Historical Reconstruction of Precipitation

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Reconstructions: Analyses from sparsely-sampled data

- Two Methods
  - 1: Using spatial covariance modes, find mode weights using gauge data
  - 2: Using covariance with SLP and SST
  - Statistics from modern (well-sampled) analyses

- Combining Methods
  - Goal to develop improved historical (pre 1979) oceanic precipitation analysis

Method 1: Using Modes

- Space points, x, and times, t
- Data: Anomalies, a, minus a first guess
- Reconstruction: First guess + weighted sum of the modes

$$D(x,t) = a(x,t) - \mu(x,t)$$

$$\mu = 1^{st}\ guess$$

$$A(x,t) = \mu(x,t) + \sum_{m=1}^{M} \psi_m(x)\, w_m(t)$$

$$\psi_m = mode\ m\ spatial\ \ pattern$$

System of Equations For Weights

- Equations to minimize error
  - Weights affected by data and sampling
  - System of equations solved each time for the set of weights

$$\sum_{m=1}^{M}\left[w_m(t) \sum_{x=1}^{K} \psi_m(x)\psi_n(x)\delta_x \cos\phi_x \right]$$

$$= \sum_{x=1}^{K} D(x,t)\psi_n(x)\delta_x \cos\phi_x, \quad for\ n = 1,2,\cdots,M$$

- Note: with complete data and orthogonal modes, computing the weights is simplified
  - EOF (or PC) time series

$$w_n(t) = \sum_{x=1}^{K}\left[D(x,t)\psi_n(x)\cos\phi_x \right]$$

Method 2: Canonical Correlation Analysis (CCA)

- Correlations between fields of predictors (SST & SLP) and the field of precipitation
- Normalized anomalies of all fields; precipitation normalization later removed
- Annual averages analyzed
- Satellite period (since 1979) used to develop CCA relationships

Cross Validation

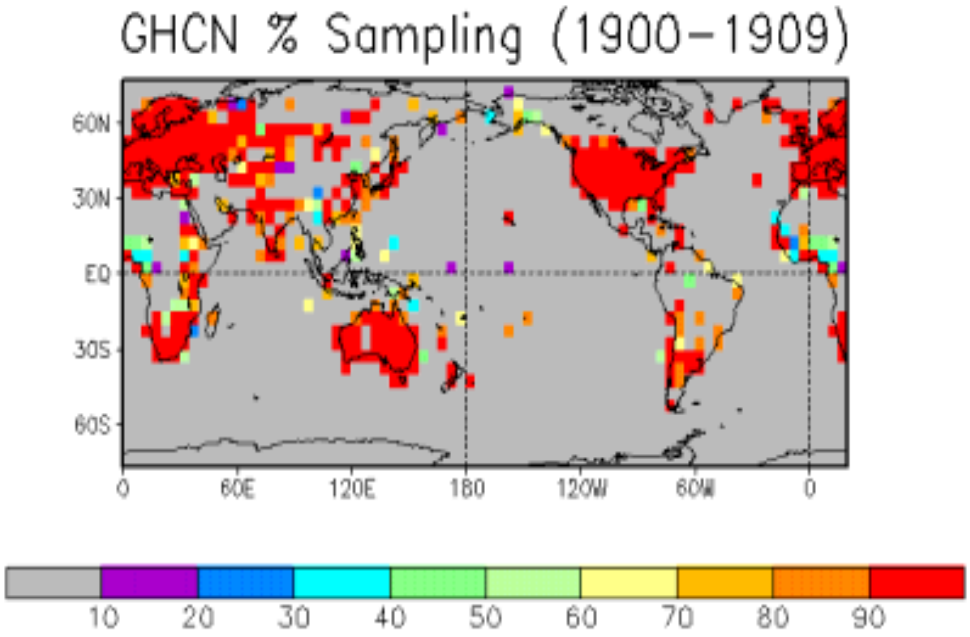
- Simulate historical analyses
  - Modes exclude data from analysis time
  - Historical sampling grid used
- Reconstruct using simulated historical conditions and compare to full data
- Used for tuning and finding its errors

Precipitation Gauge Data

- Different sets of gauges with different gauge adjustments
  - Monthly values, tested several gauge records
    - GHCN (begins 1900)
    - GPCC (begins 1951)
    - CPC (begins 1948)
- Gauge data-set differences are slight for most gauges
- For analysis, used GHCN for its longer record

Decadal Sampling (1900-1909)

- % months sampled in 5-degree areas
- Industrial population centers well sampled
- Oceans poorly sampled by island stations.



