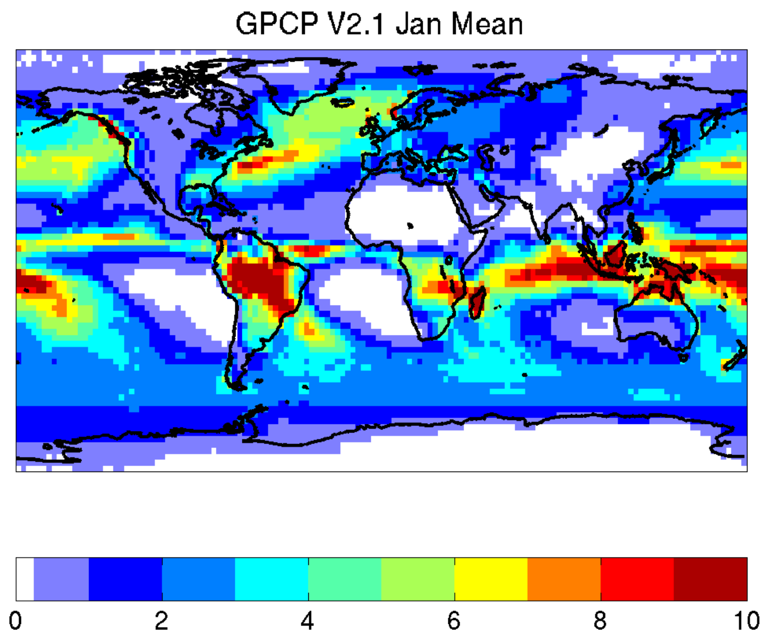
Centennial-Scale Changes in Large-Scale Precipitation in Observations and Models

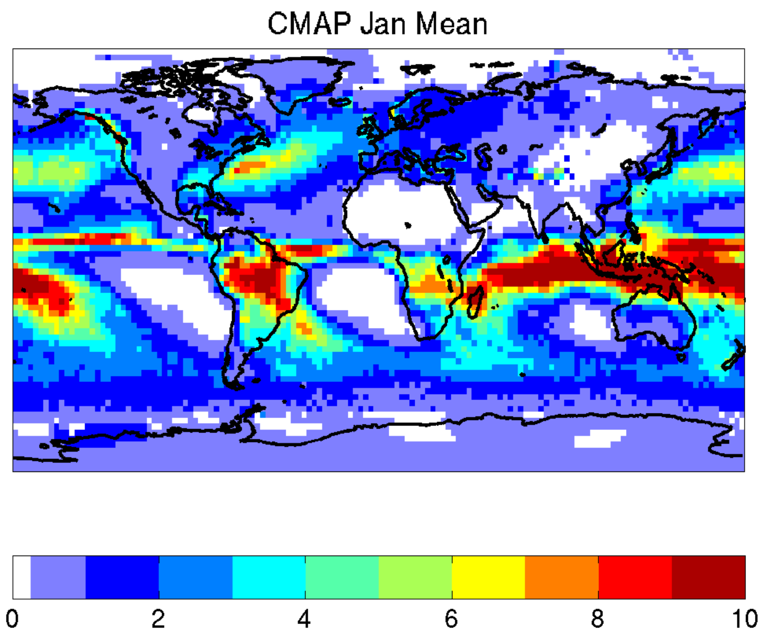
Phil Arkin, Li Ren and Ni Dai
ESSIC, University of Maryland
and
Tom Smith, NOAA/NESDIS/STAR

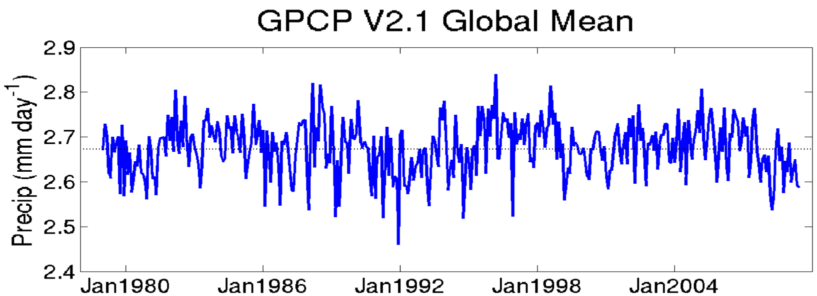
Information Sources: How are precipitation data sets created?

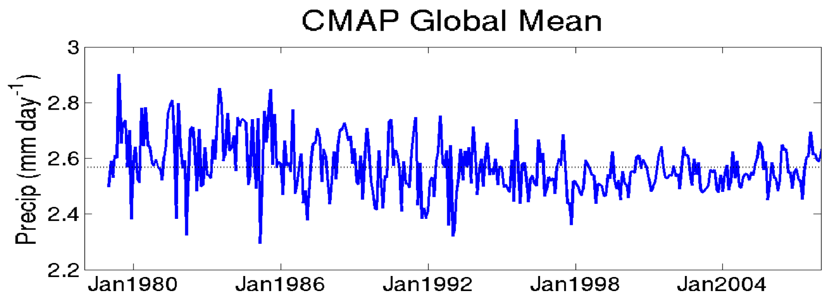
- Interpolated rain gauge values – good over some land areas (not all!)
- Radar gives excellent space/time variability, but gauges needed for calibration and quality control
- Estimates derived from satellite data useful, especially over oceans, but calibration/quality control issues similar to radar (and tougher)
- Global precipitation analyses GPCP and CMAP from combination of rain gauge observations and satellite-derived estimates for satellite era (1979 – present)
- Centennial-scale based on reconstructions –more details later

