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Systematic Errors in the Mean and Annual Cycle of the Regional Monsoons

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PCMDI
Program for Climate Model Diagnosis and Intercomparison

ESGF
Earth System Grid Federation

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Why is it important to study monsoons?

- 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 Asian-Australian Monsoon Panel
  - 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)

Outline

- Model Validation and Evaluation
  - CMIP-5 (circa 2011) vs. CMIP-3 (circa 2004)
  - CMIP-3 20c3m and CMIP-5 Historical simulations (1961-1999)
  - Multiple sources of observations to evaluate model performance in terms of observational uncertainty
  - For skill scores and difference maps, the model data have been interpolated to the observational grid

Sperber, K.R., H. Annamalai, I.-S. Kang, A. Kitoh, A. Moise, A. Turner, B. Wang, and T. Zhou (2013) The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century. Clim. Dynam., 41, 2711-2744. doi: 10.1007/s00382-01201607-6

Observations, CMIP-3, and CMIP-5 Models

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- Observations
  - AVHRR OLR; GPCP and CMAP Rainfall; ERA40, JRA25, and NCEP/NCAR Reanalysis 850hPa Winds
- CMIP-3 (22 models, 15 for BSISV)
  - BCCR BCM2.0, CCCMA CGCM3.1, CCCMA CGCM3.1 T63, CNRM CM3, CSIRO Mk3.0, CSIRO Mk3.5, GFDL CM2.0, GFDL CM2.1, GISS AOM, FGOALS 1.0g, HadCM3, HadGEM1, INGV ECHAM4, INM CM3.0, IPSL CM4, MIROC 3.2 (hi-res), MIROC 3.2 (med-res), MIUB ECHO-G, MPI ECHAM5-OM, MRI CGCM2.3.2a, NCAR CCSM3.0, and NCAR PCM1
- CMIP-5 (25 models, 16 for BSISV)
  - 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

CLIVAR AAMP: Asian Summer Monsoon
CMIP-5 vs. CMIP-3

- Climatological performance
  - Rainfall, 850hPa winds
  - Skill comparison: pattern correlations with observations
- Climatological Annual Cycle (Monsoon Onset, Peak, Withdrawal, and Duration)
  - Pentad rainfall
- ENSO-monsoon relationship
  - Lead-lag of all-India rainfall with Nino3.4 SST
  - 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, northward propagation, BSISV life-cycle

Observations vs. CMIP-5 (1961-99) JJAS Rainfall Climatology

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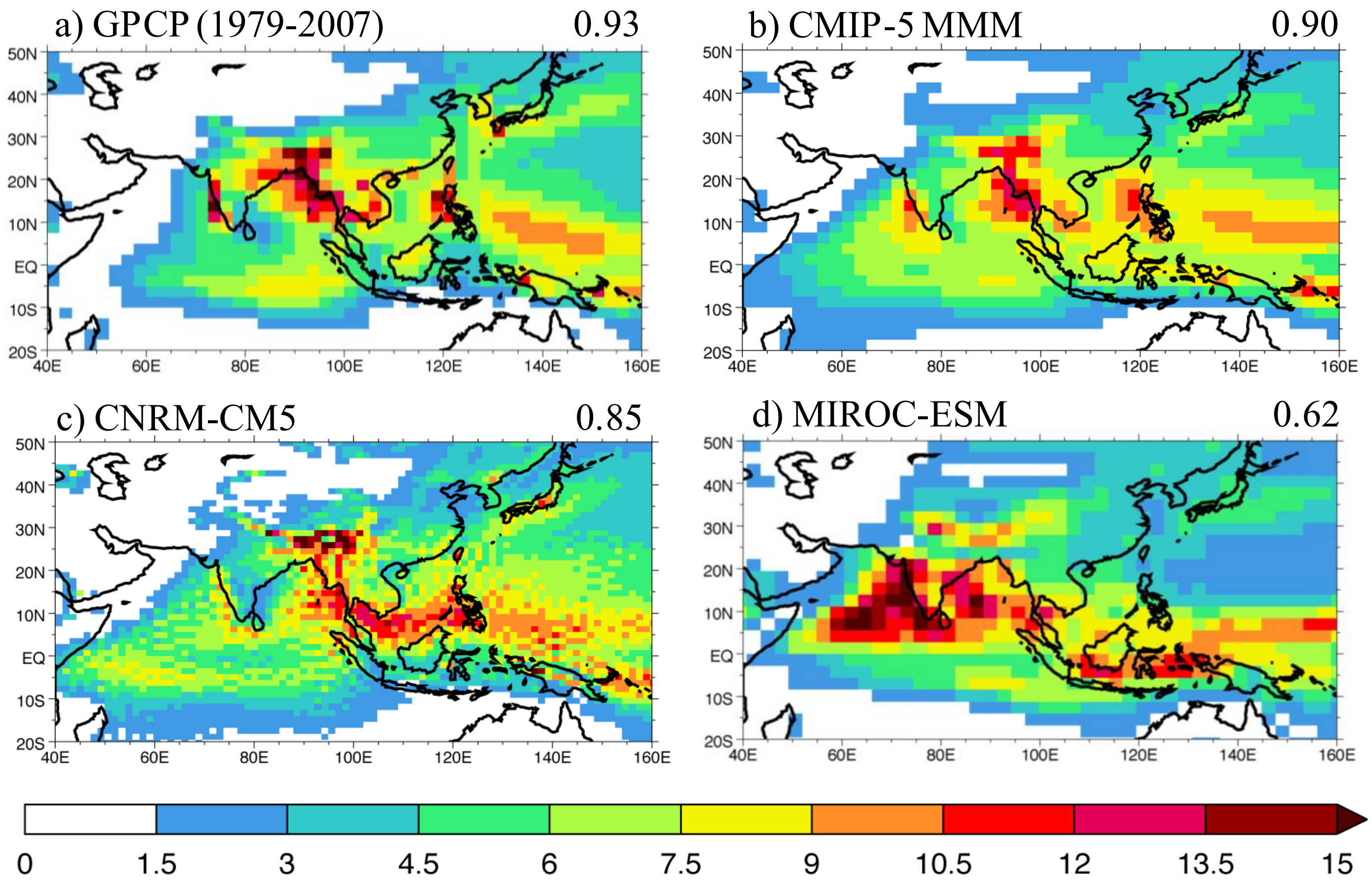
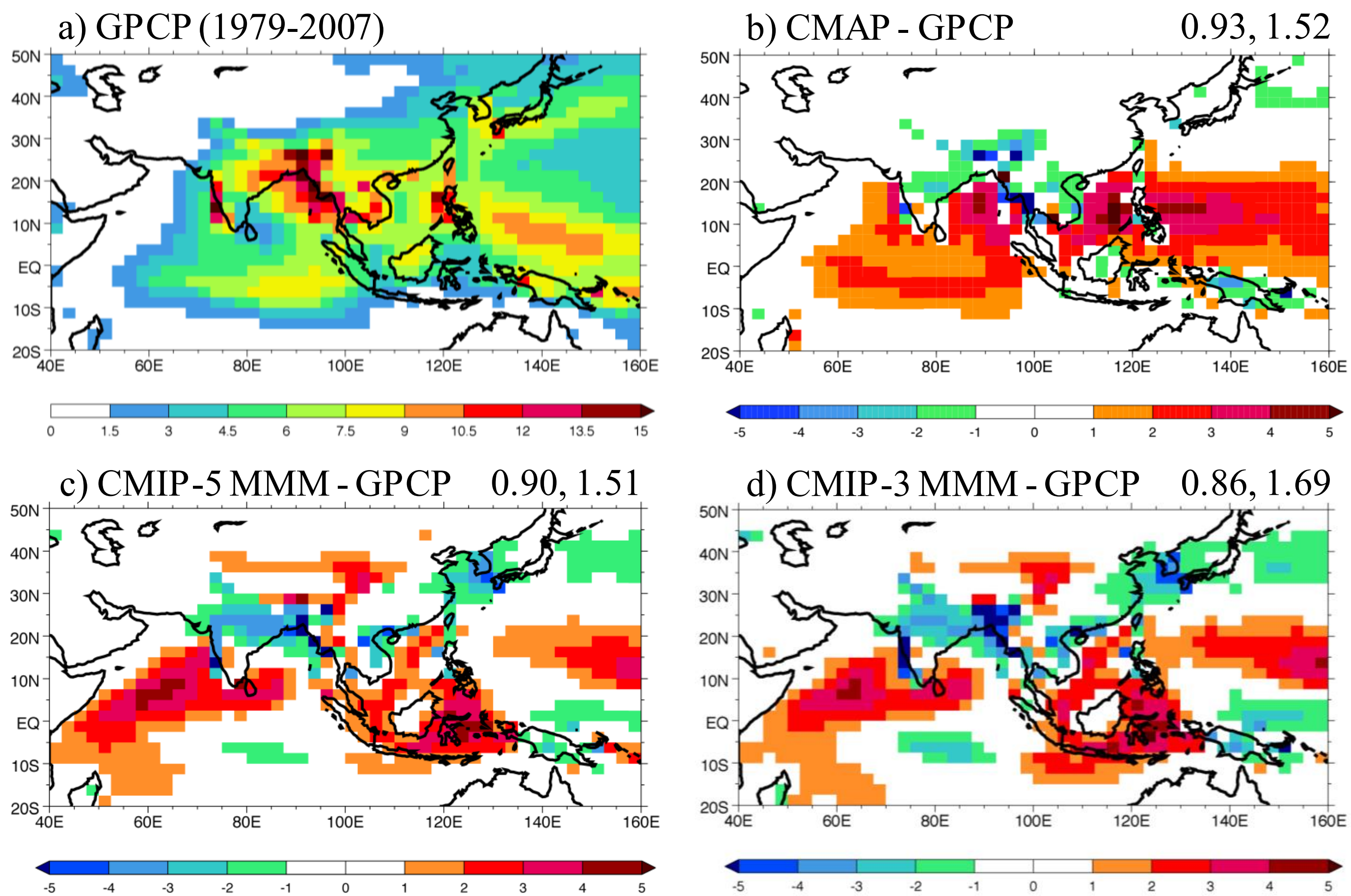
- Observed and simulated results include data from the CMIP-5 multi-model mean, and the two models that show the range of performance
  - The CMIP-5 MMM outperforms all of the individual models
  - CMIP-5 MMM has improved rainfall, especially near Ghats and Tibetan Plateau



Observations vs. CMIP-5 and CMIP-3 (1961-99) JJAS Rainfall Climatology Systematic Error

- The systematic error in rainfall is nearly identical in CMIP-5 and CMIP-3 and the error structure is similar to observational uncertainty
  - Compared to GPCP, the CMIP-5 multi-model mean has a larger pattern correlation and a smaller root-mean-square error than CMIP-3