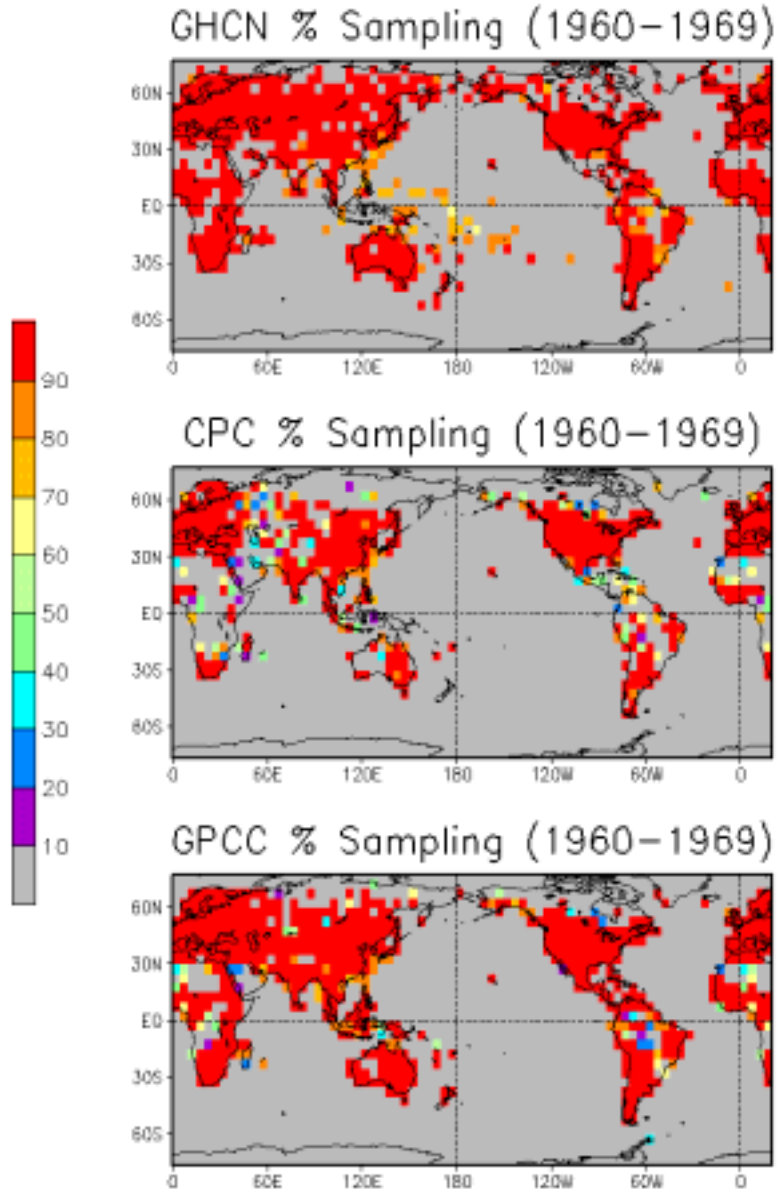
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Decadal Sampling Comparisons (1960-1969)

- Similar sampling for all
  - Most land areas sampled
  - CPC most sparse
- GHCN retains more island stations
  - Better ocean sampling and longer record
  - Use GHCN for analysis



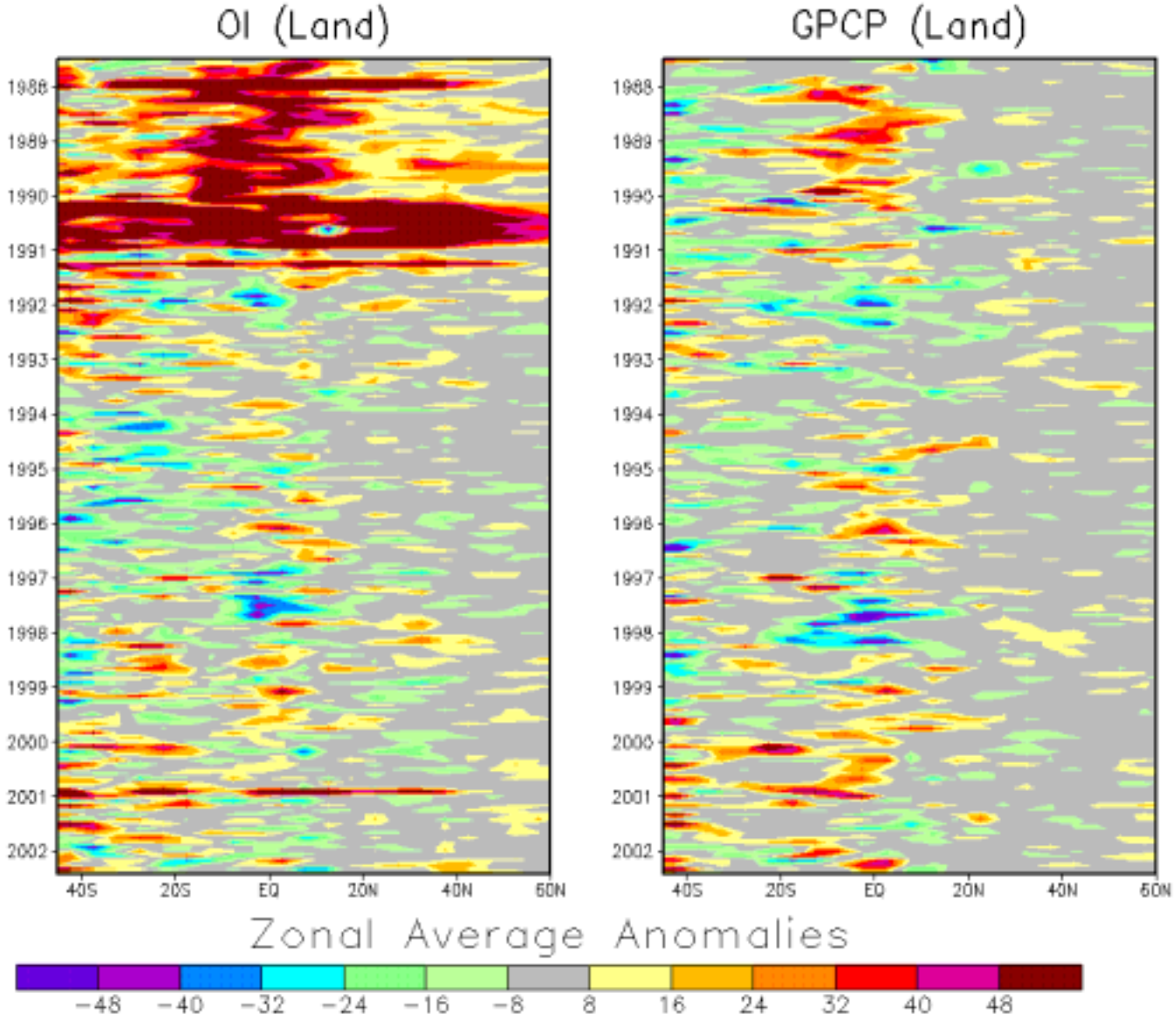
Satellite-Based Monthly Analyses

- Most combine satellite and in situ precipitation
  - GPCP uses many satellites, to maximize inputs
  - CAMS/OPI and CMAP use fewer inputs

