Progress in developing NUIST CSM

NUIST ESM Model Development Group

Acknowledge Dr. Baoqiang Xiang

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模式研发部人员 (Oct 2015)

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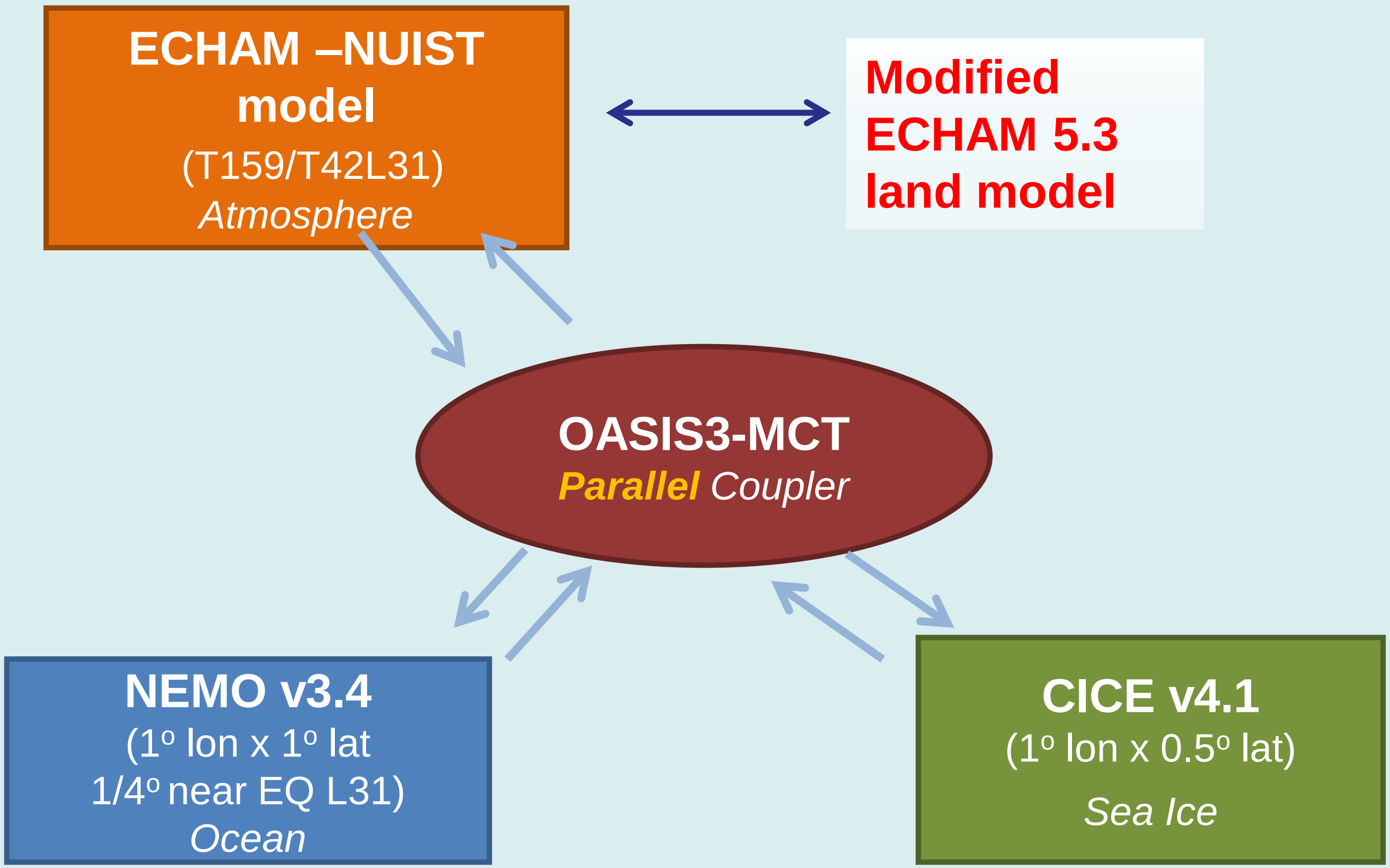
Nuist CSM v2 structure



Model descriptions

ECHAM v5.3 (T159(~0.75x0.75 degree, 31 levels, 10hPa top)

- ✓ Shortwave radiation scheme (Fouquart and Bonnel 1980)
- ✓ Longwave radiation: Rapid Radiative Transfer Model (RRTM) (Mlawer et al. 1997)
- ✓ Turbulent surface fluxes: Monin-Obukhov similarity theory (Louis, 1979).
- ✓ Cumulus convection: the bulk mass flux concept of Tieditke 1989, Nordeng (1994).
- ✓ Stratiform cloud scheme : bulk cloud microphysics (Lohmann and Roeckner 1996)
- ✓ Land surface: implicit coupling so that energy is conserved

NEMO v3.4 (ORCA2 (2x2 degree ,1/2x1/2 degree near EQ, L31)

- ✓ Ocean dynamics/biogeochemistry/sea-ice interaction
- ✓ Adaptive mesh refinement

CICE v4.1 (384x320, 1x0.5 degree)

- ✓ Computationally efficient model
- ✓ Ice thermodynamic process/multiple ice and snow category

Major progress in improvement of model

ATMOSPHERE MODEL

- Used a new shallow convection scheme based on TKE
- Used an environment RH dependent entrainment rate
- Used Tokioka constraint in deep convection scheme
- Decreased the threshold determining precipitation amount
- Reduced surface flux on steep topography region
- Calibrated cloud microphysics and cloud cover parameterization
- Corrected the Kepler's earth orbit calculation
- Decreased entrainment rate for shallow cloud
- For MJO, the shallow convection ahead of deep/organized convection was enhanced

Major progress in improvement of model

SEA ICE MODEL

(a) Improved the heat flux calculation

- Used the 2m air specific humidity and potential temperature to calculate the latent heat flux

(b) Snow and ice simulation

- Designed the temperature dependent albedo formula based on observed data
- Used the same method in snow albedo calculation
- Improved the momentum exchange between AGCM and sea ice model
- Considered mixture phase of ice and water

Major progress in improvement of model

LAND SURFACE MODEL

- Improved the snow coverage parameterization
- Incorporated soil moisture effect on soil albedo
- Used the new MODIS climatology background albedo
- Updated the leaf area index annual cycle

COUPLING Upgraded the coupler

- Used the second-order conservative remapping method
- Used the coordinate transformation after the coupler remapping
- Decreased the coupling information exchange frequency to improved the computational efficiency
- The new feature of coupler can decrease the coupling fields

Evaluation of NUIST CSM v2

Experiment design

- Fixed forcing: GHG, Solar constant et al. at 1990
- Resolution: AGCM T42 (T159)/L31 , OGCM 2^{o} L31, Sea ice 1^{o} x 0.5^{o}
- Integration: spin up 4000-y, free run 100-y

Diagnostics

- Base version: NUIST-CSM-v1a
- Modified version: MOD25
- Compared with CMIP5 models

Summary of NUIST-CSM-mod33

Observational Data (Atmosphere)

Monthly data:

•**2mT**: **University of Delaware** Air Temperature v3.01 (Willmott, C.J. and K. Matsuura 1995)
•**PRE**: Climate Prediction Center (CPC) Merged Analysis of Precip- itation (**CMAP**) dataset (Xie and Arkin 1997) and Global Precipitation Climatology Project (**GPCP**) data version 2.2 (Huffman et al. 2009). Merged CMAP and GPCP precipitation is used.
•**Wind Stress**: National Centers for Environ- mental Prediction (**NCEP**) U.S. Department of Energy (DOE) reanalysis **II** data (Kanamitsu et al. 2002)

Daily data:

•**PRE**: Global Precipitation Climatology Project (**GPCP**) data version 2.2 (Huffman et al. 2009)
•**Wind**: National Centers for Environmental Prediction (**NCEP**) U.S. Department of Energy (DOE) reanalysis **II** data (Kanamitsu et al. 2002)
•**OLR**: **NOAA** Interpolated OLR dataset (Liebmann and Smith 1996)

Observation Data (Ocean)

SST: National Climatic Data Center's Extended Reconstructed Sea Surface Temperature (**ERSST**, v3b) at 2^{o} spatial resolution for the period 1871–2012 (Smith and Reynolds 2004)

Ocean Reanalysis

WOA09: Temperature & Salinity

(1°x1°, 33 levels, climatology)

ORAS4: Ocean Current

(1°x1°, 42 levels, monthly, 1958.01~2013.04)

Observation

RAPID: AMOC Transport at 26.5N

(Single profile, 2004-2014)

Observational data (land, Sea Ice)

- PR &T2M : University of Delaware, V301 (http://www.esrl.noaa.gov/psd/data/gridded/data.UDel_AirT_Precip.html)
- Radiation: NASA CERES—Clouds and the Earth's Radiant Energy System Information and Data (http://ceres.larc.nasa.gov)
- Surface heat flux: FLUXNET-MTE (Multi-Tree Ensemble) (June et al.,2011) (https://climatedataguide.ucar.edu/climate-data/fluxnet-mte-multi-tree-ensemble)
- Sea ice concentration (%): Hadley Center, 360X180 1979-Present, Monthly data

Evaluation Metrics

1. Global energy and water balance
2. Climatology of SST and precipitation
3. ENSO
4. Monsoon
5. MJO
6. Teleconnection Modes
7. Ocean
8. Land
9. Sea Ice

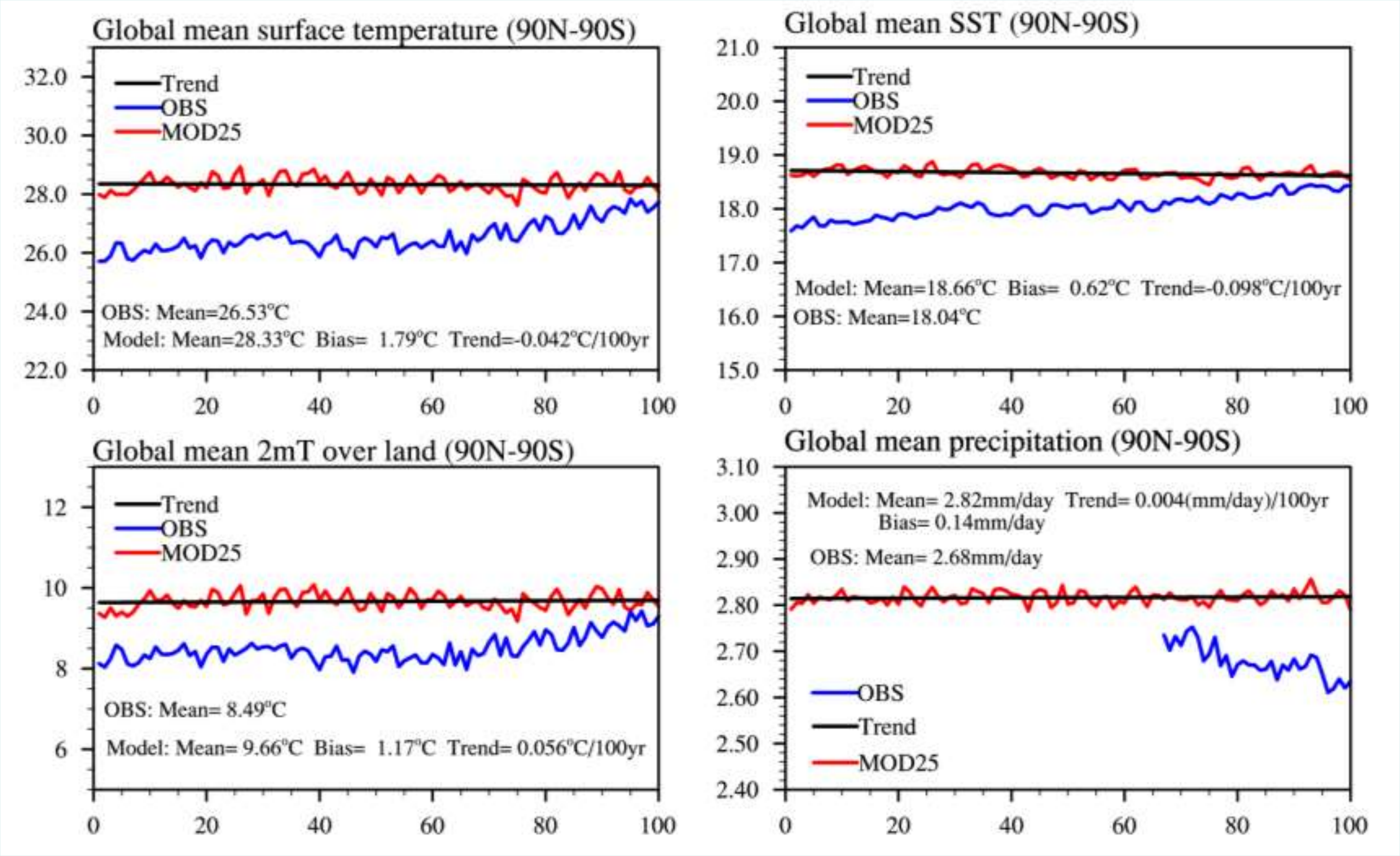
1-6: Atmosphere

1. Global energy and water balance

- Trend and bias of global mean surface temperature/SST/2mT
- Trend and bias of global precipitation;
- TOA energy budget;
- Surface energy budget;
- Trend and bias in fresh water flux (E-P);
- Cloud cover

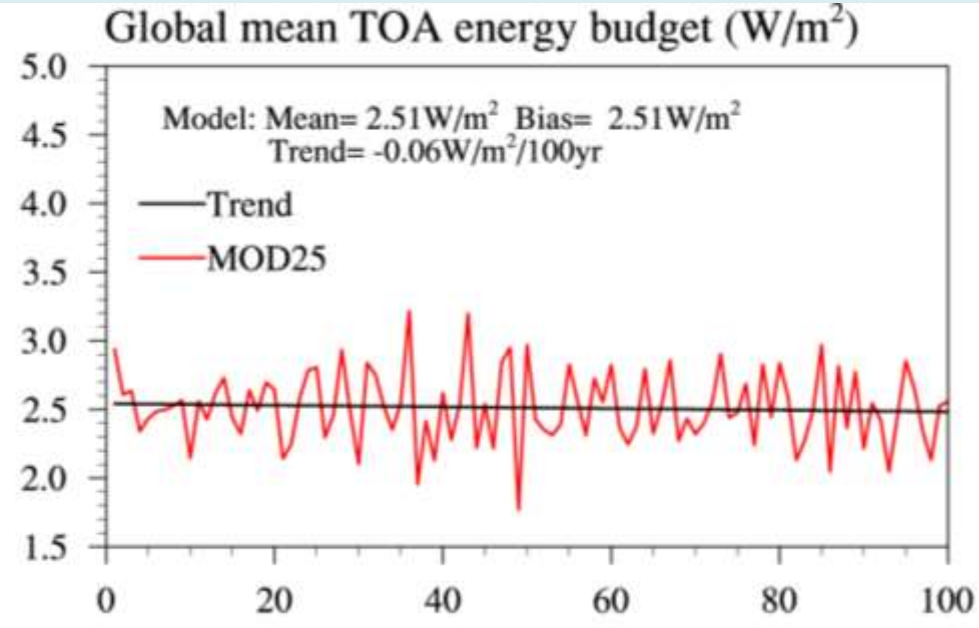
Part 1: Global energy and water balance

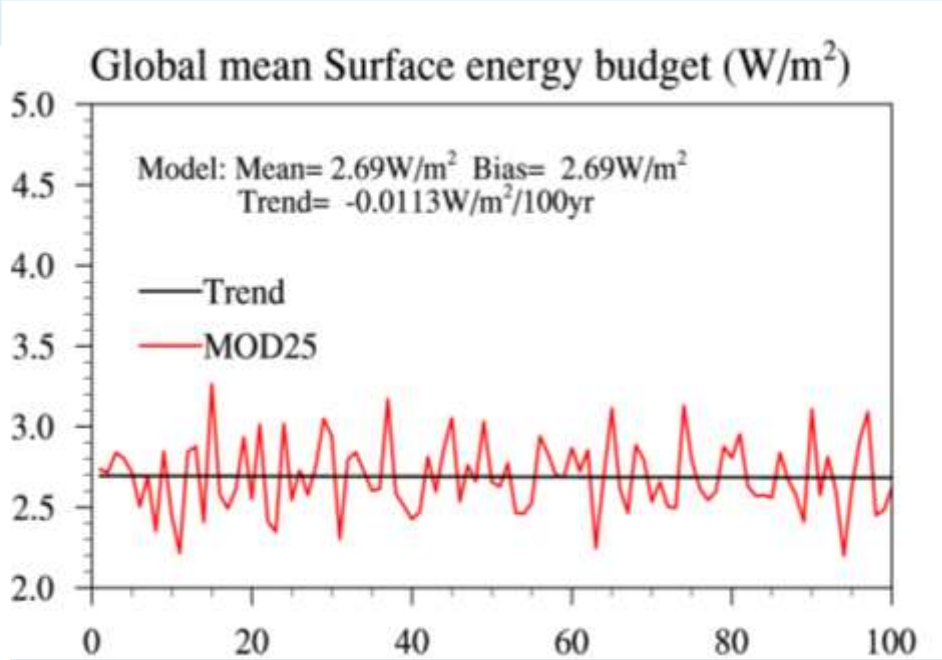
Time series of global mean surface temperature/SST/2mT/precipitation



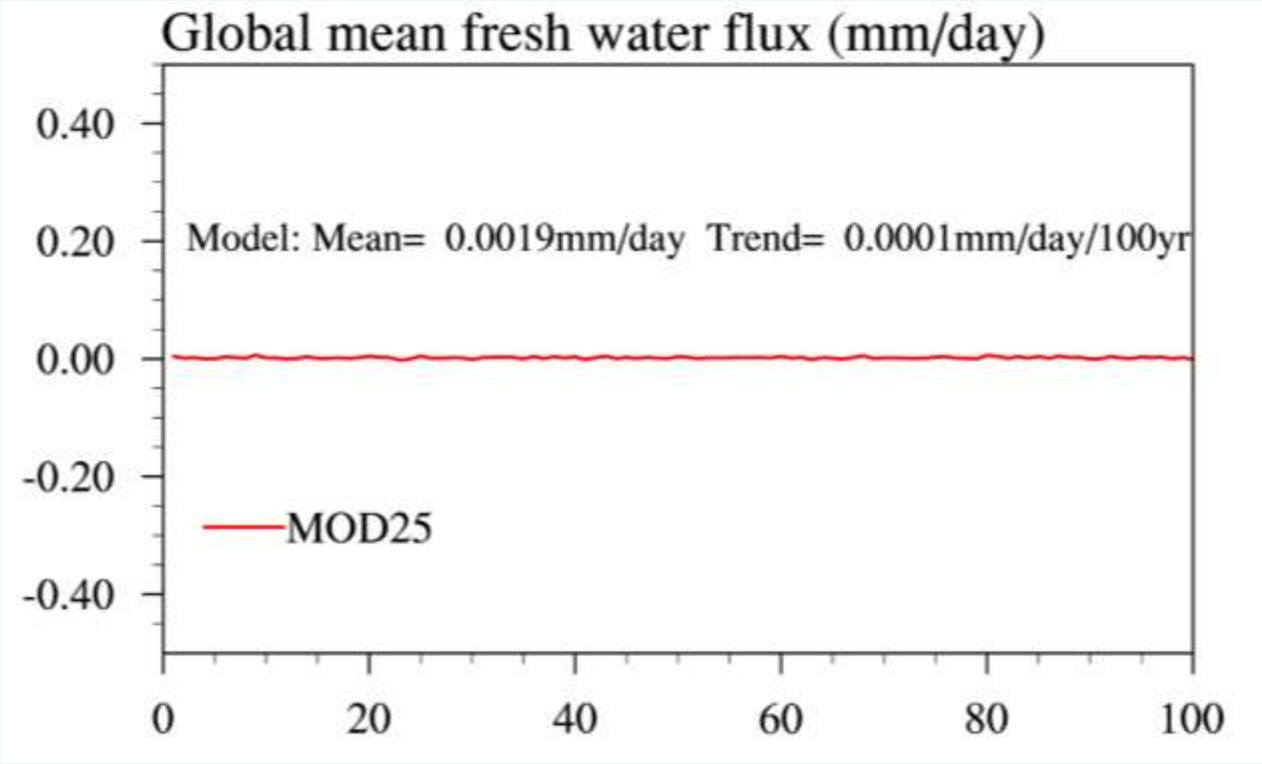
Part 1: Global energy and water balance

Time series of global mean TOA/surface energy budget

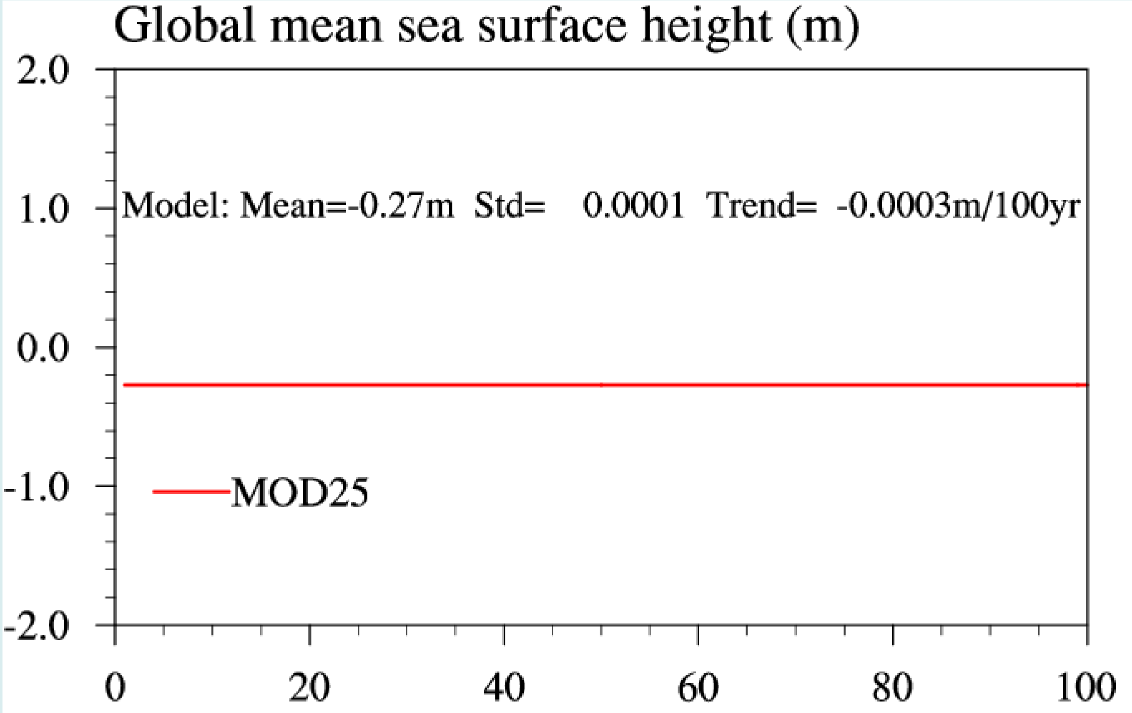




Time series of global mean Fresh water flux (E-P)



Time series of global mean Sea Surface Height



Summary of performance on surface temperature(ST), fresh water flux (E-P), top of atmosphere(TOA)/surface energy budget and sea surface height in terms of global mean Abs bias and trend, and cloud cover in terms of PCC and NRMSE

		CSMv1a	MOD25	MOD28 (30y)	MOD31	MOD33
ST	Abs Bias	0.006°C	0.76°C	0.29°C	0.09°C	0.08°C
	Trend	**0.14°C/100yr**	**0.044°C/100yr**	**-0.748°C/100yr**	**-0.338°C/100y**	**-0.156°C/100y**
Fresh water flux (E-P)	Abs Bias	0.0032mm day^{-1}	0.0019mm day^{-1}	0.0036mm day^{-1}	0.0042mm day^{-1}	0.0038mm day^{-1}
	Trend	**-0.12mm day^{-1}/100yr**	**0.0001mm day^{-1}/100yr**	**-0.0042mm day^{-1}/100yr**	**0.0020mm day^{-1}/100yr**	**-0.0015mm day^{-1}/100yr**
TOA Energy Budget	Abs Bias	3.9w m^{-2}	2.51w m^{-2}	1.21w m^{-2}	1.96w m^{-2}	2.26w m^{-2}
	Trend	**-0.70 w m^{-2}/100yr**	**-0.06 w m^{-2}/100yr**	**0.29 w m^{-2}/100yr**	**0.47 w m^{-2}/100yr**	**0.28 w m^{-2}/100yr**
Surface Energy Budget	Abs Bias	3.47w m^{-2}	2.87w m^{-2}	1.56w m^{-2}	2.29w m^{-2}	2.62w m^{-2}
	Trend	**-0.11w m^{-2}/100yr**	**-0.25w m^{-2}/100yr**	**0.31w m^{-2}/100yr**	**0.34w m^{-2}/100yr**	**0.28w m^{-2}/100yr**
Sea Surface Height	**Trend**	**1.48m/100yr**	**0.01m/100yr**	**0.0005m/100yr**	**-0.0014m/100yr**	**0.0002m/100yr**
Cloud Cover	**Trend**	**0.011%/100yr**	**-0.006%/100yr**	**-0.32%/100yr**	**0.05%/100yr**	**-0.11%/100yr**

2. Climatology of SST and precipitation

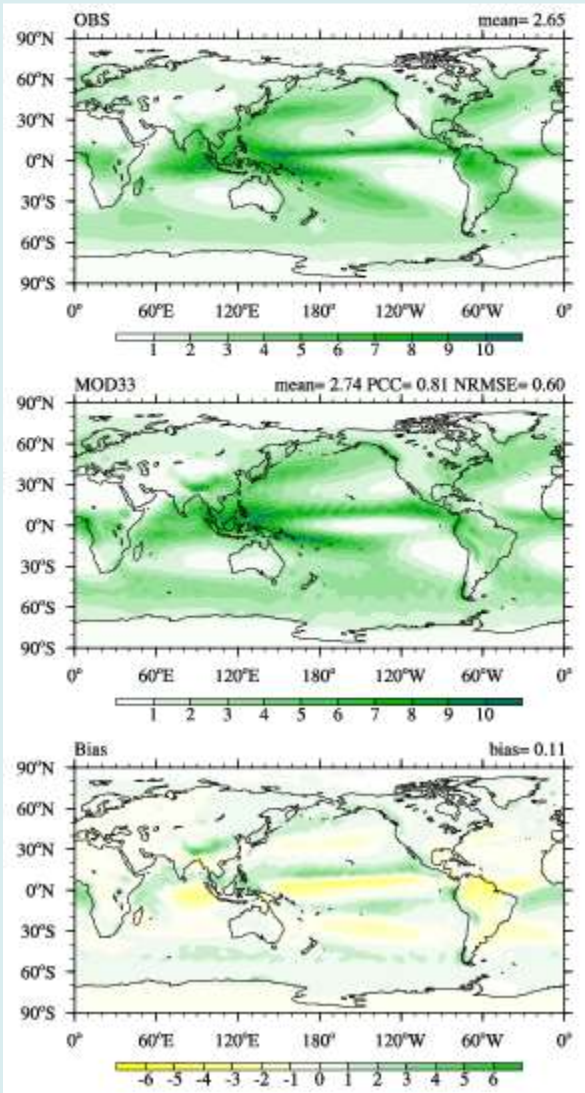
- Annual mean precipitation;
- Annual cycle of precipitation (1st and 2nd modes)
- Annual mean SST;
- Annual cycle of SST (1st and 2nd modes)
- Annual variation of SST along equatorial Pacific
- Annual variation of zonal wind stress along equatorial Pacific
- Seasonal mean cloud cover

Annual Mean precipitation

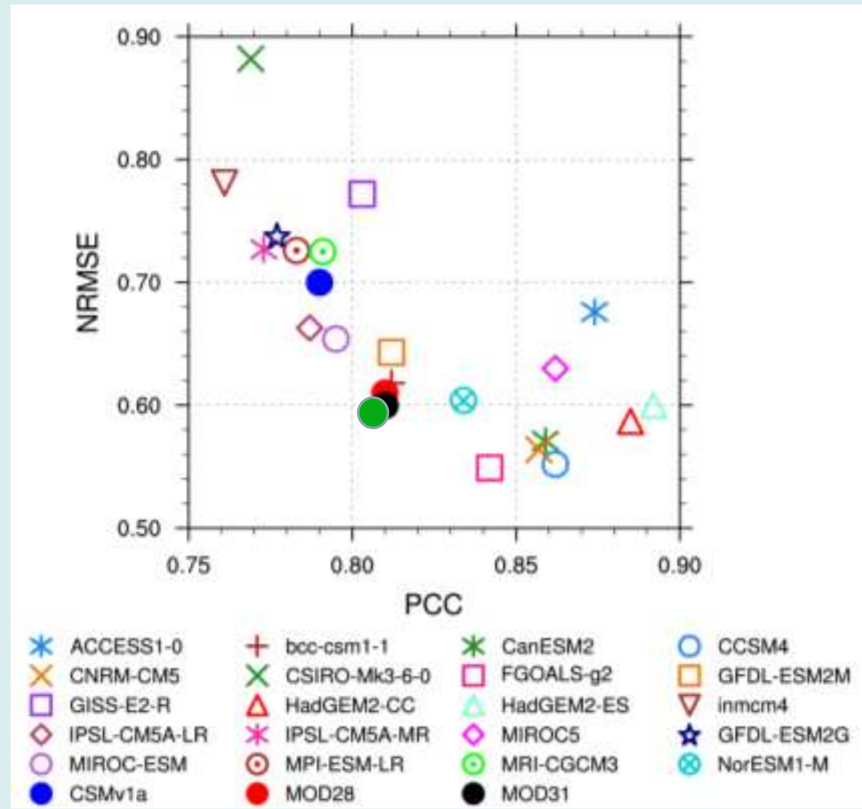
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (40S-60N)



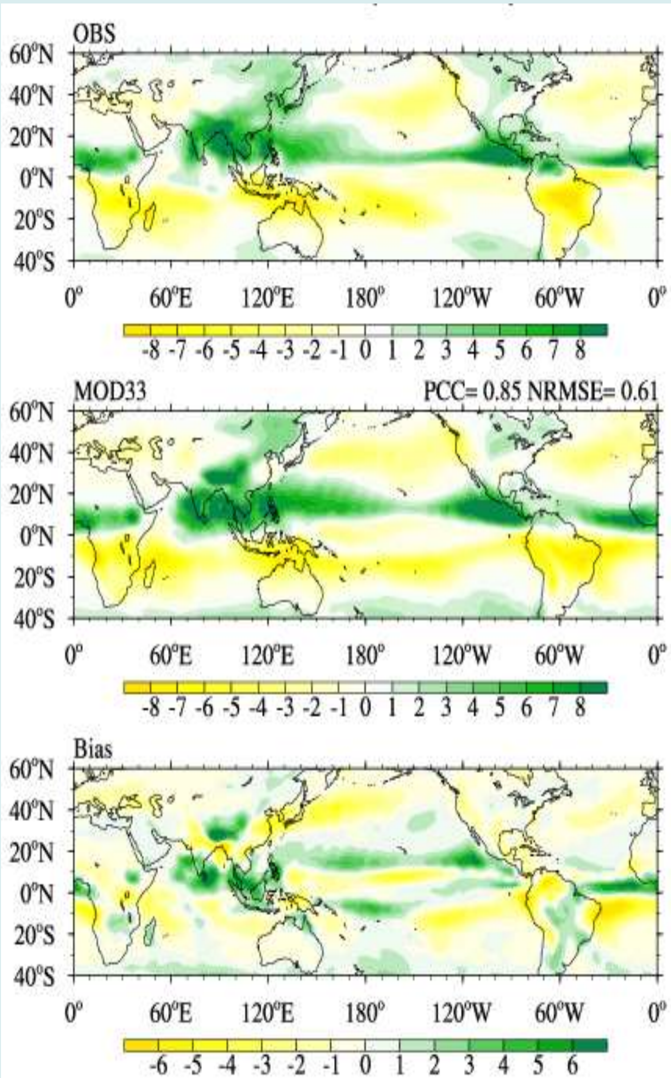
MOD33 ●

The First Annual Cycle (Solstice Mode) of precipitation

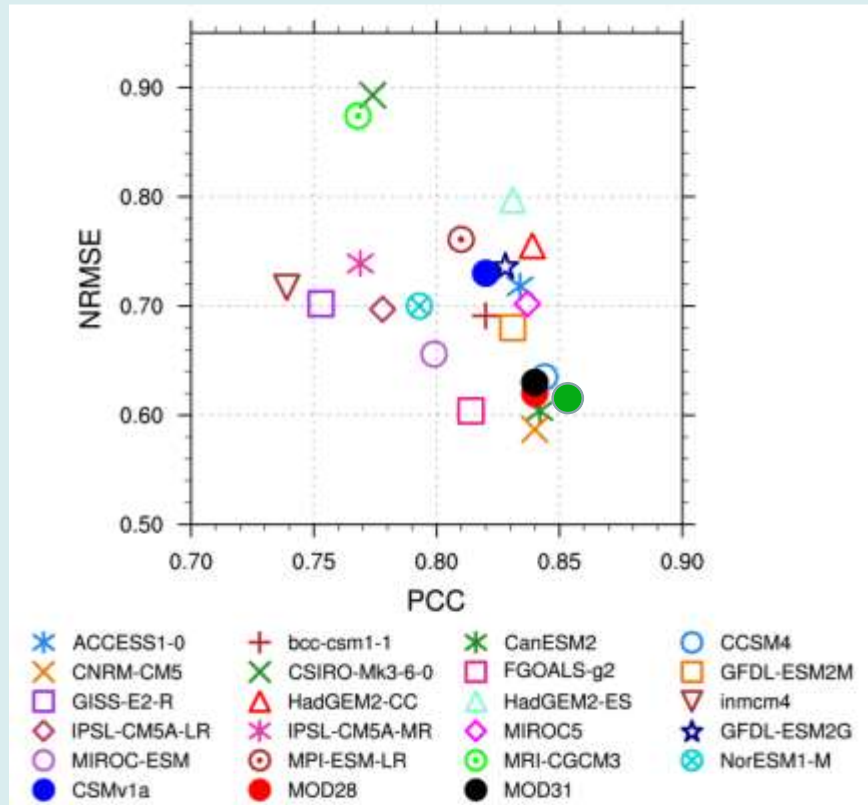
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (40S-60N)



MOD33

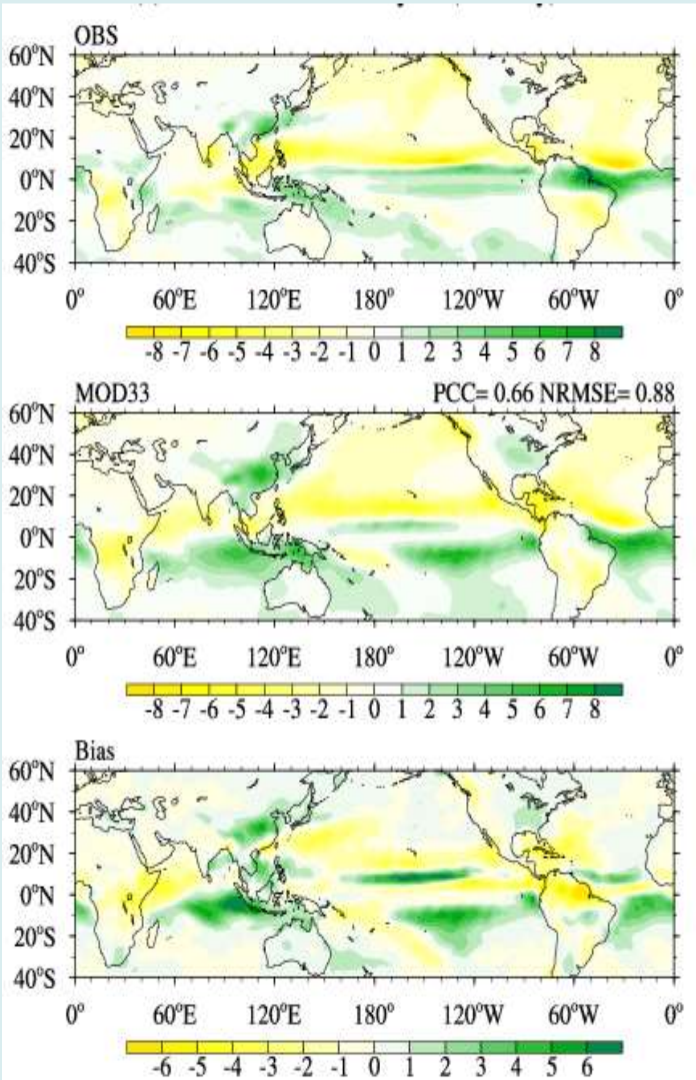
Part 2: Climatology

The Second Annual Cycle (Equinoctial Mode) of **precipitation**

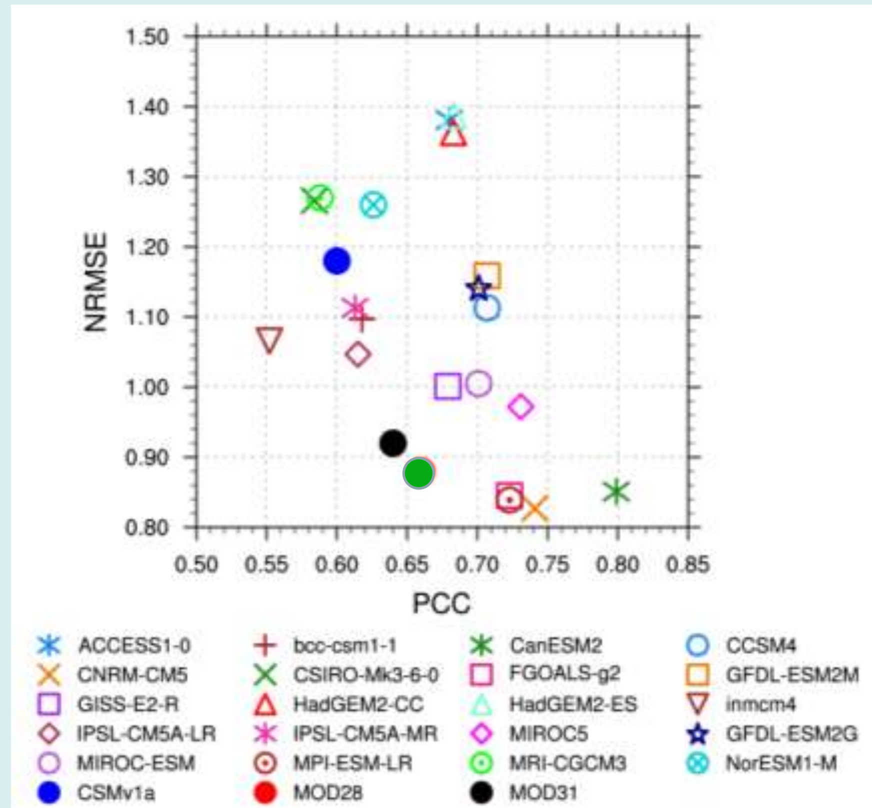
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (40S-60N)



MOD33

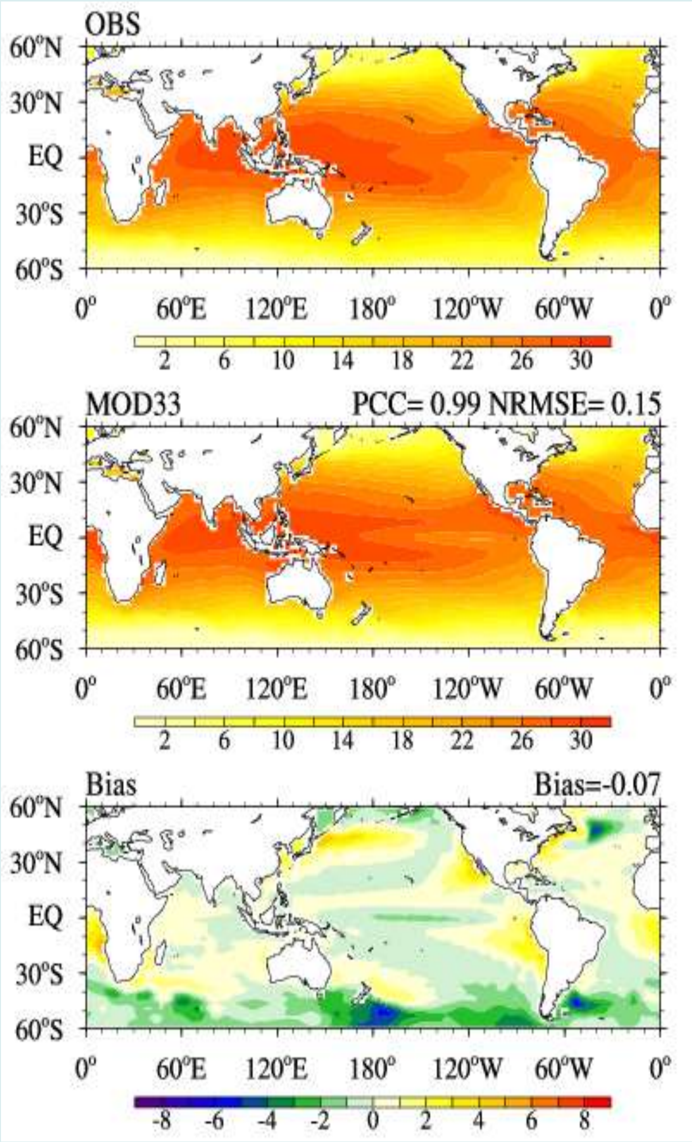
Part 2: Climatology

Annual Mean SST (ºC)

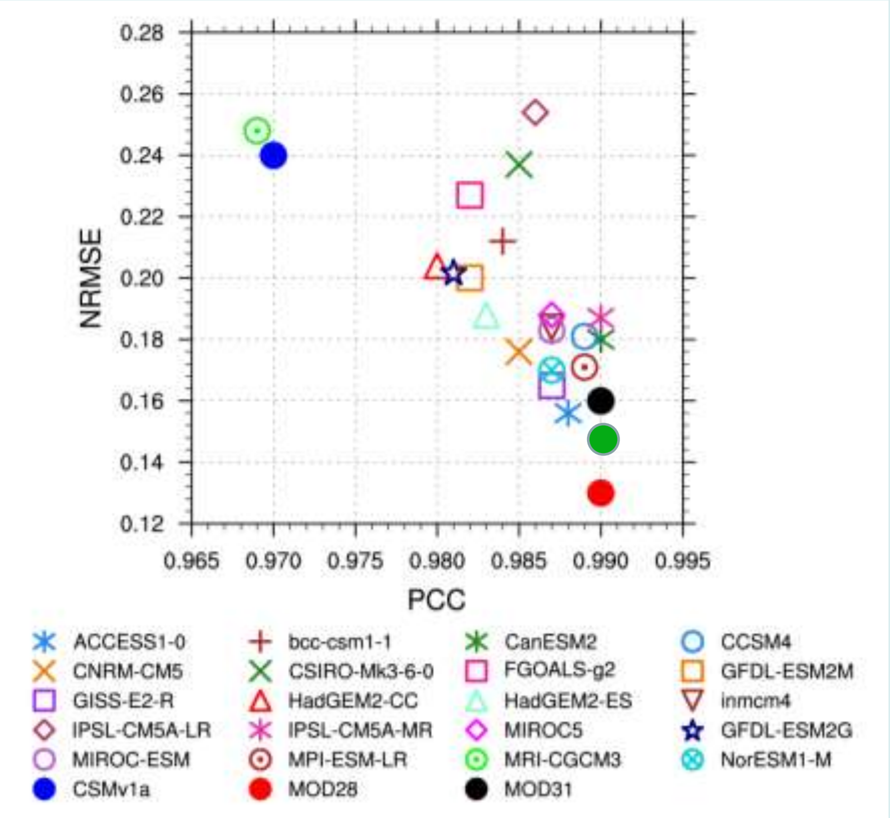
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (60S-60N)



