Diagnostics and Metrics for Evaluating GCM Simulations of the Asian-Australian Monsoon

CLIVAR Asian-Australian Monsoon Panel Diagnostics Task Team*

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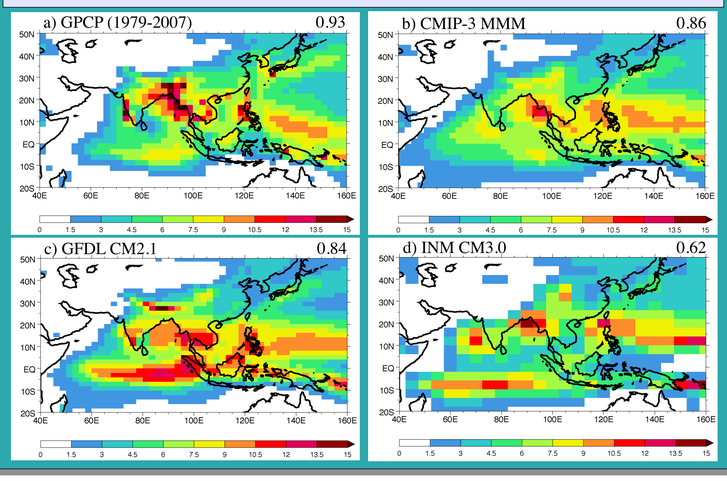
Goal: Develop a Suite of Diagnostics/Metrics to Evaluate Models and Track Improvement

- Motivation/Questions
  - Monsoon simulation fidelity varies widely among models
    - Are Revised Models Better Models?
    - Provide a suite of diagnostics/metrics that can be used to track model improvements from one model generation to another
  - IPCC AR4: Projections of climate change are highly uncertain over the Asian-Australian monsoon region
    - Can certain models be more trusted than others for assessing projections of climate change?
- 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
  - Assessment of skill in CMIP-5 vs. CMIP-3 GCM simulations
  - Assessment of the impact of climate change on the Asian-Australian Monsoon

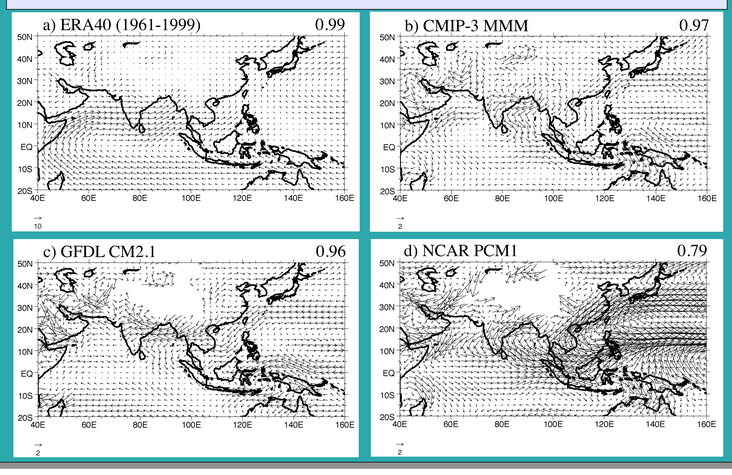
Climatological Mean Performance: JJAS Rainfall (CMIP-3: 1961-1999)

- Observed and simulated results include data from the CMIP-3 multi-model mean, and 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 to indicate observational uncertainty]
  - The CMIP-3 multi-model mean outperforms all of the individual CMIP-3 models



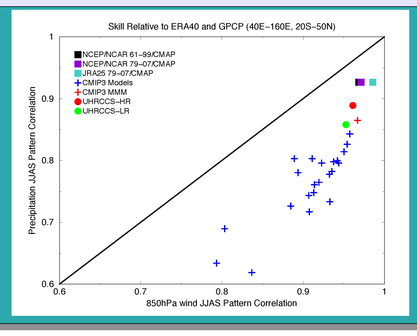
Climatological Mean Performance: JJAS 850hPa Wind (CMIP-3: 1961-1999)