Observations vs. CMIP-5 (1961-99) JJAS 850hPa Wind Climatology: Anomalies

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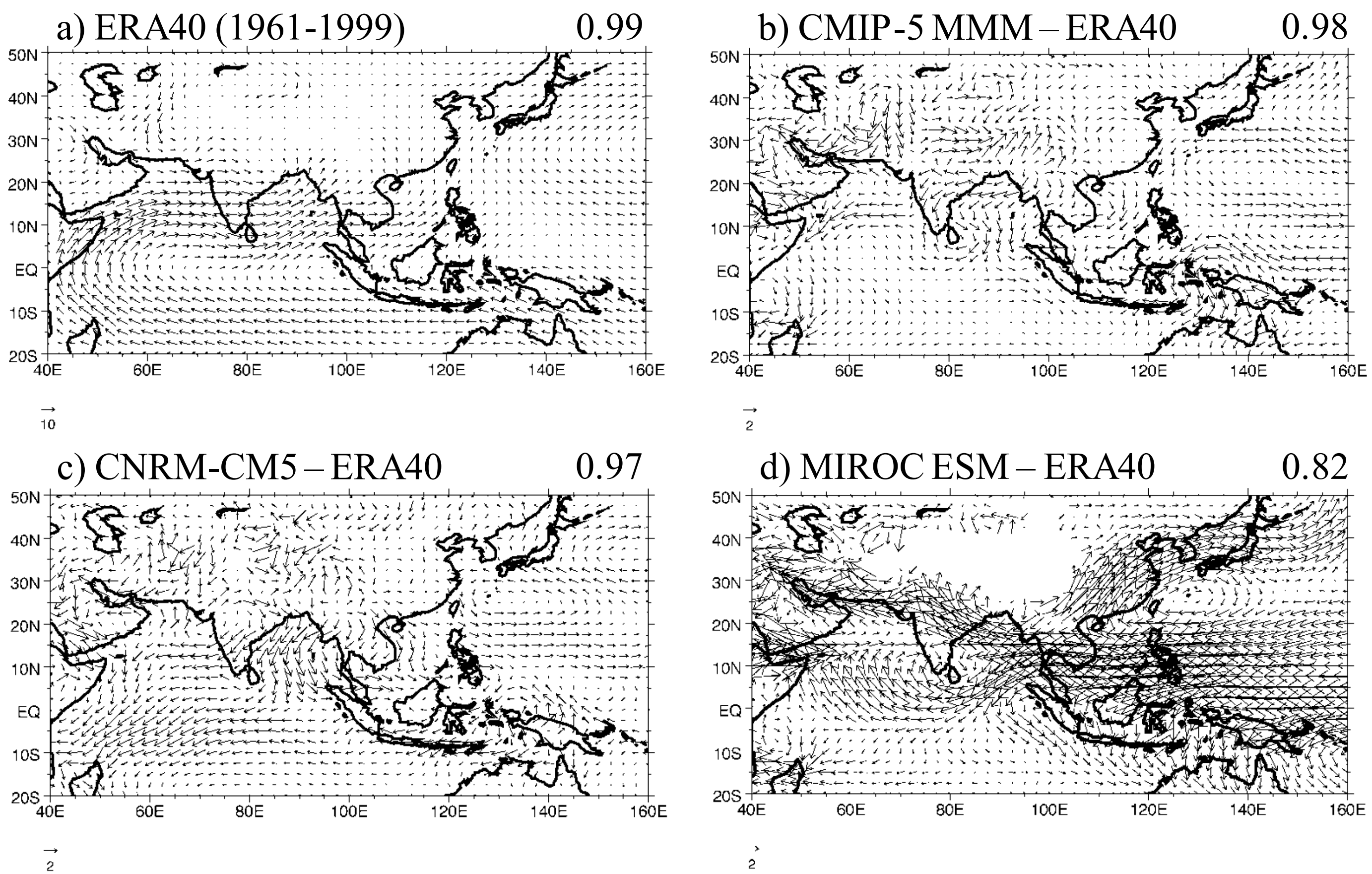
- Observed and simulated results include data from the CMIP-5 multi-model mean, and the two models that show the range of performance
  - Errors in the wind consistent with errors in the precipitation climatology



Observations vs. CMIP-3 and CMIP-5 (1961-99) JJAS 850hPa Wind Climatology: Sys. Error

Program for Climate Model Diagnosis and Intercomparison

- Observed and simulated results include data from the CMIP-3 multi-model mean, and the two models that show the range of performance
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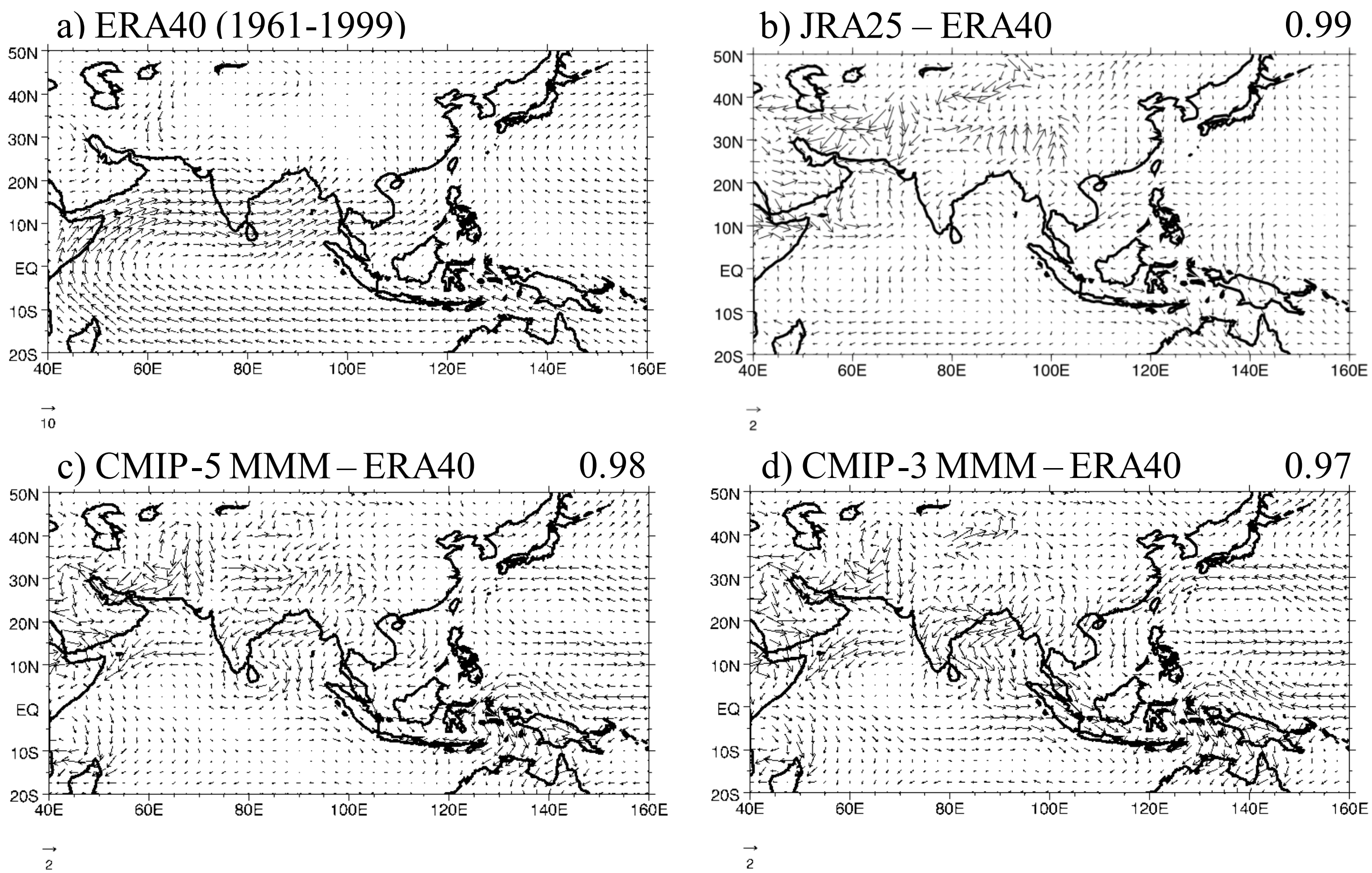
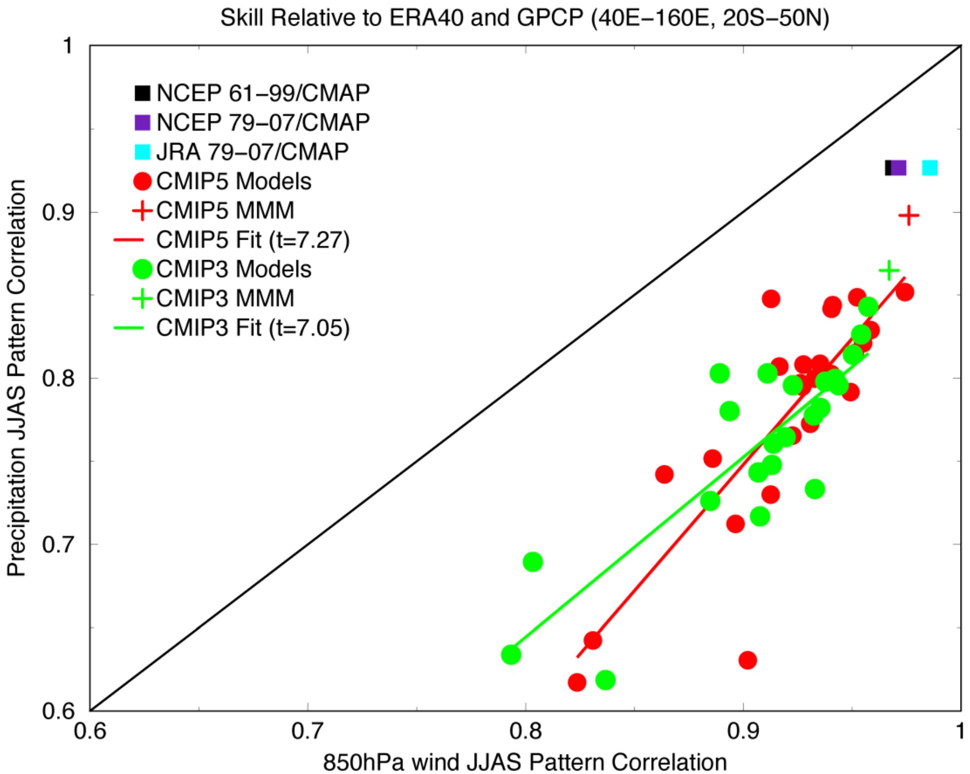


