

**International Workshop on Interdecadal Variability
of the Global Monsoons**

**The Asian Summer Monsoon: An Intercomparison of
CMIP5 vs. CMIP3 Simulations of the Late
20th Century**

September 10, 2012

**K. Sperber, H. Annamalai, I.-S. Kang, A. Kitoh,
A. Moise, A. Turner, B. Wang, T. Zhou**

Lawrence Livermore National Laboratory



Program for Climate Model Diagnosis
and Intercomparison



This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Outline

- The Participants
- Why is it important to study the monsoon?
- The Observations and Models
- The Scope of the Analysis
 - Selected Results and Summary
- Future Work

CLIVAR Asian-Australian Monsoon Panel (AAMP)

(*Diagnostics Task Team)

*Ken Sperber (co-chair)	Lawrence Livermore National Laboratory
Harry Hendon (co-chair)	Center for Australian Weather & Climate Research
*In-sik Kang	Seoul National University
*Akio Kitoh	Meteorological Research Institute
Matthieu Lengaigne	National Institute of Oceanography
Holger Meinke	University of Tasmania
Madhavan Nair Rajeevan	National Atmospheric Research Laboratory
*Andrew Turner	University of Reading
Gabriel Vecchi	Geophysical Fluid Dynamics Laboratory
*Bin Wang	International Pacific Research Center
Xubin Zeng	University of Arizona
*Tianjun Zhou	State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics

The ICPO contact for the CLIVAR Asian-Australian Monsoon Panel is [Carlos Ereño](#).

Invited Experts: *H. Annamalai and *A. Moise

Why is it important to study the monsoon?

- Monsoon variability impacts the socio-economic well-being of nearly 3 billion people
 - Agriculture (crop selection and planting time)
 - Hydrometeorological Services (flood and drought mitigation)
- Monsoon Forecasting has been a longstanding problem
 - Blanford (1884) monsoon vs. preseason snow-cover
 - Walker (1924) monsoon vs. pressure over the Pacific and Indian Oceans
- CLIVAR AAMP
 - **Assess climate variability and predictability of the A-A monsoon**
 - Observations: monitoring (Indian Ocean moored array) and evaluation
 - AAMP sponsored numerical experimentation (e.g., MJO prediction and predictability, experimental real-time forecasting with MJOTF)
 - CMIP3, CMIP5 (standardized diagnostics for the broader climate community)
 - **Improve understanding of mechanisms that modulate monsoon**
 - MJO (e.g., CINDY/DYNAMO 2011), ENSO, Interdecadal variability
 - Workshops (MJO, Interdecadal variability)

Observations, CMIP5, and CMIP3 Models (1)

- Observations
 - If available, multiple validation sources are used to evaluate model performance in terms of “the” range of observations (casually referred to as “observational uncertainty”)
- Models
 - CMIP5 (circa 2011) vs. CMIP3 (circa 2004)
 - Higher horizontal resolution (most $\sim 1^\circ$ vs. $\sim 2.5^\circ$)
 - More complete representation of the Earth system (carbon cycle, chemistry, aerosols, ...), and improved parameterizations
 - More comprehensive experiments
 - CMIP5 Historical and CMIP3 20c3m simulations
 - Modeling groups best estimates of natural and anthropogenic forcing
 - 1961-1999
 - Single realizations

Observations, CMIP5, and CMIP3 Models (2)

- Observations

- AVHRR OLR; GPCP and CMAP Rainfall; ERA40, JRA25, and NCEP/NCAR Reanalysis 850hPa Winds

- CMIP5 (25 models, 16 for intraseasonal evaluation)

- BCC-CSM1.1, CanESM2, CCSM4, CNRM-CM5, CSIRO-Mk3.6.0, FGOALS-g2, FGOALS-s2, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadCM3, HadGEM2-CC, HadGEM2-ES, INM CM4, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CHEM, MIROC4h, MIROC5, MPI-ESM-LR, MRI-CGCM3, and NorESM1-M

- CMIP3 (22 models, 15 for intraseasonal evaluation)

- bccr bcm2.0, cccma cgcm3.1, cccma cgcm3.1 t63, ccsm3.0, cnrm cm3, csiro mk3.0, csiro mk3.5, gfdl cm2.0, gfdl cm2.1, giss aom, hadcm3, hadgem1, fgoals 1.0g, ingv-sxg, inm cm3.0, ipsl cm4, miroc 3.2 (hi-res), miroc 3.2 (med-res), miub echo-g, echam5/mpi-om, mri cgcm2.3.2a, and pcm1
- Lower-case characters used to distinguish CMIP3 from CMIP5 models

The Scope of the Analysis

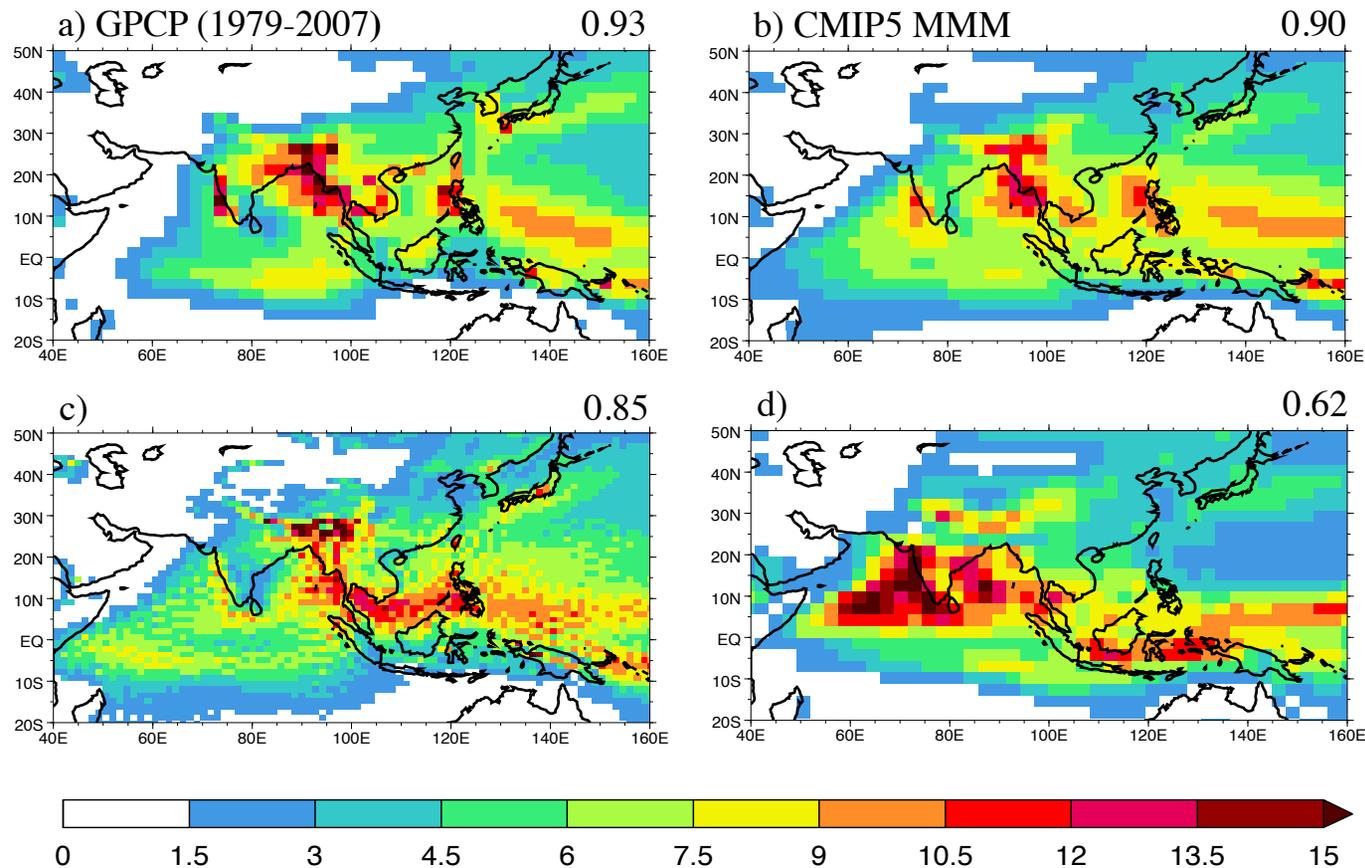
(submitted to Climate Dynamics-July 2012)

- Climatological performance
 - **Rainfall** and 850hPa winds
- Climatological Annual Cycle (Pentad rainfall)
 - Monsoon Onset, Peak, Withdrawal, and Duration
 - Extent of the monsoon domain
- ENSO-Monsoon Relationship
 - **Correlation of all-India rainfall with NINO3.4 SSTA**
 - **NINO3.4 regressions with local rainfall (Do models get the pattern correct?)**
- East Asian Summer Monsoon Interannual Variability
 - **Relationship of precipitation and 850hPa wind to zonal wind shear index**
- Boreal Summer Intraseasonal Variability (BSISV)
 - 20-100 day variance pattern and BSISV life-cycle
- Metrics of Skill Applied for each Diagnostic
 - **Pattern correlation (2-D)**, space-time correlation (BSISV life-cycle), and hit-rate and threat score (Monsoon domain)

Sperber, K. R., H. Annamalai, I.-S. Kang, A. Kitoh, A. Moise, A. Turner, B. Wang, and T. Zhou (2012) The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century. **Climate Dynamics** (submitted)

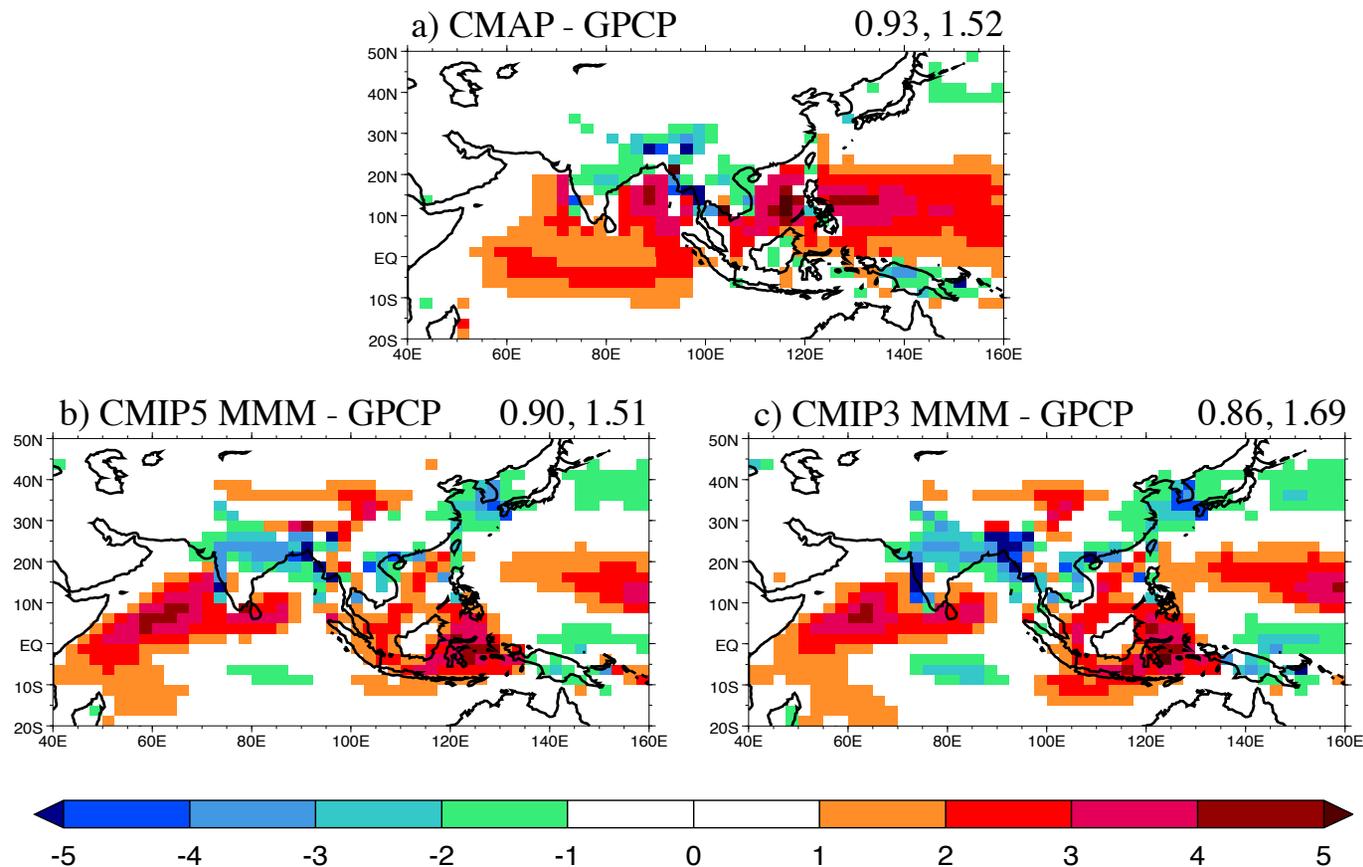
JJAS Rainfall Climatology (mm day⁻¹)