MOD33

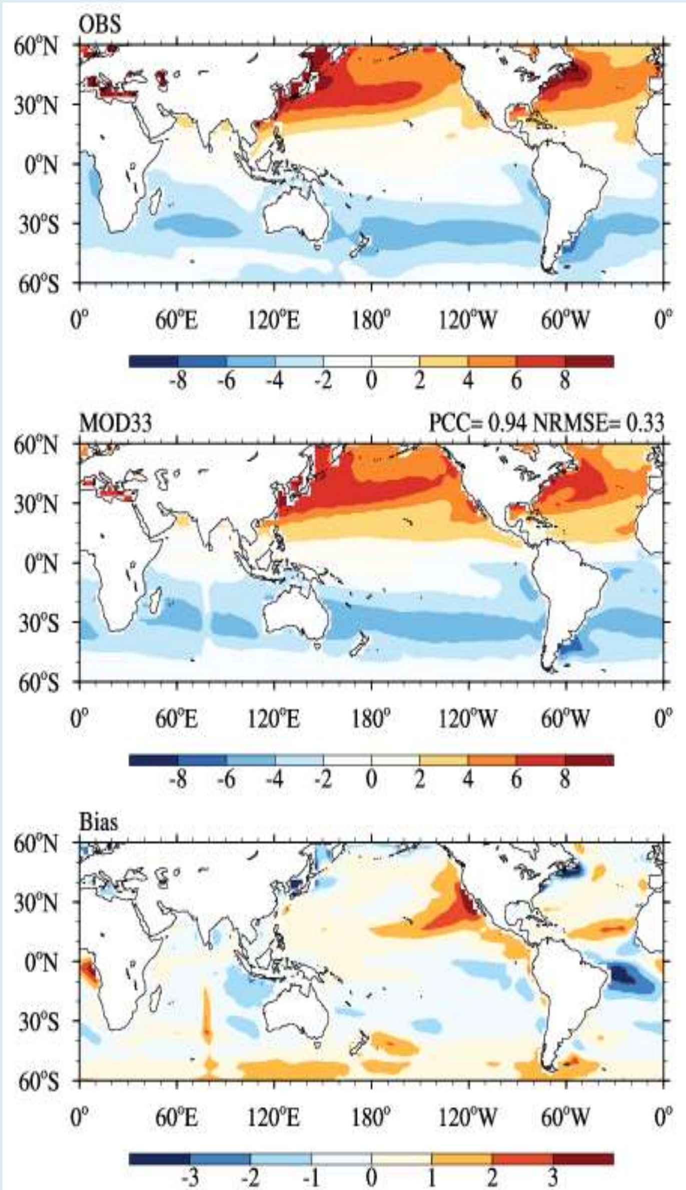
Part 2: Climatology

The First Annual Cycle of SST

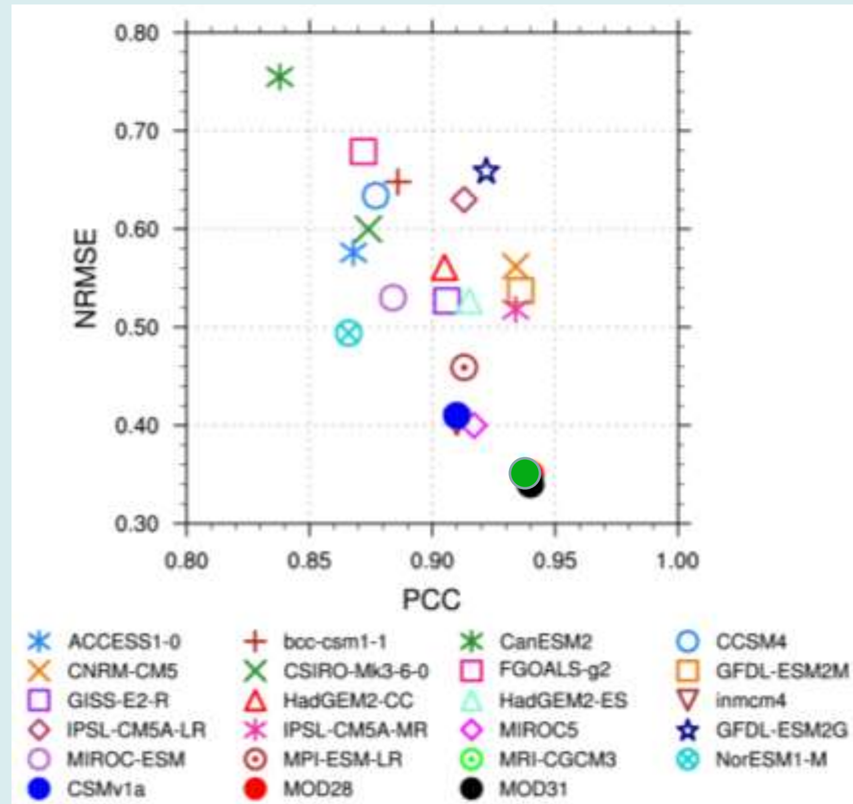
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (60S-60N)



MOD33

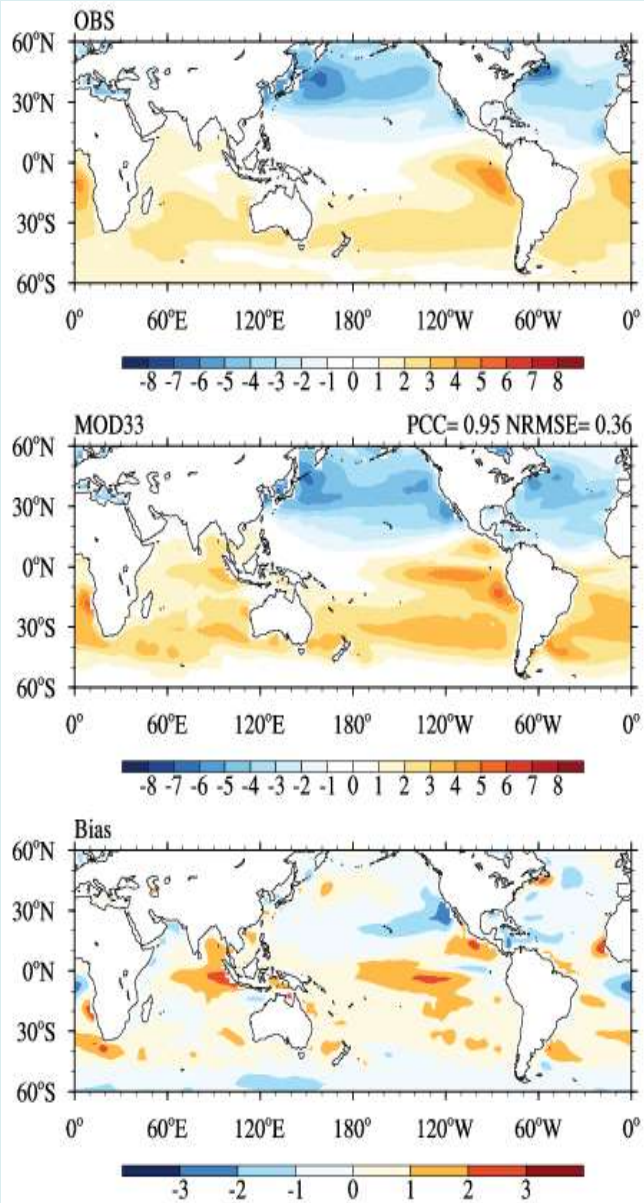
Part 2: Climatology

The Second Annual Cycle of SST

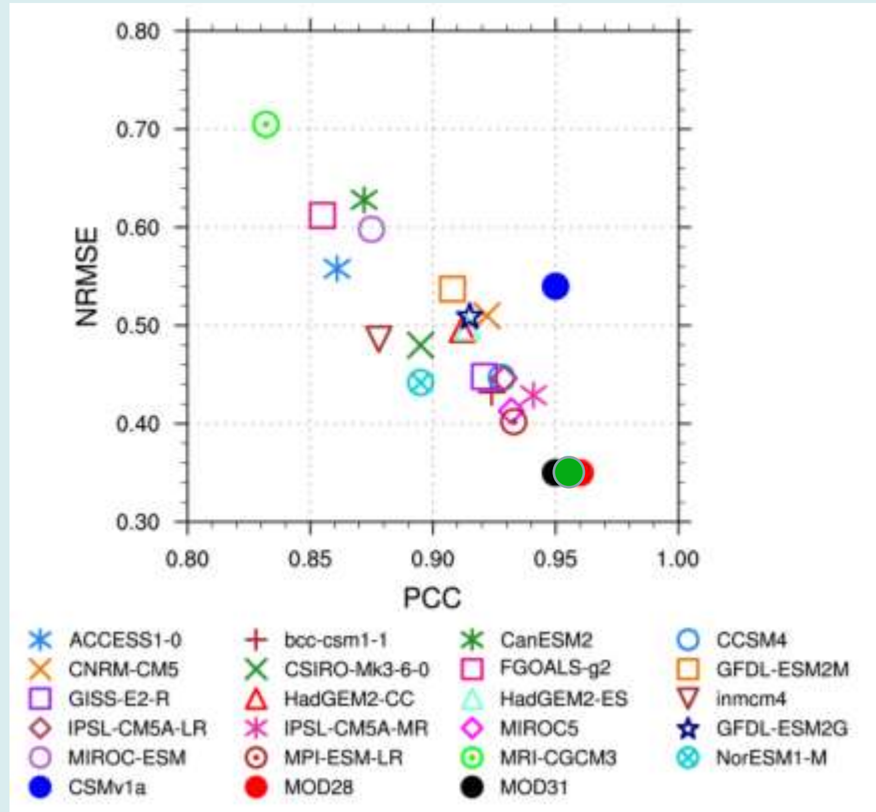
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (60S-60N)

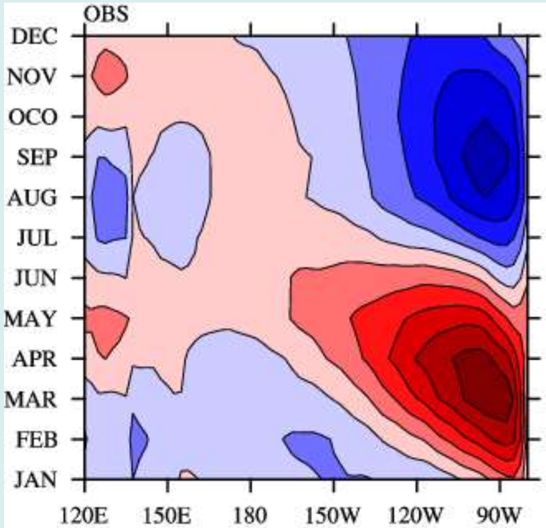


MOD33

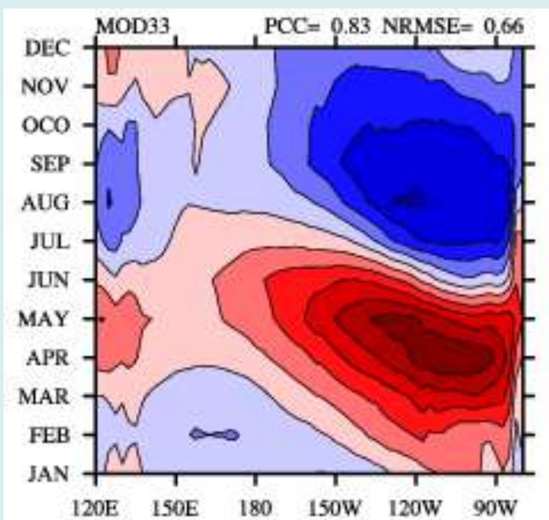
Part 2: Climatology

Annual Cycle of Equatorial SST

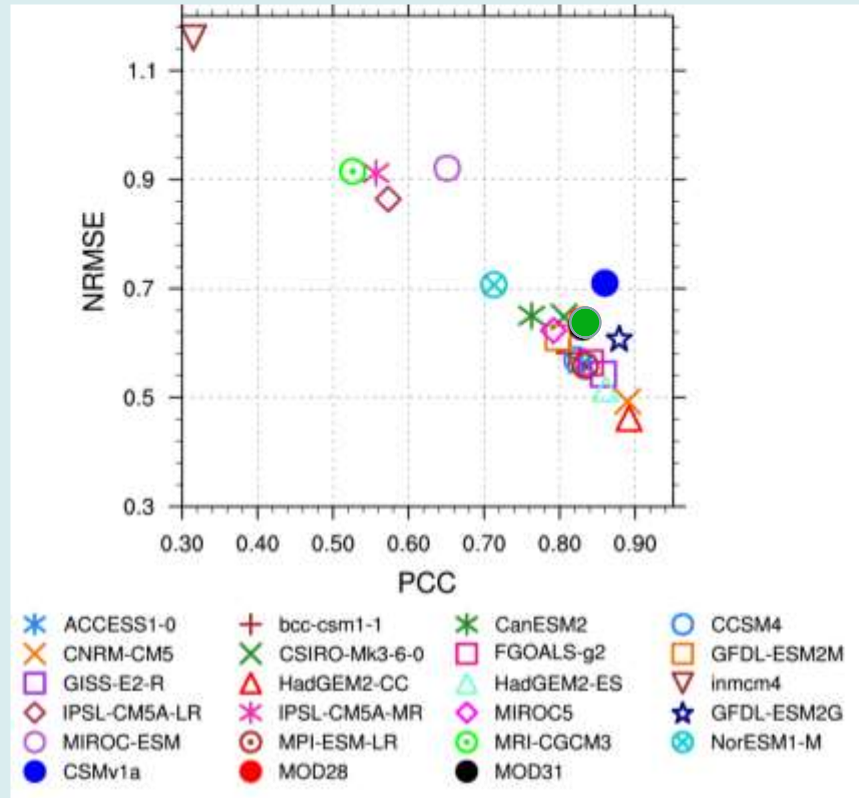
OBS



MOD33



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE

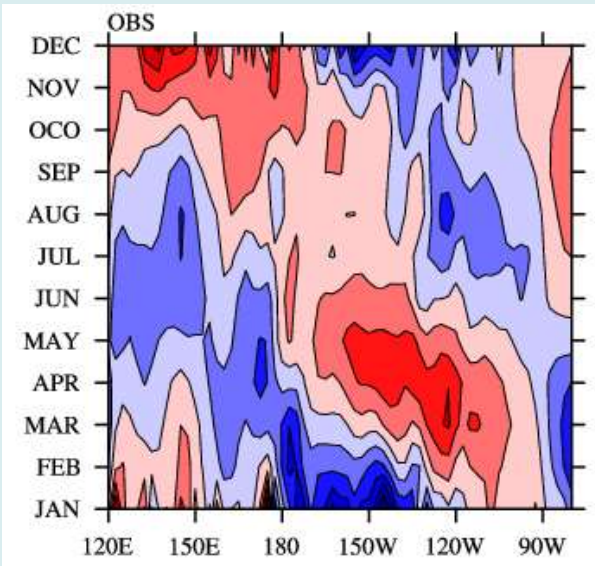


MOD33

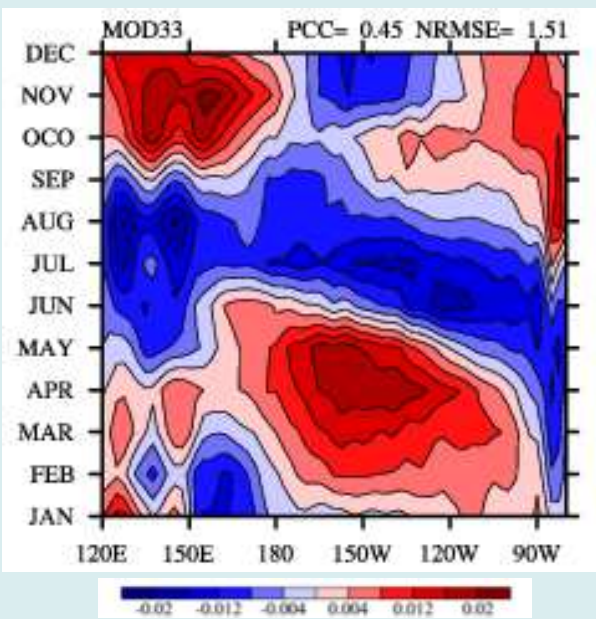
Part 2: Climatology

Annual Cycle of Equatorial Zonal Wind Stress

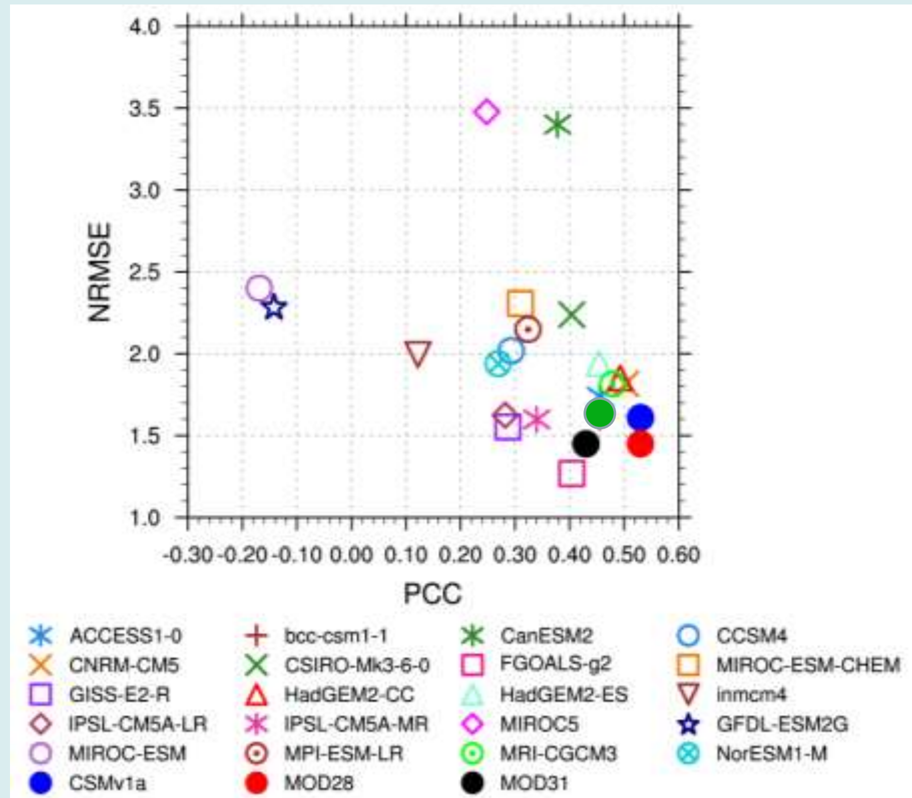
OBS



MOD33



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE



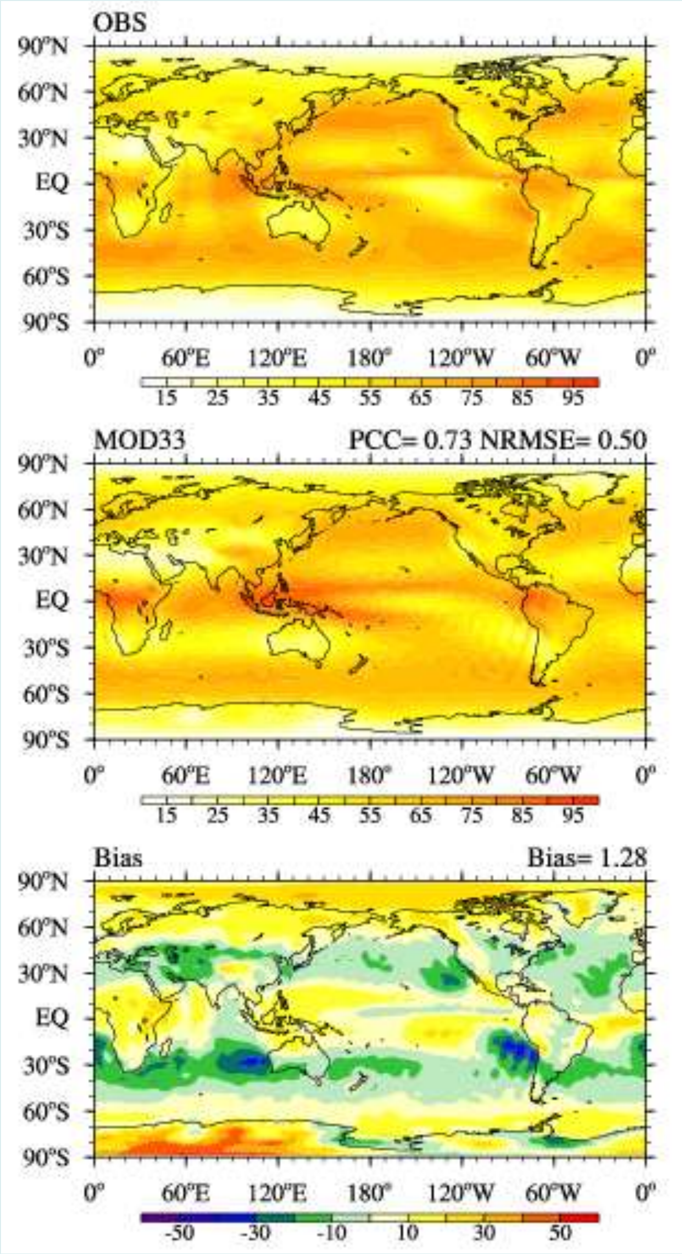
MOD33 ●

Annual Mean cloud cover

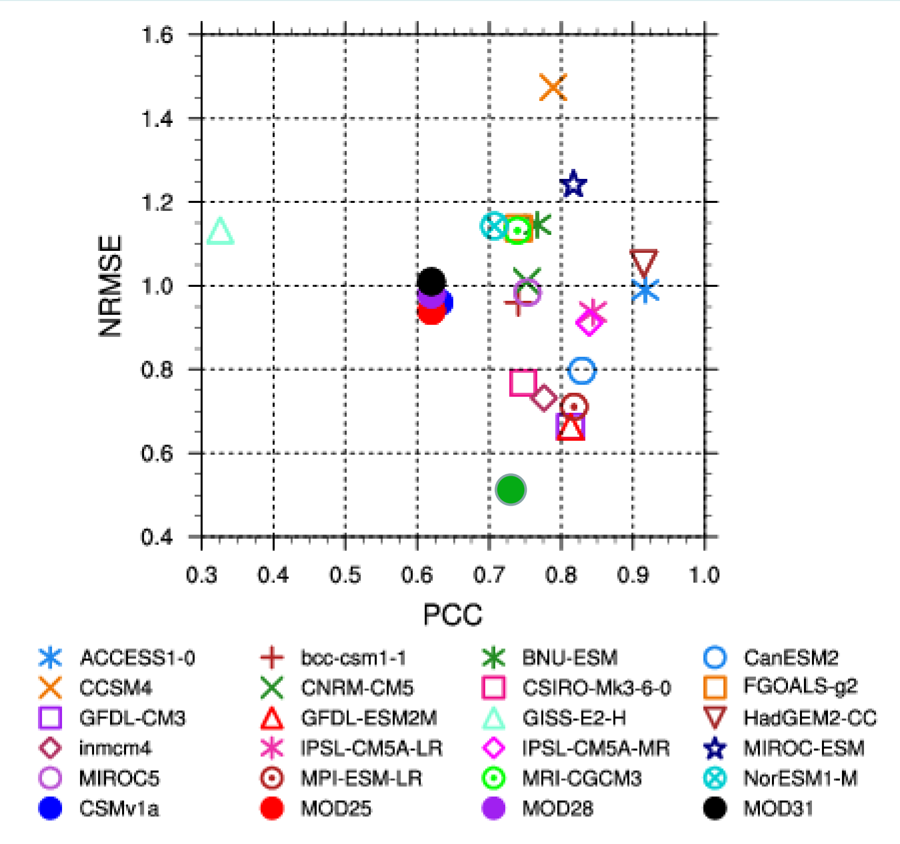
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE



MOD33

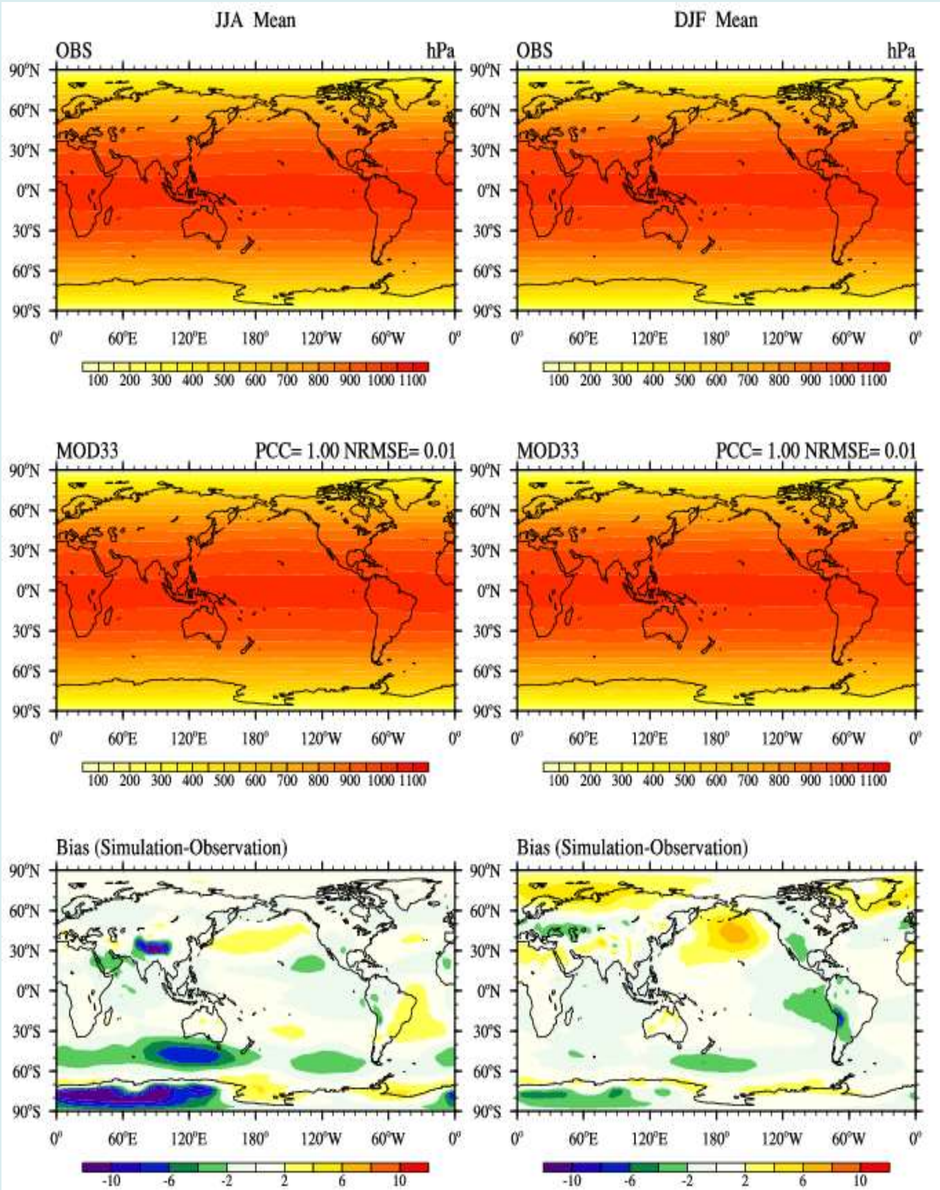
JJA and DJF Mean SLP

JJA **DJF**

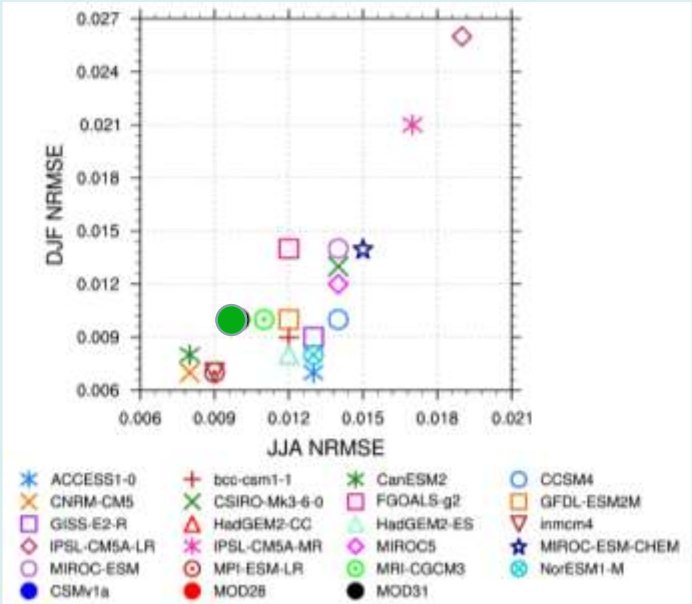
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the NRMSE in DJF and JJA



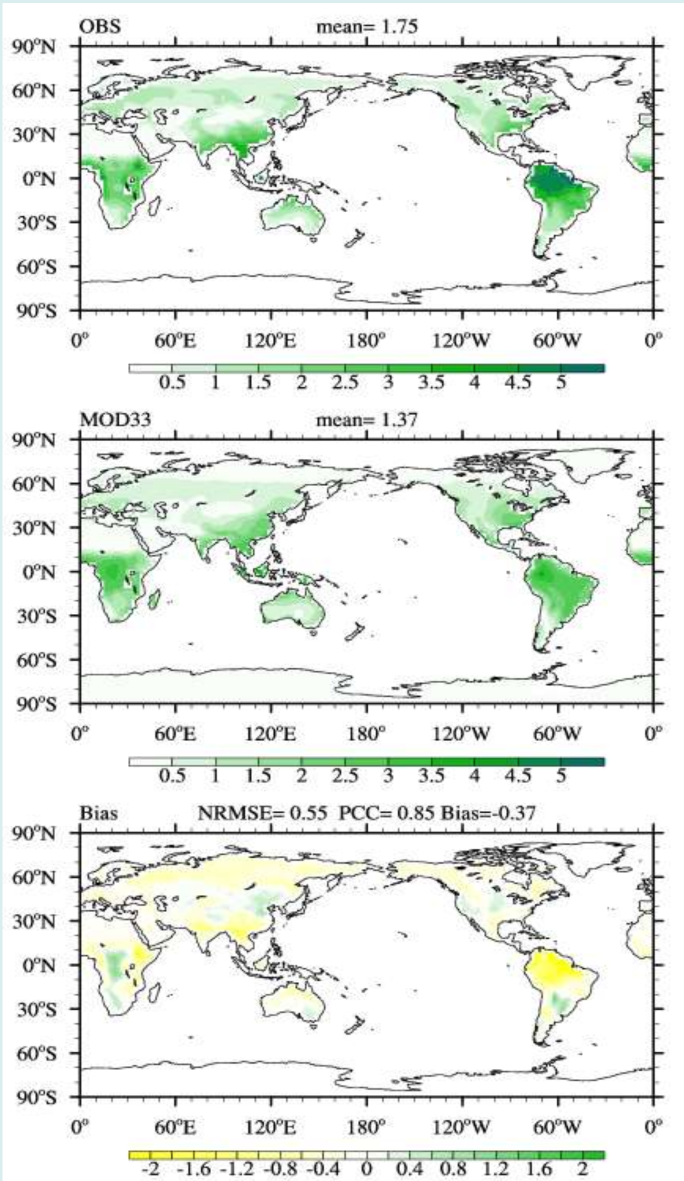
MOD33 ●

Annual Mean evaporation (land)

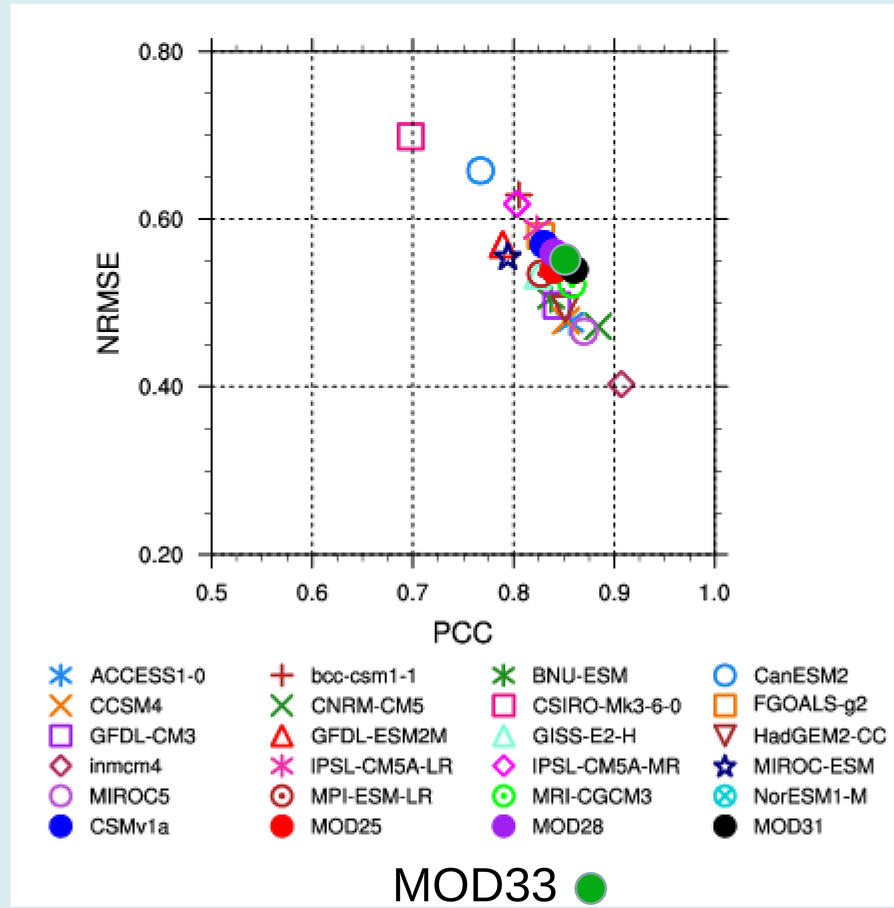
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE

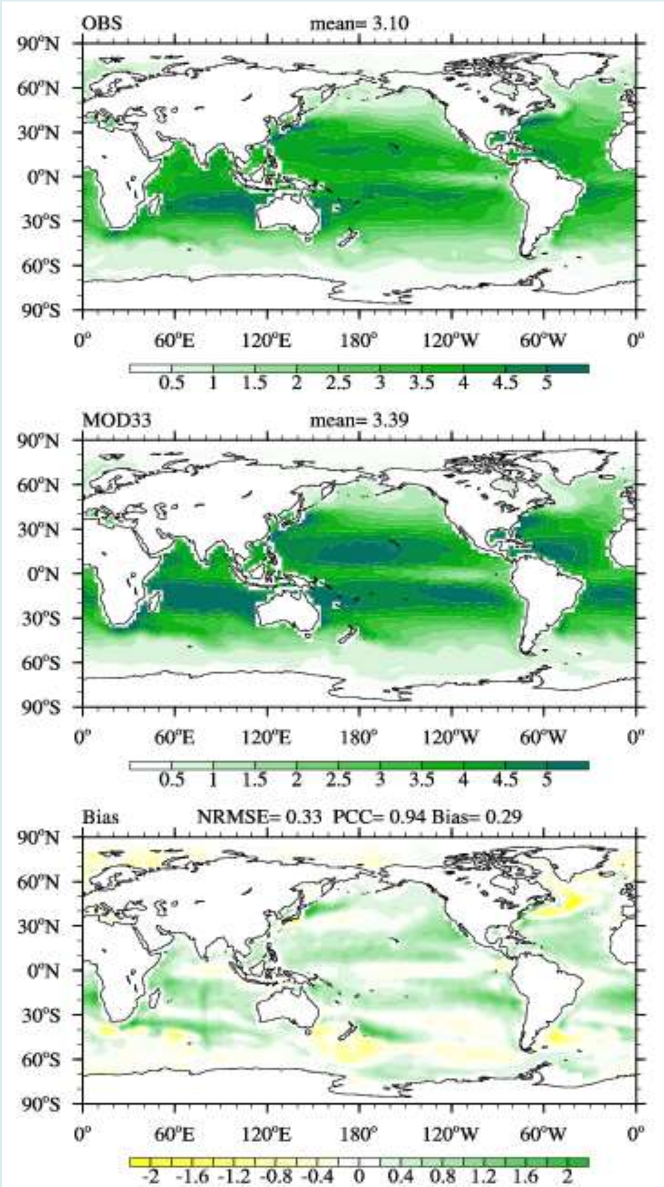


Annual Mean evaporation (ocean)

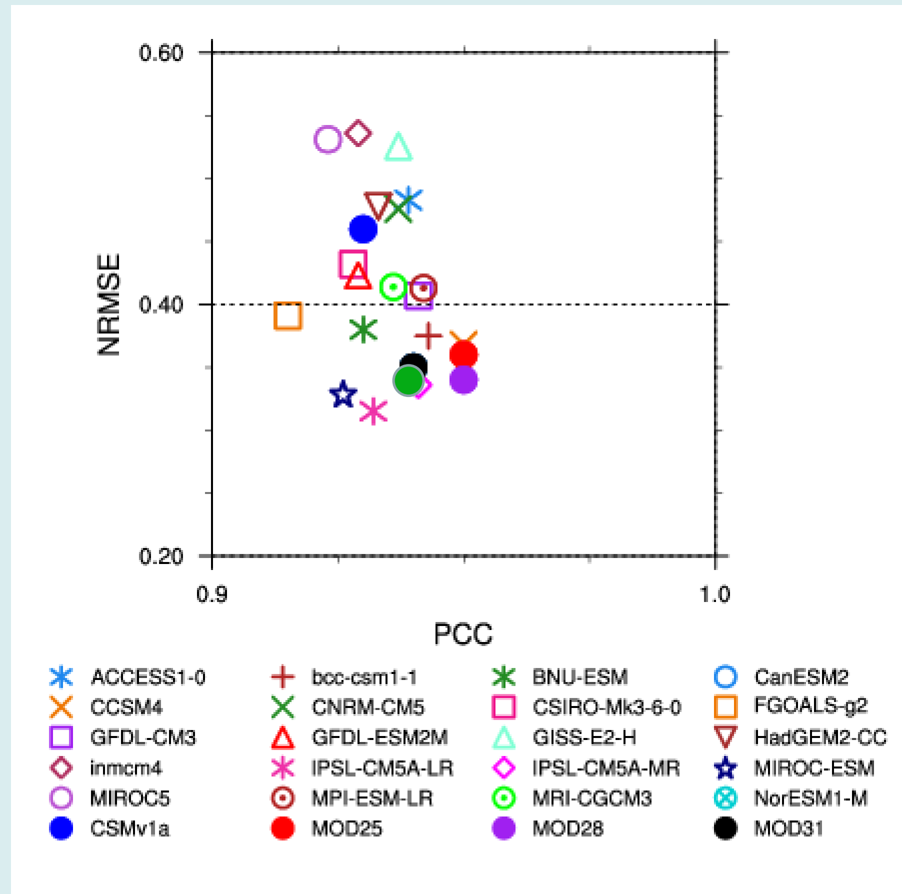
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE



MOD33

Annual Mean precipitation (land and ocean)