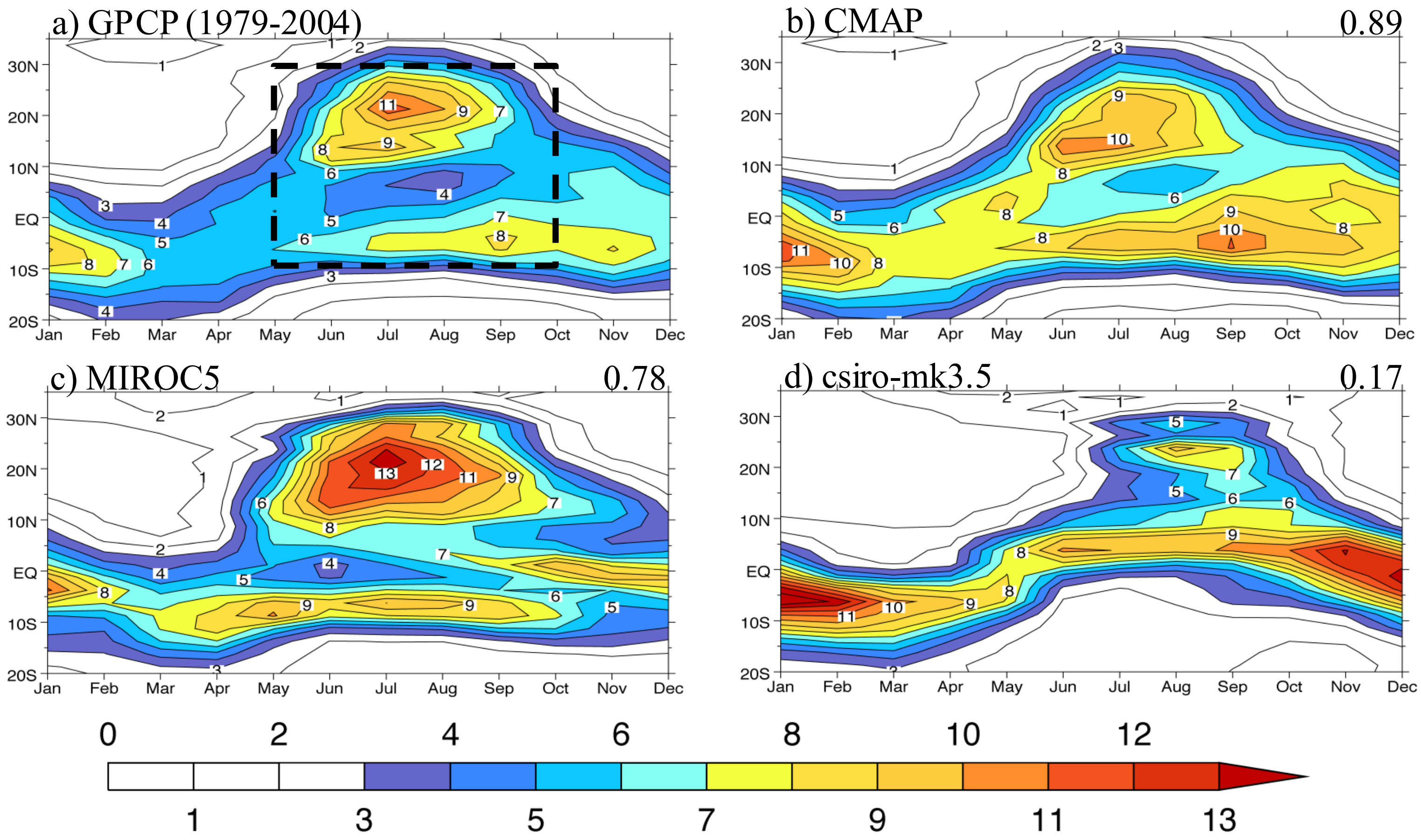
Observations vs. CMIP-5 and CMIP-3 (1961-99) JJAS 850hPa Wind vs. Rainfall: Skill

- 850hPa wind climatology pattern correlation vs. ERA40 (1961-1999)
- Rainfall climatology vs. GPCP (1979-2007)
  - Wind is better simulated than rainfall
  - Models are beginning to approach observational uncertainty in the simulation of the 850hPa wind climatology
  - CMIP-5 MMM outperforms CMIP-3 MMM



Observations vs. CMIP-5 and CMIP-3 (1961-99) Annual Cycle (70ºE-90ºE average; monthly)

- Observations and the two models that show the range of performance
  - GPCP and CMAP have a close correspondence in phasing, but differences in magnitude, which over the oceans is related to how the satellite data was calibrated against the Atoll gauge data
  - Biases: Extent of monsoon domain, amplitude, and timing



Observations vs. CMIP-5 and CMIP-3 (1961-99) Annual Cycle (70ºE-90ºE average; monthly)

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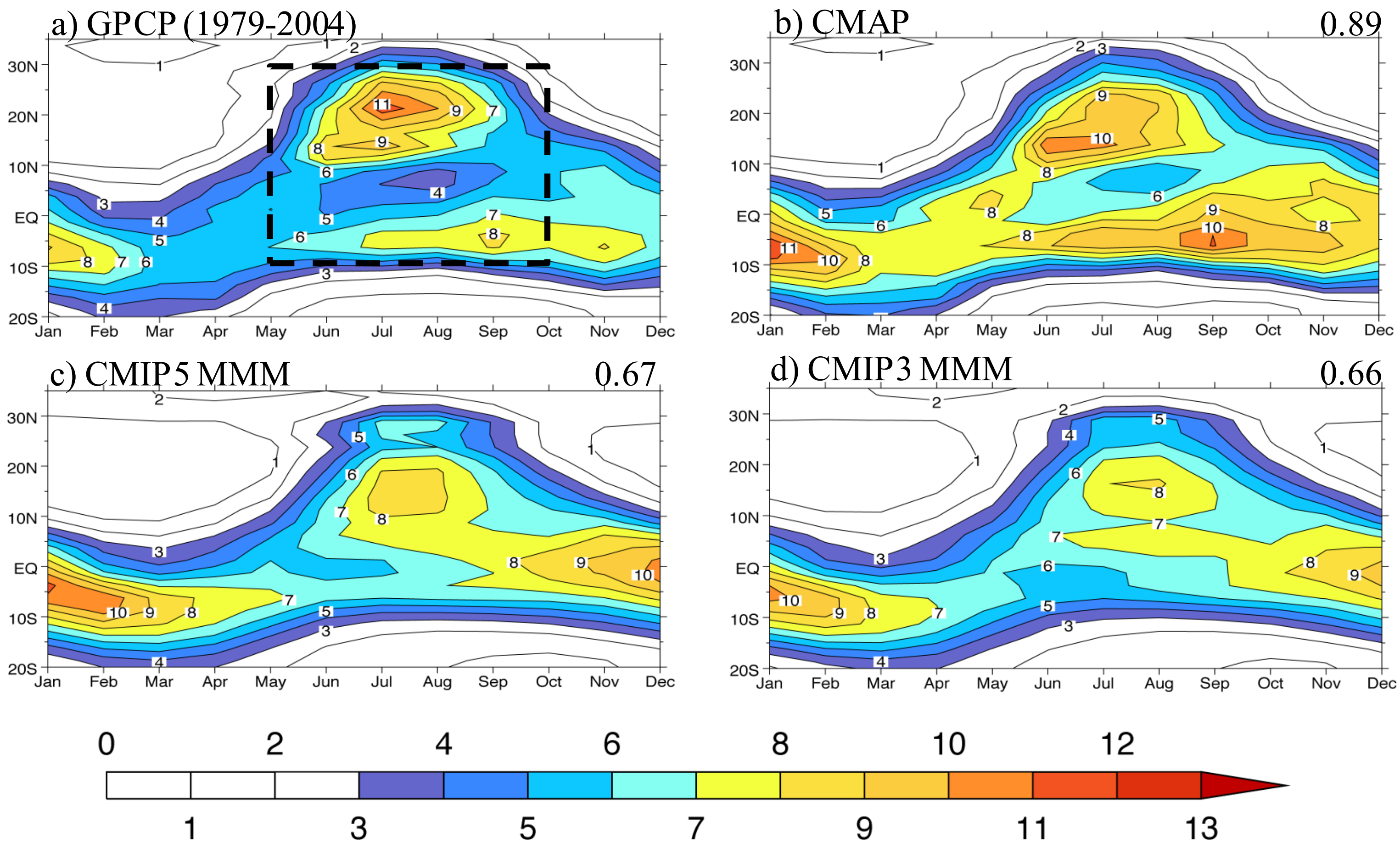
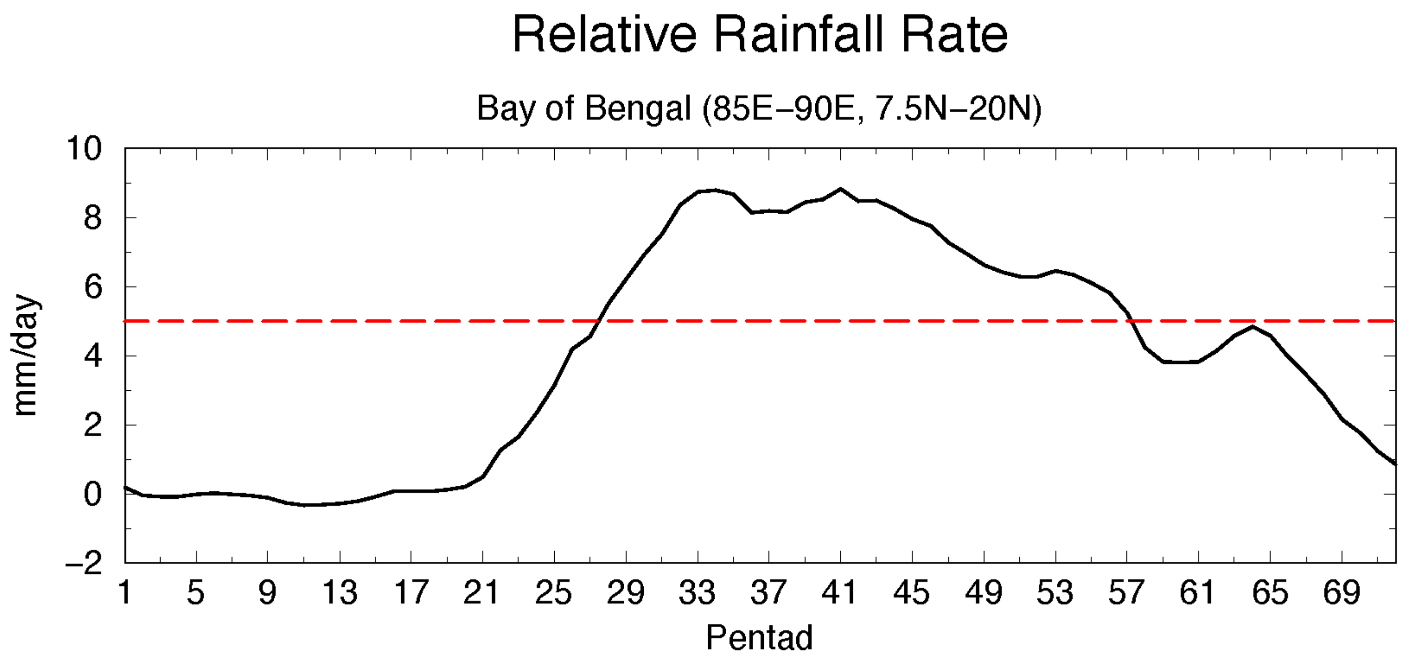
- Observed and simulated precipitation from the CMIP5 and CMIP3 MMM's
  - Individual models outperform the MMM
  - Unlike the observations, the MMM's produce a pronounced southward transition of rainfall in the boreal autumn



Climatological 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)
  - Remove 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 31 ~ June 2)