- OI: one satellite type and atmospheric reanalysis
  - One satellite type for low latitudes, reanalysis for high latitudes, and weighted blending in between
  - Designed to give a consistent analysis

Zonal Average Anomalies: Land only

- MW satellite problems before 1992: base climatology on 1992-2001



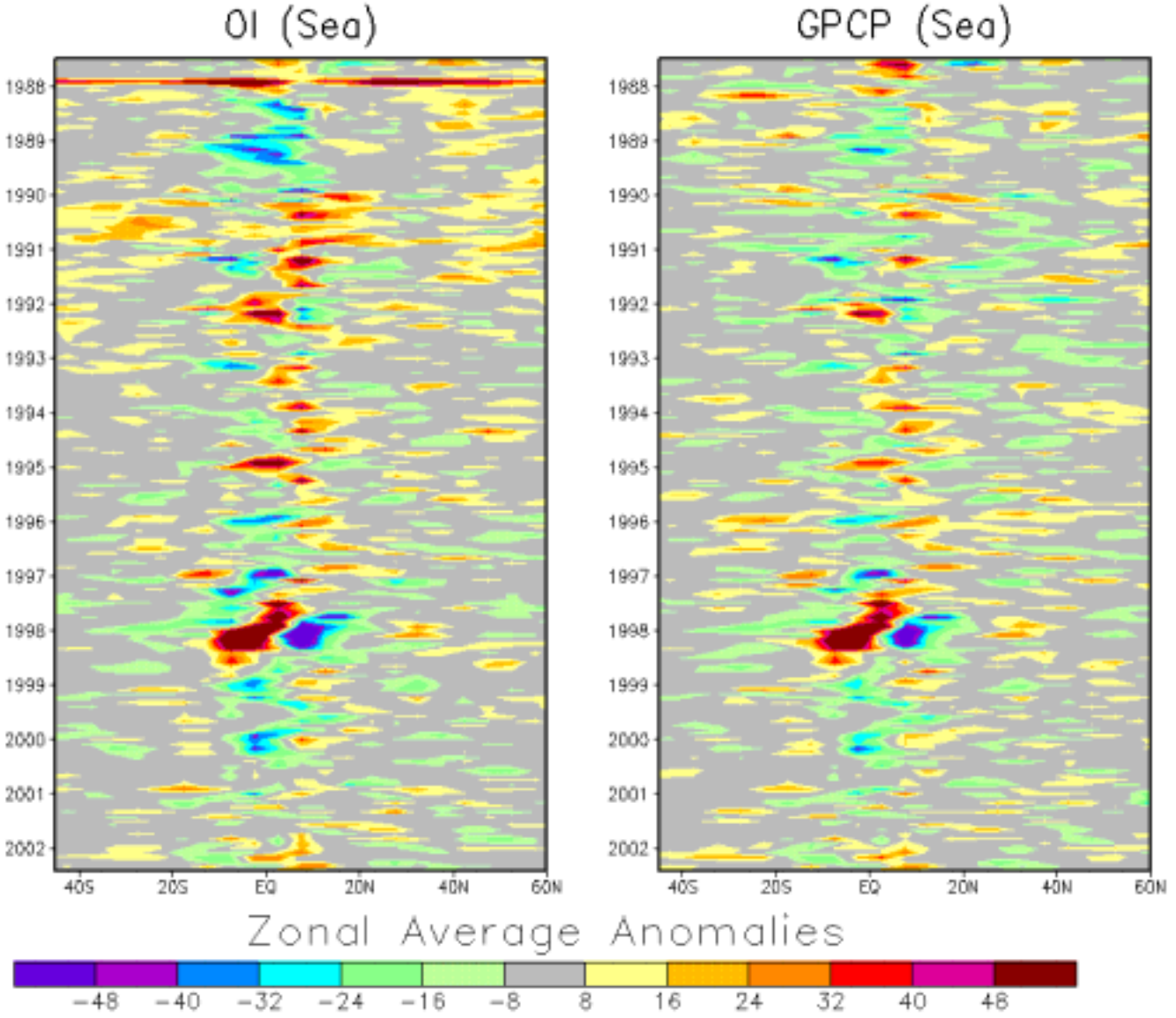
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Zonal Average Anomalies: Sea only