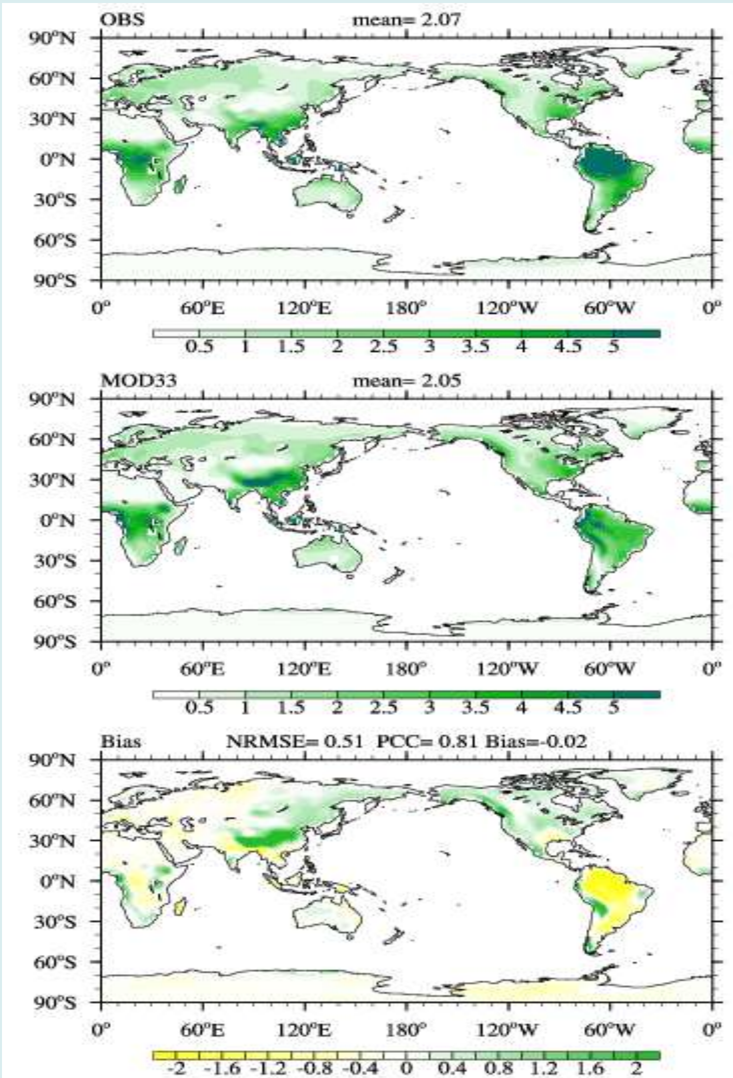
land

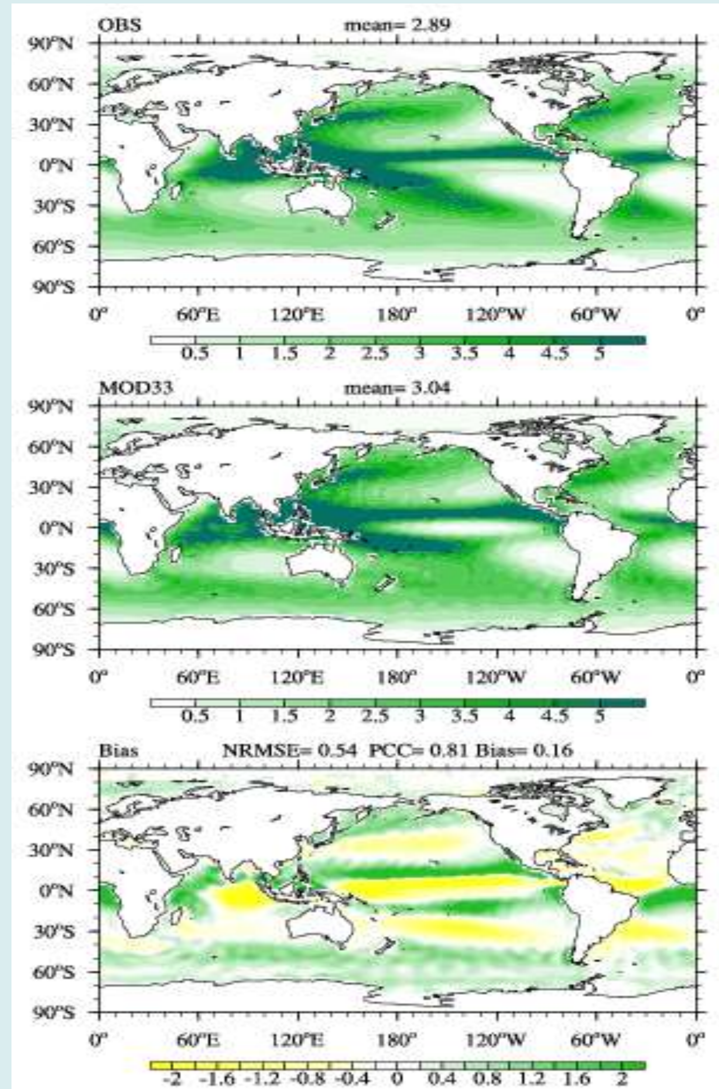
Ocean

OBS

MOD33

BIAS



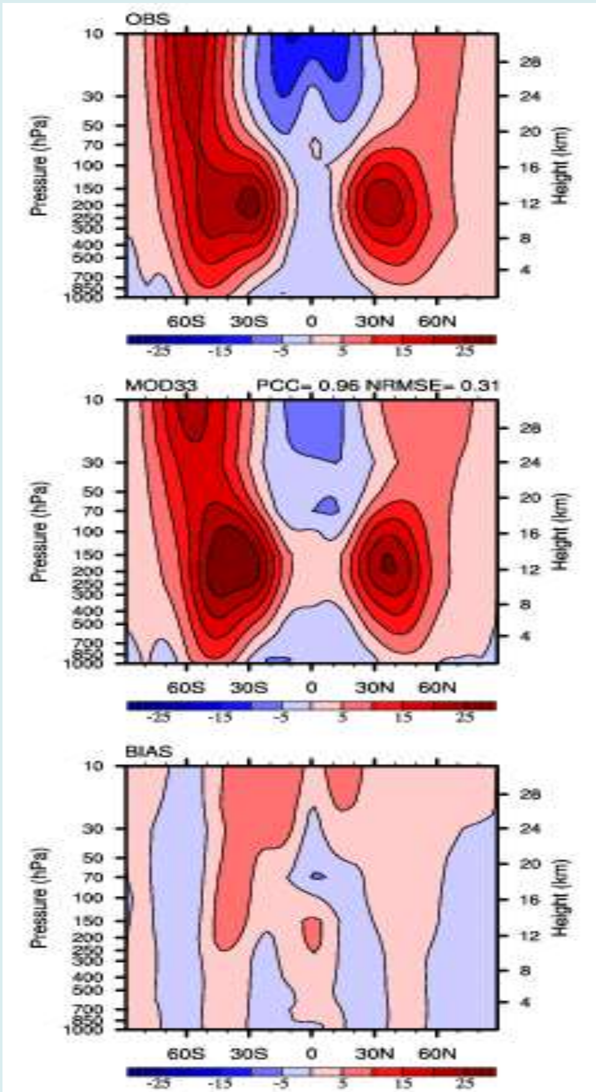


Annual Mean Zonal Mean u-wind

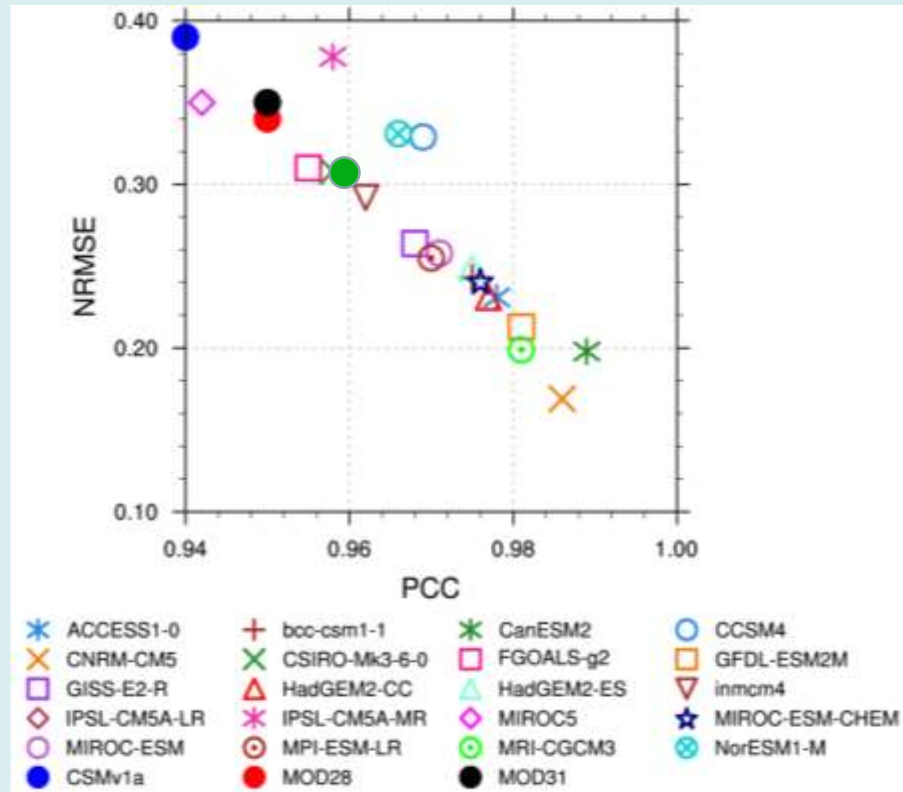
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE



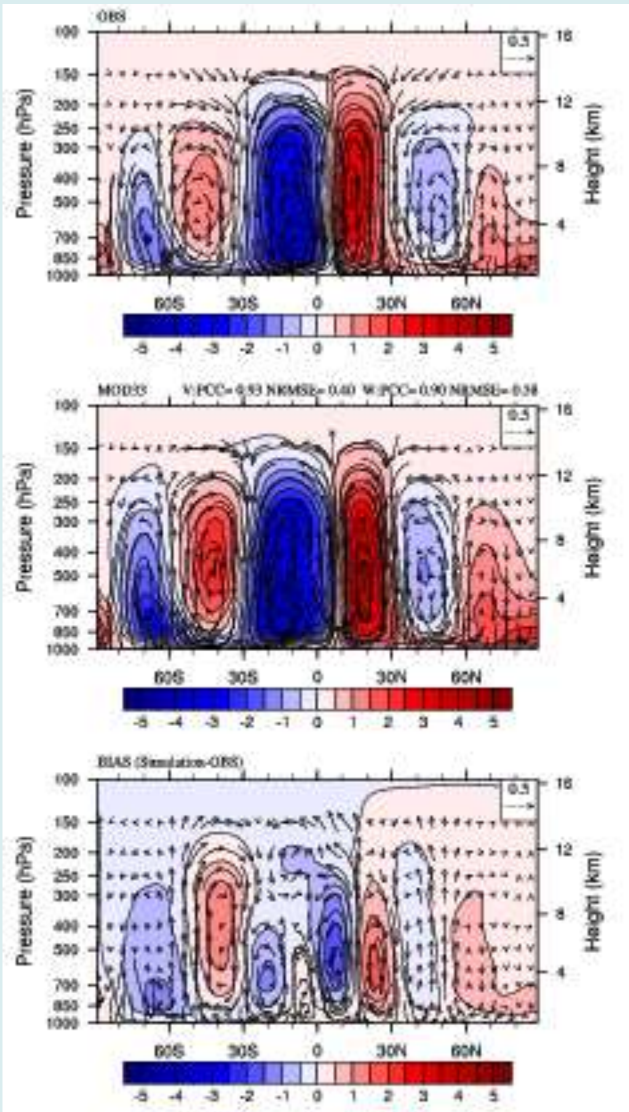
MOD33

Annual Mean Hadley Cells

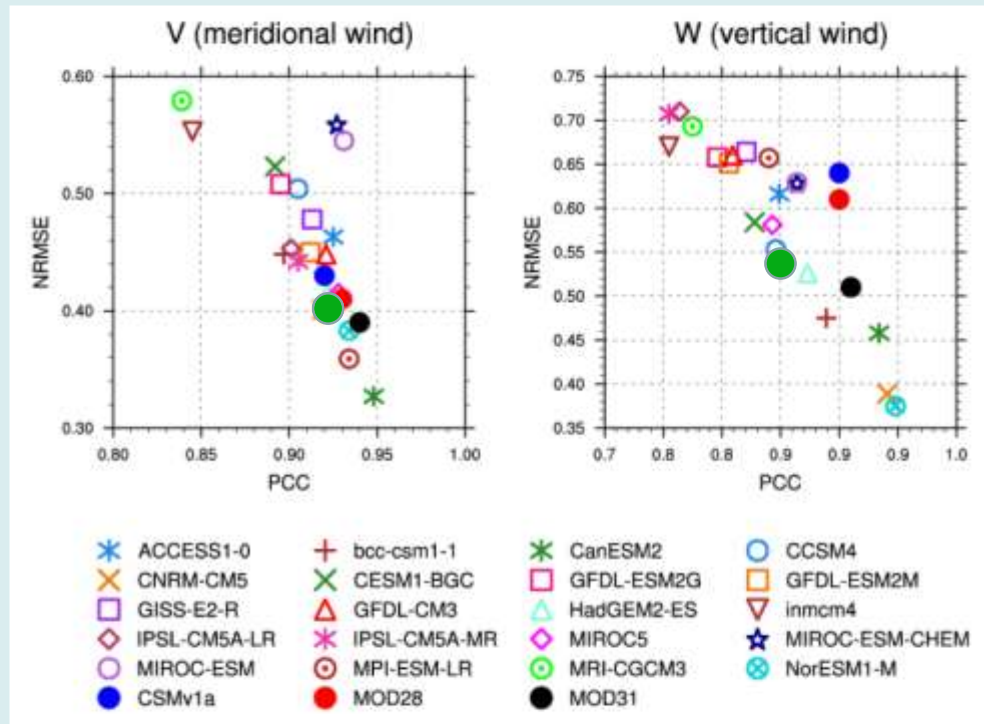
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE



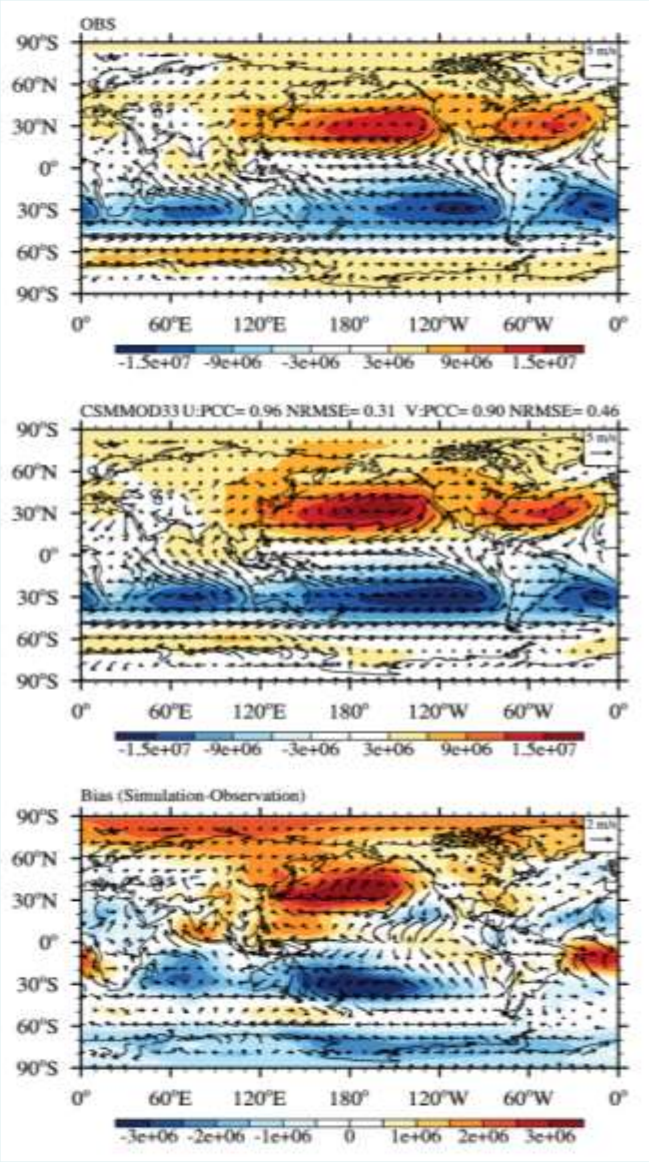
MOD33

Annual Mean Surface Winds

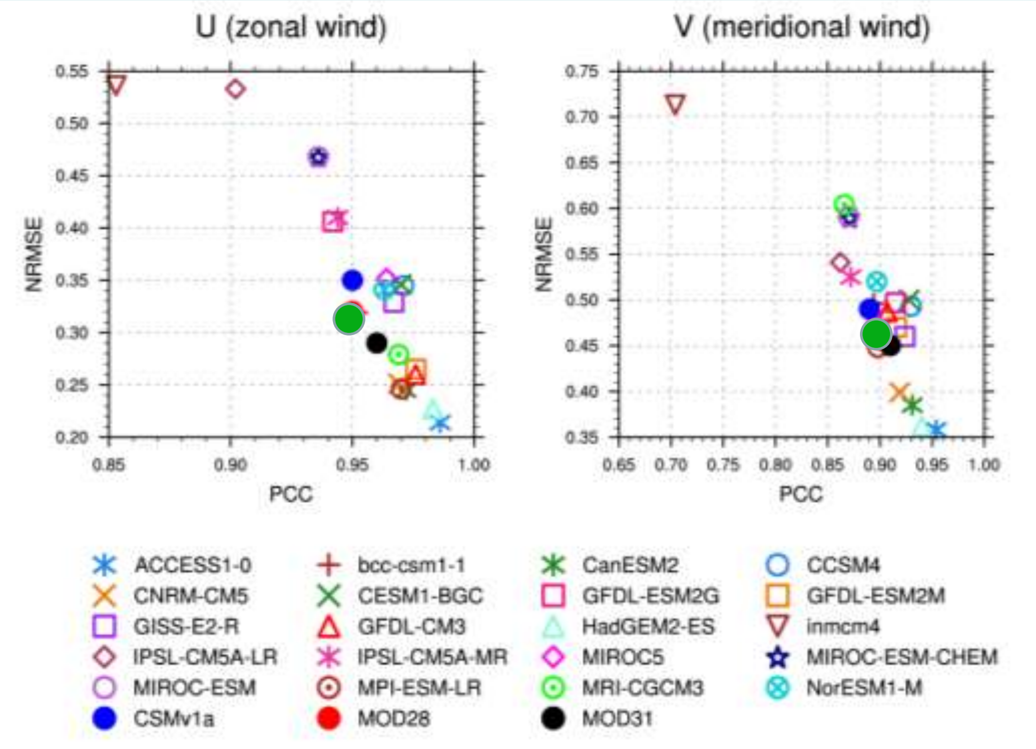
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE



MOD33

Summary of performance on climatology (Part 1) in terms of NRMSE and PCC skill (in parentheses).

		Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD28	MOD31	MOD33
Climatology	EQ SST AC*	0.56 (0.83)	0.61 (0.81)	0.71 (0.86)	0.70 (0.81)	0.64 (0.83)	0.63 (0.83)	0.66 (0.83)
	EQ ZWS AC*	1.82 (0.40)	1.94 (0.34)	1.61 (0.53)	1.57 (0.44)	1.45 (0.53)	1.45 (0.43)	1.51 (0.45)
	PRCP AM	0.60 (0.86)	0.64 (0.80)	0.70 (0.79)	0.63 (0.80)	0.61 (0.81)	0.60 (0.81)	0.60 (0.81)
	PRCP AC1	0.69 (0.83)	0.70 (0.82)	0.73 (0.82)	0.63 (0.85)	0.62 (0.84)	0.63 (0.84)	0.61 (0.85)
	PRCP AC2	1.01 (0.71)	1.10 (0.68)	1.18 (0.60)	0.92 (0.65)	0.88 (0.66)	0.92 (0.64)	0.88 (0.66)
	SST AM	0.18 (0.99)	0.19 (0.98)	0.24 (0.97)	0.16 (0.99)	0.13 (0.99)	0.16 (0.99)	0.15 (0.99)
	SST AC1	0.53 (0.91)	0.56 (0.90)	0.41 (0.91)	0.34 (0.94)	0.35 (0.94)	0.34 (0.94)	0.33 (0.94)
	SST AC2	0.45 (0.92)	0.49 (0.91)	0.54 (0.95)	0.39 (0.96)	0.35 (0.96)	0.35 (0.95)	0.36 (0.95)

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

Summary of performance on climatology (Part 2) in terms of NRMSE and PCC skill (in parentheses).

		Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD28	MOD31	MOD33
Climatology	Cloud Cover	0.61 (0.75)	0.63 (0.74)	0.53 (0.75)	0.50 (0.74)	0.51 (0.73)	0.53 (0.71)	0.50 (0.73)
	JJA SLP	0.012	0.011	0.010	0.010	0.010	0.01	0.01
	DJF SLP	0.008	0.009	0.010	0.008	0.009	0.01	0.01
	Zonal Mean U	0.24 (0.98)	0.26 (0.97)	0.39 (0.94)	0.33 (0.95)	0.34 (0.95)	0.35 (0.95)	0.31 (0.96)
	Evap (land)	0.50 (0.84)	0.53 (0.83)	0.57 (0.83)	0.54 (0.84)	0.56 (0.84)	0.54 (0.86)	0.55 (0.85)
	Evap (ocean)	0.38 (0.94)	0.41 (0.93)	0.46 (0.93)	0.36 (0.95)	0.34 (0.95)	0.35 (0.94)	0.33 (0.94)
	V (Hadley circulation)	0.44 (0.93)	0.45 (0.92)	0.43 (0.92)	0.44 (0.93)	0.41 (0.93)	0.39 (0.94)	0.40 (0.93)
	W (Hadley circulation)	0.58 (0.86)	0.63 (0.84)	0.64 (0.90)	0.59 (0.90)	0.61 (0.90)	0.57 (0.91)	0.58 (0.90)
	Surface U	0.27 (0.97)	0.33 (0.96)	0.35 (0.95)	0.33 (0.95)	0.32 (0.95)	0.29 (0.96)	0.31 (0.96)
	Surface V	0.47 (0.92)	0.49 (0.91)	0.49 (0.89)	0.48 (0.89)	0.46 (0.90)	0.45 (0.91)	0.46 (0.90)

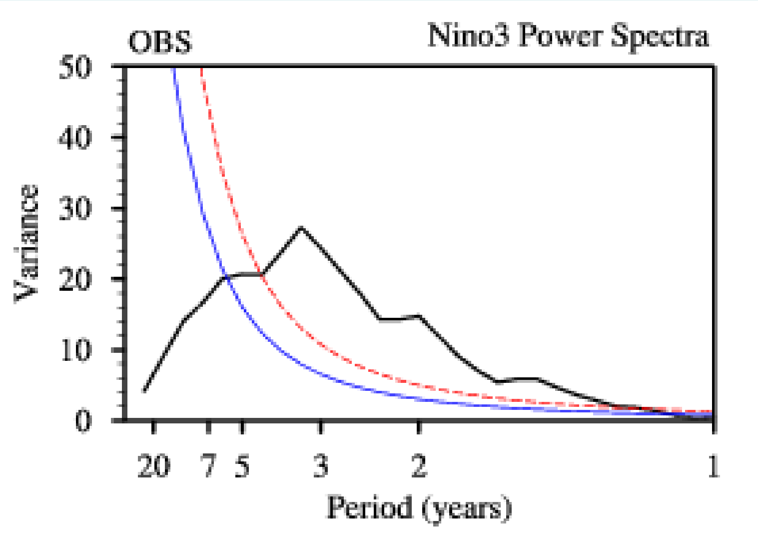
3. ENSO

- Seasonality: Phase locking
- Spectra of Nino 3.4 SST
- Amplitude (Variance)
- Structure: EOF modes of SST anomalies (first and second EOF modes)
- Evolution: Season-reliant EOF modes (QB&LF ENSO)
- CP&EP ENSO

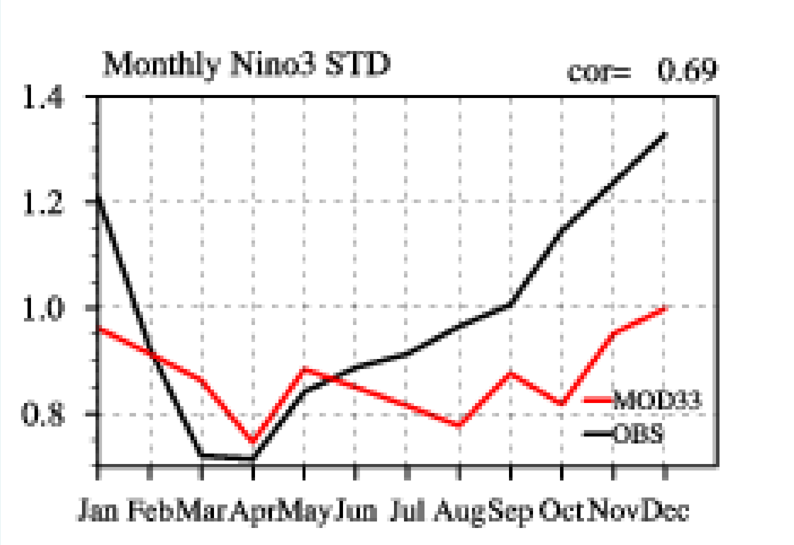
Part 3: ENSO

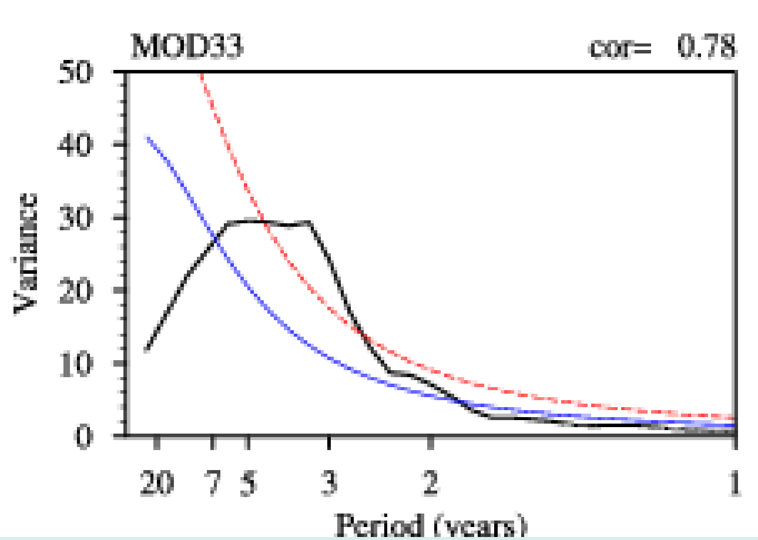
ENSO-Phase locking&Nino3 index spectrum

Nino3 index spectrum



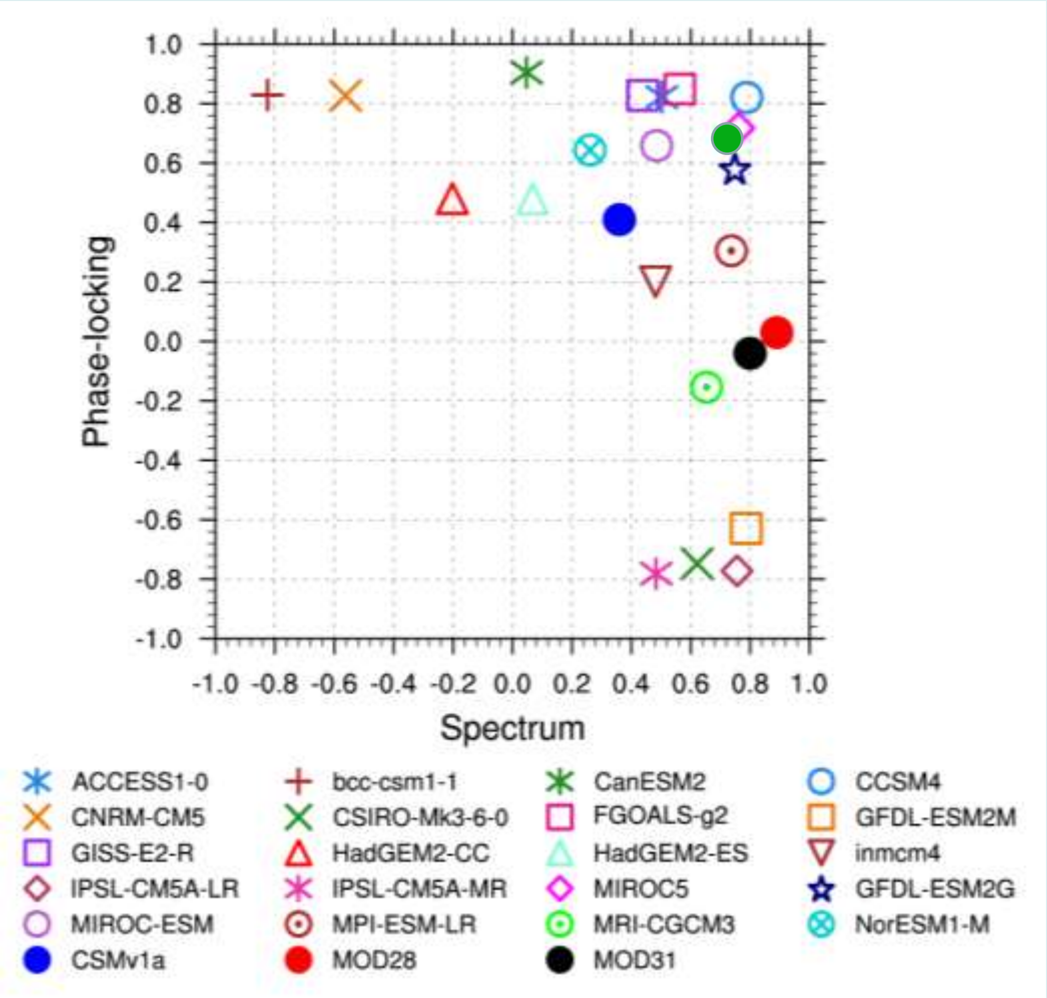
ENSO-Phase locking





Part 3: ENSO

Comparison with CMIP5 Coupled models in terms of the correlation skill for ENSO-Phase locking and that for Nino3 index spectrum (2-7yr)



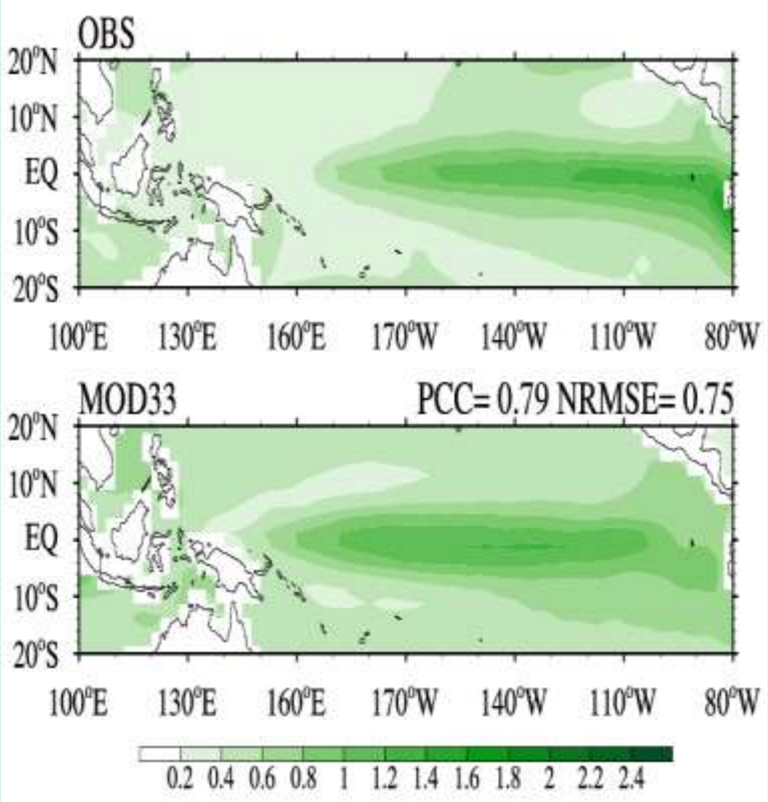
MOD33

Part 3: ENSO

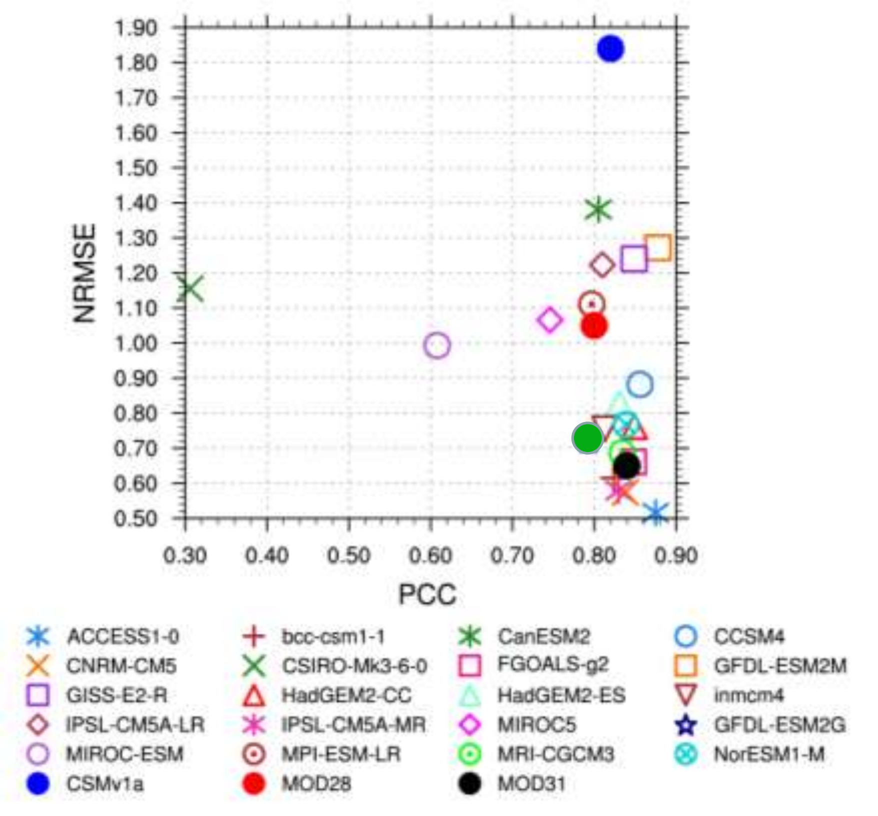
Monthly SST Variance

OBS

MOD33



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (20S-20N,100E-80W)



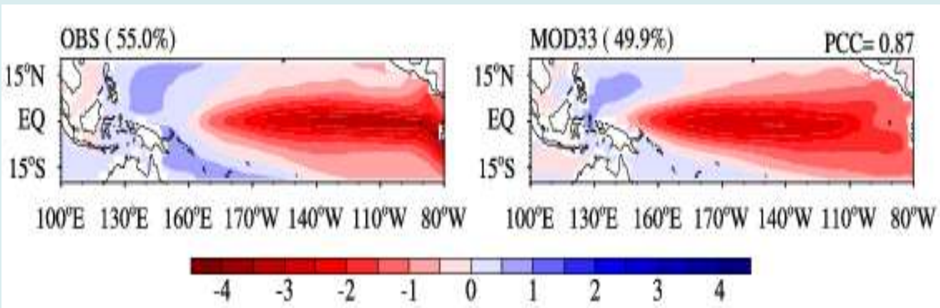
MOD33 ●

Part 3: ENSO

EOF1&2 of SST Anomalies

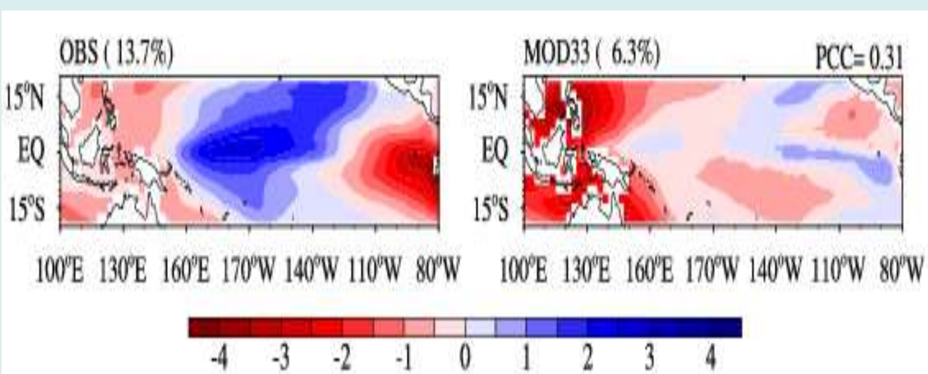
EOF1 of SST Anomalies

Observation (ERSST) **MOD33**

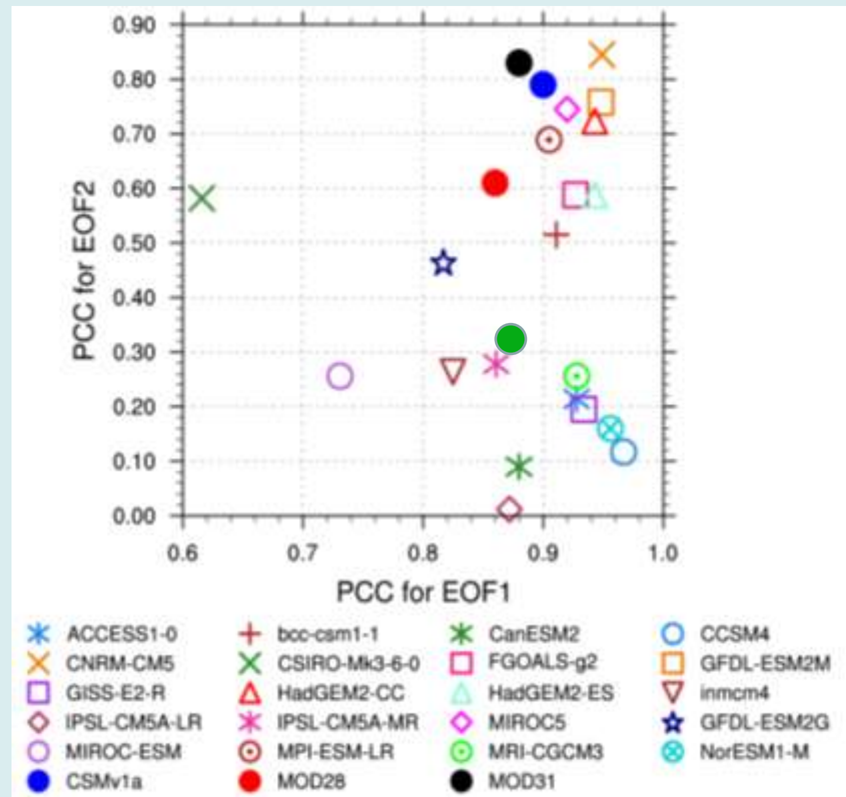


EOF2 of SST Anomalies

Observation (ERSST) **MOD33**



Comparison with CMIP5 Coupled models in terms of the PCC skill for *the first and second EOF mode of SST anomalies over the entire Pacific* (100°E-80°W, 20°S-20°N)



MOD33

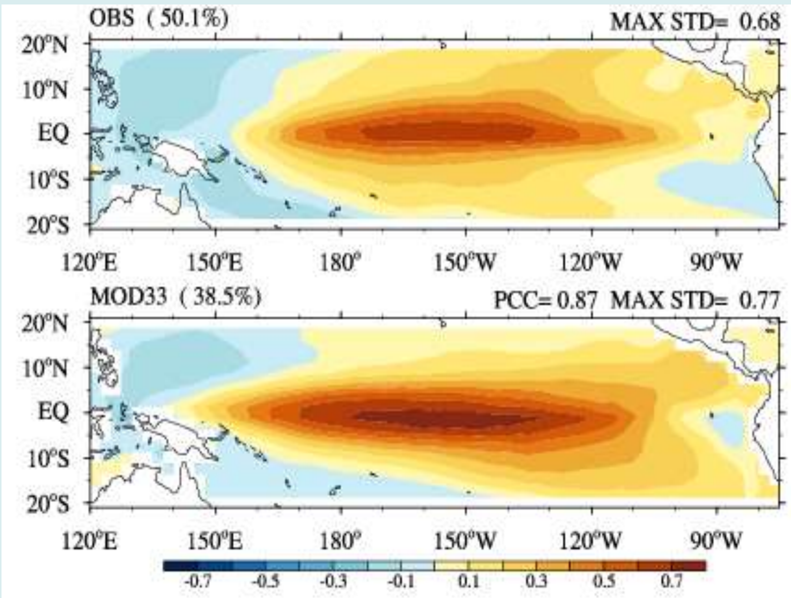
CP &EP ENSO

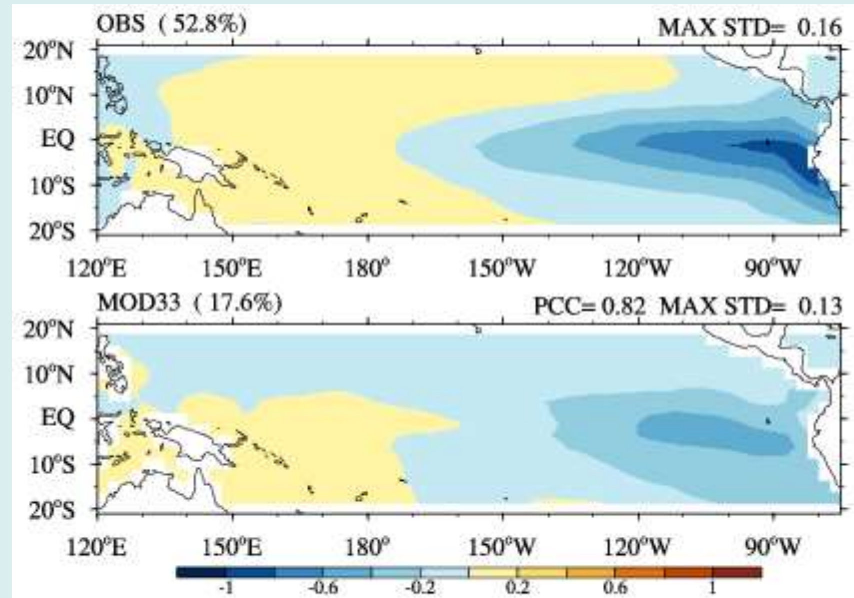
CP-ENSO

EP-ENSO

OBS

MOD33





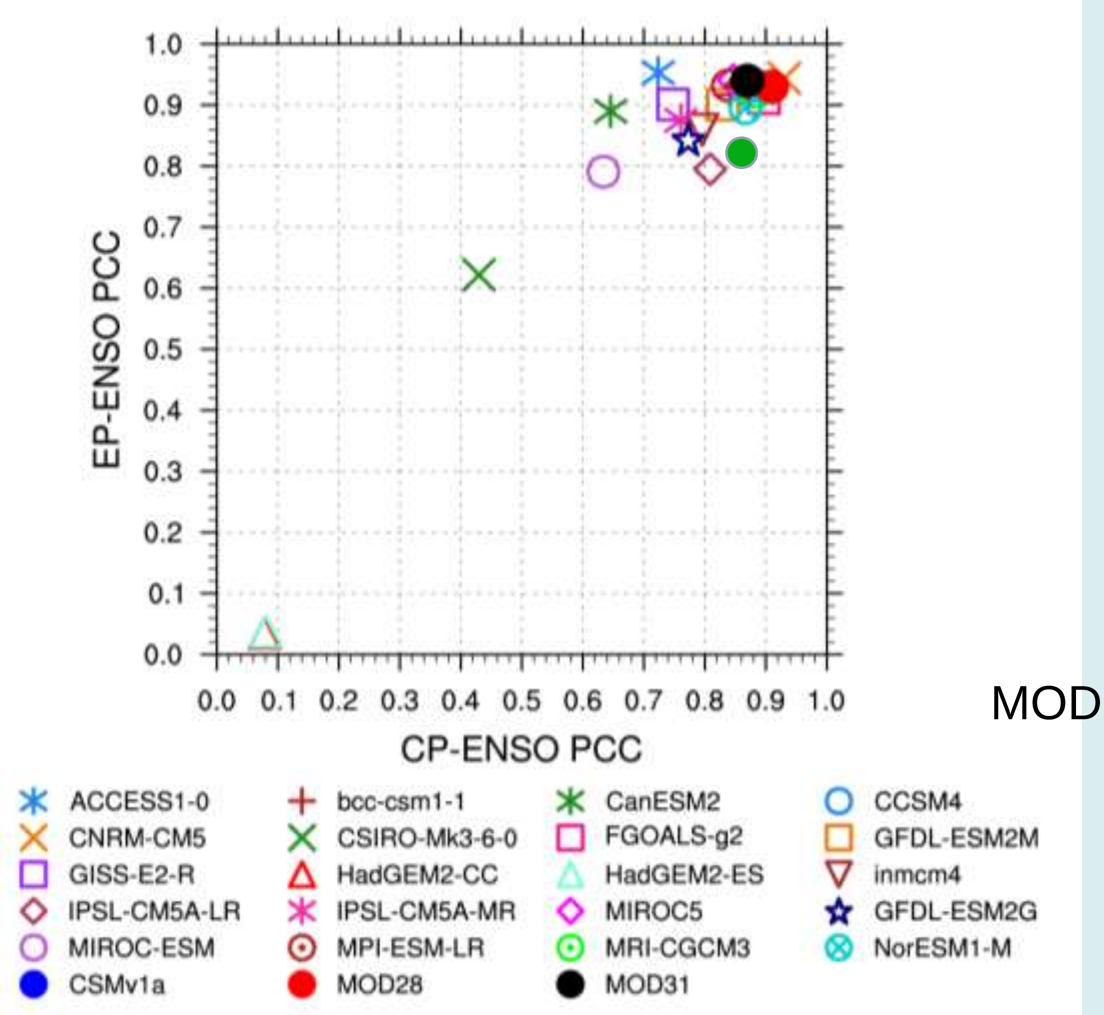
EOF applied to Residual SSTA = (SSTA)-(Regressed SSTA with Nino1+2/Nino4)

STD = loading coefficient * sqrt (eigen value)

Kim and Yu (2012)

Part 3: ENSO

Comparison with CMIP5 Coupled models in terms of the PCC skill for *the* CP-ENSO and that for EP-ENSO
***over the entire Pacific* (120ºE-80ºW, 20ºS-20ºN)**

