The Asian Summer Monsoon: An Intercomparison of CMIP-5 vs. CMIP-3 Simulations of the Late 20th Century

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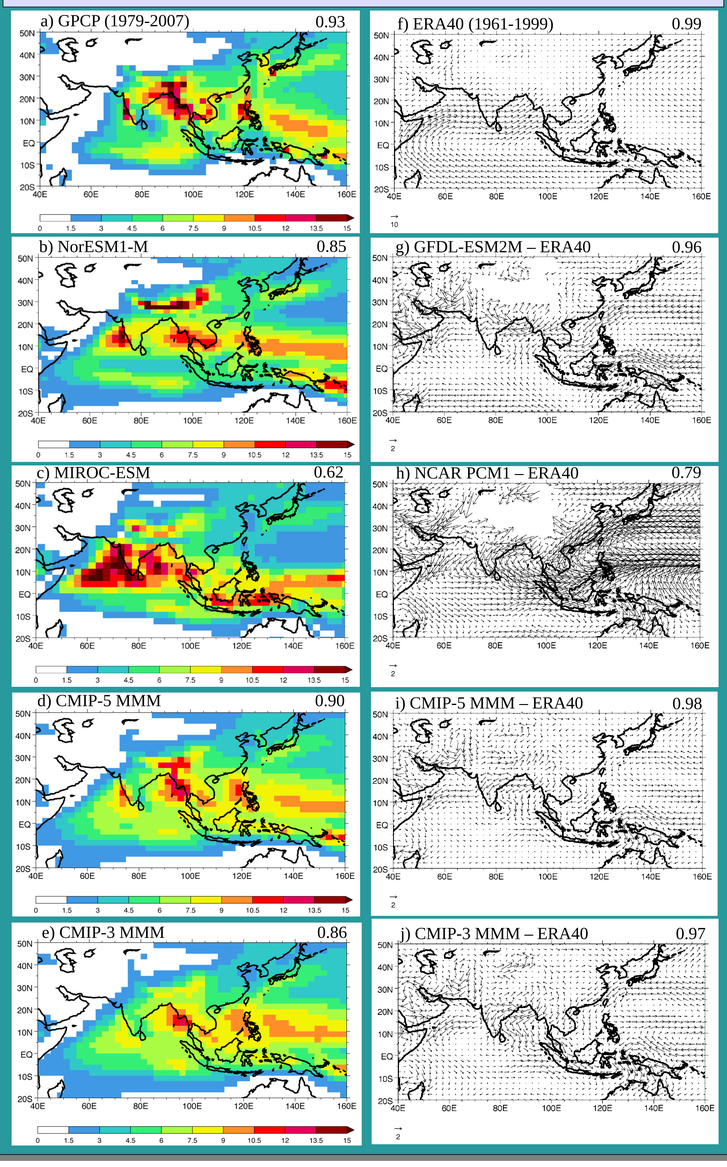
Goal: Develop a Suite of Diagnostics/Metrics to Evaluate Models and Track Improvement

- Motivation
  - Monsoon simulation fidelity varies widely among models
  - IPCC AR4: Climate change projections are uncertain over the Asian-Australian monsoon region
- Methodology
  - Evaluate Asian-Australian Monsoon on diurnal through interdecadal time scales using proven diagnostics (e.g., climatological, annual cycle, intraseasonal oscillations, monsoon-ENSO relationship, etc.)
  - Skill metric(s) for every diagnostic to provide quantitative measure(s) of model performance
- Outcomes
  - CMIP-5 more skillful than CMIP-3 for all diagnostics
- Models (1961-1999, 25 CMIP-5 Historical and 22 CMIP-3 20c3M runs)
  - CMIP5: BCC-CSM-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: BCCR BCM2.0, CCCMA CGCM3.1 T47, CCCMA CGCM3.1 T63, CCSM3, CNRM CM3, CSIRO Mk3.0, CSIRO Mk3.5, FGOALS-g1.0, GFDL CM2.0, GFDL CM2.1, GISS AOM, HadCM3, HadGEM1, INGV-SXG, 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, PCM1