- Observed and simulated results include data from the CMIP-3 multi-model mean, and the two models that show the range of performance as indicated by the pattern correlations with ERA40 [the skill score in (a) is ERA40 vs. JRA25 to indicate observational uncertainty]
  - Errors in the wind are consistent with errors in the precipitation climatology



Climatological Mean Performance: JJAS-Skill 850hPa Wind vs. Rainfall (CMIP-3: 1961-1999)

- 850hPa wind climatology pattern correlation relative to ERA40 (1961-1999)
- Rainfall climatology pattern correlation relative to GPCP (1979-2007)
  - Wind is better simulated than rainfall with models beginning to approach observational uncertainty in the simulation of the 850hPa wind climatology
  - The high-resolution development version of CCSM4 (UHRCCS-HR, 0.25° atmosphere, 0.1° ocean) has better skill than the CMIP-3 multi-model mean and any of the CMIP-3 models



This work was performed under the auspices of the U.S. Department of Energy, Office of Science, Regional and Global Climate Modelling Program at Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. (LLNL-POST-502531-DRAFT)

Climatological Annual Cycle: Monsoon Precipitation Intensity (MPI) and Domain (MPD)

- Designed by Wang and Ding (2008, *Dyn. Ocn. Atmos.*, 44, 165-183) and used in Wang et al. (2011, *Clim. Dynam.*, 37, 941-955)
  - Candidate diagnostic/metric for the WGNE/WGCM Metrics Panel

Monsoon Precipitation Intensity = Annual Range/Annual Mean

where,

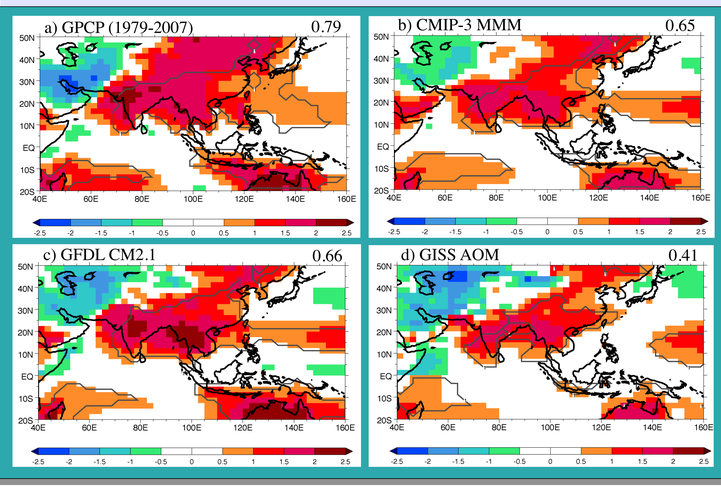
Annual Range = $Precip_{MJJAS} - Precip_{NDJFM}$ (Northern Hemisphere)

Annual Range = $Precip_{NDJFM} - Precip_{MJJAS}$ (Southern Hemisphere)

Monsoon Precipitation Domain defined where Annual Range > 2.5mm day^{-1}

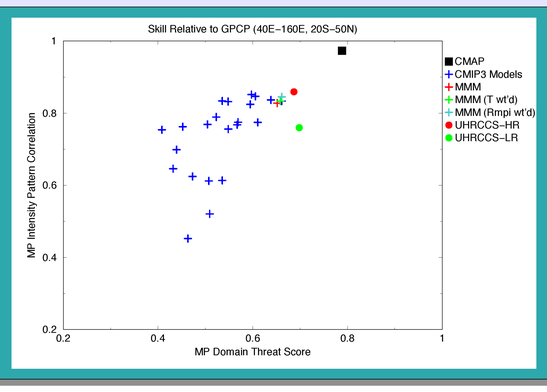
Monsoon Precipitation Intensity and Monsoon Precipitation Domain (CMIP-3: 1961-1999)