- Observed and simulated results include data from the CMIP5 multi-model mean (MMM), and the two models that show the range of performance
 - The CMIP-5 MMM outperforms all of the individual models
 - CMIP-5 MMM has improved rainfall, especially near Ghats and Tibetan Plateau



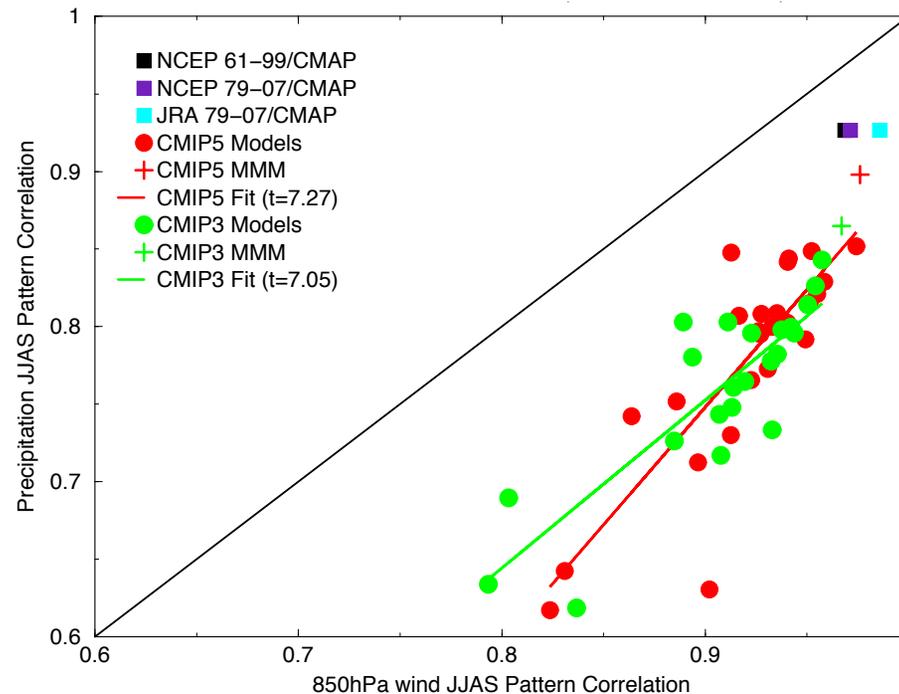
JJAS Rainfall Climatology (mm day^{-1}): Systematic Error vs. Observational Spread

- The systematic error of rainfall is nearly identical in CMIP5 and CMIP3, and their error structure is similar to the difference between CMAP and GPCP
 - Relative to GPCP, the CMIP5 MMM has a larger pattern correlation and a smaller root-mean-square error than the CMIP3 MMM



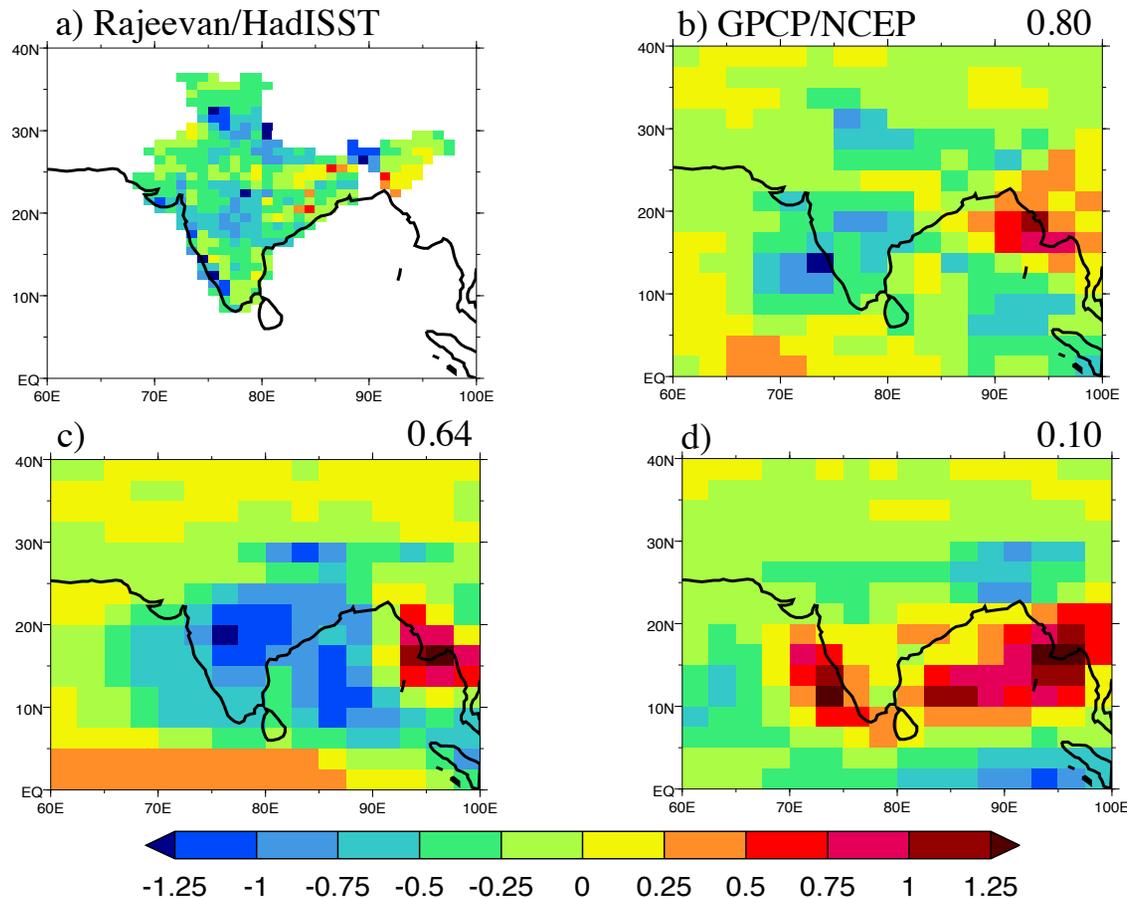
Skill: JJAS Climatology of 850hPa Wind vs. Rainfall

- 850hPa wind climatology pattern correlation vs. ERA40 (1961-1999)
- Rainfall climatology vs. GPCP (1979-2007)
 - Wind is better simulated than rainfall
 - CMIP-5 MMM more skillful than the CMIP-3 MMM
 - For 850hPa wind the models are beginning to be consistent with the spread of observations
 - Statistically significant relationship between the wind skill and the rainfall skill



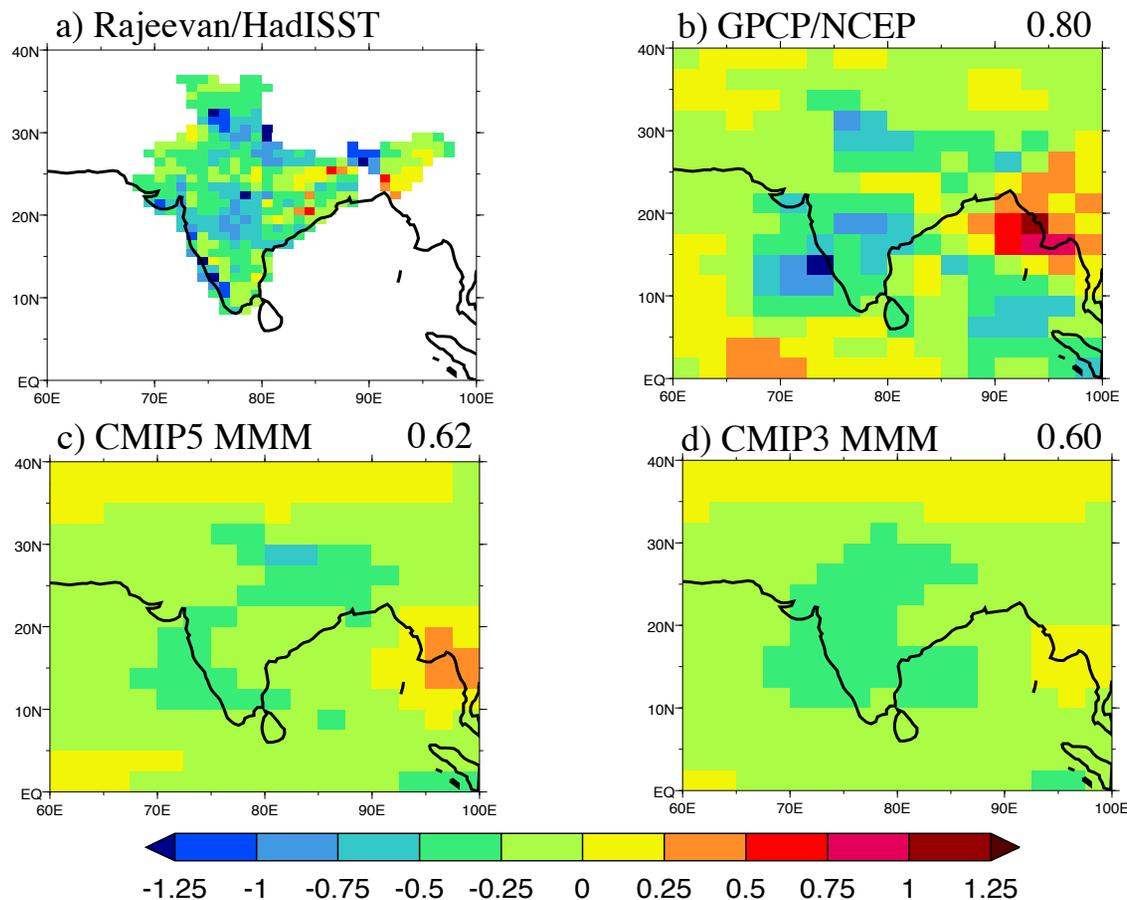
Interannual Variability: Rainfall During El Nino Regression (mm day⁻¹) Relative to NINO3.4 SSTA

- Observed and simulated results that show the range of performance
 - Good agreement between the high-resolution Rajeevan data (1961-1999) with GPCP (1979-2007)
 - Diverse skill in representing the observed rainfall pattern forced by ENSO



