Multi-Model Ensemble Coupled Prediction for Monsoon Prediction

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Contributors

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Content

Introduction

The monsoon precipitation is a principal atmospheric heat source that drives tropical and extratropical circulation and has profound impacts on agricultural planning and water resource management. Thus, **reliable prediction of the seasonal variation in monsoon system is one of the most important and challenging tasks in climate system.**

Limitation and challenges still remain in seasonal prediction of monsoon precipitation in spite of the fact that global climate models have made ground-breaking progress in the past two decades.

*The **CliPAS** (Climate Prediction and its Application to Society) team has advanced our understanding of*

- ***the current status and challenges of MME seasonal prediction through assessment of 19 models' two-decade long hindcast.***
- ***what can be expected to be predicted, which is a prerequisite to efforts in climate prediction.***

International Programs for Seasonal Climate Hindcast Experiments

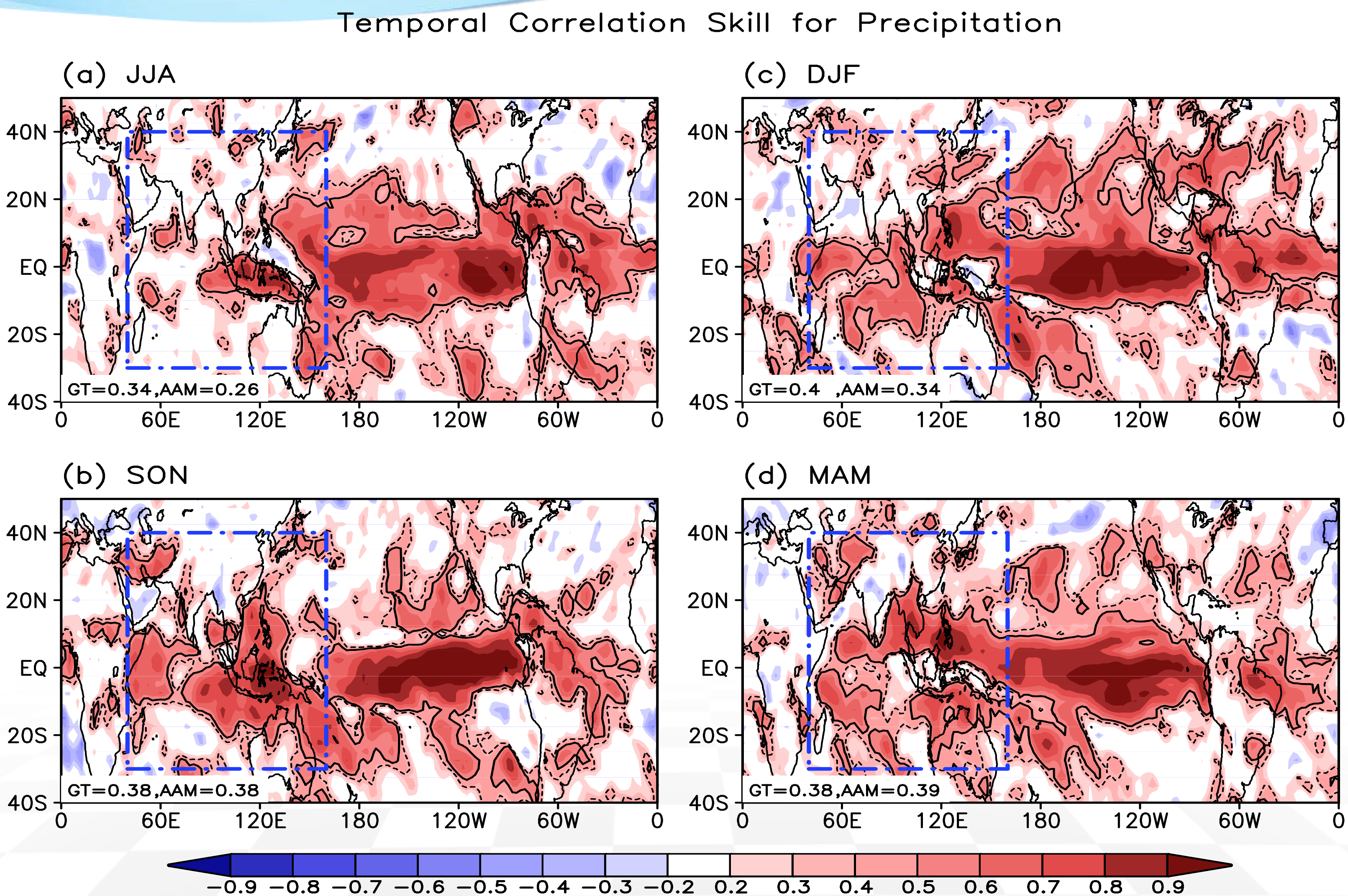
CliPAS

CliPAS Climate Prediction and its Application to Society (Wang et al. 2009; Lee et al. 2010)	7 coupled and 7 atmospheric only models (1981-2004)
APCC APEC Climate Center hindcast and real-time MME (Min et al. 2011; Sohn et al 2011)	5 coupled and 8 atmospheric only models (Hindcast: 1983-2003 Real-time Forecast: 2006-2011)
DEMETER Development of a European Multi-model Ensemble system for seasonal to inTERannual prediction (Palmer et al. 2004)	7 coupled models (1980-2001)
ENSEMBLES ENSEMBLE-based predictions of climate changes and their impactS (Weisheimer et al. 2009; Alessandri et al. 2011)	5 coupled models (1960-2005)

The CliPAS-ENSEMBLES MME System

Institute	Model Name	AGCM	OGCM	Ensemble member	Reference
BMRC	POAMA1.5	BAM 3.0d T47 L17	ACOM3 0.5-1.5º lat x 2.0º lon L31	10	Zhong et al (2005)
GFDL	CM2.1	AM2.1 2ºlat x 2.5ºlon L24	MOM4 1/3ºlat x 1ºlon L50	10	Delworth et al (2006)
NCEP	CFS	GFS T62 L64	MOM3 1/3ºlat x 5/8ºlon L27	15	Saha et al (2006)
SNU	SNU	SNU T42L21	MOM2.2 1/3ºlat x 1ºlon L40	6	Kug et al (2008)
CMCC-INGV	CMCC	ECHAM5 T63 L19	OPA 8.2 2.0º x2.0º L31	9	Alessandri et al (2011) Pietro and Masina (2009)
ECMWF	ECMWF	IFS CY31R1 T159 L62	HOPE-E 1.4º x 0.3º-1.4º L29	9	Stockdale et al. (2011) Balmaseda et al. (2008)
IFM-GEOMAR	IFM	ECHAM4 T42 L19	OPA 8.2 2.0º lat x 2.0º lon L31	9	Keenlyside et al. (2005) Jungclaus et al. (2006)
MF	MF	IFS T95 L40	OPA 8.0 182GPx152GP L31	9	Daget et al. (2009) Salas Melia (2002)
UKMO	UKMO	ECHAM5 T42 L19	MPI-OM1 2.5º lat x 0.5º-2.5º lon L23	9	Collins et al. (2008)

Current Status of Monsoon Prediction Seasonal Anomaly



The one-month lead seasonal prediction skill for the state-of-the-art **9 coupled models' multi-model ensemble (MME)** prediction from **CliPAS** and **ENSEMBLES (1981-2005)**

Current Status of Monsoon Prediction Seasonal Anomaly

Forecast Skill

- Although the ENSO, a dominant predictability source of global seasonal prediction, is reasonably well predicted, **the seasonal precipitation prediction over the A-AM region is very poor, particularly during local summer over land.**

- The spatial patterns of the AROC skill are very similar to the MME TCC skills and the AROC score of 0.7 is roughly 0.5~0.6 in the TCC skill for the deterministic forecast. The variations in the spatial patterns and the seasonality of the TCC and AROC skill suggest that **the ENSO is the primary predictability source of the tropical seasonal precipitation.**