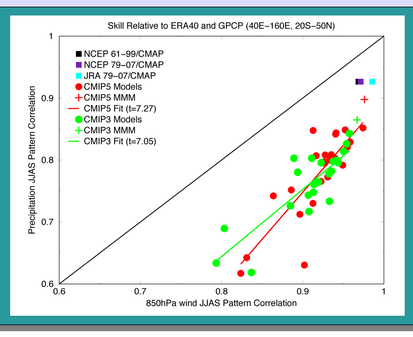
Climatological Mean Performance: JJAS Rainfall and 850hPa Wind

- Observed and simulated results include the two models that show the range of performance as indicated by the pattern correlations with GPCP [the skill score in (a) is GPCP vs. CMAP] and the pattern correlation with ERA40 [the skill score in (f) is relative to JRA25]
  - The multi-model mean outperforms all of the individual models with CMIP-5 superior to CMIP-3
  - For CMIP-5 vs. CMIP-3, the systematic error (multi-model mean – observations) has nearly identical spatial structure for wind (panels i and j) and for rainfall (not shown)



Climatological Mean Performance: JJAS Skill: 850hPa Wind vs. Rainfall

- 850hPa wind climatology pattern correlation relative to ERA40 (1961-1999)
- Rainfall climatology pattern correlation relative to GPCP (1979-2007)
  - CMIP-5 multi-model mean (MMM) outperforms CMIP-3 multi-model mean
  - Wind is better simulated than rainfall with models approaching observational uncertainty



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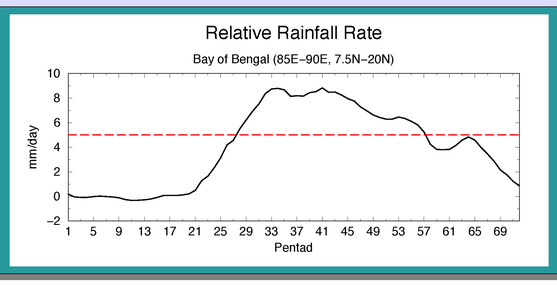
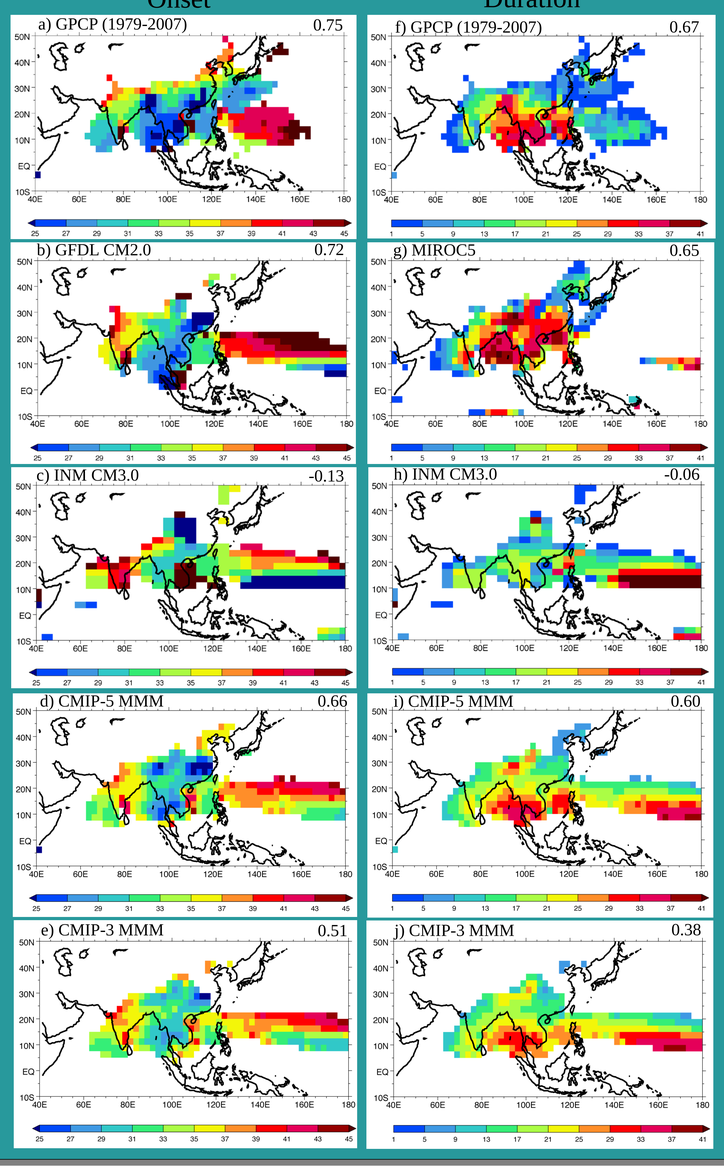
Climatological Monsoon Onset, Peak, Withdrawal, and Duration

