Simulation of Inter-annual Variability of East Asian Summer: Does Air-Sea Coupling Improve the performance?

Tianjun ZHOU

Email: zhoutj@lasg.iap.ac.cn

WCRP-JNU Training School on Monsoon Variability in Changing Climate

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Outline

- Background
- CMIP3 & CMIP5 AGCMs
- CMIP5 CGCMs
- Summary
Summer monsoon circulation and rainband: The simulation of E Asian summer monsoon has been a rigorous test for climate models.
Bias of monsoon rainfall in CAM3

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

- mean state
- Interannual variability
Outline

- Background
- CMIP3 & CMIP5 AGCMs
- CMIP5 CGCMs
- Summary
• 13 CMIP3 and 19 CMIP5 AMIP experiments.

• Observational and reanalysis data:
  – NCEP2: 850 hPa wind, air temperature;
  – GPCP: precipitation;
  – ERSST: SST;


• All the datasets are interpolated onto common grid 2.5°x2.5°

JJA mean UV850 and precipitation in CMIP3&5 models

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

Large bias of JJA rainfall in CMIP3 AGCM

CMIP3 AGCM MME minus Observation
Large bias of JJA rainfall in CMIP5 AGCM

CMIP5 AGCM MME minus Observation
Metric: Observed changes of monsoon in El Nino decaying year summer

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


- Southward shifts of the W. Pacific Anticyclone and the associated rainfall anomalies over EA; Similar bias in CMIP3 & CMIP5 models
The ridge shifts southward in CMIP3 & CMIP5 models.

Intensity of the WPAC

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

Outline

◆ Background

◆ CMIP3 & CMIP5 AGCMs

◆ CMIP5 CGCMs

◆ Summary
Model and Data

• 17 CMIP5 AGCMs and corresponding CGCMs are analyzed

• Observational and reanalysis data:
  – NCEP2&ERA40; GPCP&CMAP; ERSST

• the period for the comparison between AGCMs and CGCMs is 1979-2005

• All the datasets are interpolated into common grid 2.5°x2.5°

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

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

- Colder SST bias -> enhanced WPSH

• **CGCM**: less bias in precipitation and wind

• **AGCM**: positive bias over the western Pacific

• **From AGCM to CGCM**: better precipitation in the western Pacific

**CGCM:** SSTA over TEIO is warmer than the OBS.

- Warmer TEIO SSTA -> more precipitation -> stronger Kelvin wave response as W. Pac AC -> enhanced EASM simulation.

- Local colder SST over the W. Pac also enhances the W. Pac AC

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*Song, F., T. Zhou, 2014b. Journal of Climate*
SST (shading), wind and rainfall (contour) composite fields in 35 CMIP5 CGCMs

(a) Observation

(b) MME

(c) High-skill models

(d) Low-skill models

-0.6 -0.25 -0.05 0.15 0.4
Summary

◆ **Biases of AGCM:**

Northward shift of the WP subtropical high in mean state;

Southward shift of the WP AC in interannual variability.

◆ **Improvements of CGCM**

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

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

◆ **Dynamics:**

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


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


Thanks

www.lasg.ac.cn/staff/ztj
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Pattern correlation coefficients: precipitation vs. 850 hPa wind

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

Song, F., T. Zhou, 2014a, *Journal of Climate*
The temporal phase of the EASM is reasonably reproduced in CMIP3 (0.70) and CMIP5 MME (0.68).

The temporal correlation is also independent of horizontal resolution.

Song, F., T. Zhou, 2014a, *Journal of Climate*
Two main deficiencies of rainfall pattern simulation also exist: weaker magnitude and more southward shift; The magnitude in rainfall pattern is improved from CMIP3 to CMIP5.

• Two main deficiencies of rainfall pattern simulation also exist: weaker magnitude and more southward shift;

• The magnitude in rainfall pattern is improved from CMIP3 to CMIP5.

Song, F., T. Zhou, 2014a, *Journal of Climate*
Inter-annual variability mode of EASM in CMIP3 AGCMs

Two evident features: western Pacific anti-cyclone (WPAC) and dipole rainfall pattern;

The WPAC is better reproduced than the dipole rainfall pattern;

Two deficiencies: the weaker and southward shift of the dipole rainfall pattern.

850 hPa wind and precipitation regressed on the observed EASM index

Song, F., T. Zhou, 2014a, Journal of Climate
JJA mean UV850 and precipitation in CMIP3 models

- Monsoon rainband poorly simulated
- Bias in subtropical high

Song, F., T. Zhou, 2014a, *Journal of Climate*
JJA mean UV850 and precipitation in CMIP5 models

- Similar bias as CMIP3

Song, F., T. Zhou, 2014a, Journal of Climate
The skill score formula for inter-annual variability pattern

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

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

(Hirota et al., 2011)
### The composite models based on precipitation skill

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Song, F., T. Zhou, 2014a, *Journal of Climate*
SST (shading), wind and rainfall (contour) in El Nino decaying year summers

Contours:
- rainfall (green: positive; purple: negative)
- warmer IO
- more rainfall
- Kelvin wave response in the east, viz. WNPAC
- Improvement from CMIP3 to CMIP5 models

Song, F., T. Zhou, 2014a, Journal of Climate
North Indian Ocean (NIO) rainfall skill and equator zonal wind skill vs. EASM skill

(a) Rainfall Response vs EASM

(b) Kelvin Wave Response vs EASM

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

Red: Both the AMIP and CGCM historical run in these models are used.
Bias of CGCM resembles that of AGCM: cyclone bias over WNP and negative (positive) rainfall biases over monsoon rain band (WNP).

Improvement from AGCMs to CGCMs: enhanced WNPSH; better monsoon rainband and WNP precipitation.

Pattern Correlation is improved from 0.71 to 0.85 from AGCMs to CGCMs for precipitation, from 0.81 to 0.91 for 850 wind.

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

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

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

**High-skill models (8):**
- BNU-ESM, CCSM4, CESM1-BGC,
- CESM1-CAM5-1-FV2, FGOALS-g2,
- MRI-CGCM3, NorESM1-M,
- NorESM1-ME.

**Low-skill models (8):**
- ACCESS1-0, ACCESS1-3, CSIRO-Mk3-6-0, GFDL-ESM2G,
- HadGEM2-CC, inmcm4, MPI-ESM-LR, MPI-ESM-MR.
In the observation, the stronger EASM is related to the warmer TIO SST and cooler CP SST. However, in the CMIP5 MME, the TIO warming is weaker but CP cooling is stronger.

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

Song, F., T. Zhou, 2014b, Journal of Climate
• In the high-skill models, the observed magnitude and evolution of ENSO is well captured, while the SST in the preceding winter in the low-skill models is not corresponding to ENSO. (CSIRO-Mk3-6-0, inmcm4, MPI-ESM-LR, MPI-ESM-MR)
EA summer monsoon index defined as wind shear along WPSH

- Correlation coefficients for CMIP3 (0.70) and CMIP5 MME (0.66).
- Comparable
Tropospheric temperature and 200 hPa wind regressed on the observed EASM index

- In the observation, Indian Ocean (IO) appears as the heat source for Gill pattern, with Rossby wave to the west and Kelvin wave to the east;

- The Gill-pattern shape and high-level Kelvin wave response is better capture in high-skill models.