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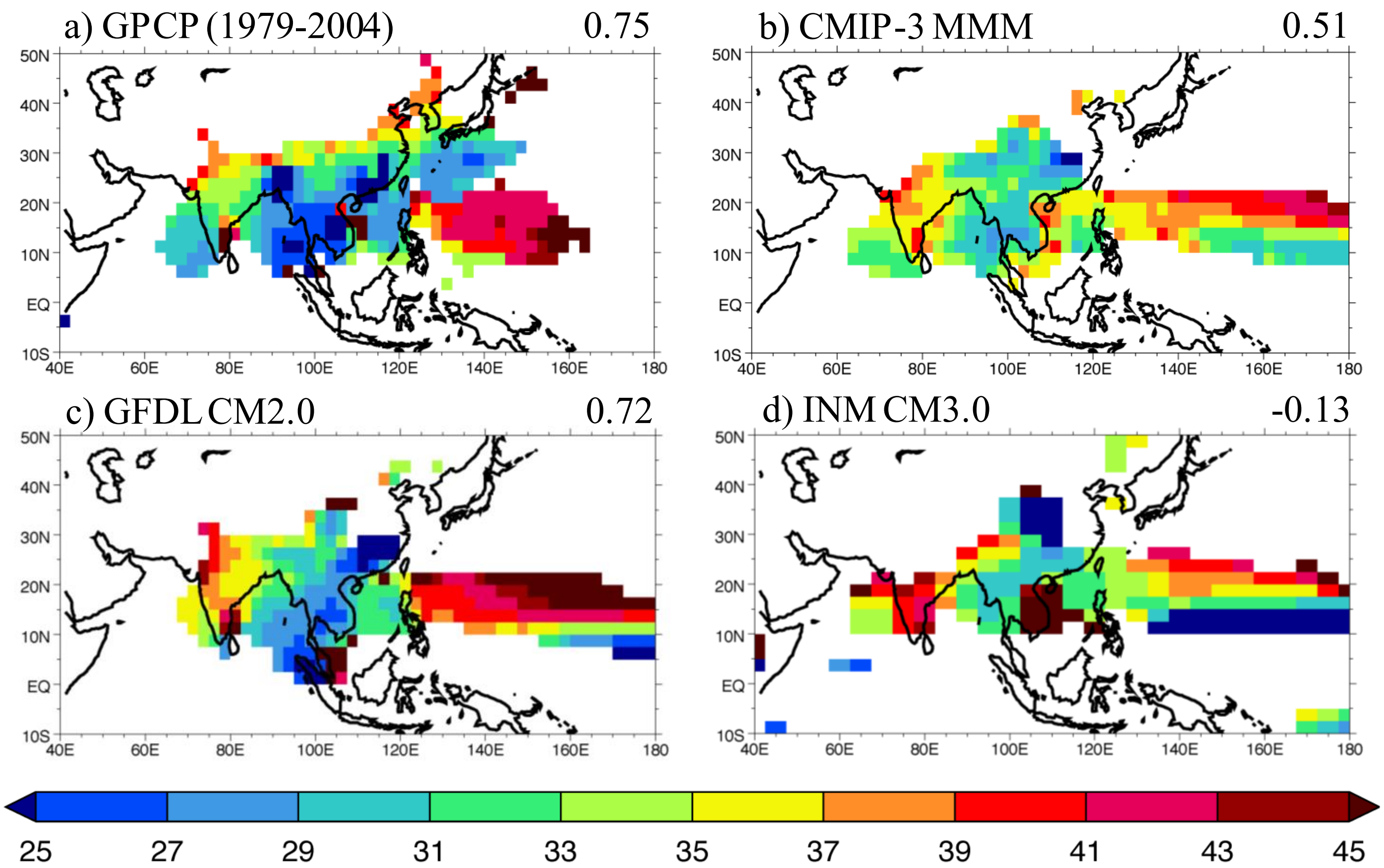
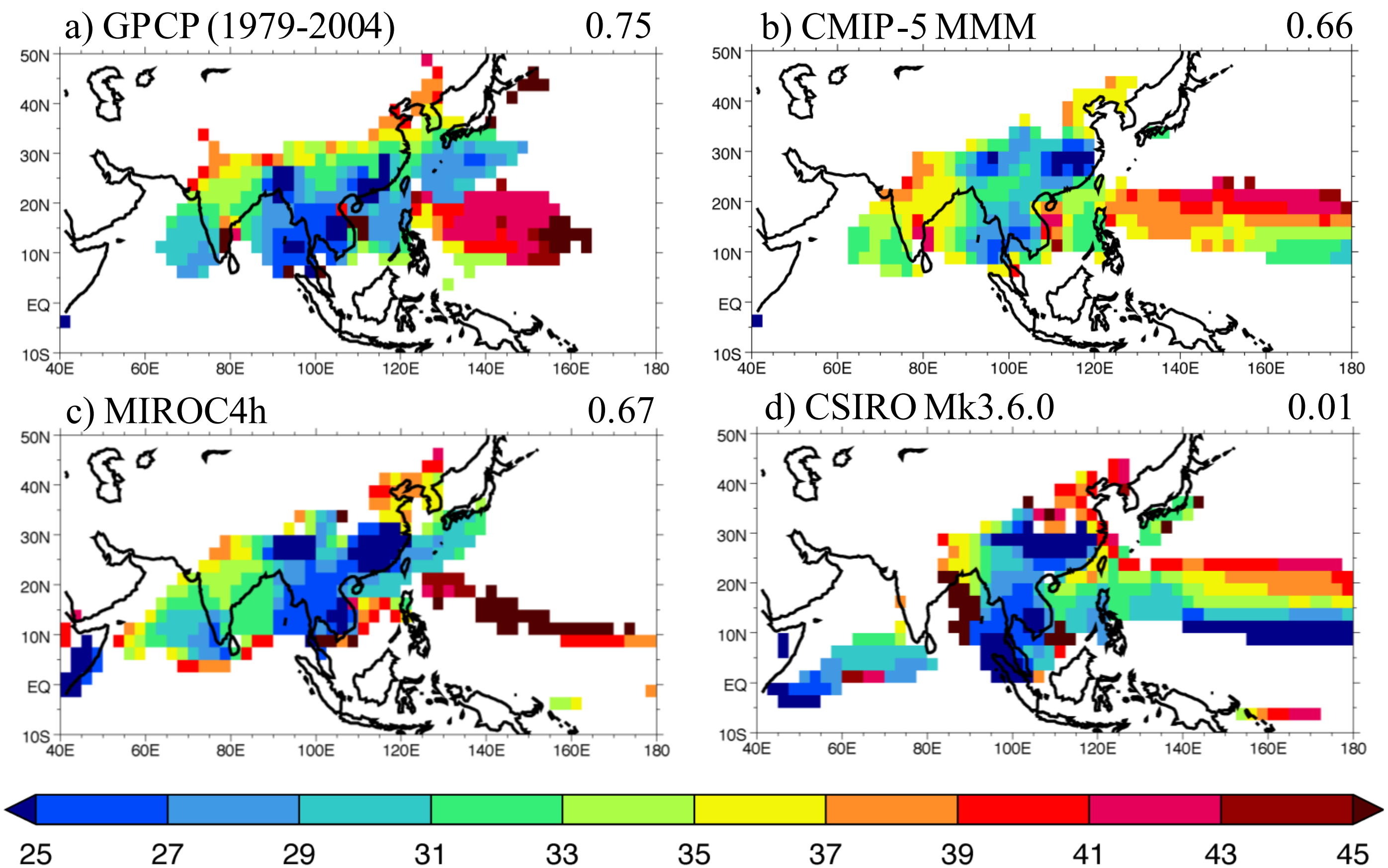
- Observed and simulated results include data from the CMIP-3 multi-model mean, and the two models that show the range of CMIP-3 performance
  - Individual models outperform the multi-model mean
  - Biases: Extent of monsoon domain; timing



Observations vs. CMIP-5 (1961-99) Climatological Monsoon Onset (pentad)

- Observed and simulated results include data from the CMIP-5 multi-model mean, and the two models that show the range of CMIP-5 performance
  - Individual models outperform the multi-model mean
  - Biases: Extent of monsoon domain; timing



Observations vs. CMIP-3 (1961-99)
Climatological Monsoon Duration (# of pentads)

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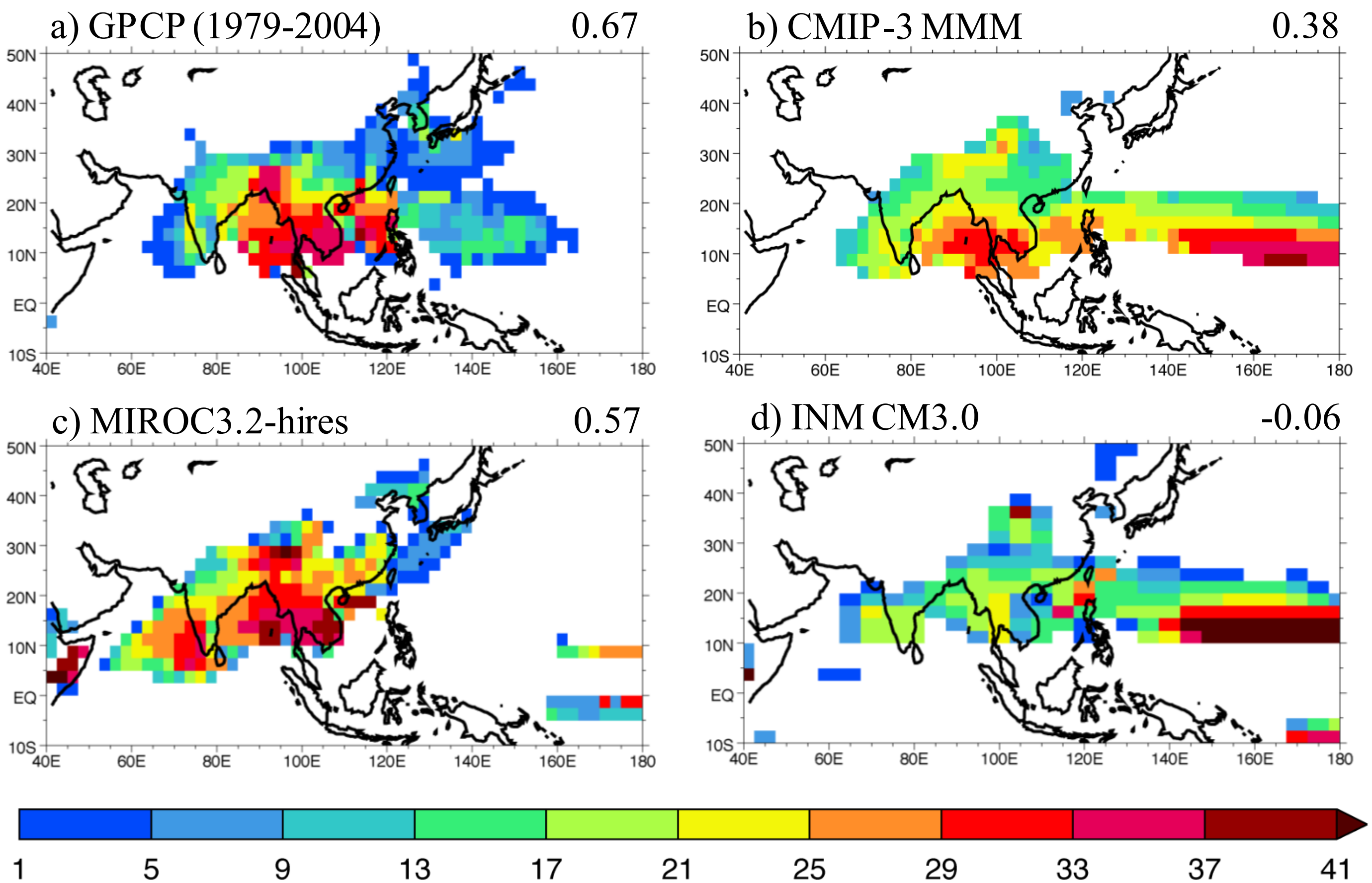
- Observed and simulated results include data from the CMIP-3 multi-model mean, and the two models that show the range of CMIP-3 performance
  - Individual models outperform the multi-model mean
  - Duration, peak, and withdrawal times are more difficult to represent than onset time