- While coupled models have difficulty in predicting summer mean precipitation anomalies over the ASM region even for a 0-month lead forecast, they are **capable of predicting zonal wind anomalies at 850-hPa** several months ahead and, consequently, satisfactorily **predict summer monsoon circulation indices for the EA region (EASMI) and for the WNP region (WNPSMI).**

Current Status of Monsoon Prediction
Seasonal Anomaly / Source of Predictability

Dependence on ENSO Strength and Phase

- **The prediction skills highly depend on the strength and phases of ENSO**. The MME PCC skill for precipitation is well correlated with the amplitude of NIÑO 3.4 SST variation especially in the boreal winter with a correlation coefficient 0.75. **The anomalous precipitation and circulation are predicted better in the ENSO-decaying JJA than in the ENSO-developing JJA over the WNP-EA region.**

- **The MME well reproduces the observed anomalies of circulation and rainfall with Tropical Indian Ocean (TIO) and South China Sea warming and cooling over southeastern flank of the surface anticyclone in summers after the mature phase of ENSO**. **Local air-sea interaction** (Wang et al. 2001) and **remote forcing by TIO SST variability** (Xie et al. 2010) play an important role on predicting WNP climate during JJA(1).

- **The lagged impacts of ENSO on the Asian summer monsoon (ASM) rainfall** in coupled models provide useful skill over some parts of ASM region for above and below normal events, although the forecast skill decreases with forecast lead time.

Factors for Limiting Monsoon Prediction : Systematic Bias

- **Correction of the inherent bias in the mean state and annual cycle is critical for improving the long-lead seasonal prediction of precipitation** because the skill for individual coupled models in predicting seasonal precipitation anomalies is **positively correlated with** its performances on prediction of the annual mean and annual cycle of precipitation

- The coupled models capture **the gross features of the seasonal march of the rainy season including onset and withdraw of the Asian-Australian monsoon system** over major subdomains, but **striking deficiencies in the coupled model predictions are observed over the South China Sea and WNP region**, where considerable biases exist in both the amplitude and phase of the annual cycle and the summer precipitation amount and its interannual variability are underestimated.

Factors for Limiting Monsoon Prediction : Predictability Limit

Predictability limits for seasonal climate variability depend on the fraction of external and internal variability. From the observed data alone, separation of the total seasonal variance into its external and internal components remains difficult and controversial issue.

How to Estimate Potential Predictability using Multi Models

1. Mean Square Error (MSE) Method (Kumar et al., 2007, J. Climate)

► **Basic Idea**: **The expected value of MSE** is the sum of three terms: **the observed internal variability**, the internal variability of the ensemble mean of model simulations, and a term that is the error in model's anomaly prediction. We can find the minimum value of MSE irrespective of which model it came from at each geographical location, and **the spatial map of the minimum value of MSE is our best estimate for the observed internal variability.**

$$MSE = (M - O)^2 = \sigma_{oi}^2 + \sigma_{mi}^2 + <(\mu_m - \mu_o)^2>$$

► **Limitation**: **Since models have large anomaly errors related to slowly varying boundary forcing, the estimation always underestimates predictability.**

Factors for Limiting Monsoon Prediction : Predictability Limit

How to Estimate Potential Predictability using Multi Models

2. Predictable Mode Analysis
(Wang et al. 2007; Lee et al. 2011; Lee and Wang, in press)

► **Basic Idea**: **PMA** relies on identification of "predictable leading modes of the observed interannual variation using both observation and the state-of-the-art MME hindcast. **The predictability is quantified by the fractional variance accounted for by these "predictable" leading modes.**

► **Reference:**

B. Wang, J.Y. Lee et al., 2007: Coupled predictability of seasonal tropical precipitation. CLIVAR Exchanges, Vol.12, No. 4, 17-18

J.-Y. Lee, B. Wang, Q. Ding et al. 2011: How predictable is the Northern Hemisphere summer upper-tropospheric circulation? Clim Dyn, 37, 1189-1203

J.-Y. Lee and B. Wang, 2012: Seasonal climate predictability of atmospheric circulation. In Climate Models, Ed. Leonard M. Druyan. In press

► **Limitation: The method depends on the identification method of predictable mode and models' quality for capturing major modes of the observed variability.**

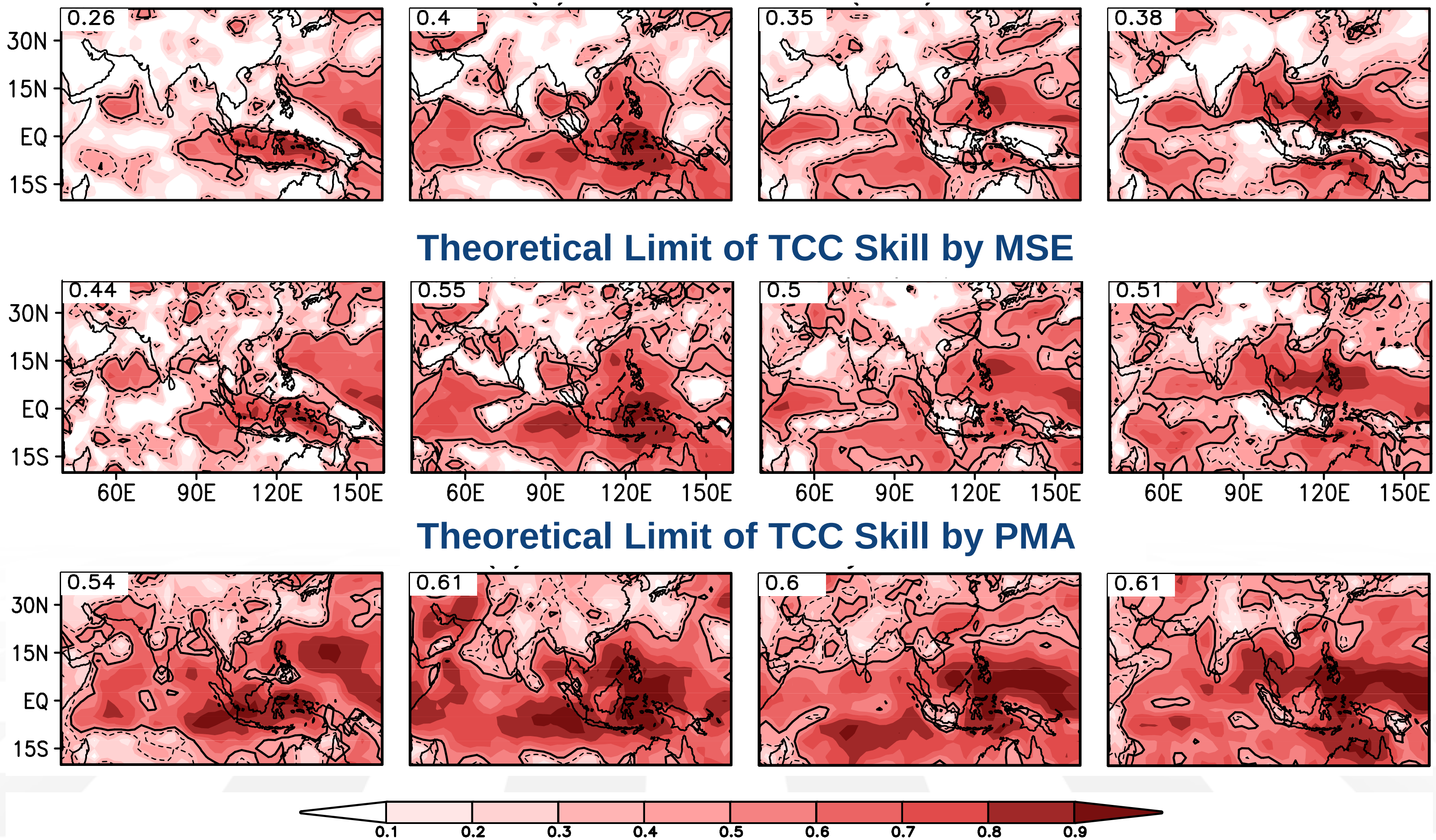
Factors for Limiting Monsoon Prediction
: Predictability Limit