- Over oceans problems less severe. Missing month in MW: December 1987



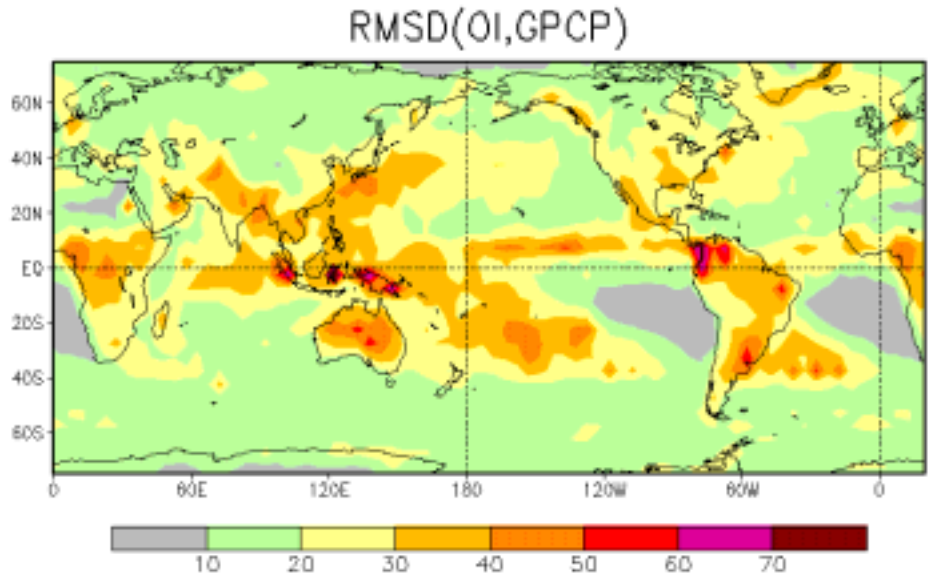
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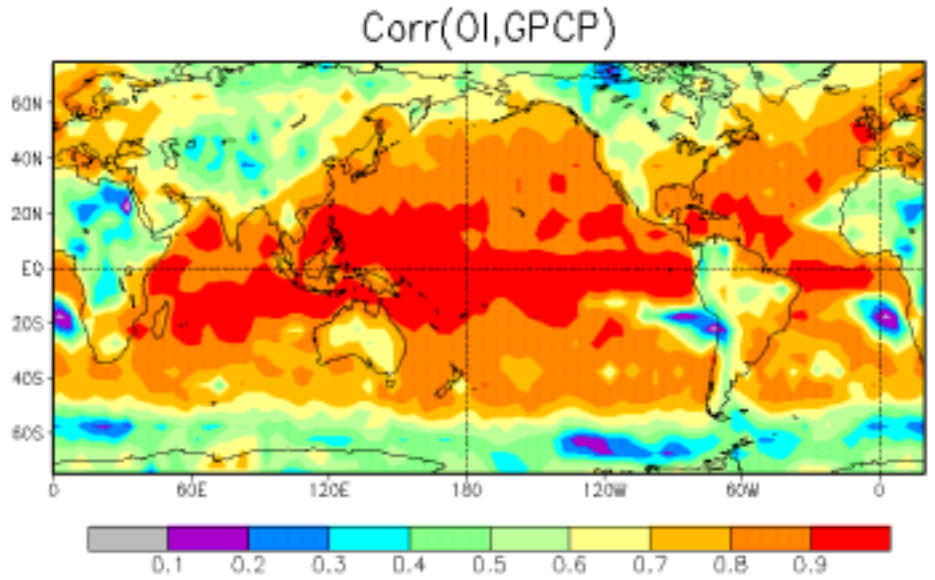
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Comparisons: OI and GPCP Anomalies (1992-2001)

- Over oceans, OI and GPCP close
- Over land comparisons are not as good
  - GPCP uses gauges





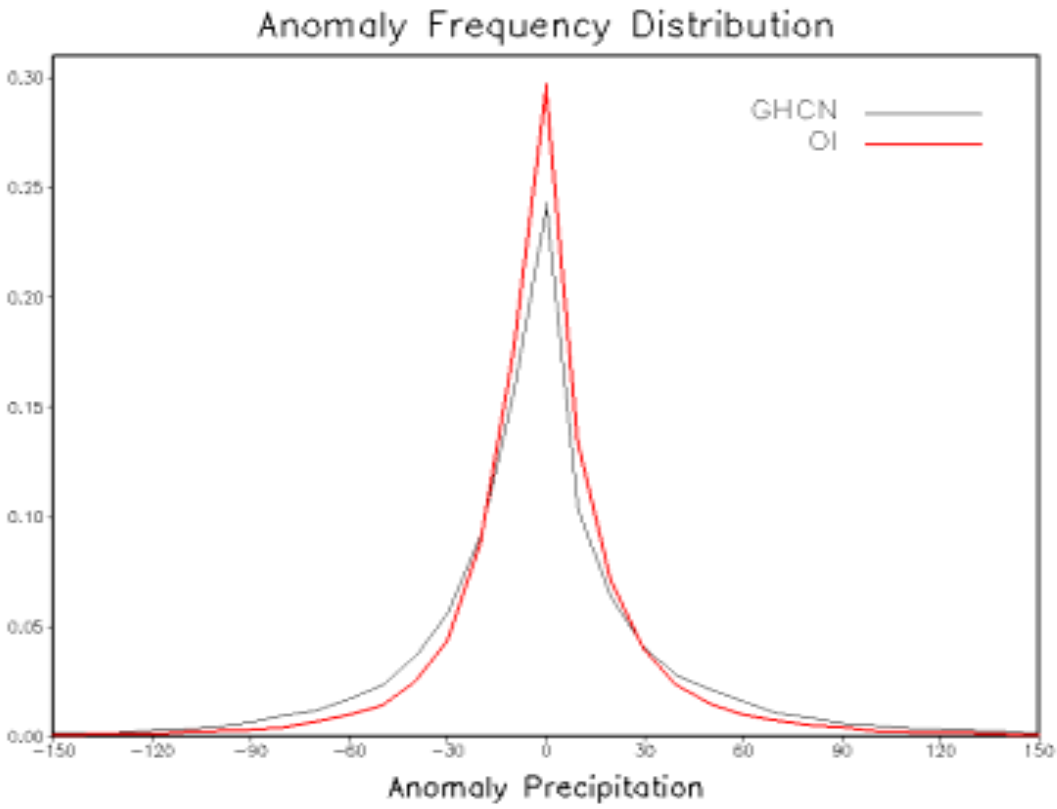
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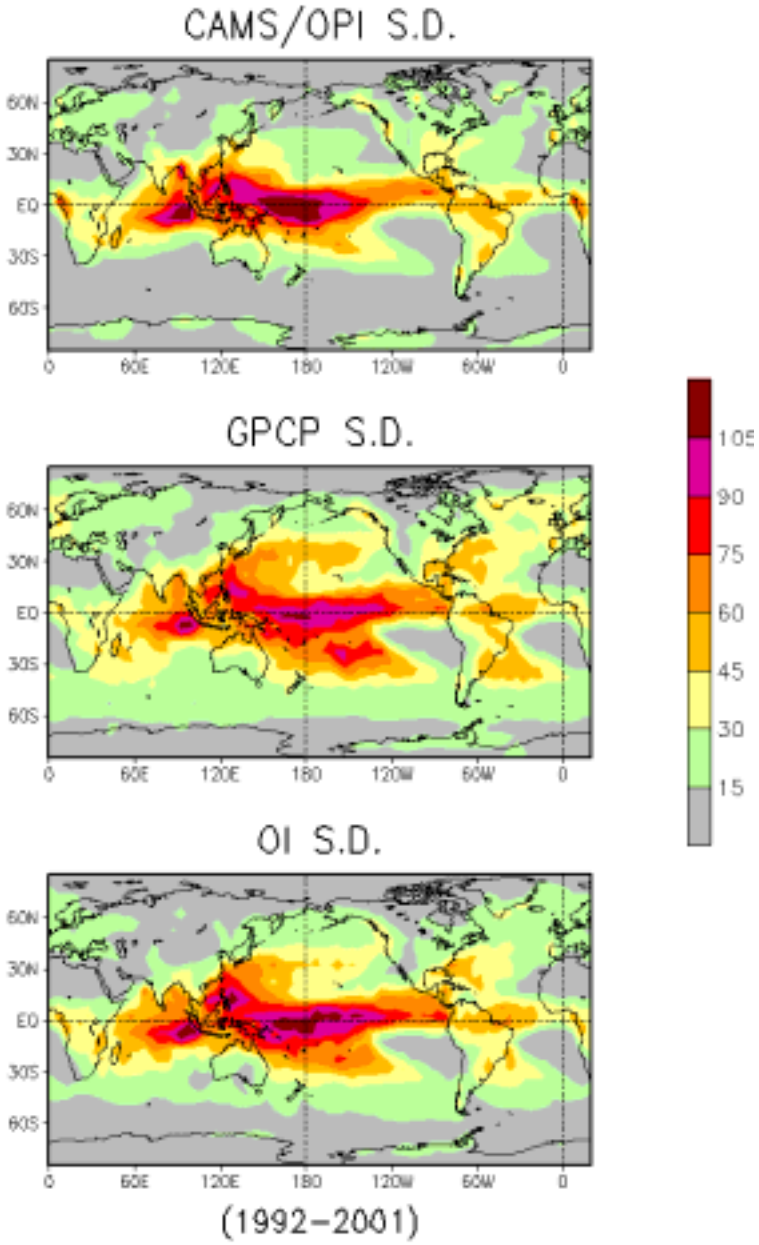
Precipitation Anomaly Distribution

