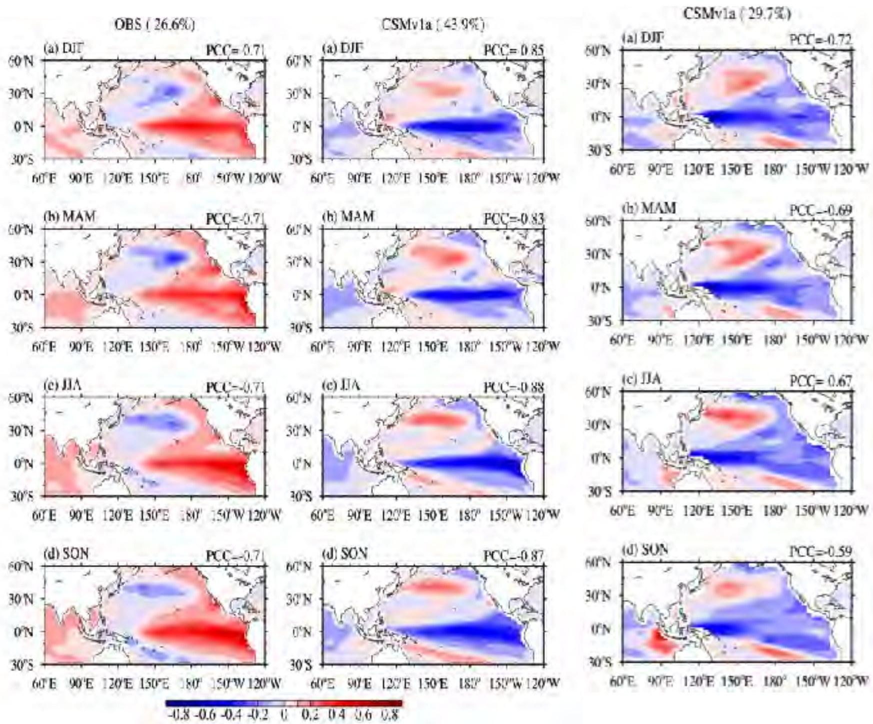
EP ENSO



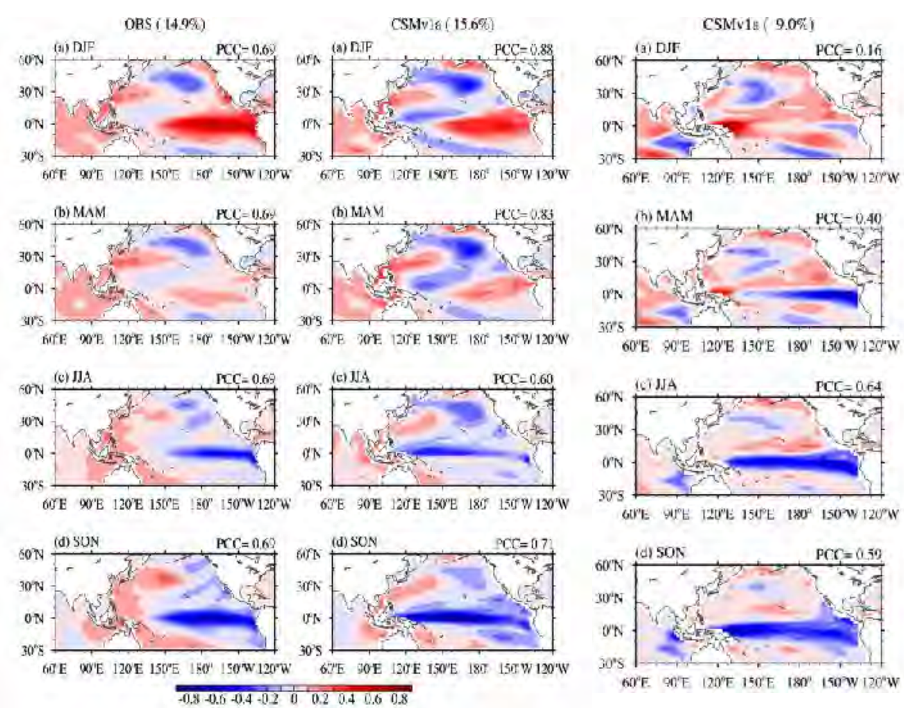


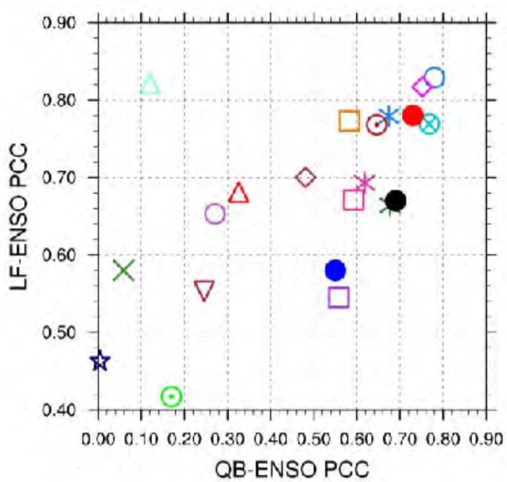
S-EOF

LF (S-EOF1)



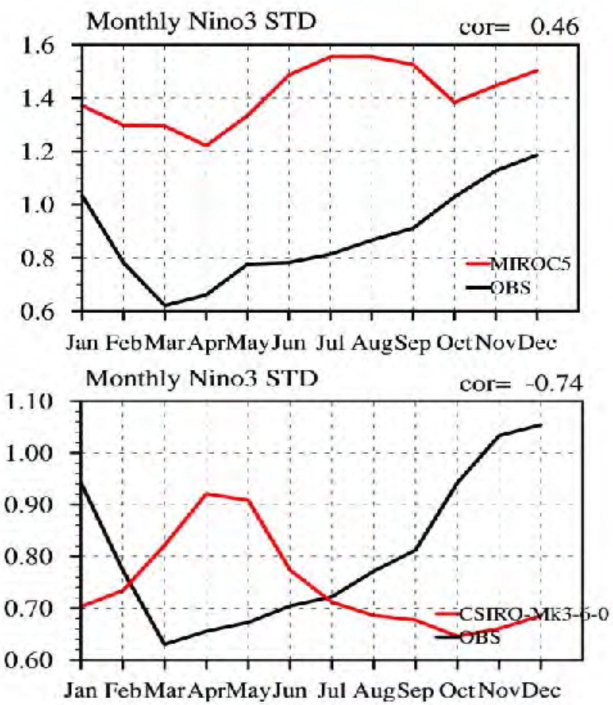
QB (S-EOF2)



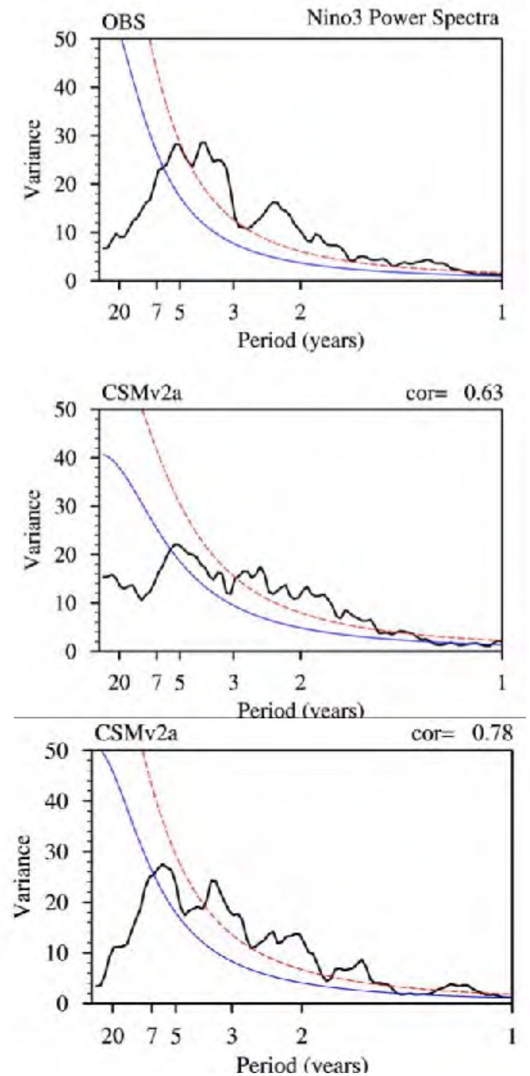


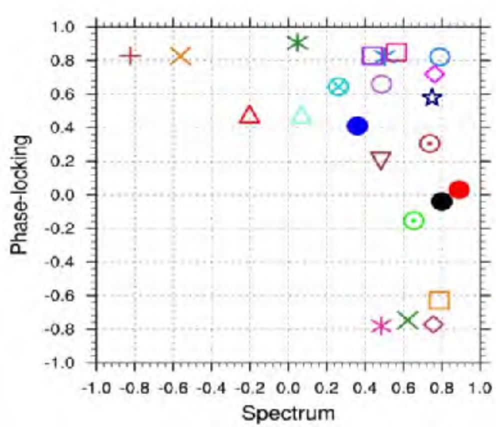
Phase-Locking/Periodicity

Phase-Locking



Periodicity





East Asian Monsoon

- East-Asian diagnostic tools (Li et al, 2018;Wang et al. 2008, 2013; Zhou and Yu 2005)
- Summer

  1) Climatology – Planetary-scale circulation : providing background

  ① Meiyou/Changma/Baiu rainbelt :EA subtropical front

  ② Location & strength of WPSH : EA rainfall

  ③ Shift of subtropical westerly jet (40N) : Movement of EA rainbelt

  ④ Moisture transport by southwesterly & WPSH

  2) Annual cycle (Zhu et al. 2012, 110-130E)

  - transition dry to rainy season (northward movement of rain band)

  3) EASM onset – change of zonal wind at South China Sea (SCS,110~130E, 5-15N)

  4) Major modes in monsoon : multi-eof (PRCP&GH850)

  5) EASM-Monsoon relationship (correlation)

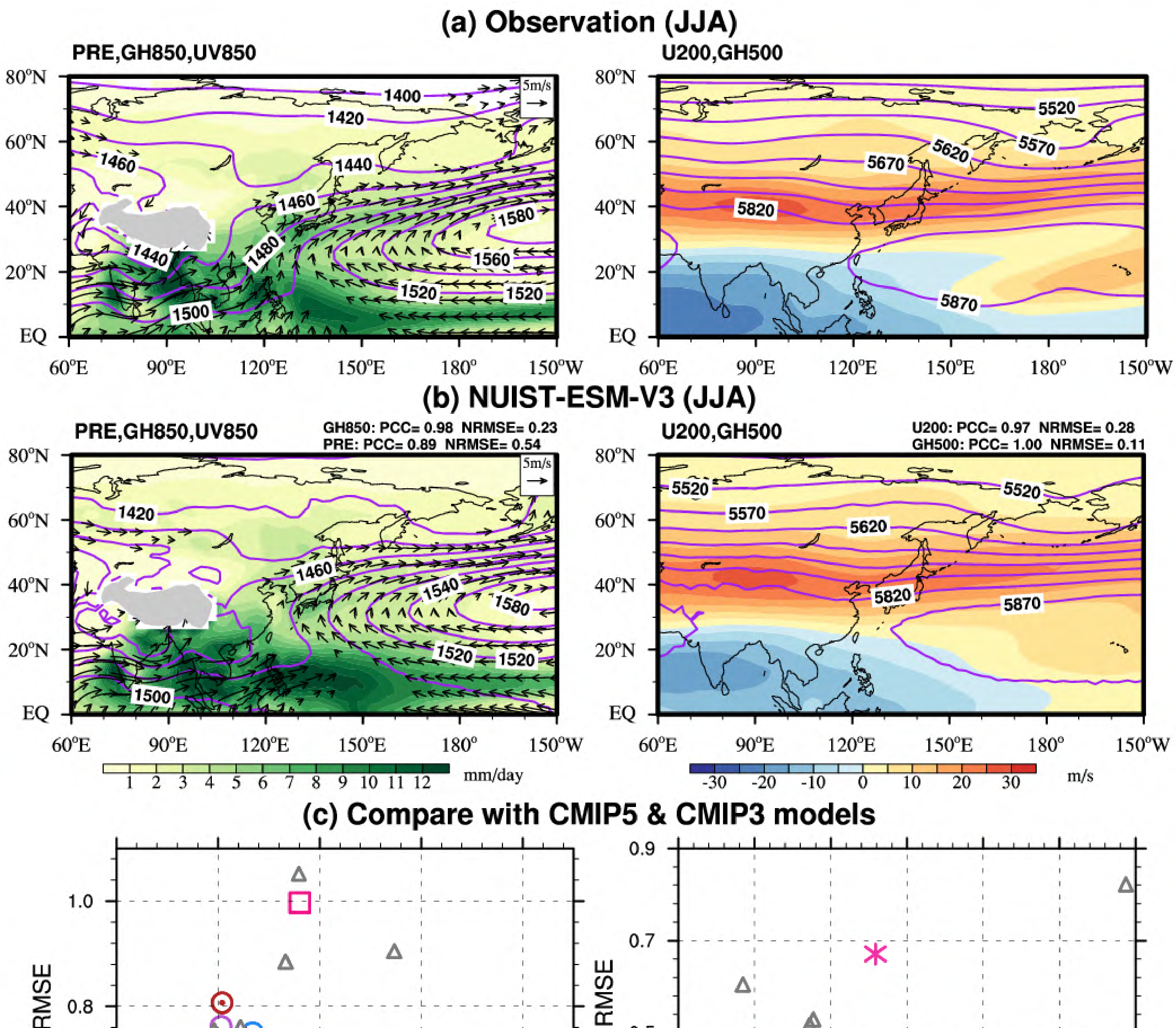
  6) teleconnection – regression of suppressed rainfall on zonal wind shear Index