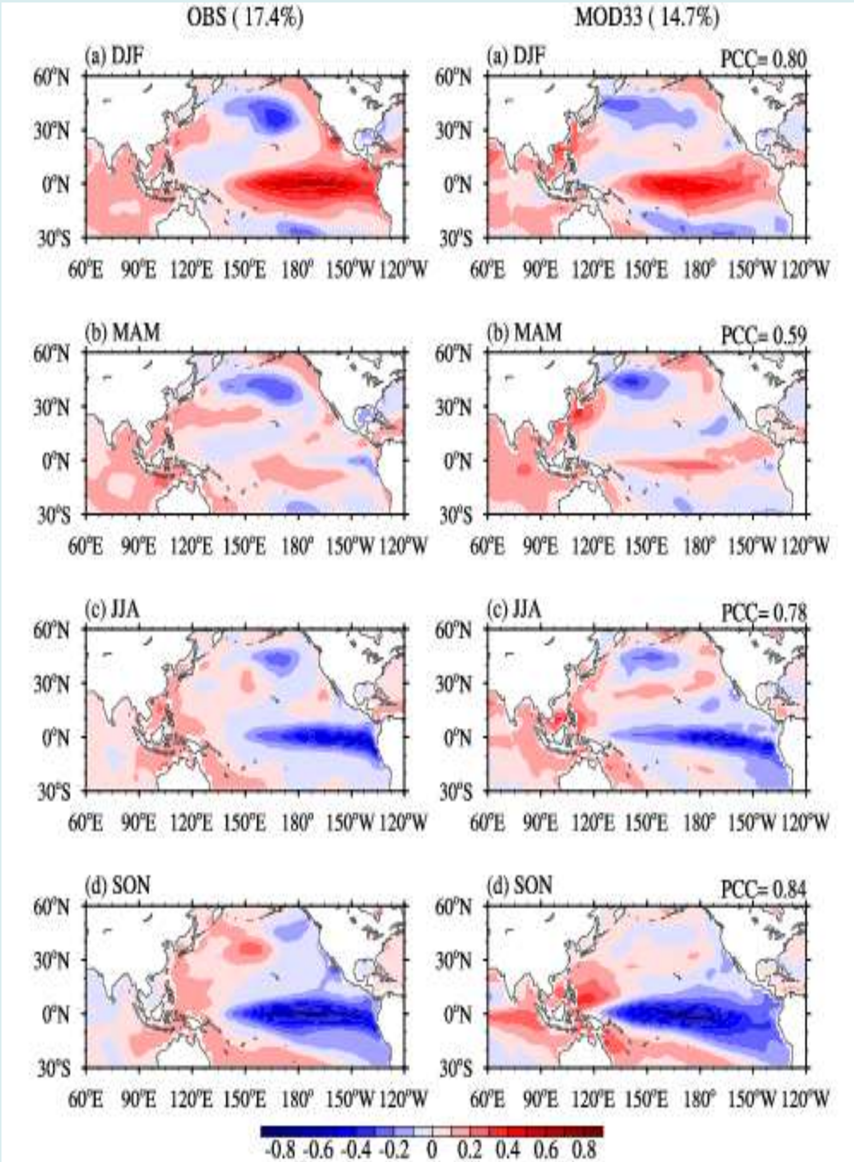


MOD33

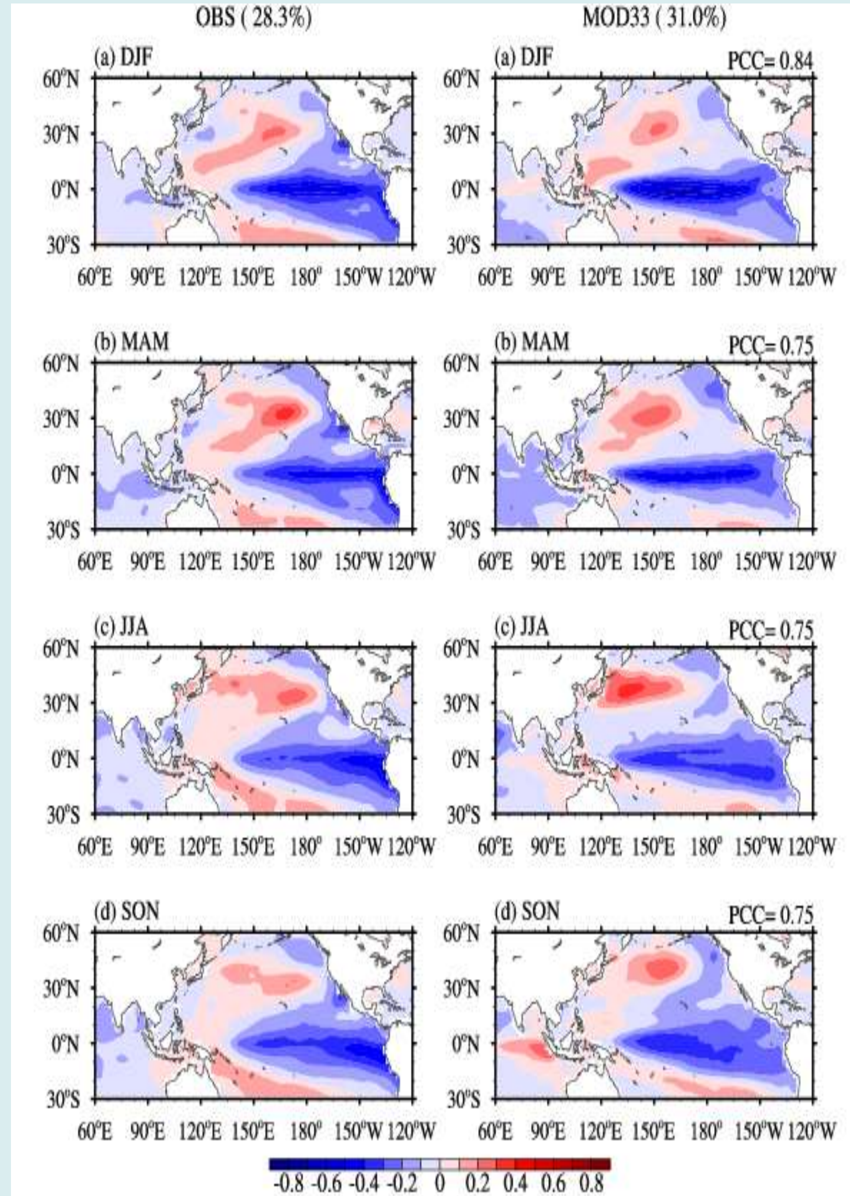
Part 3: ENSO

QB &LF ENSO

QB-ENSO

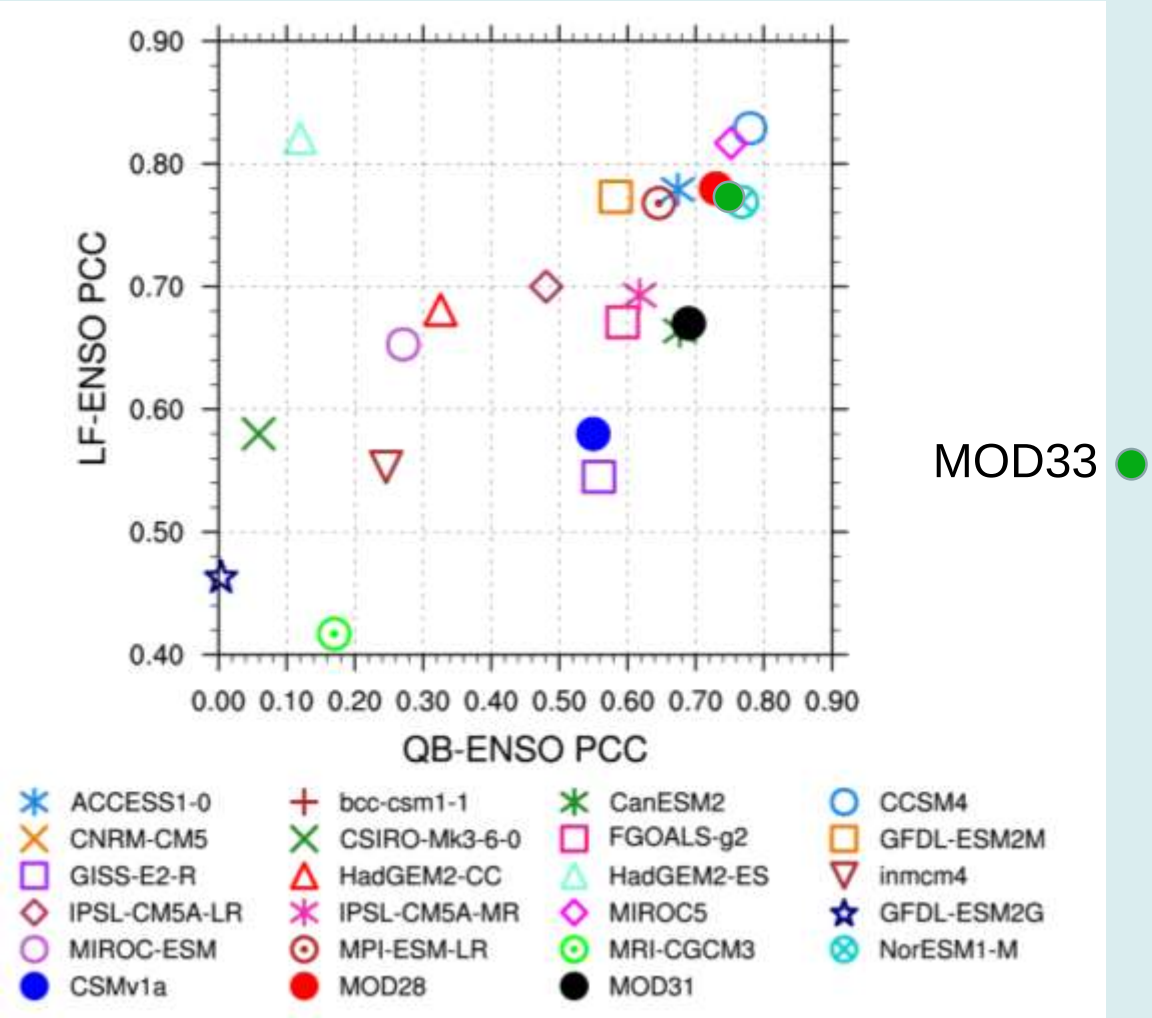


LF-ENSO



Part 3: ENSO

Comparison with CMIP5 Coupled models in terms of the PCC skill (four seasons mean) for *the* QB-ENSO and that for LF-ENSO (60^oE-120^oE, 30^oS-60^oN)



Summary of performance on ENSO in terms of NRMSE and PCC skill (or correlation skill) (in parentheses).

		Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD28	MOD31	MOD33
ENSO	**SSTV**	0.71 (0.84)	0.78 (0.82)	1.84 (0.82)	0.77 (0.80)	1.05 (0.80)	0.65 (0.84)	0.75 (0.79)
	EOF1	(0.93)	(0.92)	(0.90)	(0.89)	(0.86)	(0.88)	(0.87)
	EOF2	(0.59)	(0.47)	(0.79)	(0.47)	(0.61)	(0.83)	(0.31)
	CP-ENSO	(0.84)	(0.81)	(0.91)	(0.91)	(0.91)	(0.87)	(0.87)
	EP-ENSO	(0.92)	(0.90)	(0.93)	(0.91)	(0.93)	(0.94)	(0.82)
	Spectrum	(0.65)	(0.50)	(0.36)	(0.87)	(0.89)	(0.80)	(0.78)
	Phase-locking	(0.82)	(0.64)	(0.41)	(0.54)	(0.03)	(-0.04)	(0.69)
	LF-ENSO**	(0.77)	(0.68)	(0.58)	(0.73)	(0.78)	(0.67)	(0.77)
	QB-ENSO**	(0.61)	(0.56)	(0.55)	(0.79)	(0.73)	(0.69)	(0.75)

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

**Average of four seasons

4. Monsoon

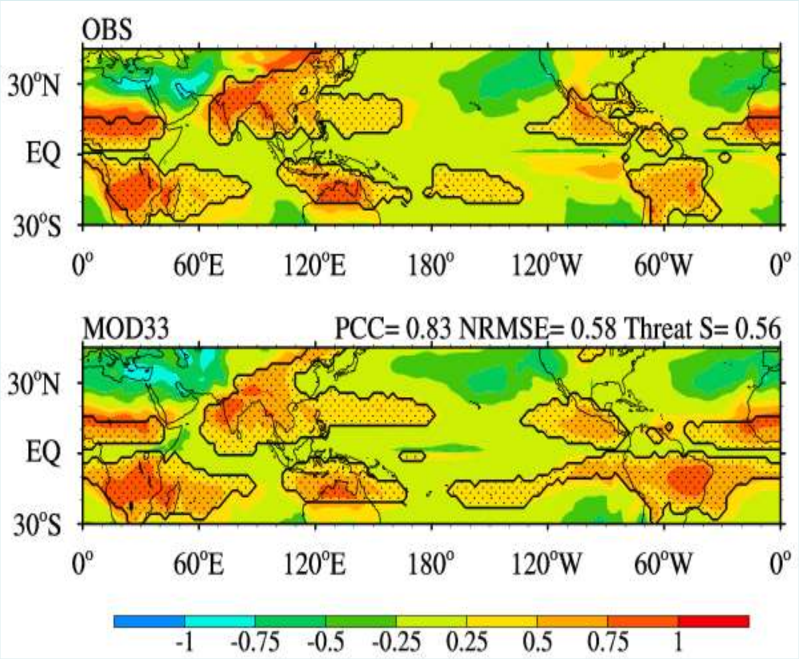
- Global monsoon Domain and precipitation intensity
- Evolution: Solstice seasonal mean precipitation
- Amplitude: Solstice seasonal variance of precipitation
- Leading mode of interannual variability :Season-reliant EOF 1 of precipitation
- Second mode of interannual variability: S-EOF 2 of precipitation
- Seasonal March of precipitation along 110-120E (East Asian Monsoon)

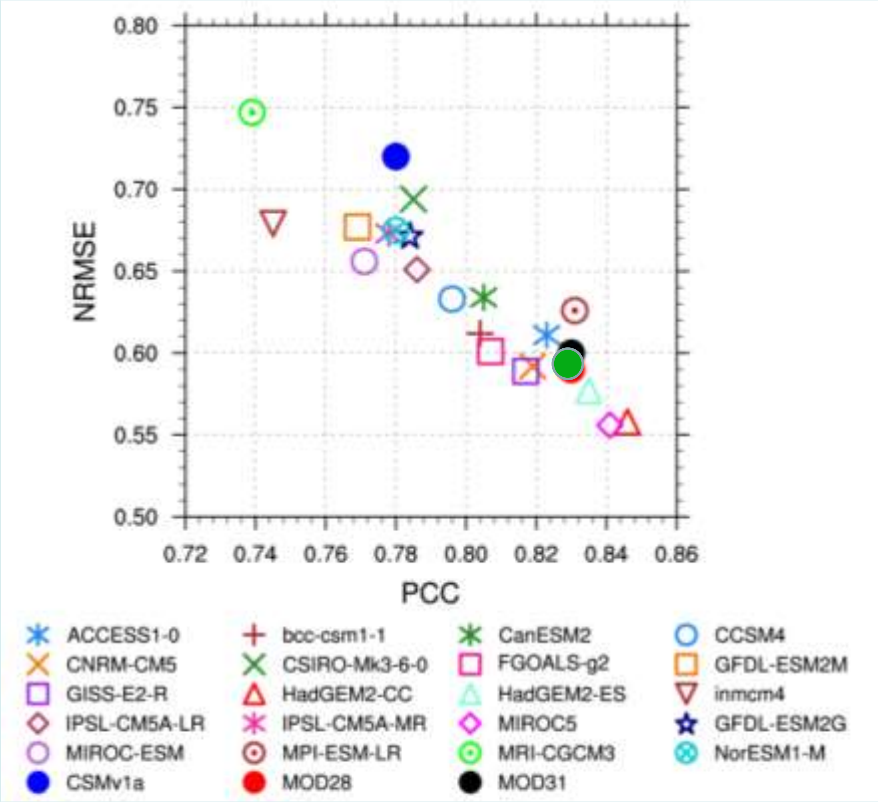
Global Monsoon Intensity and Domain

Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE of global monsoon intensity (30S-40N,0-360)

OBS

MOD33





MOD33

Part 4: Global Monsoon

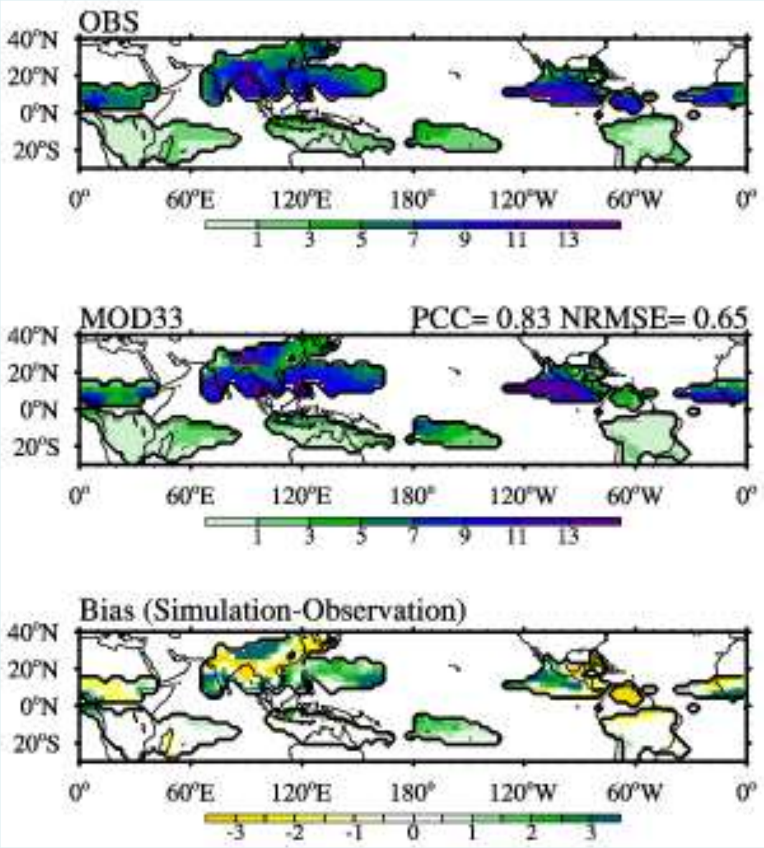
Seasonal Mean Precipitation over global monsoon domain

JJA Mean

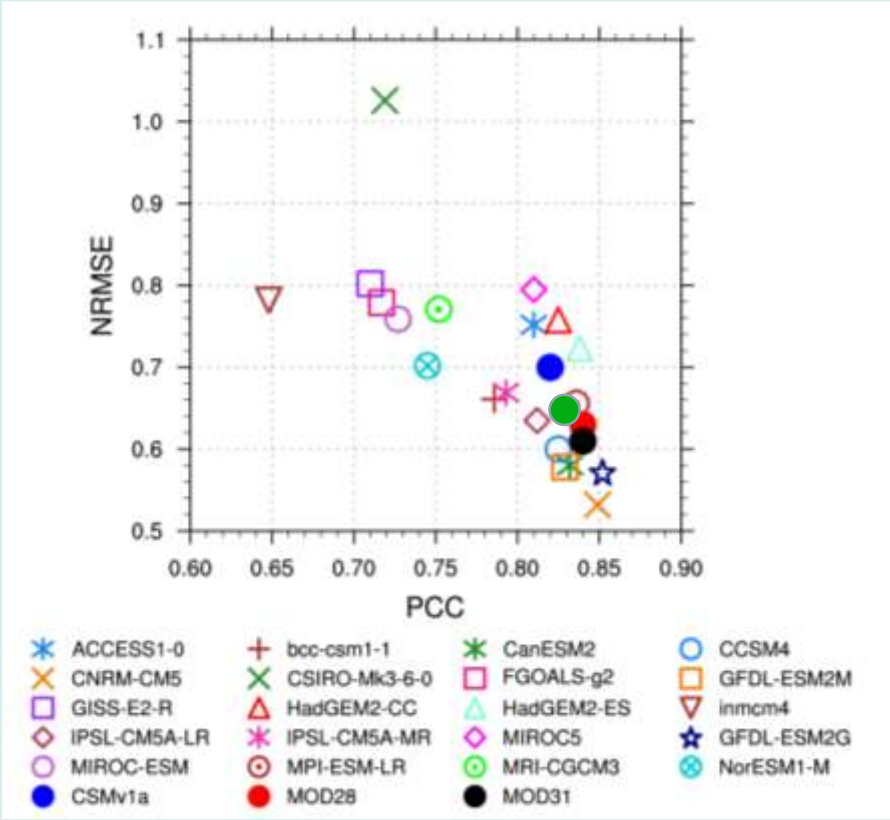
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (30S-40N,0-360)



MOD33 ●

Part 4: Global Monsoon

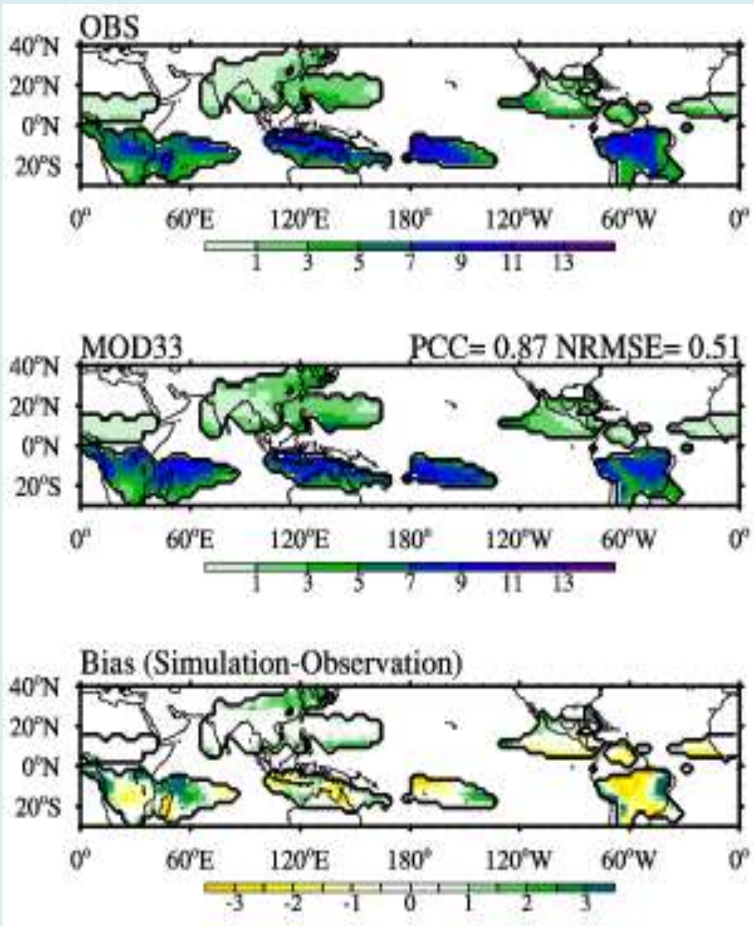
Seasonal Mean Precipitation over global monsoon domain

DJF Mean

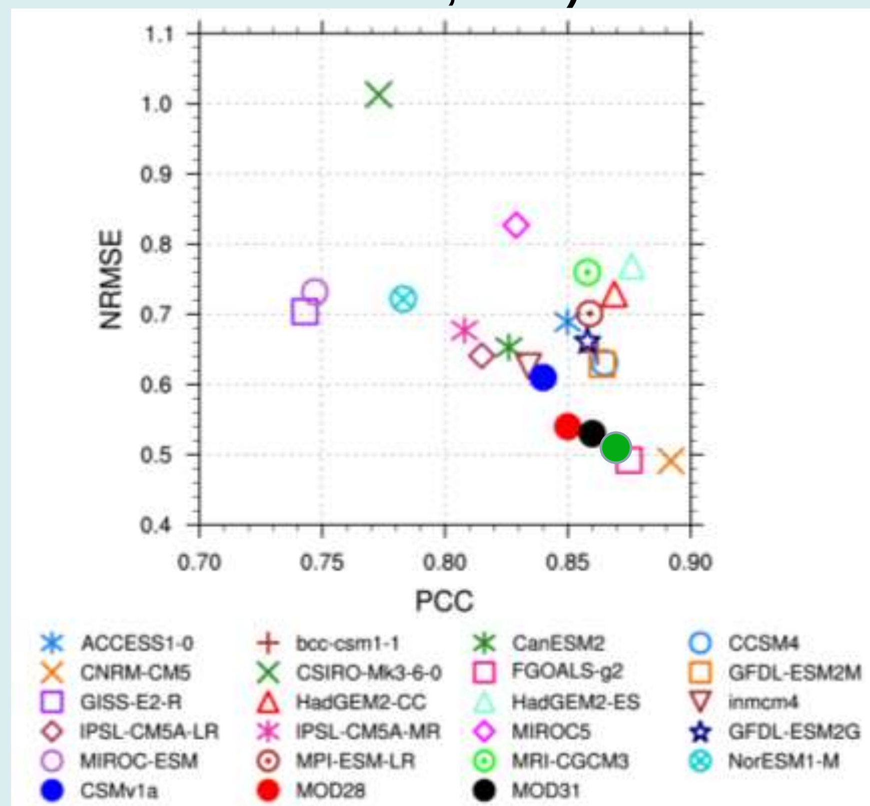
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (30S-40N,0-360)



MOD33

Part 4: Global Monsoon

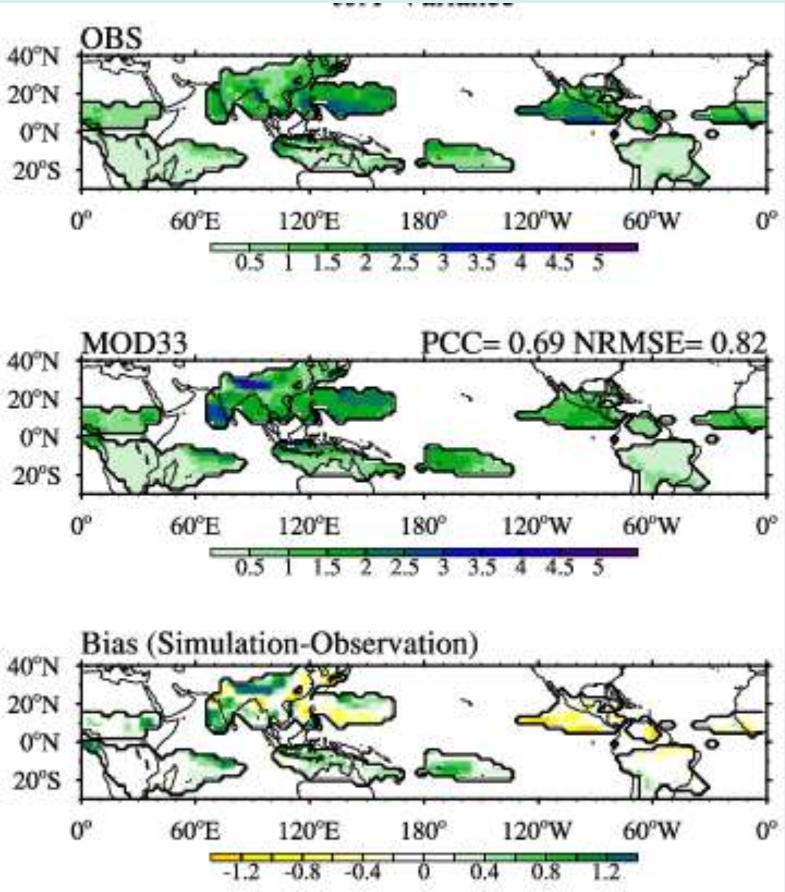
Seasonal Variance of Precipitation over global monsoon domain

JJA Variance

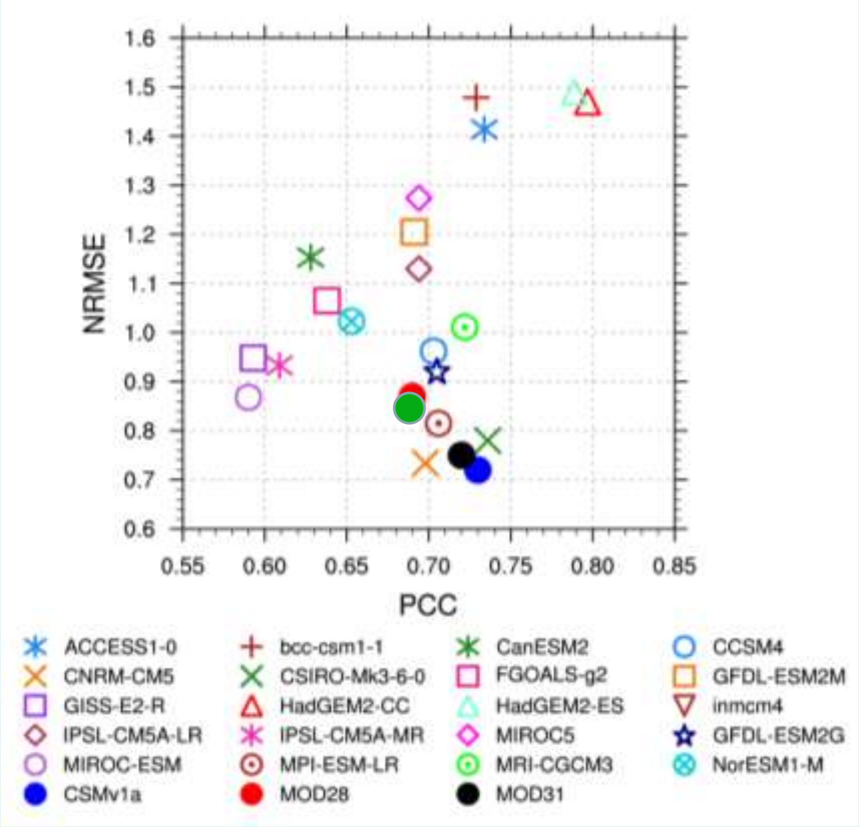
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (30S-40N,0-360)



MOD33

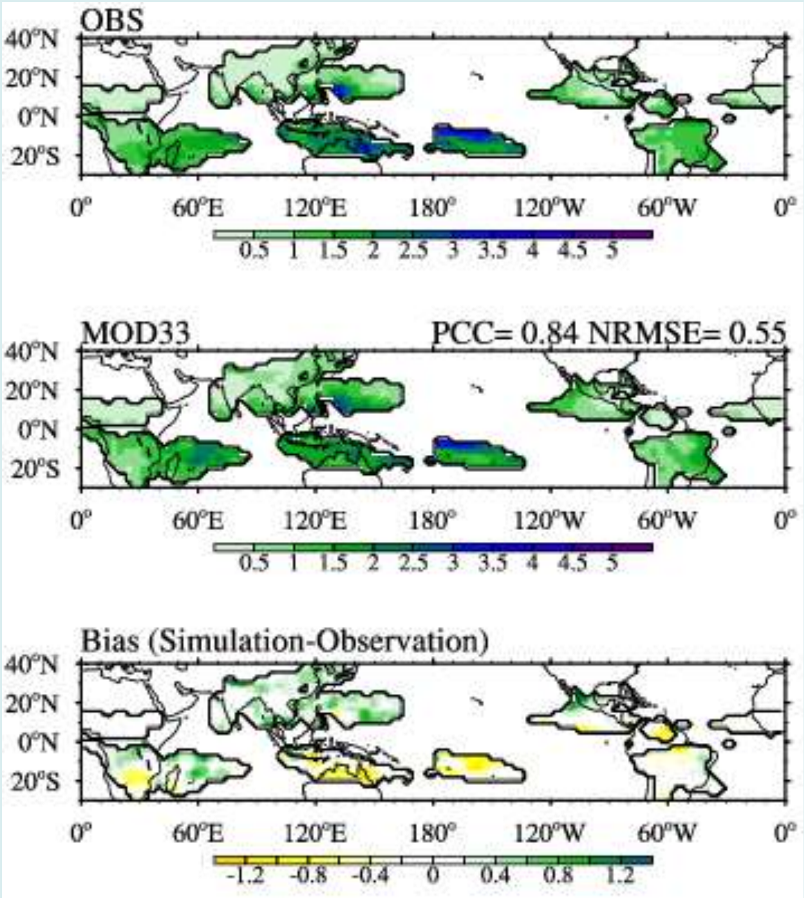
Seasonal Variance of Precipitation over global monsoon domain

DJF Variance

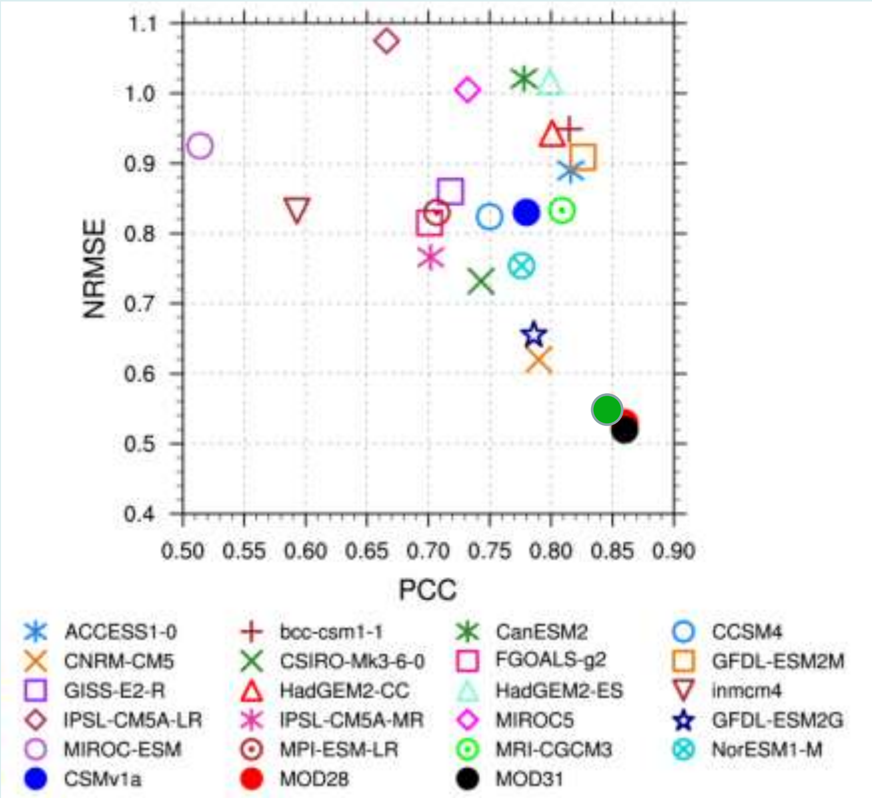
OBS

MOD33

BIAS



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE (30S-40N,0-360)

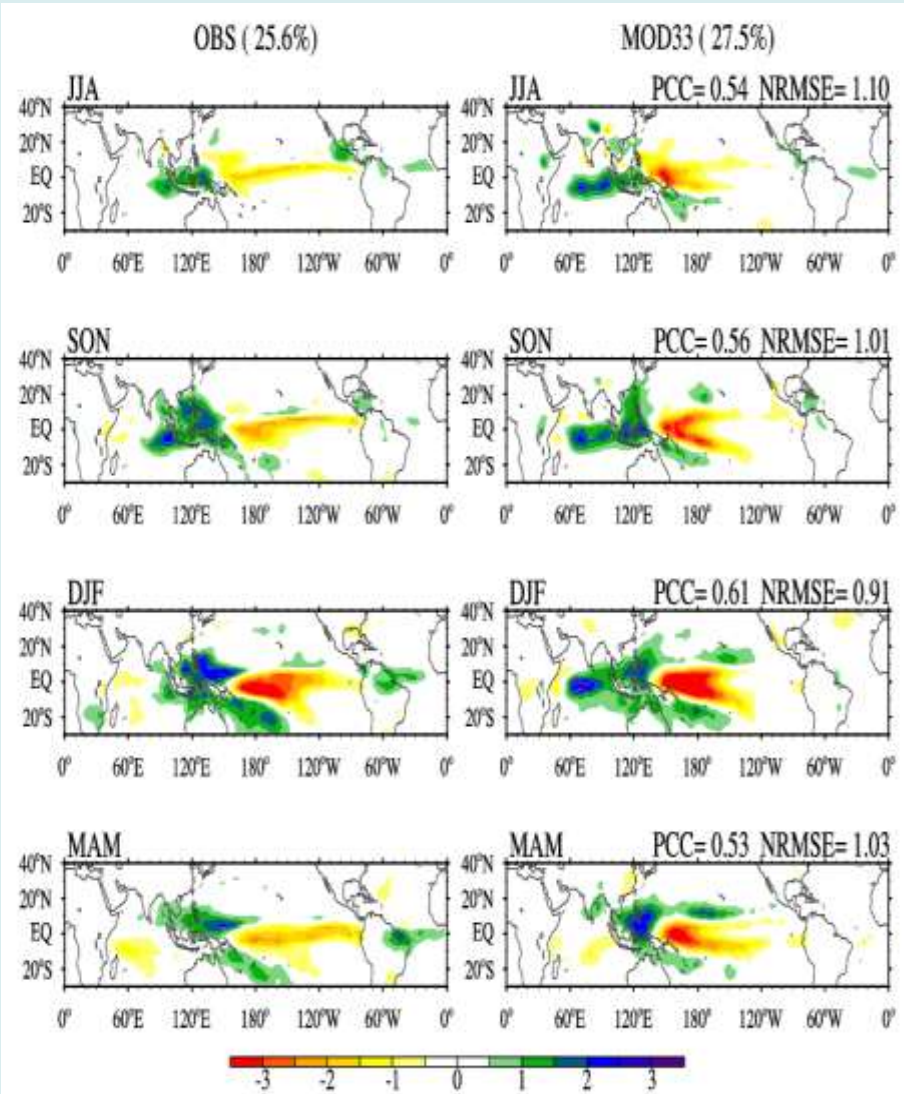


MOD33

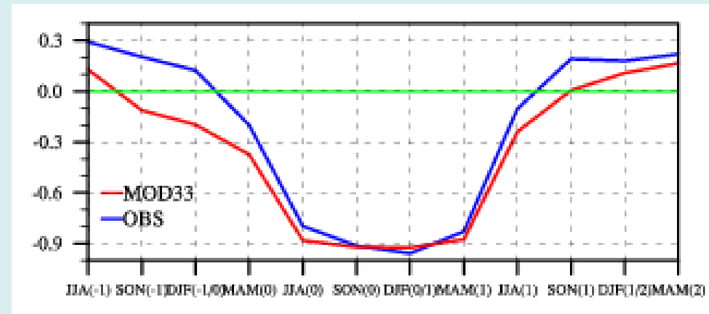
Part 4: Global Monsoon

Season-reliant EOF1 modes of precipitation

SEOF1

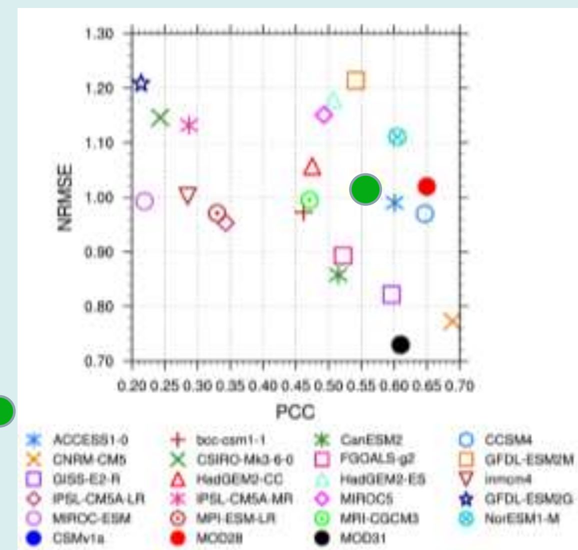


Lead-lag correlation coefficients of NINO3.4 SST index with reference to the SEOF1 principle component



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE(four seasons mean) for *SEOF1 Mode* *(30S-40N,0-360)*

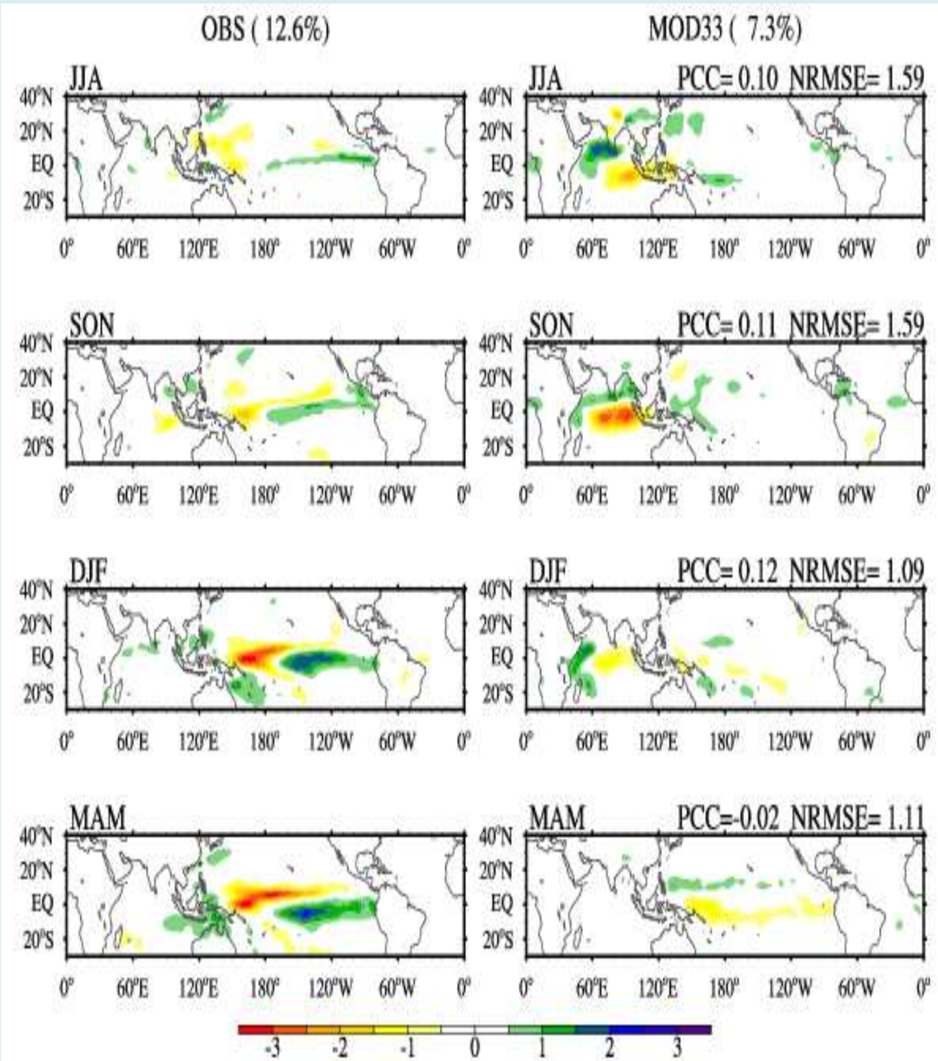
MOD33



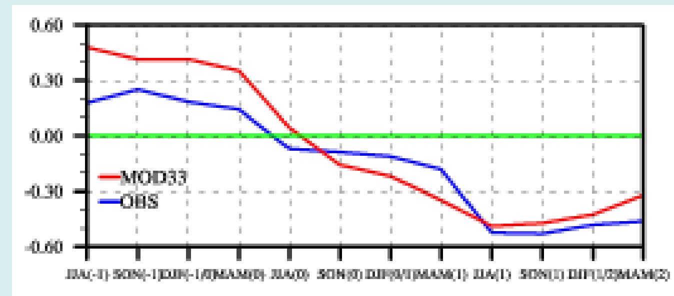
Part 4: Global Monsoon

Season-reliant EOF2 modes of precipitation

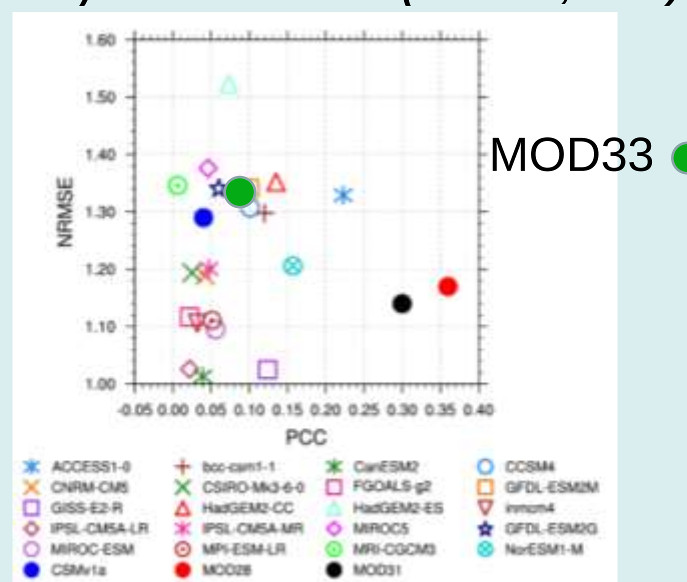
SEOF2



Lead-lag correlation coefficients of NINO3.4 SST index with reference to the SEOF2 principle component