JJA SON DJF MAM

The MME Hindcast Skill (1981-2005)

Theoretical Limit of TCC Skill by MSE

Theoretical Limit of TCC Skill by PMA



Improvement of Climate Prediction

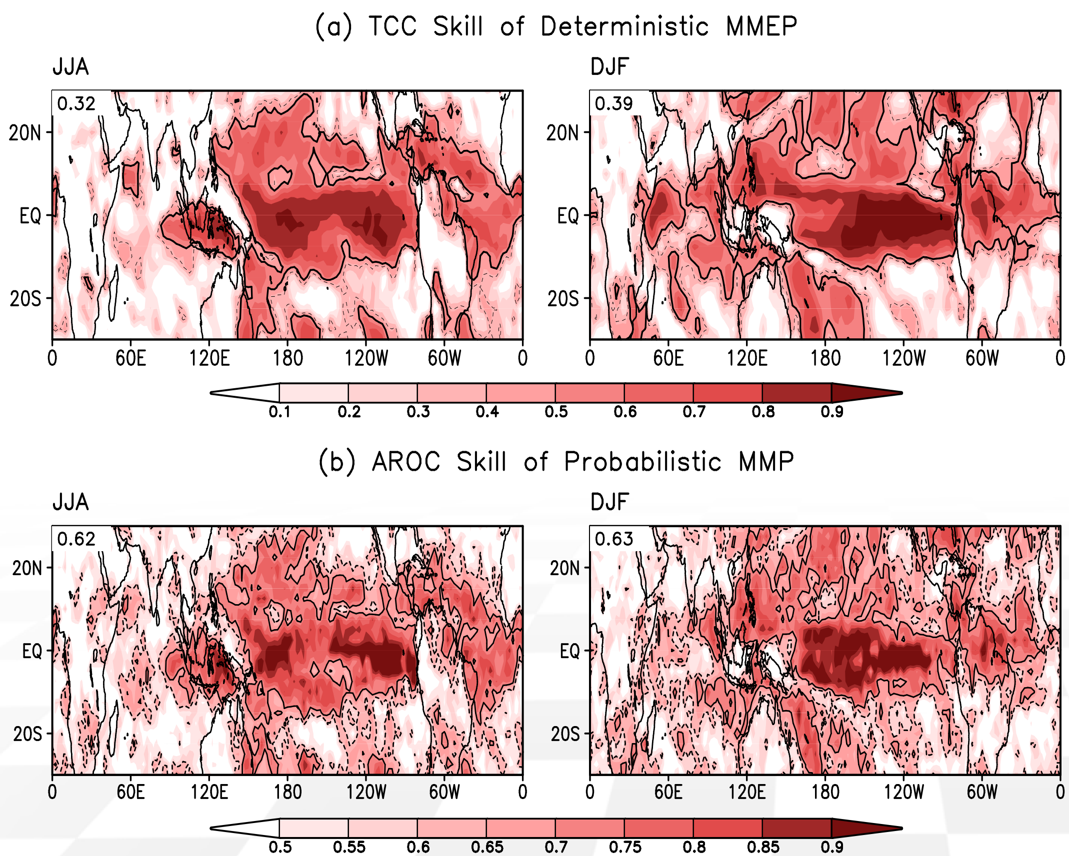
- The MME seasonal prediction skill is superior to that of any of single models, **depending on the averaged skill of individual models and their mutual independency** (Yoo and Kang, 2005, GRL; Wang et al., 2009, Clim Dyn). The MME prediction will be improved by optimal selection of a subgroup of models.

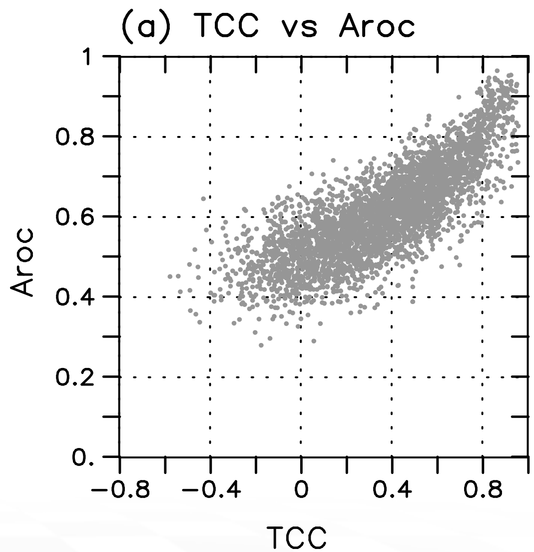
- We have developed a new MME method (MME-SPPM2), whose strengths lie in **a statistical error correction procedure and discreet selection procedure of reliable predictions among all possible candidates**. MME-SPPM2 provides significantly improved skill over the globe as a whole, especially over the land area and extratropical oceans. The conspicuous improvement of the MME-SPPM2 is achieved against other MME methods **over the regions in which the skill of individual models is poor.**

- The new APCC probabilistic multi-model prediction (PMMP) system, which uses the modified SPPM2 in conjunction with a optimal estimation of the forecast uncertainty, has improved the forecast skill for seasonal precipitation in terms of reliability and resolution during both cross-validated hindcast and independent real-time forecast period.

1-Month lead Deterministic vs Probabilistic Forecast Skill CliPAS MME (1981-2004)

- The spatial patterns of the AROC skill are very similar to the MME TCC skills and the AROC score of 0.7 is roughly 0.5~0.6 in the TCC skill for the deterministic forecast. The variations in the spatial patterns and the seasonality of the TCC and AROC skill suggest that **the ENSO is the primary predictability source of the tropical seasonal precipitation.**

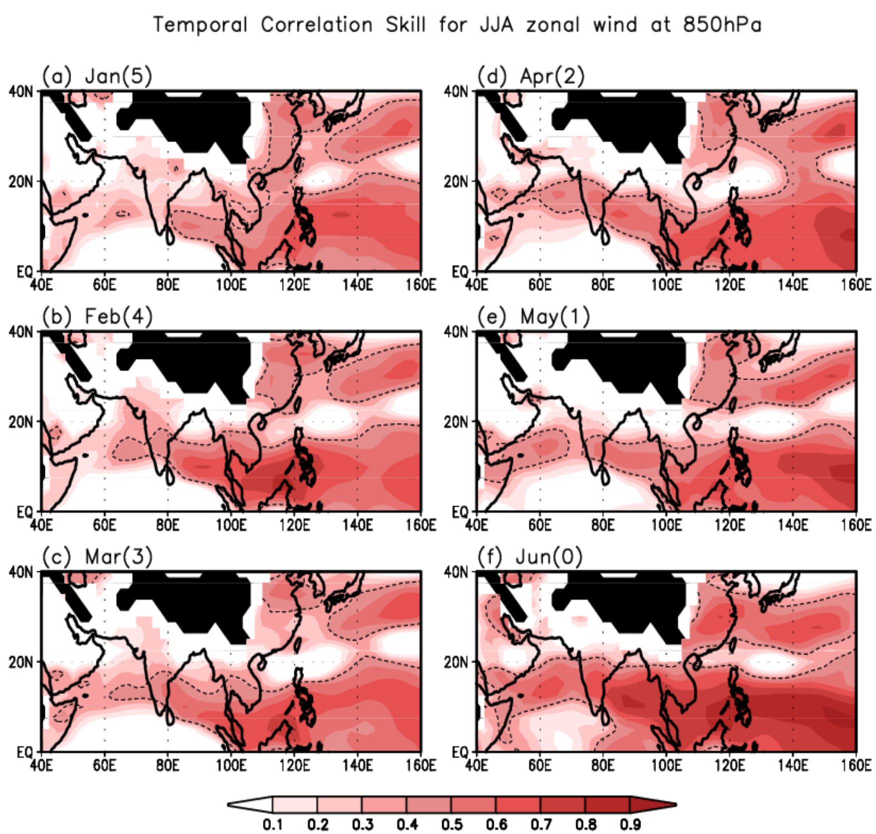




Wang, Bin, June-Yi Lee, J. Shukla, I.-S. Kang, C.-K. Park and et al., 2009: ***Advance and prospectus of seasonal prediction: Assessment of APCC/CliPAS 14-model ensemble retrospective seasonal prediction (1980-2004).*** *Clim. Dyn. 33, 93-117*