* winter

  1) climatology

  2) EOF1,2

  3) Regression of PRCP, T2m,U200,GH500



A mean
mm/day),
height
Pa winds
onal wind
500-hPa
tours, m)
(b) NUIST-
ng 1979-
mance on
ıatological
d 500hPa
well as
-80N, 60E-

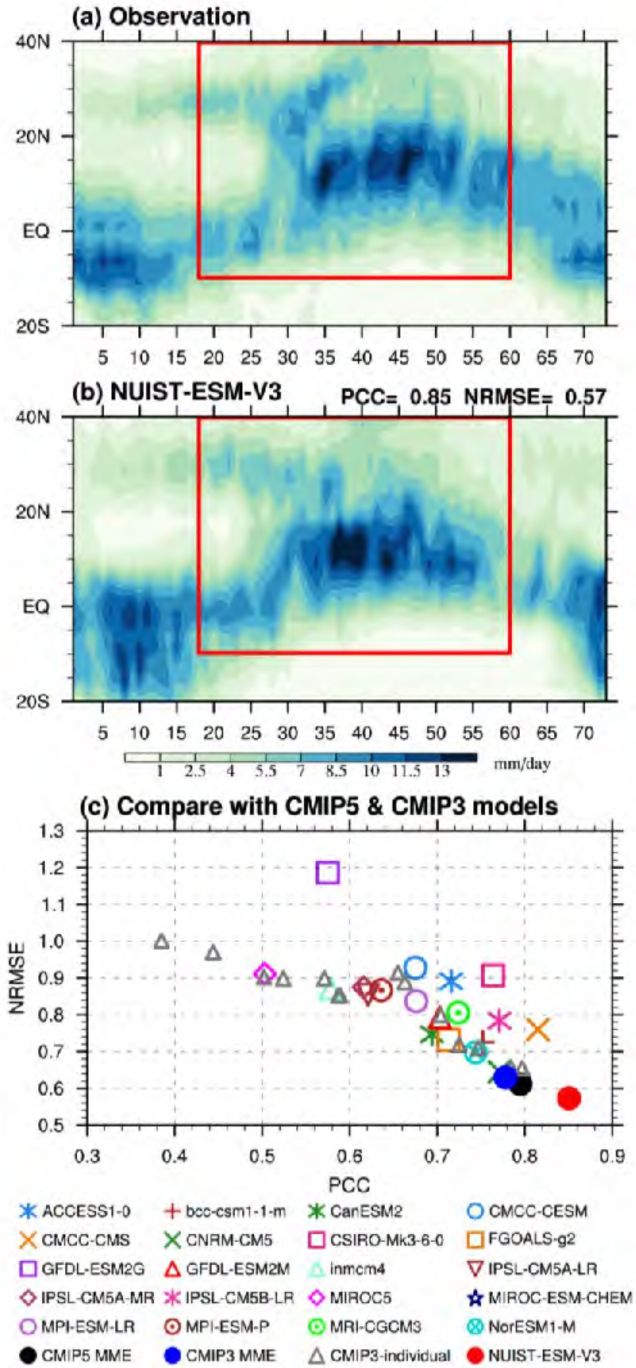


Fig.3 Annual cycle climatology (1979-2005) for pentad mean precipitation averaged between 110E and 130E from (a) observation and (b) NUIST-ESM-V3 simulation. The PCC and NRMSE skills are calculated over 10S-40N, 18-60 pentad(Apr.-Nov) (red rectangle). (c) Models' performance on simulation of climatological annual cycle of precipitation in terms of PCC and NRMSE.

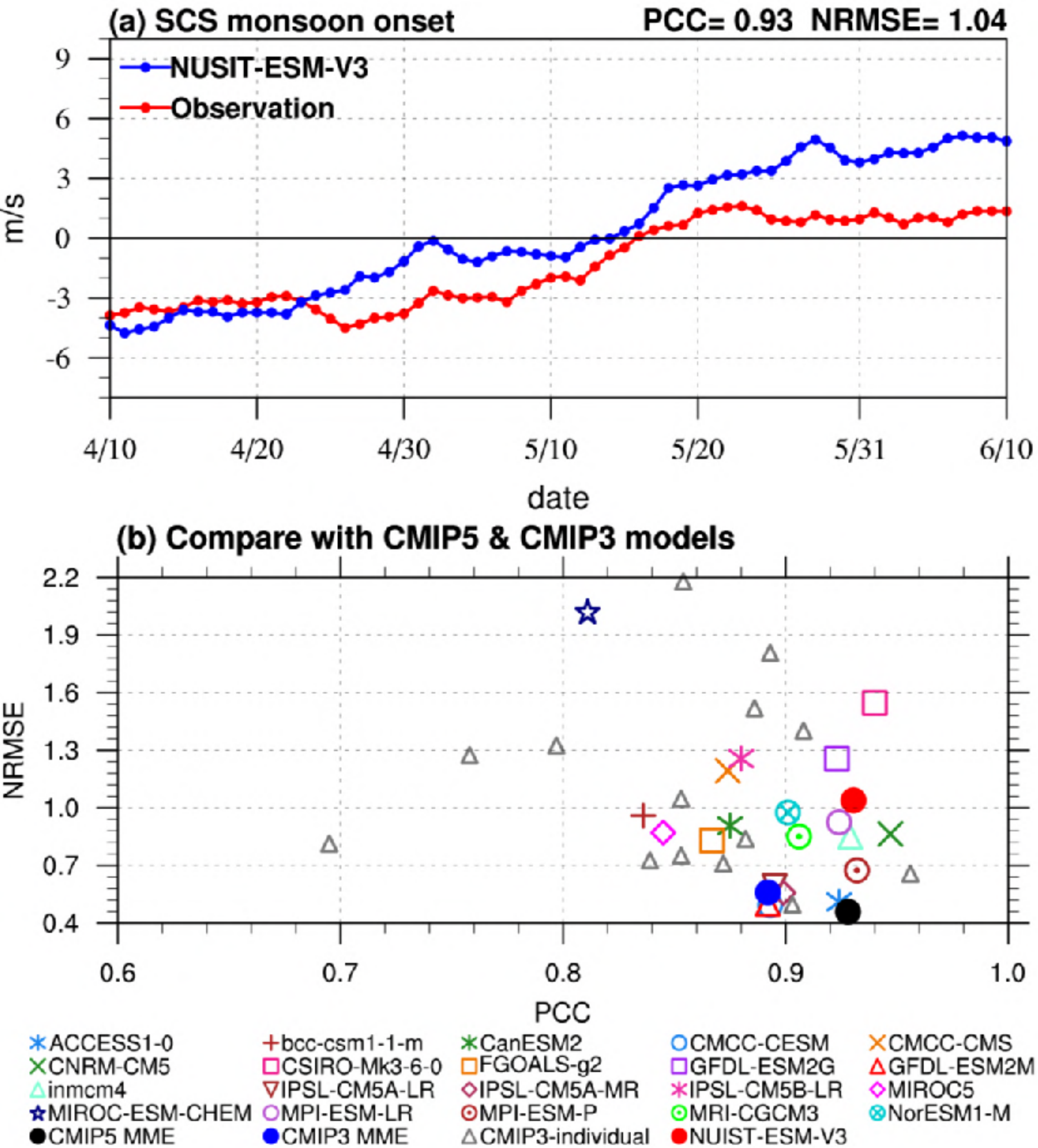


Fig. 4 (a) Time evolution of climatological mean South China Sea monsoon onset index from April 10th to June 10th during 1979-2005 obtained from observation and NUIST-ESM-V3 simulation. South China Sea monsoon onset index is defined by 850-hPa zonal winds averaged over 5 – 15N, 110 –120 E. (b) Models' performance on simulation of climatological South China Sea monsoon onset index in terms of PCC and NRMSE.

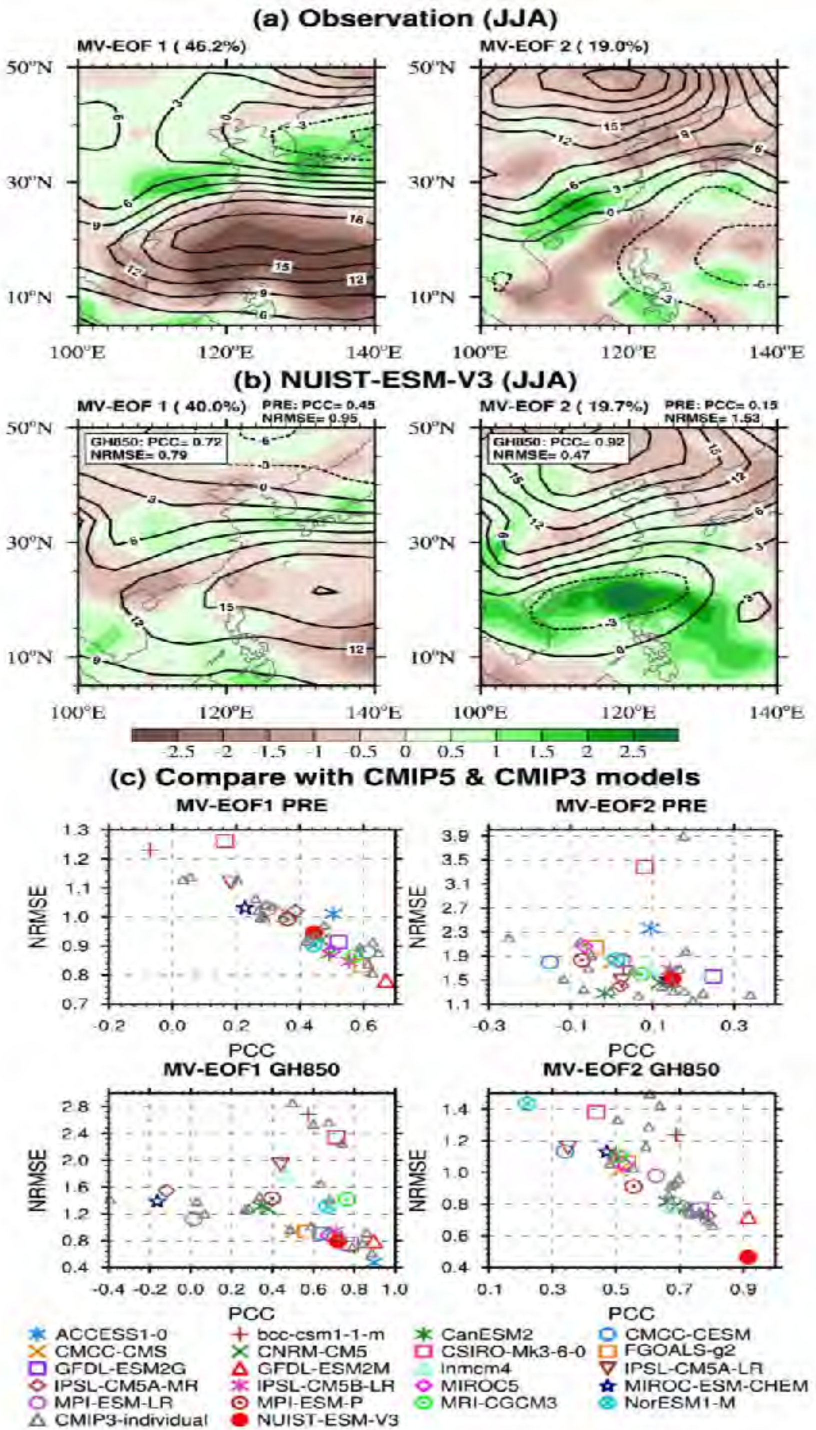
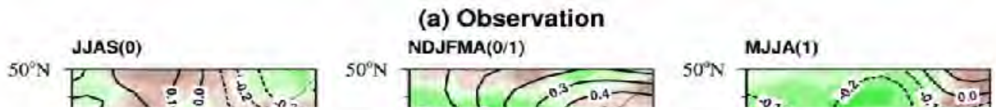


Fig. 5 Spatial patterns of first two MV-EOF modes of the East Asian precipitation (shadings) and 850-hPa geopotential height (contour) in JJA from (a) observation and (b) NUIST-ESM-V3 simulation during 1979-2005. (c) Models' performance on simulation of the first two MV-EOF modes of the East Asian precipitation and 850-hPa geopotential height in JJA in terms of PCC and NRMSE.