Global Precipitation Datasets

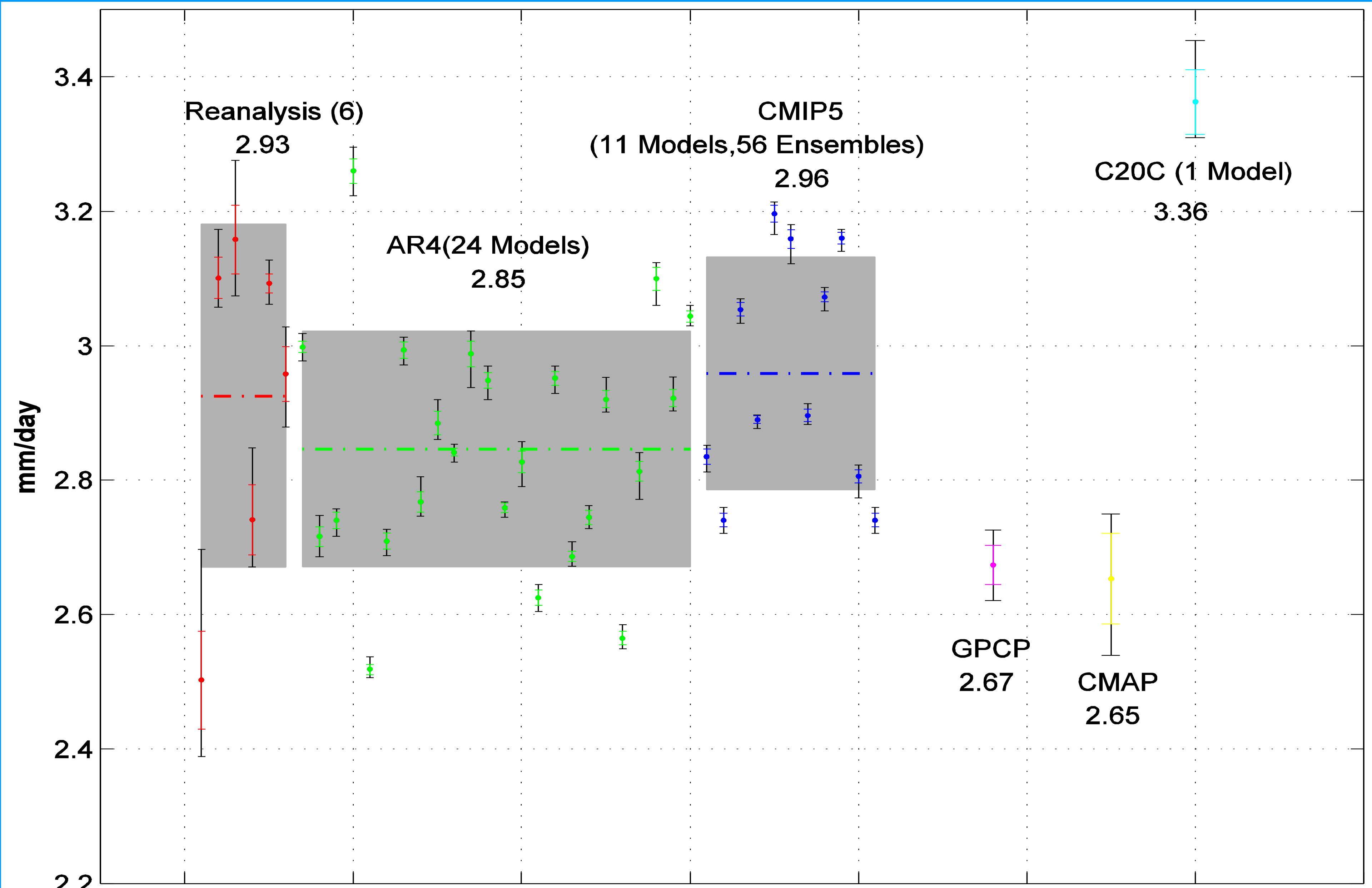








- GPCP (left)/CMAP (right) mean annual cycle and global mean time series
- Monthly/5-day; 2.5° lat/long global; both based on microwave/IR combined with gauges
- Both have greater (but poorly known) errors in high latitudes



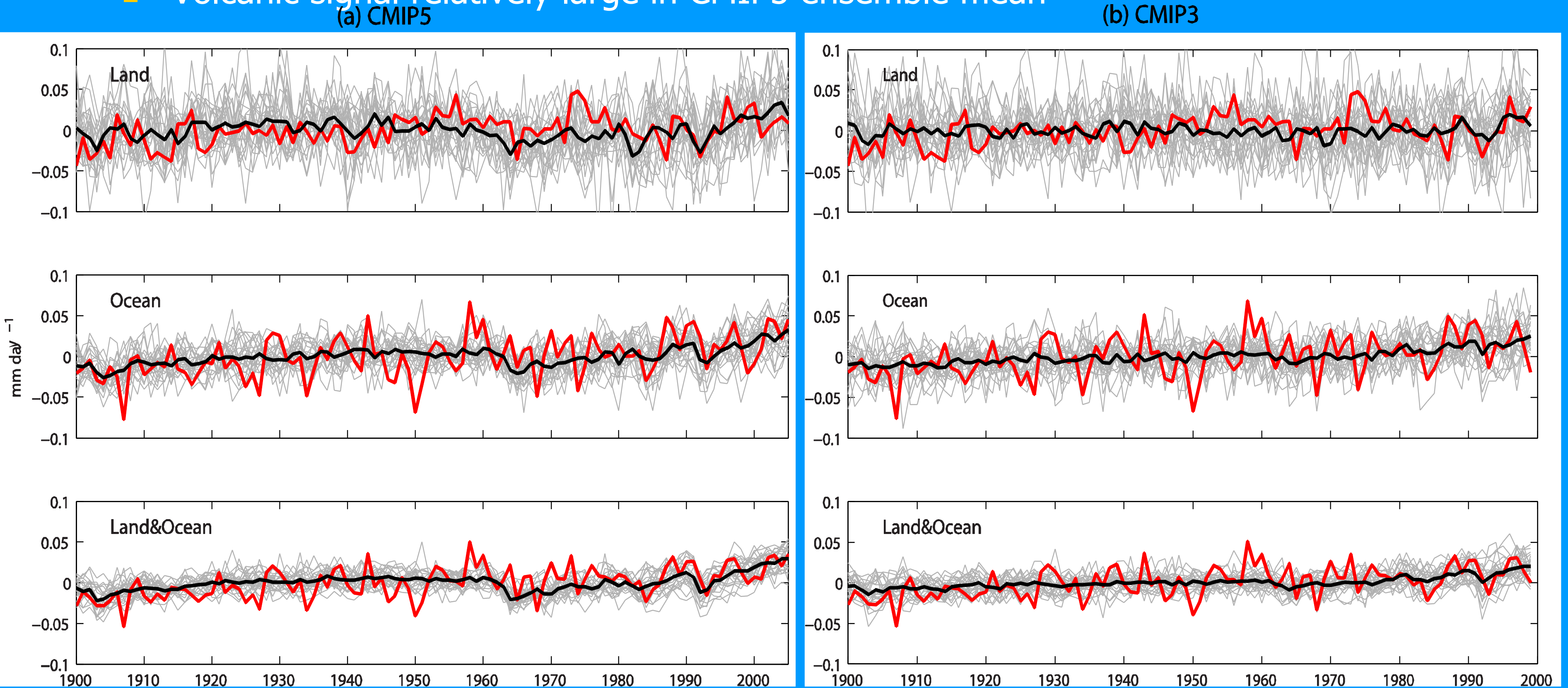
Global mean precipitation (1979-1999) from various sources: substantial lack of agreement

Multi-stage approach used to reconstruct back to 1900

- Stage 1: Indirect reconstruction of annual mean anomalies
  - Canonical correlation analysis (CCA)
  - Uses sea surface temperature (SST) and sea level pressure (SLP) as predictors for precipitation fields
  - GPCP for 1979-2008 used as calibration period
  - CCA captures decadal-centennial variability, but produces oceanic anomalies that are too intense and extensive
- Stage 2: Direct reconstruction of annual mean anomalies
  - Obtain global empirical orthogonal functions from GPCP during satellite period
  - Fit annual gauge-station data to these modes
  - Over oceans, use pseudo-observations based on CCA
  - Yields time series of annual anomalies on 5° grid
- Stage 3: Direct reconstruction of monthly anomalies
  - Monthly values obtained using higher order EOFs
  - Yields time series of monthly anomalies on 5° grid 1900-2008 that preserves multi-decadal signal
- Stage 4: Reinject gauge data to improve fidelity to direct observations
  - Only relevant over land – correlation with CRU 0.75