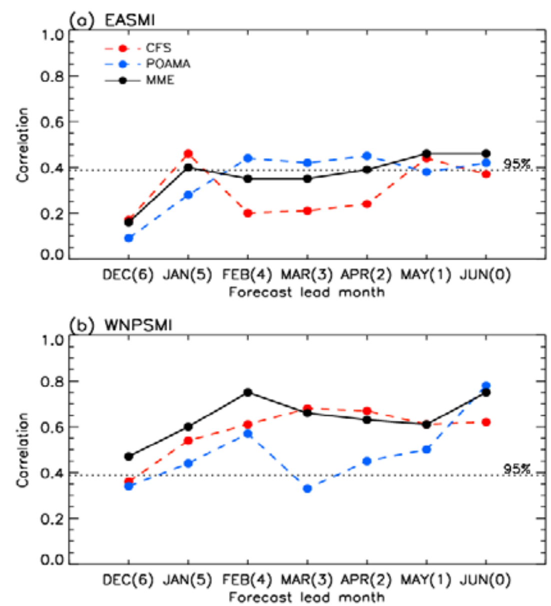
Long-Lead Forecast Skill
CFS and POAMA models (1981-2006)

- While coupled models have difficulty in predicting summer mean precipitation anomalies over the ASM region even for a 0-month lead forecast, they are capable of predicting zonal wind anomalies at 850-hPa several months ahead and, consequently, satisfactorily predict summer monsoon circulation indices for the EA region (EASMI) and for the WNP region (WNPSMI).



EASMI = [U850^2+V850^2]
(127.5º-147.5ºE, 32.5º-37.5ºN)

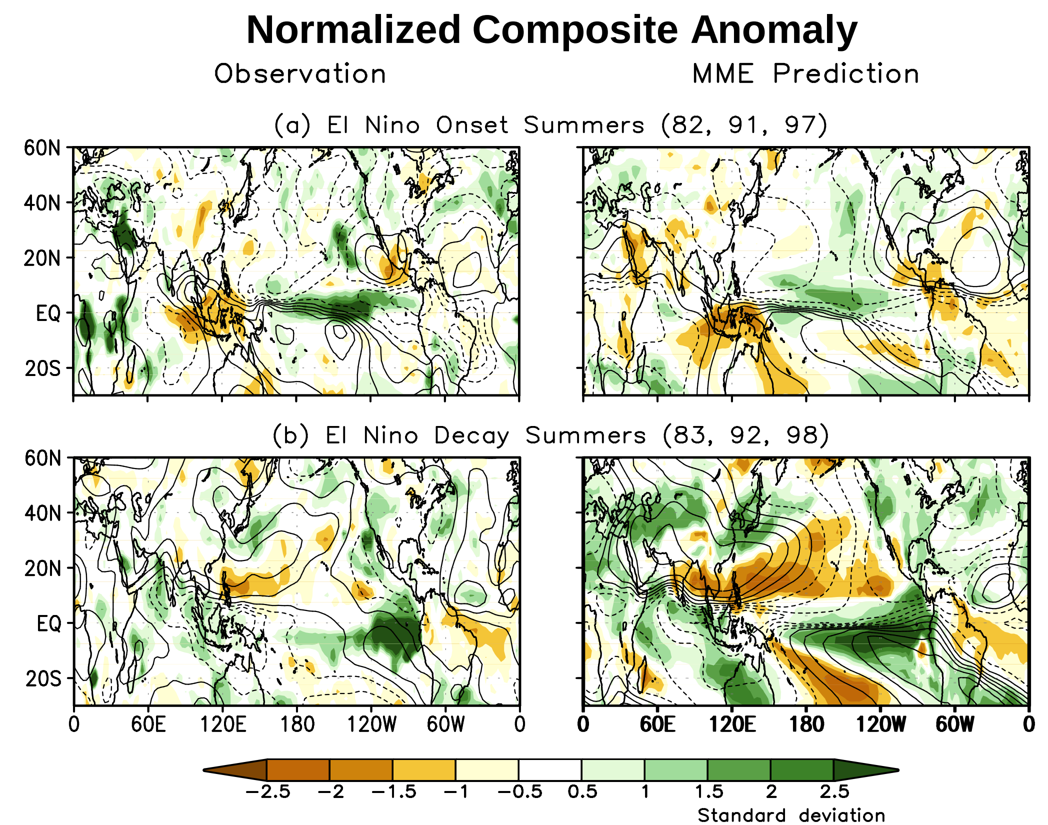
WNPSMI = U850(100º-130ºE, 5º-15ºN)
- U850(110º-140ºE, 20º-30ºN)



Lee, Sun-Seon, June-Yi Lee, K.-J. Ha, B. Wang. J. K. E. Schemm, 2011: ***Deficiencies and possibilities for long-lead coupled climate prediction of the Western North Pacific-East Asian summer monsoon.*** *Clim Dyn, 36, 1173-1188*

Dependence of Forecast Skill on ENSO CliPAS MME (1981-2004)

- **The prediction skills highly depend on the strength and phases of ENSO**. The MME PCC skill for precipitation is well correlated with the amplitude of NIÑO 3.4 SST variation especially in the boreal winter with a correlation coefficient 0.75. The anomalous precipitation and circulation are predicted better in the ENSO-decaying JJA than in the ENSO-developing JJA over the WNP-EA region.



Wang, Bin, June-Yi Lee, J. Shukla, I.-S. Kang, C.-K. Park and et al., 2009: ***Advance and prospectus of seasonal prediction: Assessment of APCC/CliPAS 14-model ensemble retrospective seasonal prediction (1980-2004).*** *Clim. Dyn. 33, 93-117*

ENSO Decaying JJA [JJA(1)] Prediction CliPAS-DEMETER MME (1981-2001)

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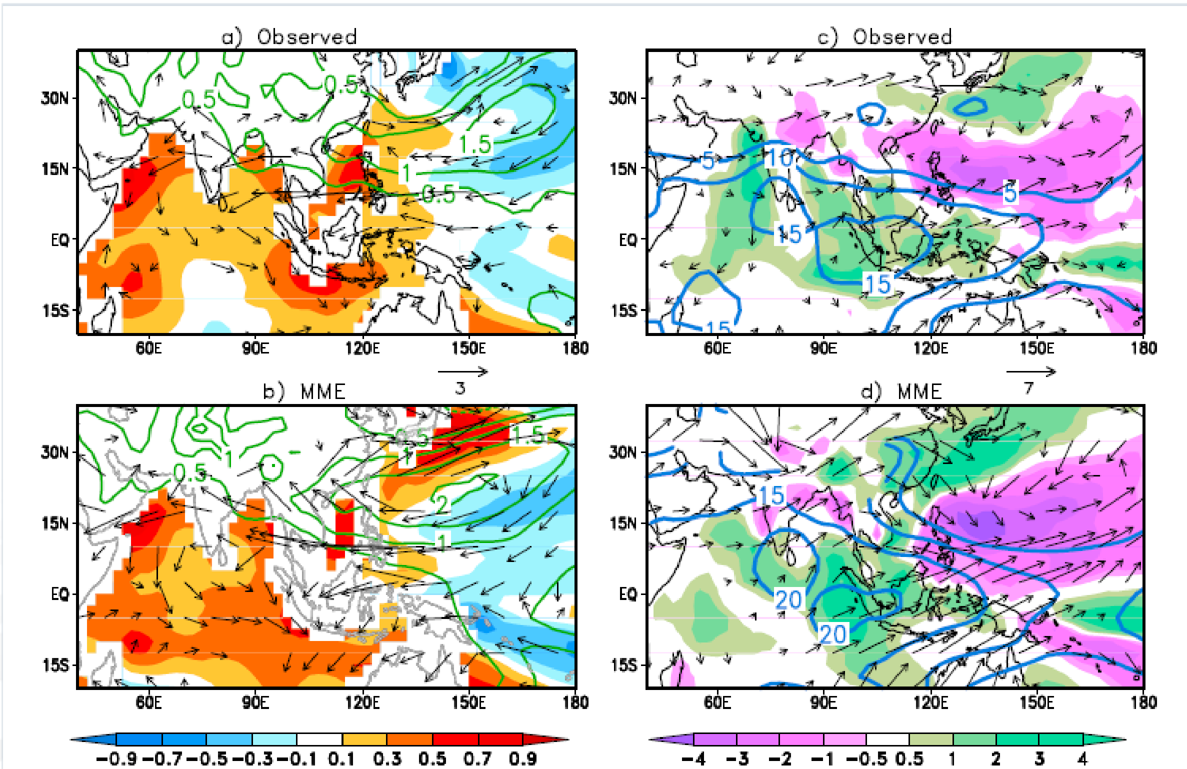
SST (shaded), SLP (Contour), 850-hPa wind (vector)