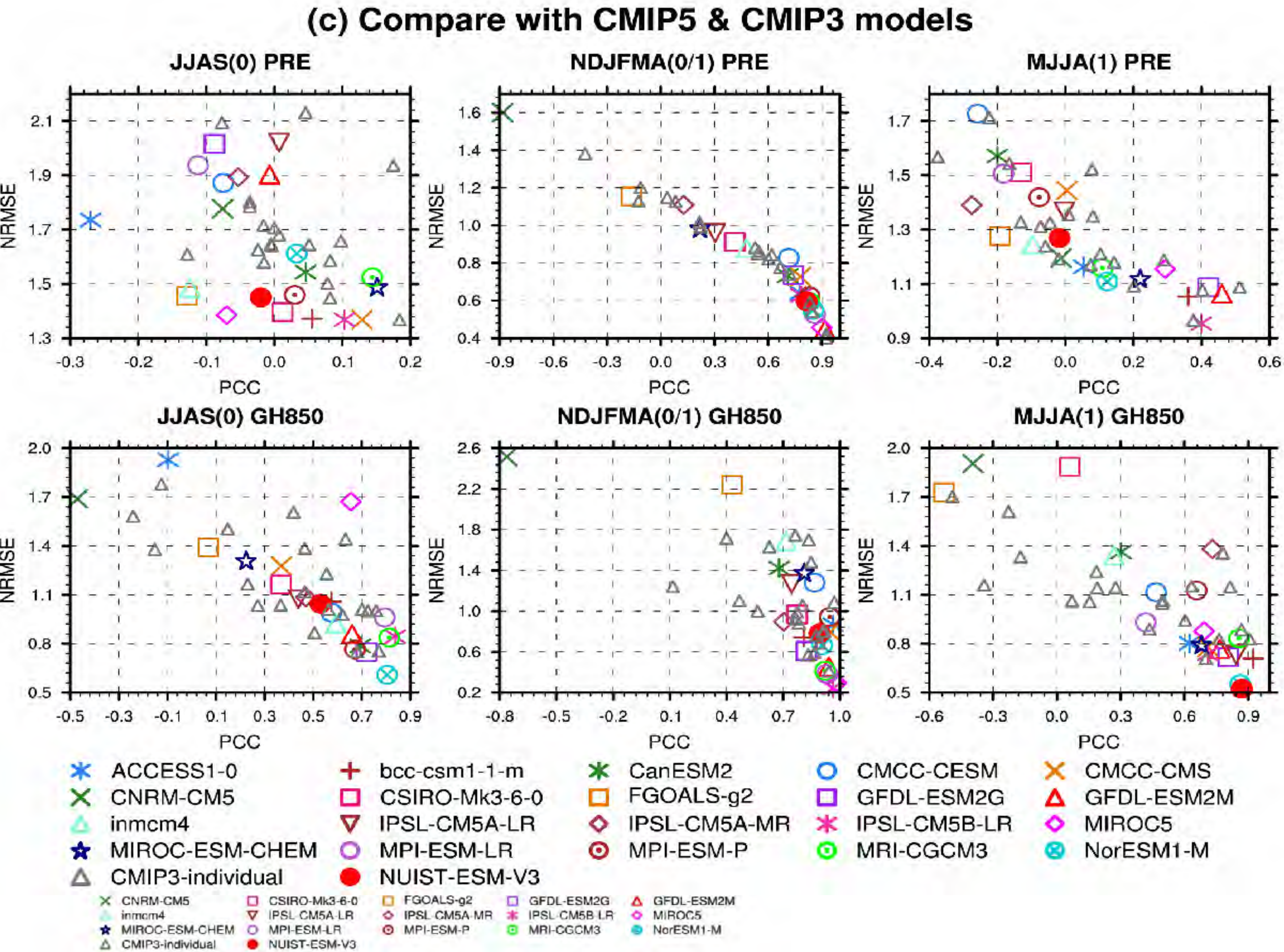


Fig 6 Correlation maps between

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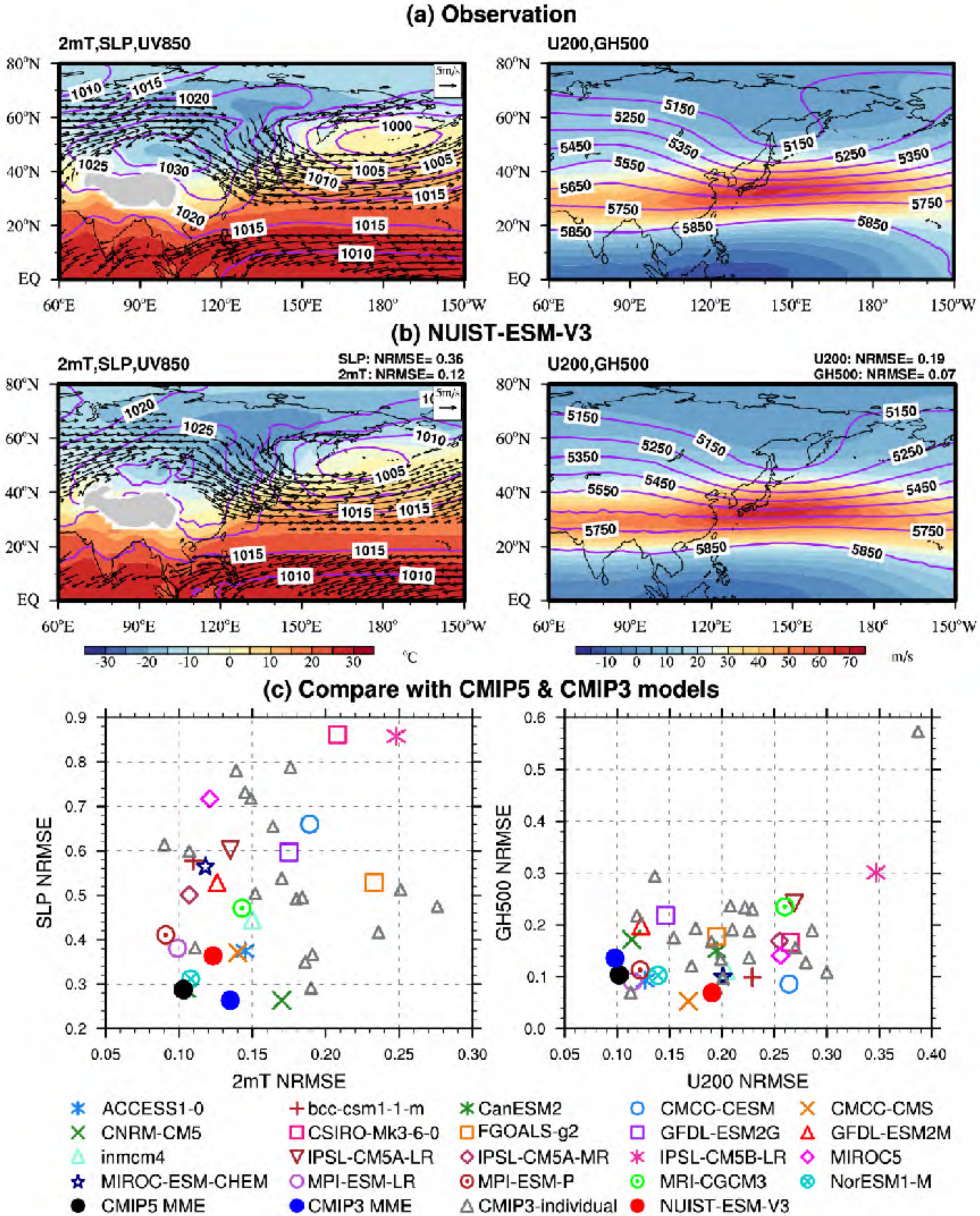


Fig.8 Climatology DJF mean 850-hPa winds (vectors, m/s), 850hPa geopotential height (contours, m), 2-metre temperature (shading, mm/day), 500-hPa geopotential height (contours, m) and 200-hPa zonal wind (shading, m/s) from (a) observation and (b) NUIST-ESM-V3 simulation during 1979-2005. (c) Models' performance on simulation of climatological DJF mean 2-metre temperature,850hPa and 500hPa geopotential height as well as 200hPa zonal wind over 0-80N, 60E-150W in terms of NRMSE.

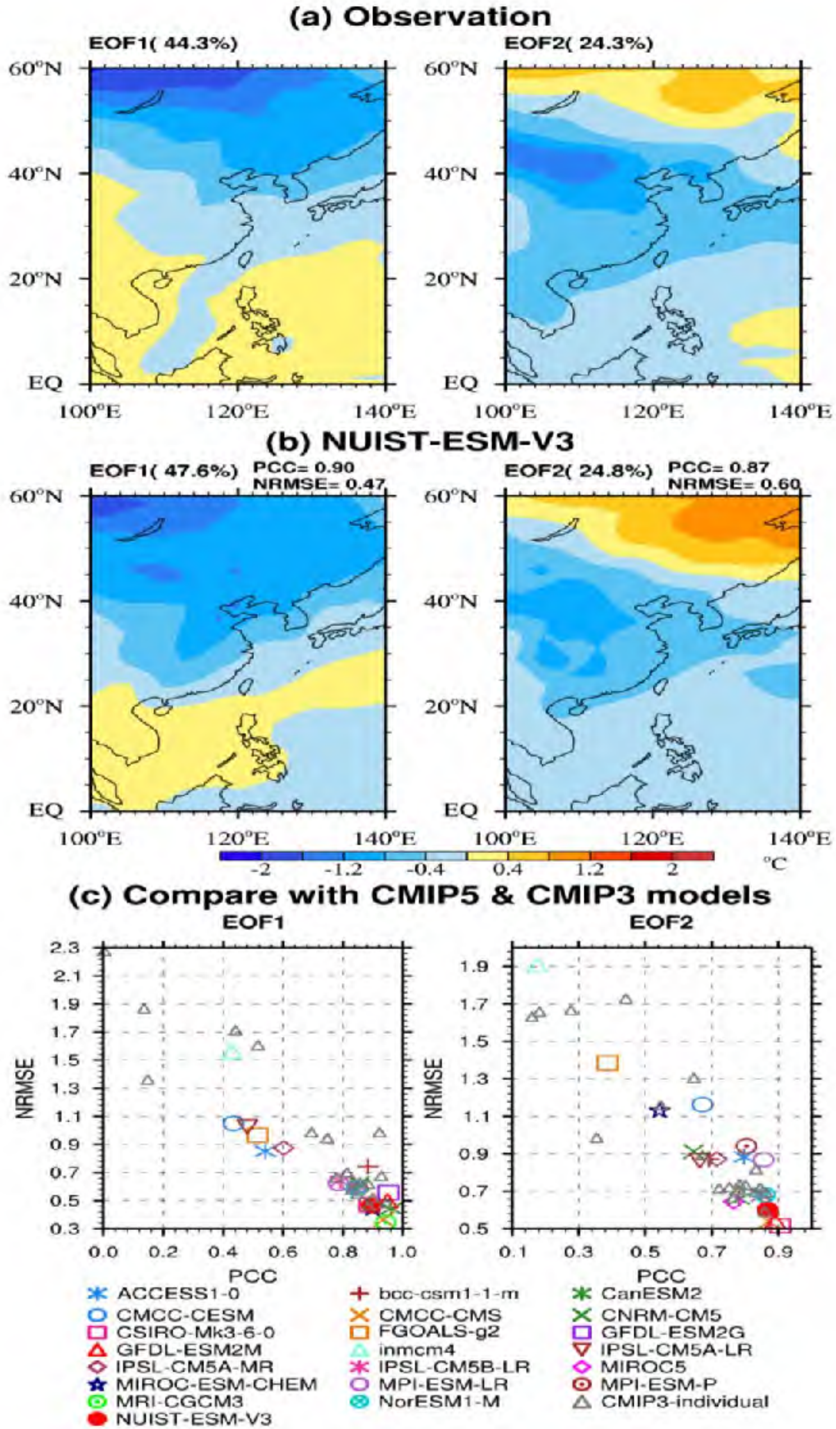


Fig. 10 Spatial patterns of the first and second EOF mode of winter (DJF) mean 2-m air temperature in the entire EAWM domain (0-60N, 100E-140E) from (a) observation and (b) NUIST-ESM-V3 simulation. (c) Models' performance on simulation of spatial patterns of the first and second EOF mode of winter (DJF) mean 2-m air temperature in the entire EAWM domain (0-60N, 100E-140E) in terms of PCC and NRMSE.

Summary of performance on Monsoon in terms of NRMSE and PCC skill (in parentheses)

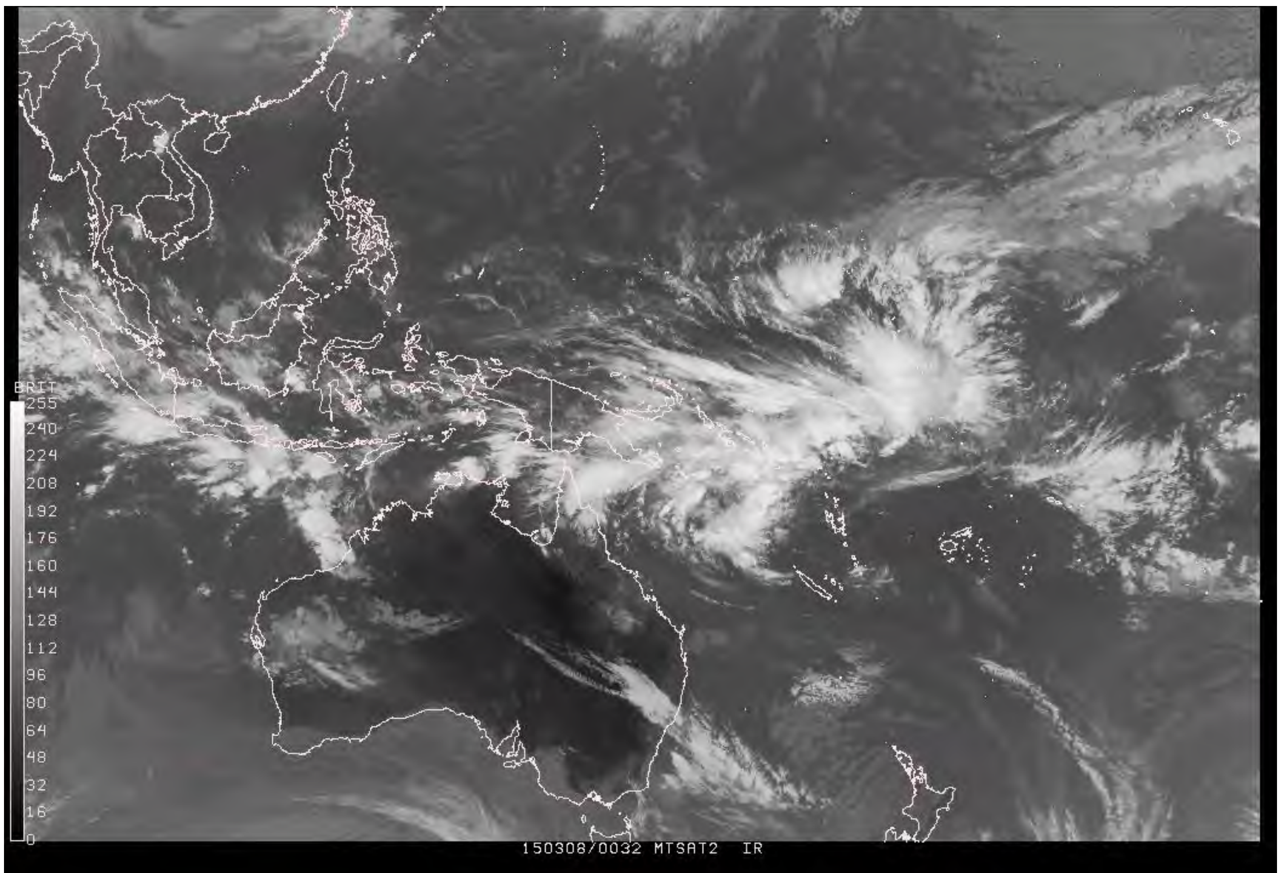
		Top 30% of CMIP5 models	Top 50% of CMIP5 models	Y27	Y30
GM	**GMPI**	0.61 (0.81)	0.66 (0.79)	0.65 (0.82)	0.65 (0.82)
	PRCP Mean in JJA	0.59 (0.83)	0.63 (0.82)	0.49 (0.90)	0.49 (0.90)
	PRCP Mean in DJF	0.68 (0.84)	0.71 (0.83)	0.72 (0.89)	0.72 (0.89)
	PRCP VAR in JJA	0.85 (0.71)	0.90 (0.69)	0.63 (0.77)	0.63 (0.77)
	PRCP VAR in DJF	0.76 (0.76)	0.80 (0.73)	0.64 (0.78)	0.56 (0.84)
	SEOF1**	0.89 (0.61)	0.92 (0.58)	0.72 (0.70)	0.62 (0.73)
	SEOF2**	1.18 (0.22)	1.20 (0.10)	1.18 (0.10)	1.02 (0.36)
EAM	**Seasonal evolution**	0.57 (0.88)	0.63 (0.87)	0.49 (0.91)	0.45 (0.92)

