Observed Global Precipitation Variability During the 20th Century

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WHY?

(Do we observe weather/climate?)

- ***It's fun!*** –we like to talk about big storms, heat waves, etc.
- ***Better sense of what's happening now*** – big picture is better than keyhole and movie is better than snapshot
- ***Helps us figure out what will happen –*** extrapolation works with many things, and observations are the only way to validate models

A crucial role for observations: validation of model simulations/predictions

How do we evaluate simulations/predictions of precipitation?

- ***Global Averages*** - do observations and models agree on global (or regional) means?
- ***Annual Cycle*** – global, hemispheric, land/ocean
- ***Long-term Change*** – models project large increases in global mean temperature. These are uniformly accompanied by increases in water vapor (7%/°), and less systematically by increases in precipitation (generally 2-3%/° but with lots of scatter).
  - Do global datasets support these model results?
- ***Modes of variability*** – ENSO, NAO, etc.

- IPCC AR4 Summary for Policy Makers" **"There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and of ice."**
- The models used in AR4 were judged to have improved representation of precipitation, based on annual mean fields and the time-mean annual cycle. However, these comparisons were based on climatologies compared to 25-year means of observations – not long enough to capture much of the important variability

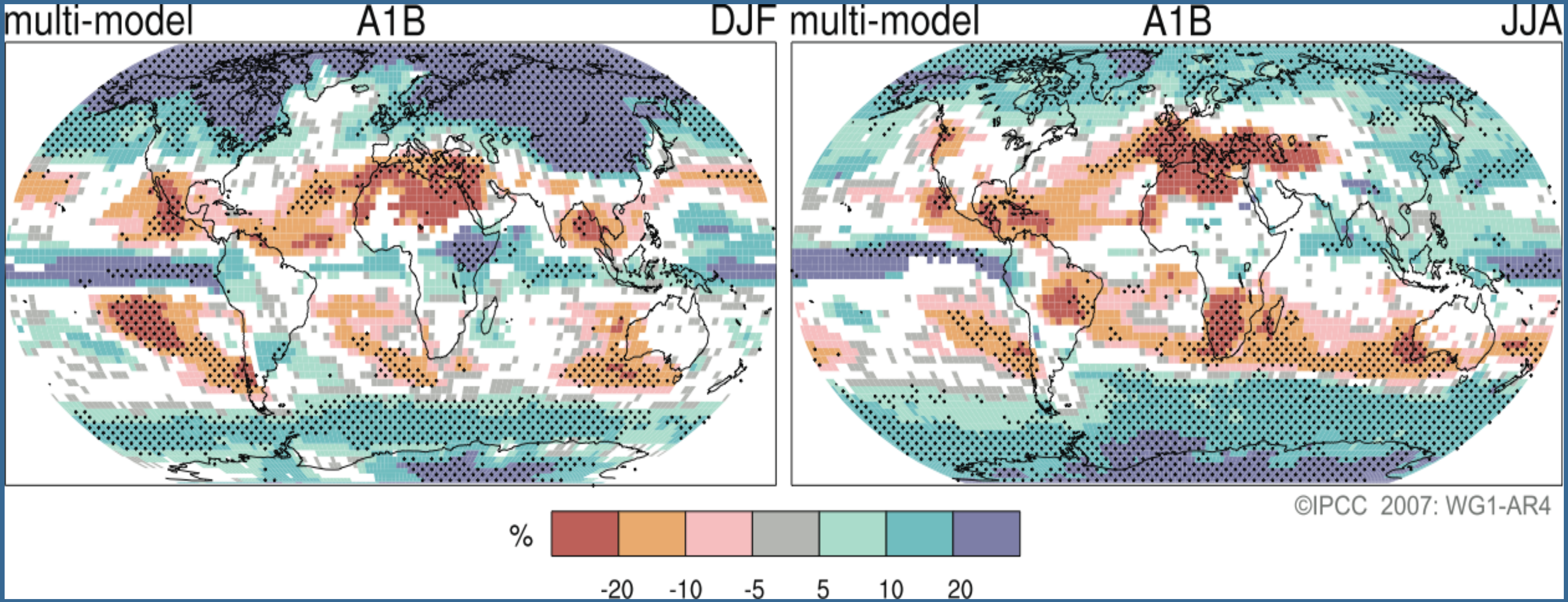
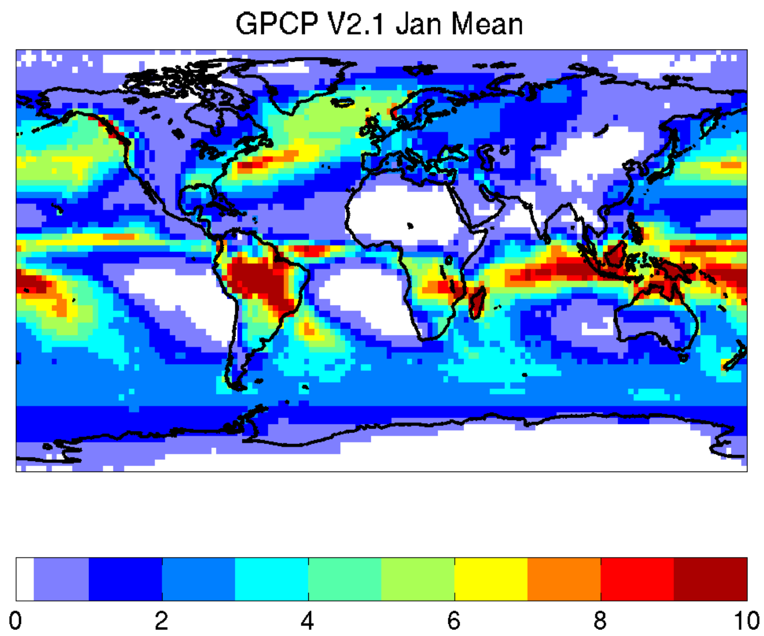


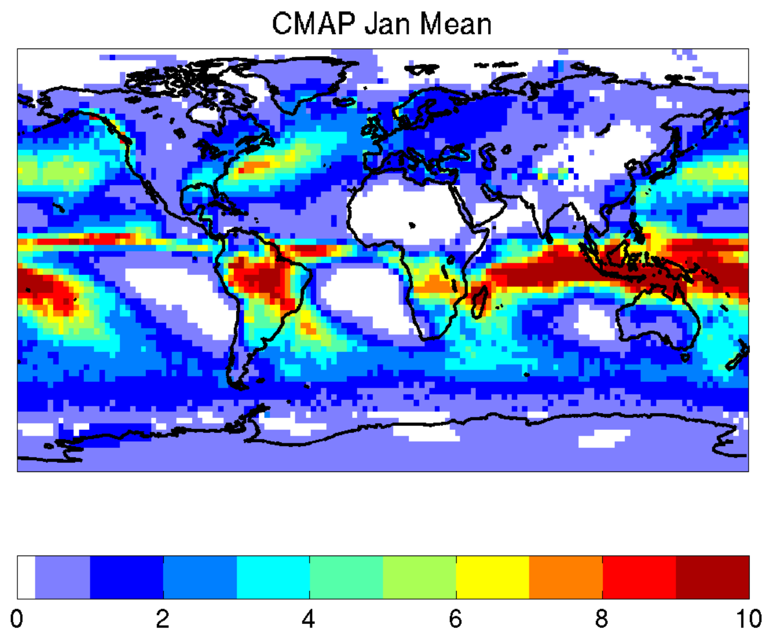
Figure SPM.7. *Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change.*

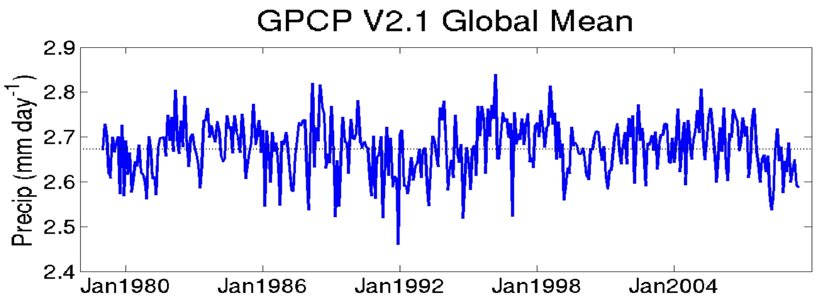
How is precipitation observed?

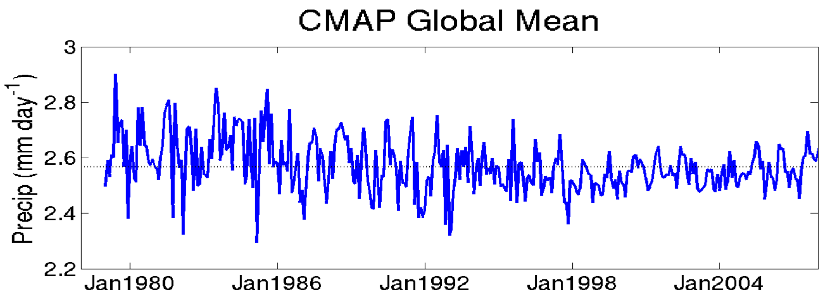
- The only direct, quantitative measurements come from rain gauges
  - Good absolute accuracy at a point
  - Poor spatial coverage
  - Generally mediocre temporal resolution
- Estimates derived from satellite observations
  - Indirect relationship to precipitation
  - Pretty good spatial/temporal coverage, but some significant gaps (high latitudes, for one)
- Estimates derived from other atmospheric observations
  - i.e., NWP model forecasts, atmospheric reanalyses
  - Only as good as initial data and model capabilities – cold season mid/high latitudes best
- Available data have complementary strengths
  - Microwave more accurate, IR better sampling
  - Gauges better absolute accuracy, poor sampling
  - Combination is better than any single source

Mature Global Precipitation Datasets



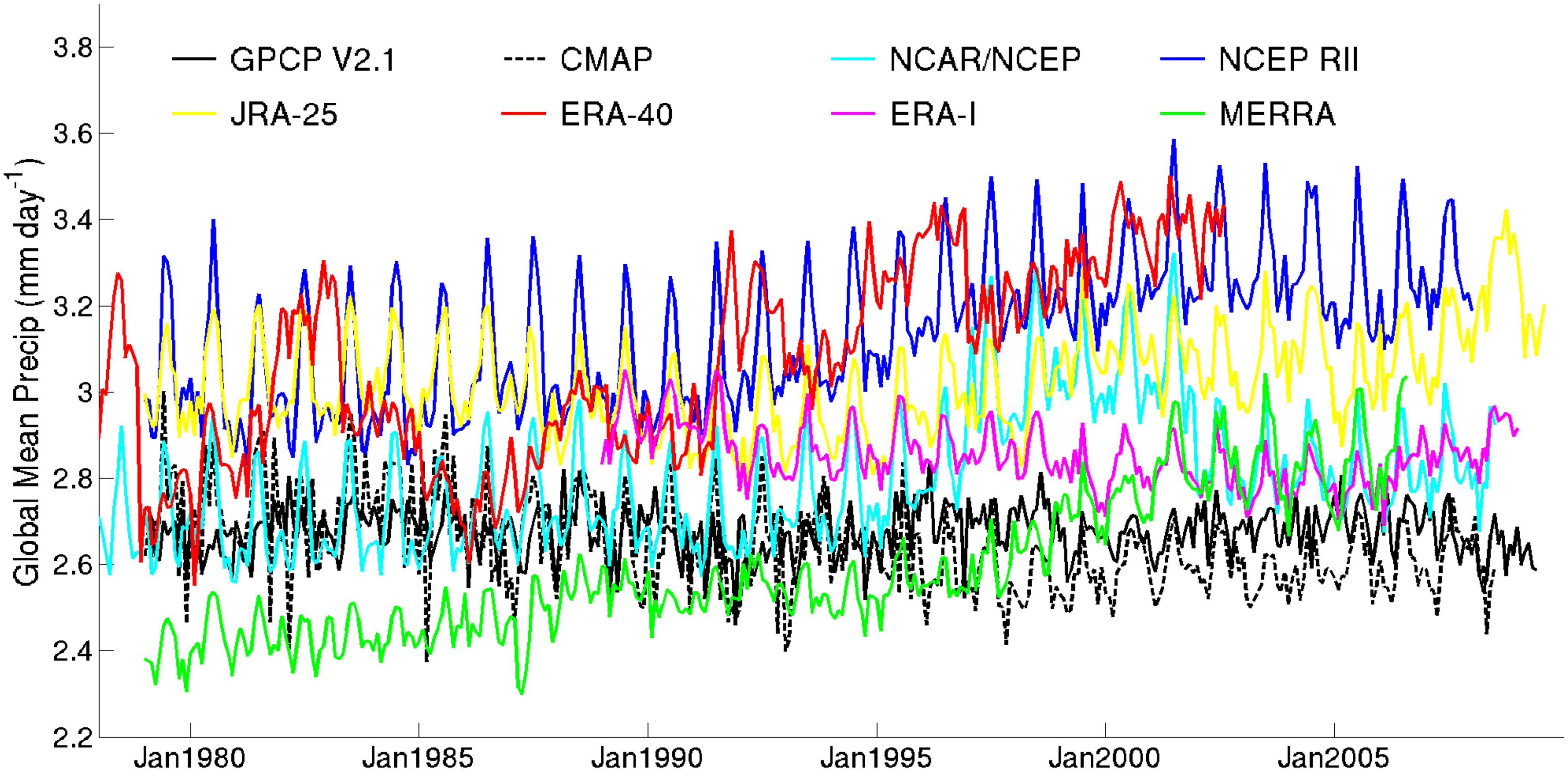






- GPCP (left)/CMAP (right) mean annual cycle and global mean time series
- Monthly/5-day; 2.5° lat/long global; both based on microwave/IR combined with gauges; both used in AR4