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE(four seasons mean) for *SEOF2 Mode* *(30S-40N,0-360)*

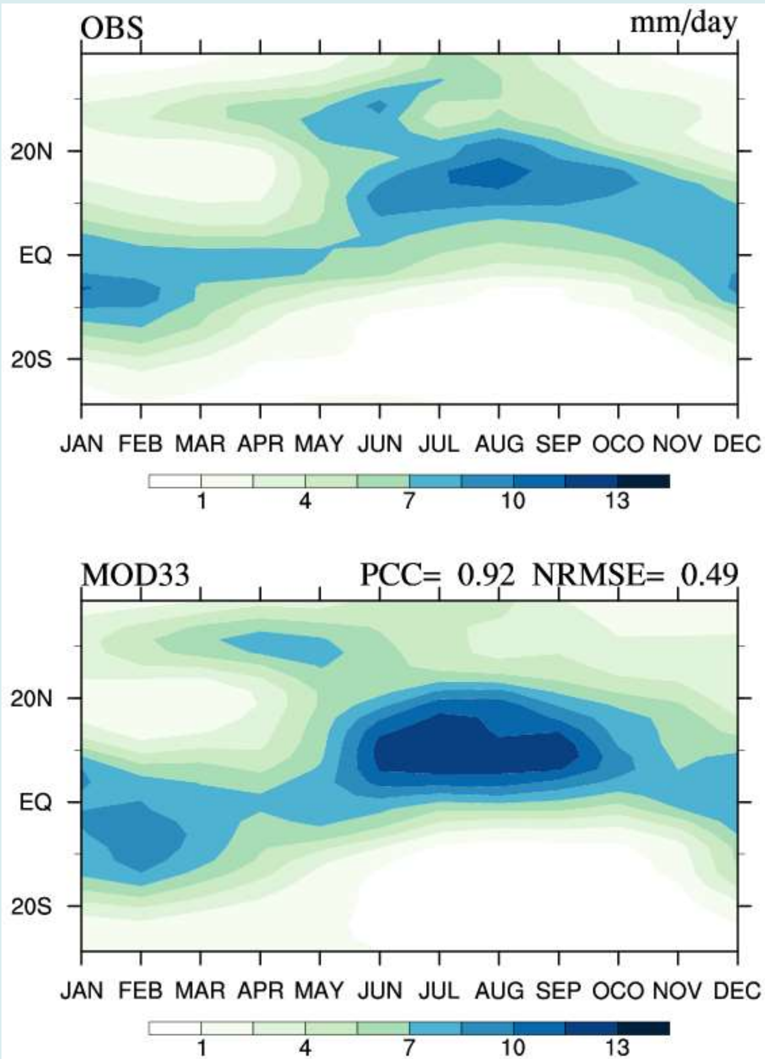


Part 6: East Asian monsoon

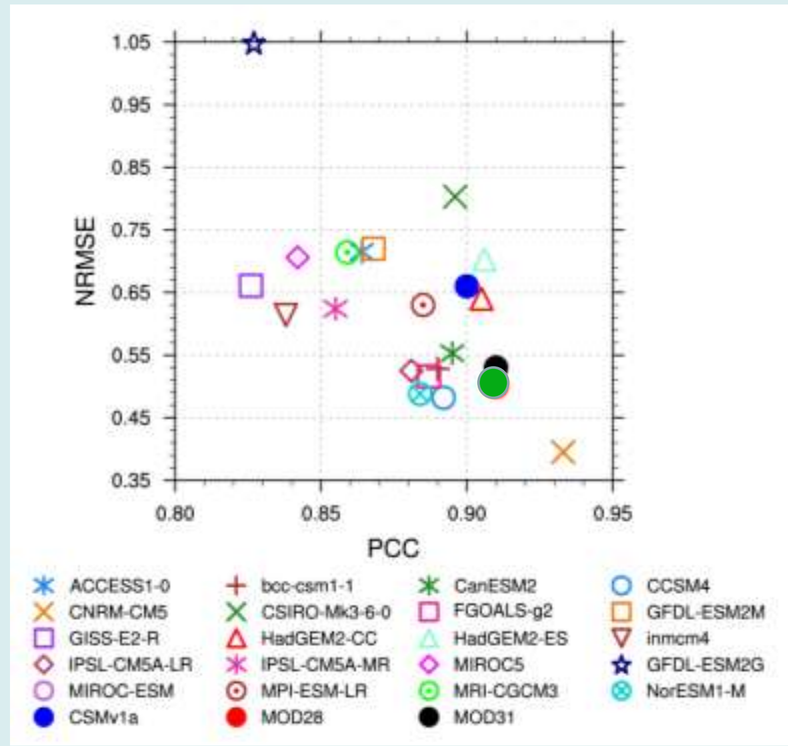
Seasonal March of precipitation along 110-130E

OBS

MOD31



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE *(30S-40N)*



MOD33

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

		Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD28	MOD31	MOD33
GM	GMPI	0.61 (0.82)	0.63 (0.80)	0.72 (0.78)	0.60 (0.83)	0.59 (0.83)	0.60 (0.83)	0.58 (0.83)
	PRCP Mean in JJA	0.66 (0.83)	0.70 (0.81)	0.70 (0.82)	0.68 (0.83)	0.63 (0.84)	0.61 (0.84)	0.65 (0.83)
	PRCP Mean in DJF	0.65 (0.86)	0.68 (0.85)	0.61 (0.84)	0.52 (0.87)	0.54 (0.85)	0.53 (0.86)	0.51 (0.87)
	PRCP VAR in JJA	0.95 (0.71)	1.01 (0.70)	0.72 (0.73)	0.81 (0.71)	0.87 (0.69)	0.75 (0.72)	0.82 (0.69)
	PRCP VAR in DJF	0.79 (0.82)	0.85 (0.80)	0.83 (0.78)	0.50 (0.88)	0.53 (0.86)	0.52 (0.86)	0.55 (0.84)
	SEOF1**	0.97 (0.52)	0.99 (0.49)	1.02 (0.56)	0.98 (0.59)	1.02 (0.65)	0.73 (0.61)	1.01 (0.56)
	SEOF2**	1.11 (0.10)	1.2 (0.06)	1.29 (0.04)	1.26 (0.13)	1.17 (0.36)	1.14 (0.30)	1.35 (0.08)
EAM	Seasonal evolution	0.55 (0.89)	0.63 (0.88)	0.66 (0.90)	0.55 (0.91)	0.50 (0.91)	0.53 (0.91)	0.49 (0.92)

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

**Average of four seasons

5. MJO

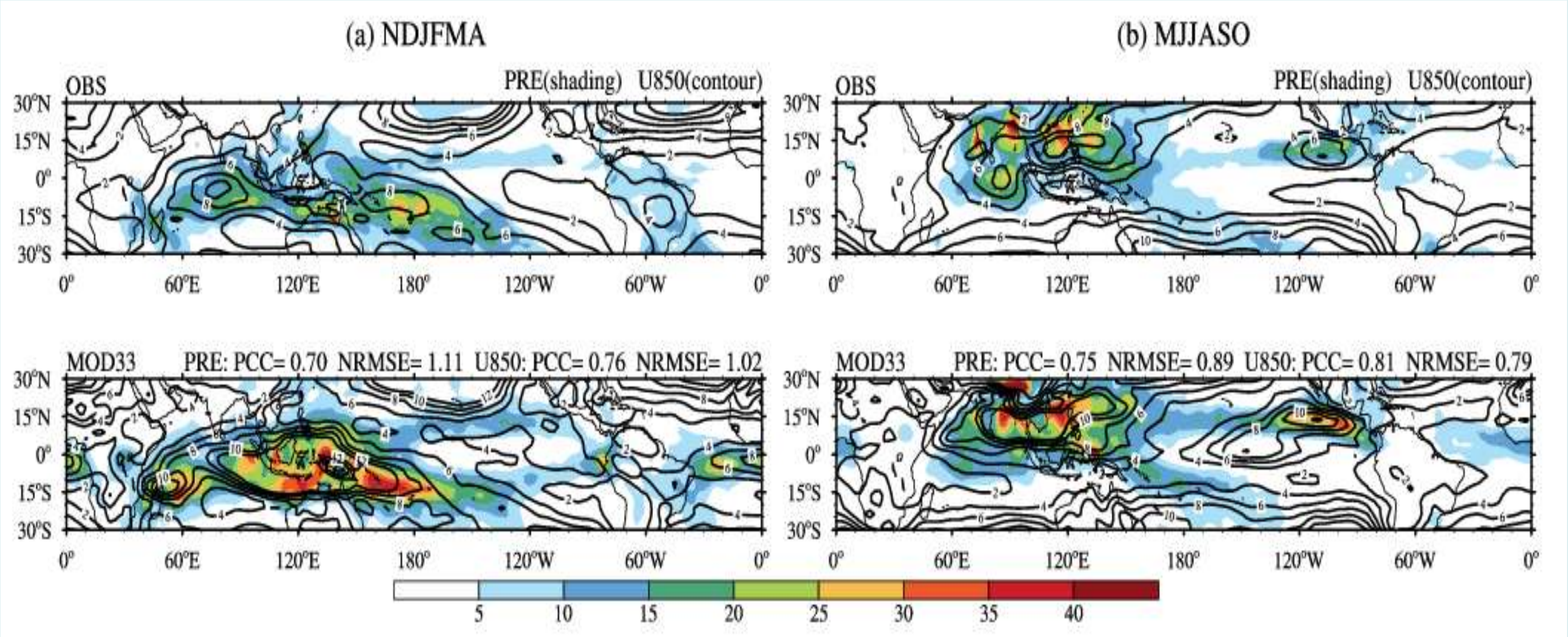
- Seasonality of variability: Variance of 20-100-day filtered precipitation NDJFMA and MJJASO
- Propagation: Lag-longitude correlation
- Wavenumber-Frequency Spectra
- Major modes of variability: All-season Real-time Multivariate MJO modes

Part 5: MJO

Variance of 20-100-day filtered Precipitation and U850

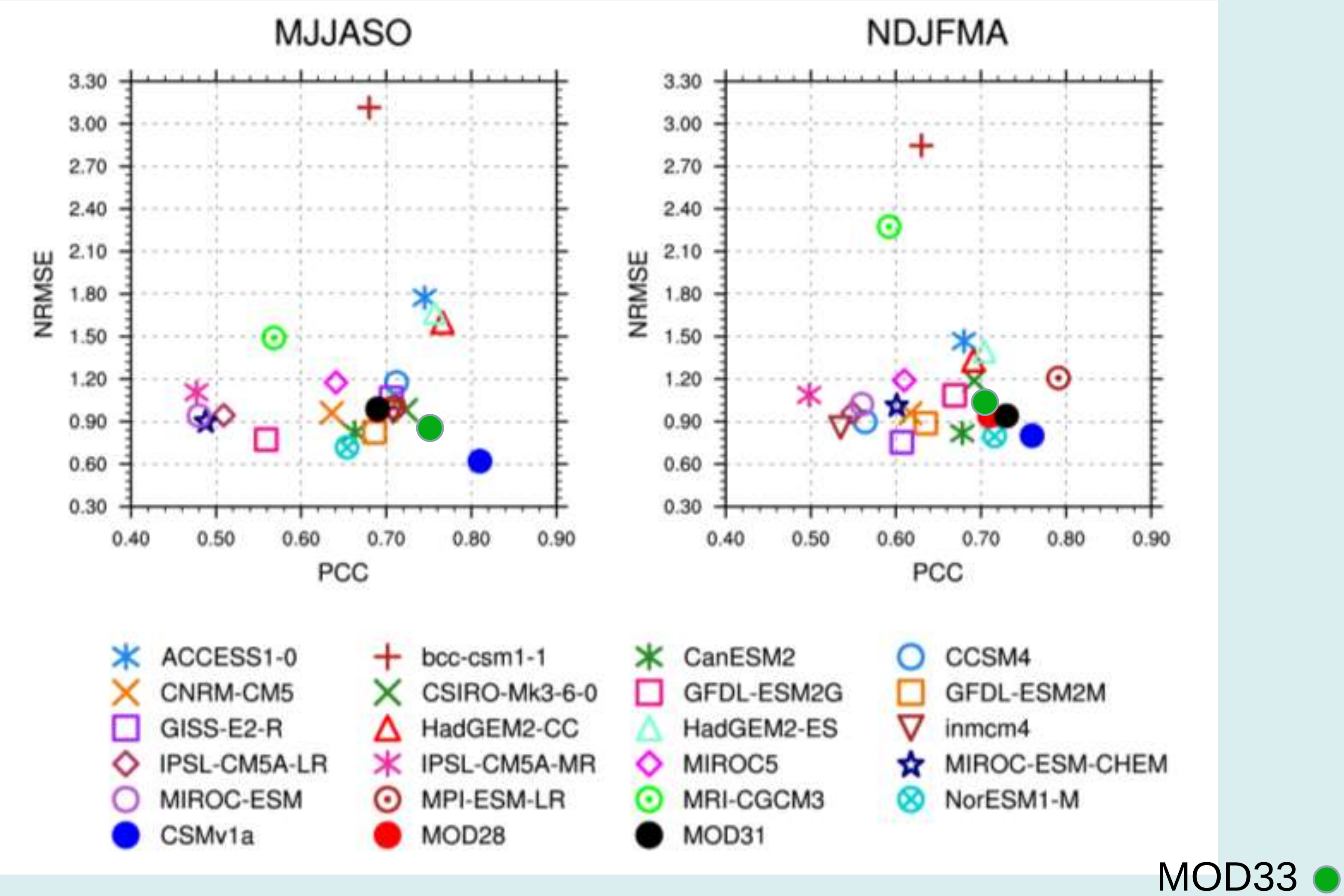
OBS

MOD33



Part 5: MJO

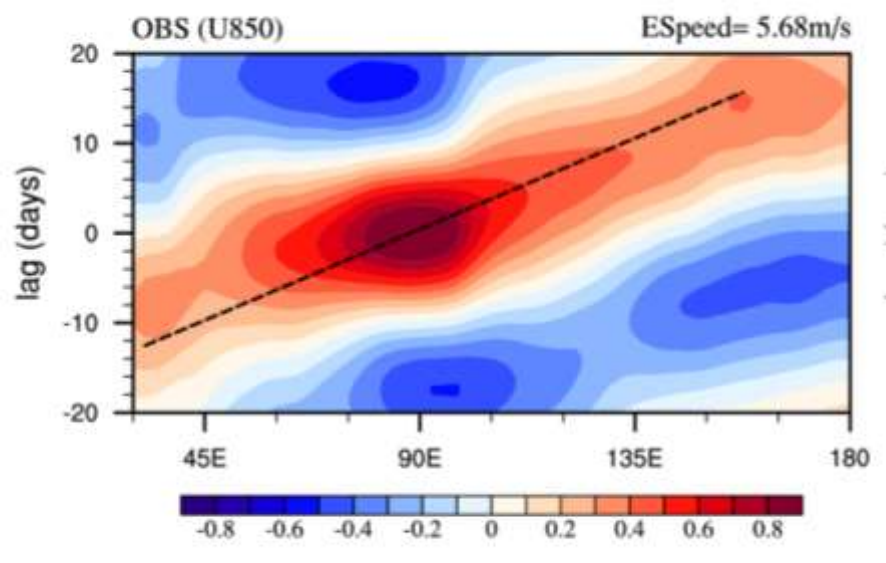
Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE for *the* Variance of 20-100-day filtered Precipitation in NDJFMA and MJJASO (30ºS-30ºN,0º-360º)



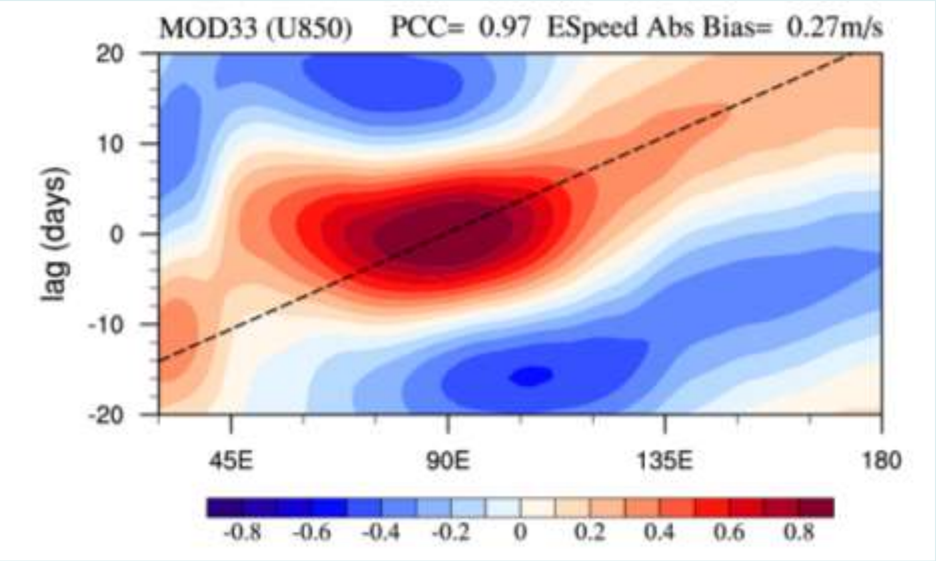
Part 5: MJO

Lag–longitude diagram of 10N–10S-averaged intraseasonal U850 anomalies correlated against U850 anomalies averaged over the Equatorial Indian Ocean (10^{o}S-10^{o}N, 80^o-100^{o}E) across all year

OBS



MOD33

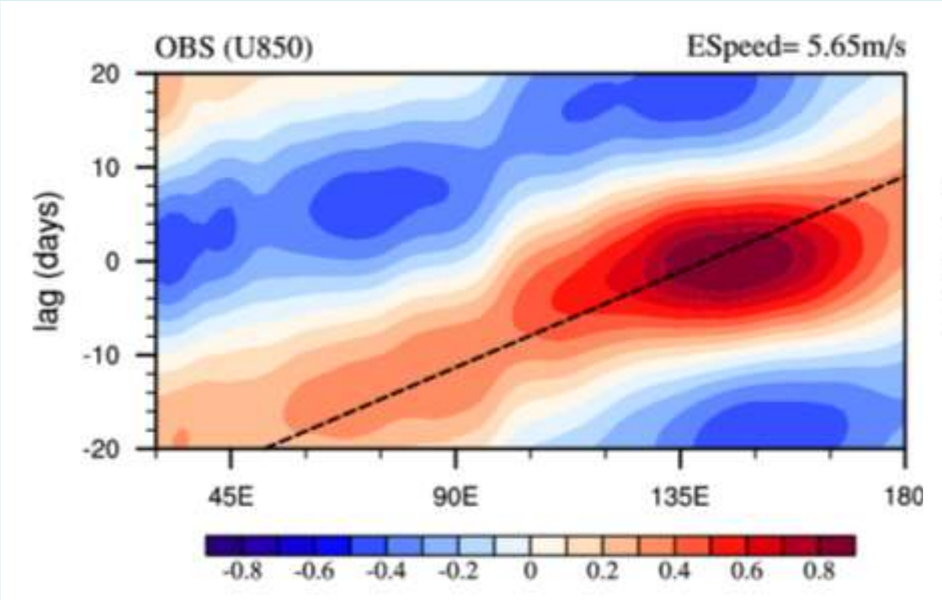


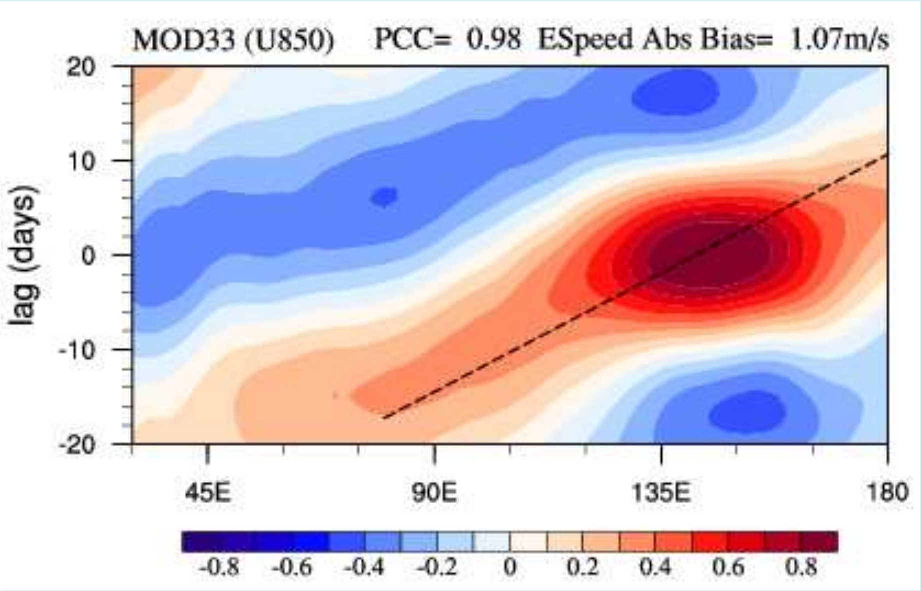
Part 5: MJO

Lag–longitude diagram of 10N–10S-averaged intraseasonal U850 anomalies correlated against U850 anomalies averaged over the Equatorial West Pacific (10^oS-10^oN, 130^oE-160^oE) across all year

OBS

MOD33



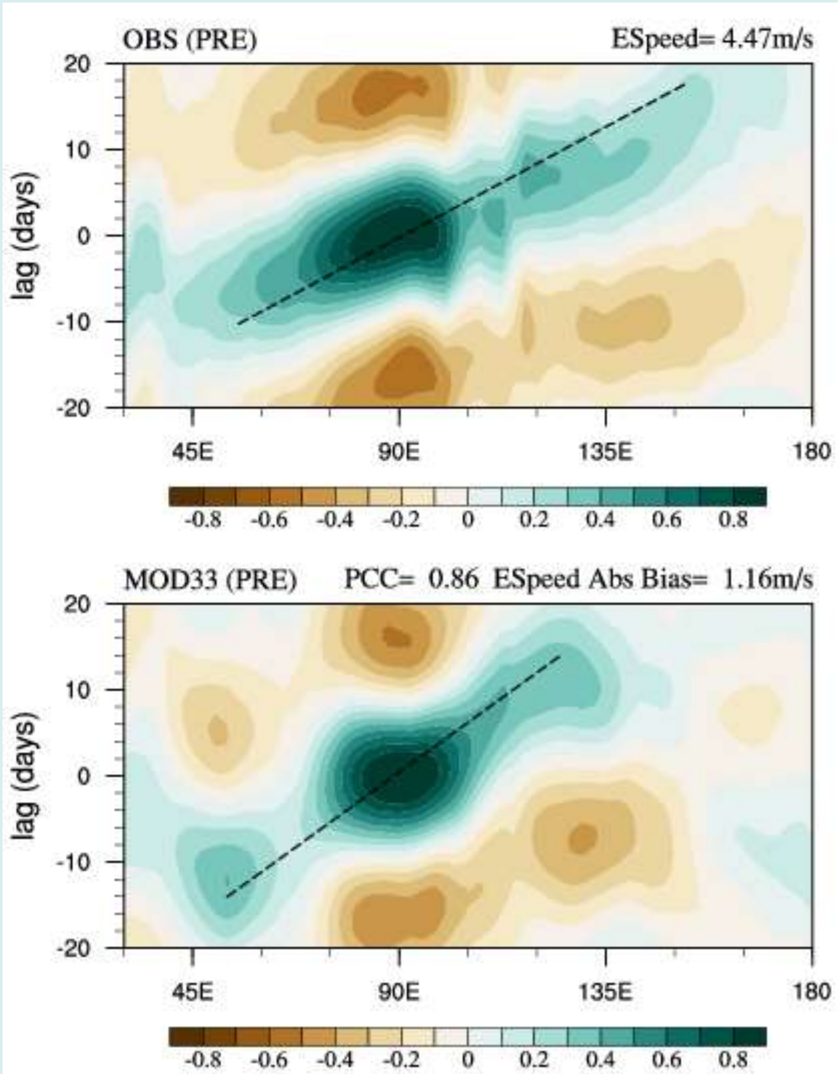


Part 5: MJO

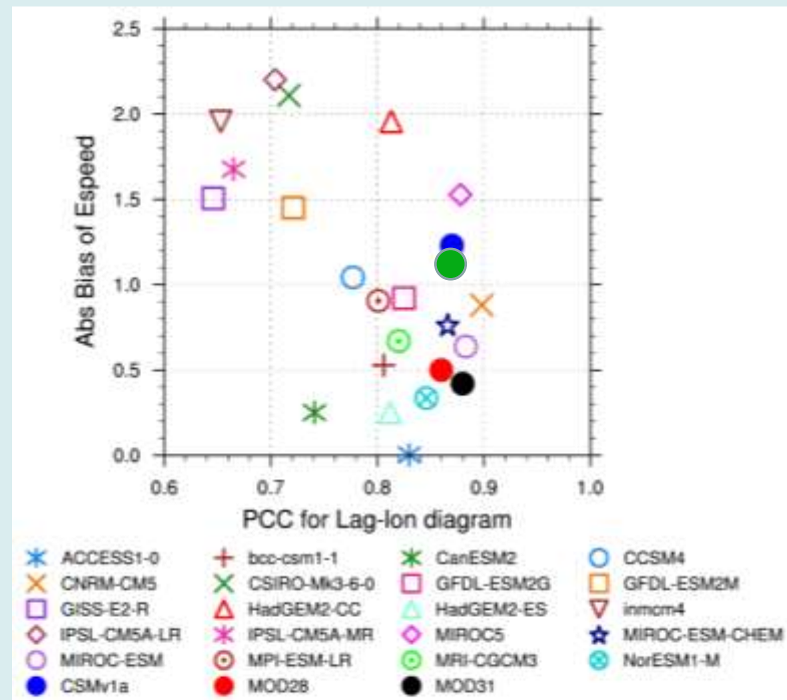
Lag–longitude diagram of 10N–10S-averaged intraseasonal precipitation anomalies correlated against precipitation anomalies averaged over the Equatorial Indian Ocean (10ºS-10ºN, 80º-100ºE) across all year

OBS

MOD33



Comparison with CMIP5 Coupled models in terms of the PCC skill for *the* Lag–longitude diagram and Abs bias for eastward propagation speed



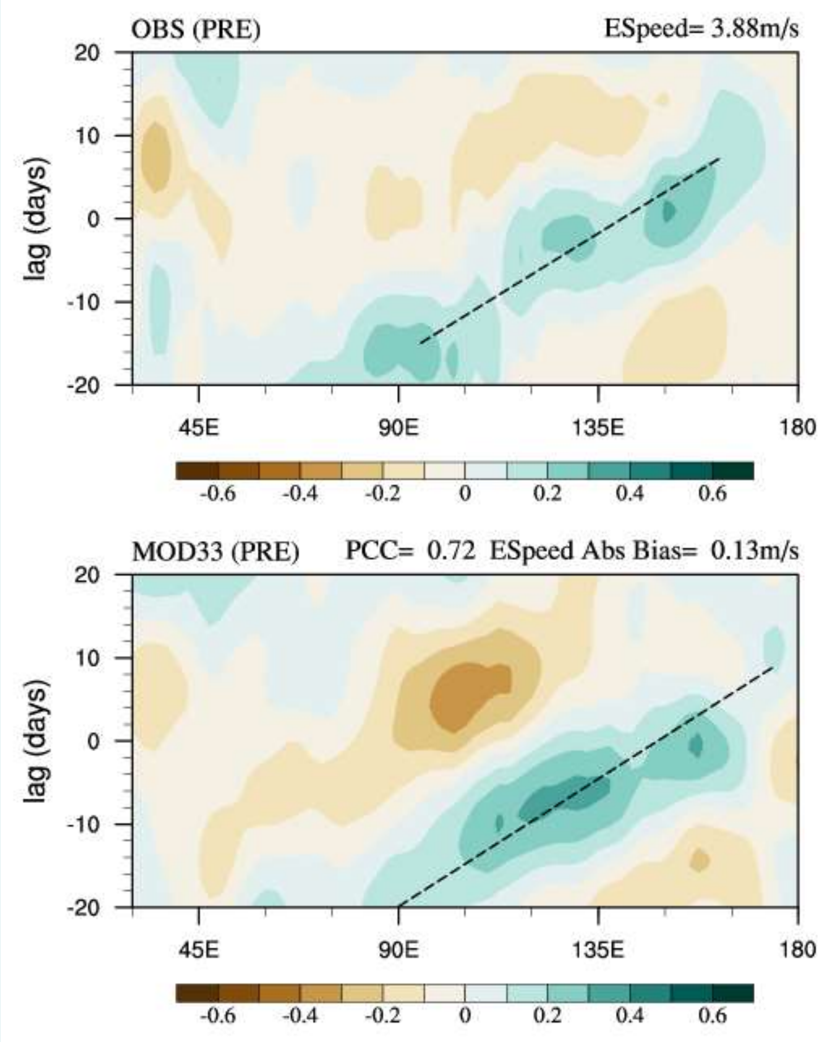
MOD33 ●

Part 5: MJO

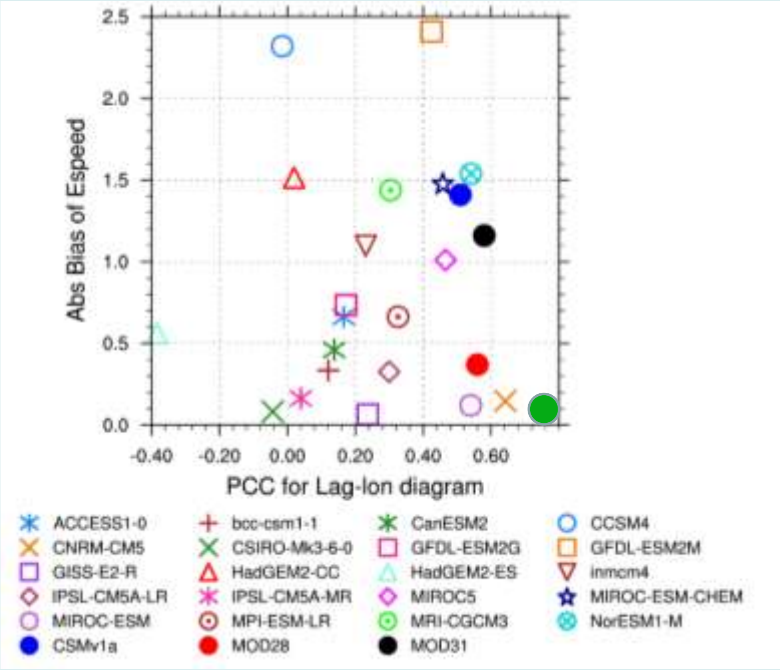
Lag–longitude diagram of 10N–10S-averaged intraseasonal precipitation anomalies correlated against precipitation anomalies averaged over the Equatorial West Pacific (10°S-10°S, 130°E-160°E) across all year

OBS

MOD33



Comparison with CMIP5 Coupled models in terms of the PCC skill for *the* Lag–longitude diagram and Abs bias for eastward propagation speed



MOD33 ●

Summary of performance on MJO in terms of NRMSE (or Abs Bias) and PCC skill (or correlation skill) (in parentheses)

		Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD28	MOD31	MOD33
MJO	**PRCP VAR in MJJASO**	0.94 (0.71)	0.98 (0.68)	0.62 (0.81)	0.58 (0.83)	0.98 (0.69)	0.99 (0.69)	0.89 (0.75)
	PRCP VAR in NDJFMA	0.96 (0.68)	1.02 (0.63)	0.80 (0.76)	0.80 (0.72)	0.94 (0.71)	0.94 (0.73)	1.11 (0.70)
	Lag–longitude correlation (EIO)	(0.83)	(0.80)	(0.87)	(0.80)	(0.86)	(0.88)	(0.86)
	Lag–longitude correlation (EWP)	(0.33)	(0.24)	(0.51)	(0.59)	(0.56)	(0.58)	(0.72)
	Eastward Propagation Speed(EIO)*	0.67	0.91	1.23	0.66	0.50	0.42	1.16
	Eastward Propagation Speed(EWP)*	0.34	0.66	1.41	1.34	0.37	1.16	0.13

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

*Eastward Propagation Speed :Abs Bias

6. Teleconnection

- Arctic Oscillation (AO)
- Antarctic Oscillation (AAO)
- Pacific-North America (PNA) teleconnection pattern

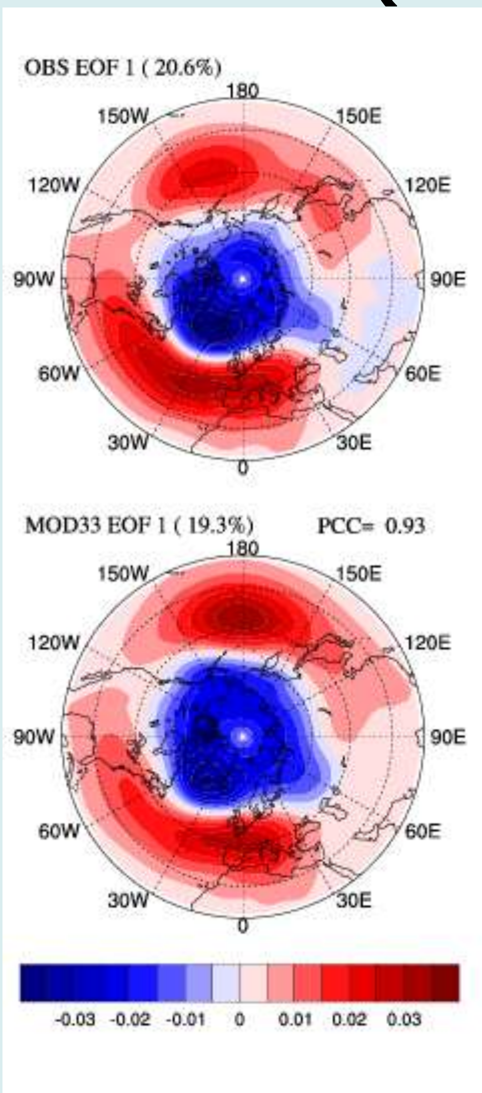
Part 6: Teleconnection

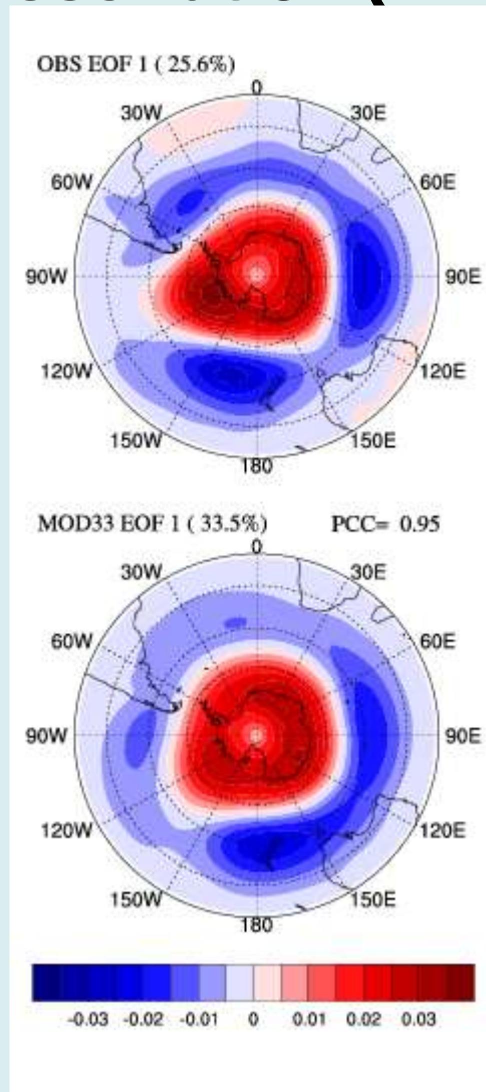
Arctic Oscillation (AO)

Antarctic Oscillation (AAO)

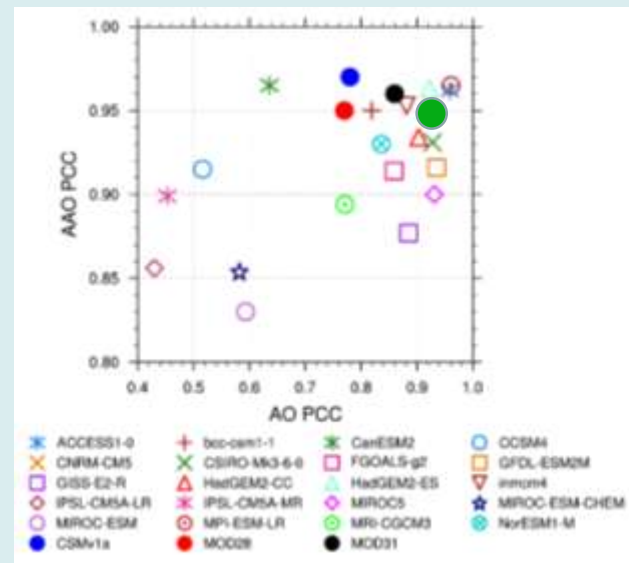
OBS

MOD33





Comparison with CMIP5 Coupled models in terms of the PCC skill for AO and AAO



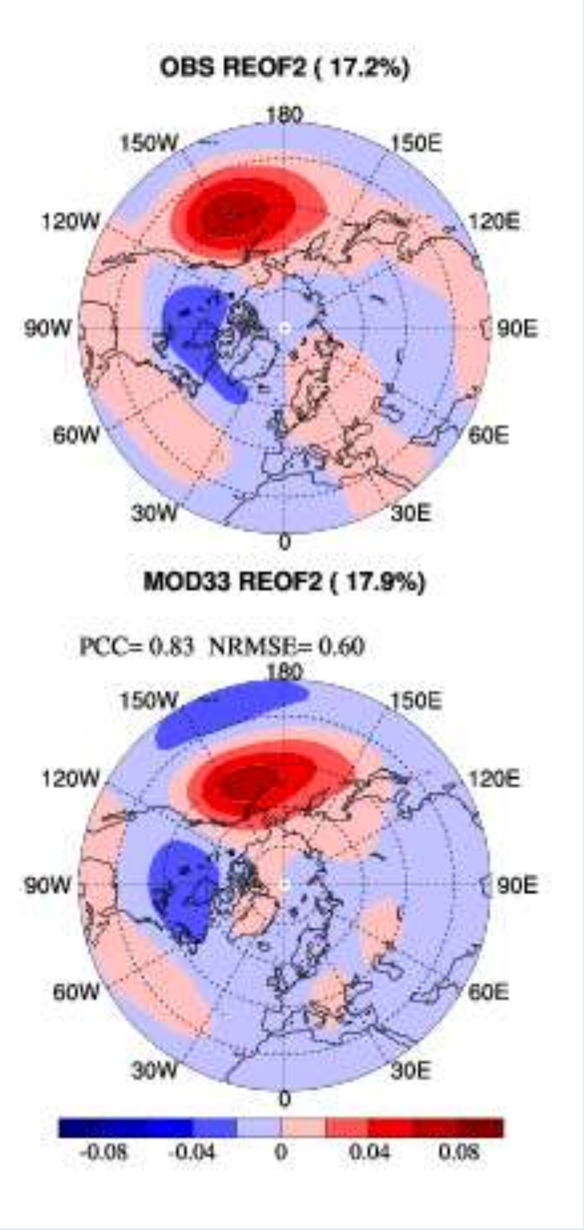
MOD33 ●

Part 6: Teleconnection

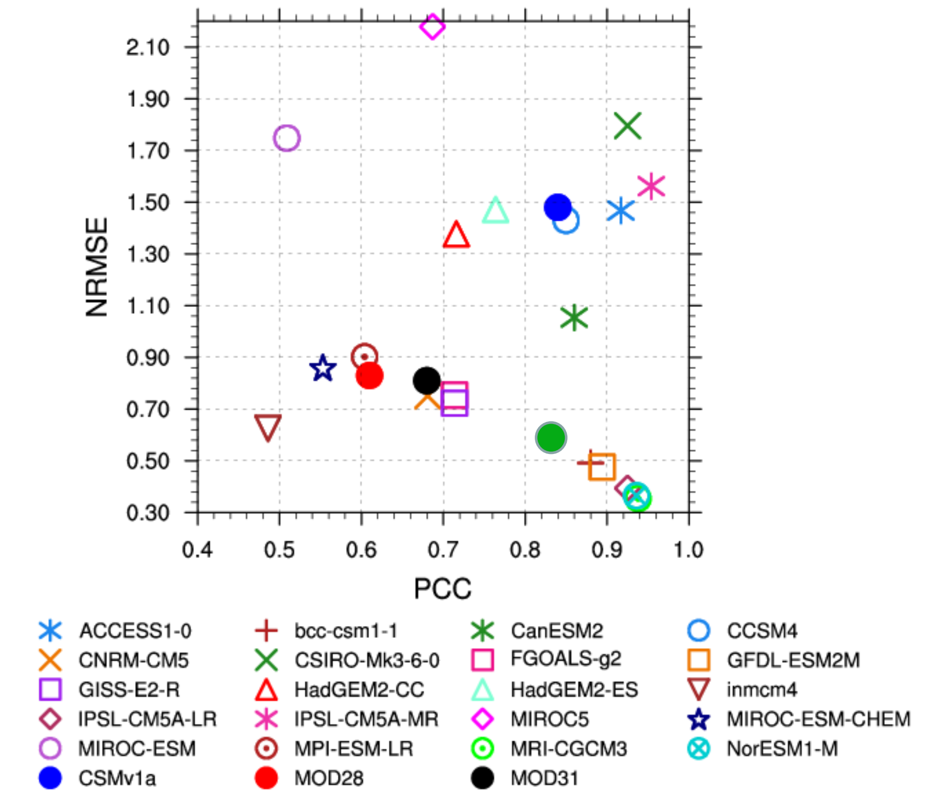
Pacific-North America teleconnection in DJF

OBS

MOD33



Comparison with CMIP5 Coupled models in terms of the PCC skill and NRMSE for *PNA* *(20-90N,150E-30W)*



MOD33

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

		Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD28	MOD31	MOD33
Teleconnection	**AO**	(0.92)	(0.88)	(0.78)	(0.82)	(0.77)	(0.86)	(0.93)
	AAO	(0.95)	(0.93)	(0.97)	(0.97)	(0.95)	(0.96)	(0.95)
	PNA	0.72 (0.89)	0.86 (0.85)	1.48 (0.84)	1.85 (0.73)	0.83 (0.61)	0.81 (0.68)	0.60 (0.83)

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

7. Ocean

7. Ocean

- Annual mean sea surface wind stress.
- Annual mean sea surface wind stress curl.
- Annual mean temperature along equator;
- Global zonal averaged annual mean temperature;
- Global annual mean sea surface salinity;
- Global zonal averaged annual mean salinity;
- Annual mean thermocline depth (using 20°C isotherm);
- Annual maximum mixed layer depth.
- Annual minimum mixed layer depth.
- Global annual mean ocean surface currents;
- Global zonal averaged annual mean zonal current;
- Annual mean zonal current in the equatorial Pacific;
- Atlantic meridional overturning circulation
- Annual mean Antarctic Circumpolar Current.