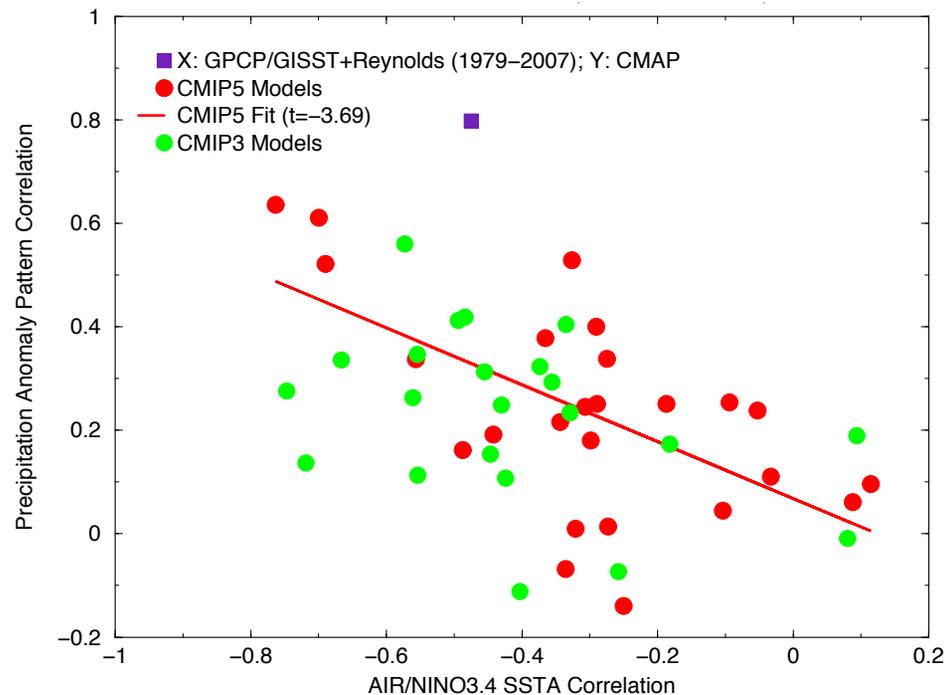
Interannual Variability: Rainfall During El Nino Regression (mm day⁻¹) Relative to NINO3.4 SSTA

- Observations, and the CMIP5 and CMIP3 multi-model means
 - The CMIP5 MMM marginally outperforms the CMIP3 MMM
 - The magnitude of the CMIP5 MMM anomalies is more realistic than those in the CMIP3 MMM, though both MMM's have weaker amplitudes than individual models



Skill: AIR/NINO3.4 Correlation vs. Pattern Correlation of the Rainfall Anomaly

- CMIP5: there is a statistically significant relationship between the AIR/NINO3.4 correlation and the rainfall anomaly pattern correlation
- Many factors affect the ENSO-monsoon relationship
 - Seasonality of the AIR/NINO3.4 relationship, location and magnitude of the ENSO SST and diabatic heating anomalies (Annamalai et al. 2007, 2012)
 - SSTA in the Pacific and Indian Oceans have opposing effects (Lau and Nath 2012)
 - Unrealistic Indian Ocean Dipole prevents ENSO signal from influencing the monsoon (Achuthavarier et al. 2012)



East Asian/West Pacific Monsoon: JJA Interannual Variability

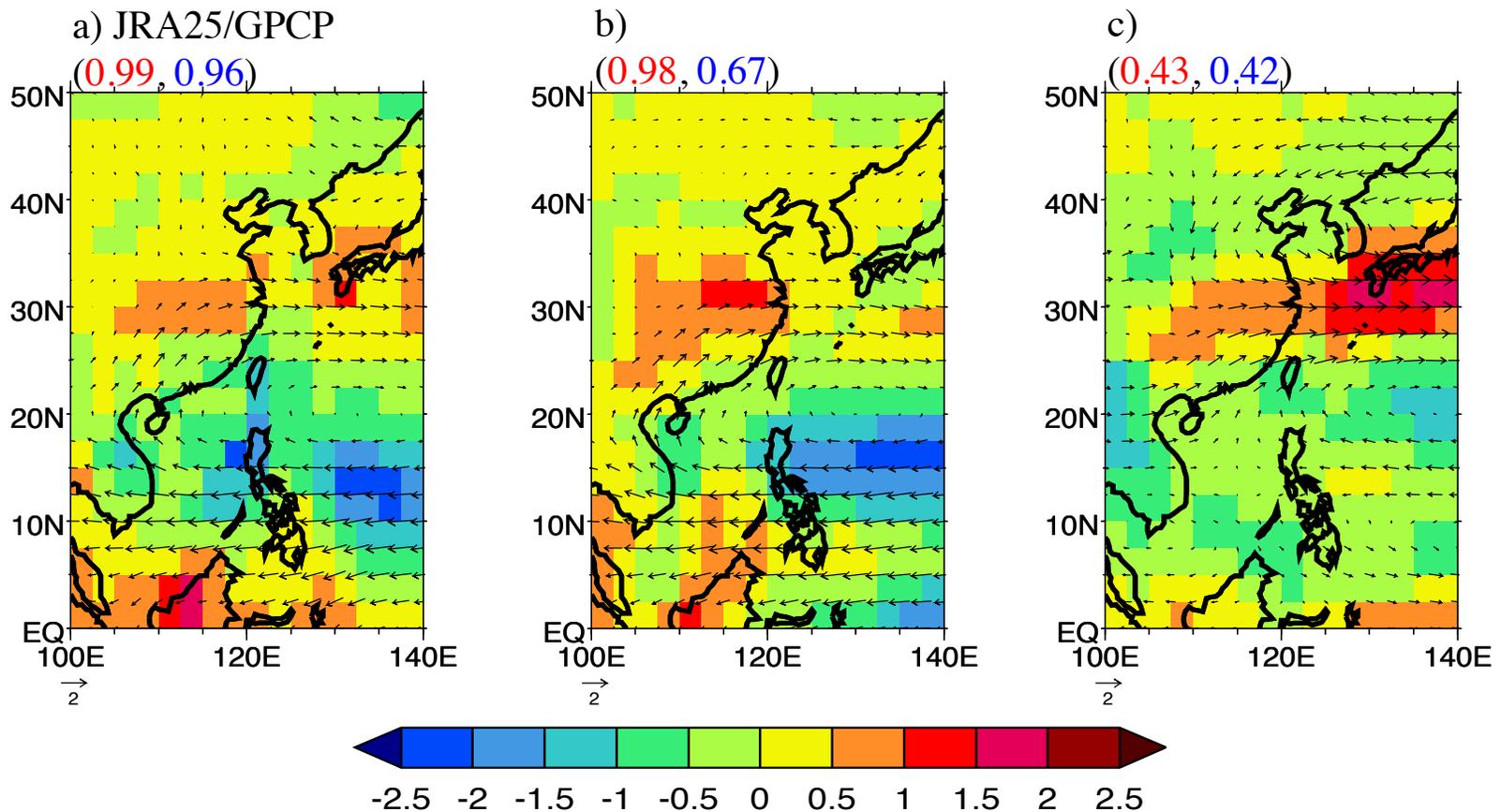
- 850hPa zonal wind shear anomaly index designed by Wang and Fan (1999, *Bull. Amer. Meteor. Soc.*, 80, 629–638), and revised, where

$$\text{Index} = u_{850} (110^{\circ}\text{E}-140^{\circ}\text{E}, 22.5^{\circ}\text{N}-32.5^{\circ}\text{N}) - u_{850} (90^{\circ}\text{E}-130^{\circ}\text{E}, 5^{\circ}\text{N}-15^{\circ}\text{N})$$

- As indicated in Wang et al. (2008, *J. Clim.*, 21, 4449-4463) this is the negative of the Wang and Fan (1999) index, such that strong monsoon corresponds to enhanced precipitation near 30°N associated with the Mei-Yu/Baiu/Changma front
- Observed and simulated 850hPa wind and rainfall anomaly (ms^{-1} and mm day^{-1}) regressions include the two models that show the range of performance as indicated by the pattern correlations with JRA25 850hPa wind and GPCP rainfall (the two rightmost columns, respectively). The **wind** and **rainfall** pattern correlations are given in brackets [the skill scores in (a) are relative to NCEP/NCAR Reanalysis 850hPa wind anomalies and CMAP rainfall anomalies]

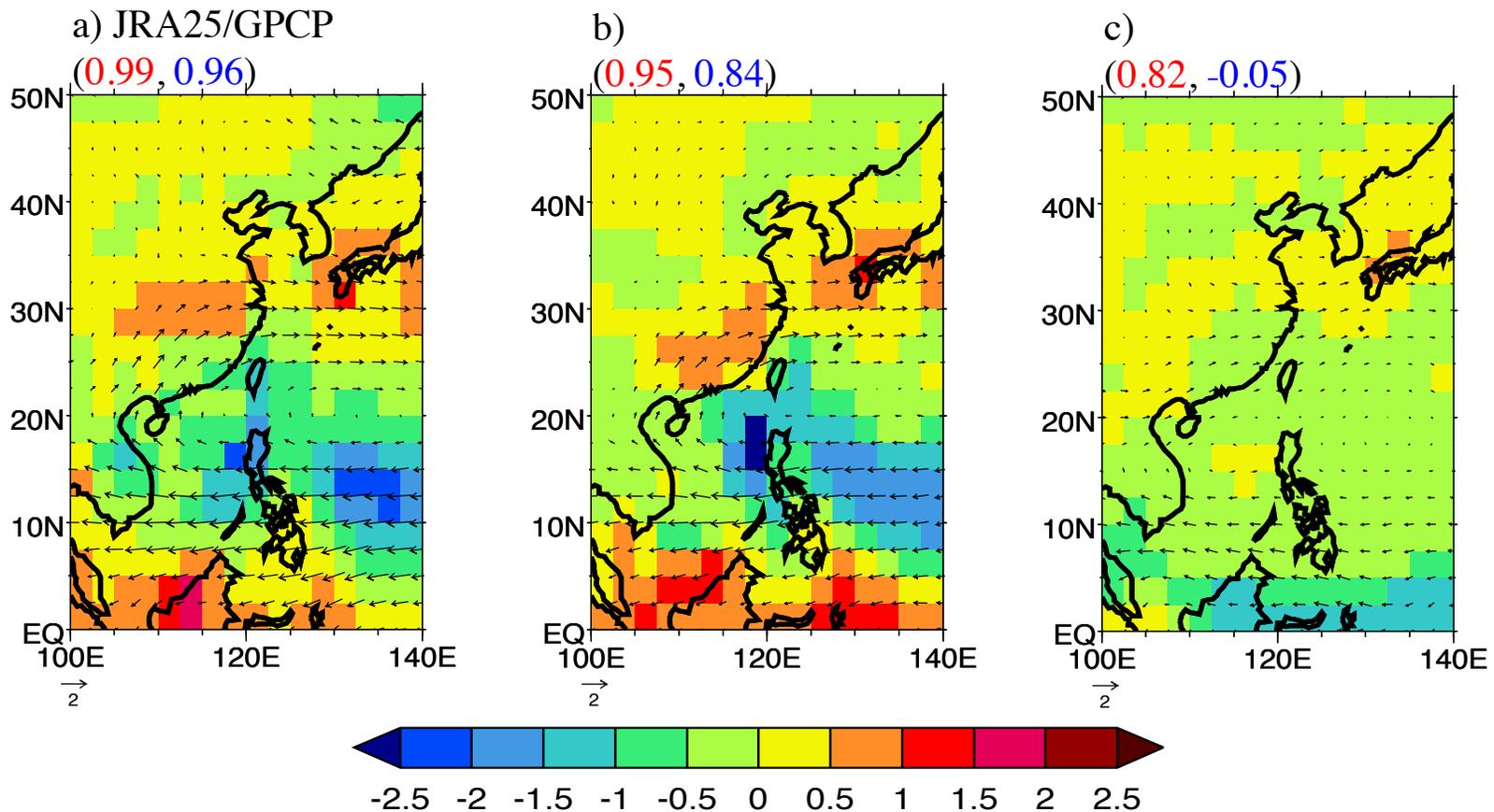
East Asian/West Pacific Monsoon: JJA Interannual Variation: 850hPa Wind Skill