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



Climatological Monsoon Onset and Duration

- Observed and simulated results include the two models that show the range of performance as indicated by the pattern correlations with GPCP [the skill score in (a) is GPCP vs. CMAP]. These skill scores are calculated for gridpoints where both model and observations exhibit the boreal summer monsoon
  - Individual models outperform the CMIP-5 and CMIP-3 multi-model means
  - The models have substantial biases in representing the time of onset as well as the spatial extent of the monsoon domain
  - Relative to onset, peak, and withdrawal, duration is more poorly represented



East Asian/West Pacific Monsoon: JJA Interannual Variation

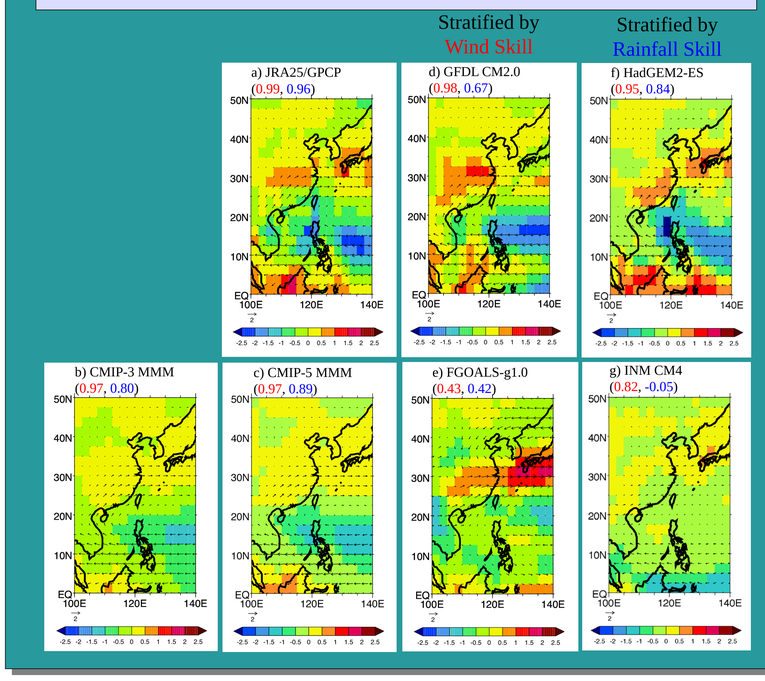
- 850hPa zonal wind shear anomaly index designed by Wang and Fan (1999, *Bull. Amer. Meteor. Soc.*, **80**, 629–638), and revised, where

Index= u850 (110°E-140°E, 22.5°N-32.5°N) - u850 (90°E-130°E, 5°N-15°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°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].