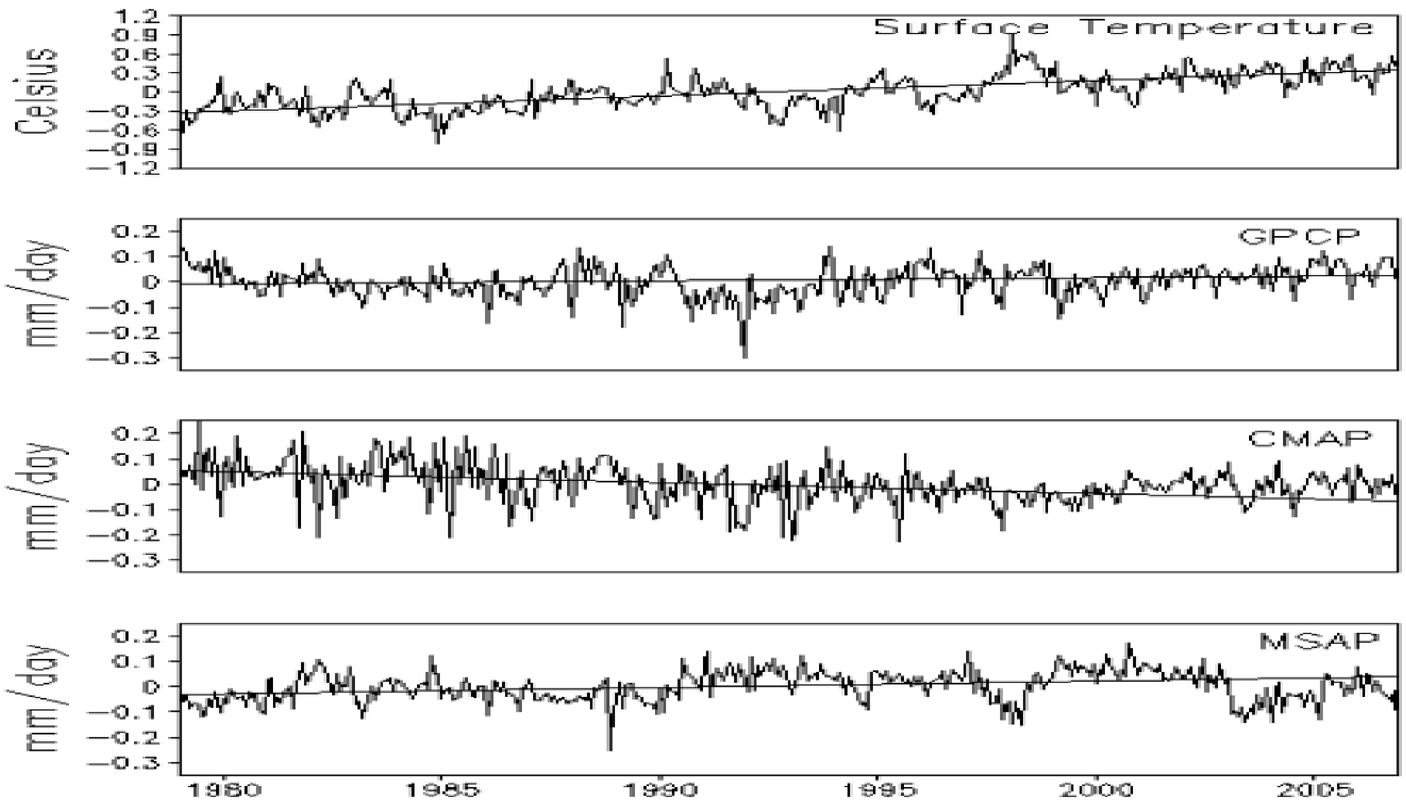
Reanalysis Precipitation



- Datasets based on observations (GPCP, CMAP) give 2.6-2.7 mm/day (AR4 range is about 3.2-3.9 mm/day)
- Data assimilation products average about 3 mm/day; also have larger mean annual cycle and greater interannual variability than GPCP/CMAP
- DA products seem unrealistically variable on interannual time scales

What about trends?

- Modern global precipitation data sets do not exhibit a consistent response to surface temperature changes since 1979
- Time period is short and data sets have many inputs
- DA precipitation not usable so far – too many observing system changes



No consistency among hydrological cycle sensitivity computed from GPCP, CMAP and MSAP

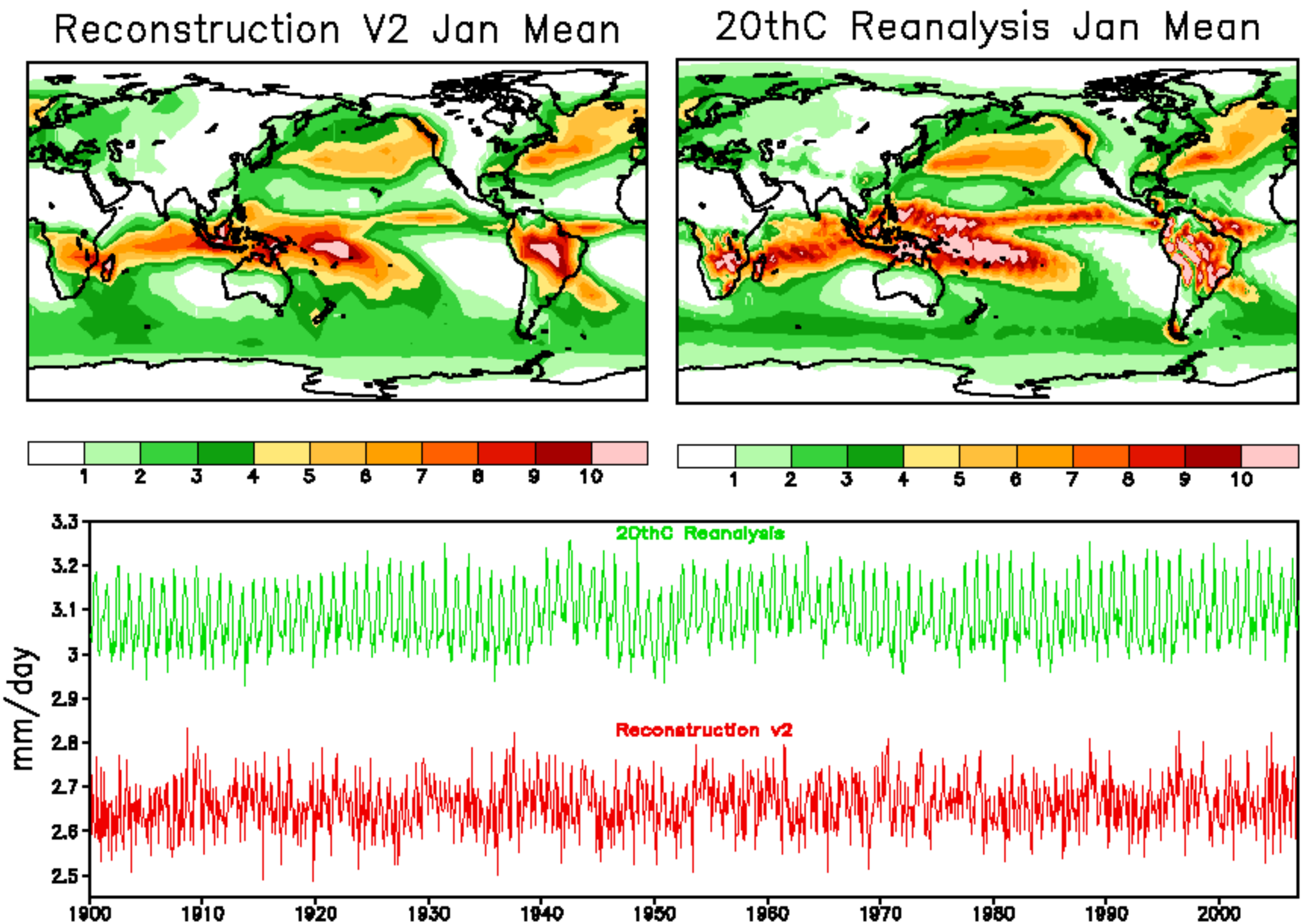
- ***Global Averages*** – reanalyses have higher global precipitation than observations
  - GPCP and CMAP have potential systematic errors that could contribute to this difference:
  - Orographic and high latitude precipitation is very poorly observed
  - There is some evidence that the passive microwave estimates may be biased low over tropical oceans
- ***Annual Cycle*** – GPCP and CMAP disagree on the (very small) annual cycle of global mean precipitation, but are generally consistent with the spatial details of the seasonal cycle
  - reanalyses generally exhibit higher values during Northern Hemisphere summer; simulations not as consistent
  - Observed data sets have pronounced hemispheric and land/ocean annual cycles that almost exactly compensate – a potential test for model simulations
- ***Trends*** – no consistent signal in modern datasets
- ***Modes of Variability*** – Quite good for seasonal to interannual scales, ENSO in particular (not discussed)

Reconstruction of Near-Global Precipitation Variations Back to 1900 Based on Gauges and Correlations with SST and SLP

(see Tom Smith for hard questions)

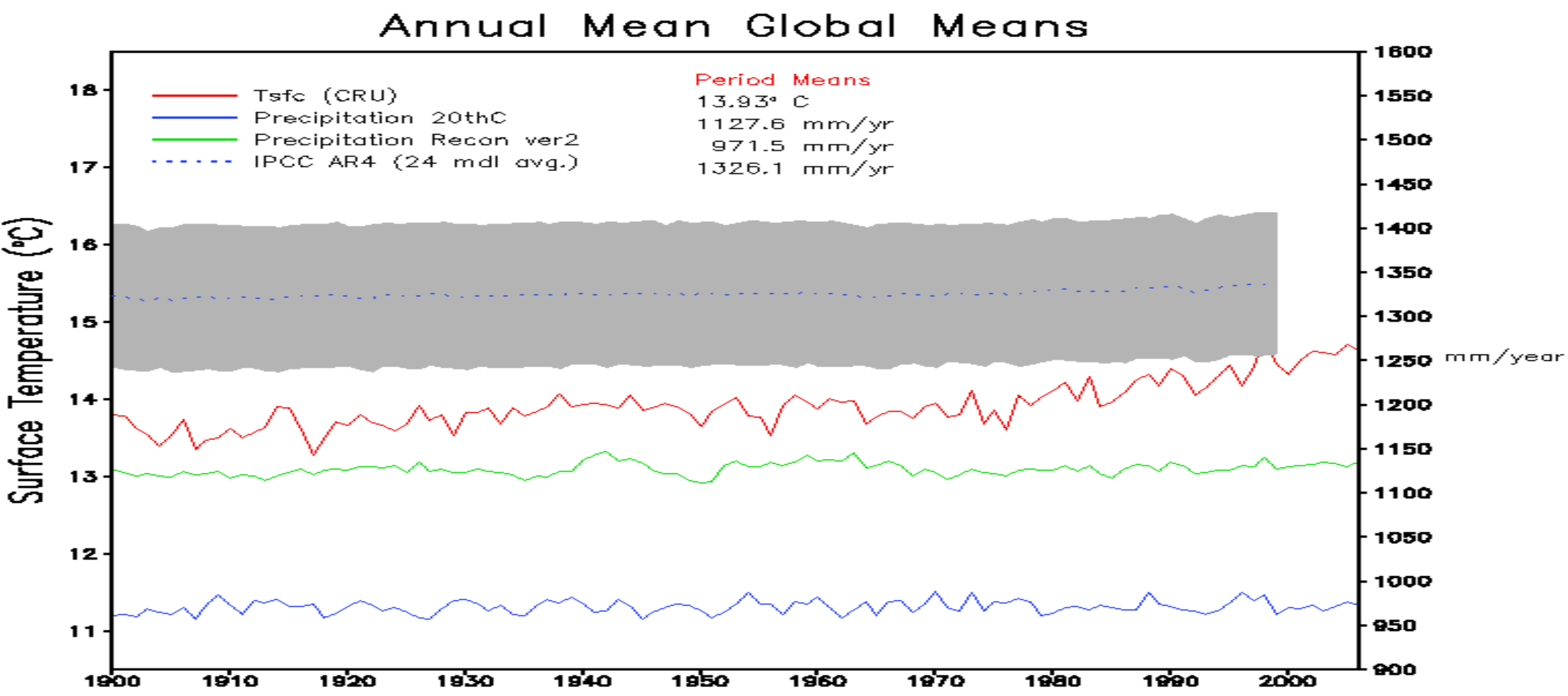
- Base Satellite Data
  - Need global satellite analyses to establish statistics
  - GPCP, CMAP and MSAP tested; GPCP works best
- Direct Reconstructions: fitting data to Empirical Orthogonal Functions – Primary Source
  - Global EOF (or PC) analysis of GPCP annual anomalies – 10 modes
  - Fit annual gauge-station data to these modes
  - Compute residual monthly modes using GPCP data – 40 modes
  - Fit residuals of monthly gauge data to these modes
  - Yields time series of monthly anomalies on 5° grid 1900-2008
  - This preserves multi-decadal signal
- Indirect Reconstructions: using Canonical Correlation Analysis – (Nearly) Independent Check
  - Correlate fields of sea-surface temperature (SST) and sea-level pressure (SLP) with fields of precipitation during satellite era
  - Both SST and SLP analyzed for the 20th century; annual anomalies

- ***Global Averages*** – we can compare AR4 model simulations and the NOAA/ESRL 20th Century reanalysis against the reconstructions (where the mean is strongly influenced by GPCP)
- ***Annual Cycle*** – reconstruction annual cycle can be compared against 20th Century reanalysis
- ***Long-term Variability*** – 100+ years should be enough to compare trends and decadal variations
- ***Modes of Variability*** – how well do reconstructions and reanalysis represent ENSO, NAO, etc.?