Red : reach the top 30% Green: reach the top 50% Blue : not reach the top 50%

**Average of four seasons

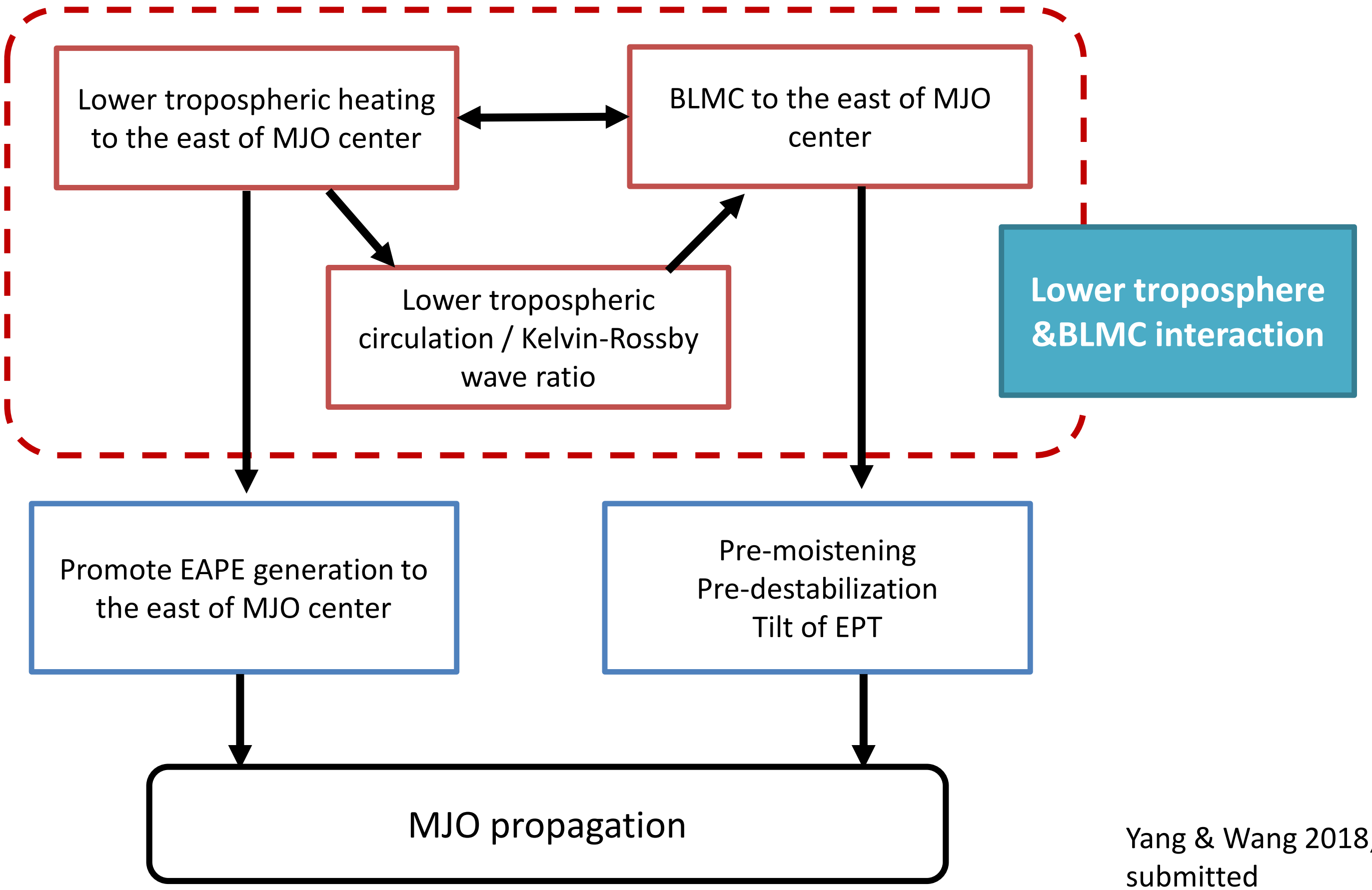
MJO

- Dynamics-oriented diagnostics (Wang et al, 2018)
- Reference : 20 CMIP5 models data
- OBS : GPCPv1.2/ERA Interim



MTSAT-2

What controls eastward propagation of MJO?



Yang & Wang 2018, submitted

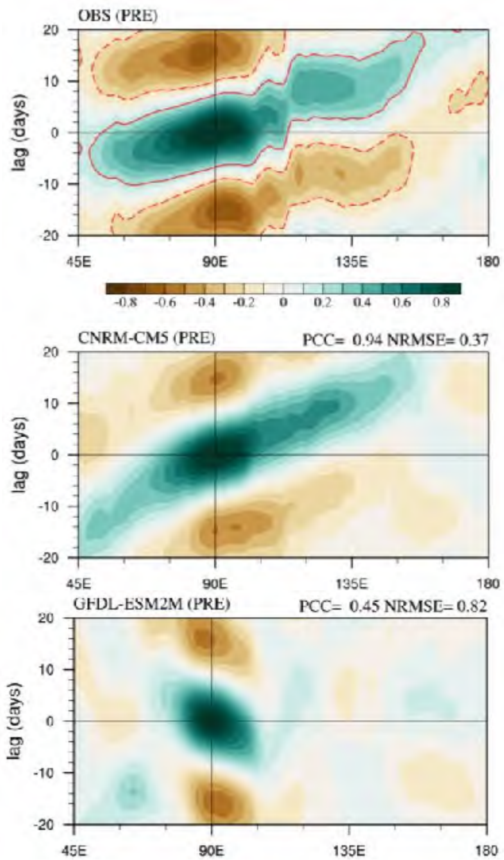
Fig. 12 Schematic diagram illustrating the mechanisms by which the modified cumulus parameterization schemes affect MJO structures and improve the MJO eastward propagation.

MJO diagnostics (24)

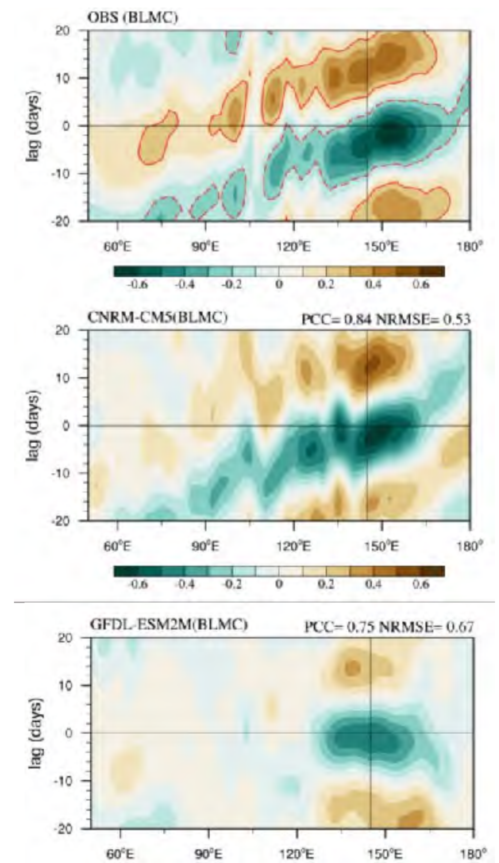
		Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	NUIST -V3SR
MJO	PRE VAR in MJJASO	0.87 (0.72)	0.90 (0.70)	0.85 (0.81)
	PRE VAR in NDJFMA	0.82 (0.69)	1.02 (0.68)	0.75 (0.80)
	Propagation diagram of PRE (EIO)	0.58 (0.81)	0.62 (0.79)	0.56 (0.91)
	Propagation diagram of PRE (EWP)	0.51 (0.86)	0.56 (0.82)	0.46 (0.90)
	Propagation diagram of 850hPa BLMC (EIO)	0.69 (0.74)	0.76 (0.65)	0.61 (0.80)
	Propagation diagram of 850hPa BLMC (EWP)	0.64 (0.76)	0.67 (0.73)	0.57 (0.80)
	Vertical structure of EPT	0.83 (0.78)	0.86 (0.73)	0.72 (0.78)
	Vertical structure of diabatic heating	0.97 (0.79)	1.0 (0.72)	0.88 (0.82)
	Horizontal structure of U850	0.72 (0.84)	0.80 (0.76)	0.59 (0.84)
	Horizontal structure of Div250	1.06 (0.75)	1.12 (0.72)	1.01 (0.75)
	Horizontal structure of Q250	0.87 (0.81)	0.92 (0.79)	0.87 (0.85)
	Vertical structure of APE	1.26 (0.72)	1.40 (0.66)	0.54 (0.79)

Examples – Propagation of precipitation & BLMC

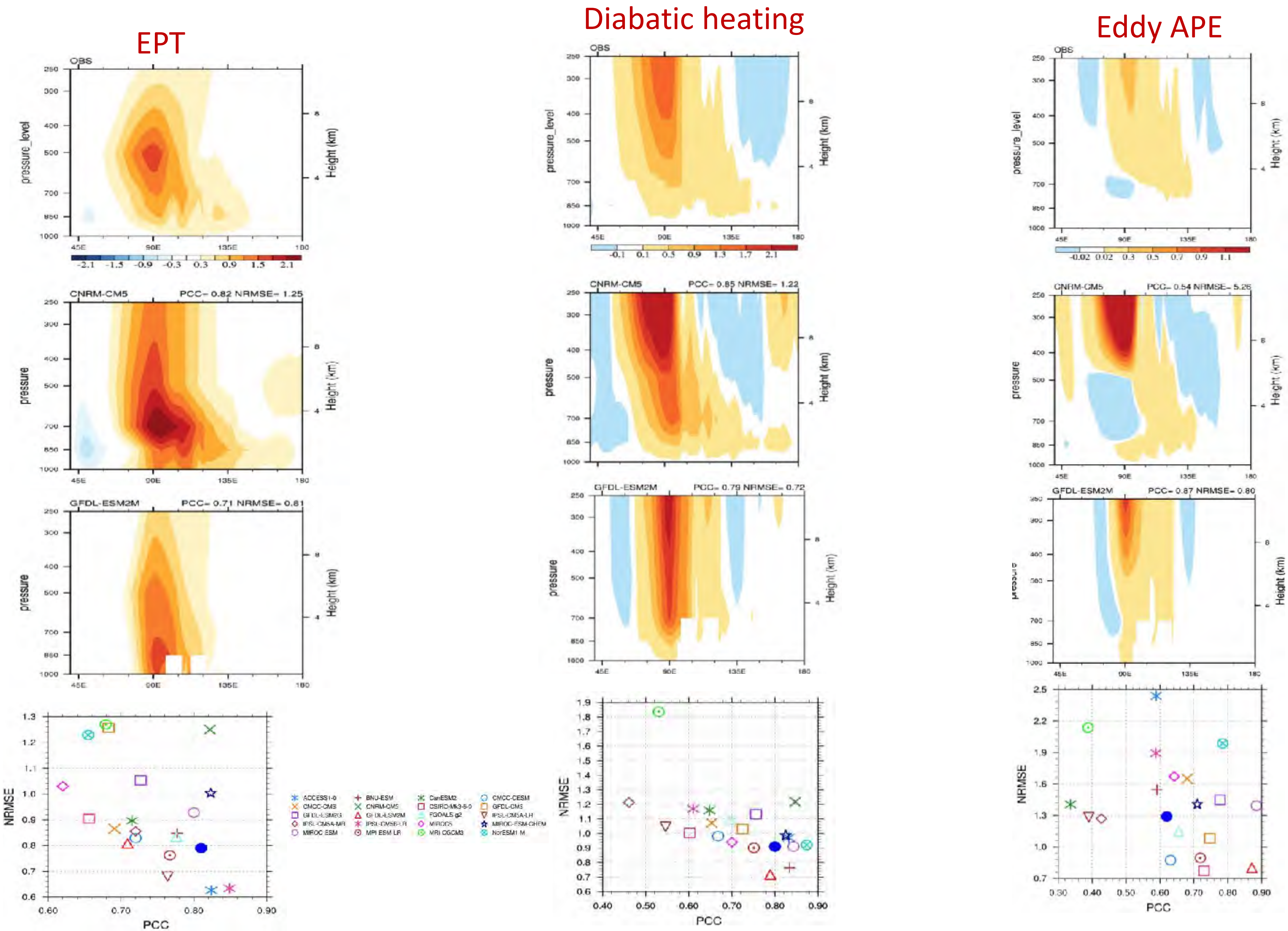
Precipitation (EIO)