Observations vs. CMIP-5 (1961-99) Climatological Monsoon Duration (# of pentads)

Program for Climate Model Diagnosis and Intercomparison

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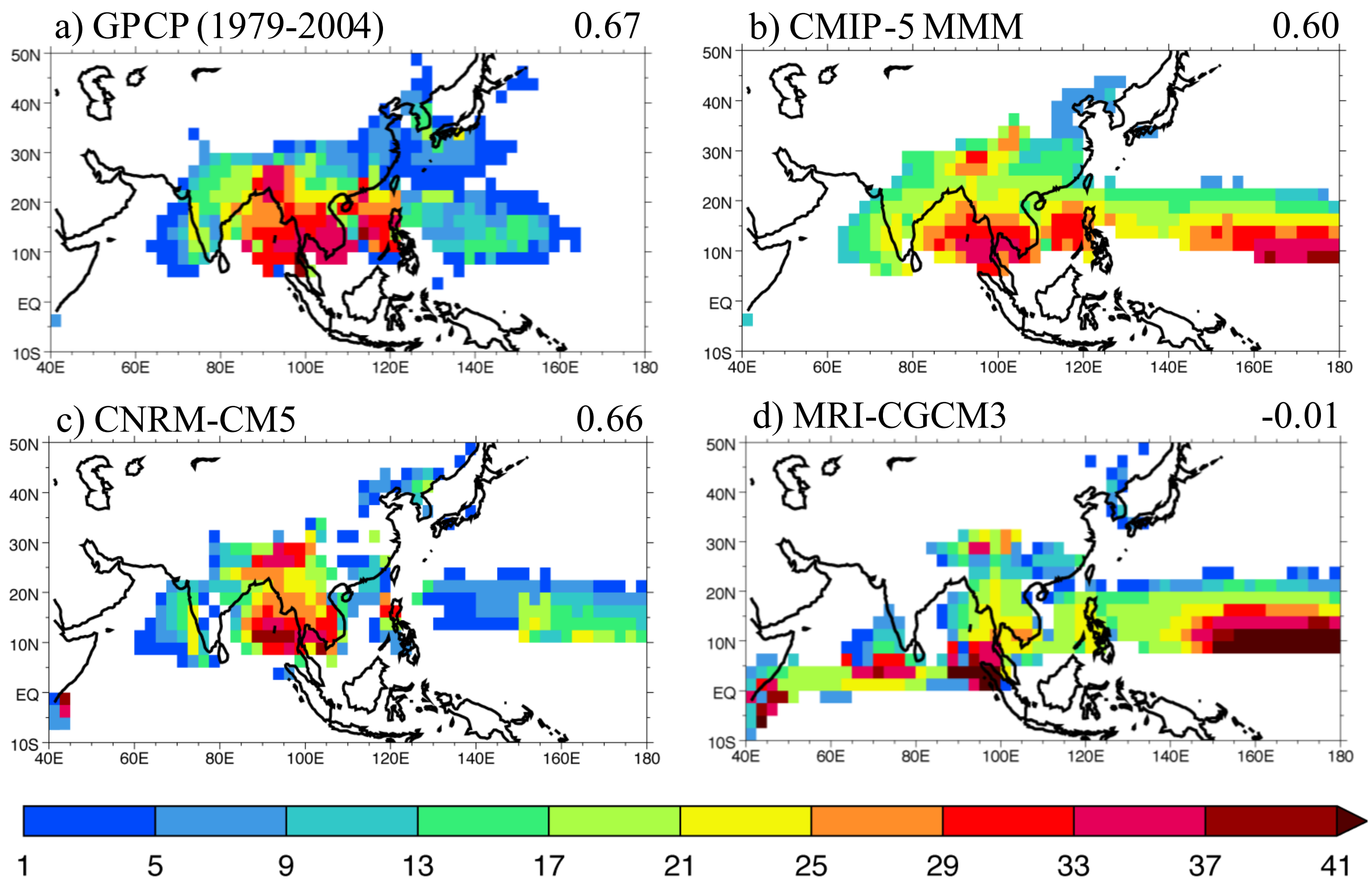
  - Duration, peak, and withdrawal times are more difficult to represent than onset time



Observations vs. CMIP-5 and CMIP-3 (1961-99)

Skill: Onset vs. Duration, and Monsoon Domain

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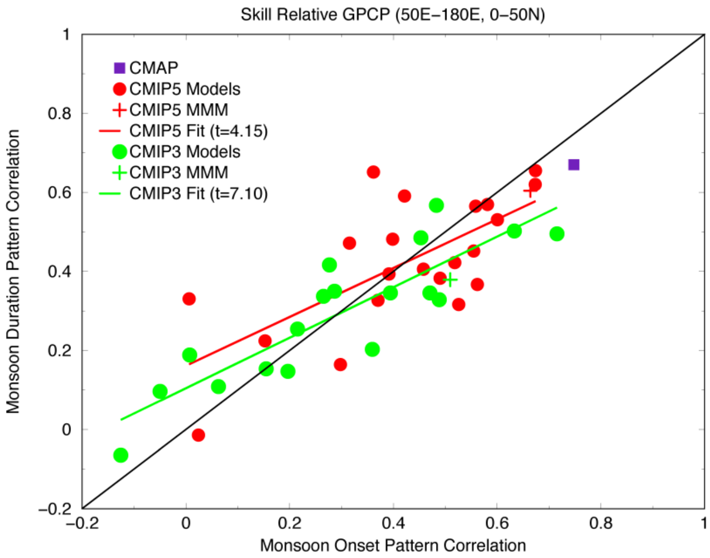
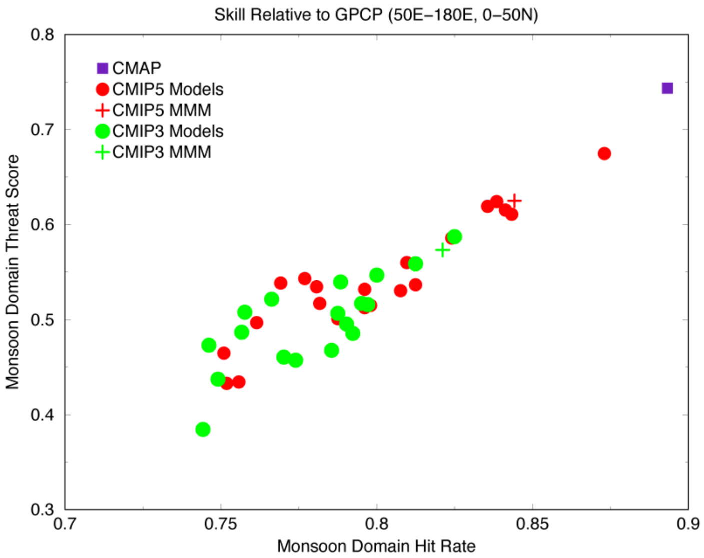
- Onset vs. Duration (left)
  - CMIP5 MMM is more skillful than the CMIP3 MMM
  - Some individual models are more skillful than the MMM's
  - Statistically significant relationship between onset skill and duration skill
- Monsoon Domain (right)
  - CMIP5 MMM more skillful than the CMIP3 MMM (Hit-rate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





Interannual Variability: Rainfall during El Nino:

Regression (mm day^{-1}) relative to NINO3.4 SSTA

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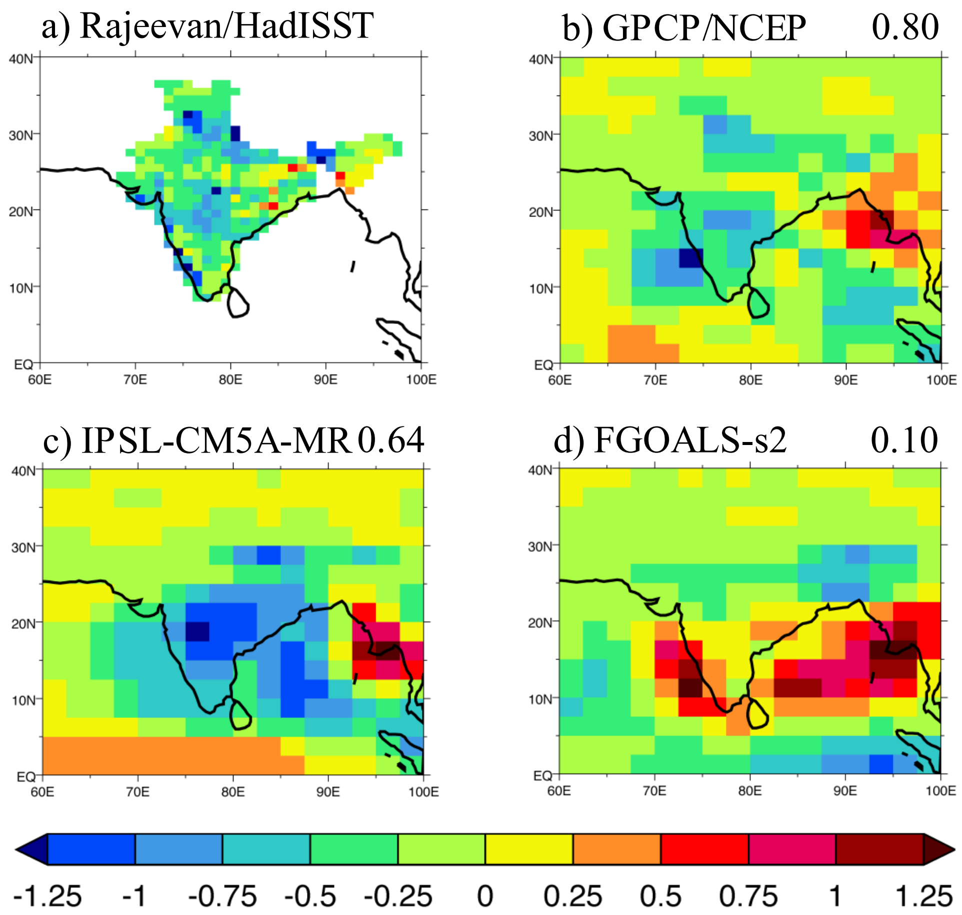
- Observed and simulated results show the range of performance
  - Good agreement between the high-resolution Rajeevan data (1961-99) with GPCP (1979-2007)
  - Diverse skill in representing the observed rainfall pattern forced by ENSO