- Observed and simulated MPI (shading) and MPD (isolines) include data from the CMIP-3 multi-model mean, and the two models that show the range of performance as indicated by the MPD threat score (categorical skill score: 0-bad, 1-good) comparison with GPCP [the skill score in (a) is GPCP vs. CMAP to indicate observational uncertainty]
  - In terms of the MPD threat score the best model outperforms the CMIP-3 multi-model mean



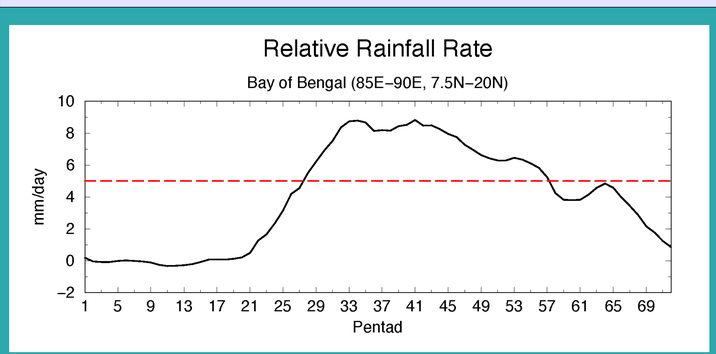
Monsoon Precipitation Intensity and Monsoon Precipitation Domain: Skill (CMIP-3: 1961-1999)

- Monsoon Precipitation Intensity pattern correlation vs. GPCP (1979-2007)
- Monsoon Precipitation Domain threat score vs. GPCP (1979-2007)
  - Weighting the models by their MPD threat score or MPI pattern correlation does not result in a substantial improvement over the uniformly weighted multi-model mean
  - The high-resolution development version of CCSM4 (UHRCCS-HR, 0.25° atmosphere, 0.1° ocean) has better skill than the CMIP-3 multi-model mean and any of the CMIP-3 models



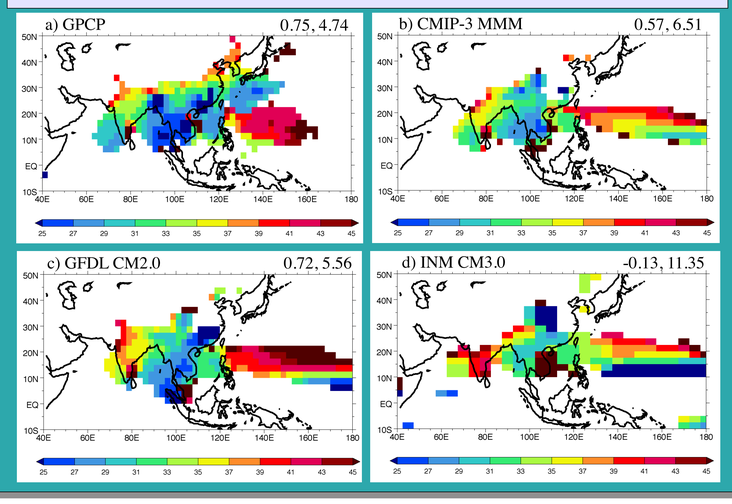
Climatological Monsoon Onset, Peak, Withdrawal, and Duration (CMIP-3: 1961-1999)

- 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



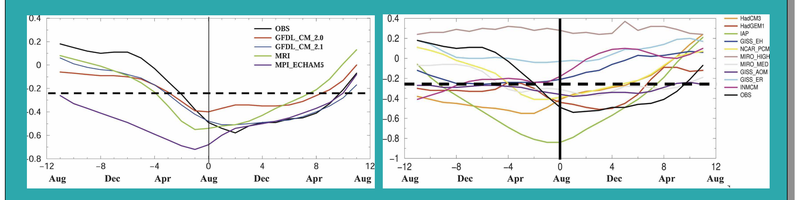
Climatological Monsoon Onset (CMIP-3: 1961-1999)