BLMC (EWP)

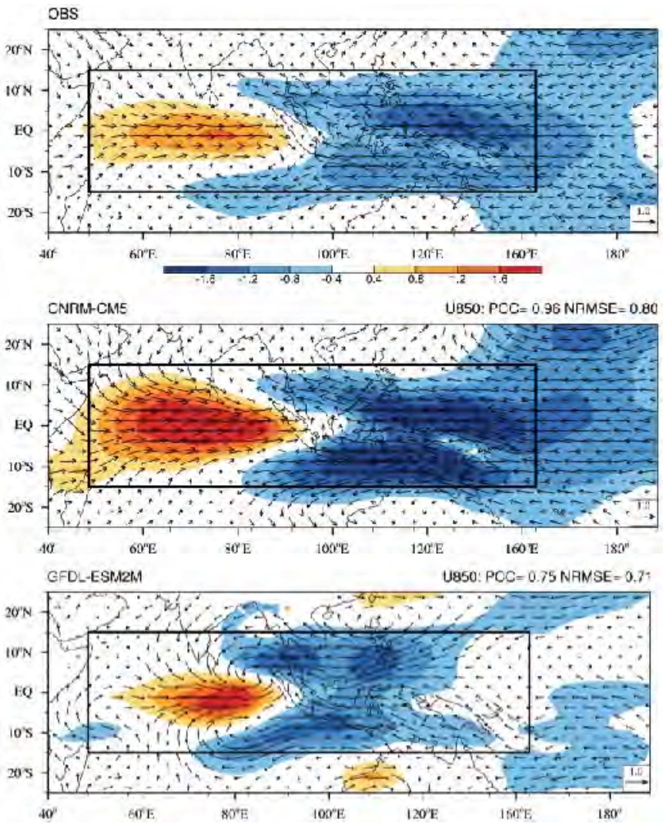


Premoistening/Predestabilization/Promoting EAPE

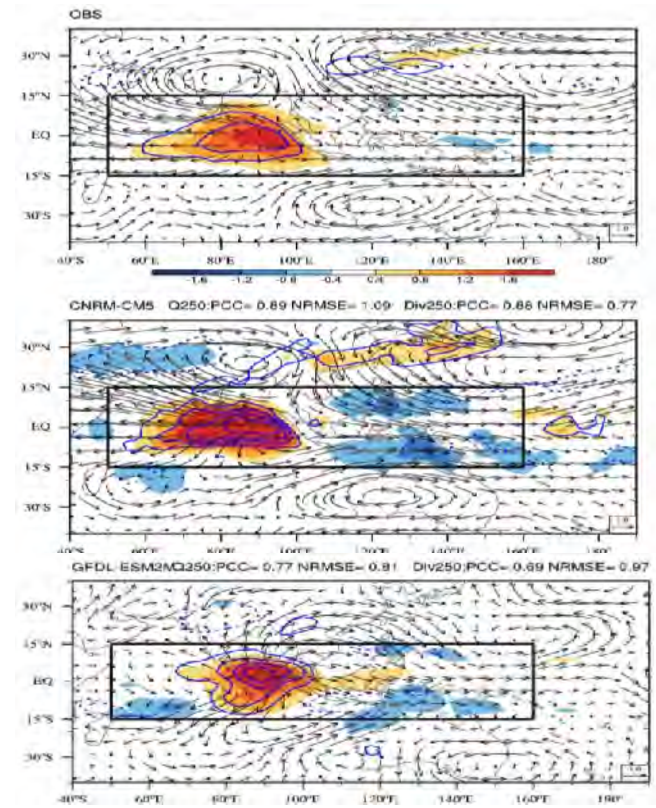


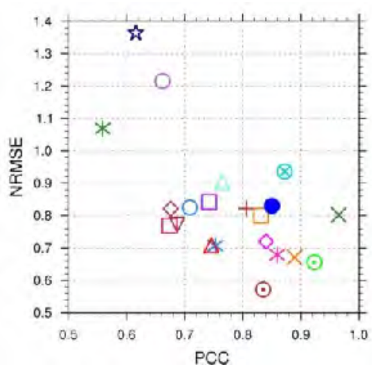
Large-scale circulation (Coupled Rossby-Kelvin Wave)

U850 & wind vector

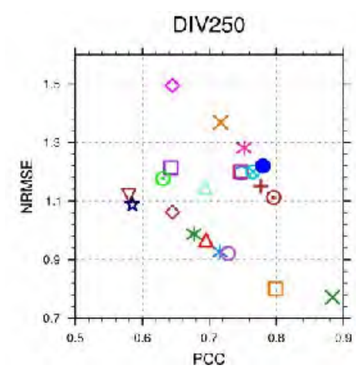


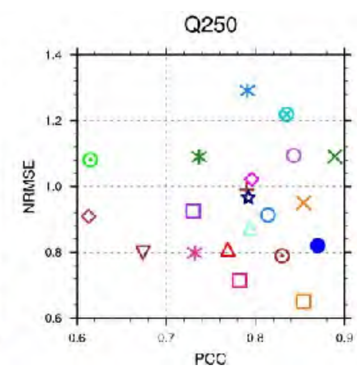
Q250/Div250





Model	Rossby/Kevin Wave ratio
Good	1.2
Poor	1.8



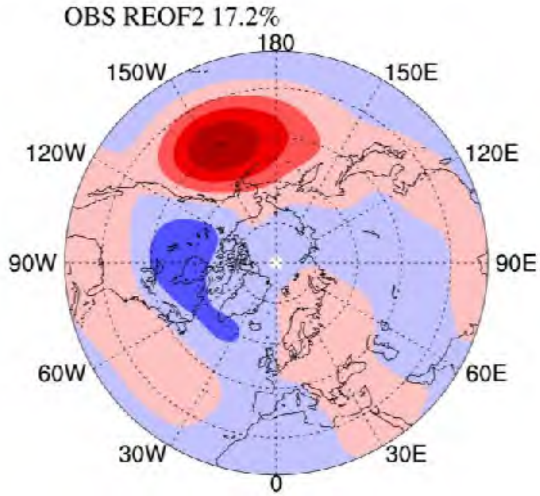


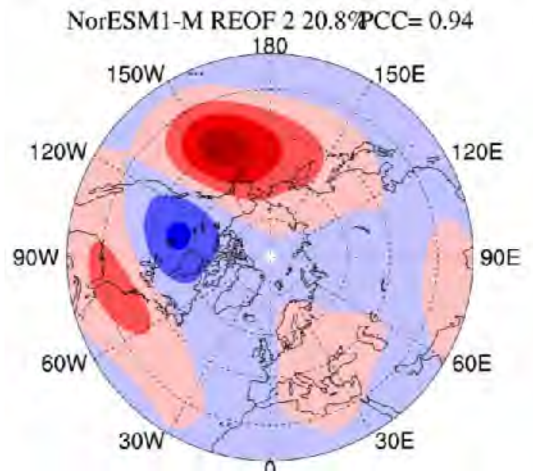
Teleconnection

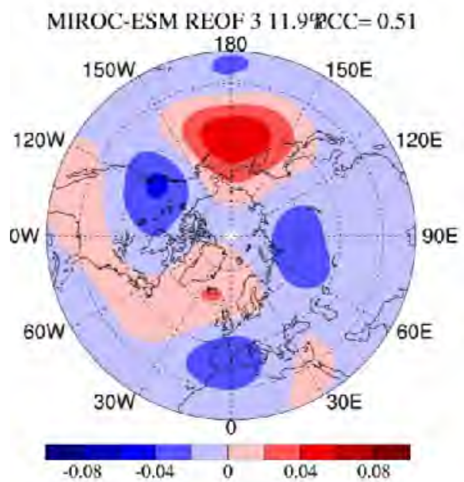
1) AO,AAO,PNA,PDO,NAO

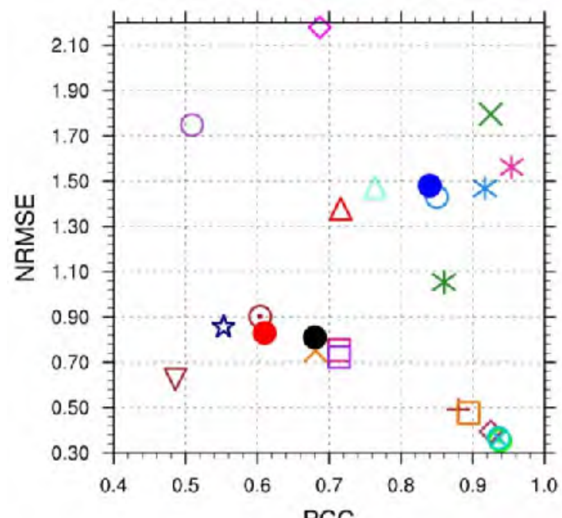
	top 30% of CMIP5 models	top 50% of CMIP5 models	ENS1	ENS2	ENS3	ENS4	ENS5	ENS mean
AO	(0.93)	(0.90)	(0.96)		(0.95)	(0.93)	(0.93)	
AAO	(0.96)	(0.94)	(0.96)		(0.96)	(0.96)	(0.97)	
PNA	0.75 (0.84)	1.76 (0.80)	1.7 (0.84)		1.7 (0.89)	1.7 (0.69)	1.7 (0.84)	
PDO	(0.78)	(0.71)	0.71		0.88	0.71	0.83	
NAO	(0.78)	(0.75)	.89		0.90	0.85	0.89	

Teleconnection - PNA





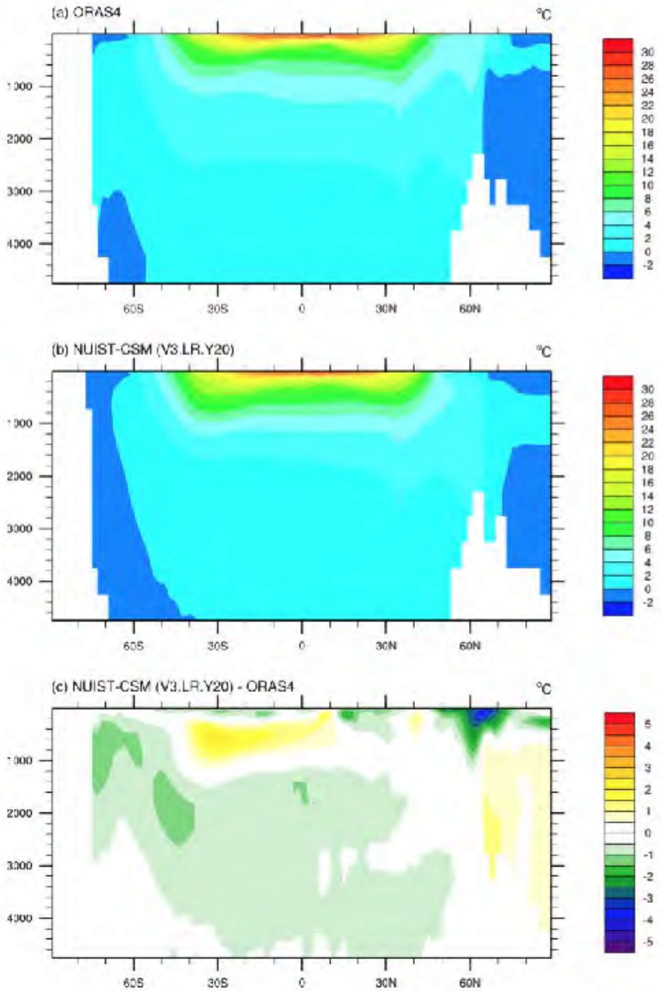




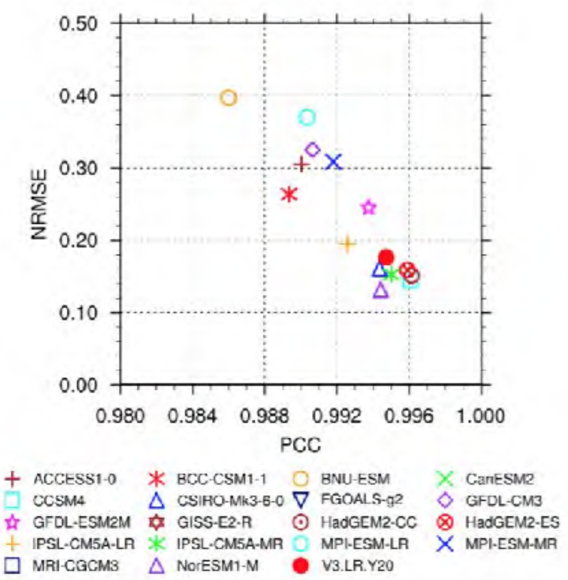
ocean

Metrics	Top 30%		Top 50%		ENS3	
	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE
Wind Stress Mag	0.92	0.43	0.90	0.47	**0.93**	**0.44**
Wind Stress Curl	0.81	0.61	0.79	0.66	**0.79**	**0.63**
Down Net Heat Flux	0.81	0.95	0.78	0.97	**0.83**	**0.88**
Down Fresh Water	0.67	0.88	0.63	0.94	**0.85**	**0.59**
Sea Surf Temp	0.99	0.12	0.99	0.13	**1.00**	**0.11**
Sea Water Temp - EQ	0.98	0.23	0.98	0.26	**0.99**	**0.26**
Sea Water Temp - GLB Zonal Avg	0.99	0.16	0.99	0.25	**1.00**	**0.11**
Sea Surf Salin	0.92	0.51	0.90	0.57	**0.94**	**0.43**
Sea Water Salin - GLB Zonal Avg	0.92	0.68	0.90	0.74	**0.90**	**0.50**
Therm Depth - 20 degC	0.85	0.59	0.81	0.63	**0.87**	**0.55**
Mixed Layer Depth – 0.5 degC	0.82	0.80	0.77	0.88	**0.81**	**1.07**
Max Mixed Layer Depth -0.5 degC	0.52	1.03	0.50	1.10	**0.63**	**1.1**
Sea Surf Height	0.99	0.28	0.98	0.57	**0.98**	**0.19**
Sea Surf Curr Mag	0.82	0.64	0.78	0.67	**0.84**	**0.57**
Upper Lev Zonal Curr - EQ Pacif	0.94	0.36	0.93	0.44	**0.86**	**0.53**
Upper Lev Zonal Curr - Pacific	0.89	0.43	0.87	0.54	**0.79**	**0.53**
GMOC	0.86	0.69	0.82	0.73	**0.91**	**0.47**
AMOC	0.68	0.90	0.62	1.03	**0.66**	**0.84**