Interannual Variability: Rainfall during El Nino:
Regression (mm day^{-1}) relative to NINO3.4 SSTA

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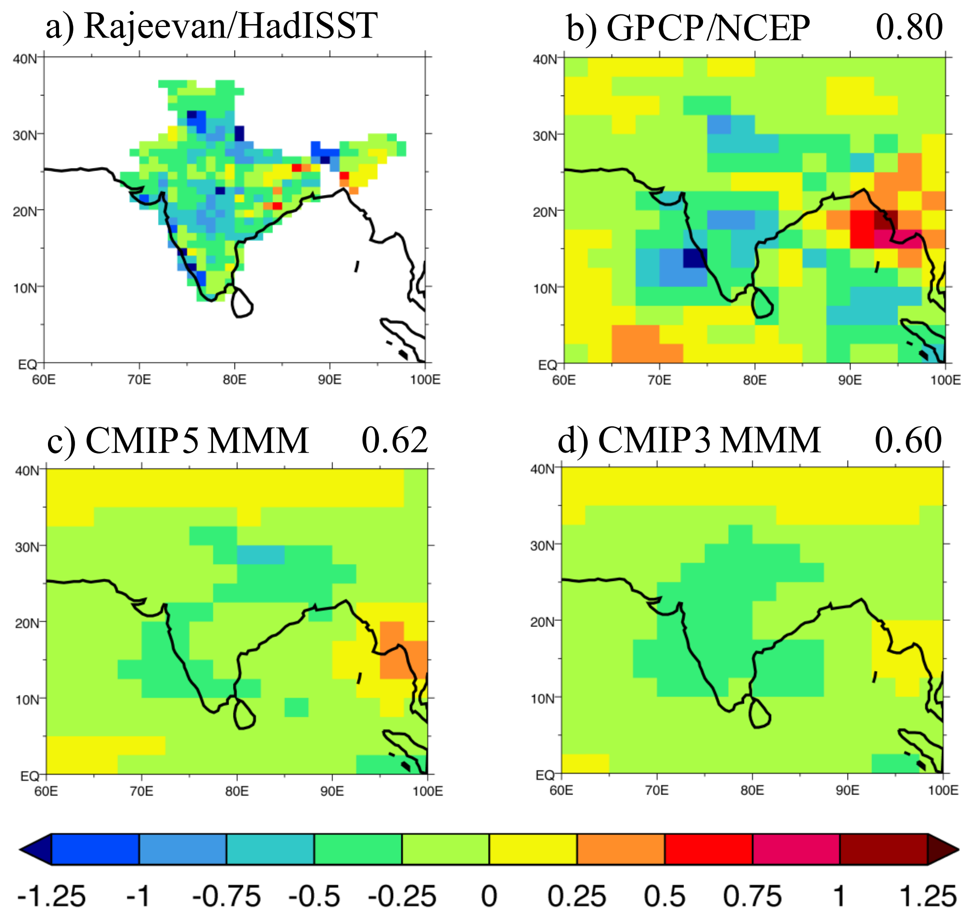
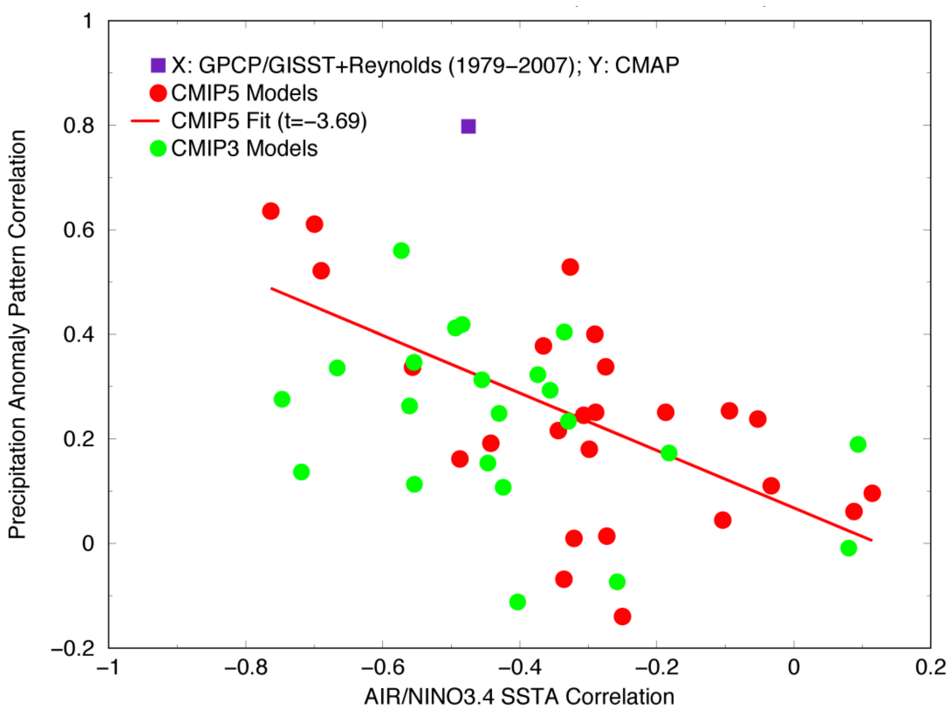
- Observations and the CMIP5 and CMIP3 MMM's
  - The CMIP5 MMM marginally outperforms the CMIP3 MMM
  - The magnitude of the CMIP5 MMM anomalies is more realistic compared to the CMIP3 MMM, though the MMM's have weaker anomalies than individual models



Skill: AIR/NINO3.4 Correlation vs. Pattern Correlation of 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 on the rainfall anomalies (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 Variation

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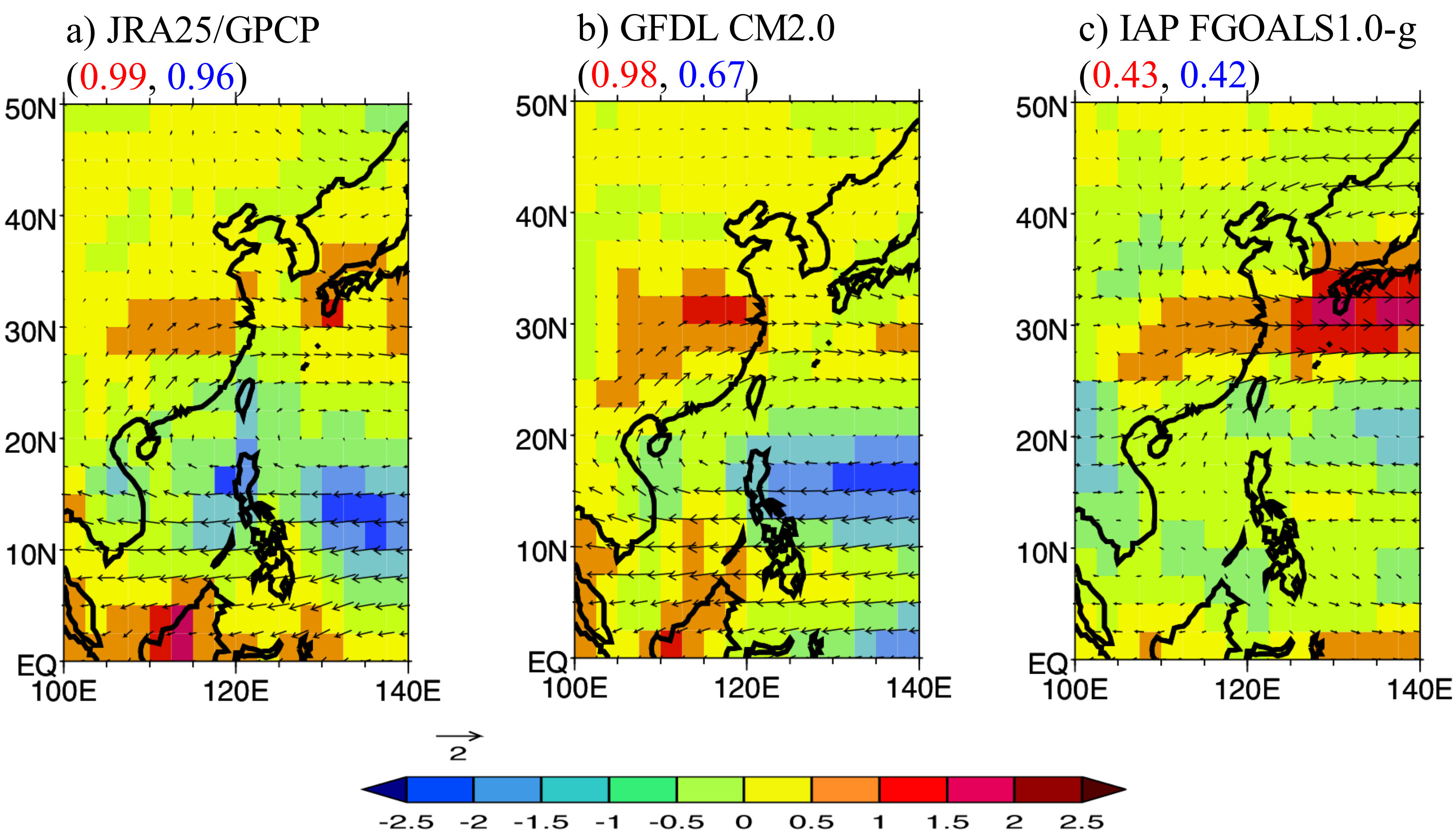
- 850hPa zonal wind shear anomaly index designed by Wang and Fan (1999, *Bull. Amer. Meteor. Soc.*, 80, 629–638), and revised, where

Index= u850 (110^{o}E-140^{o}E, 22.5^{o}N-32.5^{o}N) - u850 (90^{o}E-130^{o}E, 5^{o}N-15^{o}N)

- As suggested 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^{o}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 that show the *range of performance* from CMIP-5 and CMIP-3 models based on 850hPa wind pattern correlation
  - 850hPa wind is better represented than rainfall, though extratropical influences may incorrectly dominate in some models