- Observed and simulated results showing the *range of performance* based on the 850hPa wind pattern correlation with JRA25
 - 850hPa wind is better represented than rainfall, though extratropical influences may incorrectly dominate in some models



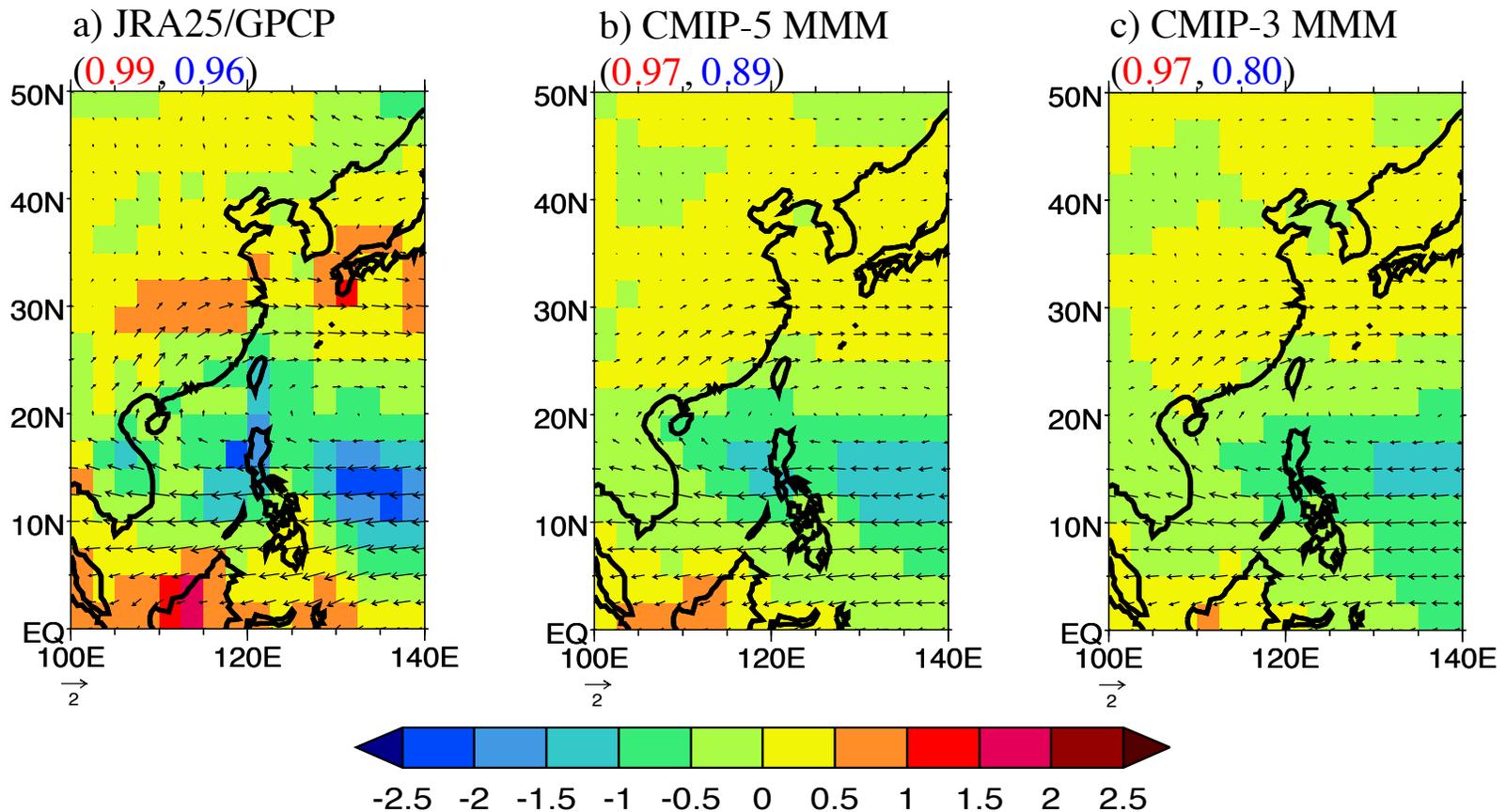
East Asian/West Pacific Monsoon: JJA Interannual Variation: Rainfall Skill

- Observed and simulated results showing the *range of performance* based on the **rainfall pattern correlation** with GPCP
 - The maximum rainfall pattern correlation is larger in CMIP-5 suggesting modest improvement in representing the interannual variation of EASM



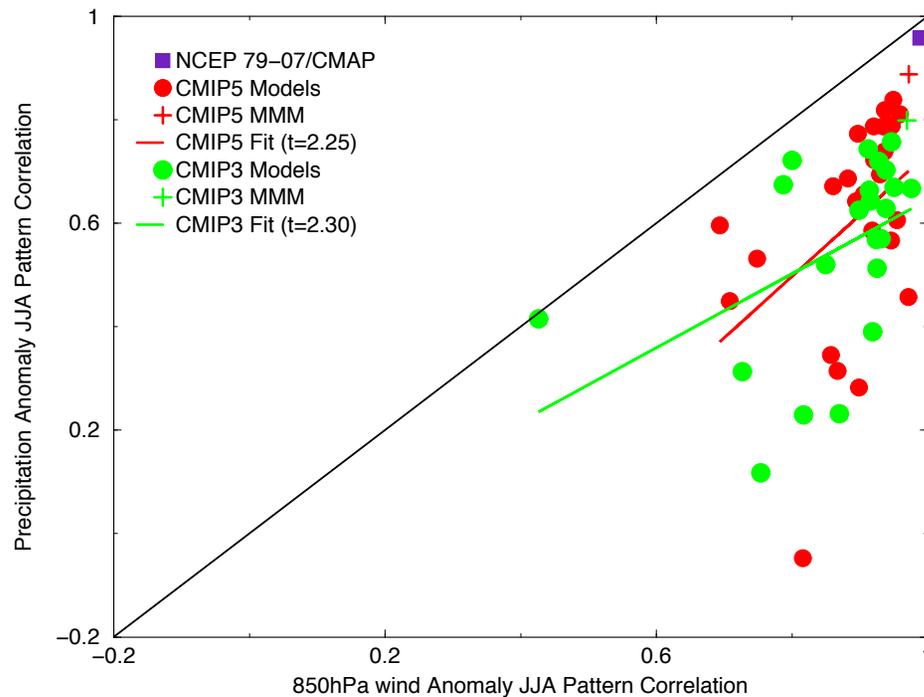
East Asian/West Pacific Monsoon: JJA Interannual Variation: Multi-Model Mean

- Observations, and CMIP5 and CMIP3 multi-model means
 - 850hPa wind pattern correlation is approaching observational spread
 - CMIP5: Improved skill in the simulation of the rainfall pattern correlation, though the anomalies are weaker than observed



Skill: EASM JJA 850hPa Wind vs. Rainfall

- 850hPa wind anomaly pattern correlation vs. JRA25 (1979-2007)
- Rainfall anomaly vs. GPCP (1979-2007)
 - Wind is better simulated than rainfall
 - Models are beginning to approach observational spread in the simulation of the 850hPa wind anomalies
 - CMIP5 MMM outperforms CMIP3 MMM
 - Statistically significant relationship between the wind skill and the rainfall skill



Asian Summer Monsoon Summary: CMIP5 vs. CMIP3

- Rainfall and 850hPa Wind
 - Rainfall: Incremental progress in the simulation of rainfall in the time mean, the annual cycle, interannual variability, and intraseasonal variability
 - 850hPa Wind: Better simulated than rainfall with the best models approaching the range of observed skill
- The Multi-Model Mean
 - Climatology: Better than individual models
 - Annual Cycle: Individual models better than the MMM
 - Interannual Variability: Individual models almost as skillful as the MMM, EASM better than ENSO-monsoon
 - Intraseasonal Variability: Despite the poor representation of the BSISV by the vast majority of models, the MMM is surprising skillful in representing the BSISV Life-Cycle

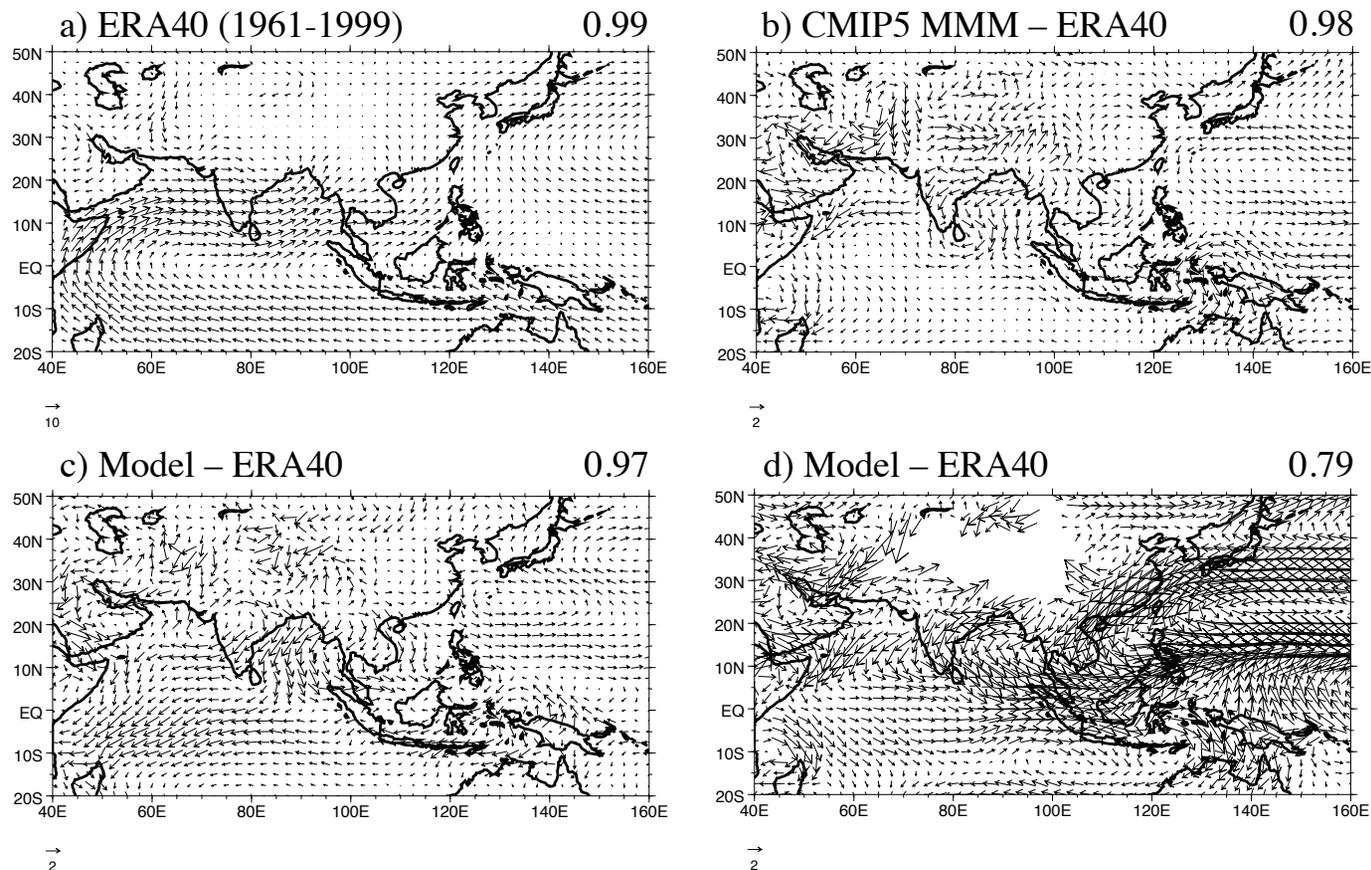
Future Work

- Annamalai et al. (2012, in preparation)
 - Detailed analysis of the ENSO-monsoon teleconnection
 - Use additional CMIP5 models, and making use of the full suite of realizations from the historical and RCP8.5 scenarios
 - The teleconnection is sensitive to the time-mean monsoon rainfall, the ENSO-related SST and diabatic heating anomalies, and the regional SST anomalies over the Indian Ocean
- Sperber et al. (2012, in preparation)
 - Exploit the improved simulation of the BSISV to evaluate the potential impact of climate change on the characteristics of intraseasonal variability