Reconstruction V2 Jan Mean
20thC Reanalysis Jan Mean
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10
20thC Reanalysis
Reconstruction v2
mm/day
3.3 3.2 3.1 3 2.9 2.8 2.7 2.6 2.5
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000

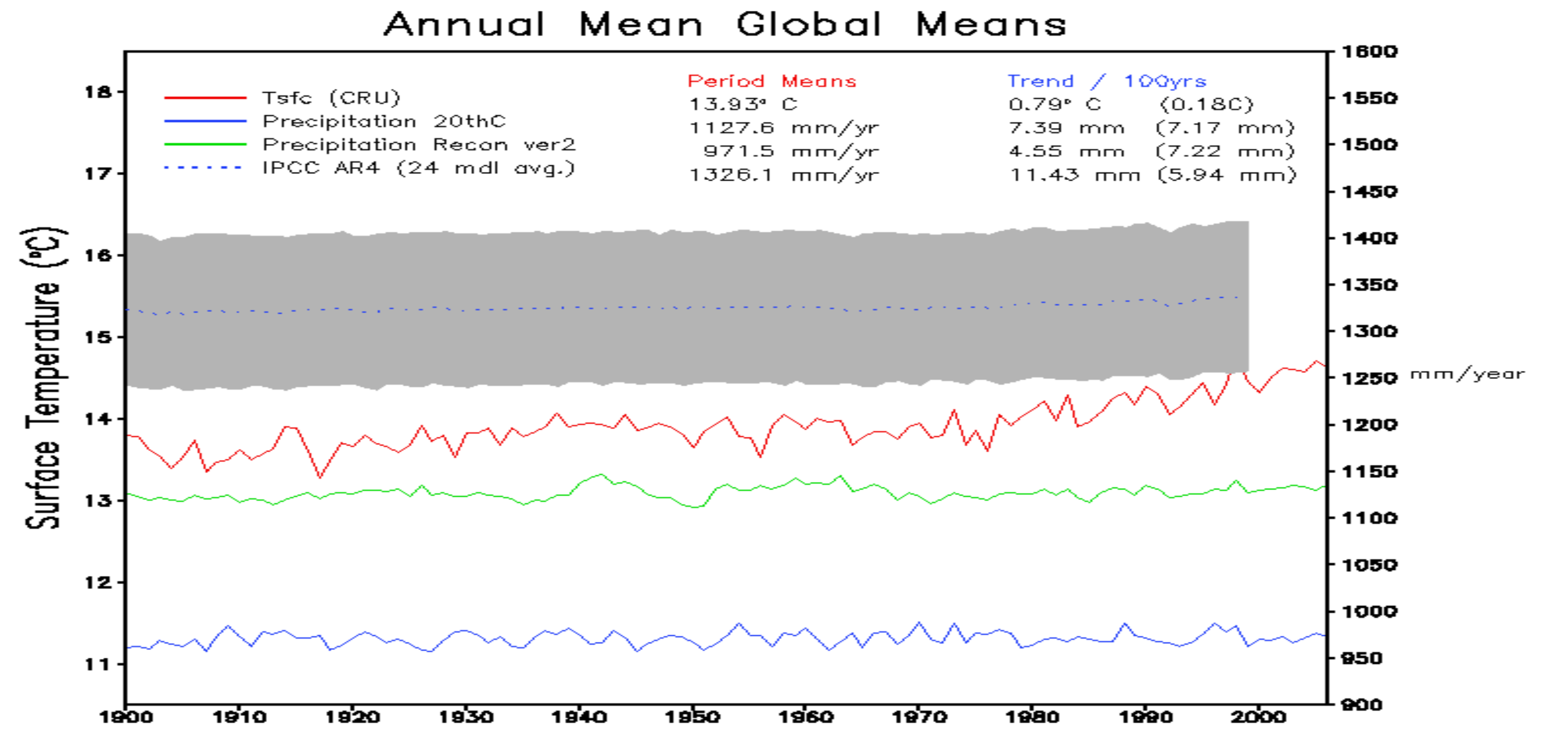
Global Mean Precipitation

- Lowest (blue) curve (2.66 mm/day) is reconstruction mean (where totals are obtained by adding GPCP climatology)
- Green curve (3.09 mm/day) is from 20th Century reanalysis
- Upper (blue dotted) curve (3.63 mm/day) is mean of 24 model simulations from AR4; gray area is ±1 standard deviation of the model means
- Red is global mean temperature (from CRU)



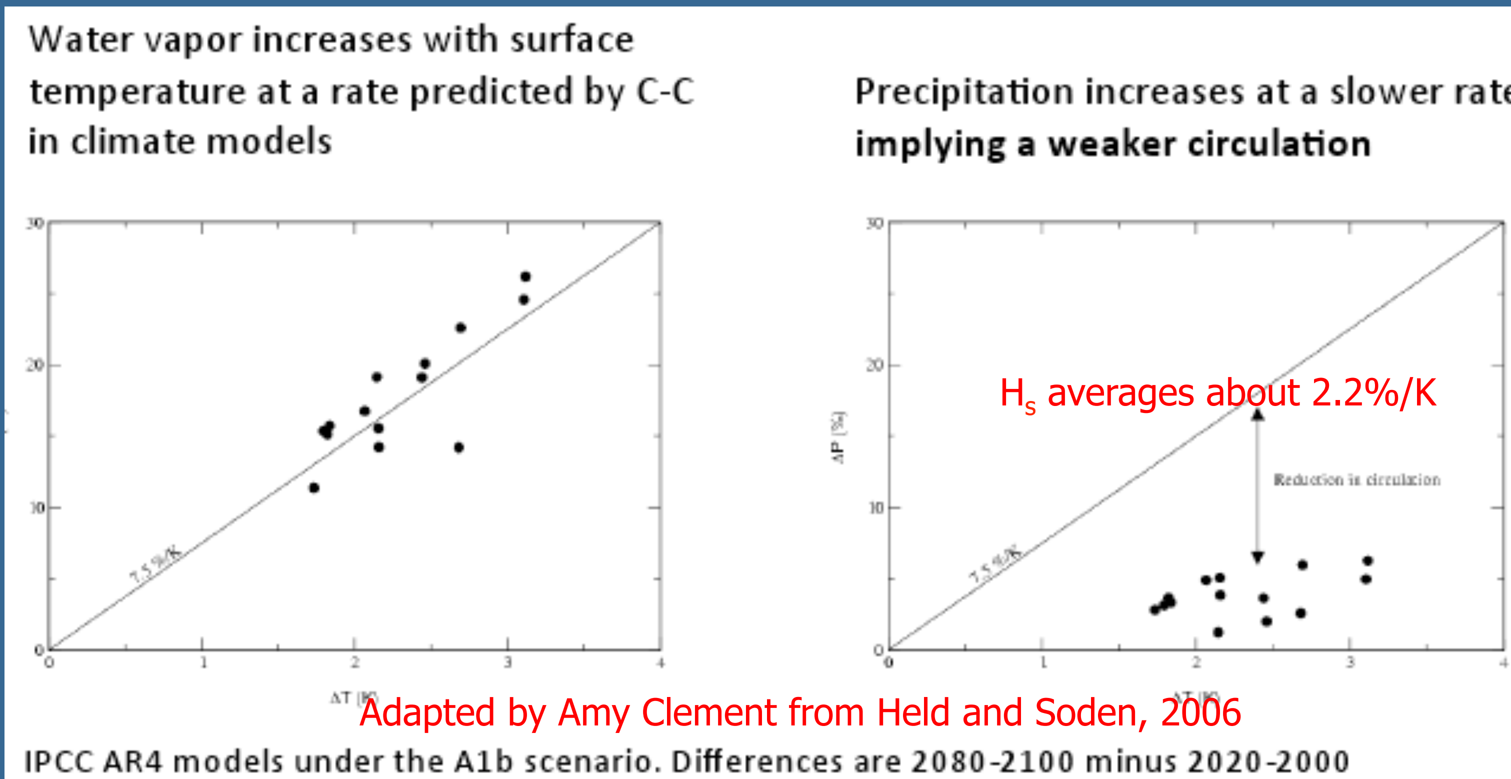
Centennial Trends in Global Mean Precipitation

- Temperature trend is 0.79° over the century
- Reconstructed, reanalyzed and simulated (ensemble mean) precipitation all show increasing trend (significance unclear) over same period
- The precipitation data are nearly independent of one another:
  - Simulations are from coupled models
  - Reanalysis used observed SST and SLP
  - Reconstruction used GPCP EOFs and gauge observations

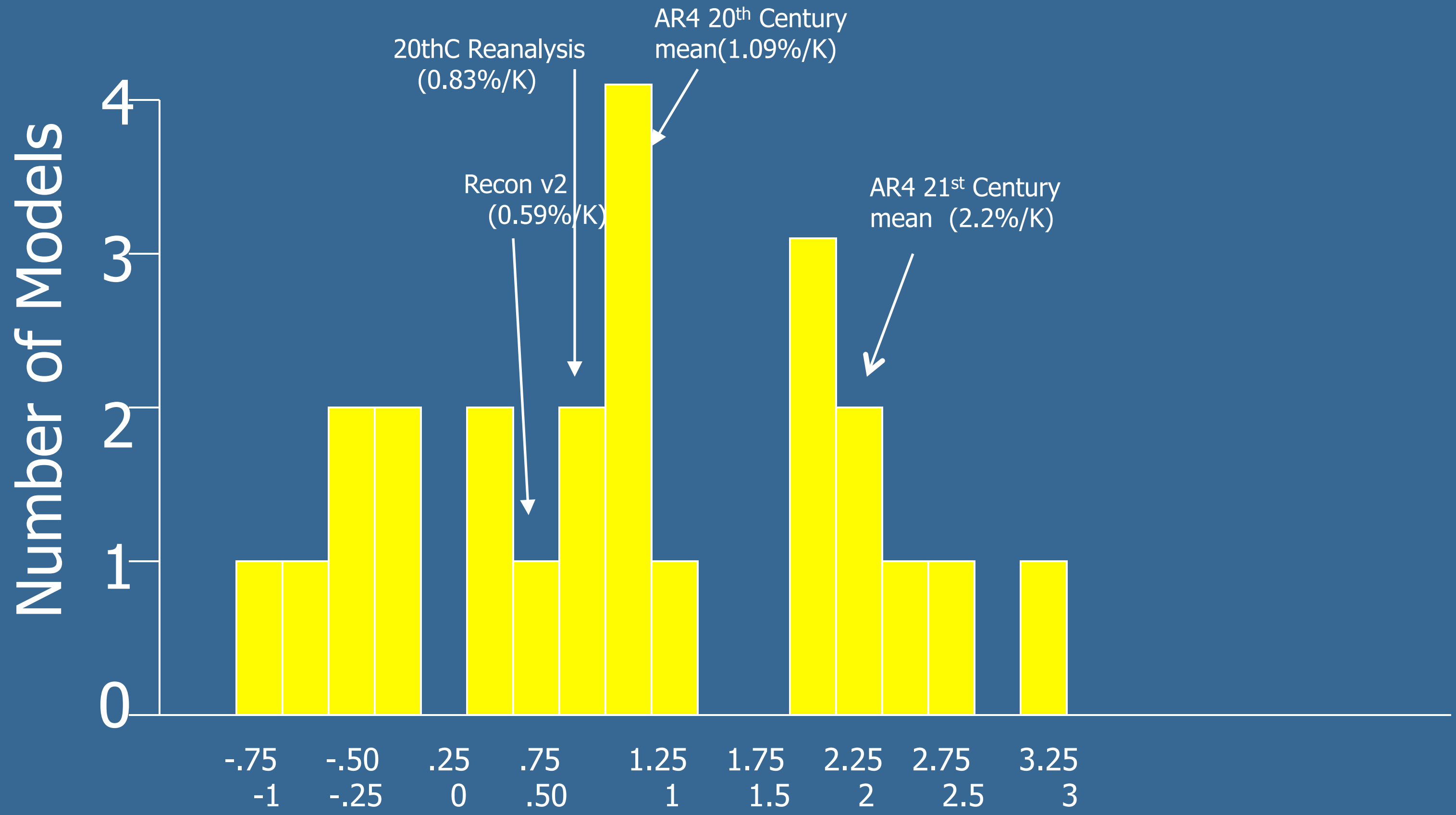


Sensitivity of Global Hydrological Cycle

- Analogous to climate sensitivity, which is change in global mean T for some specified change in radiative forcing
- H_S = % change in mean global P per unit change in mean global T



- Using CRU observed temperature change over 1900-2000:
  - Reanalysis H_S = 0.83 %/K
  - Reconstruction H_S = 0.59 %/K
  - AR4 ensemble mean H_S = 1.09 %/K