Precipitation (shaded), Tropospheric Temperature (Contour)



JJA(1) composite (1983, 1992, 1998)

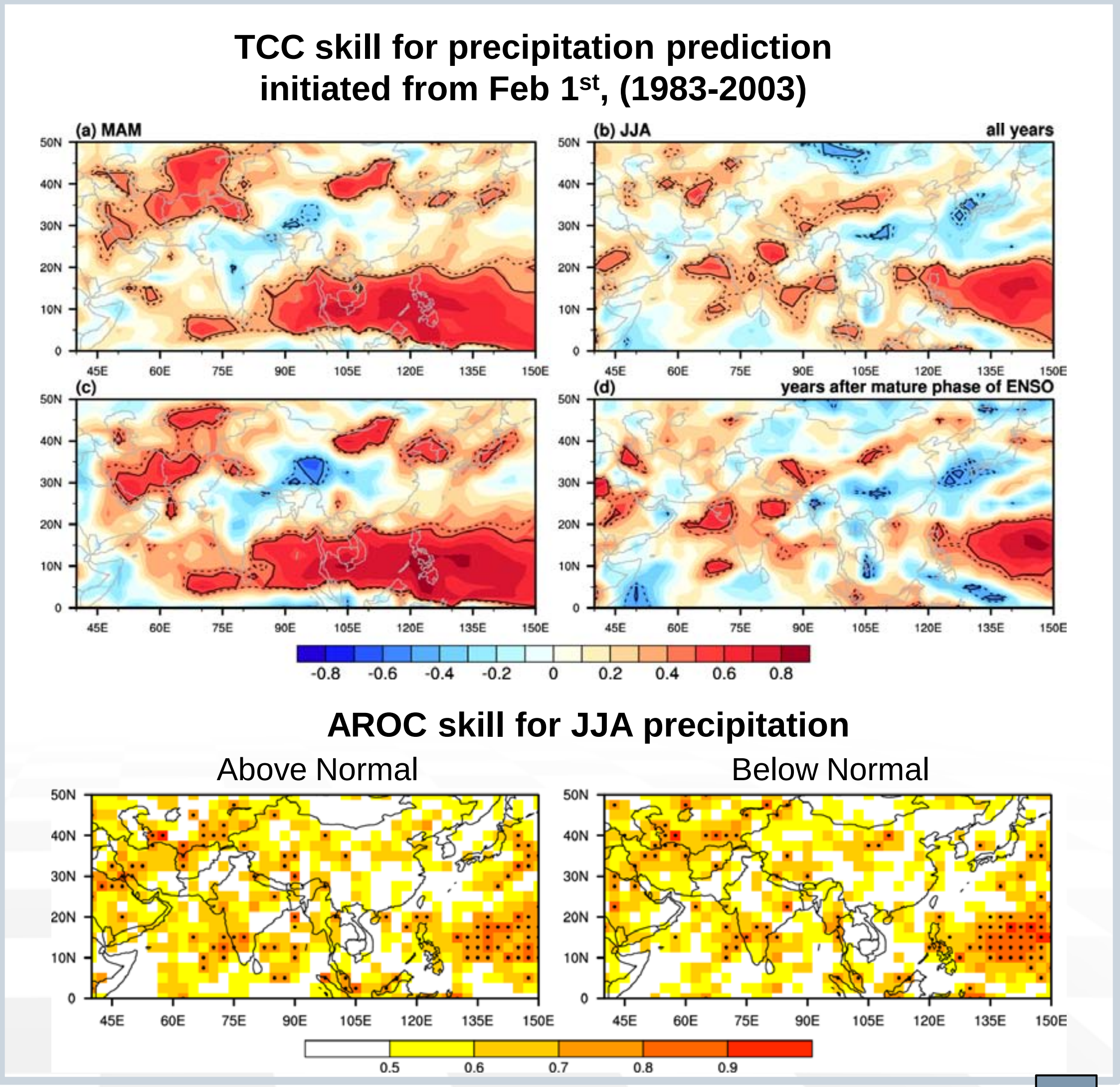
Chowdary, J., S.-P. Xie, J.-Y. Lee, Y. Kosaka, and B. Wang, 2010: ***Predictability of summer Northwest Pacific climate in eleven coupled model hindcasts: local and remote forcing****. J. Geophys. Res., 115, D22121*

Long-Lead Forecast Skill
APCC Hindcast (1983-2003)

- The lagged impacts of ENSO on the Asian summer monsoon (ASM) rainfall in coupled models provide useful skill over some parts of ASM region for above and below normal events, although the forecast skill decreases with forecast lead time.

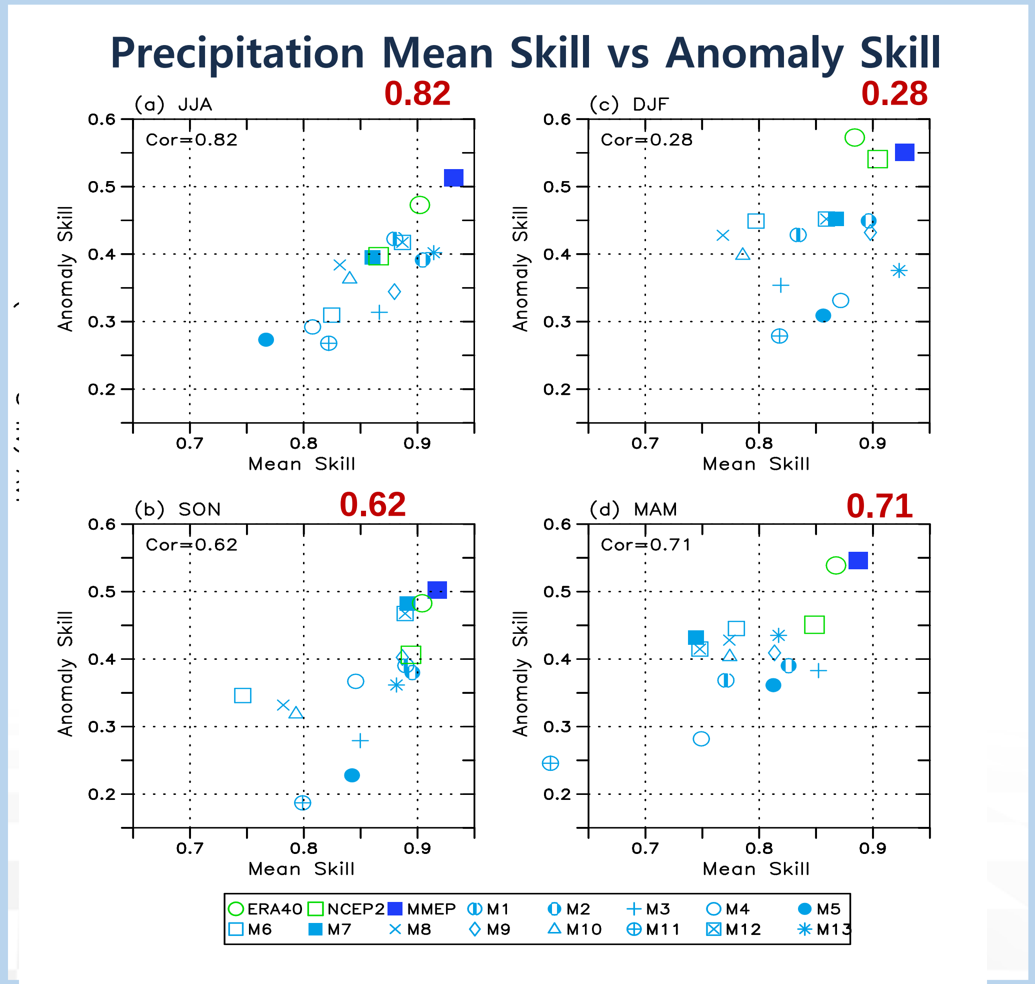
- APCC coupled MME prediction initiated from Feb 1st for 21 years of 1983-2003.