- Precipitation not symmetric
  - No negatives
  - Reconstruction best with symmetric data
- Precipitation monthly anomalies are *nearly* symmetric
  - Anomalies from same areas & times for gauges (GHCN) and OI



Satellite-Base Data S.D.

- Upper panel: merged land gauges and IR satellite ocean values
  - Oceanic extra tropics damped
- Middle panel: merged land gauges and MW satellites, ocean IR and MW values
  - Changing inputs
- Lower panel: merged MW satellite and dynamic reanalysis at high latitudes
  - Consistent inputs, used for reconstruction



Precipitation Anomaly EOF Modes

- EOFs for reconstruction in 3 overlapping areas
  - Cross-validation to find best maximum number in each region (**bold**) and for screening critical value (0.05)
  - Maximum number limited by sampling and spatial scales
- Reconstructions merged for global analysis
- Test reconstruction using different gauge data sets

For each region's EOF (80ºS-20ºS, 30ºS-30ºN, and 20ºN-80ºN) the cumulative % variance explained by the given number of modes.

Number Modes	1	3	6	9	11	12	15
20ºN-80ºN	7.4	18.6	30.4	39.6	**44.7**	47.1	53.2
30ºS-30ºN	17.0	30.2	40.2	47.1	50.9	**52.4**	56.8
80ºS-20ºS	9.6	23.1	**36.1**	45.4	50.7	53.0	58.9