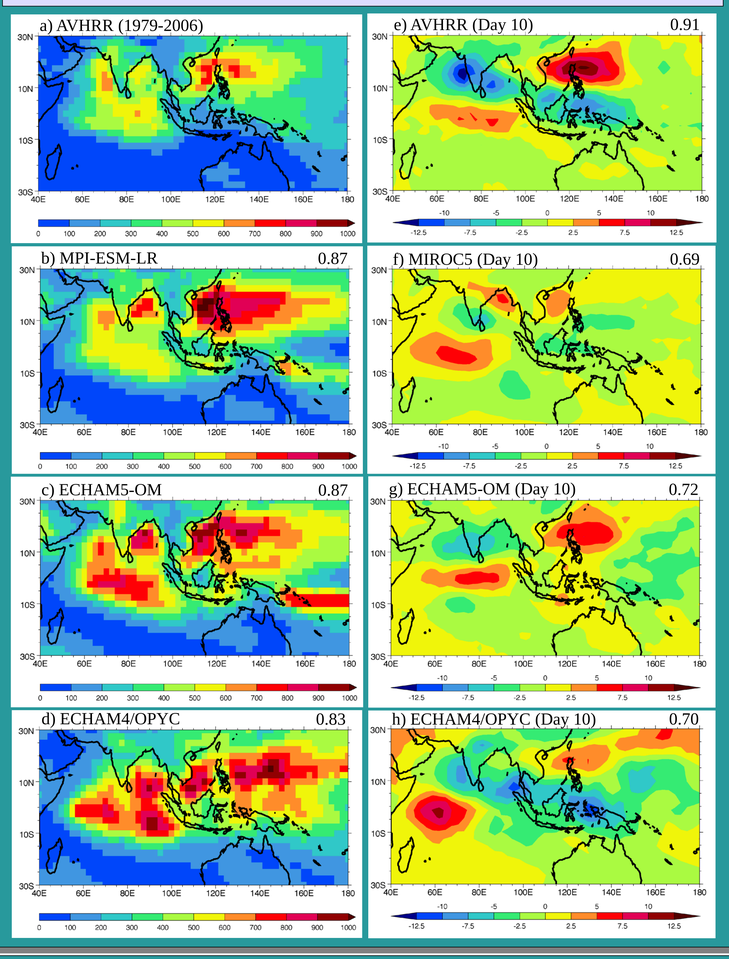
East Asian/West Pacific Monsoon: JJA Interannual Variation (con't)

- The wind anomalies are better represented than the rainfall anomalies
- For the multi-model mean, CMIP-5 rainfall anomalies are better represented than in CMIP-3



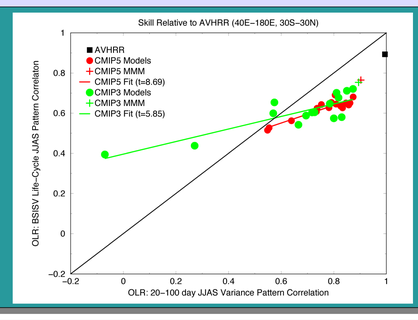
Intraseasonal Variability: JJAS

- 20-100 day bandpass filtered variance of outgoing longwave radiation (OLR)
- Boreal summer intraseasonal variability (BSISV) life-cycle of OLR: best matching Day 10 pattern for CMIP5 and CMIP3 models with the largest pattern correlations of the space-time BSISV life-cycle
  - In the left column the pattern correlations are with respect to the data in panel (a)
  - In the right column the pattern correlations are with respect to the BSISV OLR life-cycle obtained from Cyclostationary EOF analysis of AVHRR OLR (Annamalai and Sperber, 2005, *J. Atmos. Sci.*, **62**, 2726-2748; Sperber and Annamalai, 2008, *Clim. Dynam.*, **31**, 345-372)
  - Intraseasonal variability is perhaps the most difficult aspect of the monsoon to simulate



Intraseasonal Variability: JJAS Skill: OLR Variance vs. BSISV OLR Life-Cycle

- Pattern correlation of 20-100 day filtered OLR variance relative to that from AVHRR OLR
- Space-time pattern correlation of BSISV life-cycle relative to AVHRR Cyclostationary EOF's
  - The life-cycle of the BSISV is better simulated in models that have a better pattern correlation with AVHRR observations in their simulation of the 20-100 day bandpass filtered variance (the linear regressions are significant at better than the 1% level)
  - The CMIP5 MMM outperforms the CMIP3 MMM, and all individual models



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