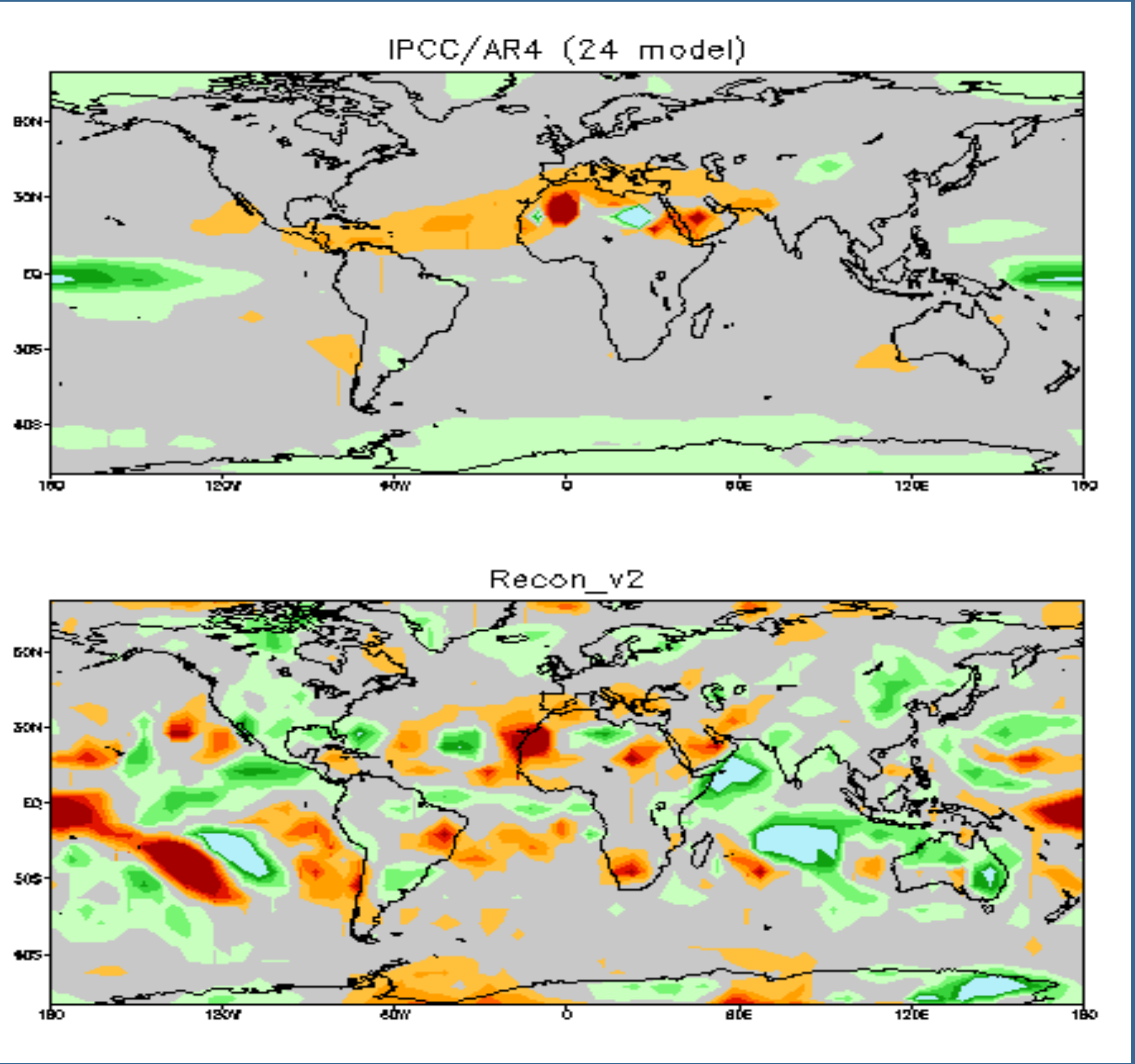


Hydrological Cycle Sensitivity over the 20th Century for 24 Individual AR4 Models

Spatial Distribution of 20th Century Trends

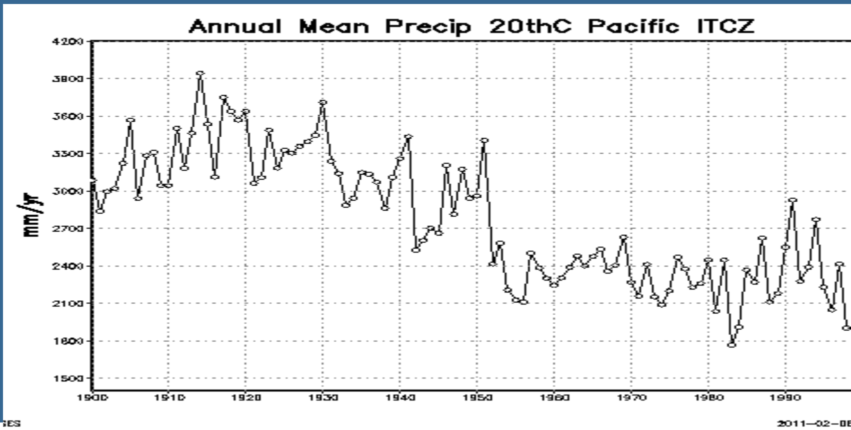
Model (upper) : equatorial Pacific/ polar regions wetter; subtropics dryer from Central America to Middle East dryer

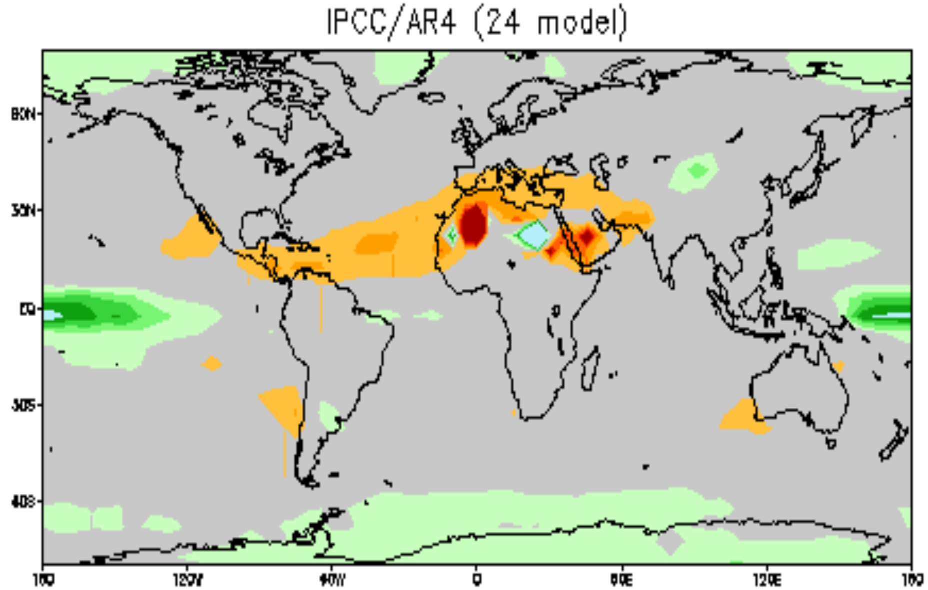
Reconstruction: much more spatial variability (noise, maybe from interannual-decadal fluctuations?)

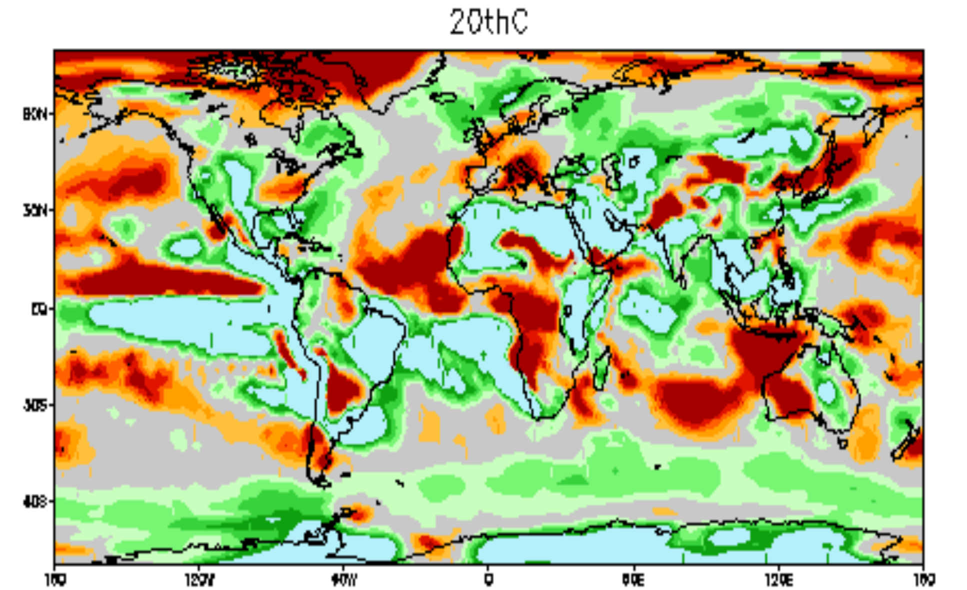


Spatial Distribution of 20th Century Trends: Models vs. Reanalysis

Some big features are similar: tropical North Atlantic, equatorial Pacific, Antarctic
Reanalysis has a lot of odd-looking features – negative trend in East Pacific ITCZ results from abrupt change in 1951-52





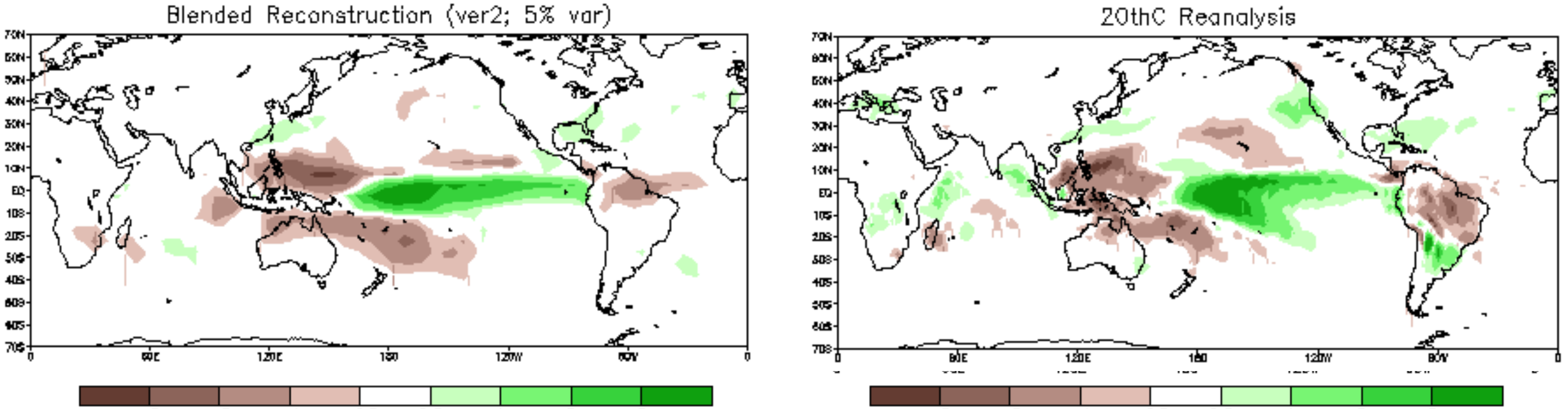


- ***Modes of Variability*** – in examining temperature, precipitation and circulation data, climate scientists have identified a number of coherent phenomena that have consistent patterns of behavior that cover large parts of the world and last for extended periods of time
  - ENSO, NAO, AO/AAO, etc.
- *The goal here is to compare the ability of reconstructions and reanalyses to resolve these signals in global precipitation*

El Niño/Southern Oscillation (ENSO)

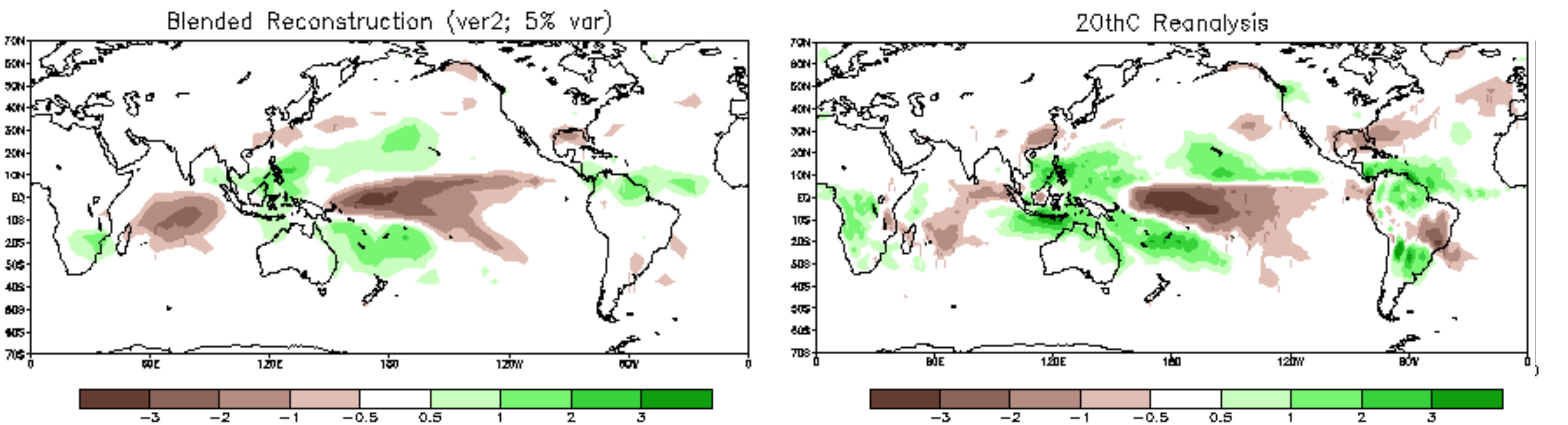
Warm Episode Composite DJF Precip Anomalies

Composite of 12 Strongest events (1900–1998; BMRC)
(year of December)