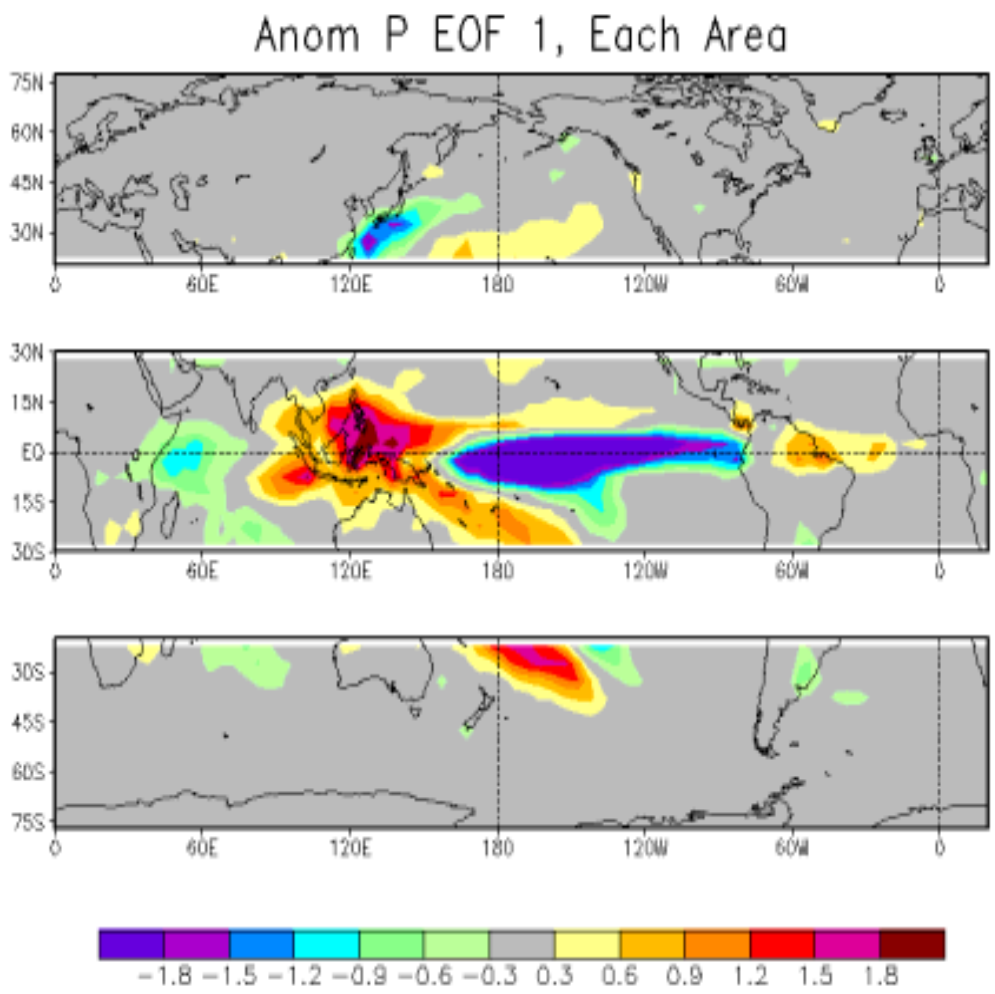
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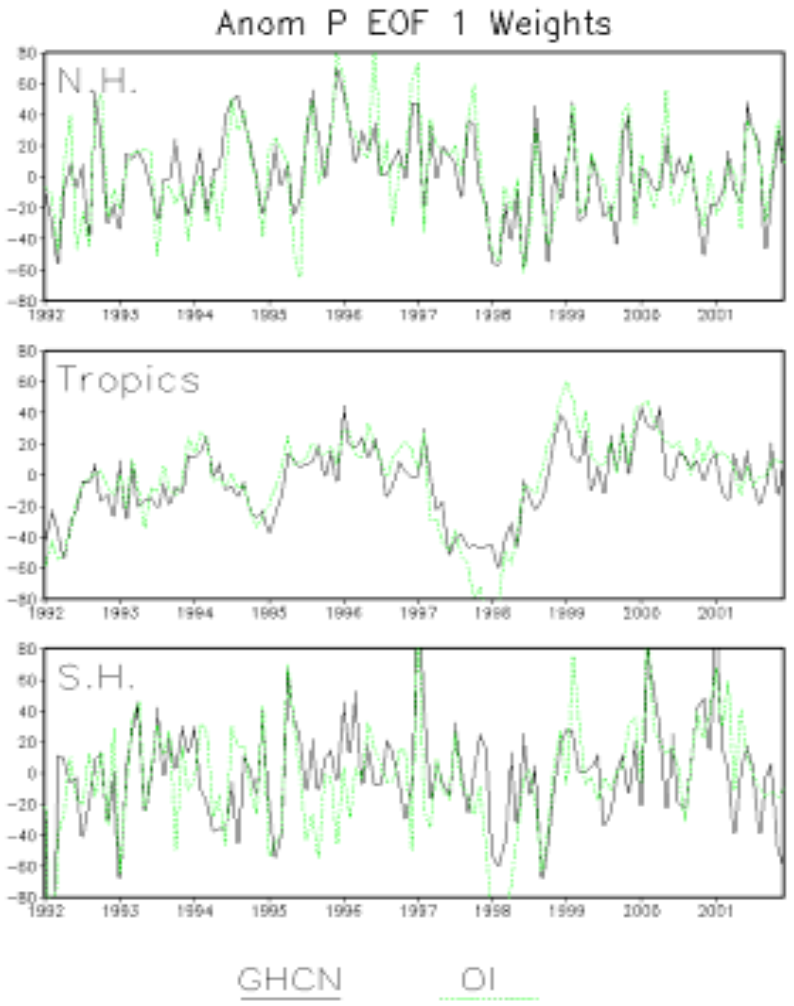
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Mode 1 EOFs and Weights