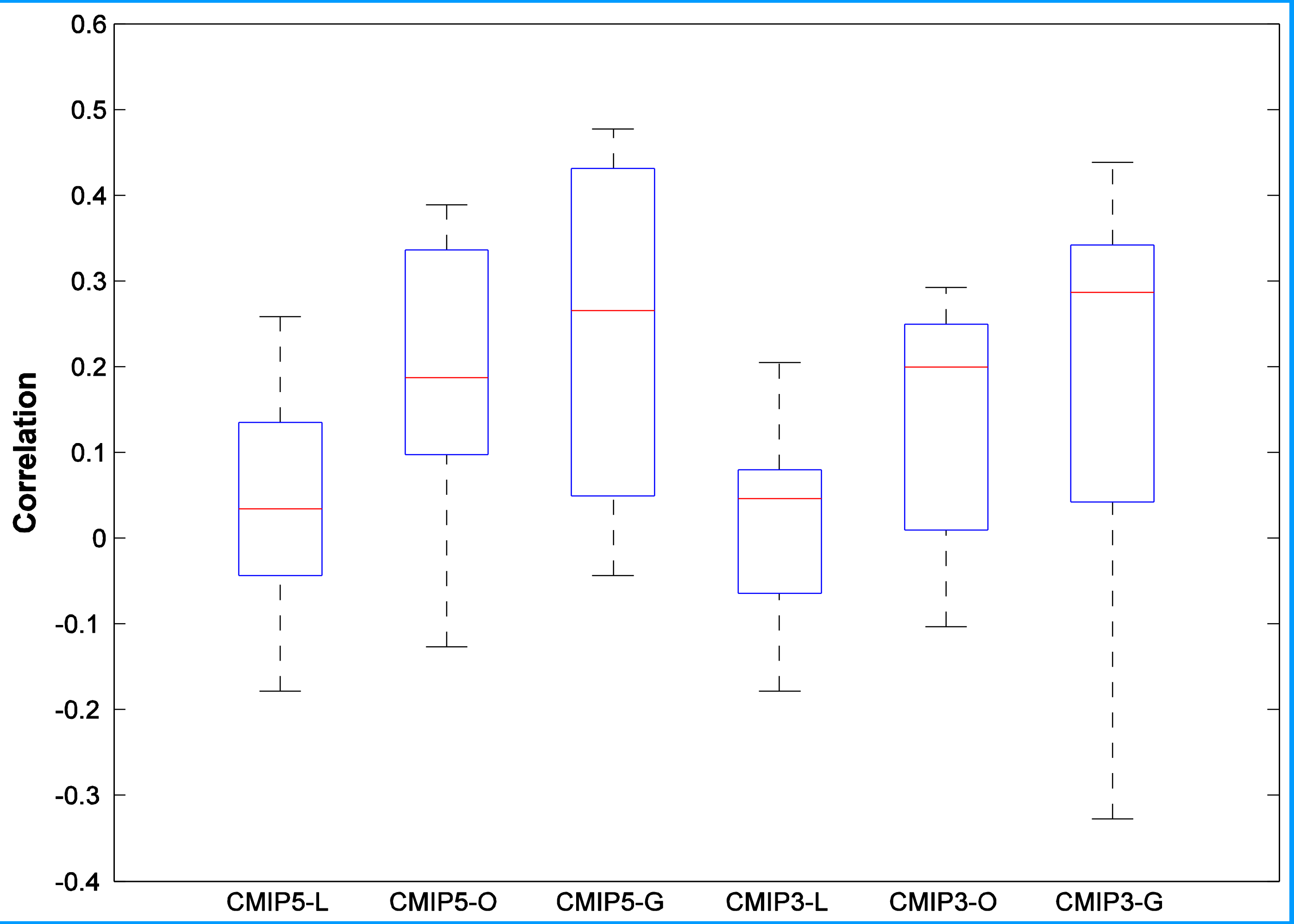
Centennial Trends in Global Mean Precipitation

- Temperature trend is 0.71° over the century from 1900 to 2005.
- Reconstructed and simulated (ensemble mean) precipitation tend to show increasing trend over same period
- The reconstructed precipitation and models are independent of one another:
  - Simulations are from CMIP3 (right, 24 models) and CMIP5 (left, 22 models) coupled runs
  - Reconstruction (red) used GPCP EOFs and gauge observations
  - Volcanic signal relatively large in CMIP5 ensemble mean



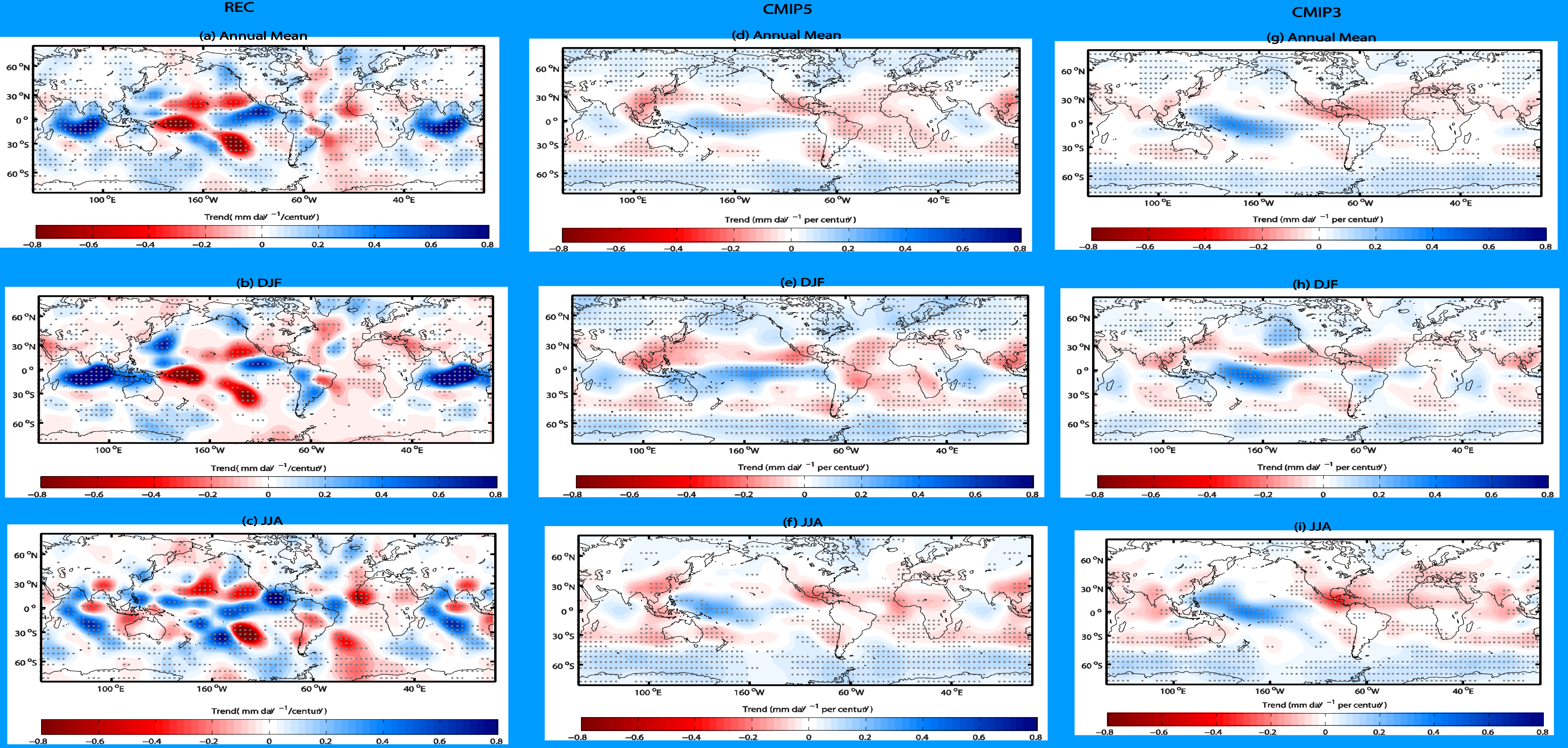
Slides 6-11 from Ren et al., 2013, JGR-Atm

Correlation of Near-Global Mean Precipitation Anomalies between Models and Observations