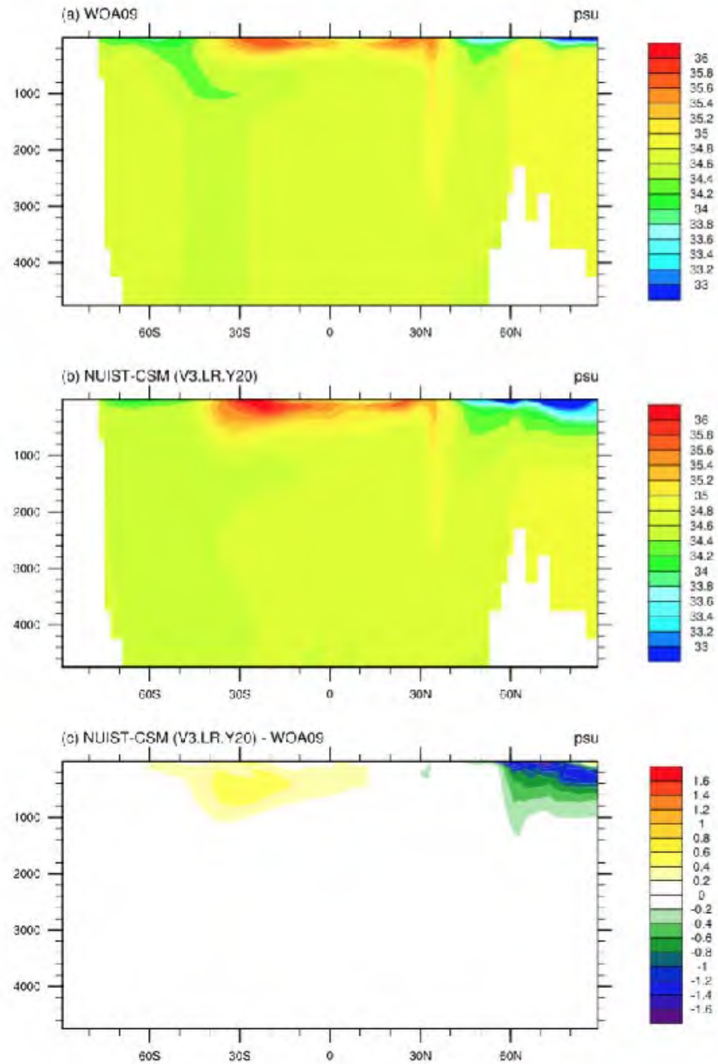
11.16 Sea Water Temperature Latitude-Depth Section



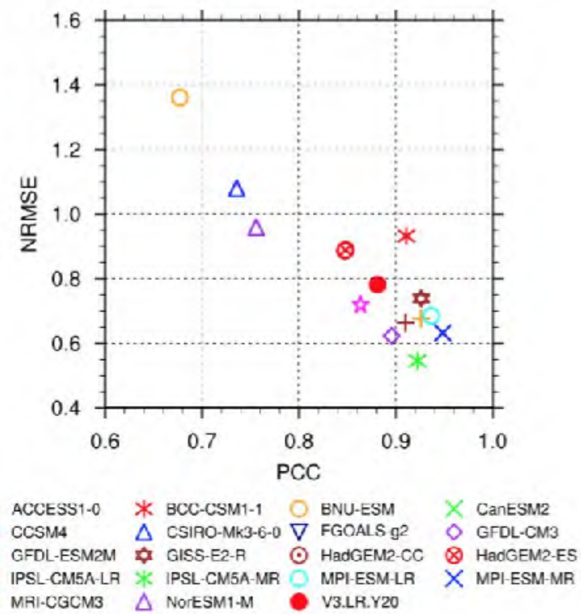
Comparison with CMIP5 models by PCC and NRMSE



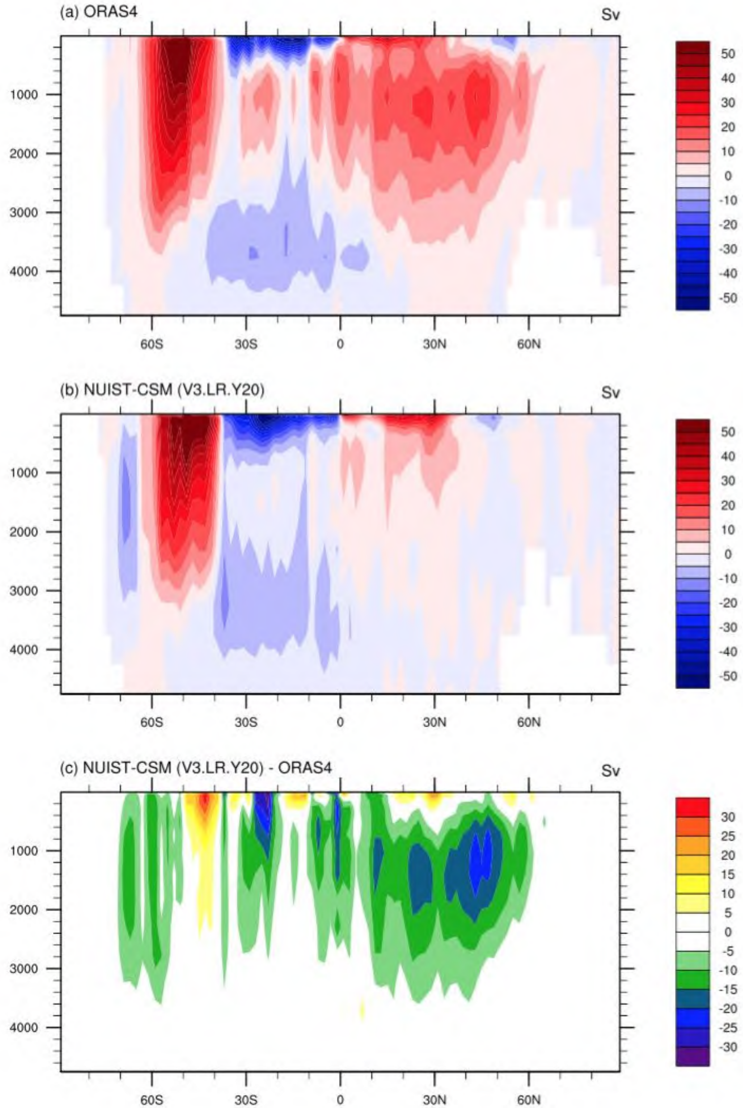
12.16 Sea Water Salinity Longitude-Depth Section



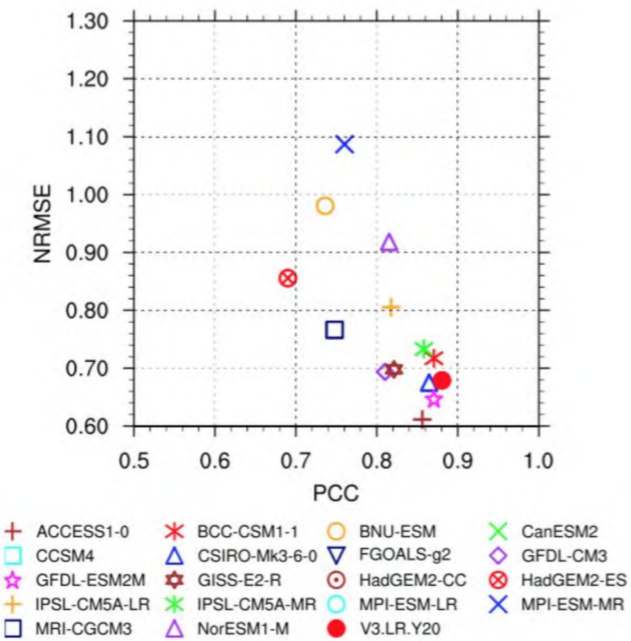
Comparison with CMIP5 models by PCC and NRMSE



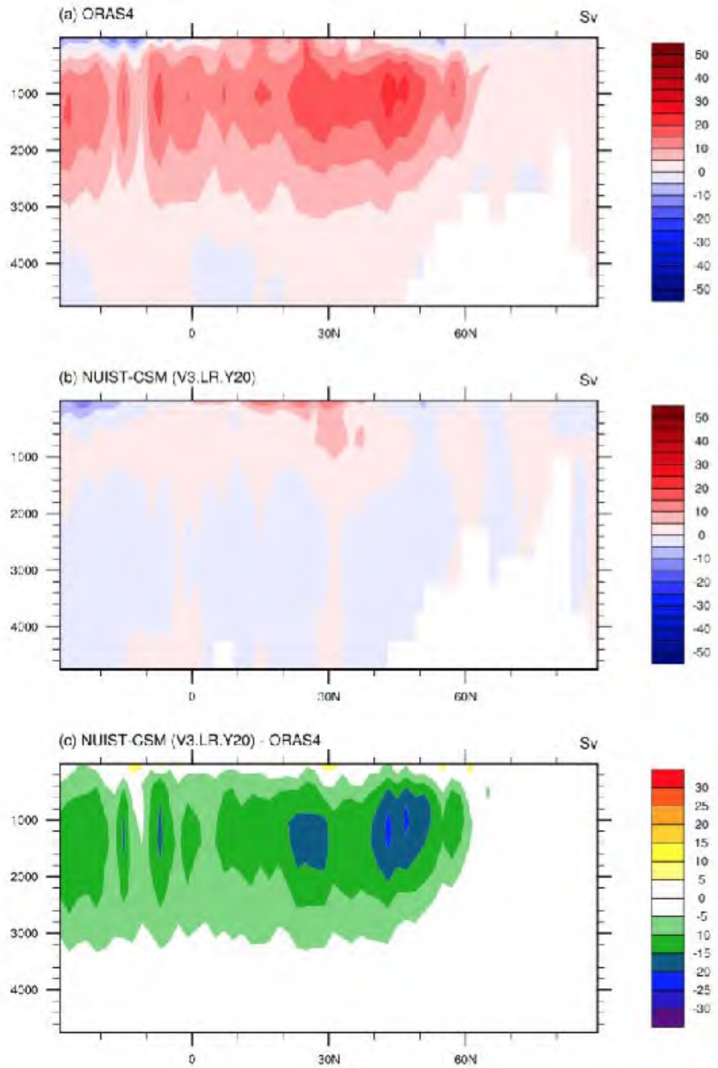
23.16 Meridional Overturning Streamfunction (Global)



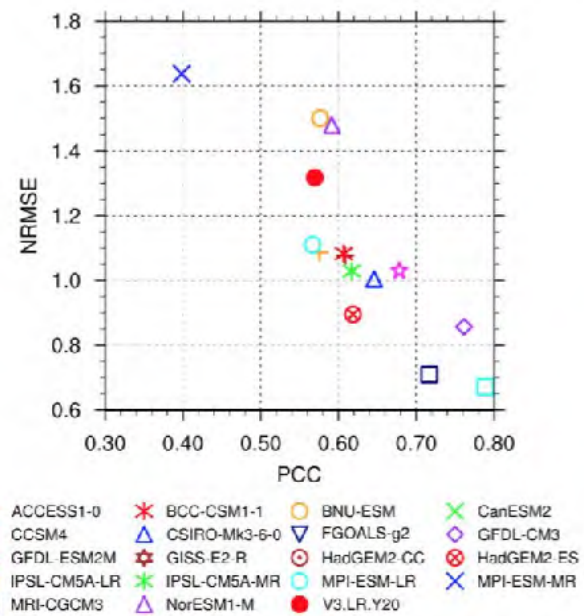
Comparison with CMIP5 models by PCC and NRMSE