Cold Episode Composite DJF Precip Anomalies

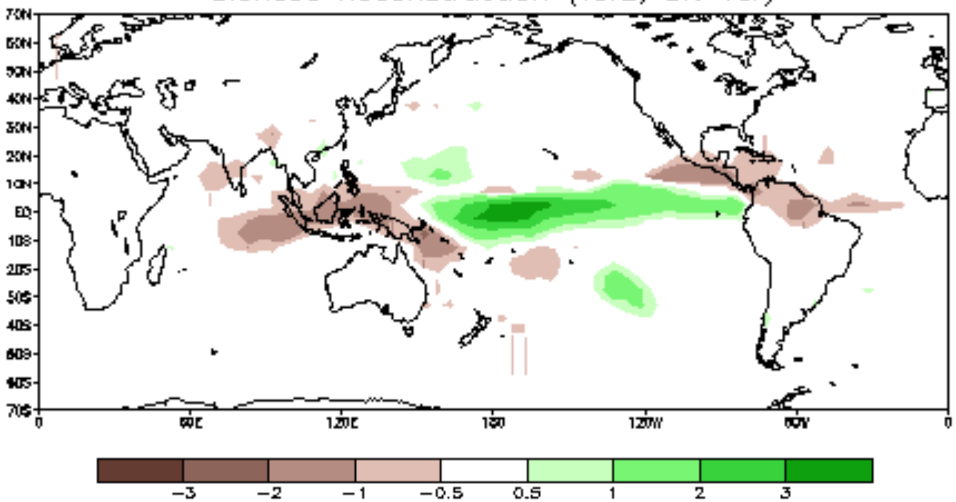
Composite of 11 Strongest events (1900–1998; BMRC)
(year of December)



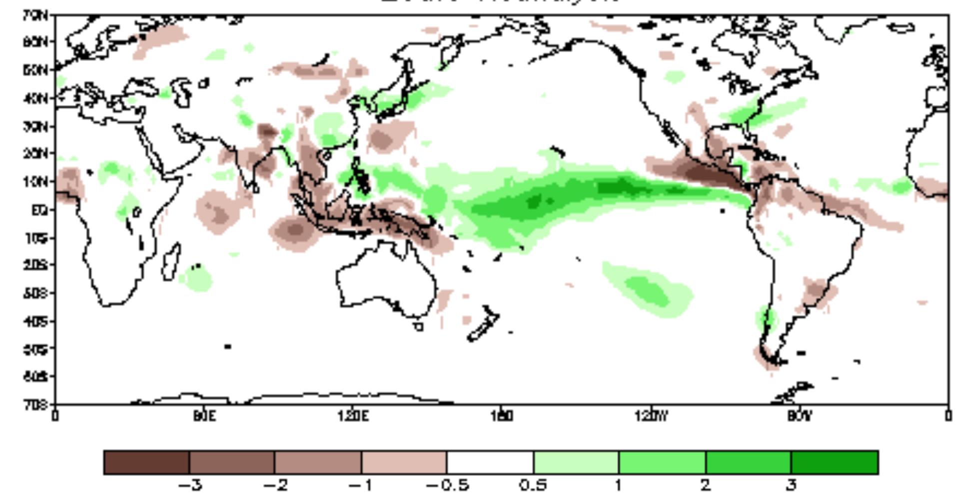
Warm Episode Composite JJA Precip Anomalies

Composite of 12 Strongest events (1900–1998; BMRC)

Blended Reconstruction (ver2; 5% var)



20thC Reanalysis



Cold Episode Composite JJA Precip Anomalies

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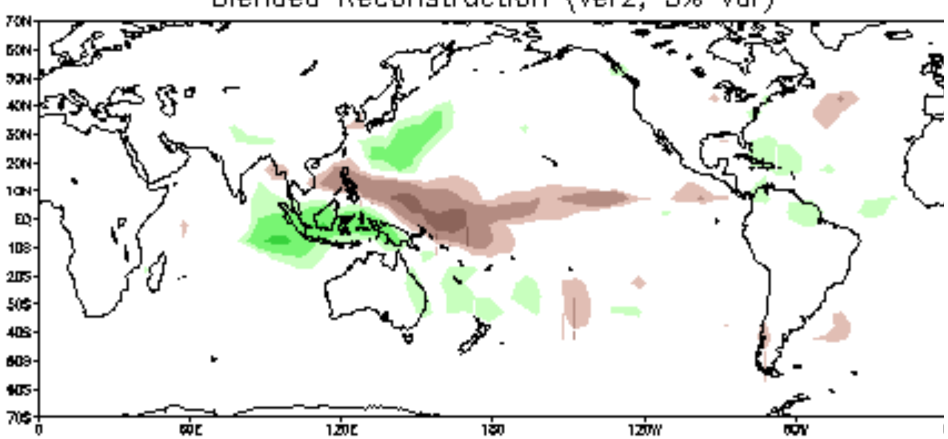
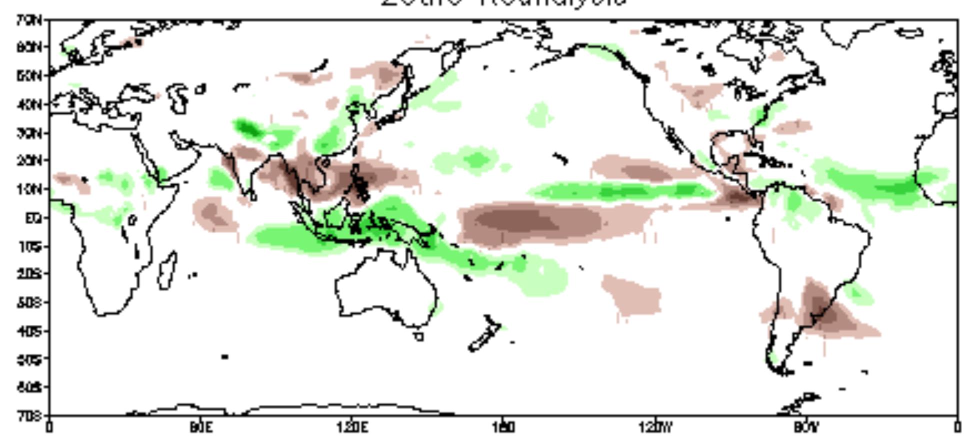
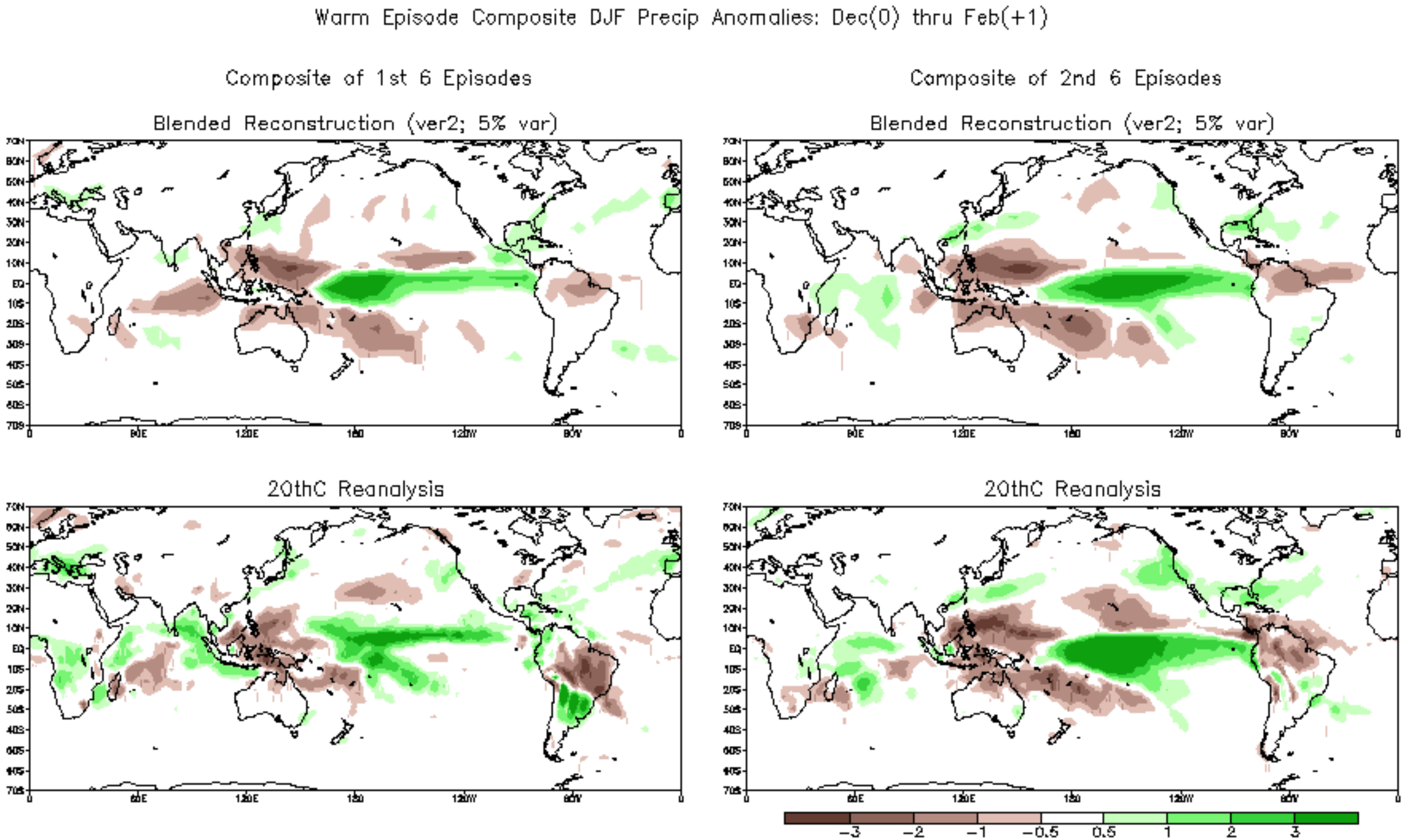


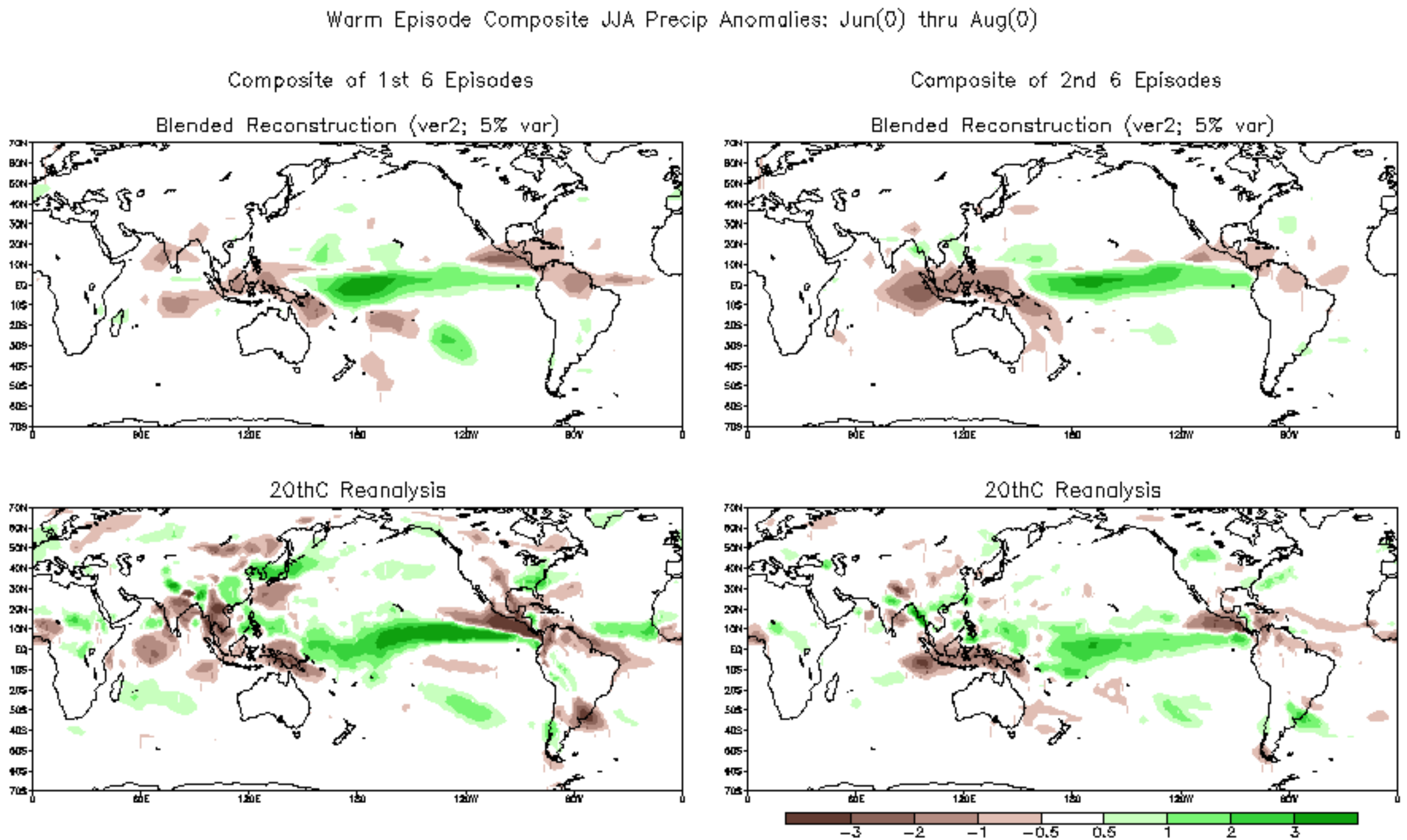
20thC Reanalysis



How does the ENSO signal vary between first and second half of the Century?