OI sampling at GHCN
Modes based on 1992-2001 anomalies

Correlations	
NH	0.83
TR	0.89
SH	0.70





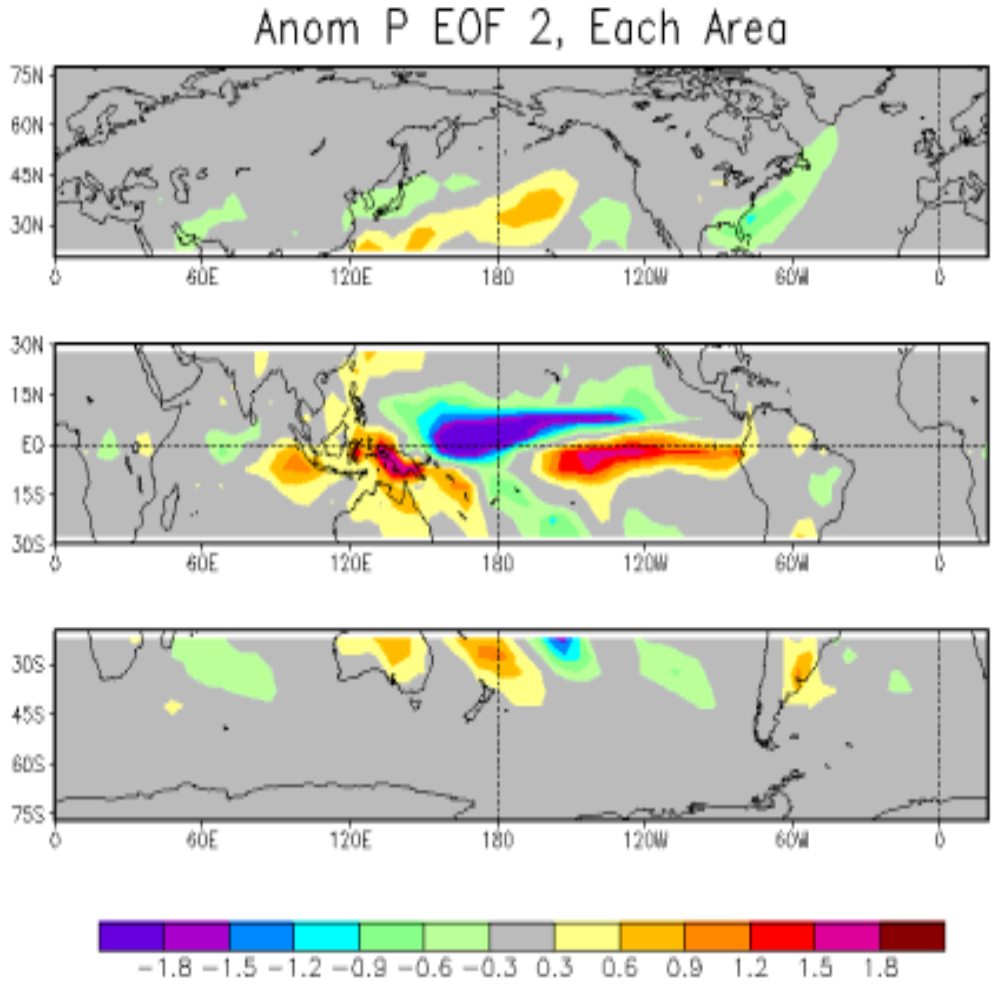
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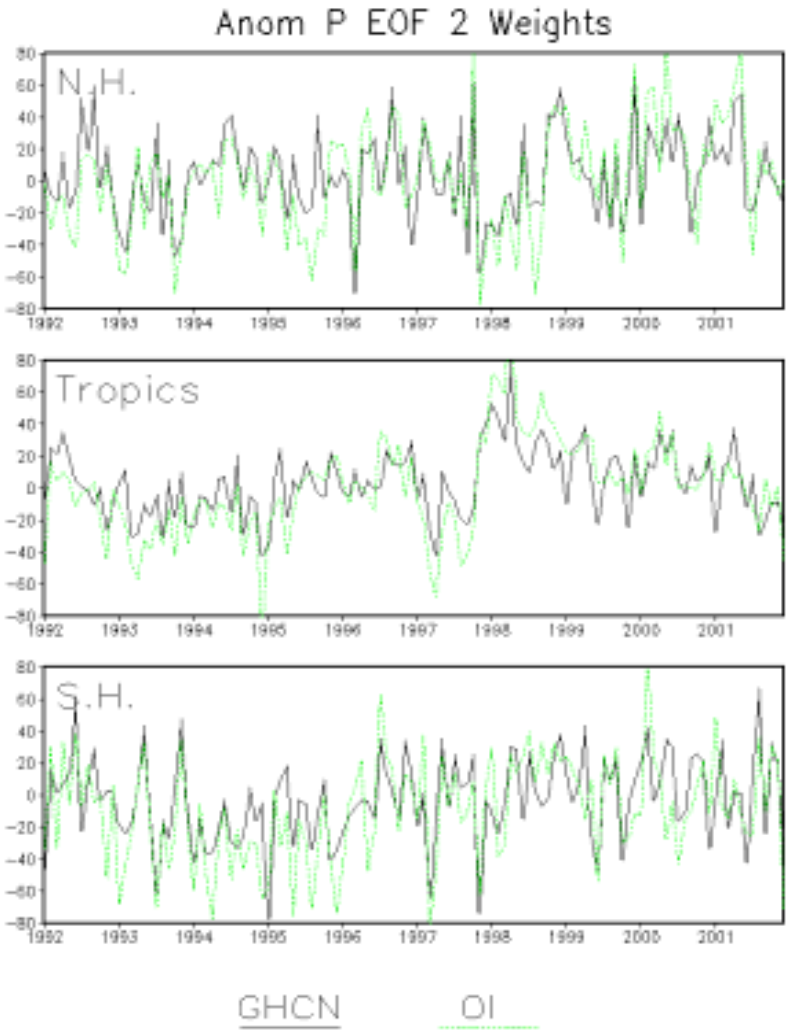
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Mode 2 EOFs and Weights