Sohn, S.-J., Y.-M. Min, J.-Y. Lee, C.-Y. Tam et al. 2011: ***Assessment of probabilistic long-lead prediction of the APCC multi-model system and statistical model for the Asian summer monsoon precipitation (1983-2010).*** *Submitted to JGR (revision)*



Mean Performance vs Anomaly Prediction:
CliPAS-DEMETER MME (1981-2001)

- **Correction of the inherent bias in the mean state and annual cycle is critical for improving the long-lead seasonal prediction of precipitation** because the skill for individual coupled models in predicting seasonal precipitation anomalies is **positively correlated with** its performances on prediction of the annual mean and annual cycle of precipitation

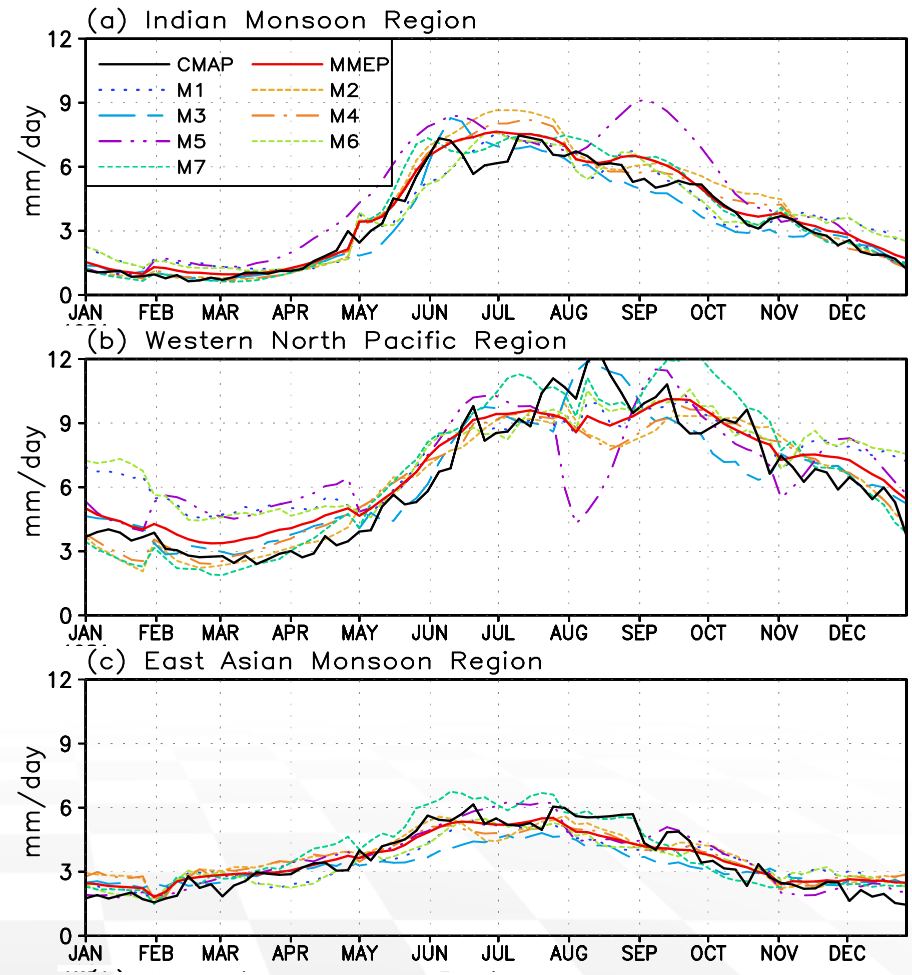


Lee, June-Yi, B. Wang, I.-S. Kang, J. Shukla et al., 2010: ***How are seasonal prediction skills related to models' performance on mean state and annual cycle? Clim. Dyn, 35, 267-283***

Mean Performance vs Anomaly Prediction:
DEMETER MME (1981-2001)

- The coupled models capture **the gross features of the seasonal march of the rainy season including onset and withdraw of the Asian-Australian monsoon system** over major subdomains, but **striking deficiencies in the coupled model predictions are observed over the South China Sea and WNP region**, where considerable biases exist in both the amplitude and phase of the annual cycle and the summer precipitation amount and its interannual variability are underestimated.

Indian Monsoon
[IM, 5-30°N, 60-105°E]
Western North Pacific Monsoon
[WNPM, 5-20°N, 105-160°E]
East Asian Monsoon
[EAM, 20-45°N, 110-140°E]



*Lee, June-Yi, B. Wang, I.-S. Kang, J. Shukla et al., 2010**: How are seasonal prediction skills related to models' performance on mean state and annual cycle?*** *Clim. Dyn, 35, 267-283*

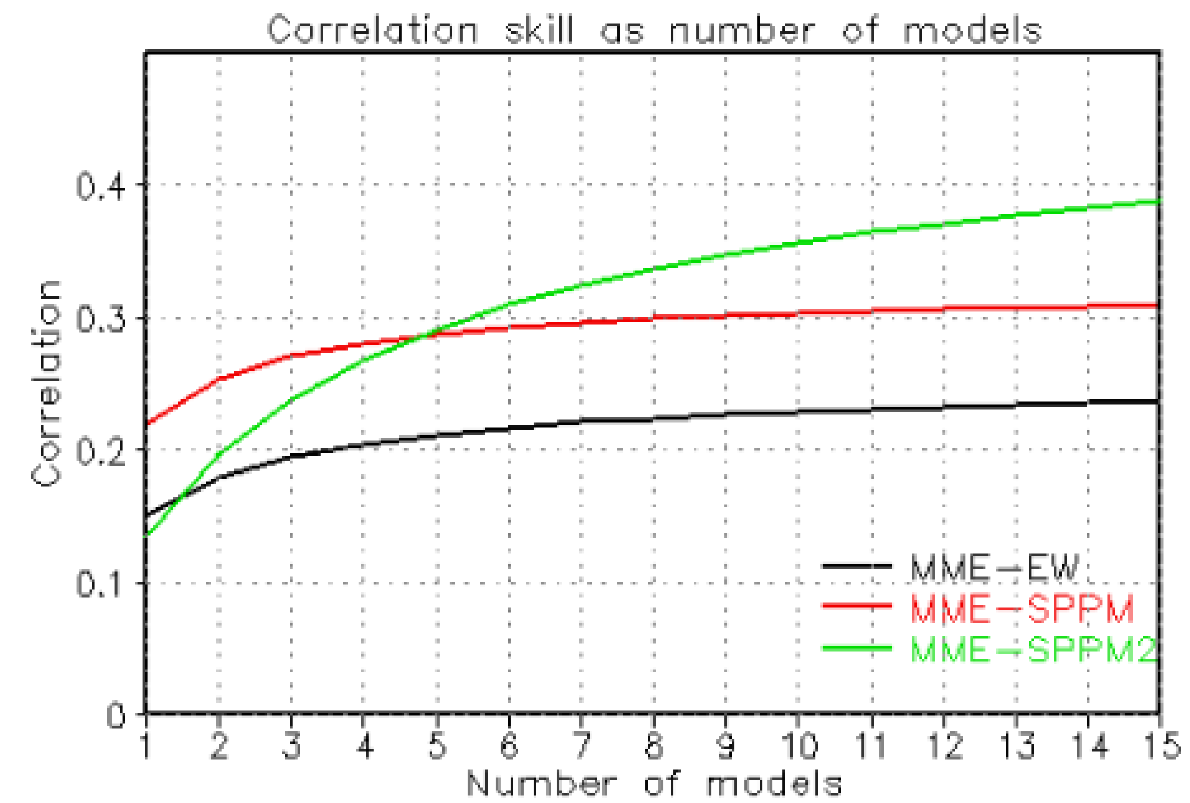
Improvement of Climate Prediction:

MME Techniques

- We have developed a new MME method (MME-SPPM2), whose strengths lie in **a statistical error correction procedure and discreet selection procedure of reliable predictions among all possible candidates**. MME-SPPM2 provides significantly improved skill over the globe as a whole, especially over the land area and extratropical oceans. The conspicuous improvement of the MME-SPPM2 is achieved against other MME methods **over the regions in which the skill of individual models is poor.**

MME1: simple composite
MME2: multiple linear regression
MME3: MME-SPPM v1
MME3.1: MME-SPPM v2

* All MME method were applied to retrospective forecasts of JJA precipitation from 15 climate models in CliPAS and DEMETER projects.

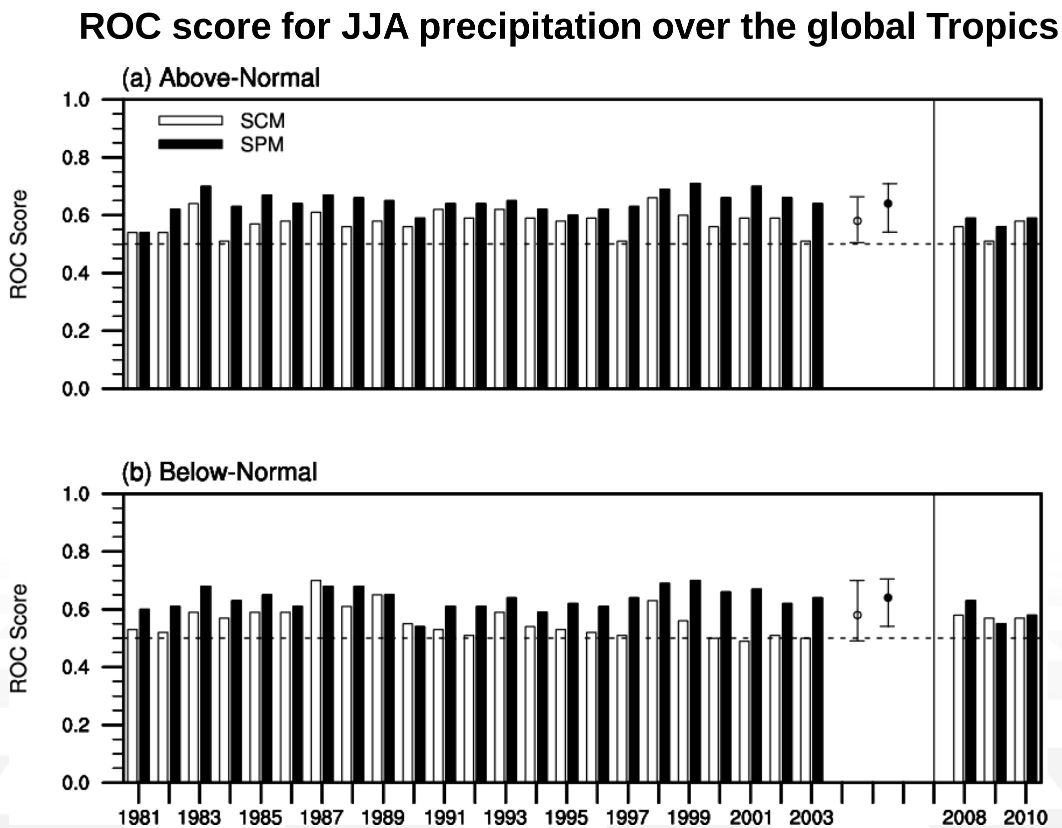


0.2 0.3 0.4 0.5 0.6 0.7 0.8

Kug, J.-S., J.-Y. Lee, I.-S. Kang, B. Wang, and C.-K. Park, 2008: ***Optimal multi-model ensemble method in seasonal climate prediction****. Asian Pacific J. Atmos. Sci, 44, 259-267*

Improvement of Climate Prediction:
Development of APCC Probabilistic MM Prediction System

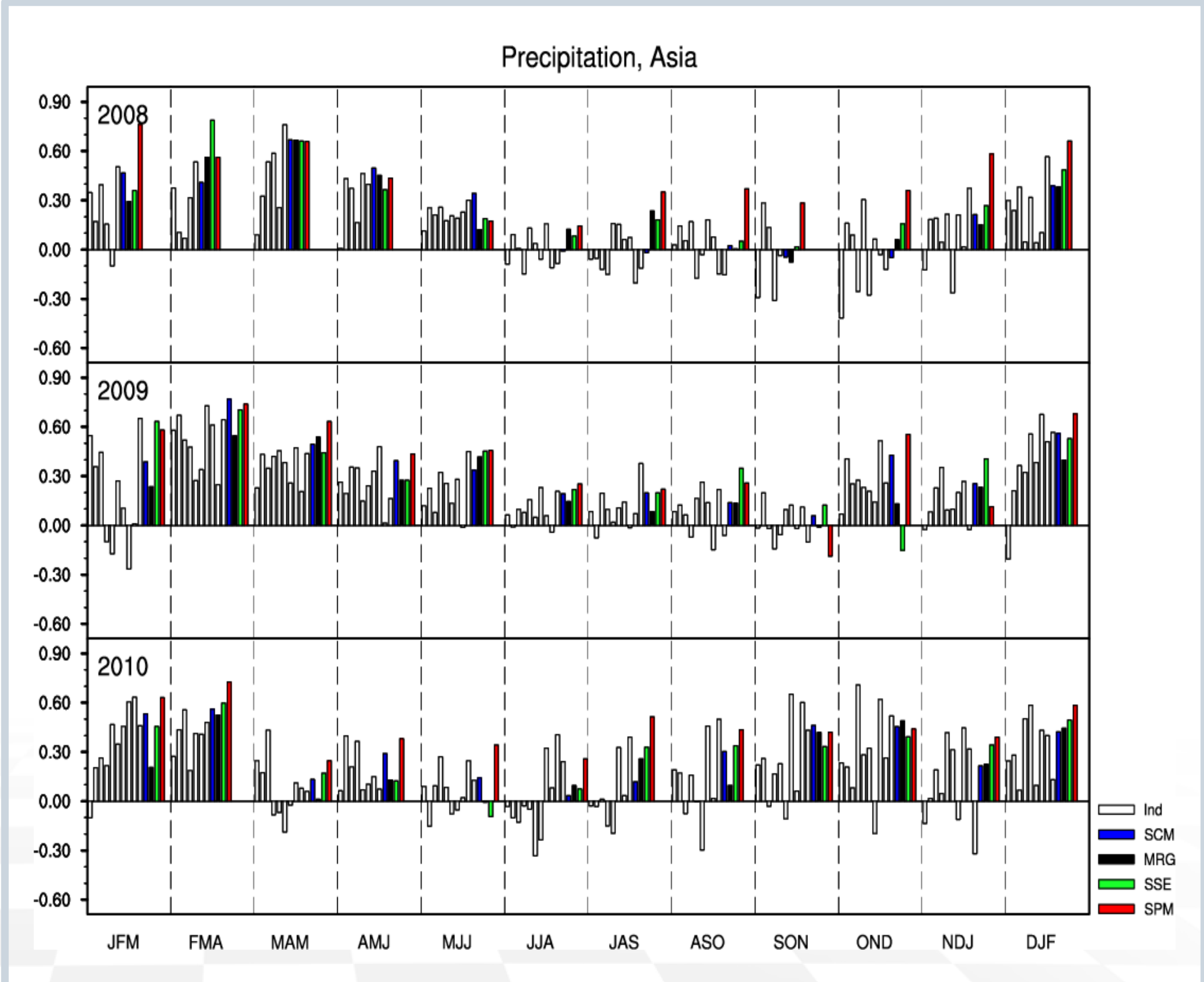
- The new APCC probabilistic multi-model prediction (PMMP) system, which uses the modified SPPM2 in conjunction with a optimal estimation of the forecast uncertainty, has improved the forecast skill for seasonal precipitation in terms of reliability and resolution during both cross-validated hindcast and independent real-time forecast period.