Summary of performance on climatology in terms of NRMSE

Metrics	Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD31	MOD33
Wind stress	0.58	0.61	-	0.44	0.41	0.44
Wind stress curl	0.88	0.94	-	0.61	0.59	0.60
Temperature - EQ	0.21	0.25	0.31	0.23	0.22	0.22
Zonal avg temp - Pacific	0.23	0.28	0.46	0.42	0.23	0.27
Sea surface salinity	0.08	0.11	0.13	0.11	0.11	0.06
Zonal avg salinity	0.57	0.63	1.43	1.39	0.75	0.76
Thermocline depth	0.50	0.60	0.71	0.69	0.58	0.57
Maximum mixed layer depth	1.00	1.30	1.00	1.08	0.84	0.87
Minimum mixed layer depth	0.86	0.91	1.00	0.90	0.84	0.82
Zonal ocean currents	0.59	0.63	0.59	0.62	0.63	0.64
Meridional ocean currents	0.70	0.73	0.72	0.72	0.70	0.70
Zonal ocean current - EQ	0.40	0.45	0.43	0.39	0.42	0.39
Zonal current avg - Pacific	0.53	0.55	0.55	0.55	0.56	0.53
AMOC	1.04	1.12	0.61	0.74	1.12	0.95

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

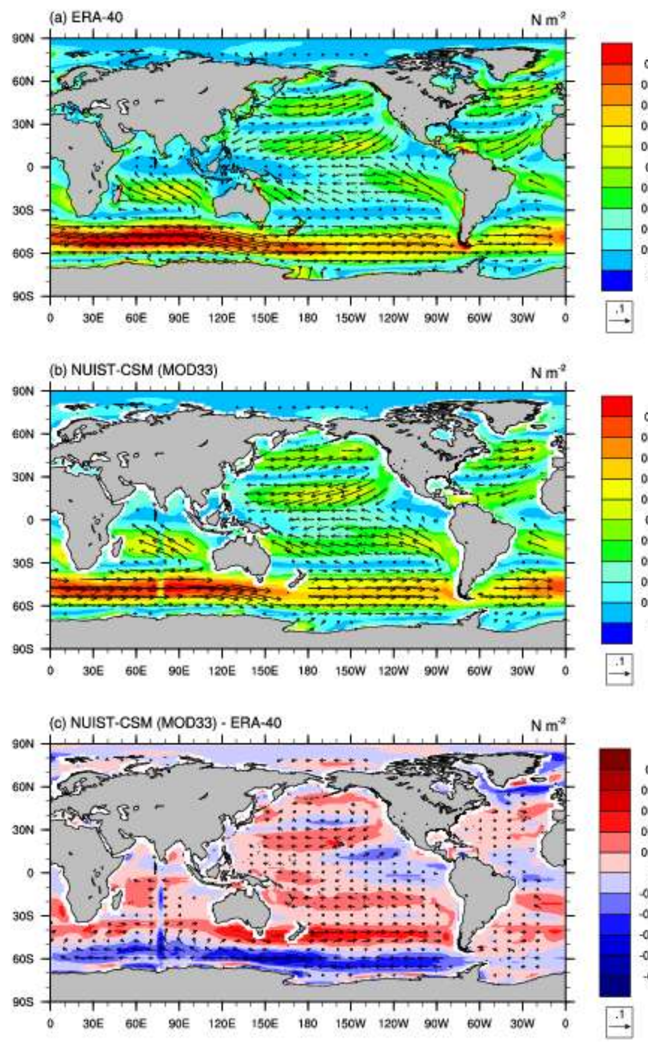
Ocean

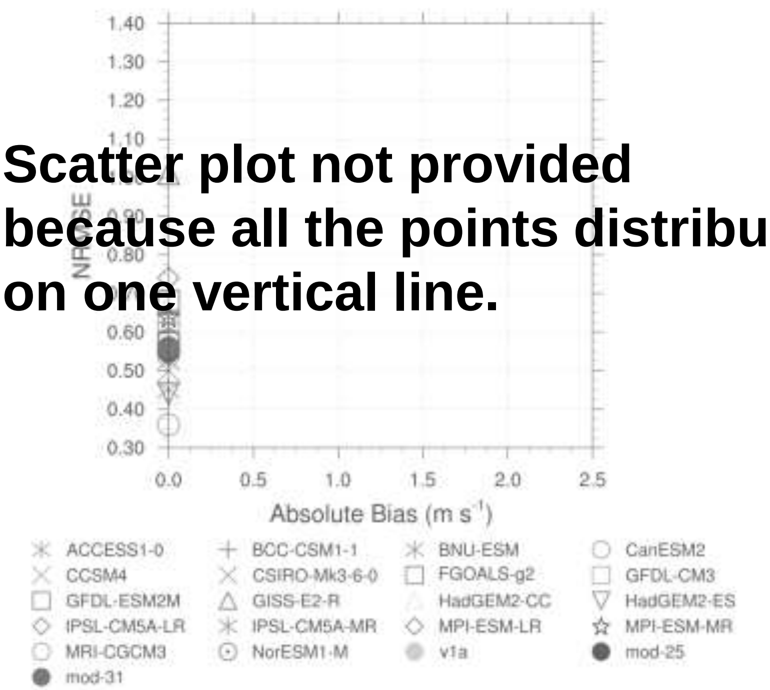
Annual mean sea surface wind stress (vector) and wind stress magnitude (shaded)

ERA-40

MOD31

BIAS





Scatter plot not provided because all the points distribute on one vertical line.

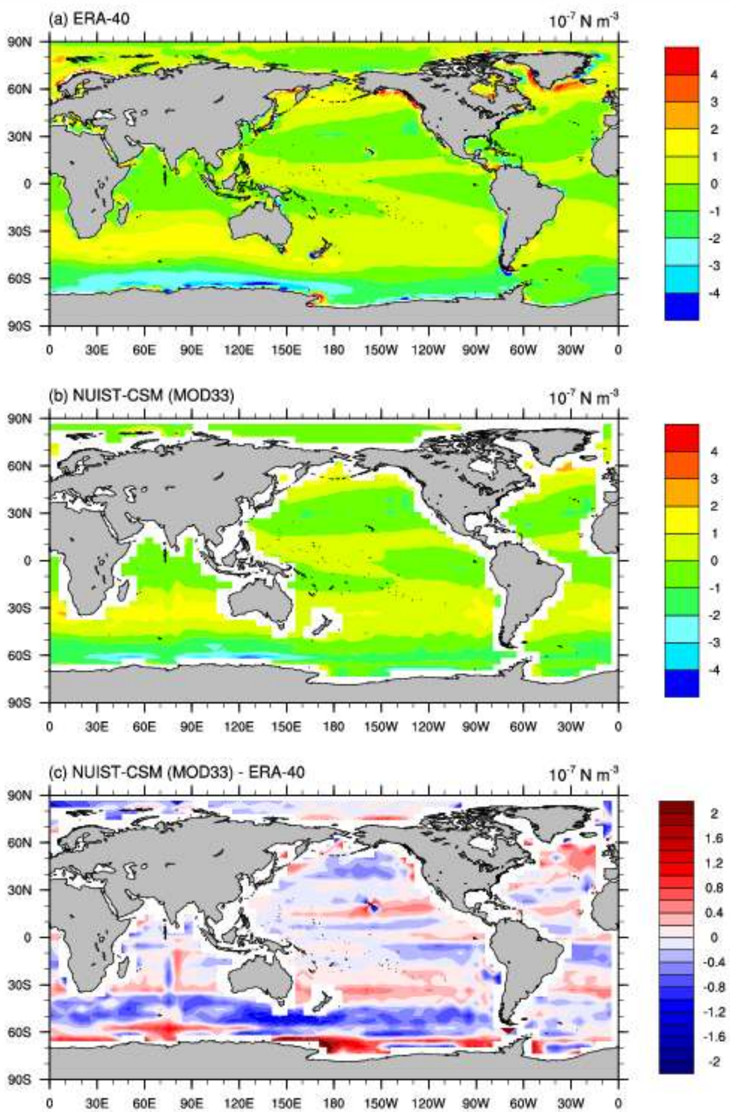
Ocean

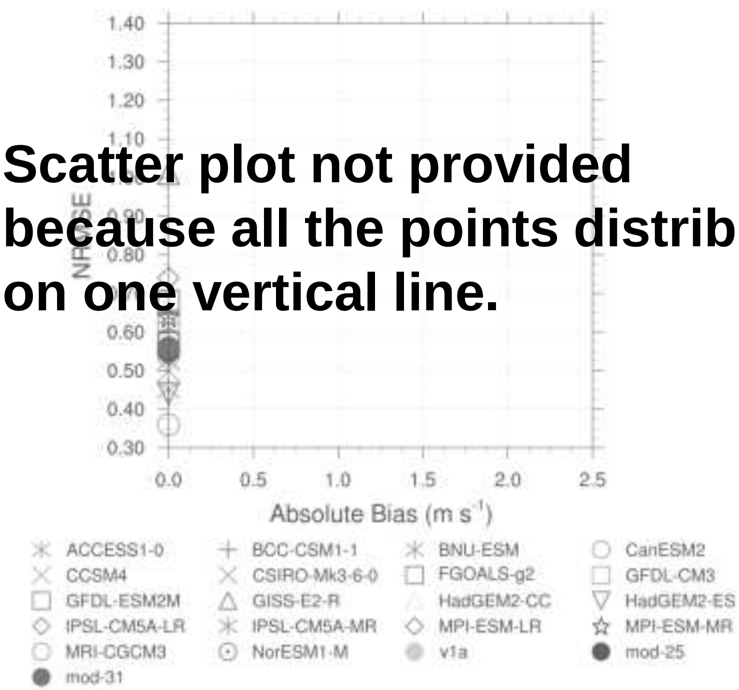
Annual mean sea surface wind stress curl

ERA-40

MOD31

BIAS





Scatter plot not provided because all the points distribute on one vertical line.

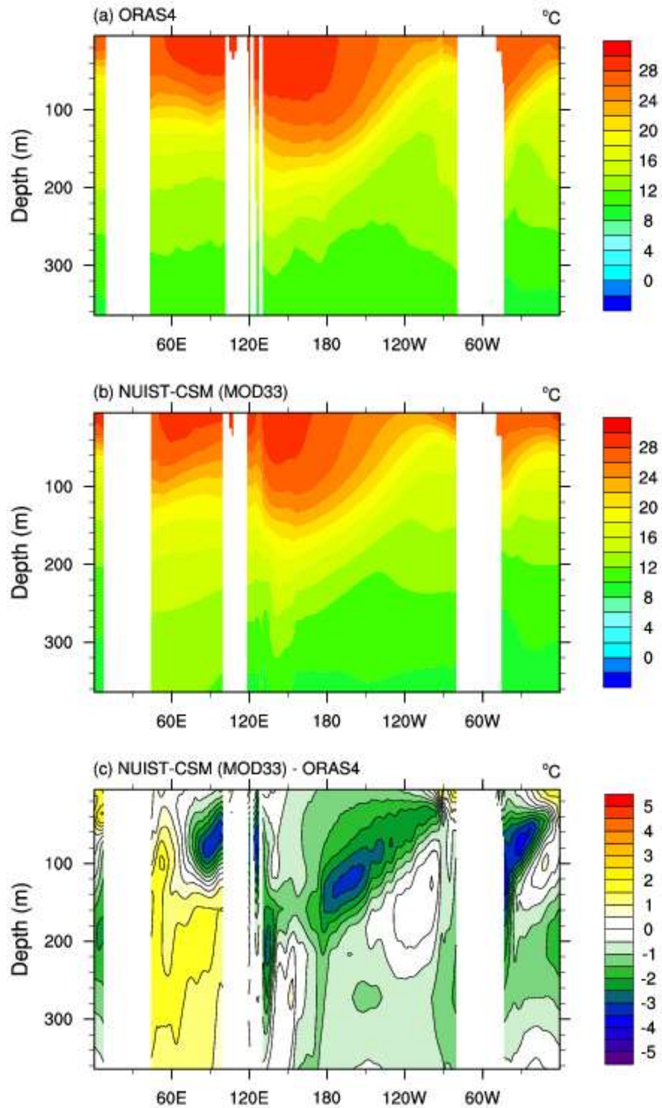
Ocean

Annual mean sea water temperature along equator
(averaged between 2°S-2°N)

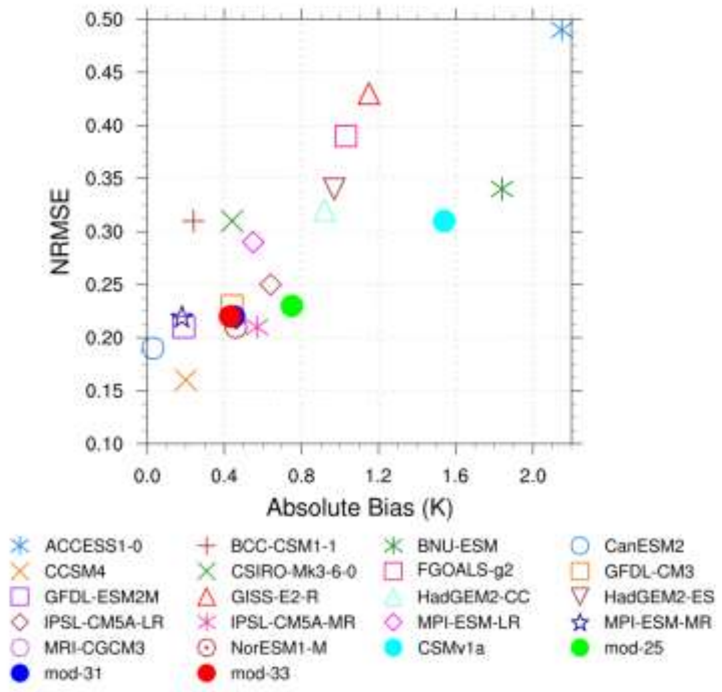
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE

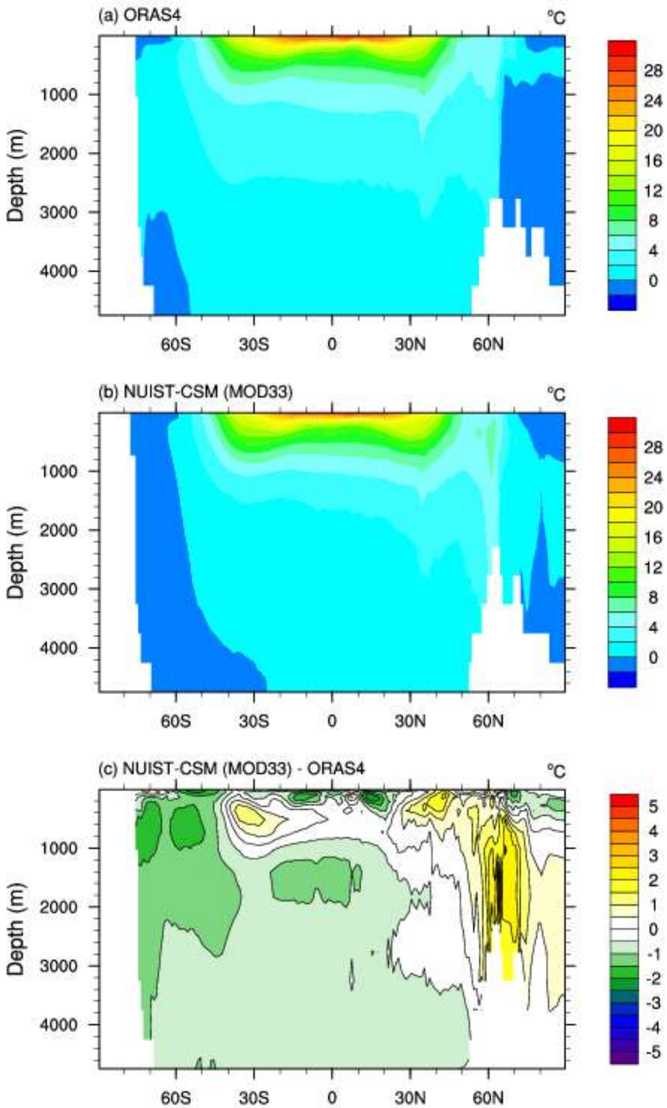


Global zonal averaged annual mean sea water temperature

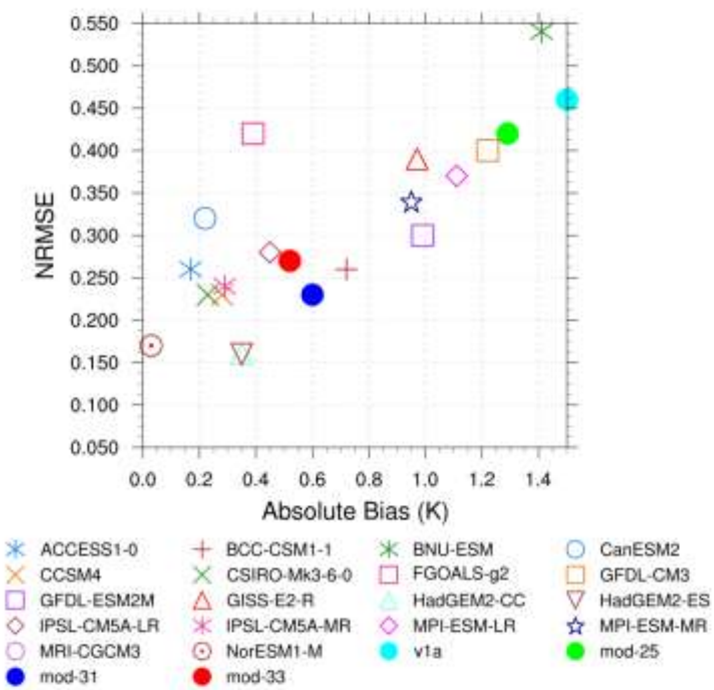
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



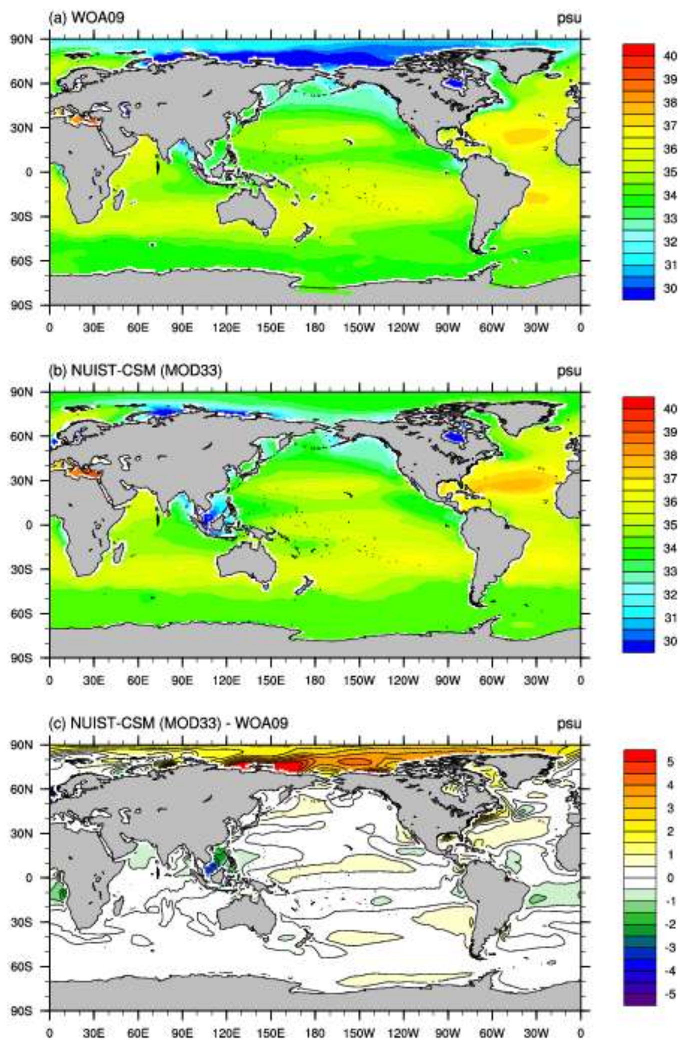
Ocean

Global distribution of annual mean sea surface salinity

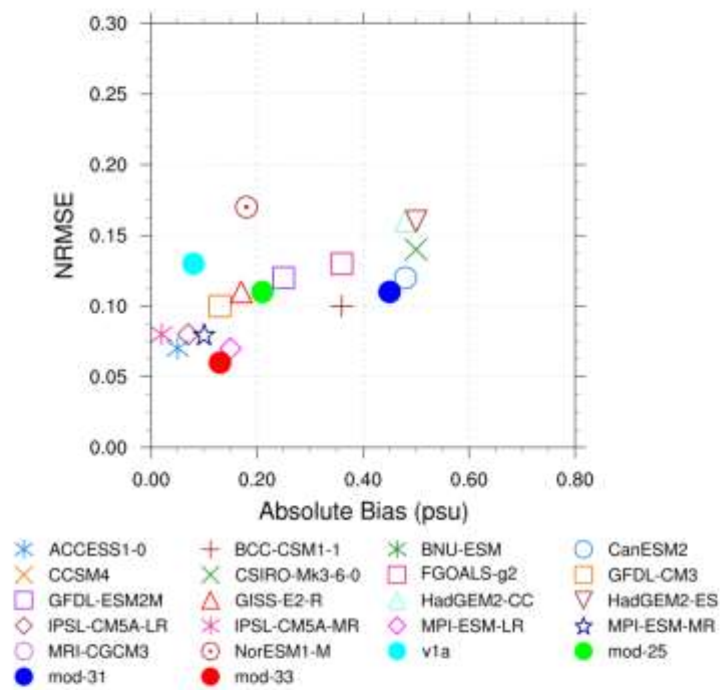
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



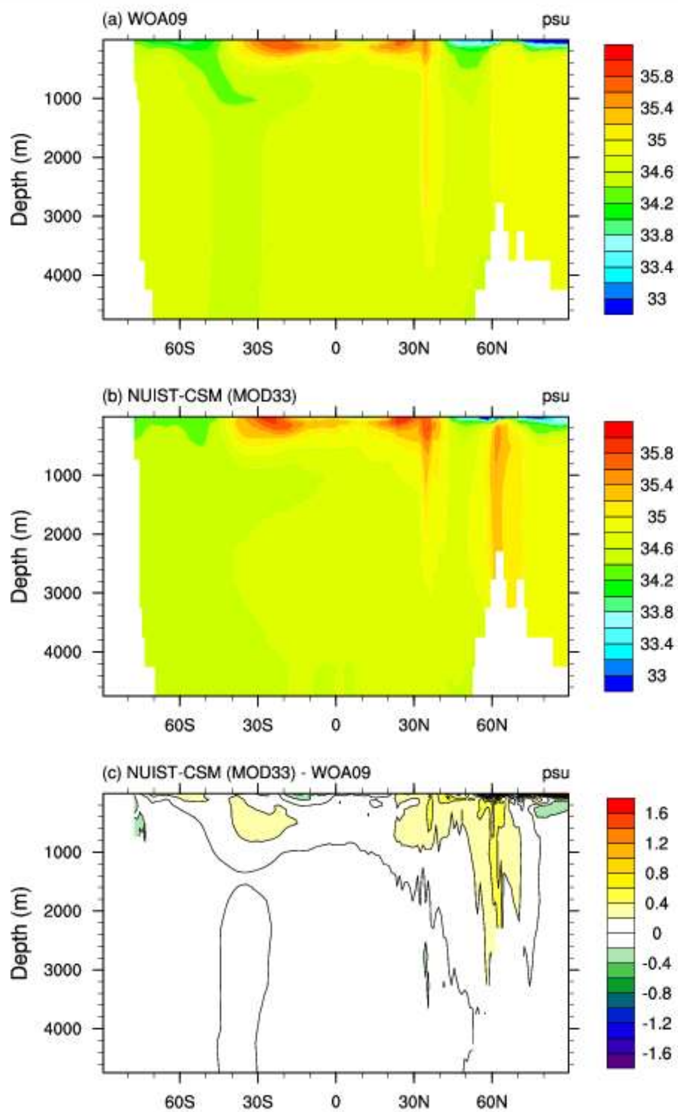
Ocean

Global zonal mean annual mean sea water salinity

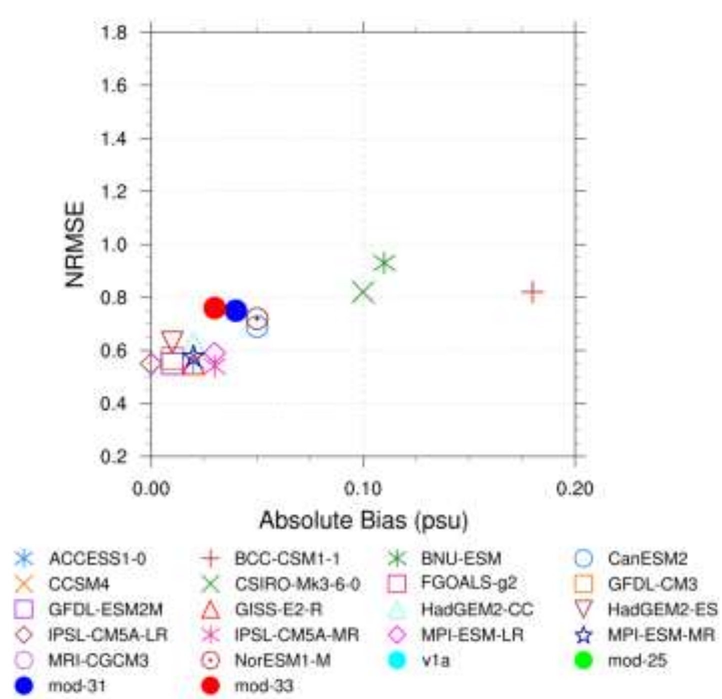
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



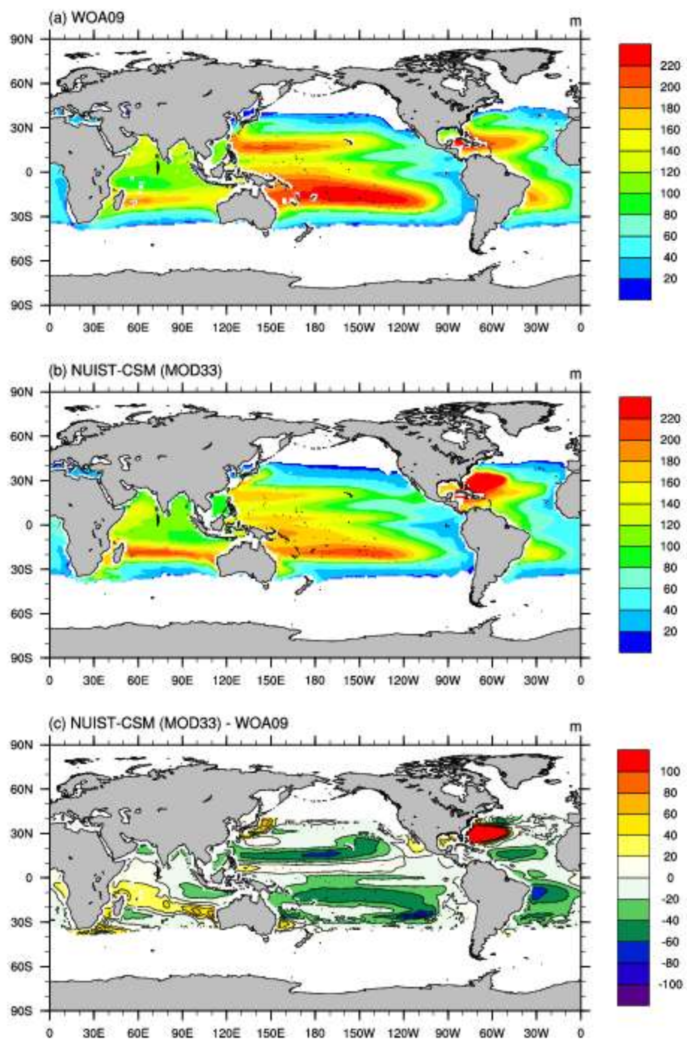
Ocean

Global distribution of annual mean thermocline depth (20° C isotherm depth)

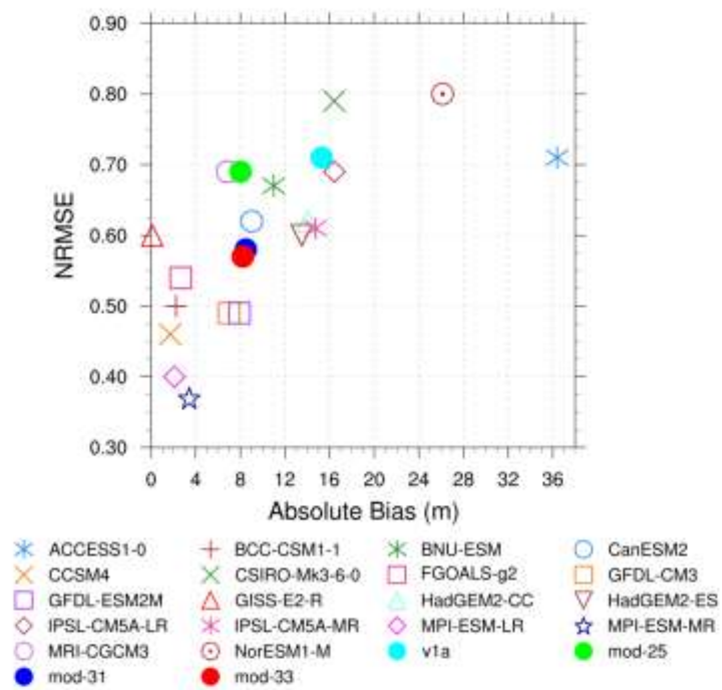
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



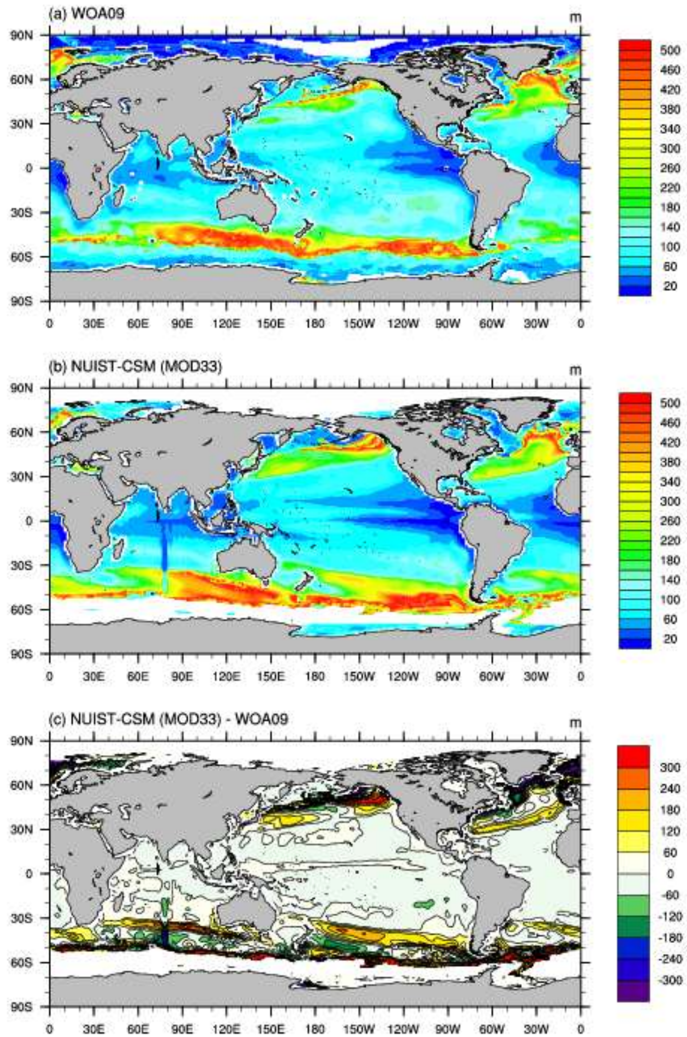
Ocean

Global distribution of annual maximum mixes layer depth (0.5° C potential temperature difference from sea surface)

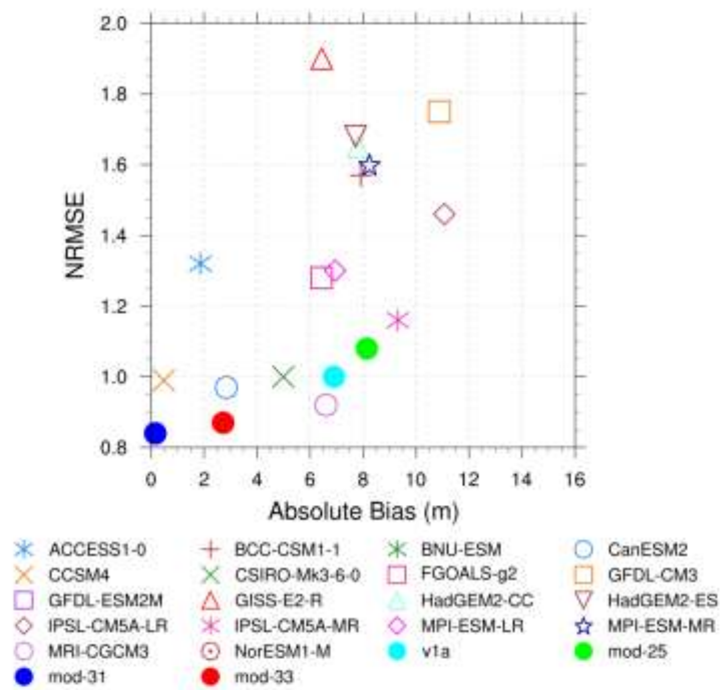
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



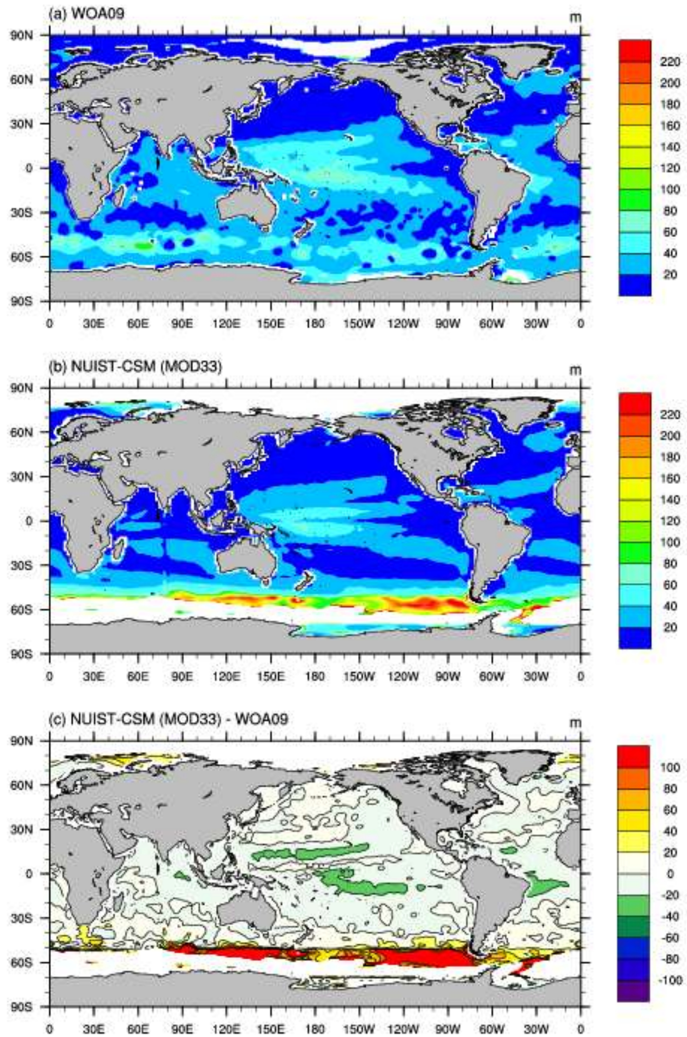
Ocean

Global distribution of annual minimum mixes layer depth (0.5° C potential temperature difference from sea surface)

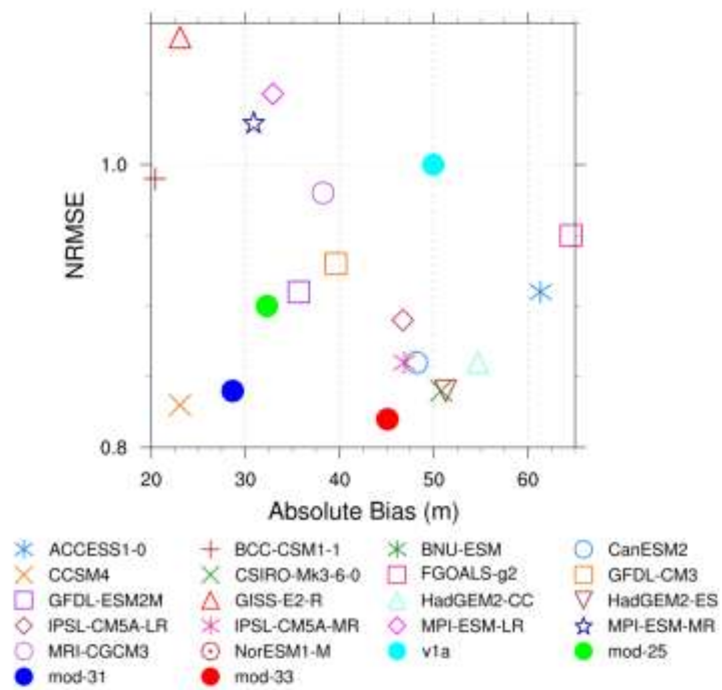
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



Ocean

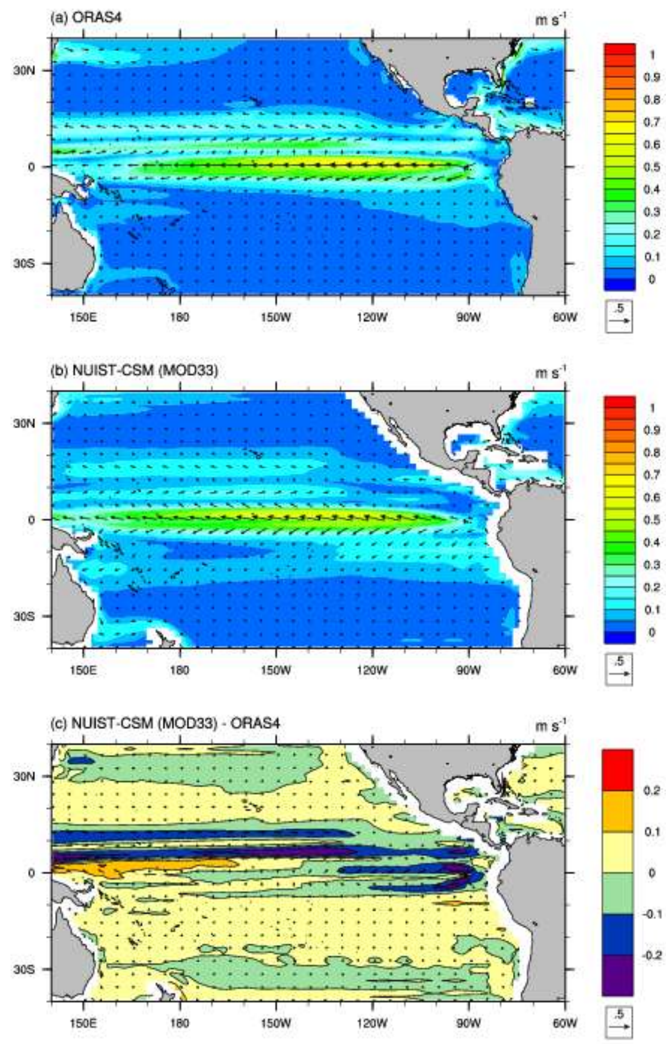
Annual mean equatorial currents in Pacific

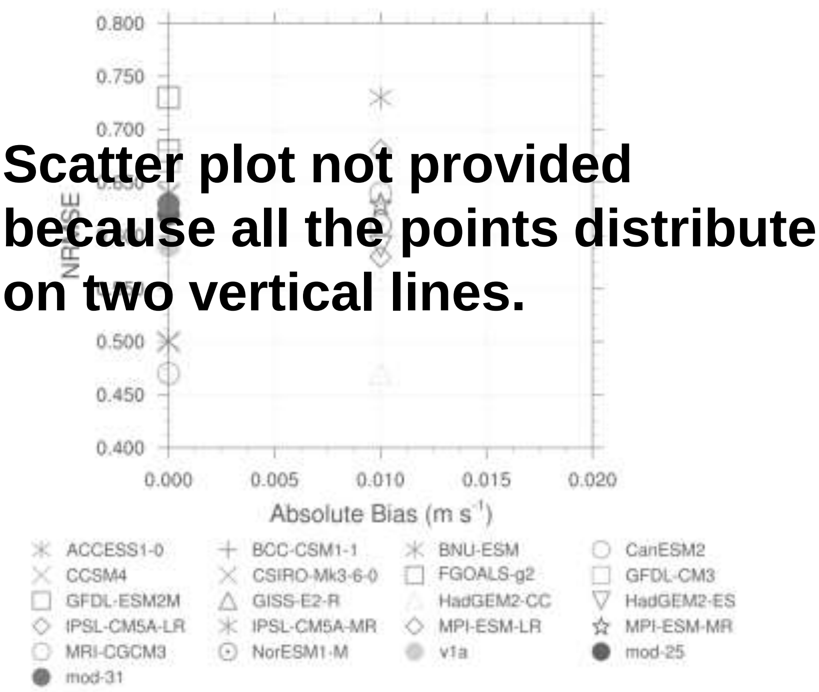
（vector: ocean current; color shading: magnitude of ocean current）

ORAS4

MOD31

BIAS





Scatter plot not provided because all the points distribute on two vertical lines.