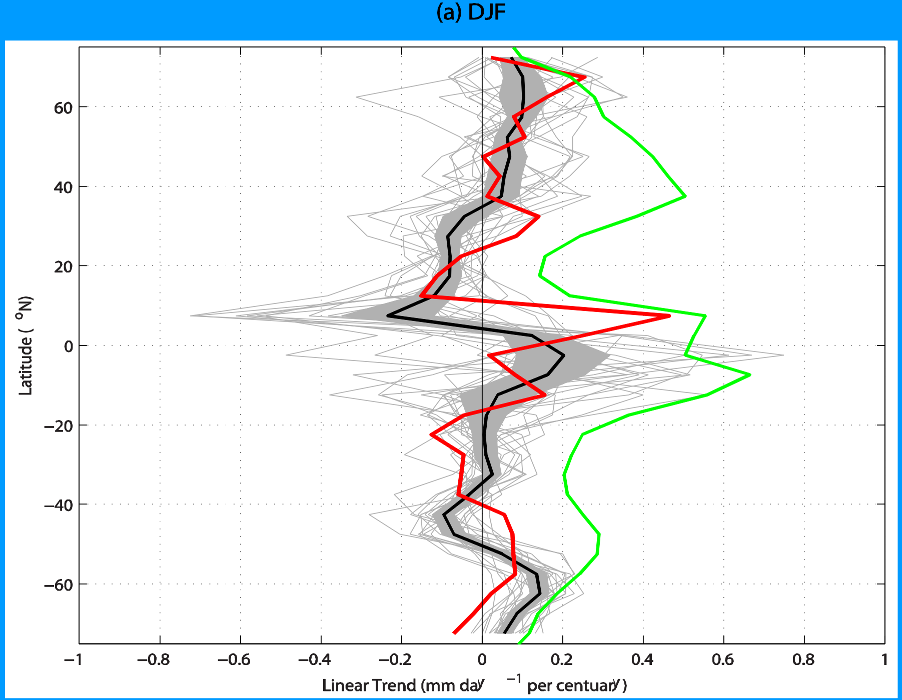


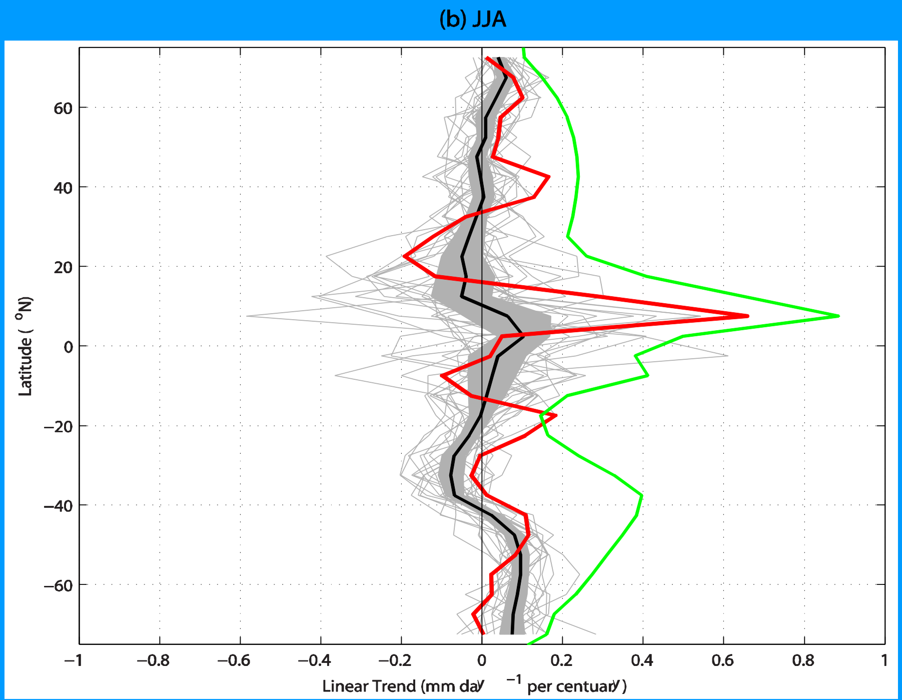
- Non-zero correlations due only to external forcing (GHG, solar, aerosols)
- Simulations tend to correlate better with observations over ocean than over land
- Large volcanic eruptions followed by larger, longer-lasting decreases in CMIP5 than in others

Red lines mark the medians; the bottom of the box marks the 25th percentile ; the top of the box marks the 75th percentile; lines extending from the top of the boxes mark the 98th percentile and from the bottom of the boxes mark the 2th percentile.



Trends from Reconstruction (left), CMIP5 (center) and CMIP3 (right) model ensemble means - stippling represents areas where trend is significantly different from zero. Annual is top row, DJF center, JJA bottom.





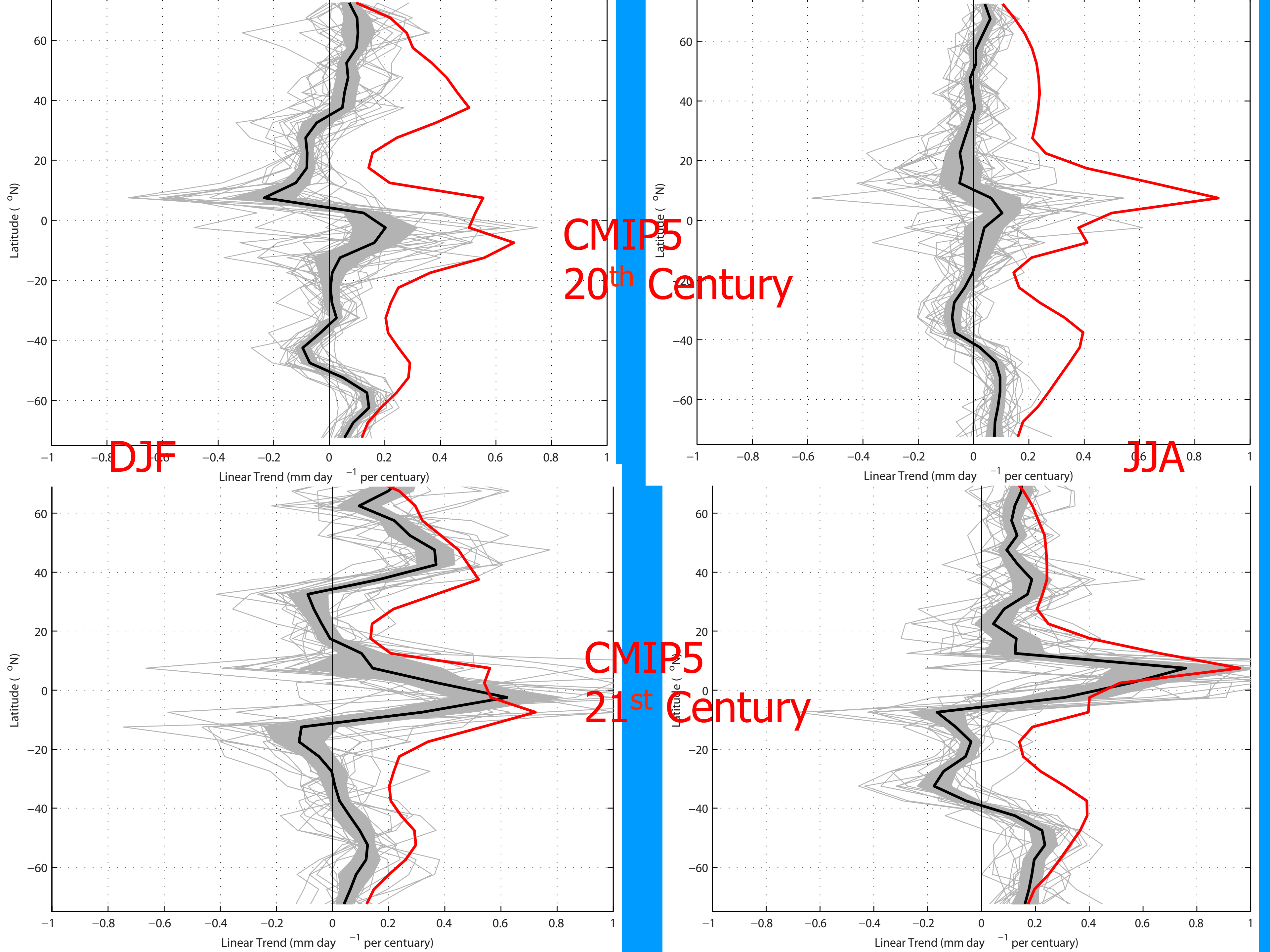
DJF

JJA

CMIP5 trends for DJF/JJA (gray lines, ensemble mean is black line) compared to trends from reconstruction (red). Green line is the CMIP5 climatology.