*Min, Y.-M., J.-Y. Lee, J.-S. Kug, B. Wang, V. N. Kryjov, S.-J. Shon, J.-H. Yoo, and J.-H. Oh 2011: **Improvement of the APCC probabilistic multi-model seasonal prediction by systematic error correction and uncertainty estimation.** Submitted to Clim Dyn (revision)*

APCC Operational MME Prediction
for 3-month Mean Precipitation

- The operational MME prediction at APCC during recent three years shows limited forecast skill for precipitation during warm season.



June-Yi Lee, Jin-Ho Yoo, Young-Mi Min et al.: ***Multi-model ensemble seasonal hindcast (1983-2003) and real-time prediction (2007-2011) at APCC.*** *In preparation.*

Challenges and Directions

- The MME can only capture a moderate portion of the precipitation variability. Improvement of the MME skill relies on good models, thus **improvement of models is essential and remains a long-term goal**.
- Monsoon prediction remains a major challenge for climate prediction. There is an urgent need to determine **to what extent the intrinsic internal variability of monsoon limits its predictability**, and to **what extent improved land processes can contribute to improved predictive skill**.
- **The accuracy and consistency of the initial conditions** of the coupled ocean-atmosphere system is important for improving short-lead seasonal prediction.
- **Continuing improvement to the models' representation of the slow coupled dynamics** (e.g., properties of the coupled ENSO mode) is essential for improving ENSO and long-lead seasonal predictions.
- The poor performance over the continental monsoon region may be partially due to poor quality of the land surface initial conditions and the models' deficiencies in the representation of atmosphere-land interaction. **Global land surface data assimilation is an urgent need.**
- We need to determine predictability of ISO and make statistical and dynamical forecast of ISO and monthly prediction.
- High resolution global models are necessary for prediction of TC and other extreme events.

Thank You!

Summary

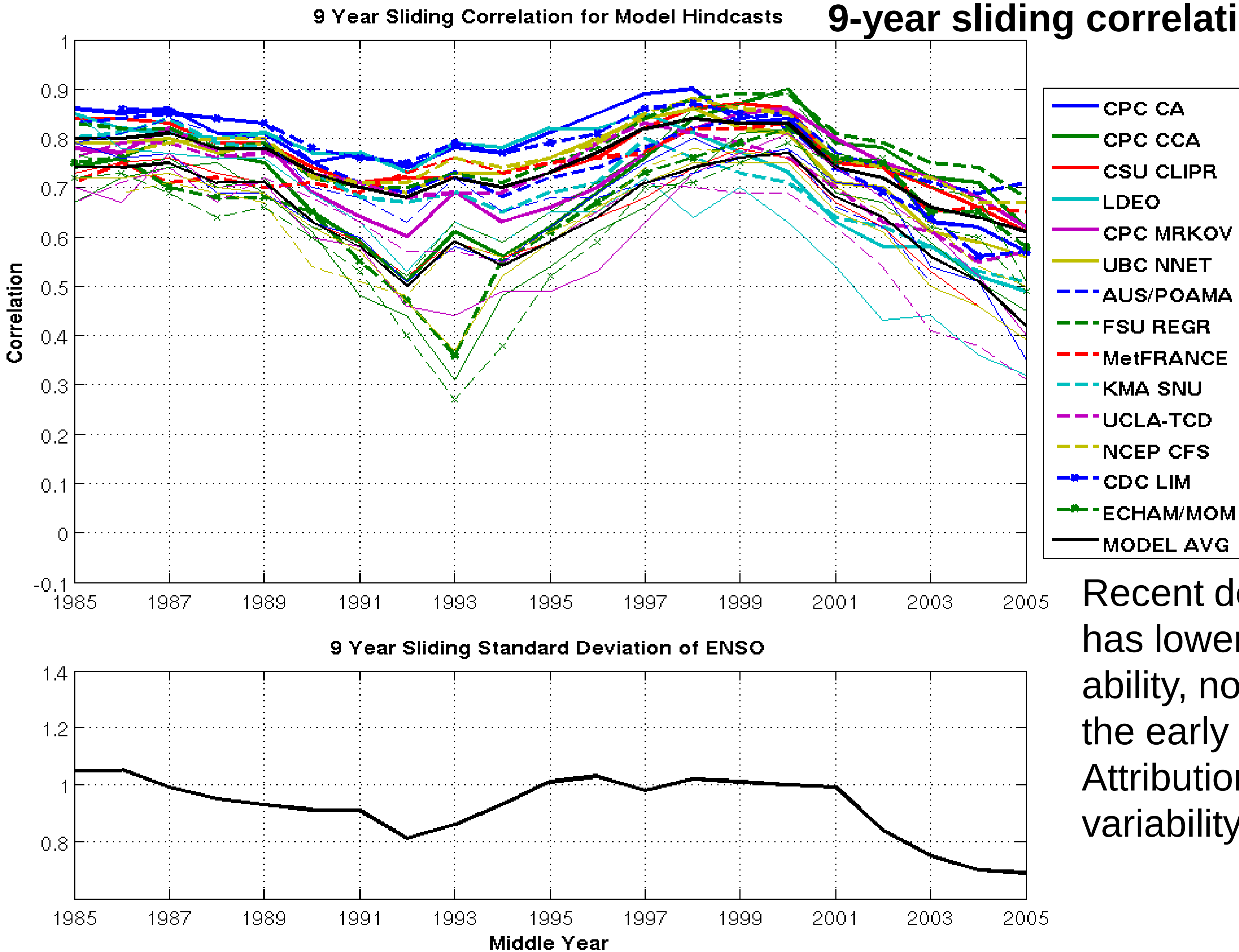
We suggest **a new MISO index that is defined by the first four multivariate EOF modes of daily OLR and U850 anomaly** over the ASM region (10°S-40°N, 40°-160°E).

The RMM index captures the OLR variability primarily in the equatorial region whereas **the MISO index captures large portion of the variability in the off-equatorial region**, yielding more realistic variance pattern.

The MISO index describes better ISO variability center and represents better northward as well as eastward propagating pattern in the ASM domain than the RMM index

The northward-propagating MISO component can be monitored using the phase diagram between the first and second PC similar as the eastward-propagating MJO. Taking into account distinct regional characteristics of MISO with smaller horizontal scale than MJO, the reconstructed field from the first four modes may provide more useful information.

9-year sliding correlation



Recent decade
has lower pred
ability, not unlik
the early 1990s
Attribution to lo
variability.