23.17 Meridional Overturning Streamfunction (Atlantic)



Comparison with CMIP5 models by PCC and NRMSE

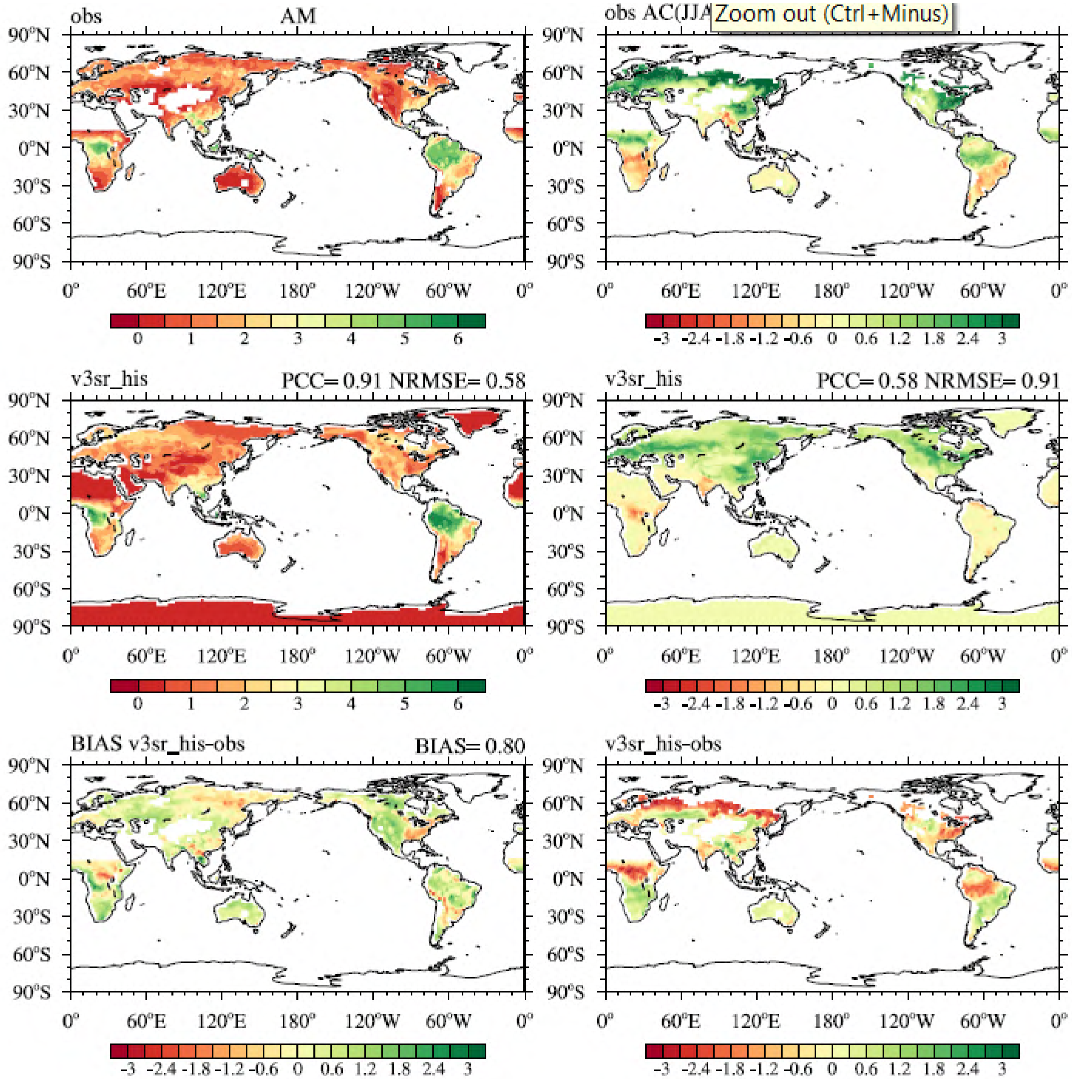


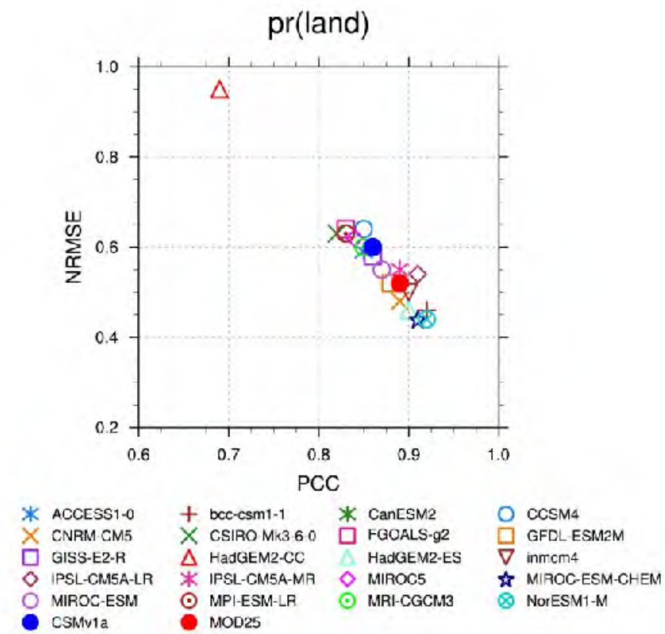
Land diagnostic variables

No.	Variables	Features	Observations
01	Air surface temperature at 2m	Temperature	CRU&UDEL
02	Maximal air surface temperature		
03	Minimal air surface temperature		
04	Surface albedo	Surface energy budget	MODIS
05	Net solar radiation at surface		CERES
06	Net radiation at surface		
07	Net solar radiation at surface (clear sky)		
08	Downwelling solar radiation at surface		
09	Net longwave radiation at surface		
10	Net longwave radiation at surface (clear sky)		
11	Downwelling longwave radiation at surface		
12	Sensible heat flux		FLUXNET-MTE
13	Latent heat flux		
14	Outgoing longwave at TOA (OLR)	Energy budget at TOA	CERES
15	Net radiation at TOA		
16	Net solar radiation at TOA		
17	Incoming solar radiation at TOA		
18	Total cloud cover	Cloud	ISCCP
19	Precipitation	Surface hydrologic features	CRU&UDEL
20	Soil moisture		CCI
21	Runoff		GRDC
22	Snow depth		CMC
23	Surface wind speed at 10 m	Wind	ECMWF-interim
24	U at 10m		
25	V at 10m		

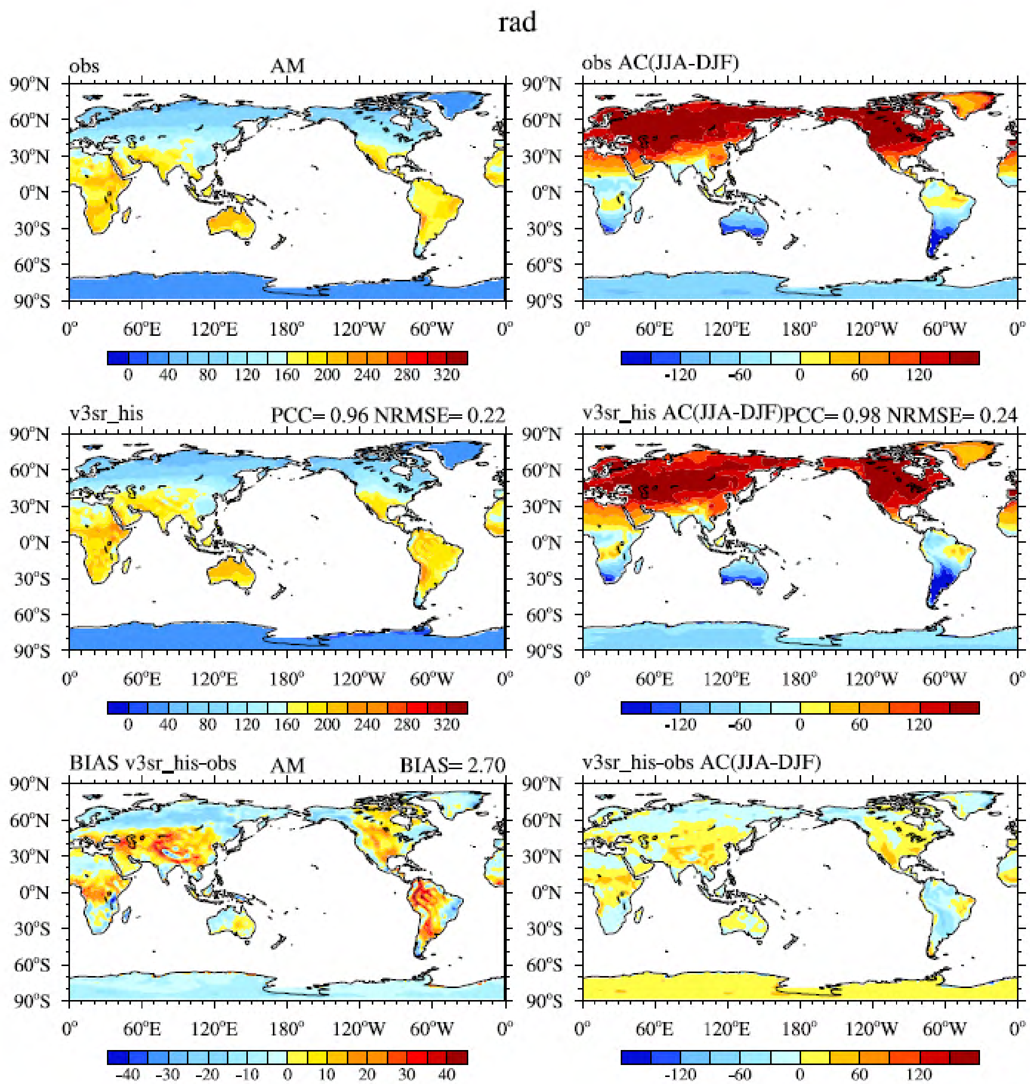
Variables	Term	CMIP5 top 1/3		CMIP5 top 1/2		**ENS1**		**ENS2**		**ENS3**		**ENS4**		**ENS5**		**ENS MEAN**	
		NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC
PR	AM	0.61	0.79	0.65	0.76					0.6	0.85	0.6	0.85	0.6	0.85		
	AC	0.71	0.76	0.72	0.74					0.7	0.85	0.7	0.85	0.7	0.85		
T2M	AM	0.16	0.99	0.17	0.98					0.17	0.98	0.17	0.98	0.17	0.98		
	AC	0.27	0.98	0.27	0.98					0.21	0.98	0.21	0.98	0.21	0.98		
	Abs-BIAS	0.34		0.47						0.34		0.34		0.34			
RAD	AM	0.19	0.97	0.2	0.97					0.22	0.96	0.22	0.96	0.22	0.96		
	AC	0.3	0.97	0.33	0.97					0.25	0.98	0.25	0.98	0.25	0.98		
	Abs-BIAS	2.01		5.56						1.85		1.85		1.85			
SHFLX	AM	0.77	0.78	0.84	0.77					0.82	0.84	0.82	0.84	0.82	0.84		
	AC	0.8	0.87	0.86	0.86					0.65	0.86	0.65	0.86	0.65	0.86		
LHFLX	AM	0.55	0.89	0.58	0.87					0.49	0.92	0.49	0.92	0.49	0.92		
	AC	1.12	0.65	1.24	0.62					0.56	0.92	0.56	0.92	0.56	0.92		
LAI	AM	0.76	0.79	0.93	0.79					0.64	0.81	0.64	0.81	0.60	0.89		
	AC	0.75	0.72	0.96	0.57					0.93	0.56	0.93	0.56	0.89	0.60		