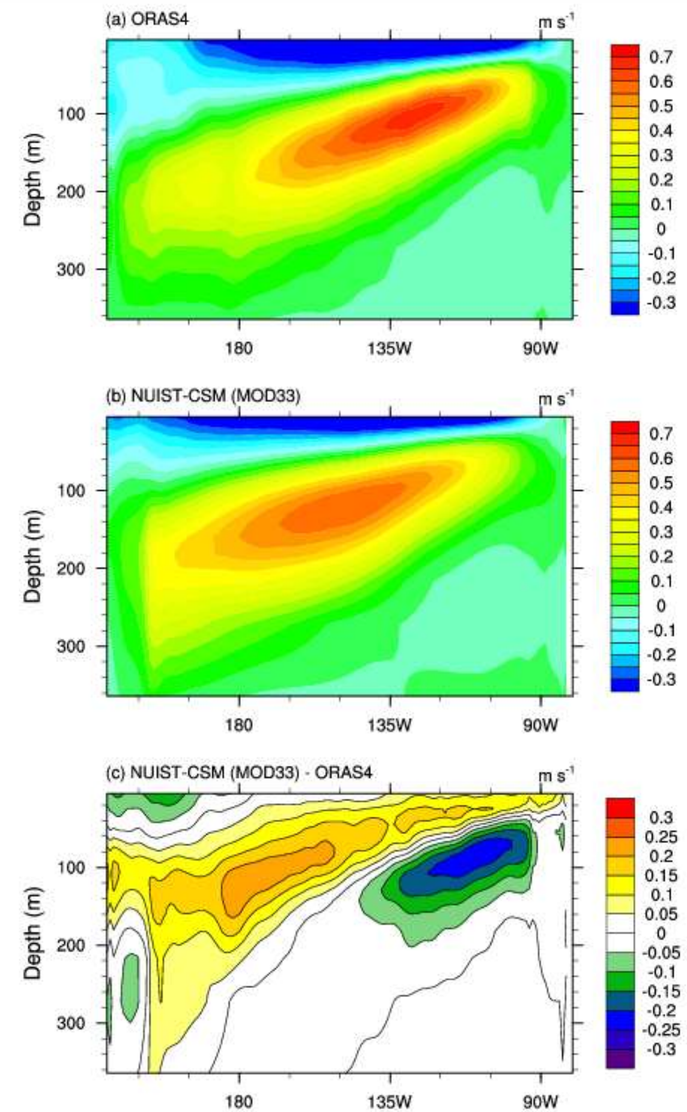
Ocean

Annual mean equatorial current in Pacific
(averaged between 2°S-2°N)

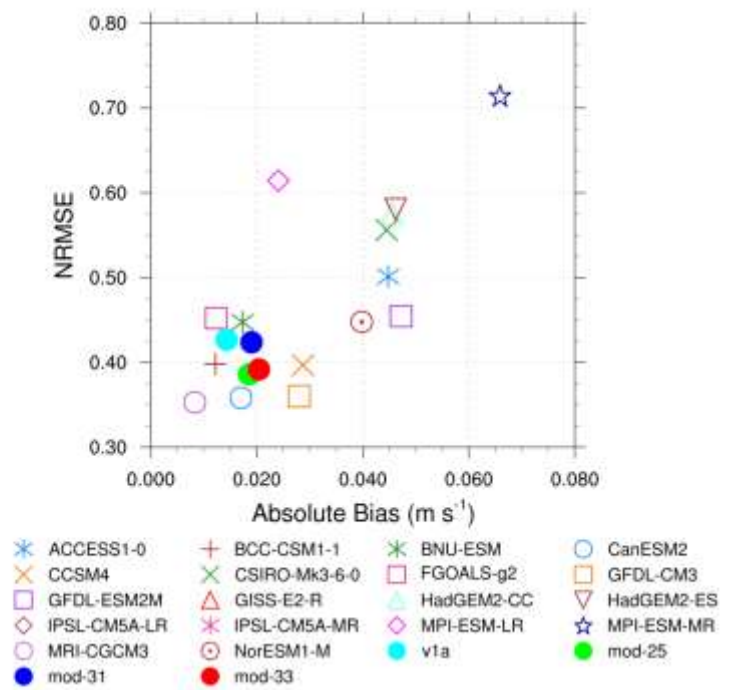
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



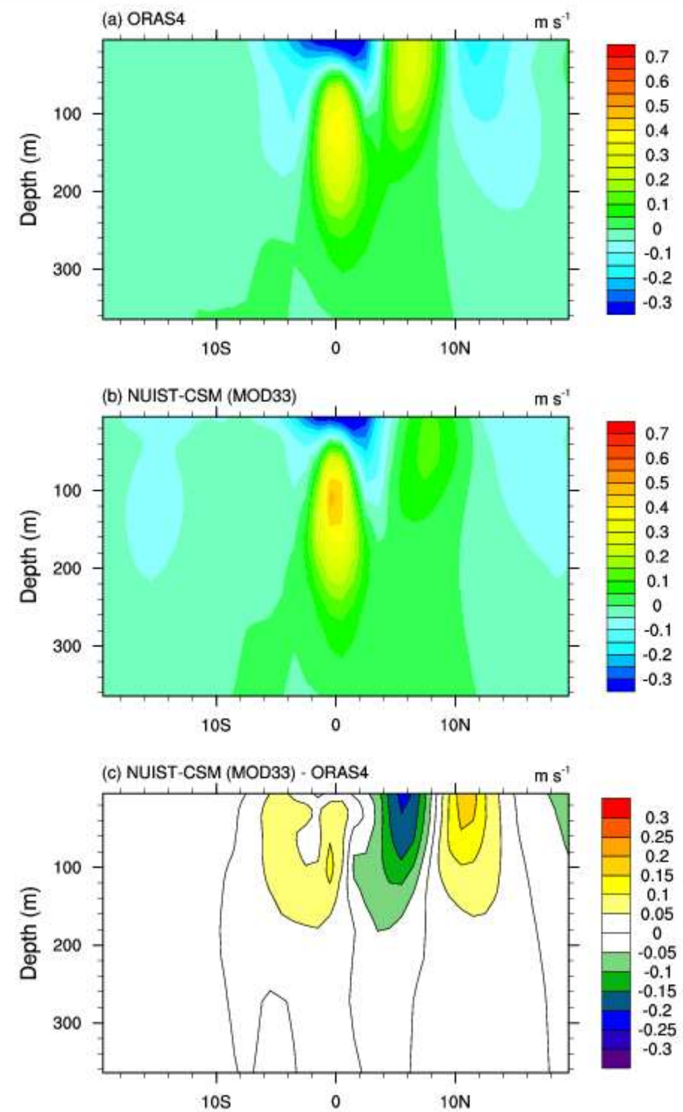
Ocean

Annual mean equatorial current in Pacific
(averaged between 140°E-80°W)

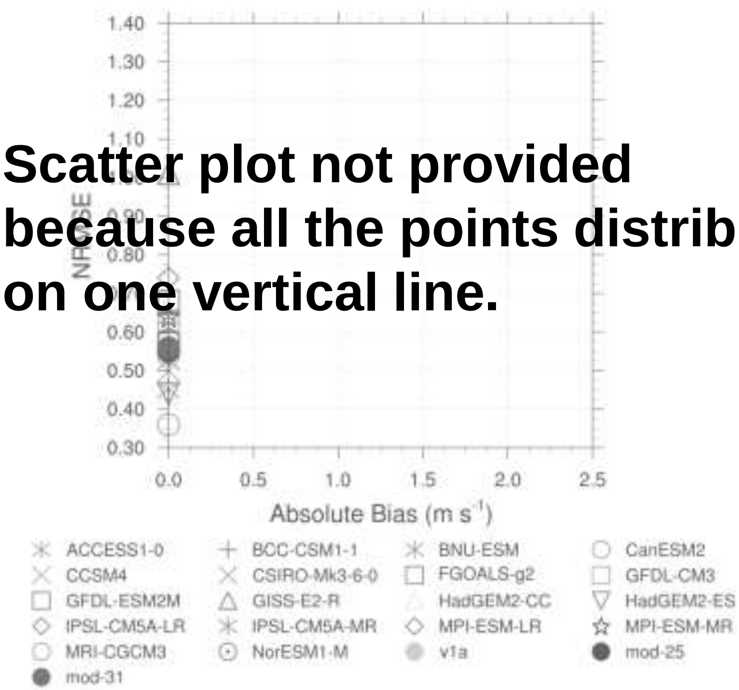
ORAS4

MOD31

BIAS



Scatter plot not provided because all the points distribute on one vertical line.



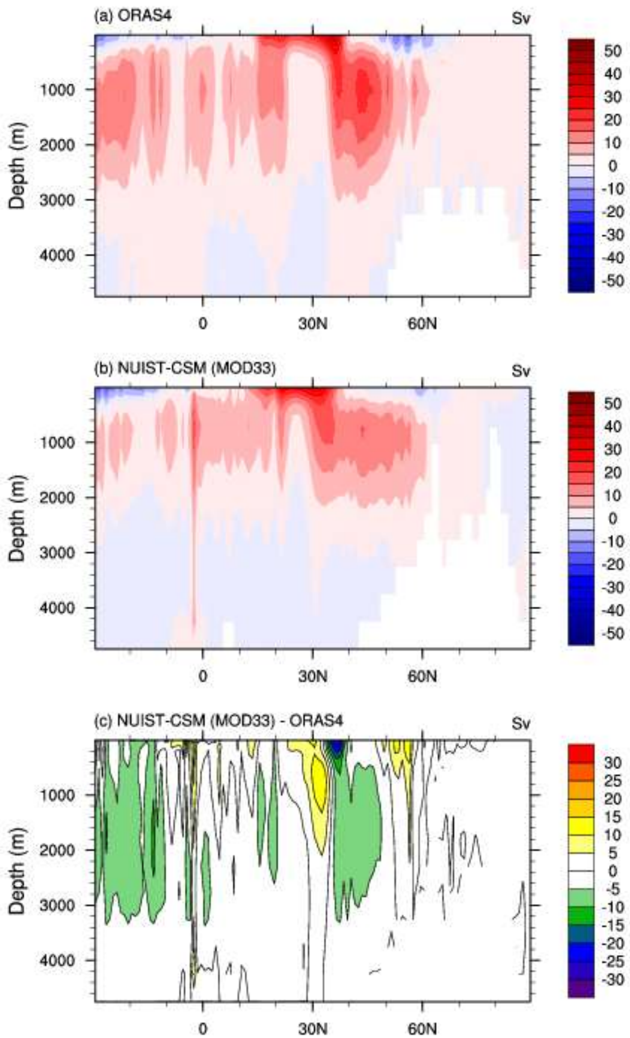
Ocean

Atlantic Meridional Overturning Circulation

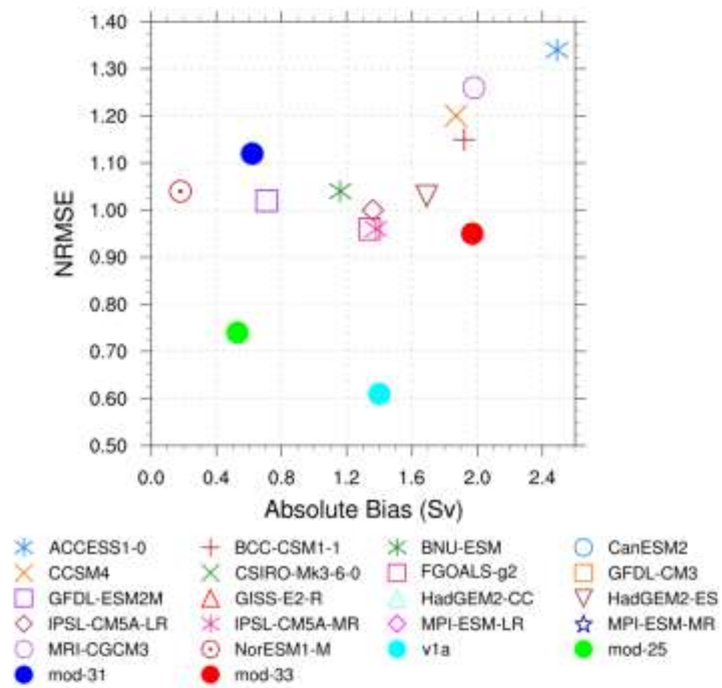
ORAS4

MOD31

BIAS



Comparison with CMIP5 models in terms of Abs. Bias and NRMSE



Antarctic Circumpolar Current

Metrics	Observation	CSMv1a	MOD25	MOD31	MOD33
Antarctic Circumpolar Current	~125	206.8	150.9	144.4	143.3

ACC performance on climatology in terms of Absolute Bias

Metrics	Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv1a	MOD25	MOD31	MOD33
Antarctic Circumpolar Current	19.75	21.97	81.77	25.94	19.35	18.33

8. Land

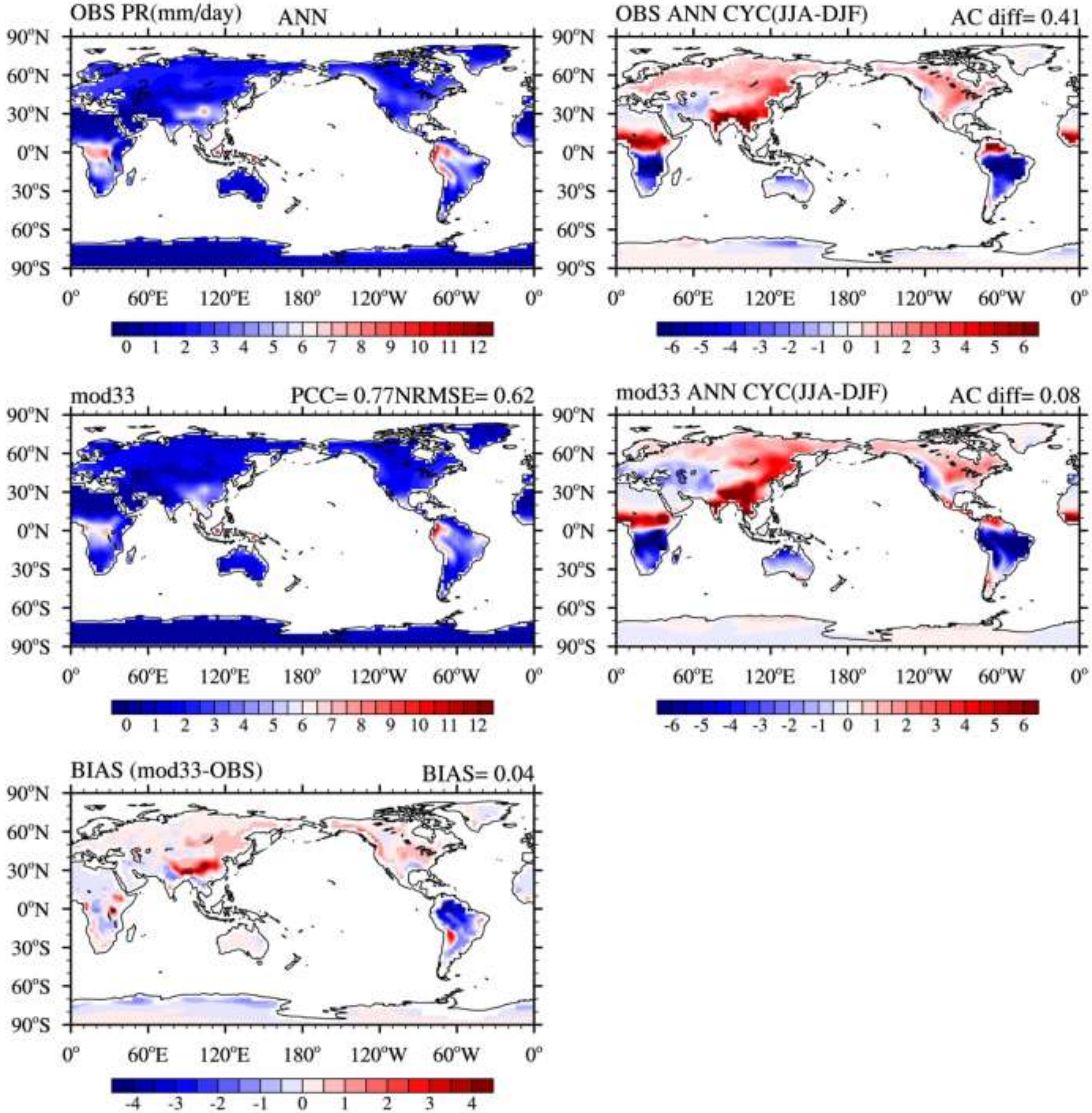
Main problems

- Contrast warm and cold bias pattern between west and east hemisphere
- Respectively underestimated and overestimated Pr in south America and Tibetan Plateau (TP)
- Overall underestimated surface net solar radiation (equatorial Africa)
- Underestimated sensible heat flux in north hemisphere

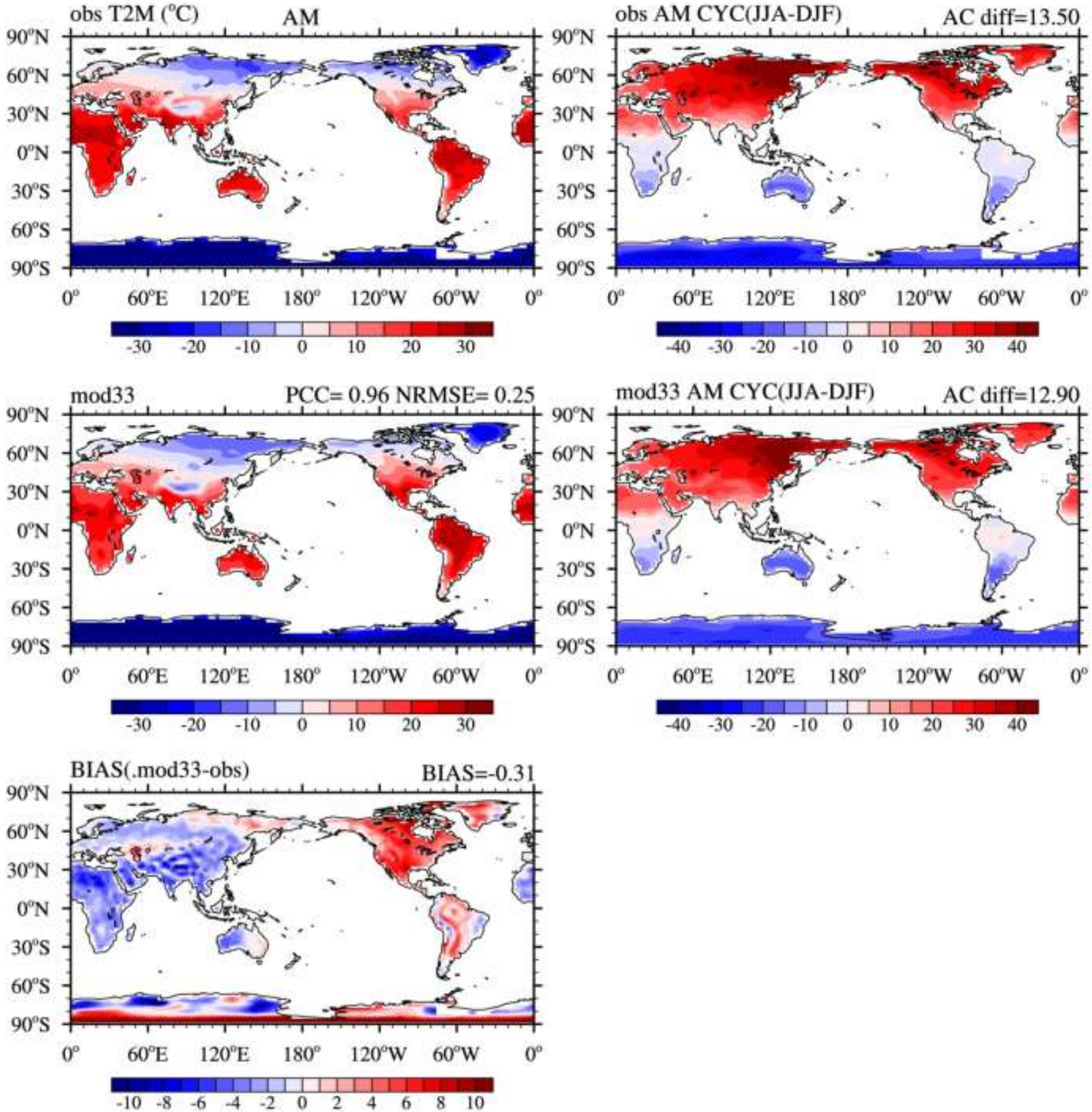
Summary table

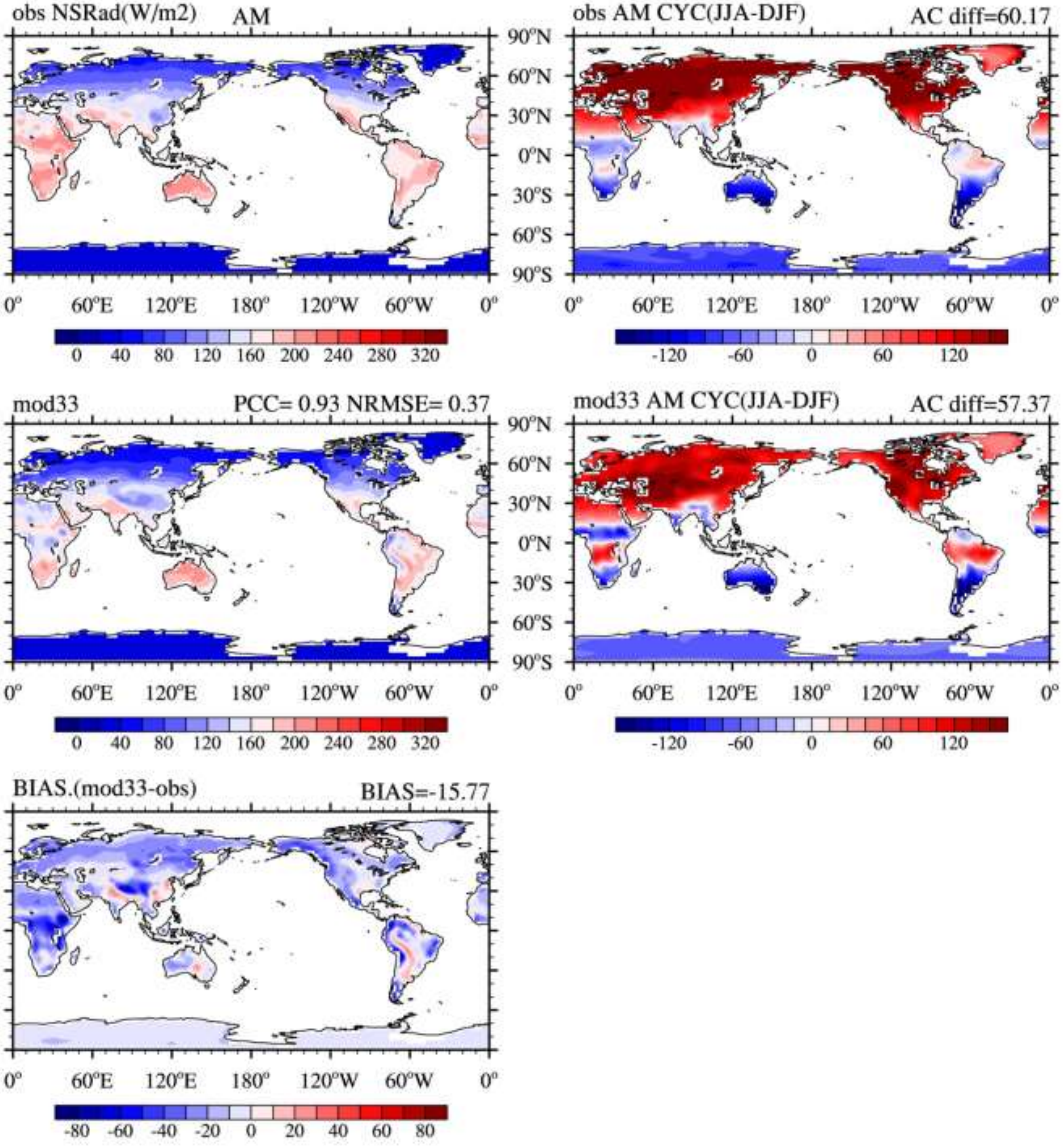
Vars	Term	CMIP 5 top 1/3		CMIP 5 top 1/2		csmv 1a		Mod 25		Mod 28		Mod 31		Mod 33		Mod 35a	
		NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC	NRMSE	PCC
Pr	AM	0.55	0.83	0.62	0.81	0.55	0.82	0.64	0.77	0.62	0.76	0.61	0.77	0.62	0.77	0.62	0.76
	AC	0.5	0.91	0.55	0.9	0.41	0.91	0.49	0.9	0.45	0.9	0.47	0.9	0.47	0.9	0.46	0.9
t2m	AM	0.16	0.99	0.16	0.98	0.28	0.95	0.26	0.96	0.24	0.96	0.24	0.96	0.25	0.96	0.25	0.96
	AC	0.28	0.97	0.29	0.97	0.4	0.94	0.34	0.96	0.42	0.95	0.43	0.94	0.34	0.96	0.33	0.96
shflx	AM	0.74	0.78	0.82	0.74	1.17	0.71	1.01	0.71	1.07	0.71	1.04	0.74	0.96	0.73	0.96	0.73
	AC	0.87	0.84	0.95	0.82	1.2	0.66	1.11	0.72	1.17	0.67	1.15	0.67	1.09	0.72	1.09	0.73
lhflx	AM	0.55	0.88	0.58	0.86	0.57	0.85	0.47	0.88	0.46	0.87	0.45	0.88	0.43	0.88	0.43	0.88
	AC	1.07	0.66	1.22	0.57	1.1	0.63	1.2	0.62	1.12	0.6	1.1	0.64	1.14	0.63	1.15	0.63
rad	AM	0.23	0.95	0.25	0.95	0.31	0.96	0.34	0.93	0.41	0.93	0.41	0.94	0.37	0.93	0.37	0.93
	AC	0.57	0.93	0.57	0.92	0.56	0.9	0.54	0.93	0.69	0.89	0.66	0.89	0.57	0.93	0.58	0.93

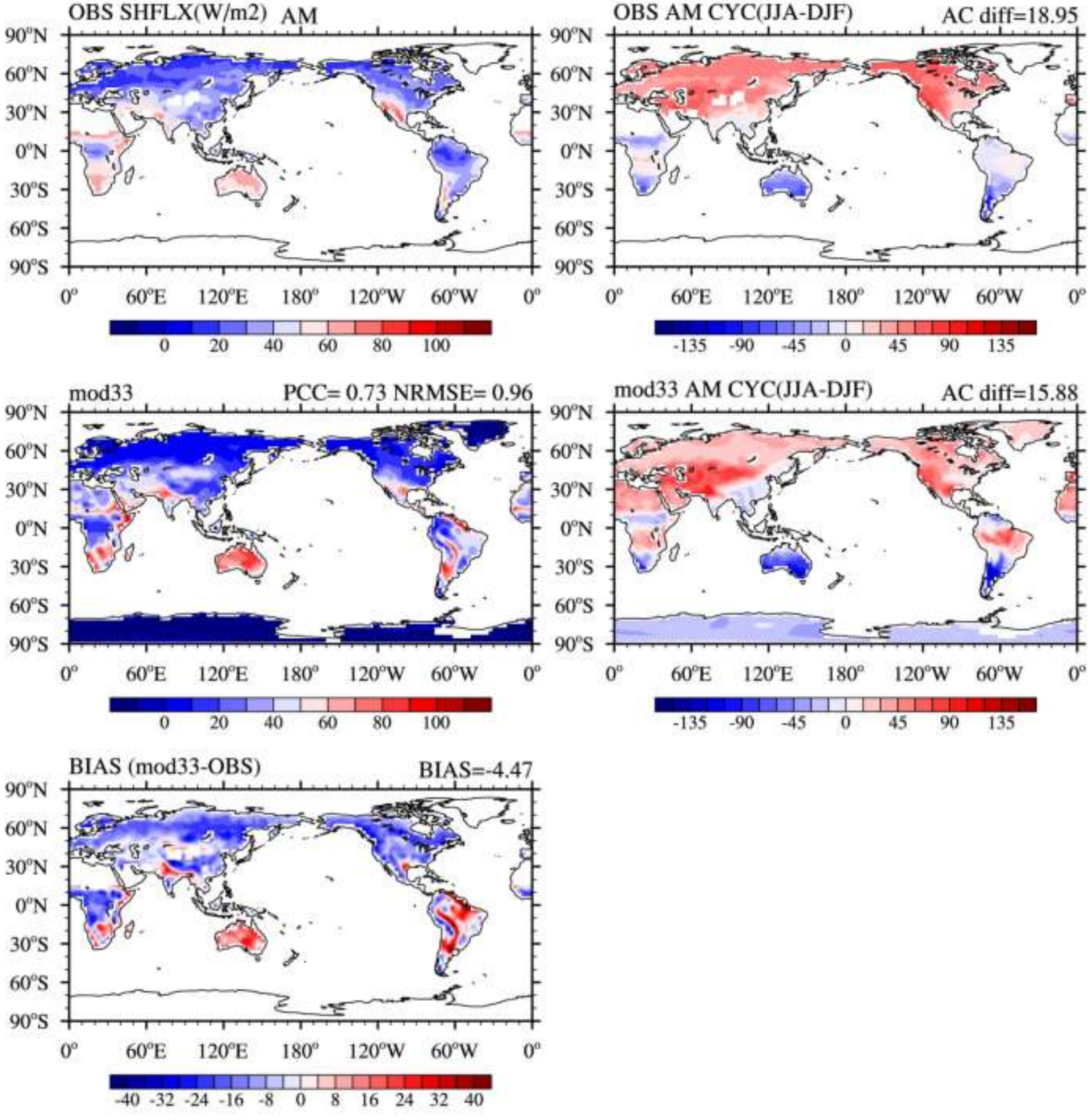
Red: Reach top 30%; Green: Reach top 50%; Blue: Not reach top 50%



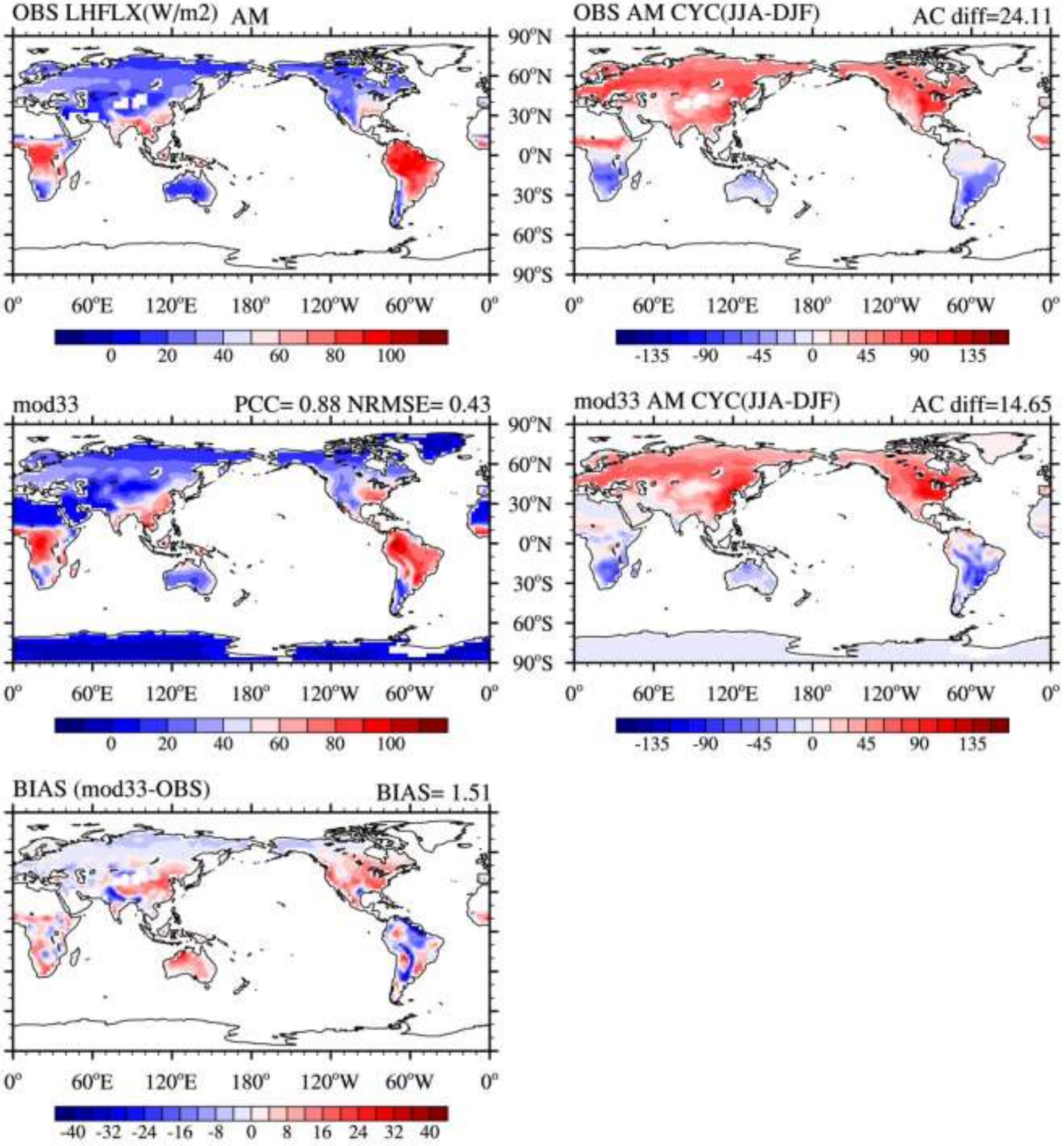
OBS PR(mm/day) ANN
OBS ANN CYC(JJA-DJF) AC diff= 0.41
mod33 PCC= 0.77NRMSE= 0.62
mod33 ANN CYC(JJA-DJF) AC diff= 0.08
BIAS (mod33-OBS) BIAS= 0.04
90°N 60°N 30°N 0°N 30°S 60°S 90°S
0° 60°E 120°E 180° 120°W 60°W 0°
0 1 2 3 4 5 6 7 8 9 10 11 12
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
-4 -3 -2 -1 0 1 2 3 4


obs T2M (°C)
AM
obs AM CYC(JJA-DJF)
AC diff=13.50
mod33
PCC= 0.96 NRMSE= 0.25
mod33 AM CYC(JJA-DJF)
AC diff=12.90
BIAS(.mod33-obs)
BIAS=-0.31

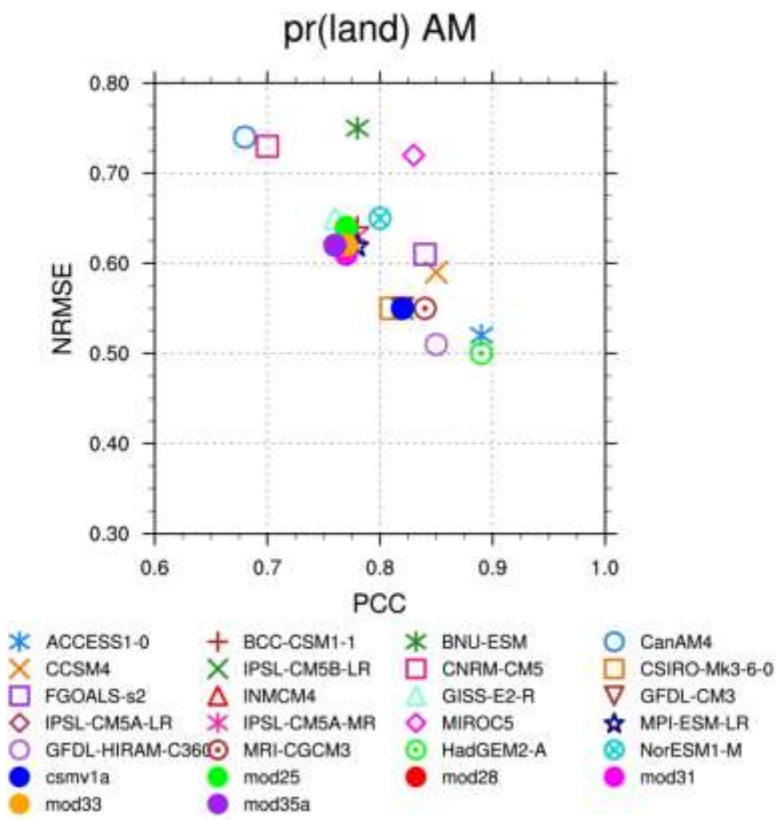

obs NSRad(W/m2)
AM
obs AM CYC(JJA-DJF)
AC diff=60.17
mod33
PCC= 0.93 NRMSE= 0.37
mod33 AM CYC(JJA-DJF)
AC diff=57.37
BIAS.(mod33-obs)
BIAS=-15.77
90°N 60°N 30°N 0°N 30°S 60°S 90°S
0° 60°E 120°E 180° 120°W 60°W 0°
0 40 80 120 160 200 240 280 320
-120 -60 0 60 120
-80 -60 -40 -20 0 20 40 60 80



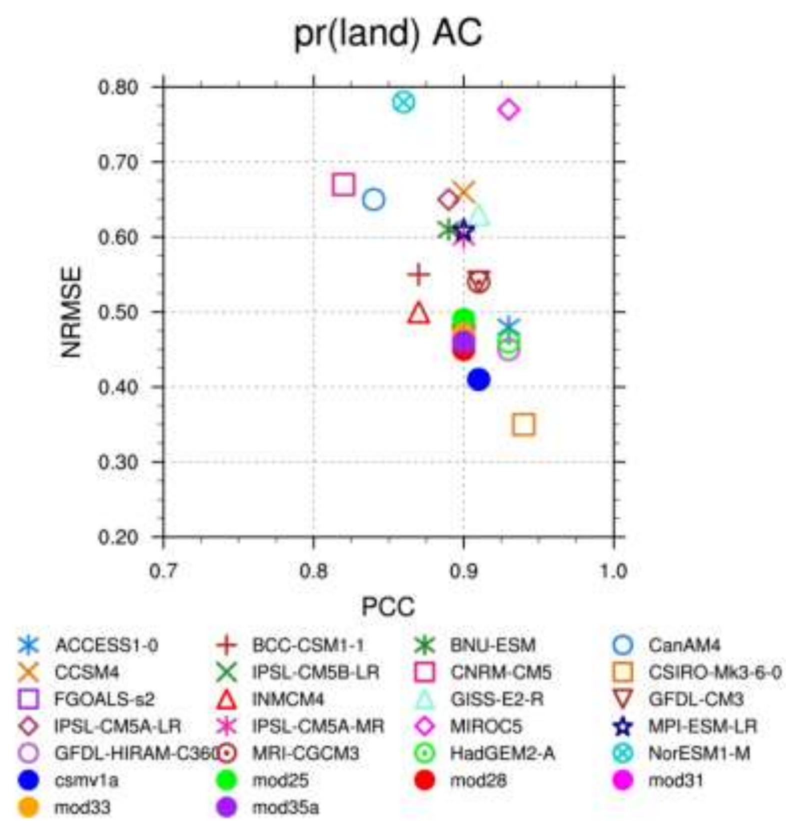
OBS SHFLX(W/m2) AM
OBS AM CYC(JJA-DJF)
AC diff=18.95
mod33
PCC= 0.73 NRMSE= 0.96
mod33 AM CYC(JJA-DJF)
AC diff=15.88
BIAS (mod33-OBS)
BIAS=-4.47
90°N 60°N 30°N 0°N 30°S 60°S 90°S
0° 60°E 120°E 180° 120°W 60°W 0°
0 20 40 60 80 100
-135 -90 -45 0 45 90 135
-40 -32 -24 -16 -8 0 8 16 24 32 40



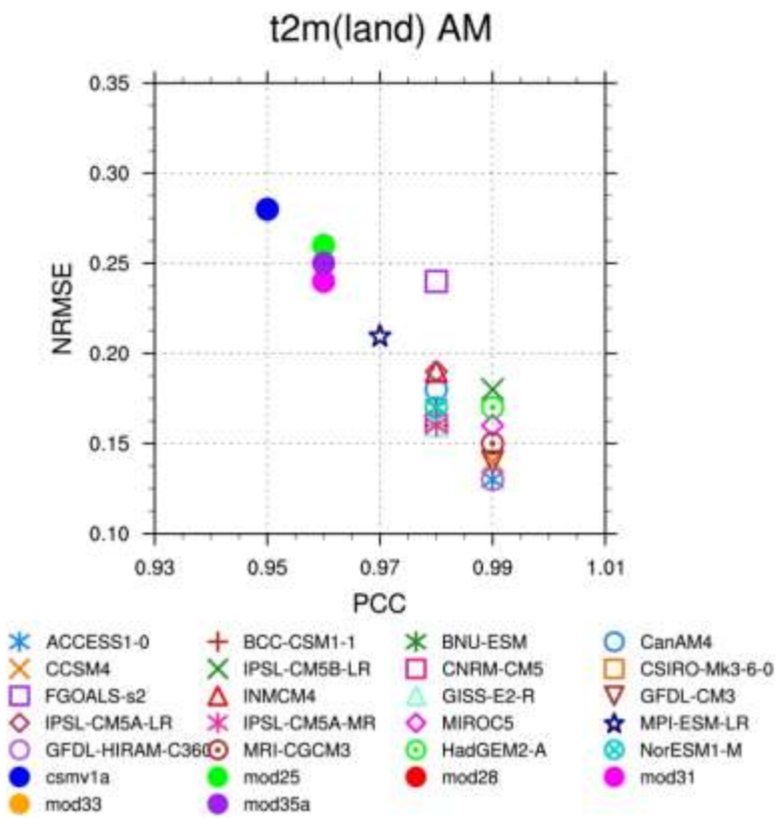
OBS LHFLX(W/m2) AM
OBS AM CYC(JJA-DJF)
AC diff=24.11
mod33
PCC= 0.88 NRMSE= 0.43
mod33 AM CYC(JJA-DJF)
AC diff=14.65
BIAS (mod33-OBS)
BIAS= 1.51
90°N 60°N 30°N 0°N 30°S 60°S 90°S
0° 60°E 120°E 180° 120°W 60°W 0°
0 20 40 60 80 100
-135 -90 -45 0 45 90 135
-40 -32 -24 -16 -8 0 8 16 24 32 40

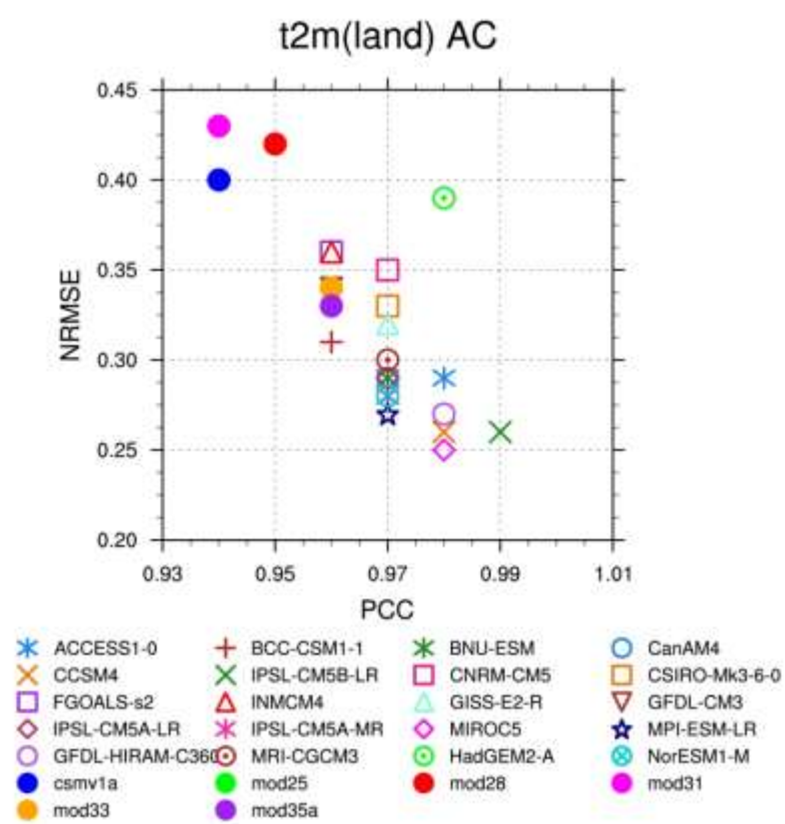


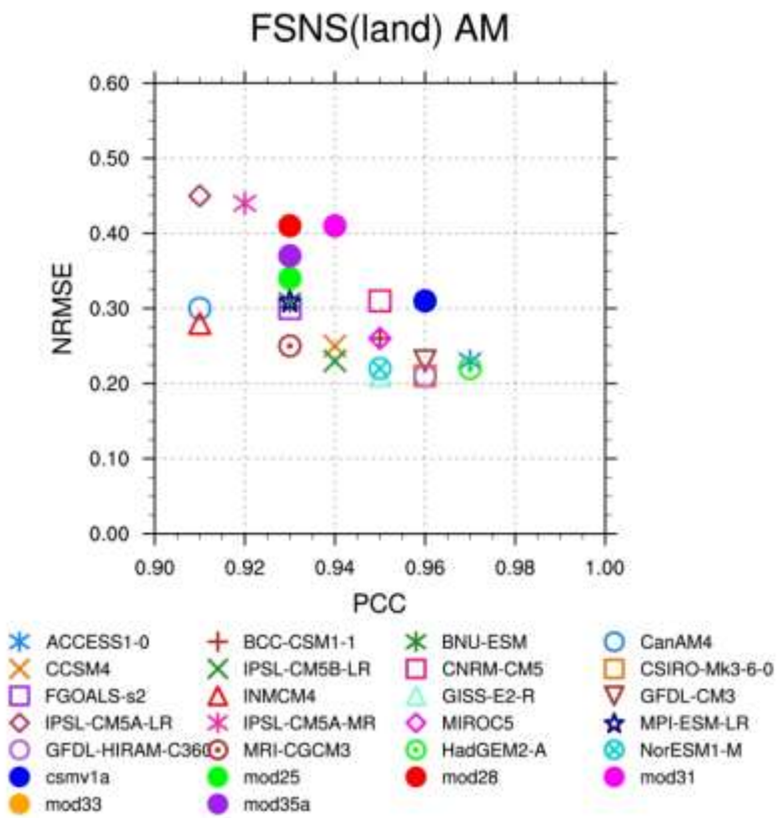
pr(land) AM
NRMSE
PCC
0.80
0.70
0.60
0.50
0.40
0.30
0.6
0.7
0.8
0.9
1.0
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a