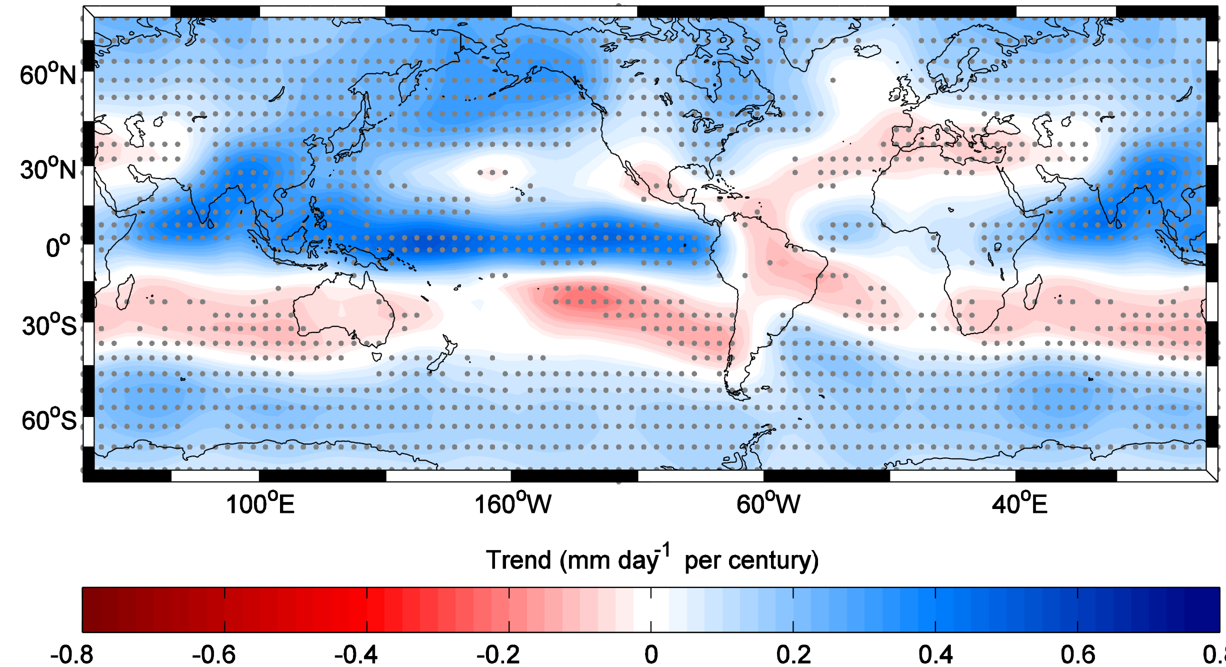
Notes:

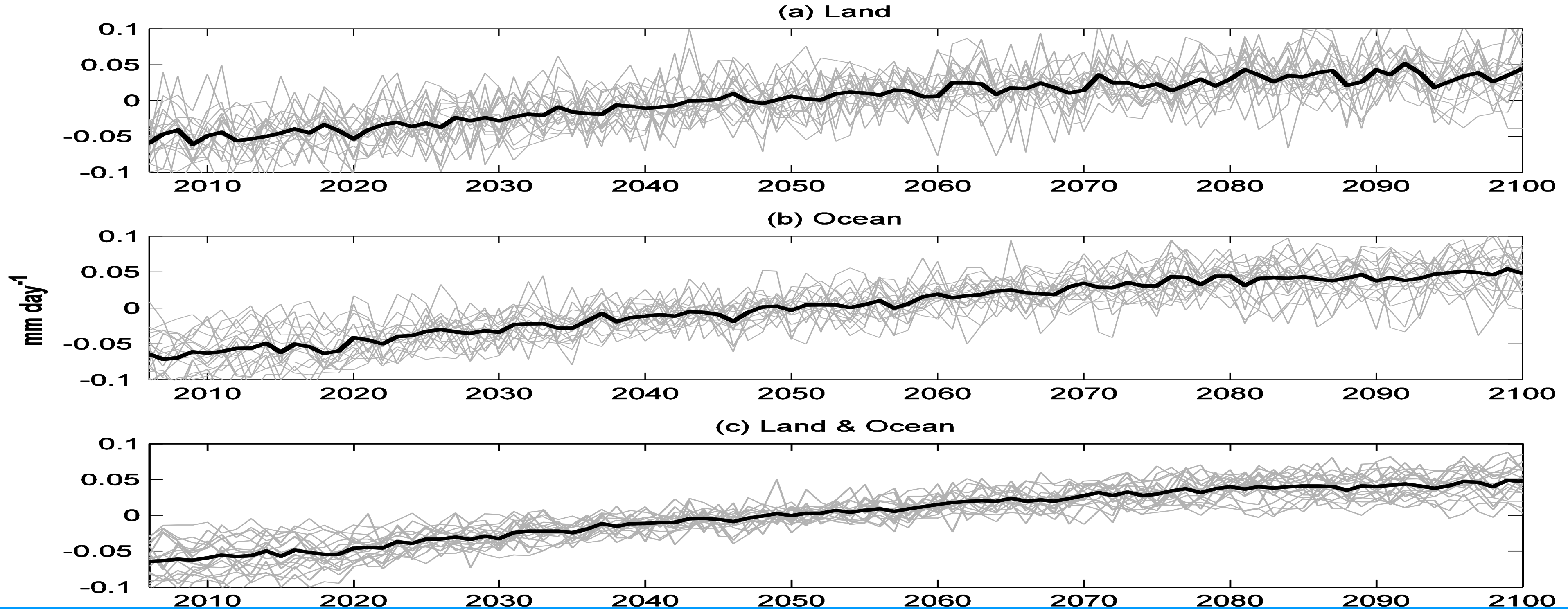
1. Both models and reconstruction show tendency to sharpen the ITCZ
2. Models have strong double ITCZ in DJF, but not in JJA.
3. Both models and REC tend to shift mid-latitude storm tracks poleward in winter hemisphere.



CMIP5
20th Century
CMIP5
21st Century
DJF
JJA
Latitude (°N)
Linear Trend (mm day −1 per centaury)