Extra Slides

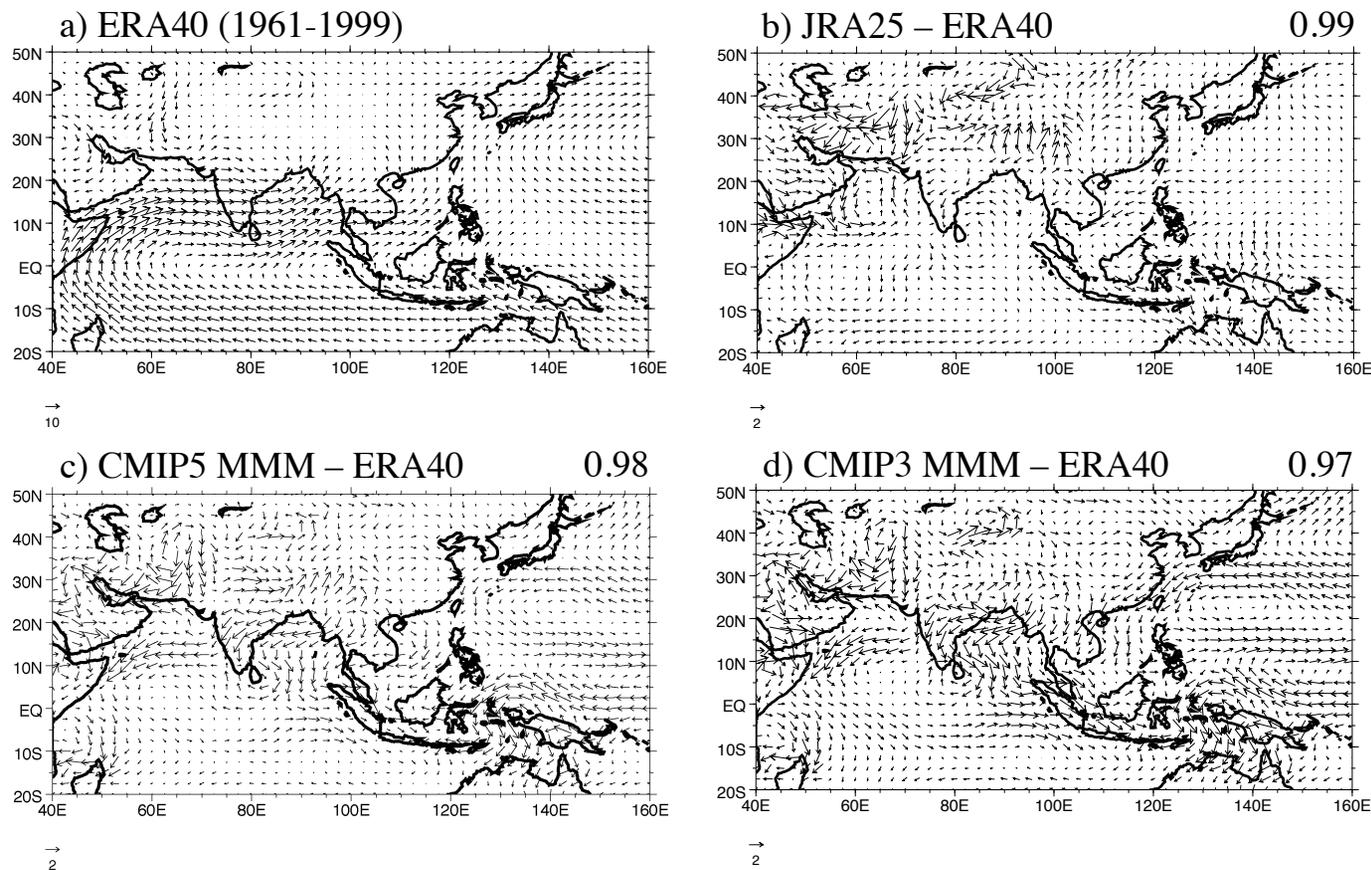
JJAS 850hPa Wind Climatology: Anomalies

- Observed and simulated results include data from the CMIP5 MMM, and the two models that show the range of performance
 - Errors in the wind consistent with errors in the precipitation climatology



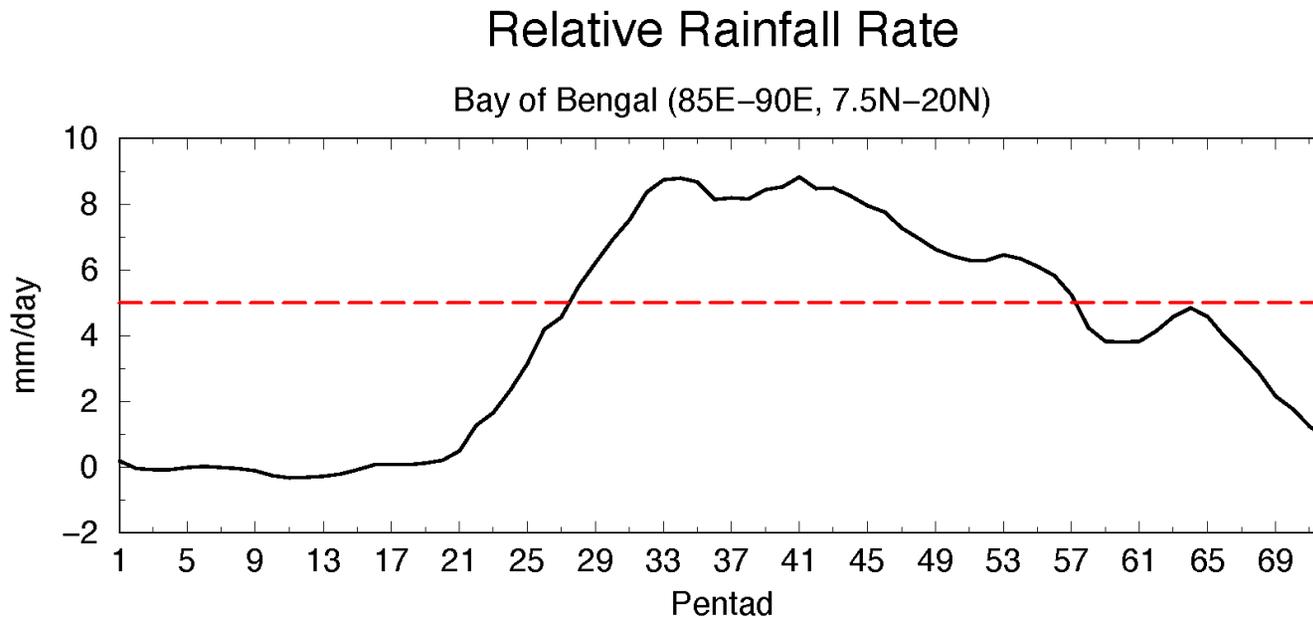
JJAS 850hPa Wind Climatology: Anomalies

- The systematic error is nearly identical in CMIP5 and CMIP3
- Compared to observational spread, the models have similar error structure over India, Pakistan, and Saudi Arabia, but larger error over the ocean



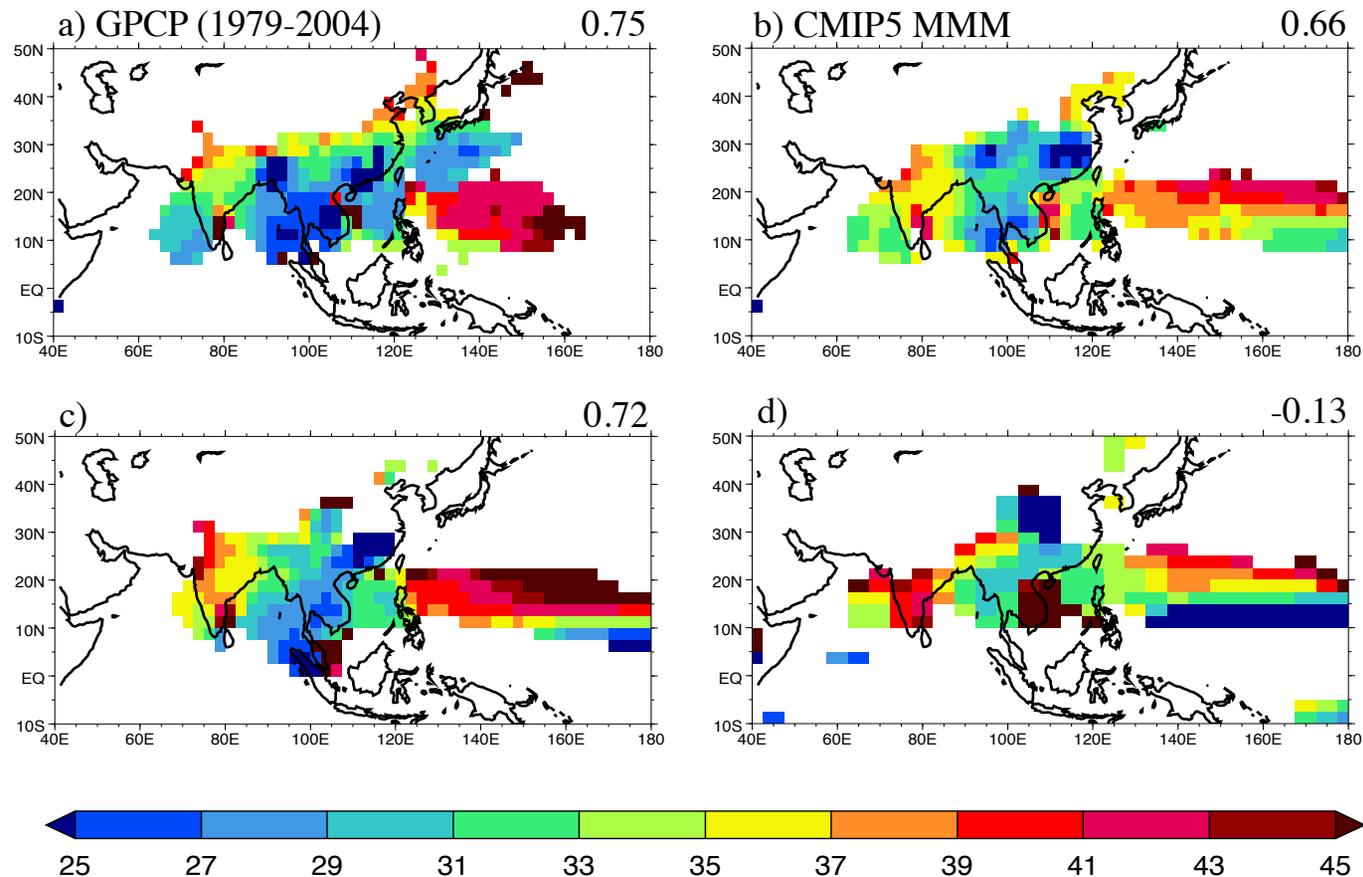
Climatological Annual Cycle: Monsoon Onset, Peak, Withdrawal, and Duration