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

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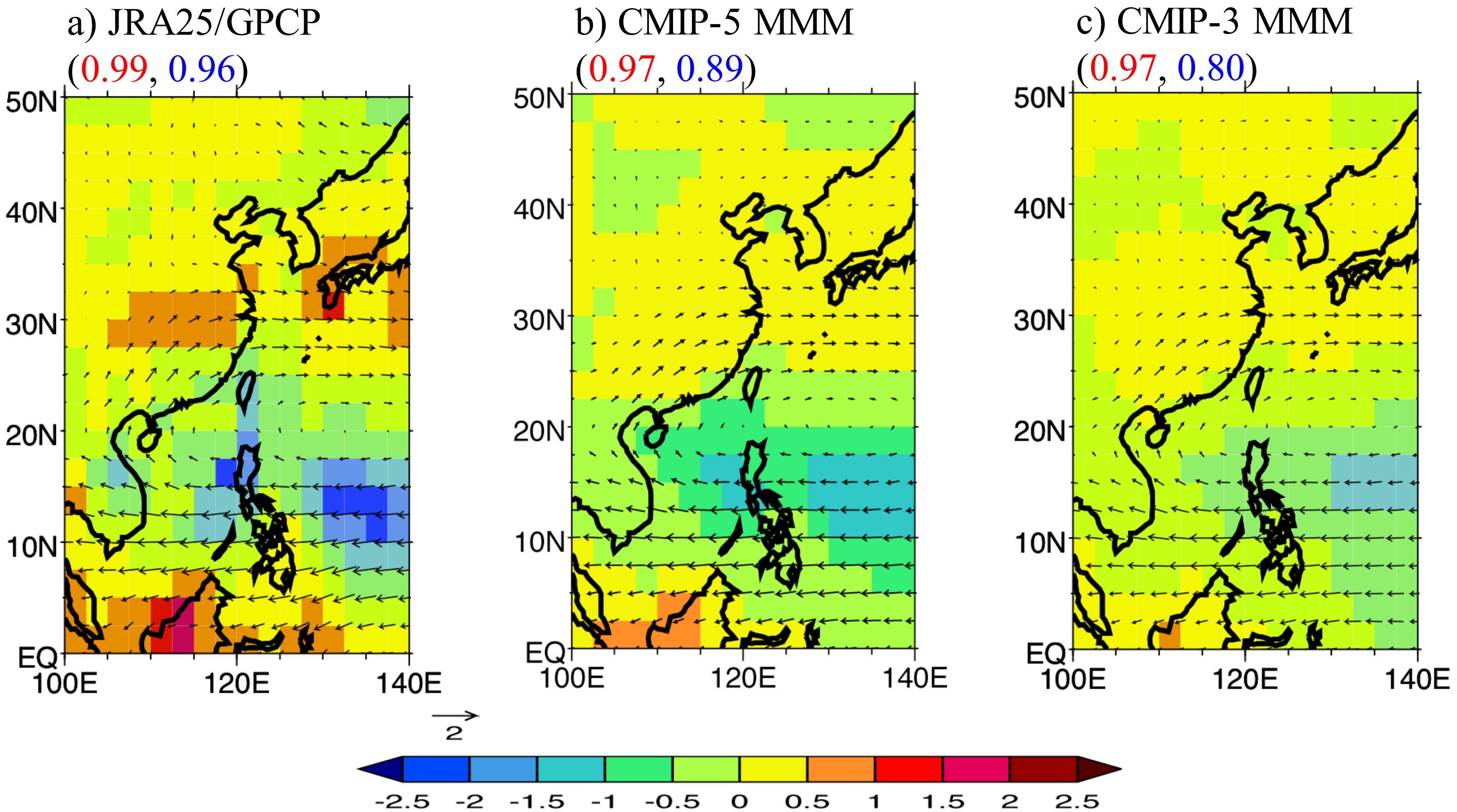
- Observations, and CMIP-5 and CMIP-3 multi-model means
  - Individual models have skill comparable to the multi-model mean
  - Skill in simulating the 850hPa wind pattern correlation is approaching observational uncertainty
  - CMIP-5: Improved skill in the simulation of the rainfall pattern correlation



Boreal Summer Intraseasonal Variability (BSISV): CMIP-3 + ECHAM4/OPYC

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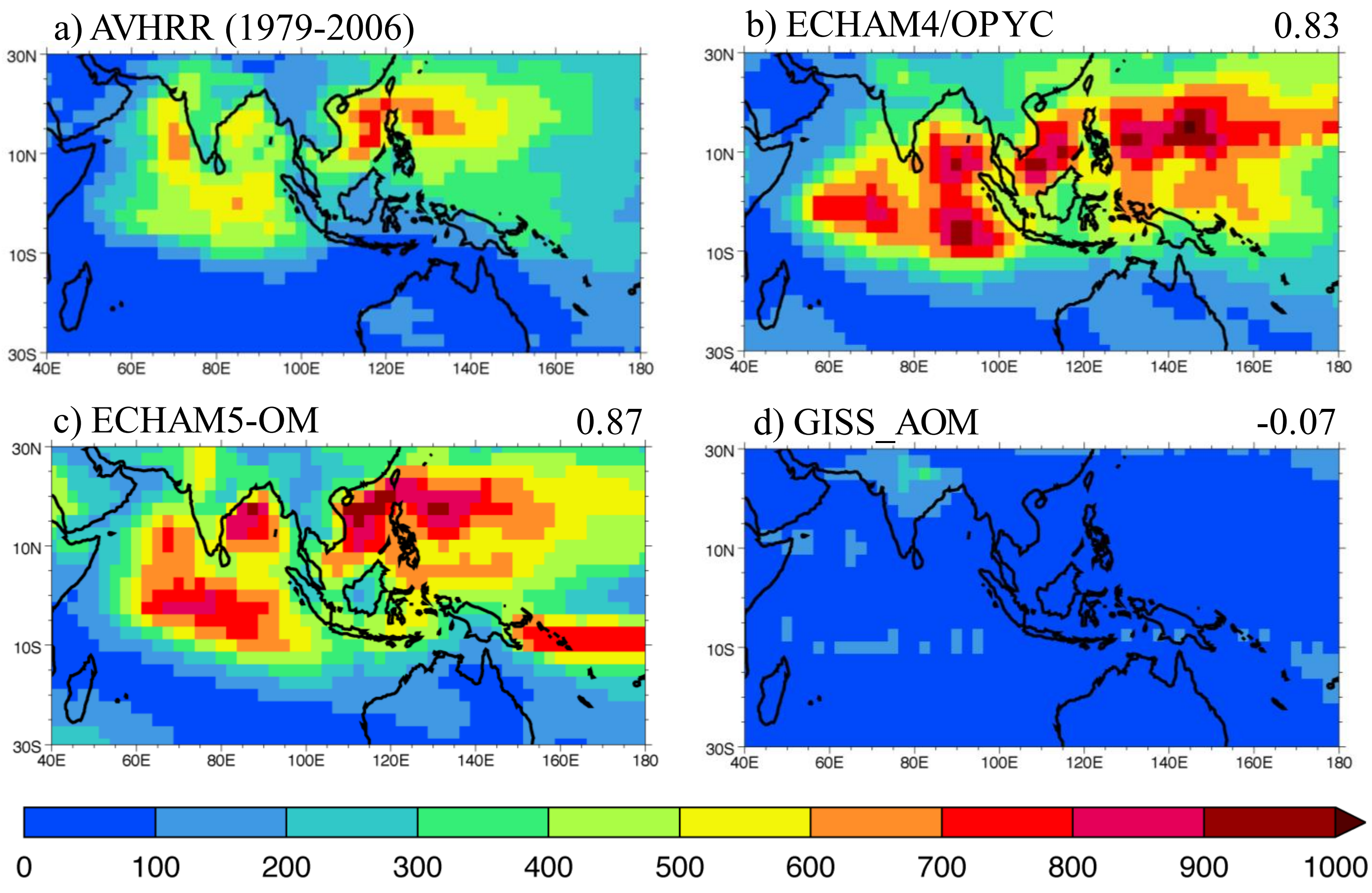
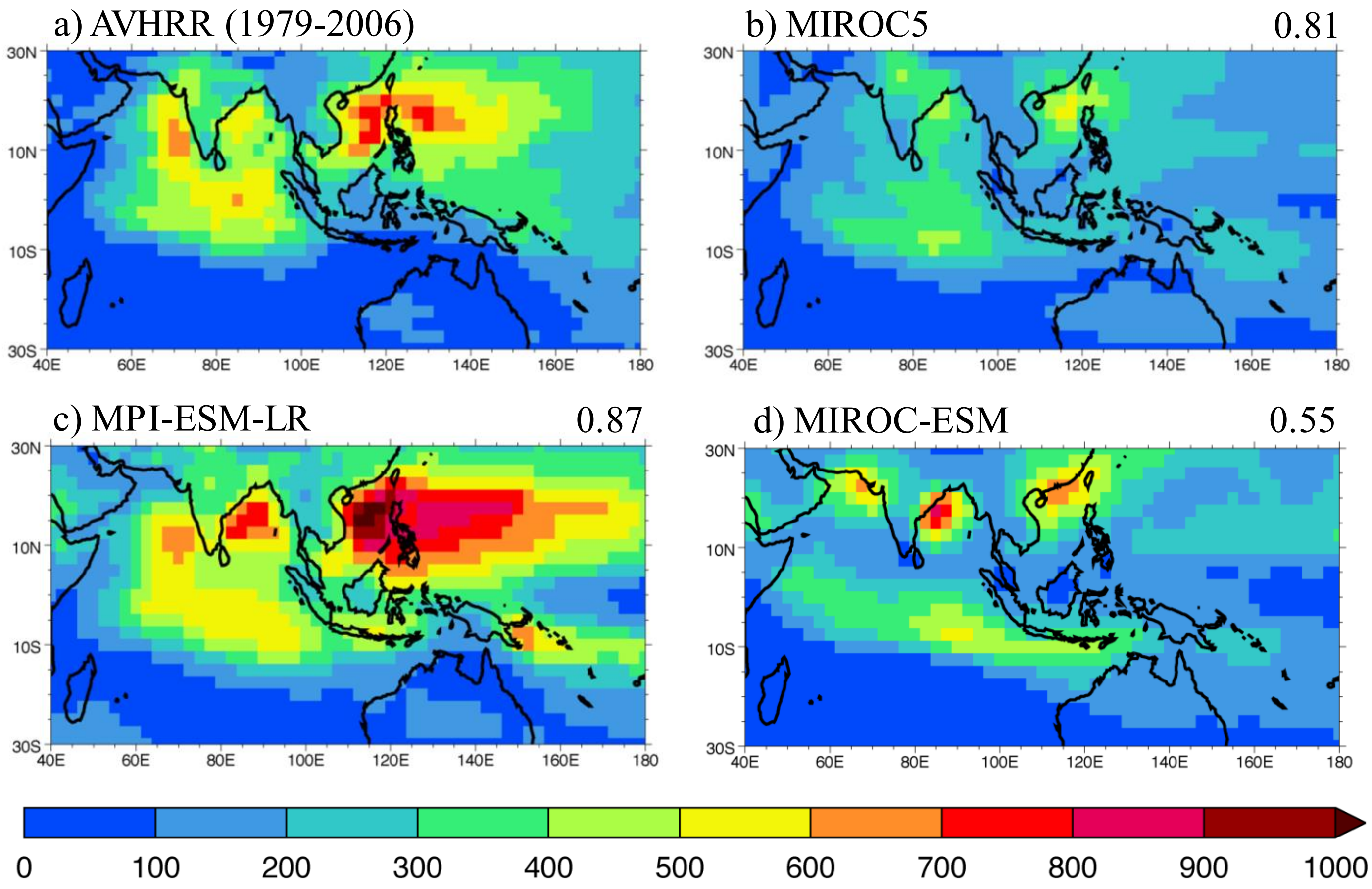
- Variance of 20-100 day bandpass filtered OLR (JJAS)
  - ECHAM4/OPYC, the predecessor to ECHAM5-OM, also has a large pattern correlation with the AVHRR OLR filtered variance