Trends in 21st Century Precipitation

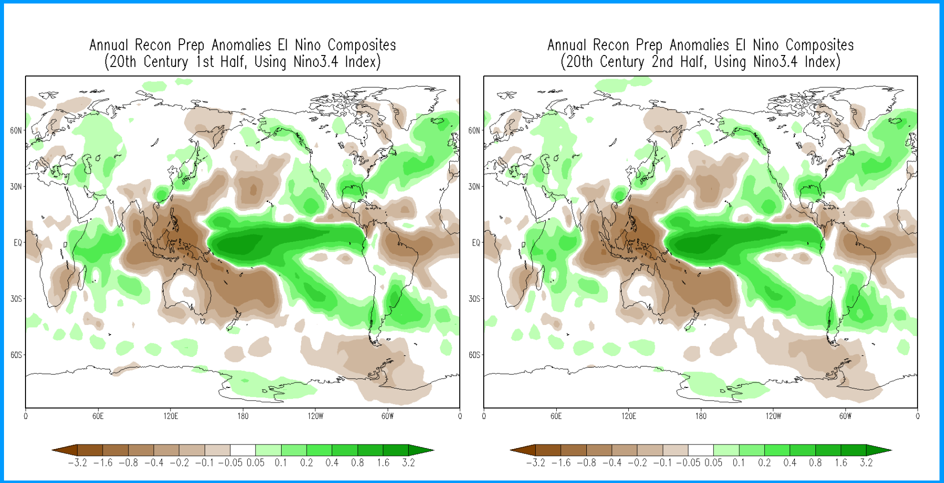


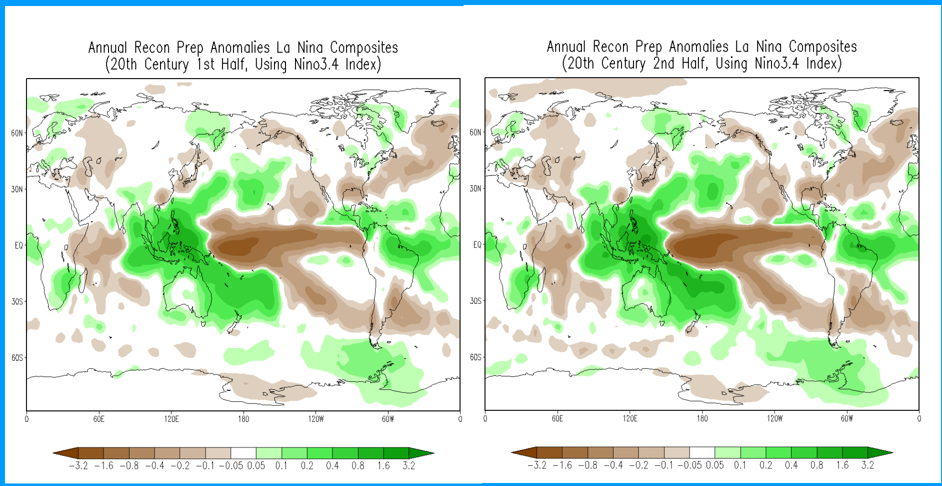


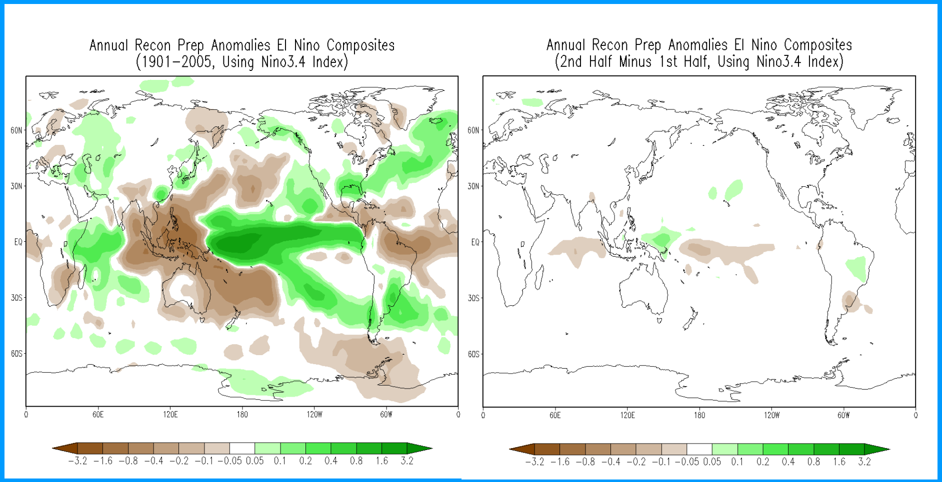
Internal variability: ENSO (or, in model space, the leading mode of seasonal to interannual coupled atmosphere-ocean variability)

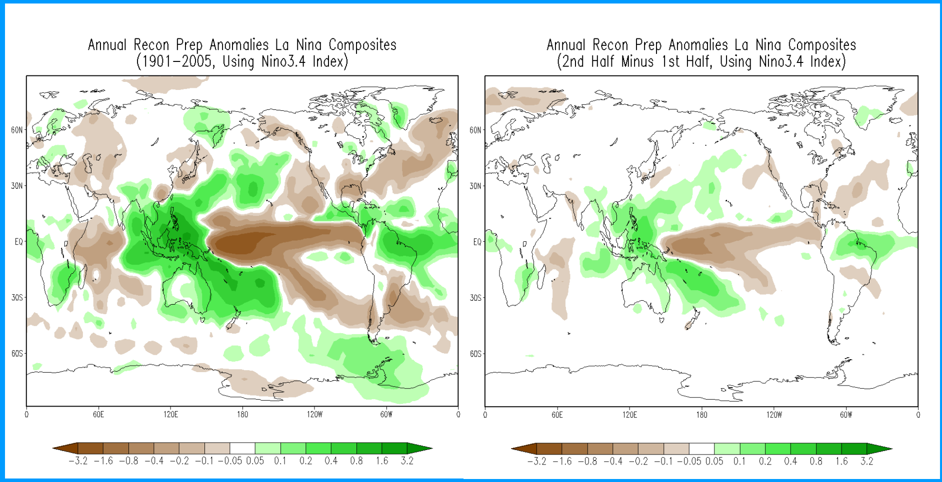
- Precipitation variability associated with El Niño/ Southern Oscillation (ENSO) is largest signal after annual cycle
- Some indications that spatial pattern has changed during 20th Century
- How well do models reproduce ENSO signal and its changes?
- Work of Ni Dai, PhD student in ESSIC/AOSC at Maryland, with Tom Smith and me, and Sam Shen of SDSU

Composite annual precipitation anomalies for El Niño /La Niña during first/second half of reconstruction record