- Based on the approach of Wang and LinHo (2002, *J. Clim.*, 15, 386-398)
 - Calculate pentad climatology of rainfall
 - Smooth the data, retaining intraseasonal time scales (5 pentad running mean)
 - Subtract the January mean from each pentad: Relative Rainfall Rate
 - Onset: Relative Rainfall Rate exceeds 5mm/day during May-September
 - Withdrawal: Relative Rainfall Rate drops below 5mm/day
 - Duration = Withdrawal - Onset



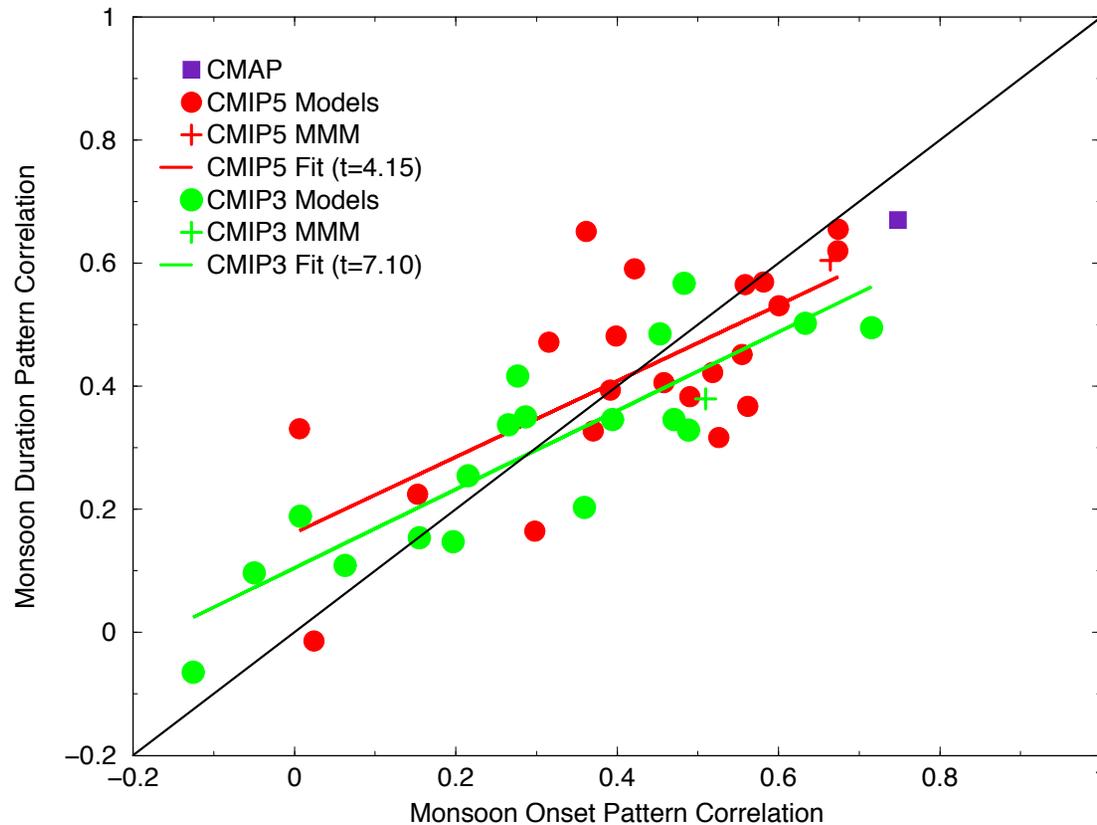
Climatological Monsoon Onset (Pentad)

- Observed and simulated results include data from the CMIP5 MMM, and the two models that show the range of performance
 - Individual models outperform the multi-model mean
 - Biases: Extent of monsoon domain; timing



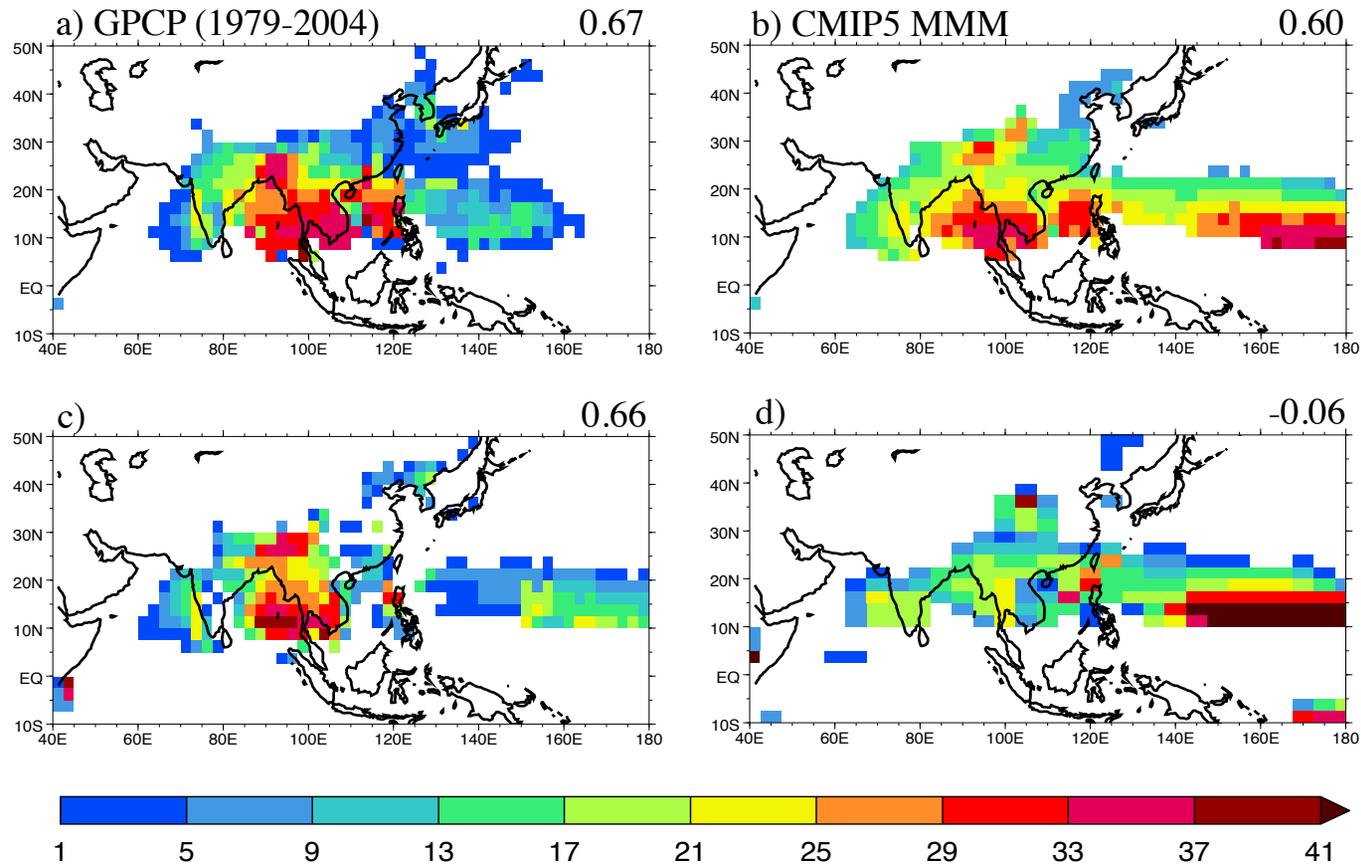
Skill: Onset vs. Duration

- Onset vs. Duration (relative to GPCP, 1979-2007)
 - CMIP5 MMM is more skillful than the CMIP3 MMM
 - Some individual models are more skillful than the MMM's
 - Statistically significant relationship between the onset skill and the duration skill



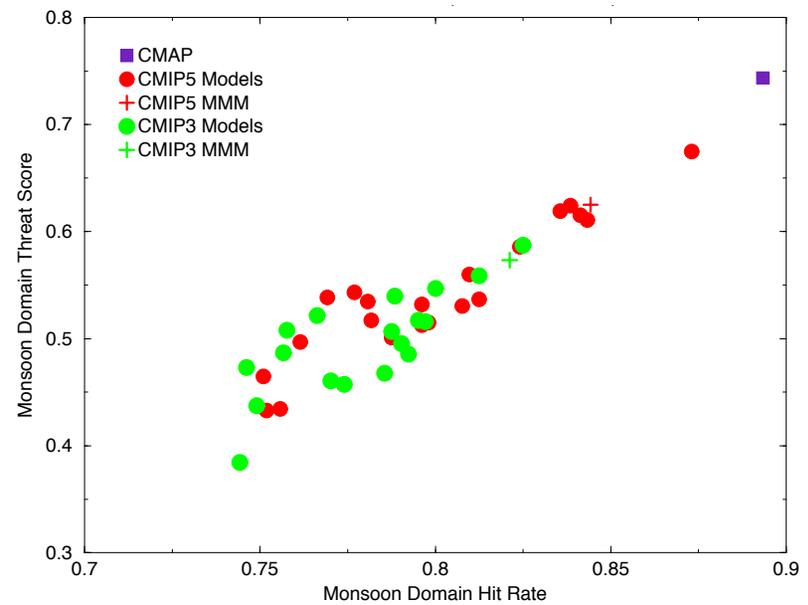
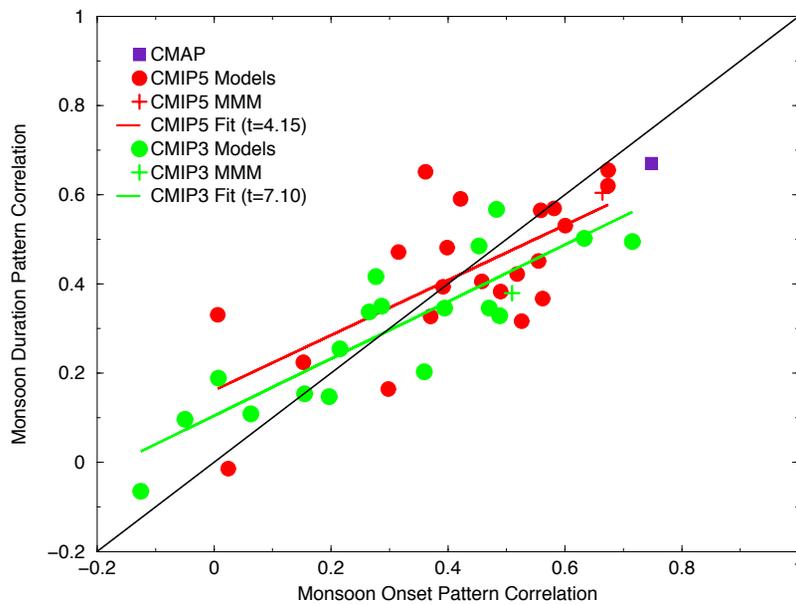
Climatological Monsoon Duration (# of Pentads)