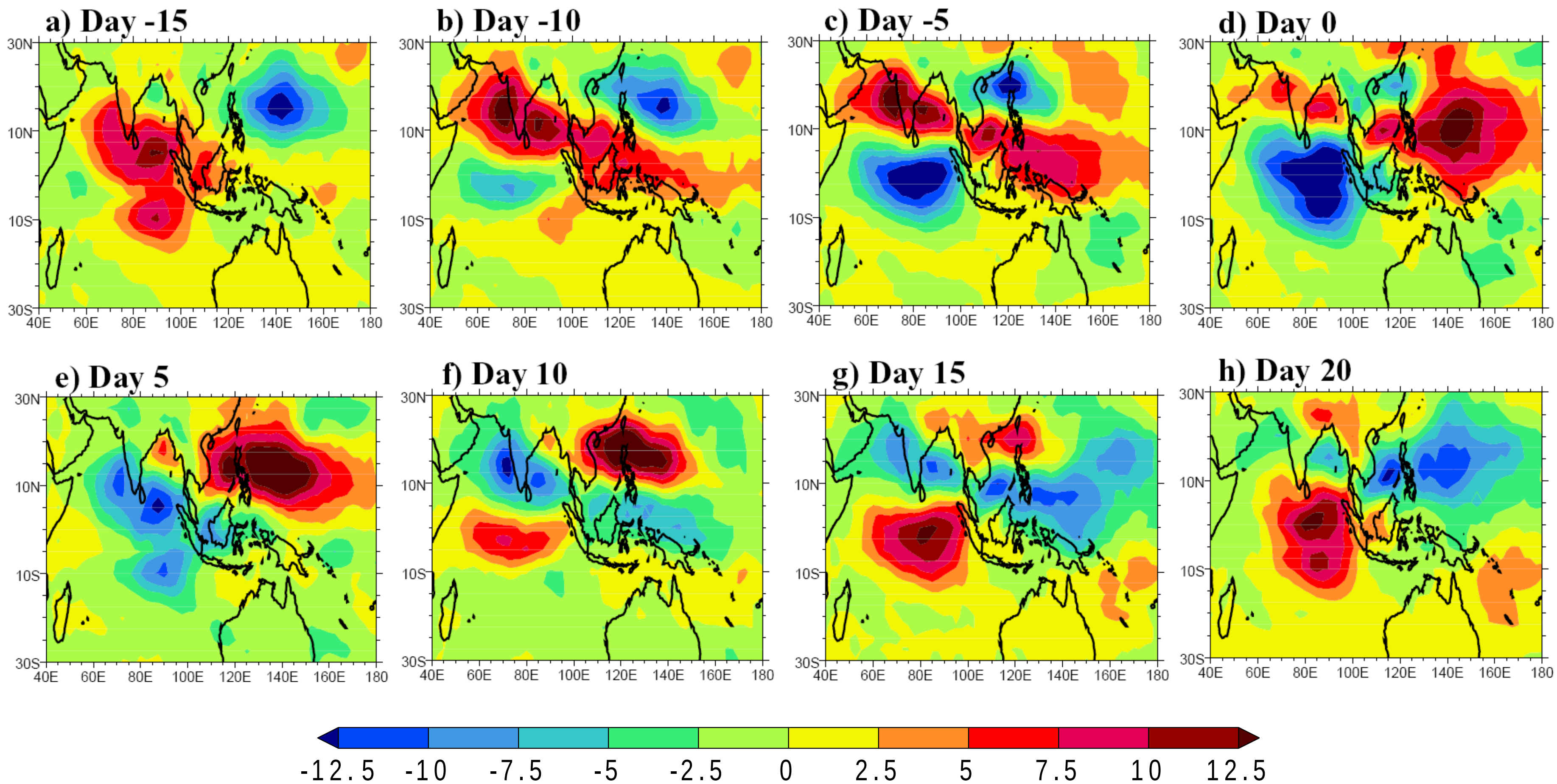
Boreal Summer Intraseasonal Variability (BSISV): CMIP-5

- Variance of 20-100 day bandpass filtered OLR (JJAS)
  - MIROC5 also has a large pattern correlation with the AVHRR OLR filtered variance, but the variance is underestimated



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

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



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

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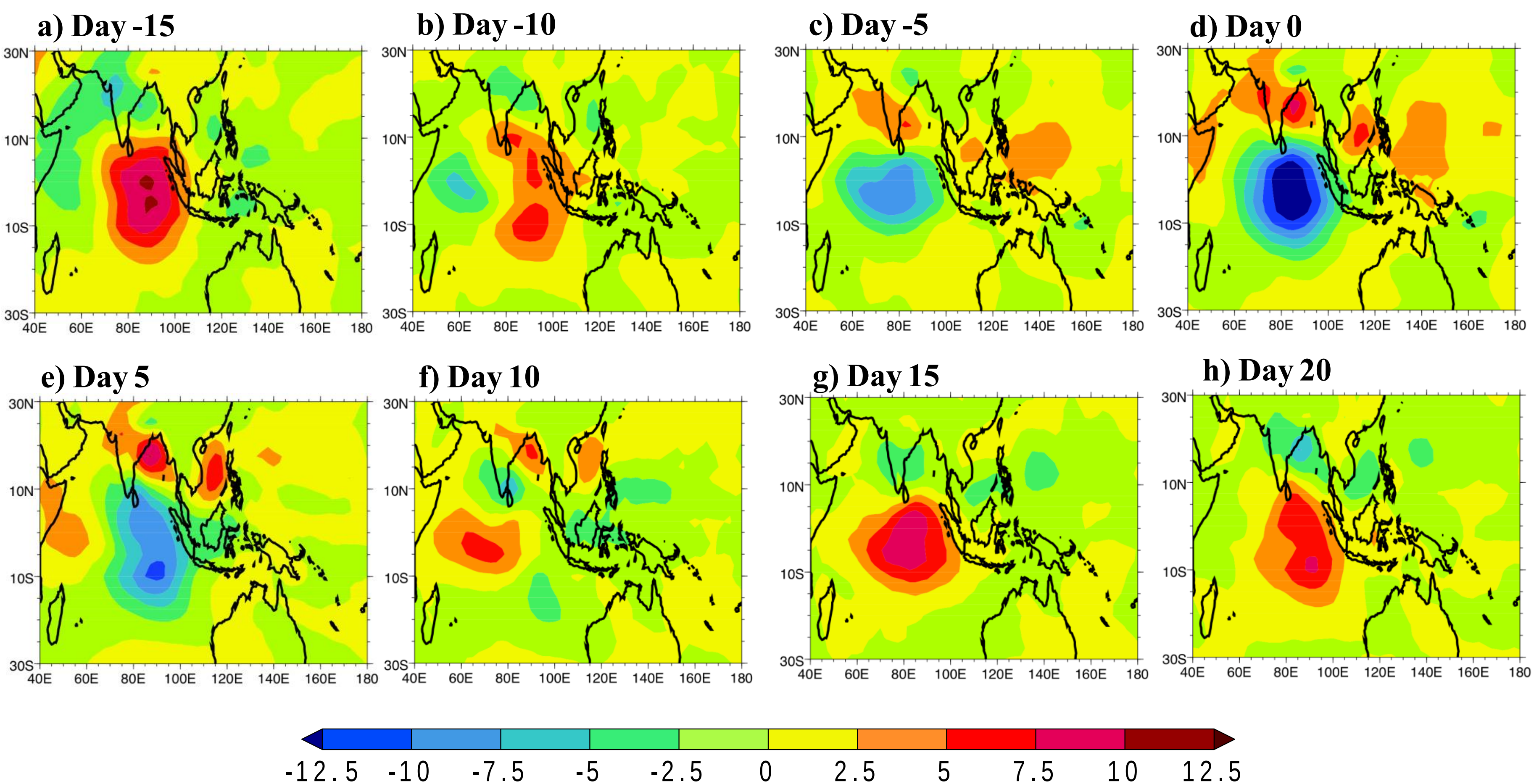
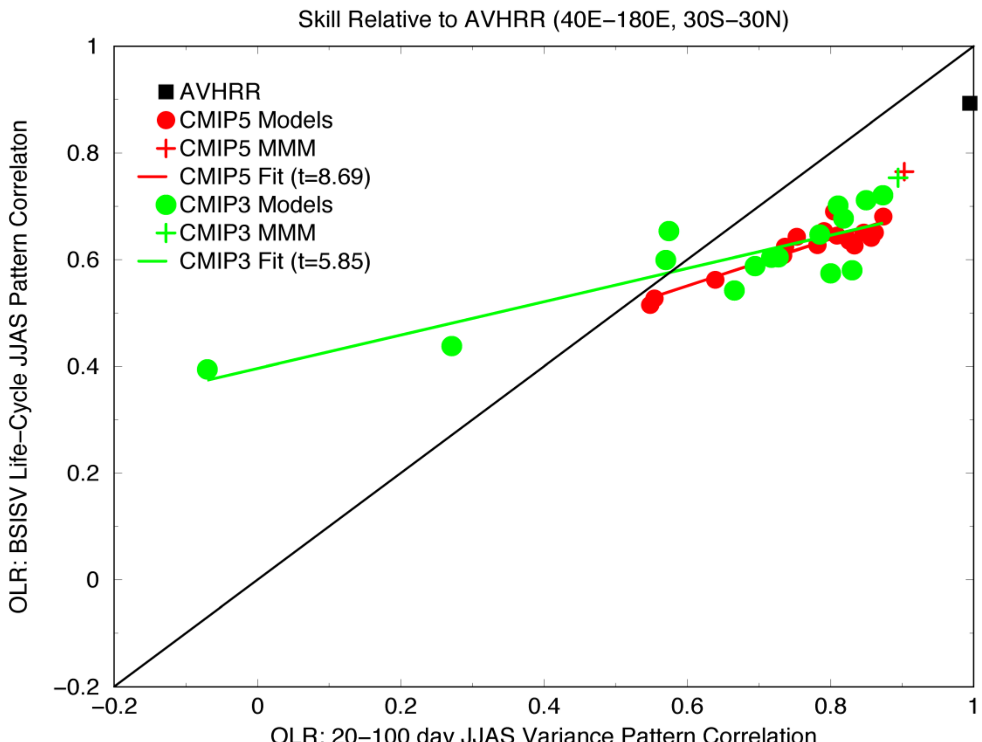
- Eastward and northward propagating OLR anomalies show evolution similar to that observed, but the anomalies are weaker than observed
- Only non-ECHAM based model to “reasonably” simulate BSISV



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

- Evaluate the skill of simulating the life-cycle of the BSISV vs. the skill at simulating the 20-100 day filtered variance
  - For both CMIP-3 and CMIP-5, 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)
  - The CMIP-3 and CMIP-5 MMM’s outperform individual models
    - BSISV MMM life-cycle: If more than half of the models have a statistically significant anomaly (irrespective of sign) the mean anomaly is plotted



CMIP-5 vs. CMIP-3: Asian Summer Monsoon Findings

- 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 observational uncertainty
- The Multi-Model Mean
  - Time-Mean State: better than individual models
  - Annual Cycle: individual models better than the MMM
  - EASM Interannual Variability: Individual models and MMM have comparable skill
  - Intraseasonal Variability: MMM exceeds skill of individual models