- Shown is the pentad at which boreal summer monsoon onset occurs. Observed and simulated results include data from the CMIP-3 multi-model mean, and the two models that show the range of performance as indicated by the pattern correlations with GPCP. Also given is the RMSE with respect to GPCP [the skill scores in (a) are GPCP vs. CMAP to indicate observational uncertainty]. These skill scores are calculated for gridpoints where both model and observations exhibit the boreal summer monsoon based on the onset criteria
  - Individual models outperform the CMIP-3 multi-model mean
  - The models have substantial biases in representing the time of onset as well as the spatial extent of the monsoon domain



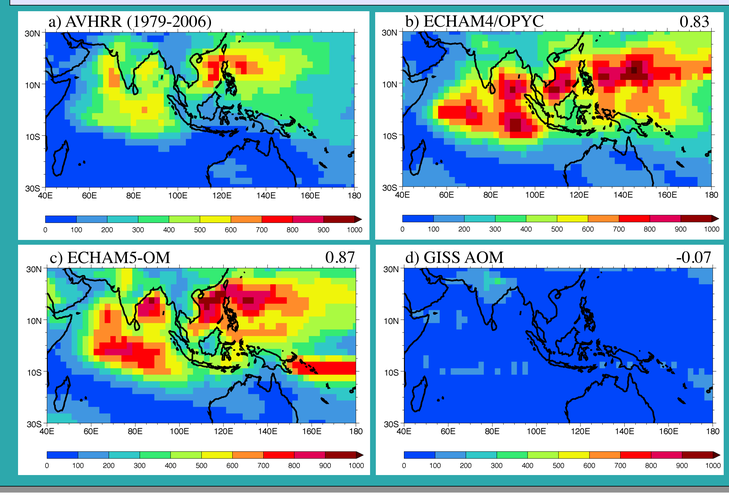
Lead-Lag Correlation of All-India Rainfall vs. NINO3.4 SSTA (CMIP-3: 1961-1999)

- Based on the analysis of Annamalai et al. (2007, *J. Clim.*, 20, 1071-1092) the models were stratified by their ability to simulate a realistic monsoon precipitation climatology and realistic ENSO variability
  - The observed lead-lag correlation between AIR and NINO3.4 SSTA is best represented in models with a good representation of the monsoon precipitation climatology and ENSO variability (left panel)



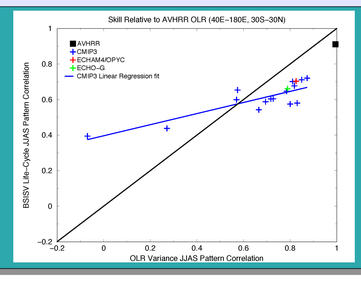
Intraseasonal Variability: 20-100 Day Variance (CMIP-3: 1961-1999)

- 20-100 day bandpass filtered outgoing longwave radiation (OLR) during boreal summer (JJAS)
- Observed and simulated results include data from the ECHAM4/OPYC, the predecessor to ECHAM5-OM, and the two CMIP-3 models that show the range of performance as indicated by the pattern correlations with AVHRR OLR (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 (CMIP-3: 1961-1999)

- Pattern correlation of 20-100 day filtered OLR relative to AVHRR
- Space-time pattern correlation of BSISV life-cycle relative to AVHRR
  - For the CMIP-3 models 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 regression is significant at better than the 1% level)
  - **CAUTION on Metrics:** Though ECHAM4/OPYC has a smaller life-cycle pattern correlation than two of the CMIP-3 models, physical interpretation indicates that it is actually the most realistic of the models evaluated (Sperber and Annamalai, 2008, *Clim. Dynam.*, 31, 345-372)



Next Steps: (1) Incorporate additional diagnostics/metrics to evaluate performance over East Asia, (2) Evaluate CMIP-5 models to ascertain if models have improved in their simulation of the Asian-Australian Monsoon, and (3) Investigate climate change over this monsoon domain