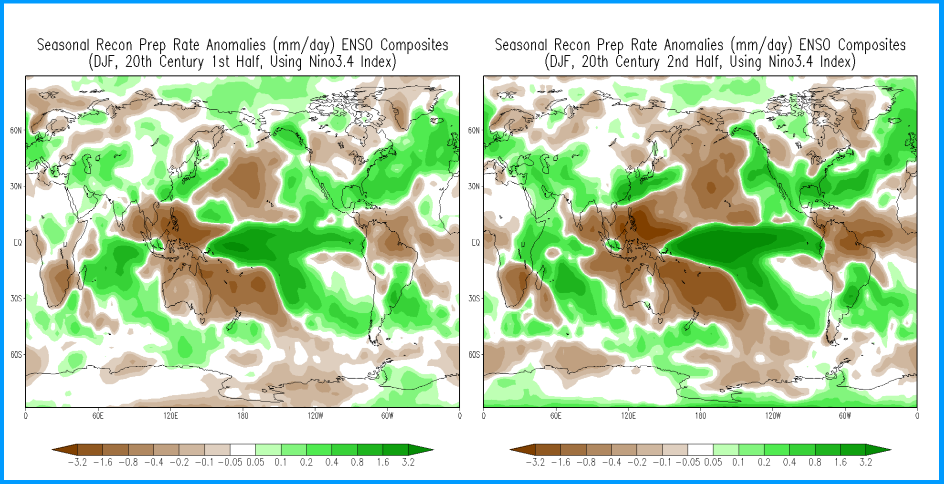


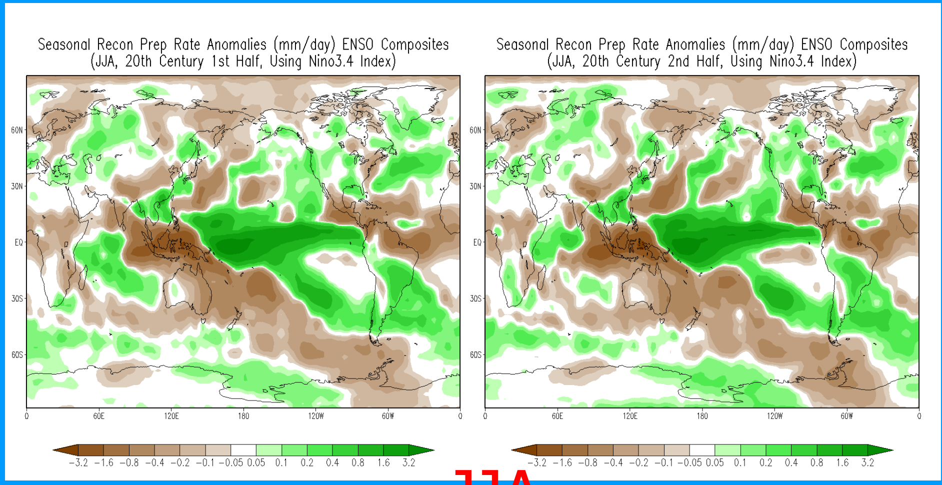




More difference in La Niña signal

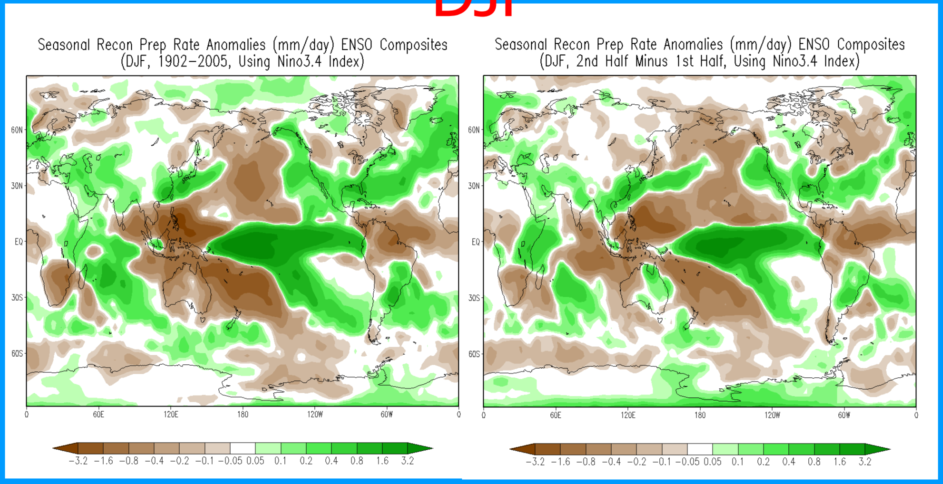
ENSO Composite Precipitation Anomalies
1st/2nd
Mean/Difference