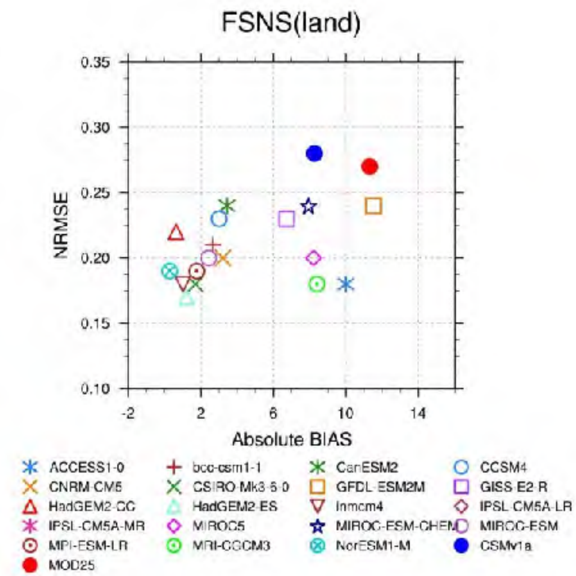
Land - precipitation





Land-radiation

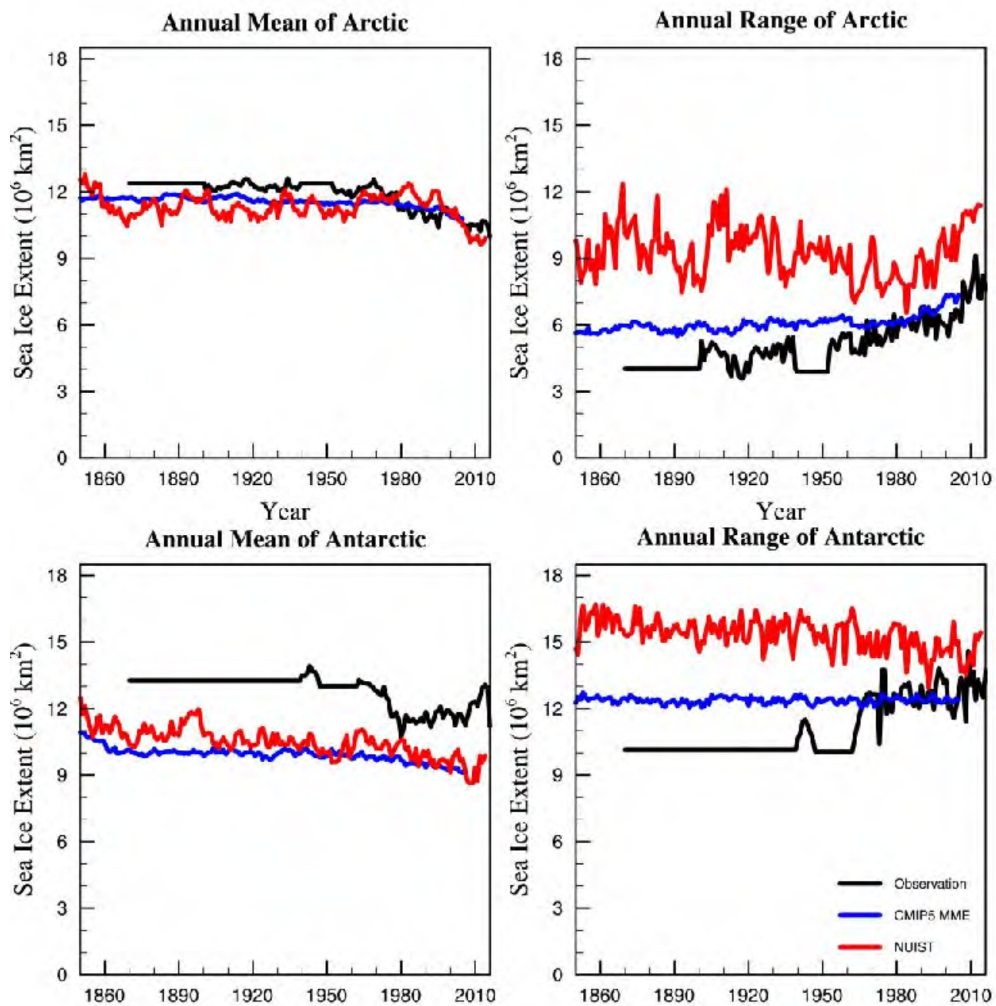




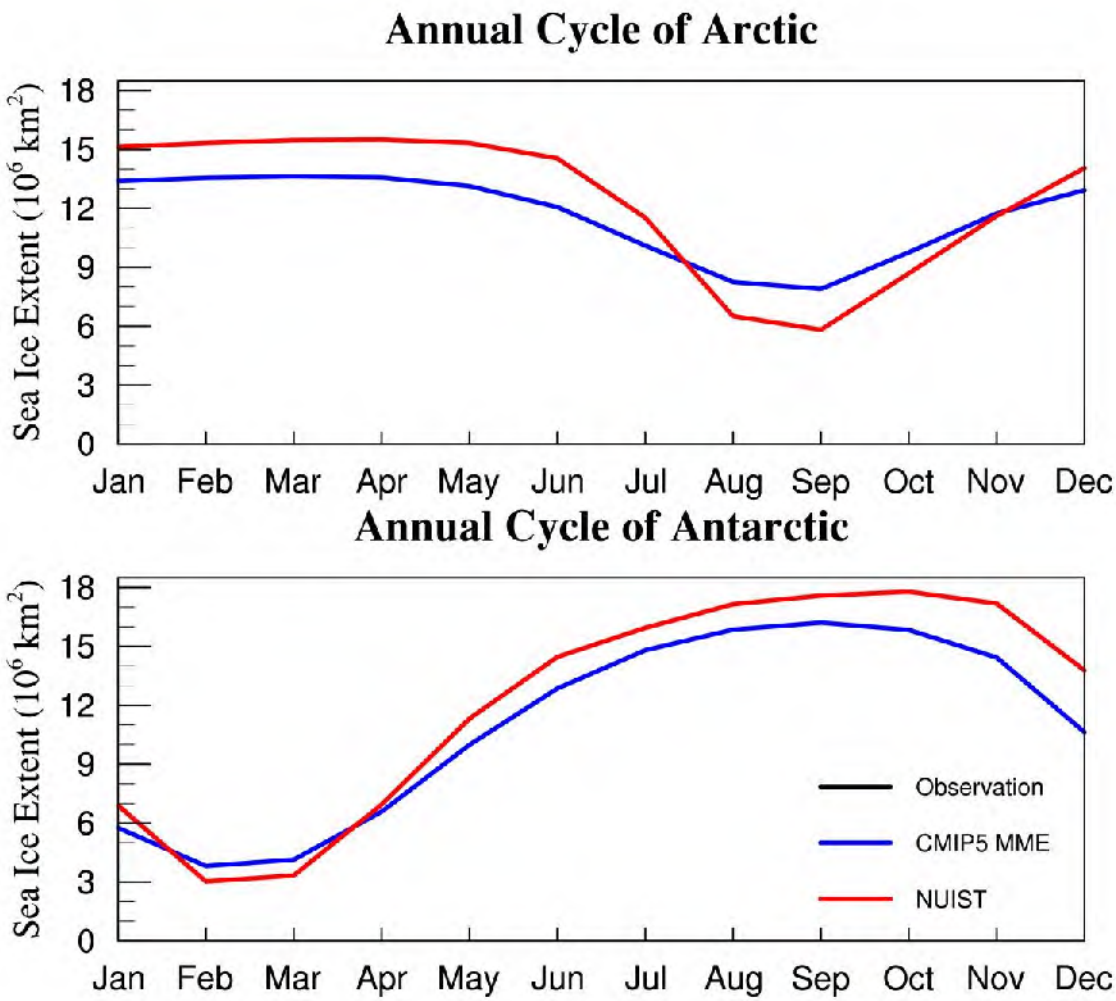
Sea ice

Vars			CMIP5 top 1/3	CMIP5 top 1/2	V3.SR-Y27
Arctic	Sea Ice Area (SIA) Bias	AM	0.322	0.699	−0.105
		AR	0.713	1.476	1.575
	Sea Ice Concentration (SIC) NRMSE	AM	0.502	0.615	0.311
		Feb	0.525	0.673	0.363
		Sep	0.616	0.736	0.670
Antarctic	Sea Ice Area (SIA) Bias	AM	1.074	3.156	−1.481
		AR	1.028	2.646	0.057
	Sea Ice Concentration (SIC) NRMSE	AM	0.792	0.913	0.876
		Feb	0.897	1.024	0.977
		Sep	0.793	0.893	1.073

Sea ice

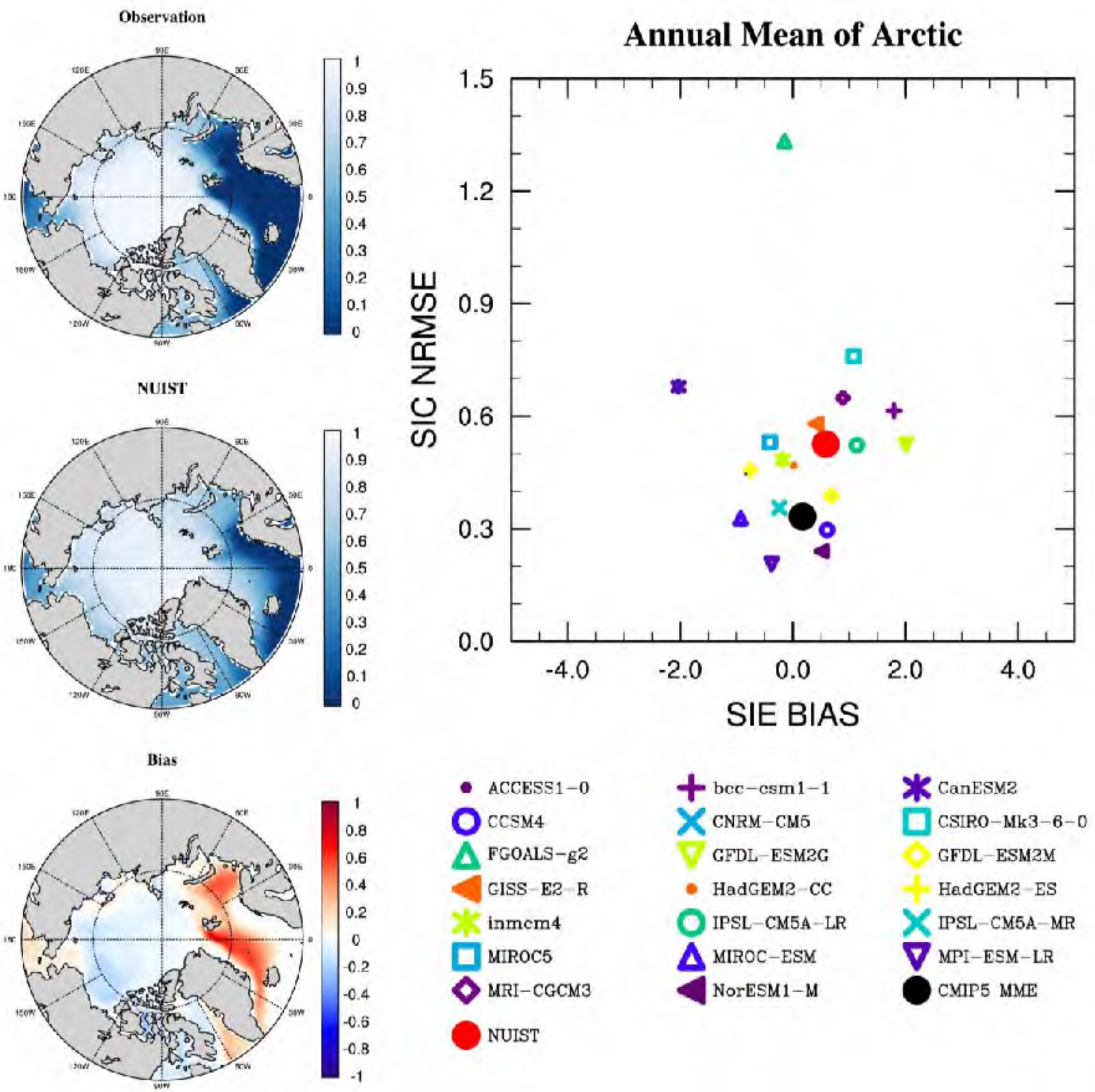

Annual Mean of Arctic
Annual Range of Arctic
Annual Mean of Antarctic
Annual Range of Antarctic
Sea Ice Extent (10^6 km^2)
Year
0
3
6
9
12
15
18
1860
1890
1920
1950
1980
2010
Observation
CMIP5 MME
NUIST

Sea ice

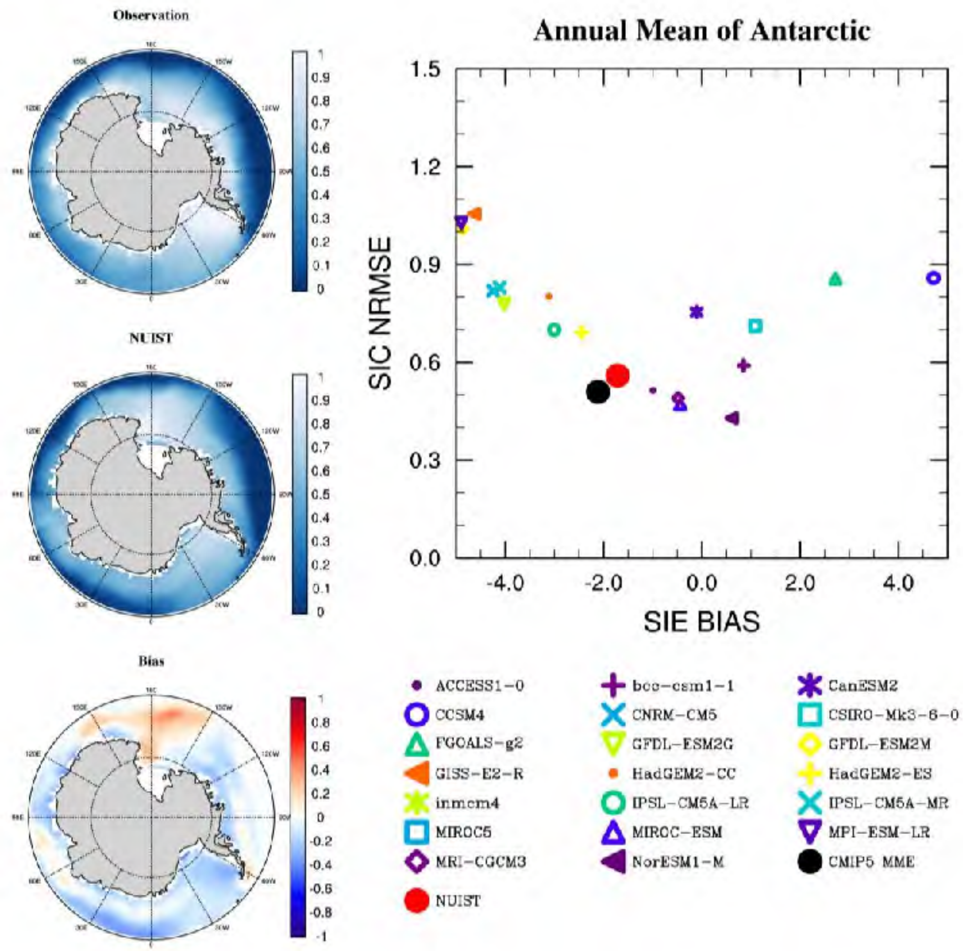


Annual Cycle of Arctic
Sea Ice Extent (10^6 km^2)
18
15
12
9
6
3
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Annual Cycle of Antarctic
Sea Ice Extent (10^6 km^2)
18
15
12
9
6
3
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observation
CMIP5 MME
NUIST

Sea ice


Observation
NUIST
Bias
Annual Mean of Arctic
SIC NRMSE
SIE BIAS
ACCESS1-0
bcc-csm1-1
CanESM2
CCSM4
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-g2
GFDL-ESM2G
GFDL-ESM2M
GISS-E2-R
HadGEM2-CC
HadGEM2-ES
inmcm4
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MIROC-ESM
MPI-ESM-LR
MRI-CGCM3
NorESM1-M
CMIP5 MME
NUIST

Sea ice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CMIP5 MME
NUIST

Summary

- The tools is relatively easy to use (semi-automatic)
- All methods are coherent and relevant dynamically and physically
- The tool can show how our model is good?
- This tools shows Key factor where we should improve parameterization if model is poor (e.g. MJO)

- CMIP5 models are improved compared to CMIP3 but not much.
- All CMIP5 model performance are limited for MJO and monsoon, particularly EA.
- Antarctic sea ice simulation is relatively poor in CMIP5 models
- AMOC is one of critical simulation in CMIP5 models

Limitation

- Weak for model inter-comparision & future projection (e.g. ESMvalTOOL)
- Not include environmental factors (e.g. Aerosol, chemistry, biology)

Mahalo!