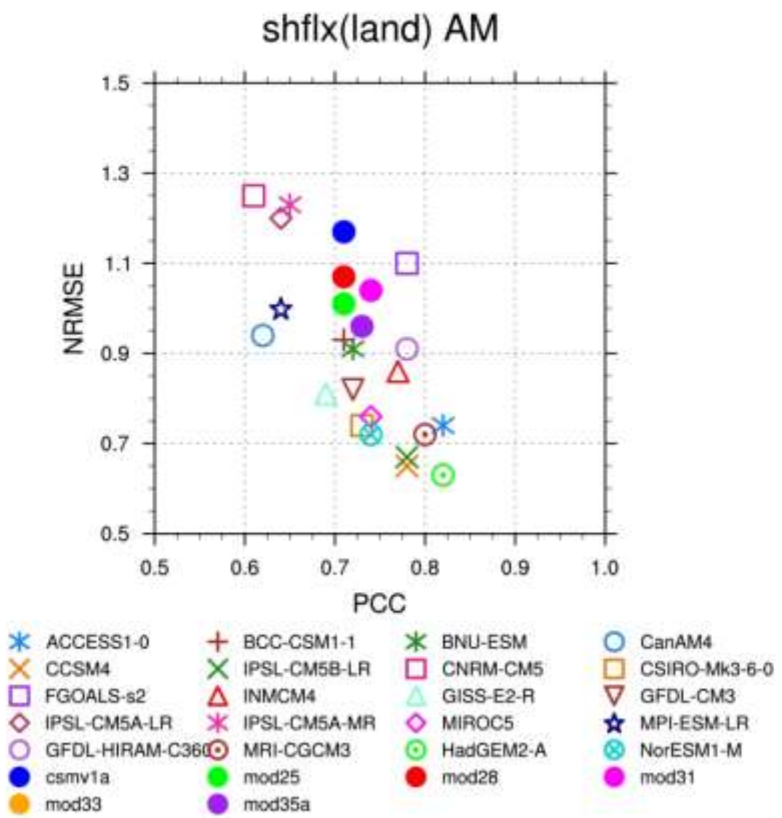


pr(land) AC
NRMSE
PCC
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.7
0.8
0.9
1.0
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a


t2m(land) AM
NRMSE
PCC
0.35
0.30
0.25
0.20
0.15
0.10
0.93
0.95
0.97
0.99
1.01
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a


t2m(land) AC
NRMSE
PCC
0.45
0.40
0.35
0.30
0.25
0.20
0.93
0.95
0.97
0.99
1.01
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a


FSNS(land) AM
NRMSE
PCC
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.90
0.92
0.94
0.96
0.98
1.00
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a


shflx(land) AM
NRMSE
PCC
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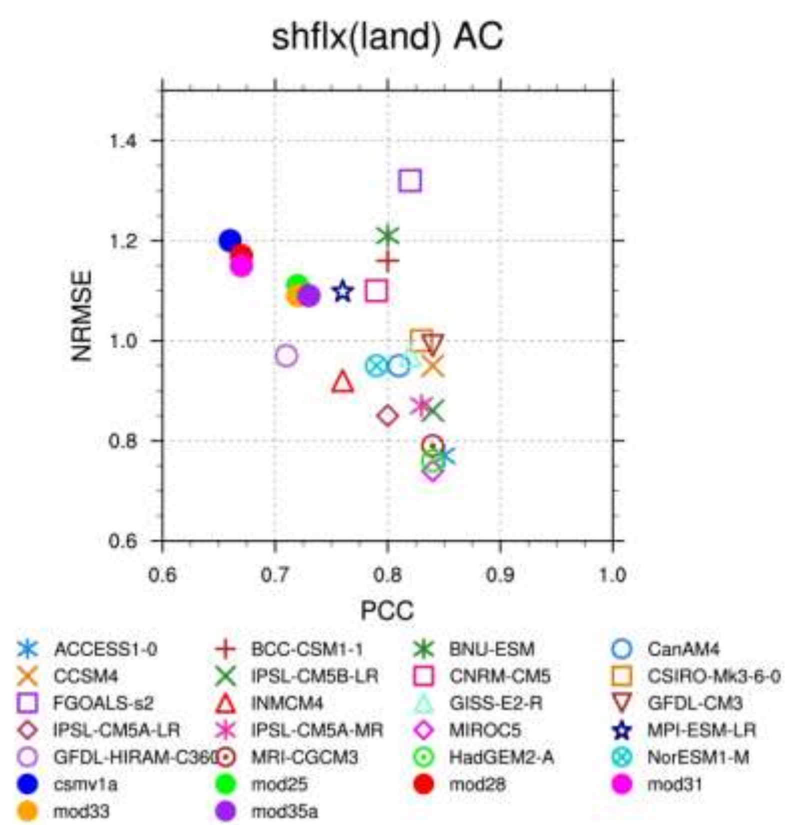
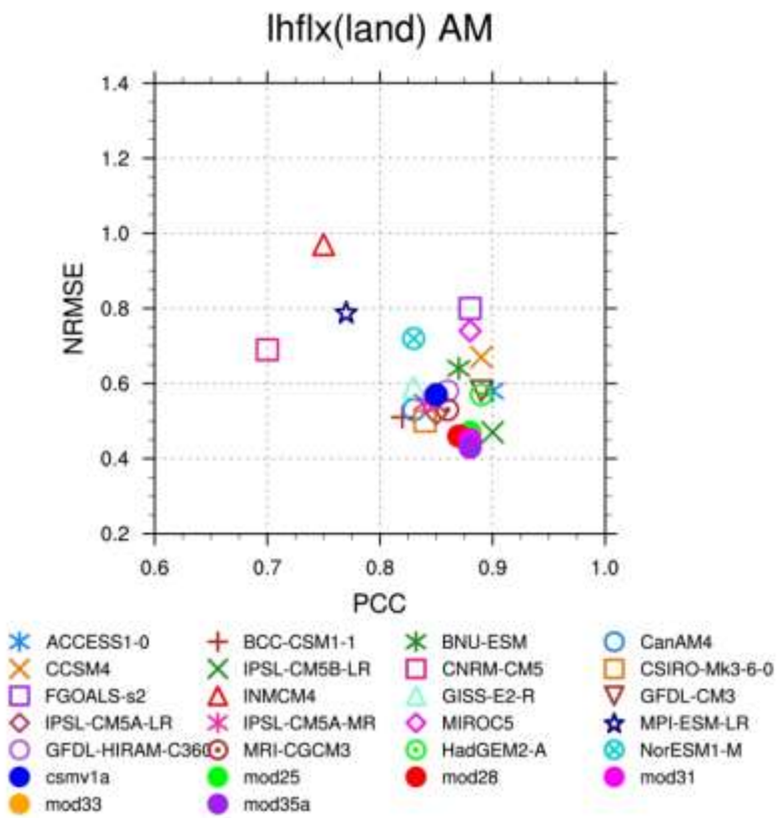
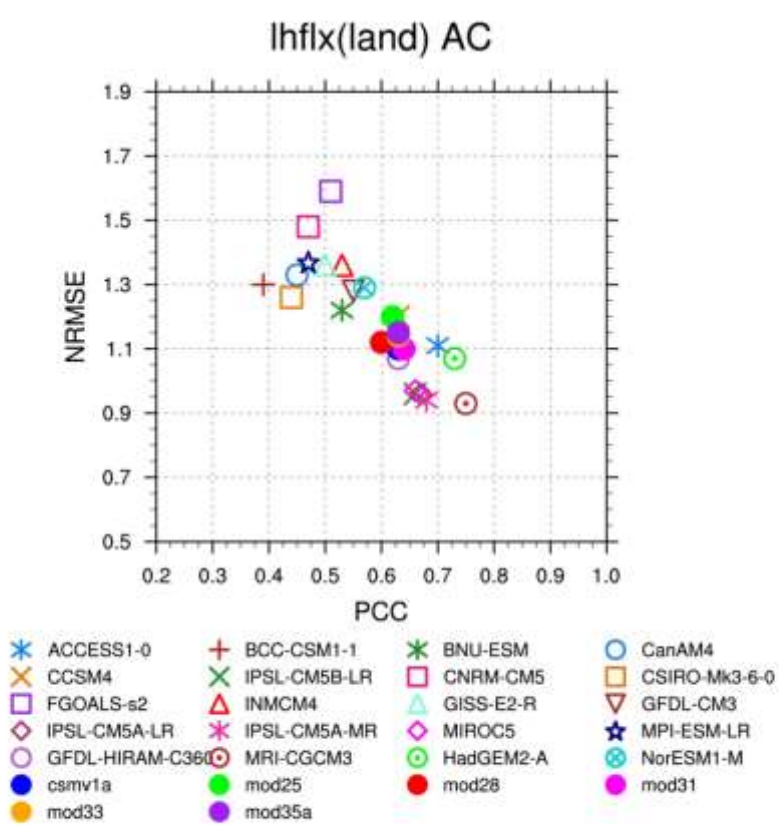
1.3
1.1
0.9
0.7
0.5
0.5
0.6
0.7
0.8
0.9
1.0
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a


shflx(land) AC
NRMSE
PCC
1.4
1.2
1.0
0.8
0.6
0.6
0.7
0.8
0.9
1.0
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a



lhflx(land) AM
NRMSE
PCC
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.6
0.7
0.8
0.9
1.0
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a

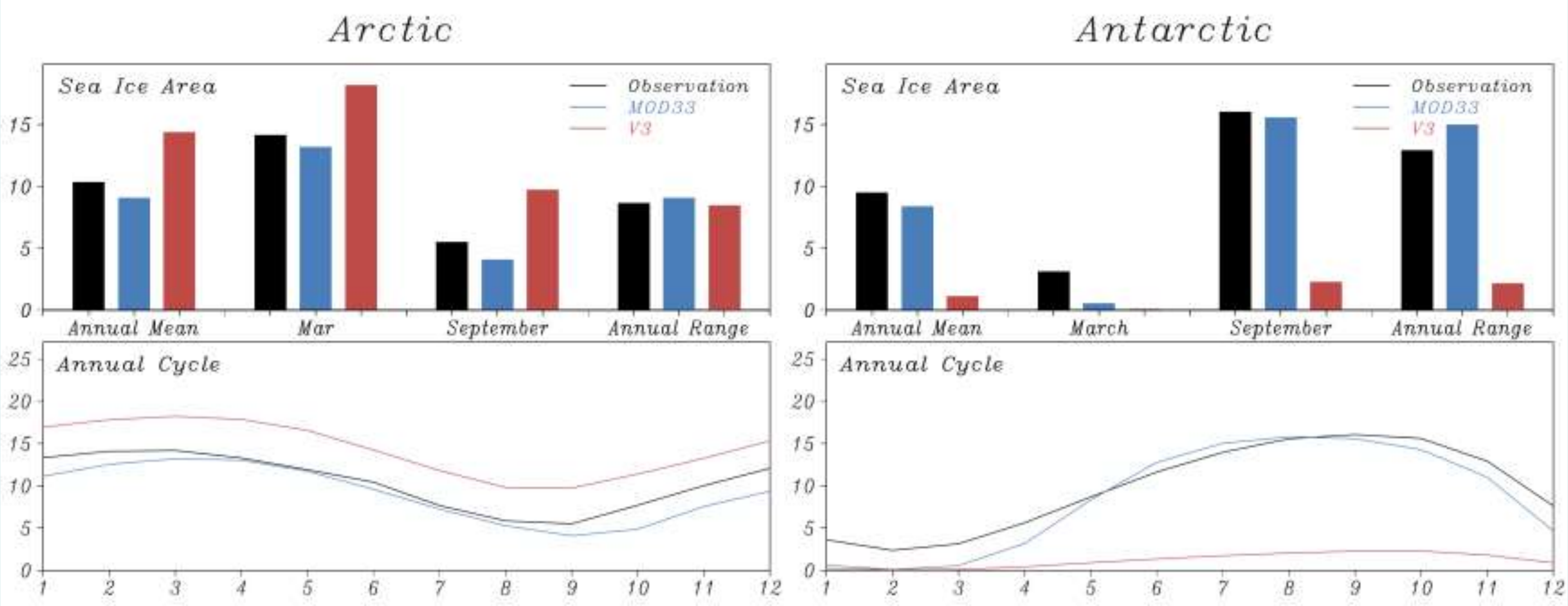


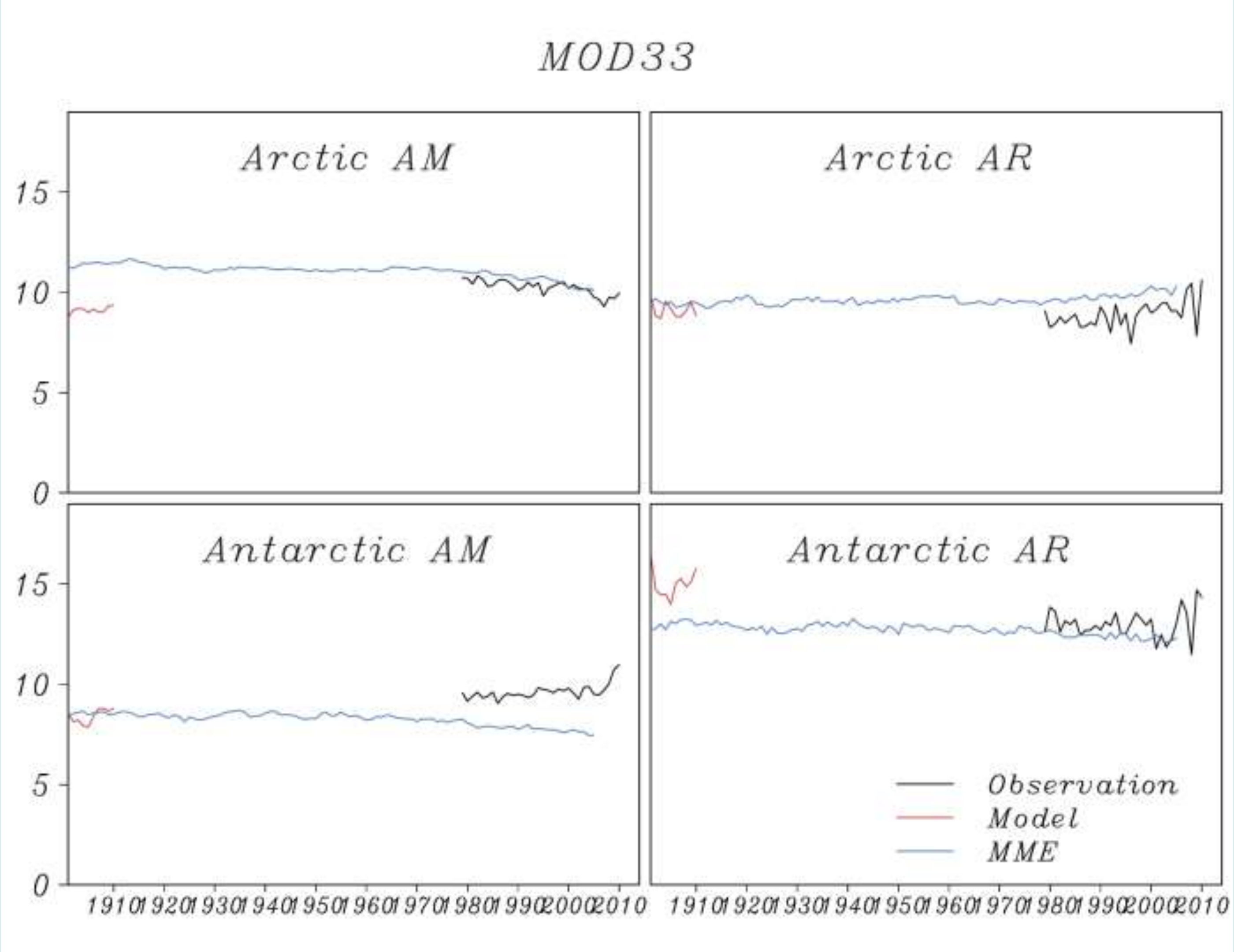
lhflx(land) AC
NRMSE
PCC
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
ACCESS1-0
BCC-CSM1-1
BNU-ESM
CanAM4
CCSM4
IPSL-CM5B-LR
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
INMCM4
GISS-E2-R
GFDL-CM3
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
GFDL-HIRAM-C360
MRI-CGCM3
HadGEM2-A
NorESM1-M
csmv1a
mod25
mod28
mod31
mod33
mod35a

9. CICE Diagnosis

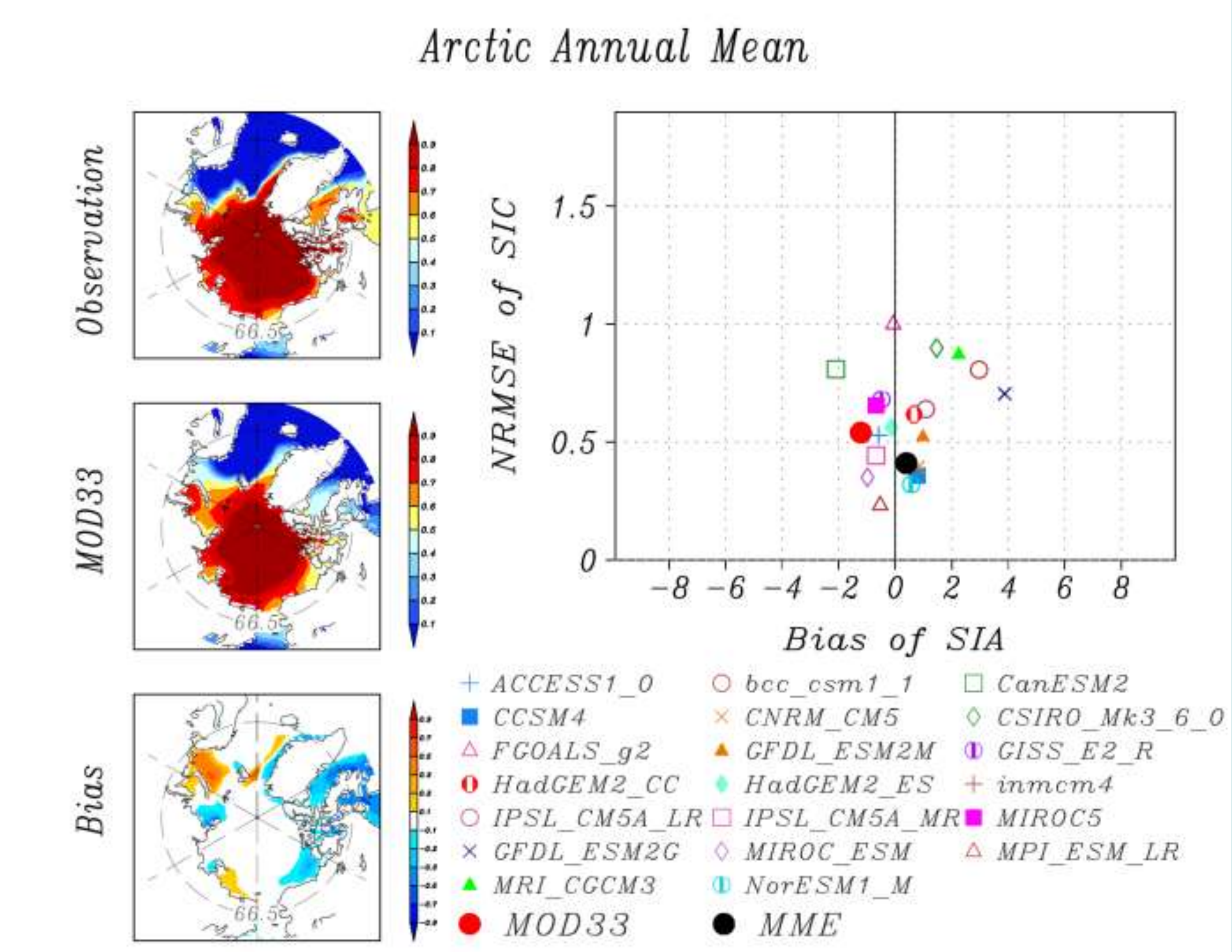
Free Run			Boundary of top 30% of CMIP5 models	Boundary of top 50% of CMIP5 models	CSMv2 (MOD35)	MOD33	V3 (Original)
Arctic	Sea Ice Area (SIA)	AM	0.669	0.811	0.065	−1.247	4.045
		AR	1.387	2.350	−1.273	0.424	−0.187
	Sea Ice Concentration (SIC) NRMSE	AM	0.524	0.618	0.456	0.539	0.873
		Mar	0.526	0.680	0.476	0.575	0.698
		Sep	0.652	0.763	0.870	0.799	1.414
Antarctic	Sea Ice Area (SIA)	AM	1.486	3.349	−0.117	−1.093	−8.373
		AR	1.433	2.332	1.621	2.097	−10.763
	Sea Ice Concentration (SIC) NRMSE	AM	0.777	0.884	0.691	0.780	1.857
		Mar	0.887	1.011	0.934	1.077	1.170
		Sep	0.811	0.880	0.618	0.687	2.097
Red:Reach Top 30% Green:Reach top 50% Blue:Not Reach top 50%							

MOD33 and V3-Original

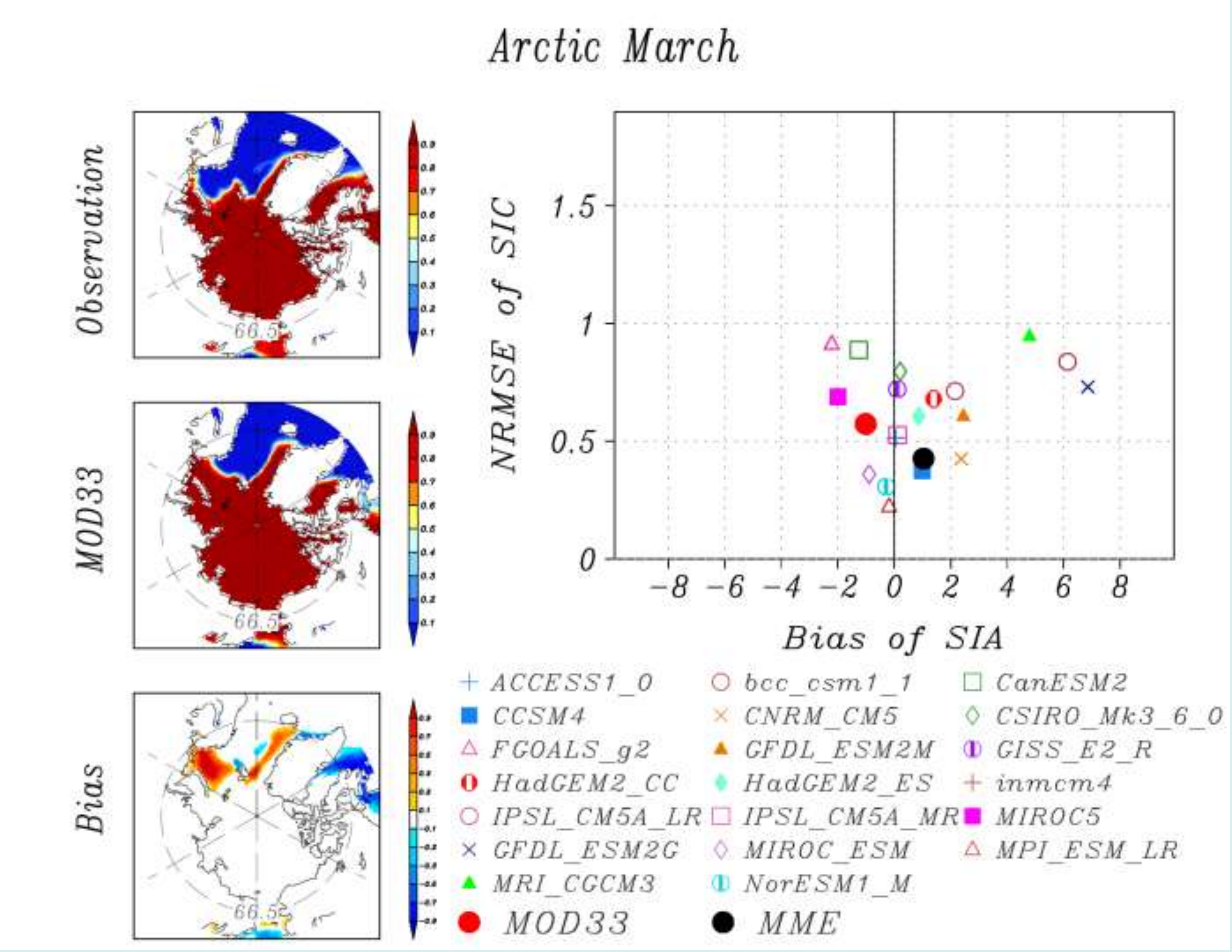


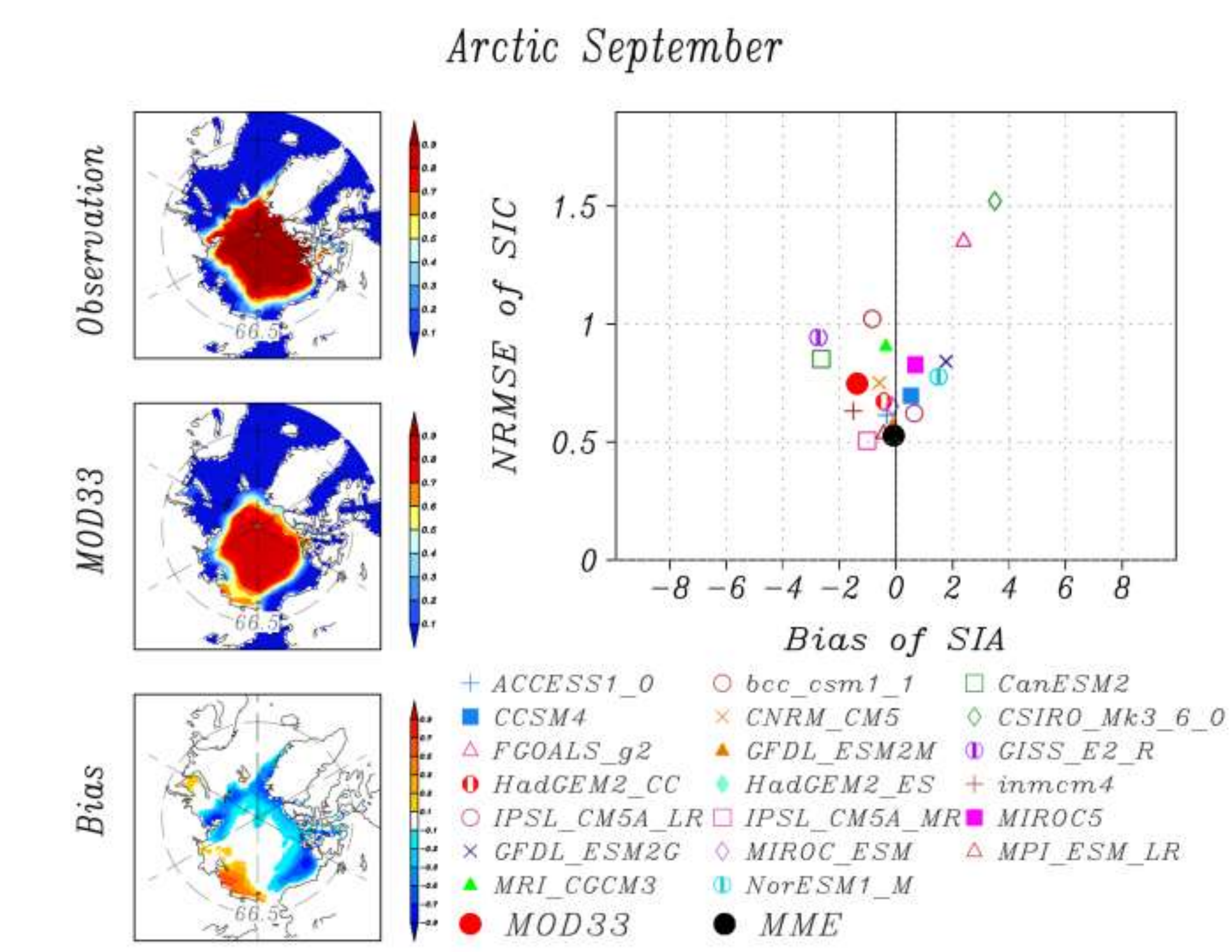


MOD33
Arctic AM
Arctic AR
Antarctic AM
Antarctic AR
0
5
10
15
0
5
10
15
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Observation
Model
MME

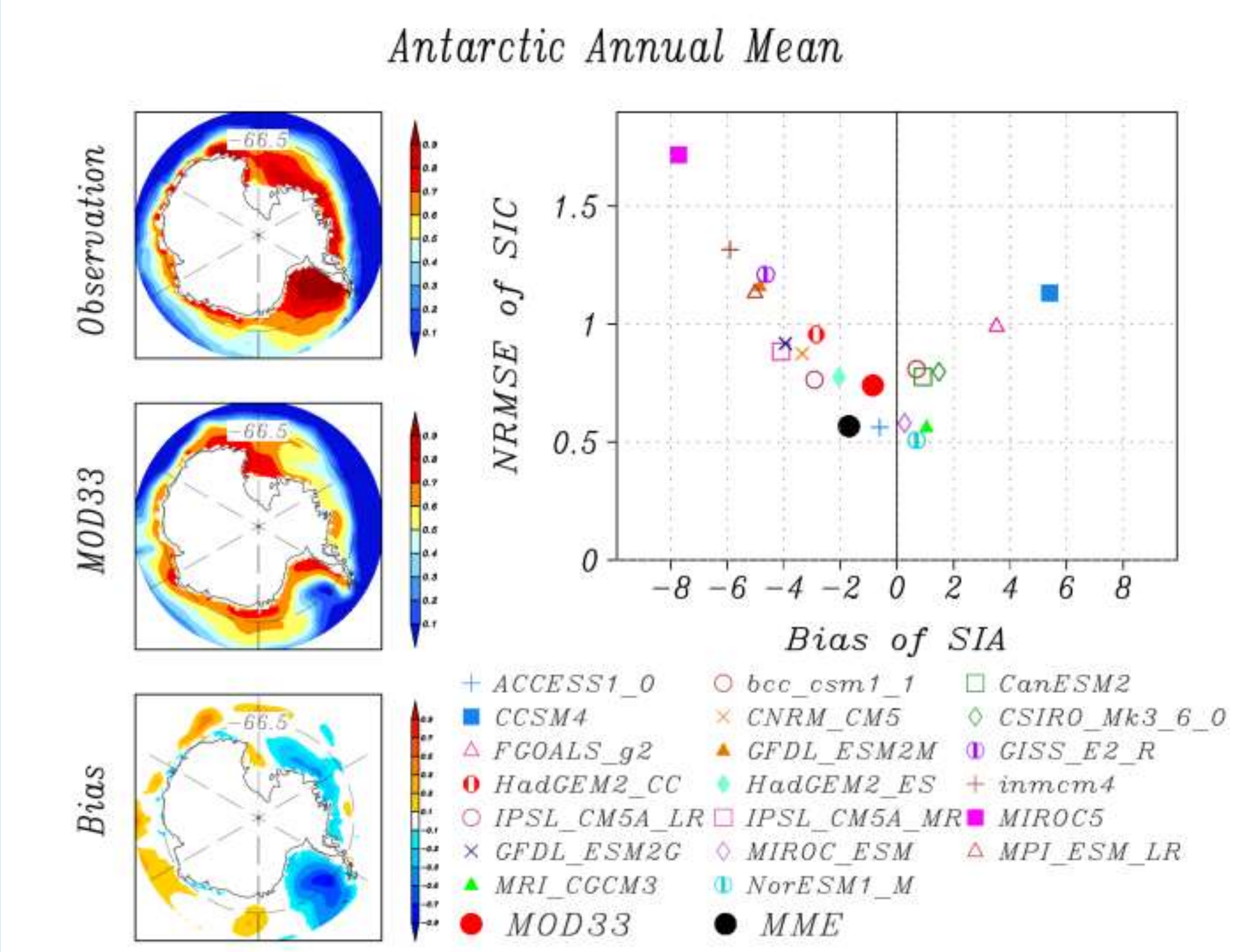


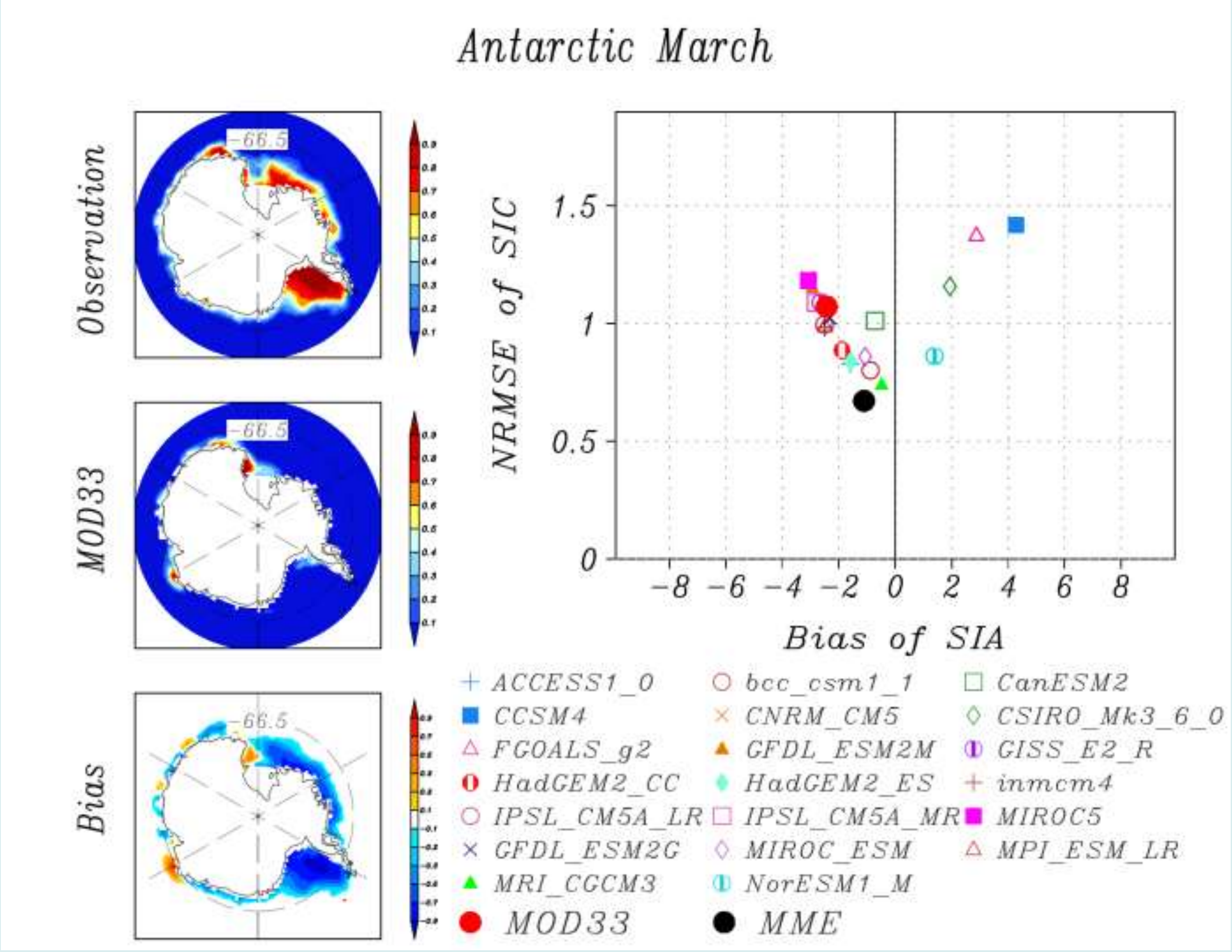
Arctic Annual Mean
Observation
MOD33
Bias
66.5
NRMSE of SIC
Bias of SIA
1.5
1
0.5
0
−8 −6 −4 −2 0 2 4 6 8
ACCESS1_0
bcc_csm1_1
CanESM2
CCSM4
CNRM_CM5
CSIRO_Mk3_6_0
FGOALS_g2
GFDL_ESM2M
GISS_E2_R
HadGEM2_CC
HadGEM2_ES
inmcm4
IPSL_CM5A_LR
IPSL_CM5A_MR
MIROC5
GFDL_ESM2G
MIROC_ESM
MPI_ESM_LR
MRI_CGCM3
NorESM1_M
MOD33
MME


Arctic March
Observation
MOD33
Bias
66.5
NRMSE of SIC
Bias of SIA
0
0.5
1
1.5
−8
−6
−4
−2
0
2
4
6
8
ACCESS1_0
bcc_csm1_1
CanESM2
CCSM4
CNRM_CM5
CSIRO_Mk3_6_0
FGOALS_g2
GFDL_ESM2M
GISS_E2_R
HadGEM2_CC
HadGEM2_ES
inmcm4
IPSL_CM5A_LR
IPSL_CM5A_MR
MIROC5
GFDL_ESM2G
MIROC_ESM
MPI_ESM_LR
MRI_CGCM3
NorESM1_M
MOD33
MME

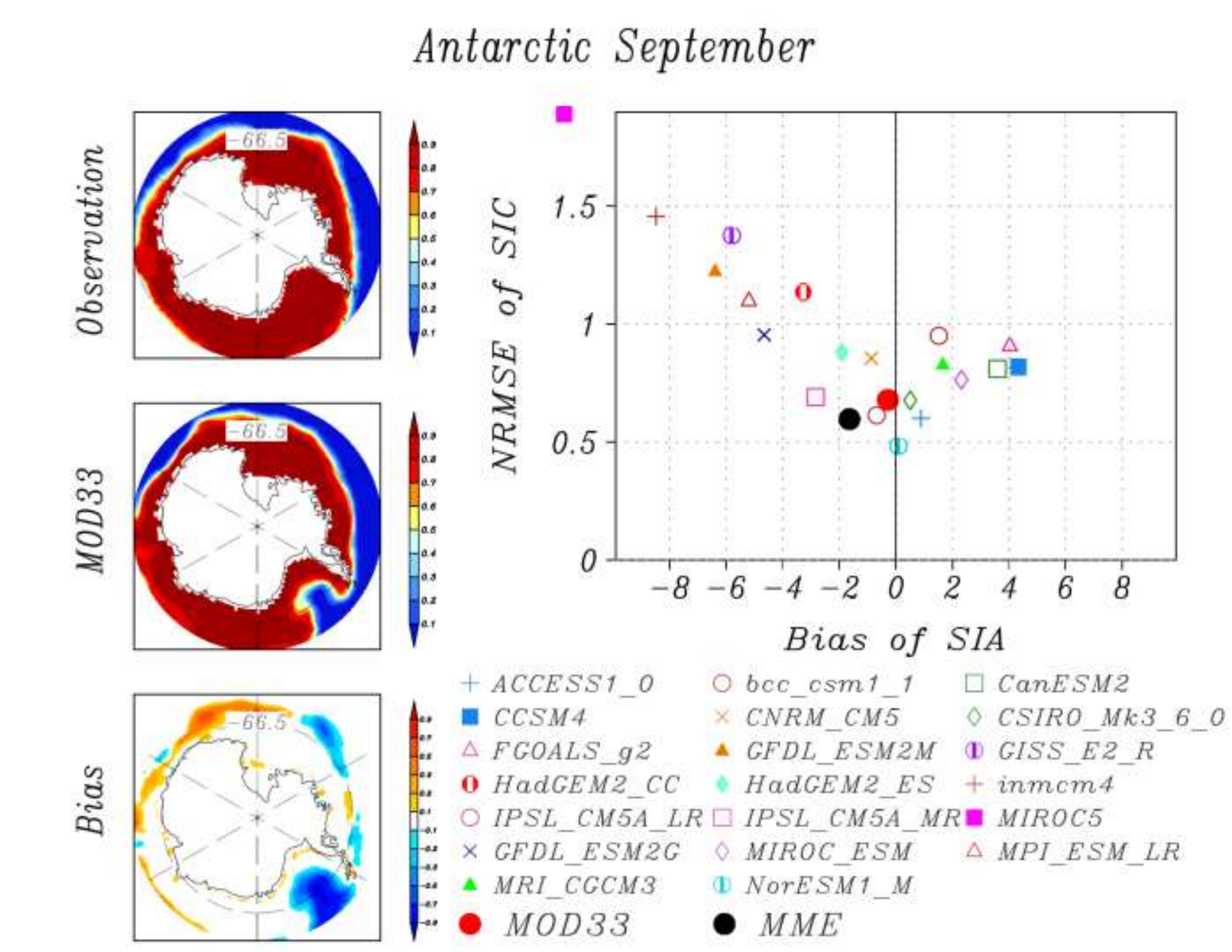


Arctic September
Observation
MOD33
Bias
66.5
NRMSE of SIC
Bias of SIA
0
0.5
1
1.5
−8 −6 −4 −2 0 2 4 6 8
ACCESS1_0
bcc_csm1_1
CanESM2
CCSM4
CNRM_CM5
CSIRO_Mk3_6_0
FGOALS_g2
GFDL_ESM2M
GISS_E2_R
HadGEM2_CC
HadGEM2_ES
inmcm4
IPSL_CM5A_LR
IPSL_CM5A_MR
MIROC5
GFDL_ESM2G
MIROC_ESM
MPI_ESM_LR
MRI_CGCM3
NorESM1_M
MOD33
MME


Antarctic Annual Mean
Observation
MOD33
Bias
-66.5
NRMSE of SIC
Bias of SIA
0
0.5
1
1.5
−8 −6 −4 −2 0 2 4 6 8
ACCESS1_0
bcc_csm1_1
CanESM2
CCSM4
CNRM_CM5
CSIRO_Mk3_6_0
FGOALS_g2
GFDL_ESM2M
GISS_E2_R
HadGEM2_CC
HadGEM2_ES
inmcm4
IPSL_CM5A_LR
IPSL_CM5A_MR
MIROC5
GFDL_ESM2G
MIROC_ESM
MPI_ESM_LR
MRI_CGCM3
NorESM1_M
MOD33
MME



Antarctic March
Observation
MOD33
Bias
-66.5
NRMSE of SIC
Bias of SIA
0
0.5
1
1.5
−8 −6 −4 −2 0 2 4 6 8
ACCESS1_0
bcc_csm1_1
CanESM2
CCSM4
CNRM_CM5
CSIRO_Mk3_6_0
FGOALS_g2
GFDL_ESM2M
GISS_E2_R
HadGEM2_CC
HadGEM2_ES
inmcm4
IPSL_CM5A_LR
IPSL_CM5A_MR
MIROC5
GFDL_ESM2G
MIROC_ESM
MPI_ESM_LR
MRI_CGCM3
NorESM1_M
MOD33
MME



Antarctic September
Observation
MOD33
Bias
-66.5
NRMSE of SIC
Bias of SIA
ACCESS1_0
bcc_csm1_1
CanESM2
CCSM4
CNRM_CM5
CSIRO_Mk3_6_0
FGOALS_g2
GFDL_ESM2M
GISS_E2_R
HadGEM2_CC
HadGEM2_ES
inmcm4
IPSL_CM5A_LR
IPSL_CM5A_MR
MIROC5
GFDL_ESM2G
MIROC_ESM
MPI_ESM_LR
MRI_CGCM3
NorESM1_M
MOD33
MME

Summary:

MOD34 is based on MOD33

Major problems:

1 Seasonal shifts of annual cycle in both Arctic and Antarctic regions. It also causes the bias of the sea ice concentration on March and September.

2 The bias of mean state of sea ice area in Antarctic (about -2 million km^2)

The performance of MOD34a and MOD34b are almost similar. Version b is a little better in Arctic and a little worse in Antarctic. The major problem is still the seasonal shift problem.

End