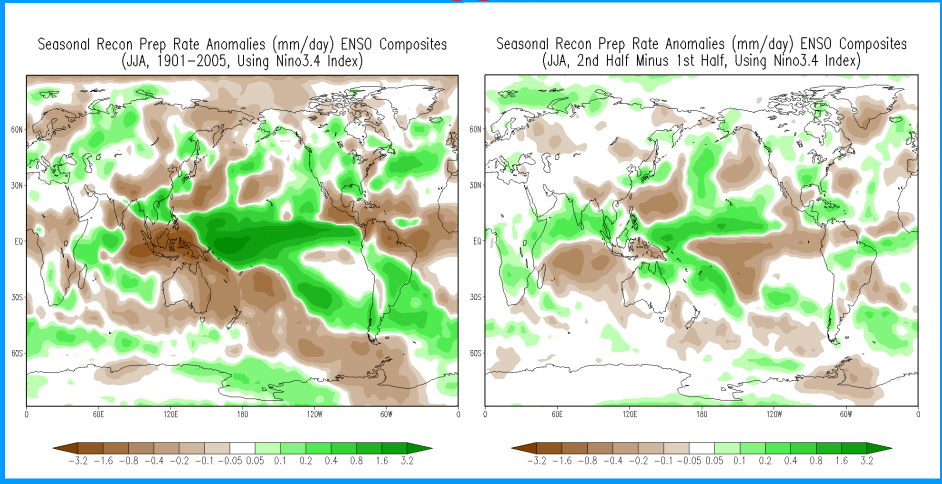




DJF

JJA

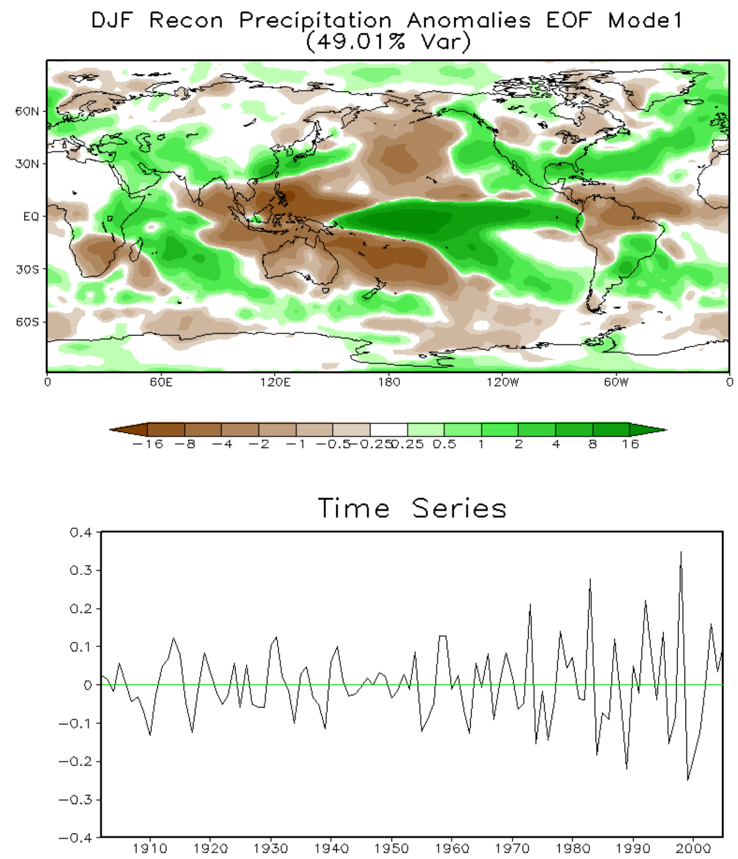


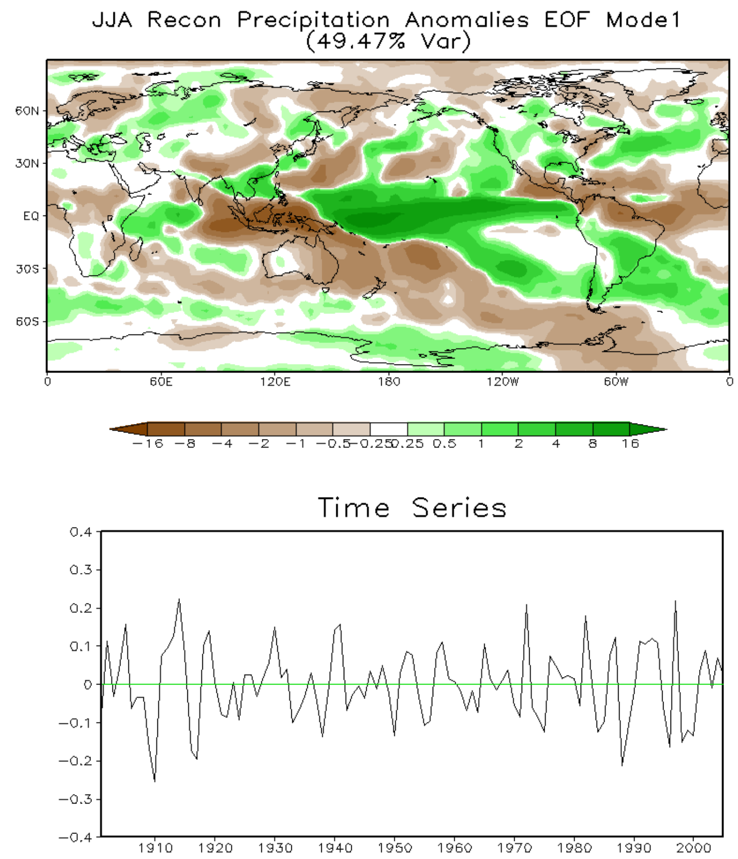


DJF and JJA changes quite different: DJF is amplification, JJA more of a shift

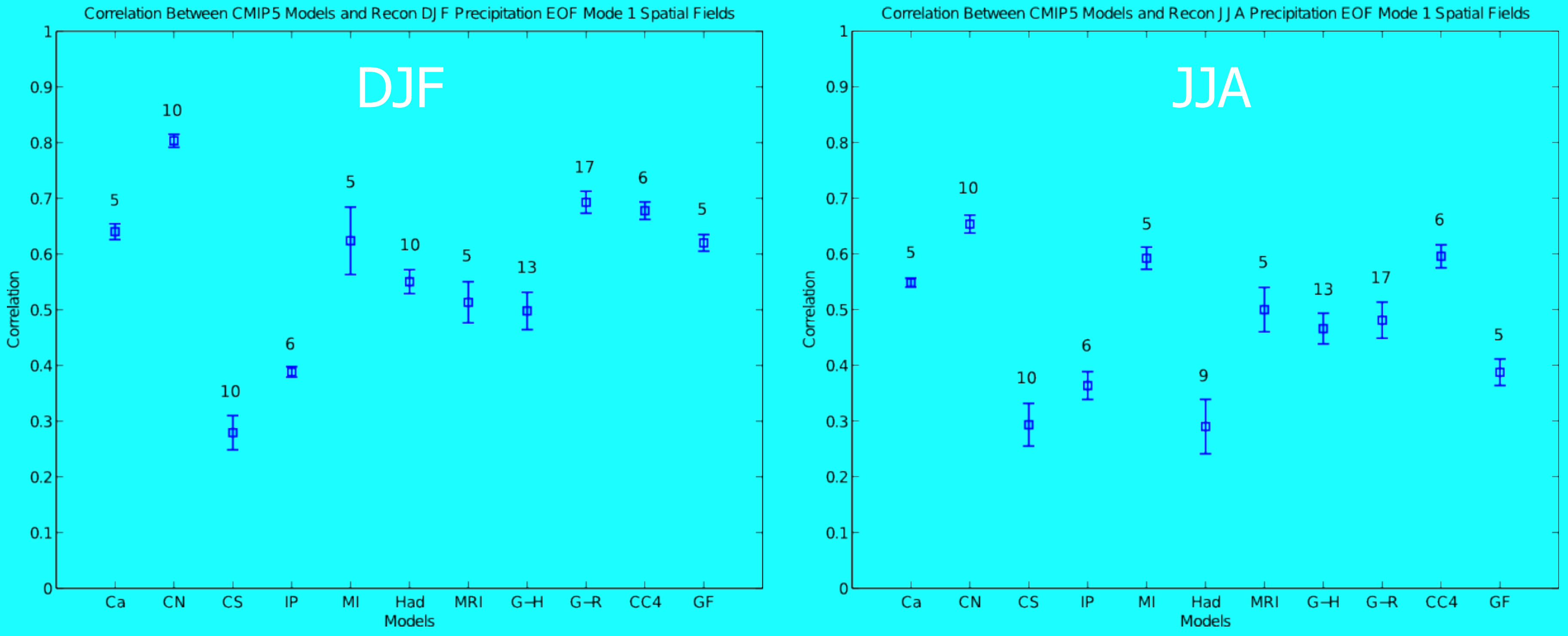
Composite ENSO Anomalies from SSTA EOF1

Model SST and precipitation climatologies differ, but essentially all of them have some mode of air-sea interaction that varies on seasonal-to-interannual time scale. Using EOF of SSTA is "fair" to each model – optimally isolates the precipitation signal related to that mode and allows us to investigate how it behaves in the models compared to its behavior in observations.



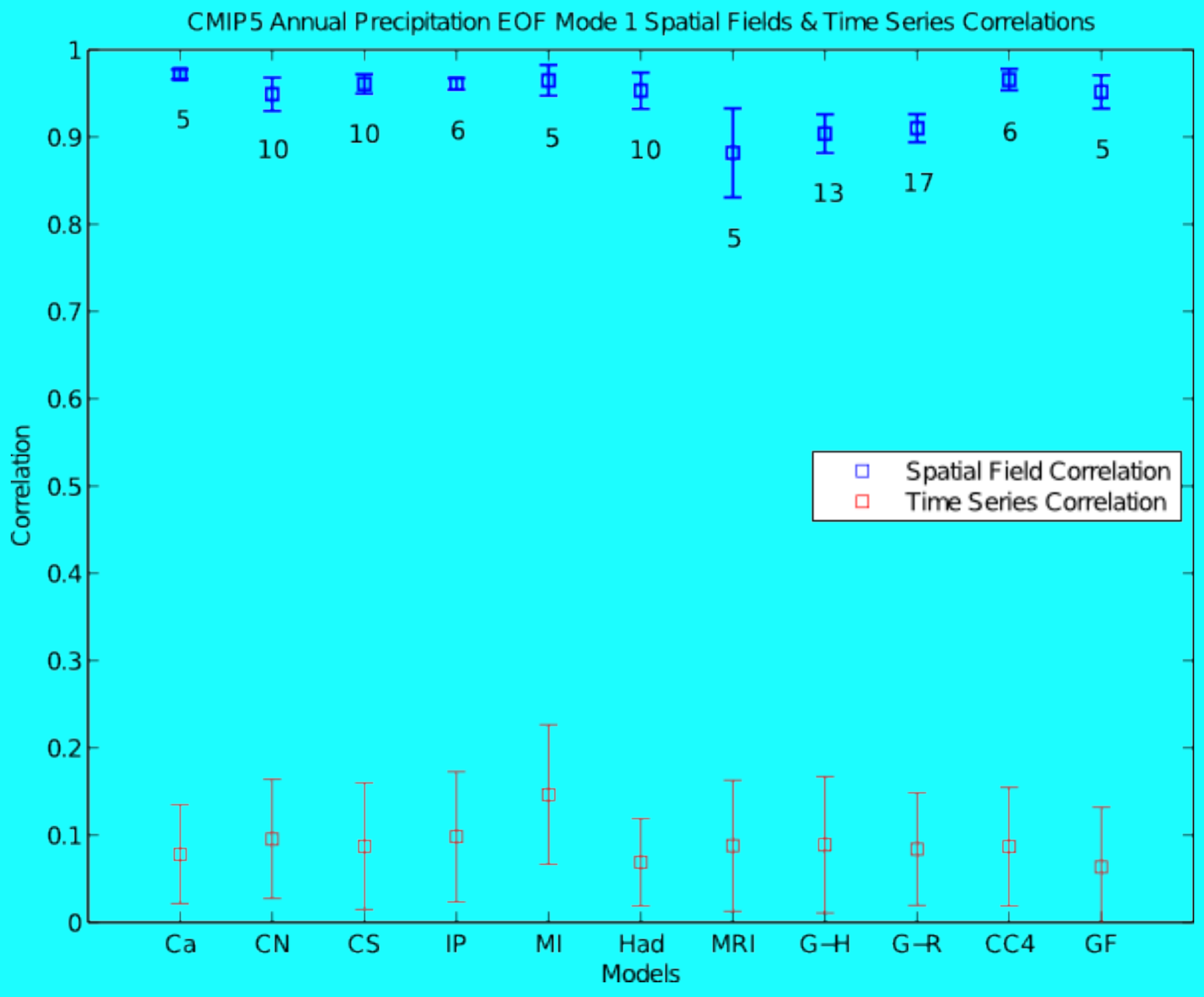


Pattern Correlations between EOF 1 of CMIP5 Model Precipitation Anomalies and EOF 1 of Reconstructed Precipitation



Reasonably strong resemblance between modeled and observed ENSO signals in precipitation.
Not too surprising, since model developers knew what they wanted to get.

Cross correlation of EOF 1 spatial patterns and time series with those from other runs of the same model



Time series uncorrelated, as they should be. Spatial patterns highly correlated, indicating that models give very consistent spatial signals.

Questions

- Do the CMIP5 models reproduce the apparent evolution of ENSO during the 20th Century?
- Are the atmospheric circulation changes associated with ENSO consistent with the precipitation signal?
- Do the model "ENSO" signals exhibit inter-event variability similar to that found in observations?
- Can the C20C models (and the 20th Century reanalysis) be used to improve our understanding of these behaviors?