- Observed and simulated results include data from the CMIP5 MMM, and the two models that show the range of performance
 - Individual models outperform the multi-model mean
 - Duration is more difficult to represent than onset, peak, and withdrawal times



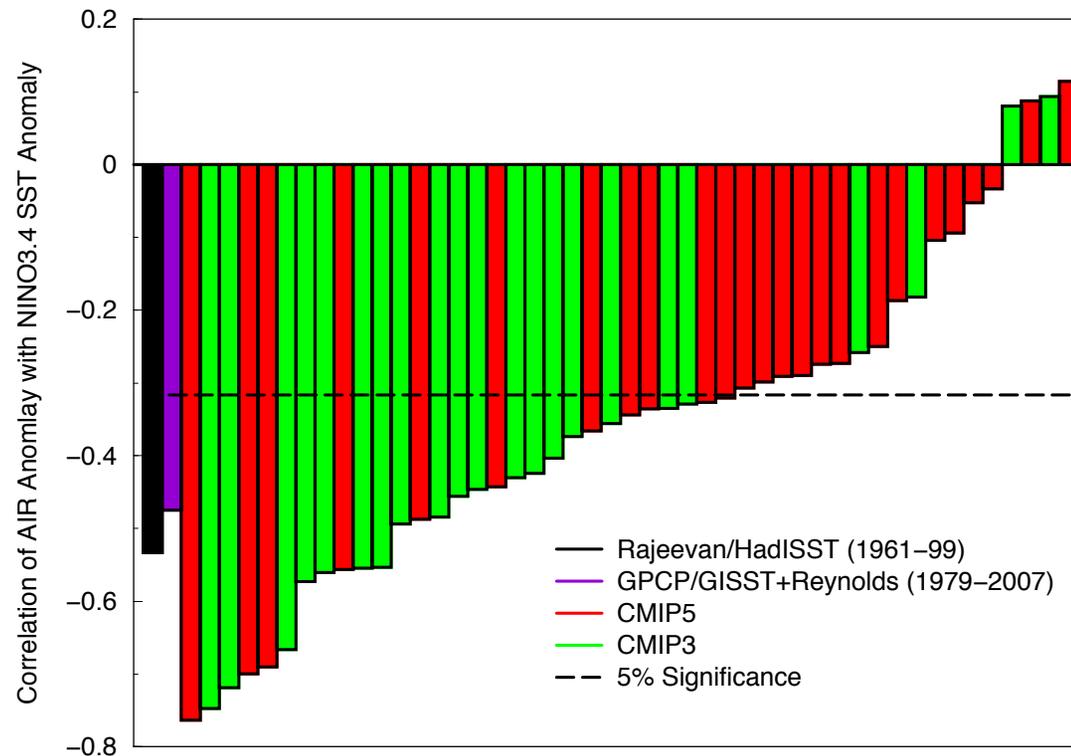
Skill: Onset vs. Duration, and Monsoon Domain

- Onset vs. Duration (left figure)
 - CMIP5 MMM is more skillful than the CMIP3 MMM
 - Some individual models are more skillful than the MMM's
 - Statistically significant relationship between the onset skill and the duration skill
- Monsoon Domain (right figure)
 - CMIP5 MMM more skillful than the CMIP3 MMM (Hit-Rate and Threat Score)
 - The domain does not extend far enough north over China, Korea, and Japan
 - The domain extends too far east over the western/central Pacific Ocean



Interannual Variability: All-India Rainfall/ENSO Teleconnection (JJAS)

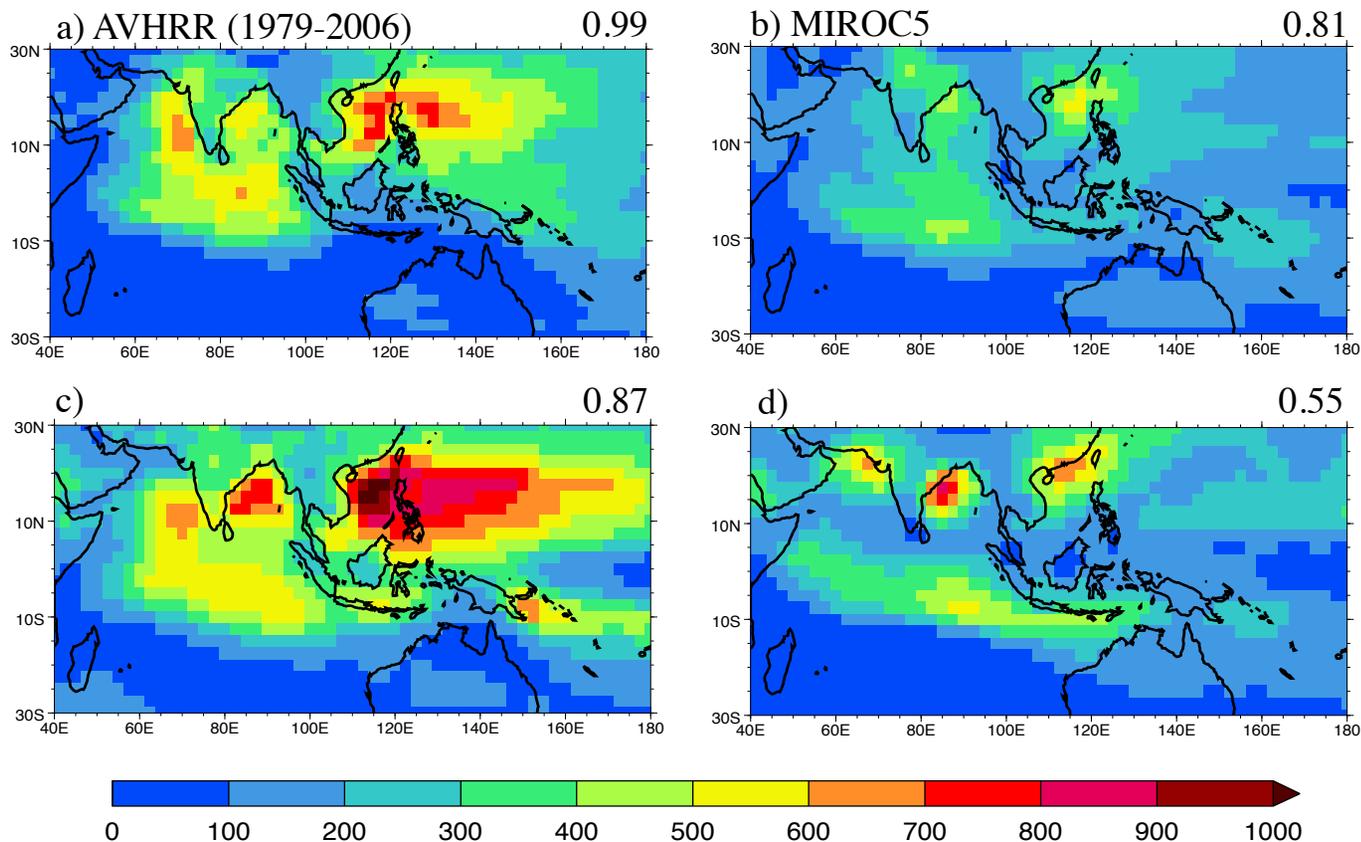
- All-India Rainfall: Land-only gridpoints over 65°E-95°E, 7°N-30°N
- NINO3.4 SST anomalies
- The CMIP3 models tend to have a stronger AIR/ENSO teleconnection than do the CMIP5 models



Models Stratified by AIR/NINO3.4 SSTA Correlation

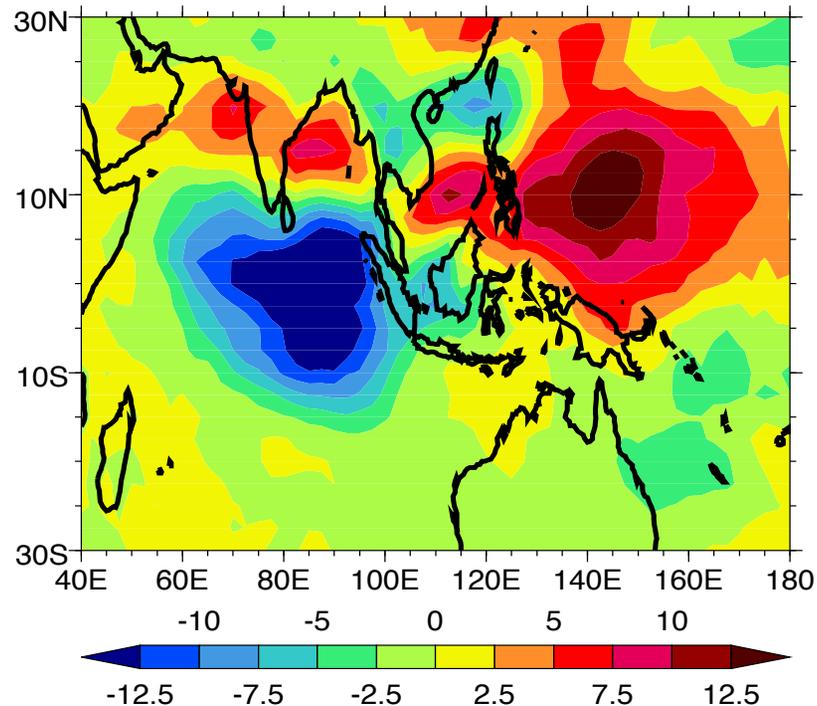
Boreal Summer Intraseasonal Variability (BSISV): 20-100 day Variance (Wm^{-2})²

- CMIP3 and CMIP2+ discussed in detail in Sperber and Annamalai (2008)
 - Only 1 model, ECHAM4/OPYC, gave a high-quality representation of the BSISV
- Variance of 20-100 day bandpass filtered OLR (JJAS)
 - Includes propagating and standing components of intraseasonal variability