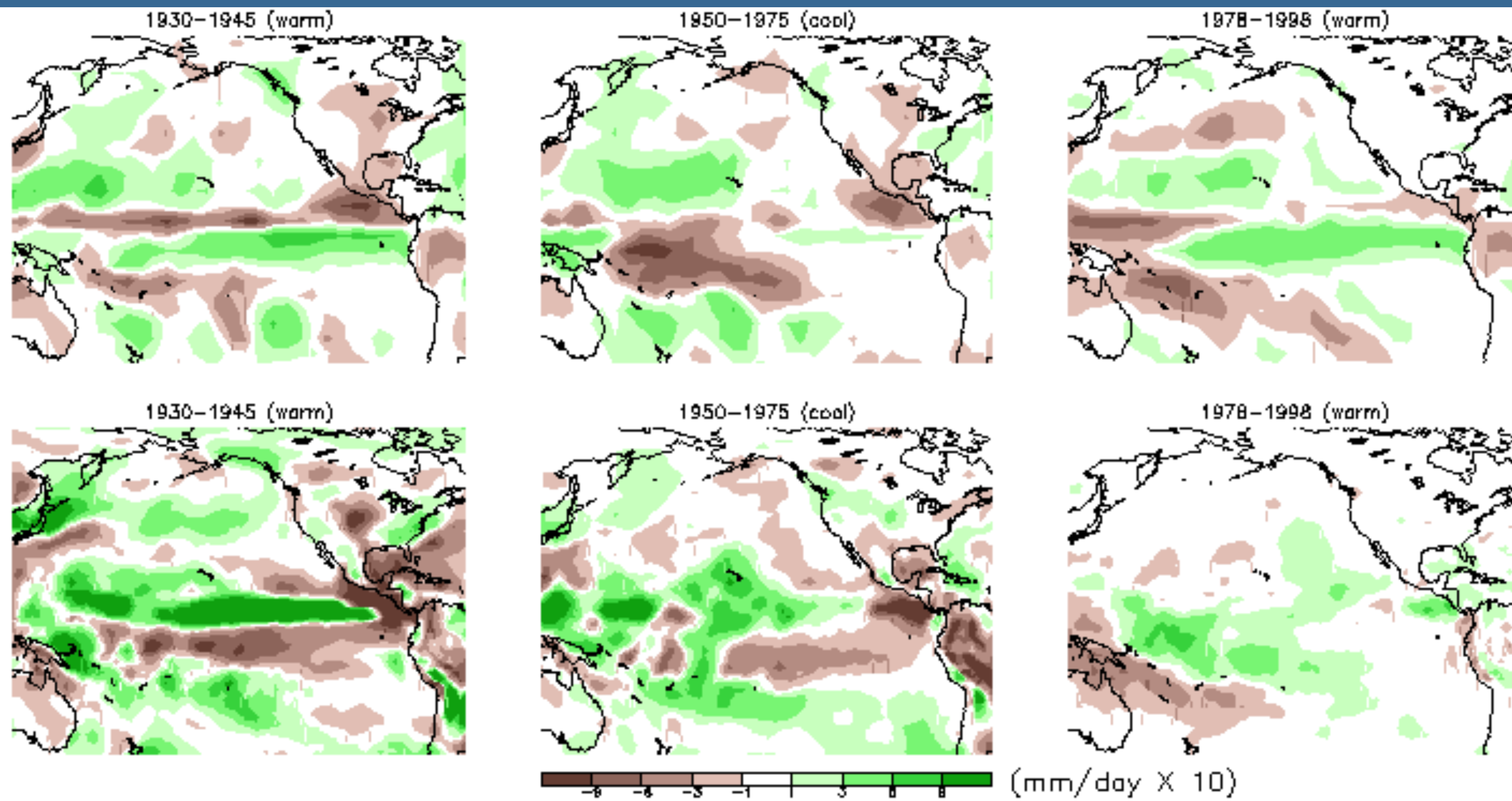
Changes in reconstruction and reanalysis are consistent in some cases: central equatorial Pacific positive anomaly is stronger further east after 1950; Indian subcontinent drying in JJA before 1950 but not clear after



PDO Composite Annual Precipitation Anomalies

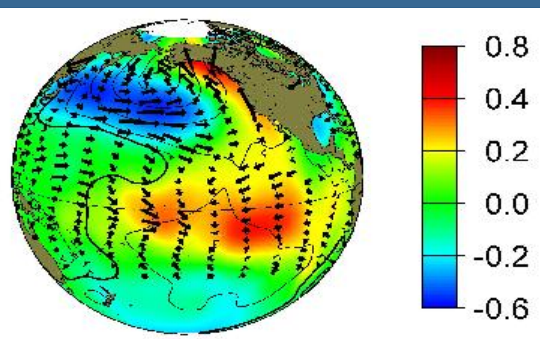
Blended Recon (ver2; 5% var.)

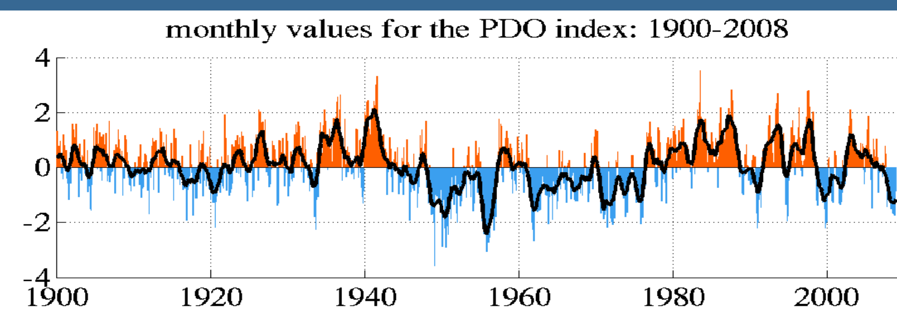
20thC Reanalysis



Warm Phase

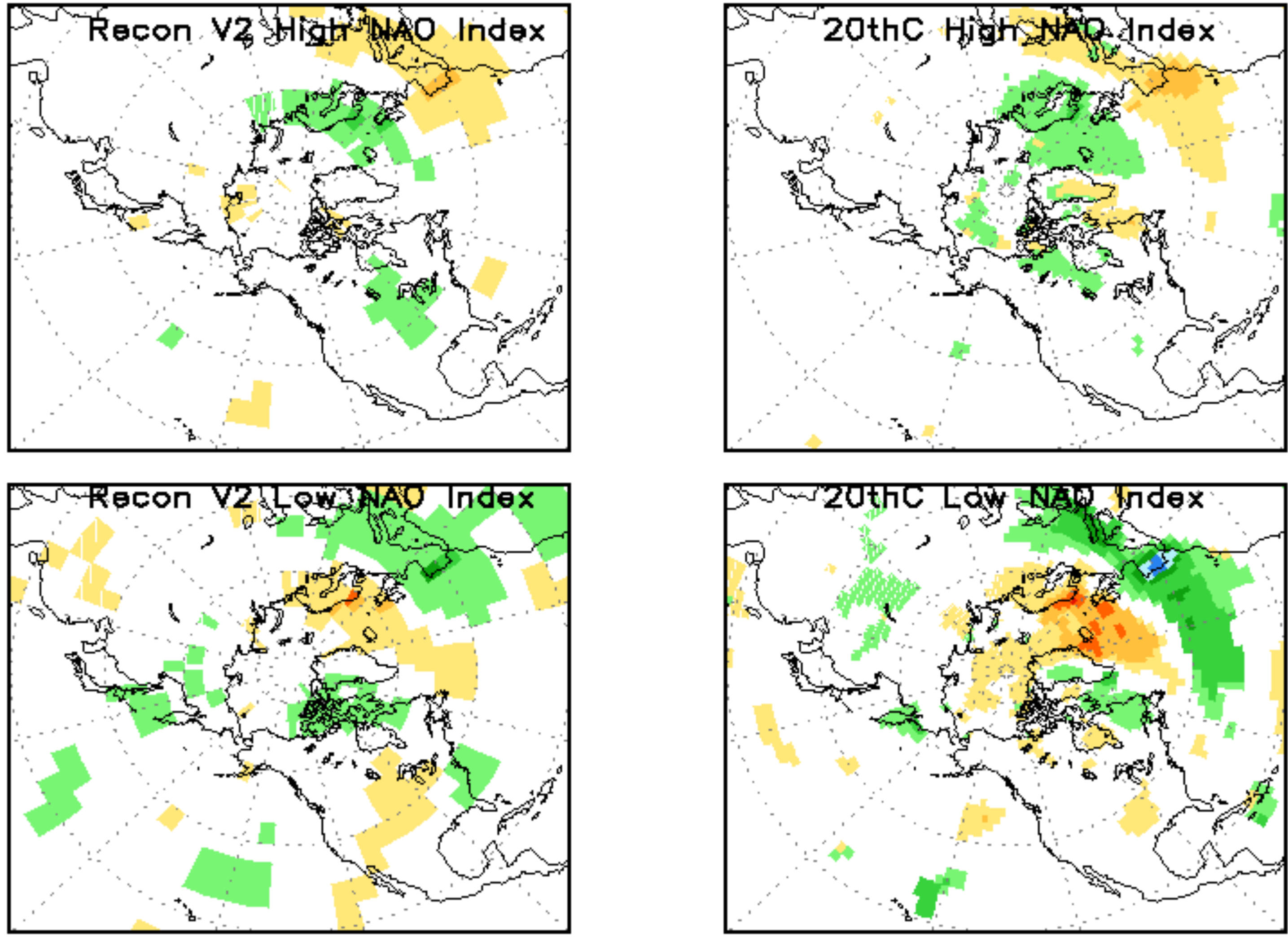
Cool Phase

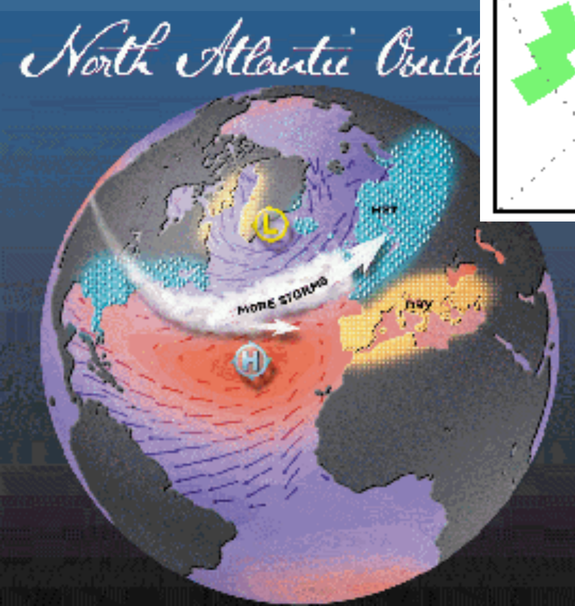


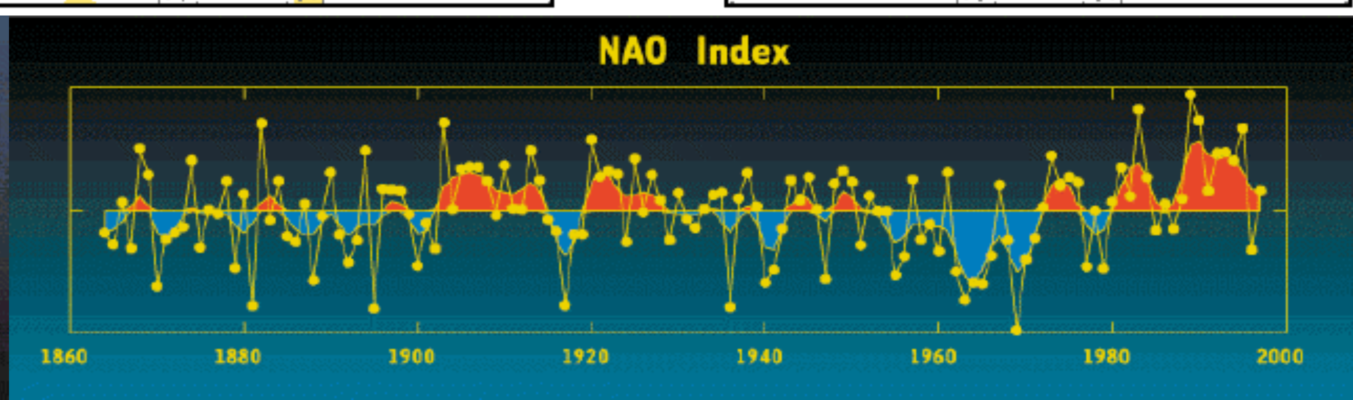


NAO Composite Precipitation Anomalies

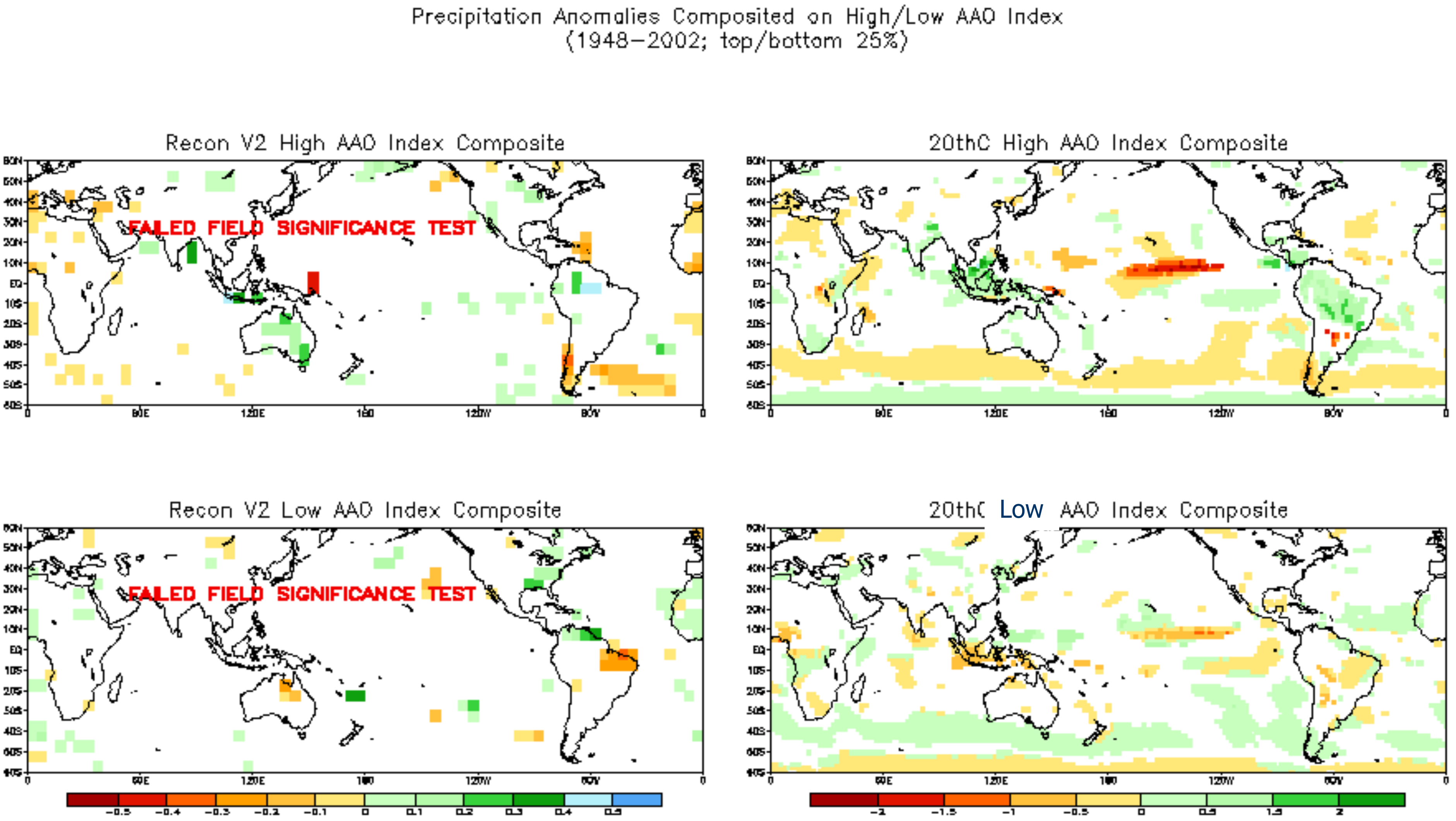
(DJFM-highest/lowest quartiles; reconstruction left, reanalysis right l)



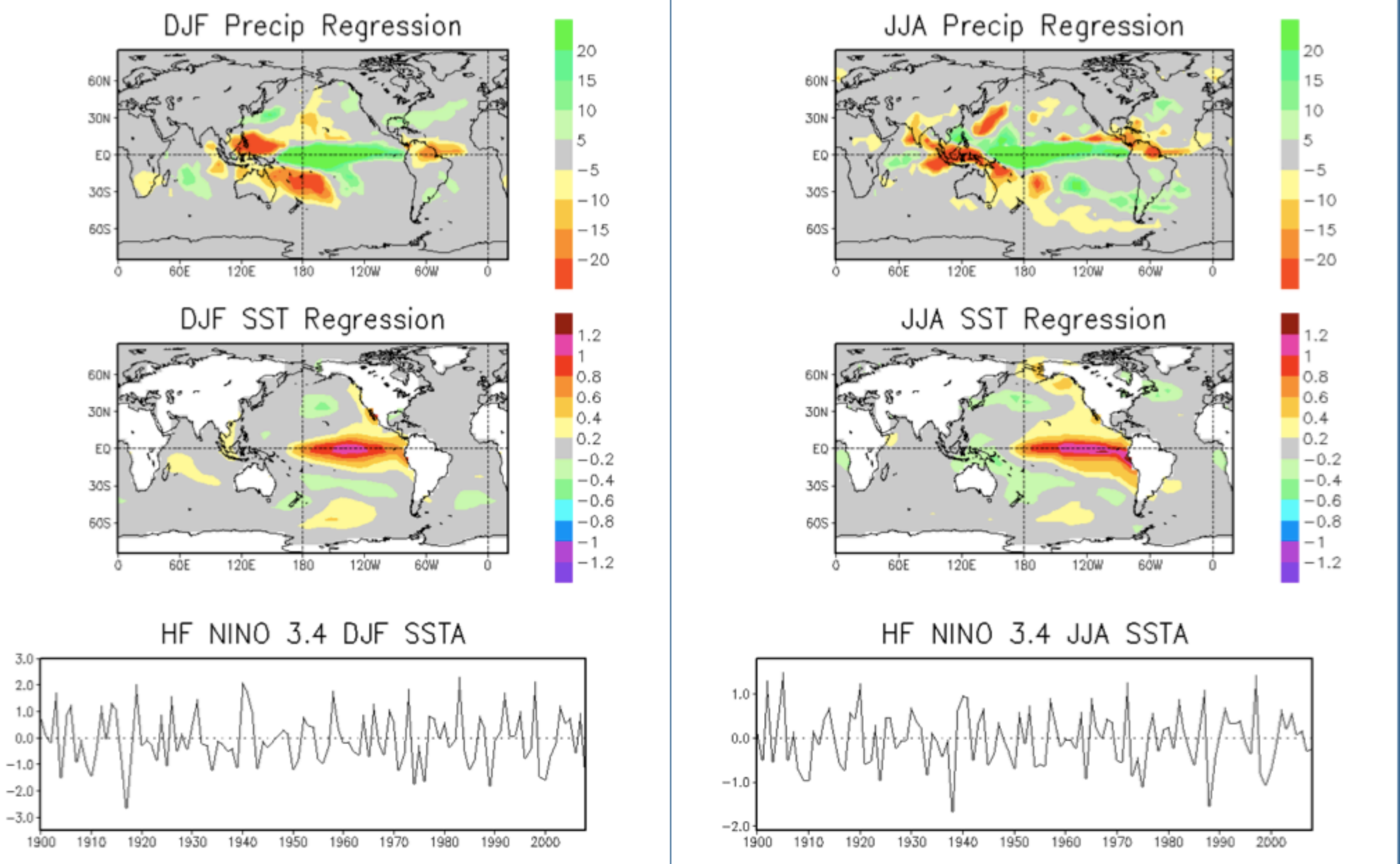




We believe that the reconstruction has least skill in the mid and high latitude Southern Hemisphere, where the Antarctic Oscillation should have its main signal – 20th Century reanalysis has a more believable manifestation

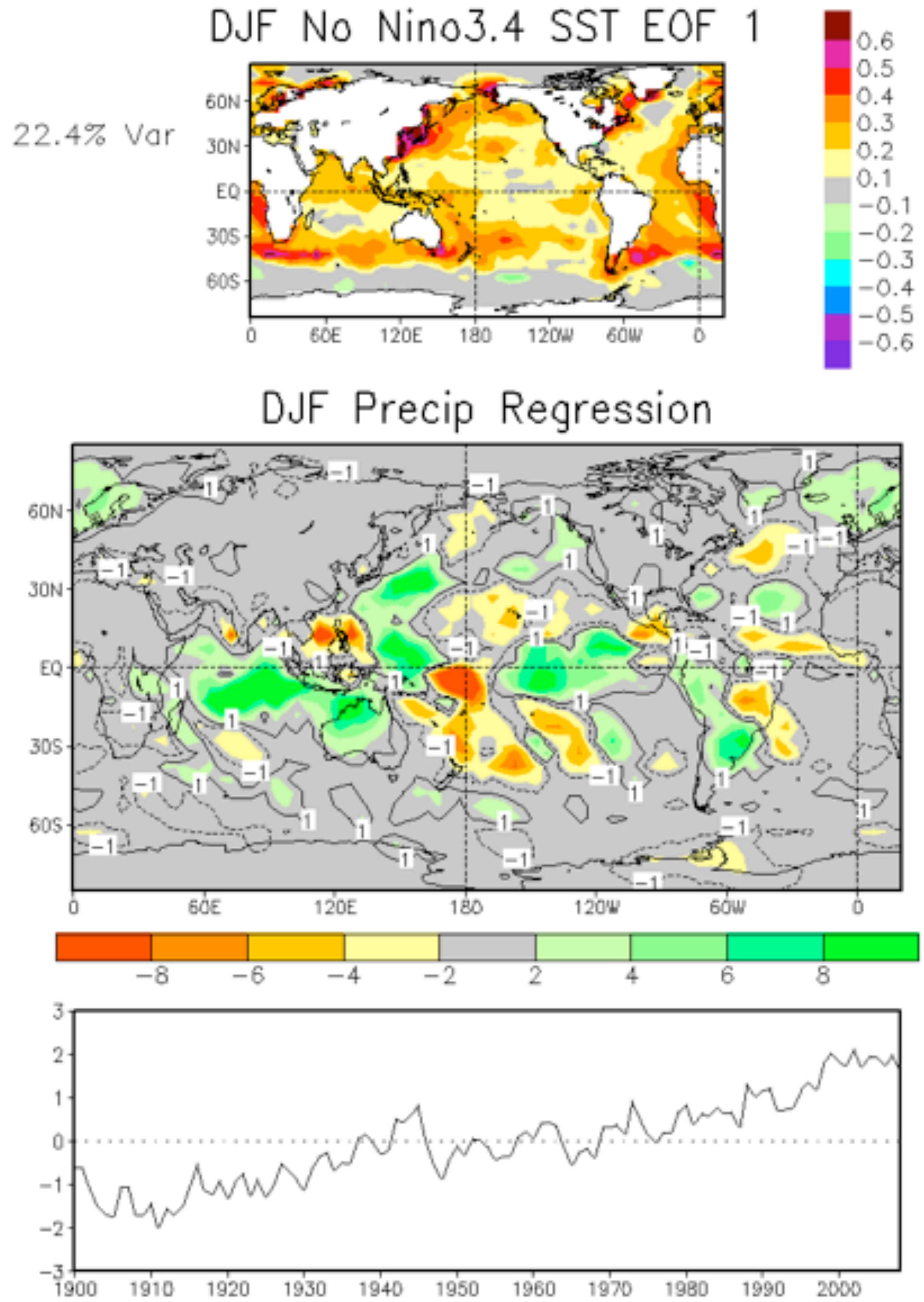


Both ENSO and long-term warming have strong impacts over the 20th Century – filter the high frequency ENSO signal for clarity



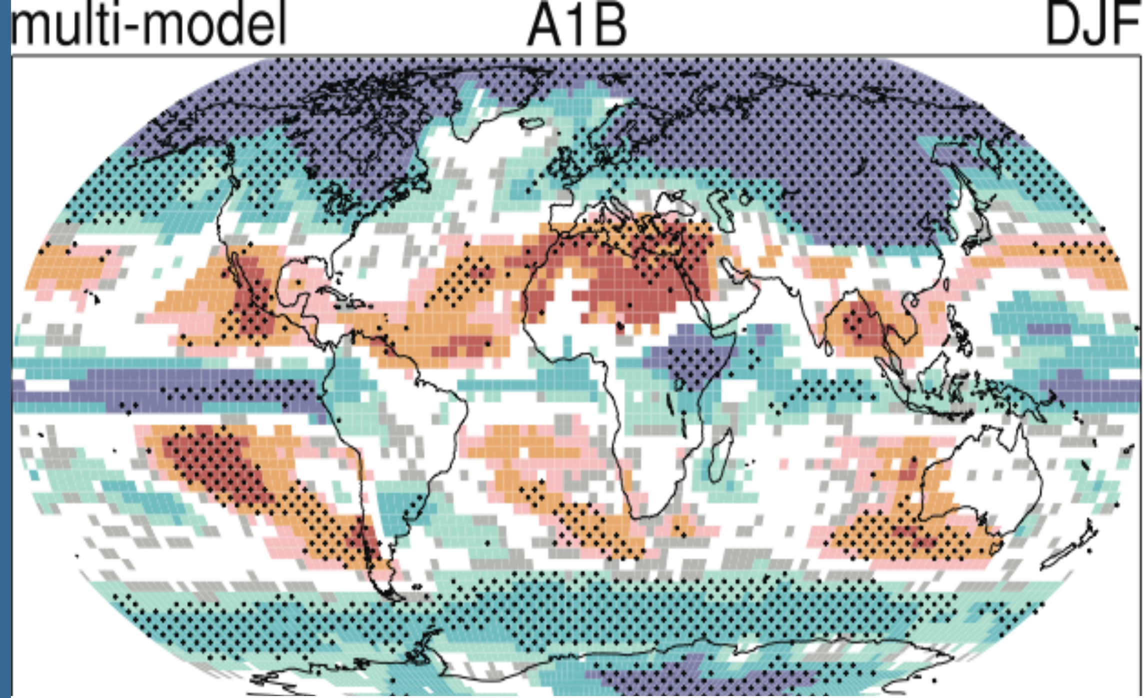
EOF Analysis of ENSO-Filtered SST and Associated Precipitation