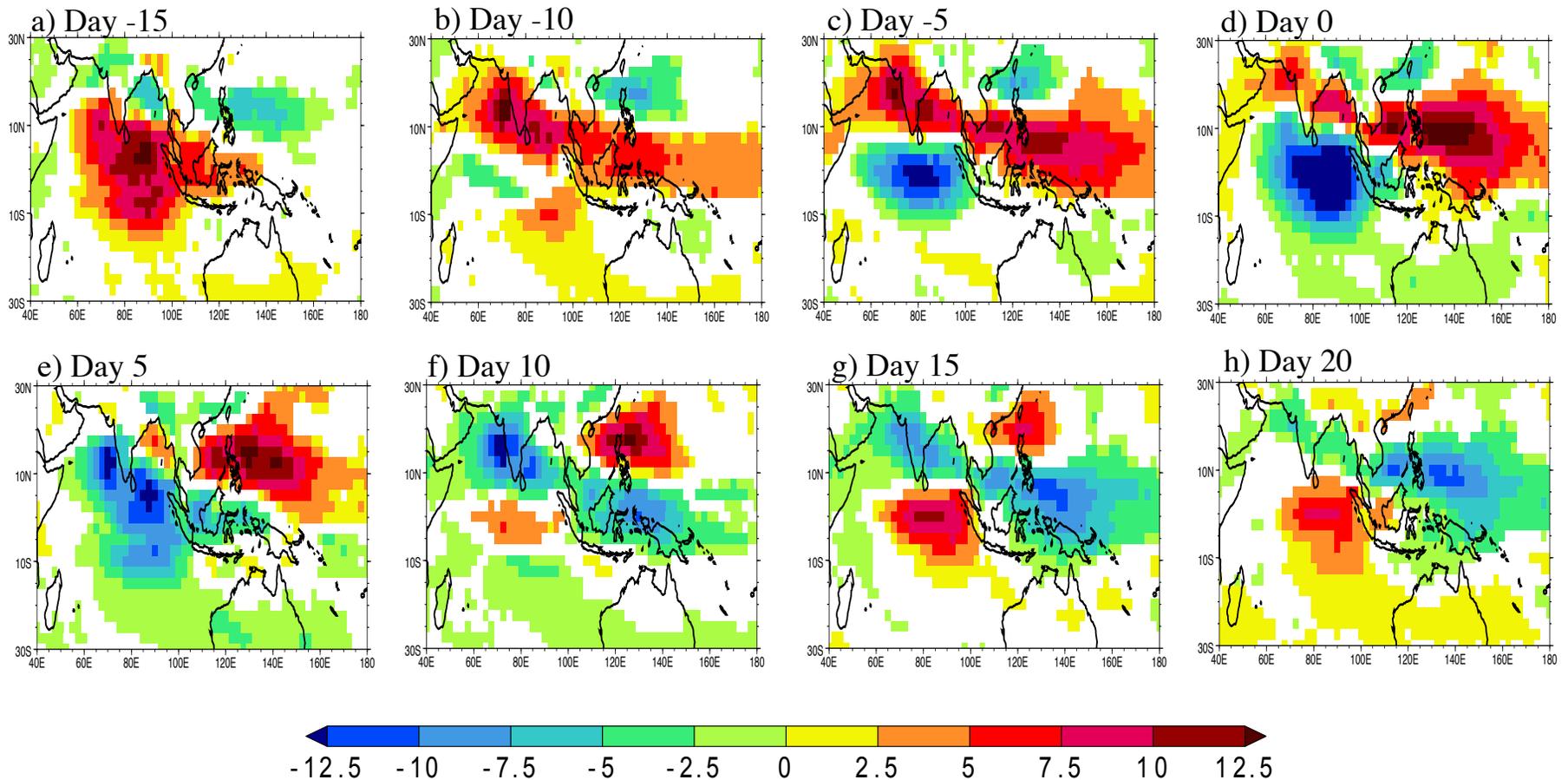
BSISV Life-Cycle: Outgoing Longwave Radiation (Wm^{-2})

- Unified Approach to Model Diagnosis
 - Regrid model data to AVHRR OLR grid, and apply 20-100 day bandpass filter
 - Project model filtered OLR onto the Day 0 Cyclostationary EOF pattern obtained from 20-100 day filtered AVHRR OLR (Annamalai and Sperber 2005, *JAS*, 62, 2726-2748)
 - The resulting PC is used for lag regression to reconstruct the BSISV Life-Cycle (the regression fit is for 1 standard deviation of the PC)



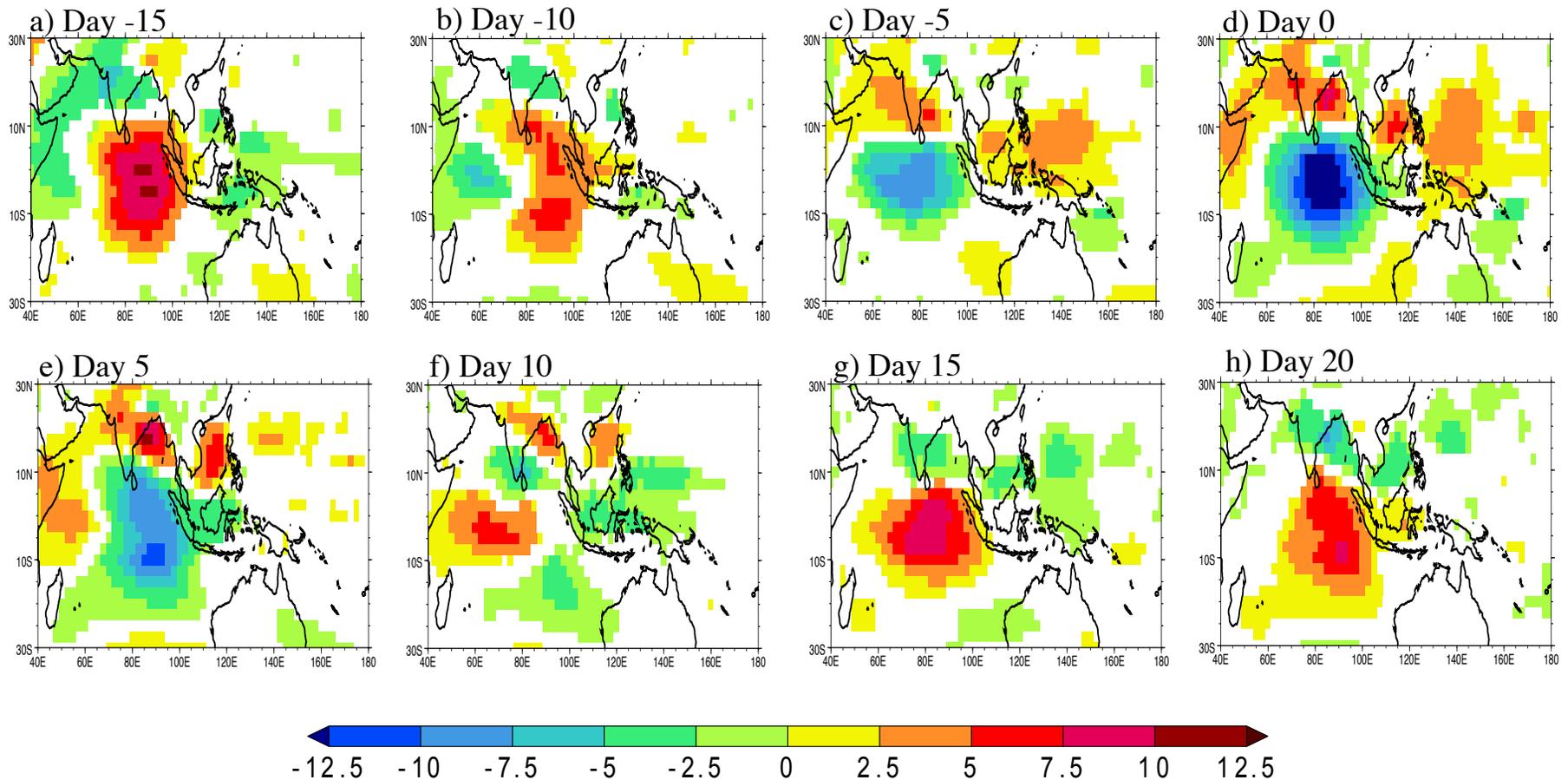
BSISV Life-Cycle: Cyclostationary EOF using 20-100 day Filtered AVHRR OLR (Wm^{-2})

- Eastward and northward propagating OLR anomalies (Annamalai and Sperber 2005, *JAS*, 62, 2726-2748)
- The Day 10 tilted rainband is a key component of the BSISV



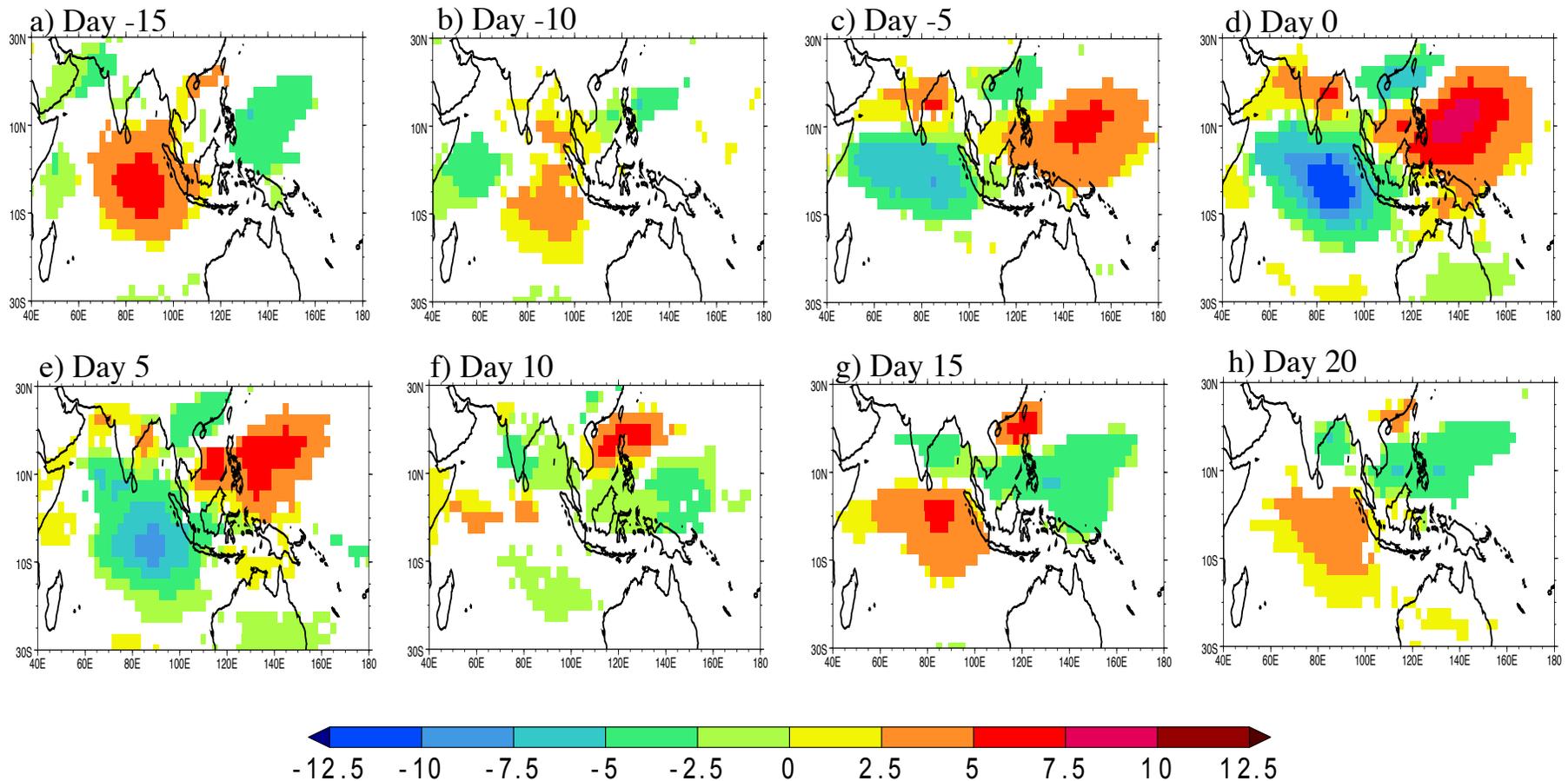
BSISV Life-Cycle: MIROC5 20-100 day Filtered AVHRR OLR (Wm^{-2})

- Similar evolution as observed, but the anomalies are weaker
- Only non-ECHAM-4 based model to “reasonably” simulate BSISV
 - MRI-CGCM3, and to a lesser extent GFDL-ESM2G, have the tilted rainband



BSISV Life-Cycle: **CMIP5 MMM** 20-100 day Filtered AVHRR OLR (Wm^{-2})

- Despite the poor simulation of the BSISV by the vast majority of models, the MMM gives a good representation of the BSISV life-cycle, and the MMM's exceed that skill of the individual models



Skill: 20-100 day Variance vs. BSISV Life-Cycle

- For both CMIP3 and CMIP5, the BSISV is better simulated in models that have a better pattern correlation in their simulation of the 20-100 day filtered variance (the linear regression fits are significant at better than the 1% level)
- This suggests that the location and strength of the filtered variance maxima are largely determined by the propagating BSISV