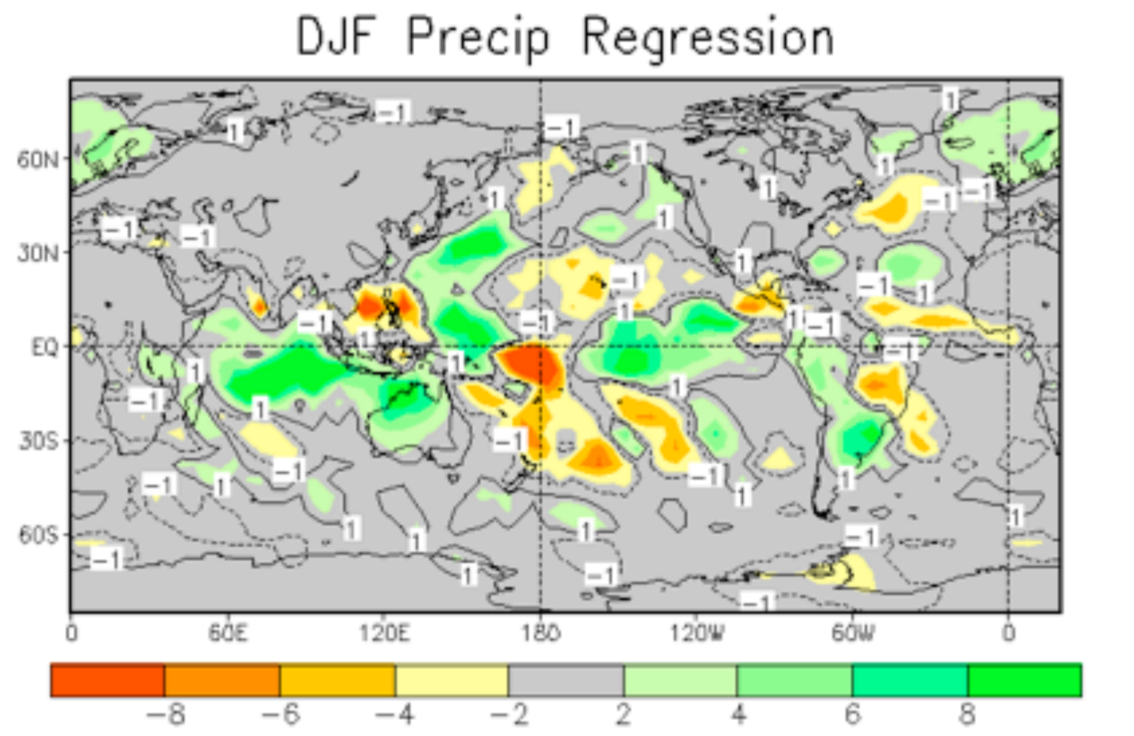
- SST DJF EOF 1:
  - Near global warming
  - Small decreases in Southern Ocean
  - General warming over the century except for decrease in 1940s – data issue?
- Precipitation:
  - Largely oceanic signal – strongest in tropics
  - Little signal in Southern Ocean where data are suspect



20th vs. 21st Century DJF

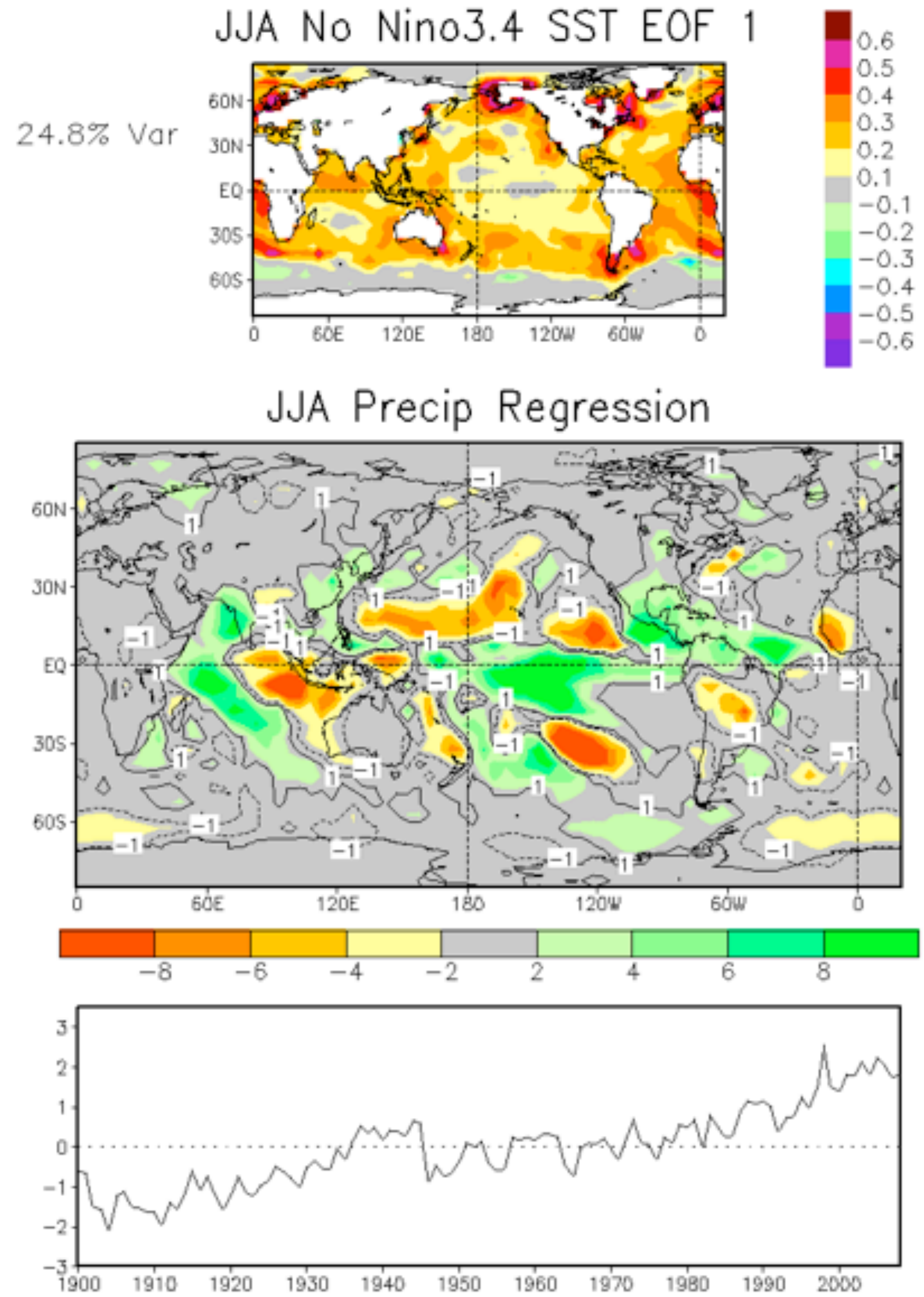
- Not really the same thing – need to do this using the 20th Century model runs
- Quite a few similarities!
  - Increases in tropical Indian and east Pacific Oceans
  - Subtropical drying
  - High latitude increases not seen in reconstruction – should look at reanalysis
- Some distinct differences
  - Australia – opposite sign
  - West Pacific increases in reconstruction not seen in models





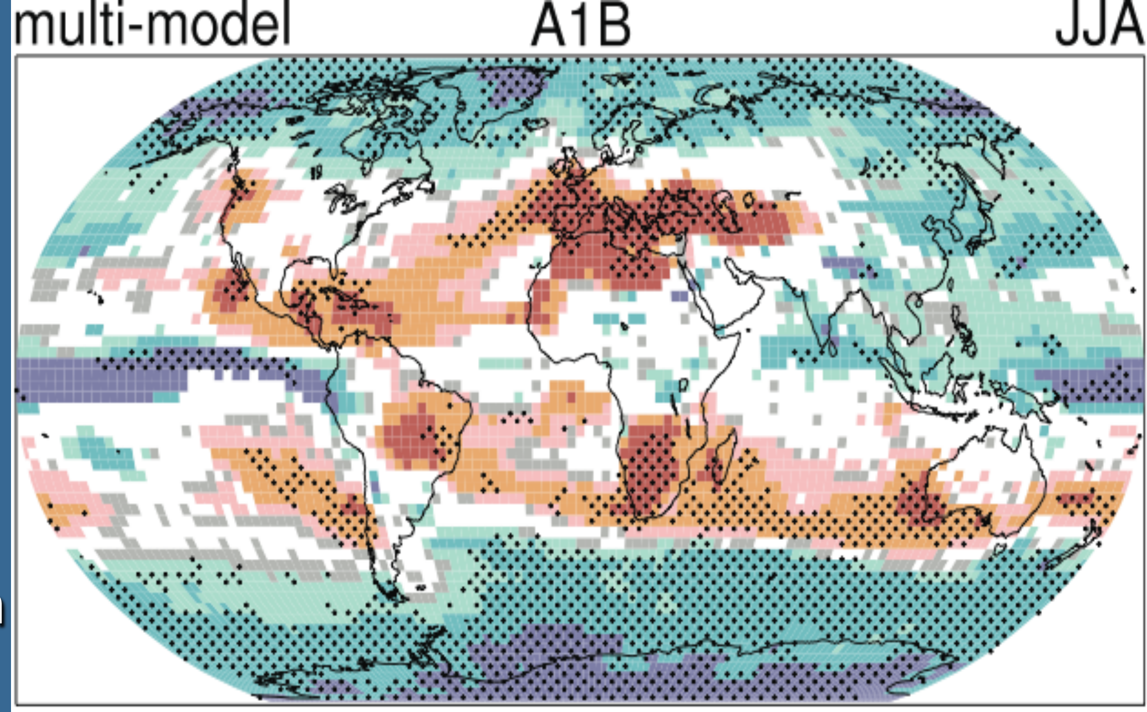
EOF Analysis of ENSO-Filtered SST and Associated Precipitation

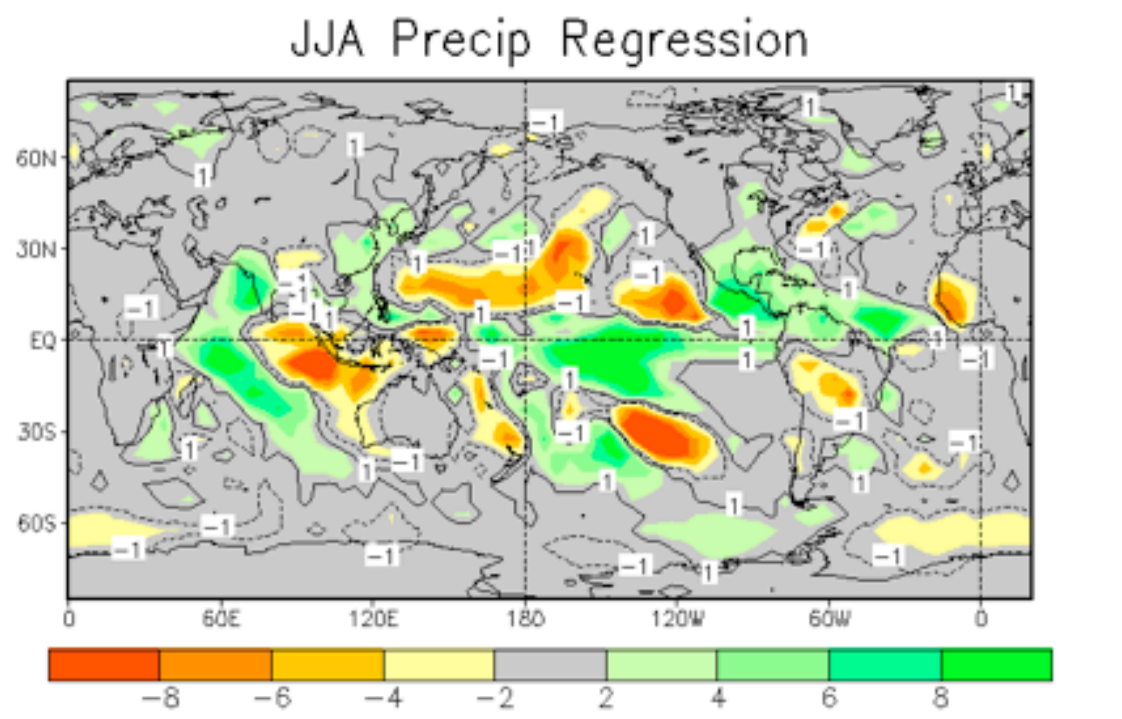
- SST JJA EOF 1:
  - Generally similar to DJF
- Precipitation:
  - How do these regressions relate to global warming signal?



20th vs. 21st Century JJA

- Some notable disagreements
  - Mediterranean/South African drying not seen in reconstruction
  - Similarly with SH dry axis from South America eastward to Australia
- Strong equatorial Pacific increases seen in both
- Not much high latitude signal in reconstruction – need to see what 20th Century reanalysis shows





- ***Global Averages*** – wide disparity among the available sources
  - Reconstruction is lowest, simulations are highest, reanalysis in between
  - 3.1 mm/day +/- 20%
  - None of the specific values is particularly believable
- ***Annual Cycle*** – Given the highly asymmetric distribution of land/ocean between the hemispheres, a small annual cycle in global mean precipitation is not unreasonable
  - 20^{th} Century reanalysis ranges from 3-3.2 mm/day; reconstruction, based on GPCP, exhibits similar range of variability but not as clearly tied to the seasonal cycle
- ***Trends*** – reconstruction, reanalysis and ensemble mean of AR4 simulations all exhibit positive trend
  - All three give hydrological cycle sensitivity (for 20^{th} Century) lower than AR4 projections; greater than 0; within range of model suite
  - Some similarity in patterns among models, reconstruction, reanalysis
- ***Modes of Variability*** – Both reanalysis and reconstruction appear to capture main signals
  - Might be possible to create a combined product that is superior to either alone
  - Didn’t try to evaluate models

Conclusions

- Validating model simulations/hindcasts against observed precipitation crucial to enhance confidence in predictions/ projections
  - Better "observations" necessary – still not certain what is really happening
  - Standard protocol/set of metrics desirable
- "Modern" precipitation data sets (GPCP, CMAP) still useful
  - Shortcomings remain – resolution, estimates of uncertainty
  - Development continues
- 20th Century precipitation reconstruction and reanalysis available
  - Different methods give sufficiently similar results to indicate some validity
  - Useful for testing global models