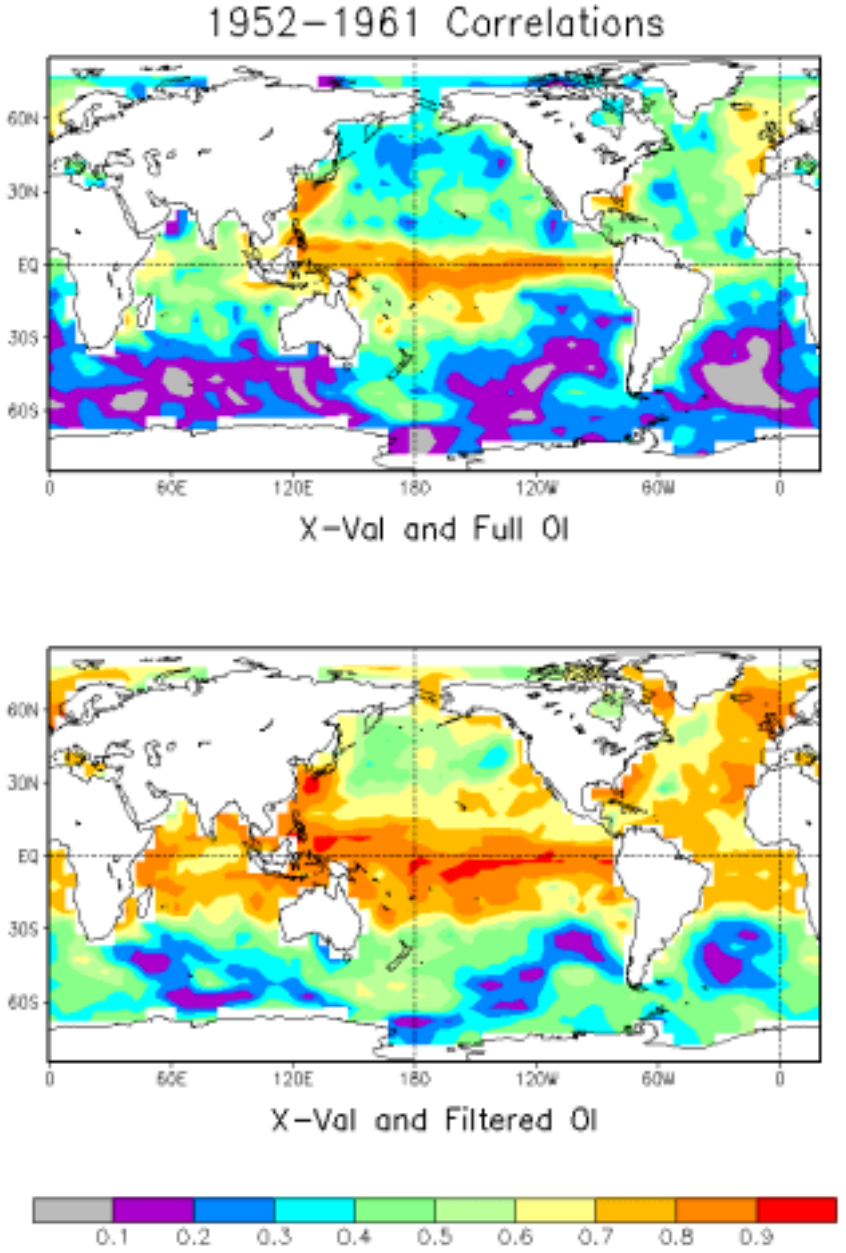
Correlations	
NH	0.77
TR	0.83
SH	0.71





Cross-validation correlations using OI data

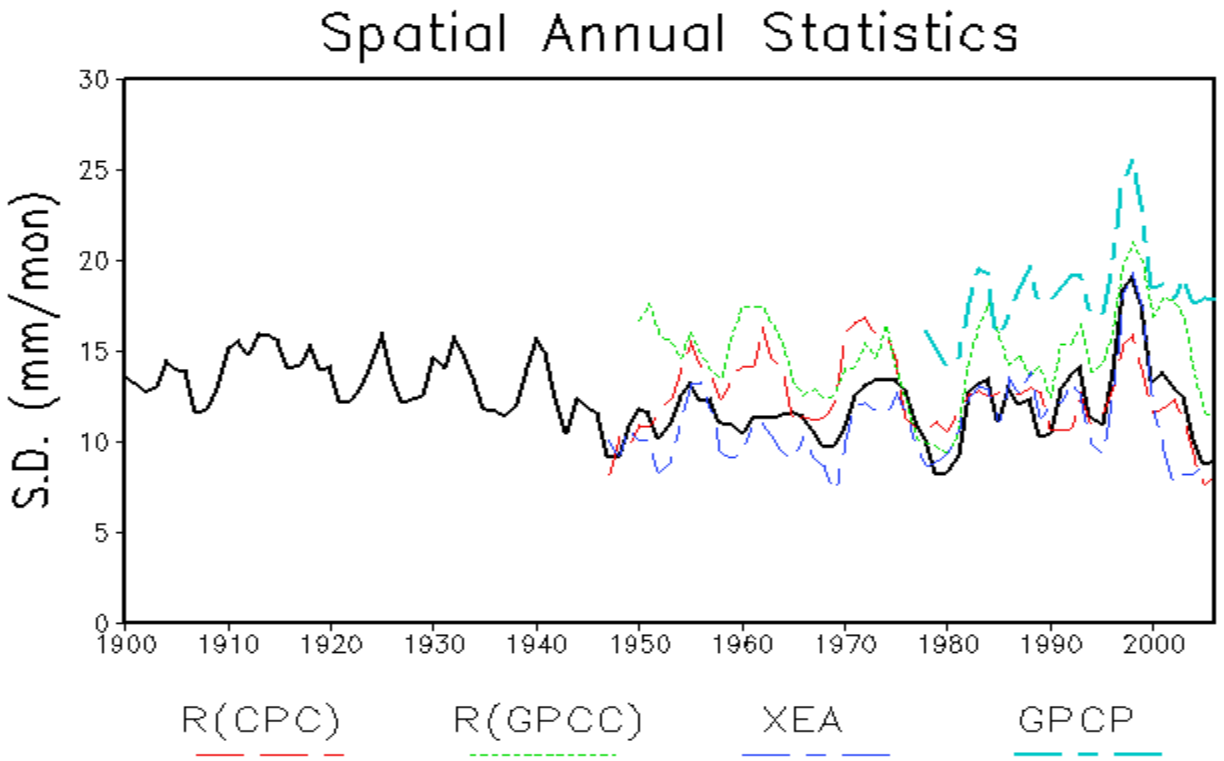
- 1952-1961 sampling grid
  - For other decades results are similar
  - Ocean validation only shown
- Upper panel: anomaly correlation with full base data
- Lower panel: anomaly correlation with filtered base data
  - Filtered using the 1st 15 EOF modes in each region (about 55% variance)
  - Keeps most climate-scale variations
- Skill in tropics and N.H.



Global Spatial S.D.

- S.D. of annual averages
- 4 reconstructions & GPCP
  - R(CPC) & R(GPCC) use same methods, different gauge data
  - XEA recon uses different methods and data
  - GPCP satellite and gauge data analysis

- Solid black line: R(GHCN)
- Satellite data give highest variance, shortest record
- R(GPCC) data yield consistently higher variance: data differences
- All recons give similar interannual variations



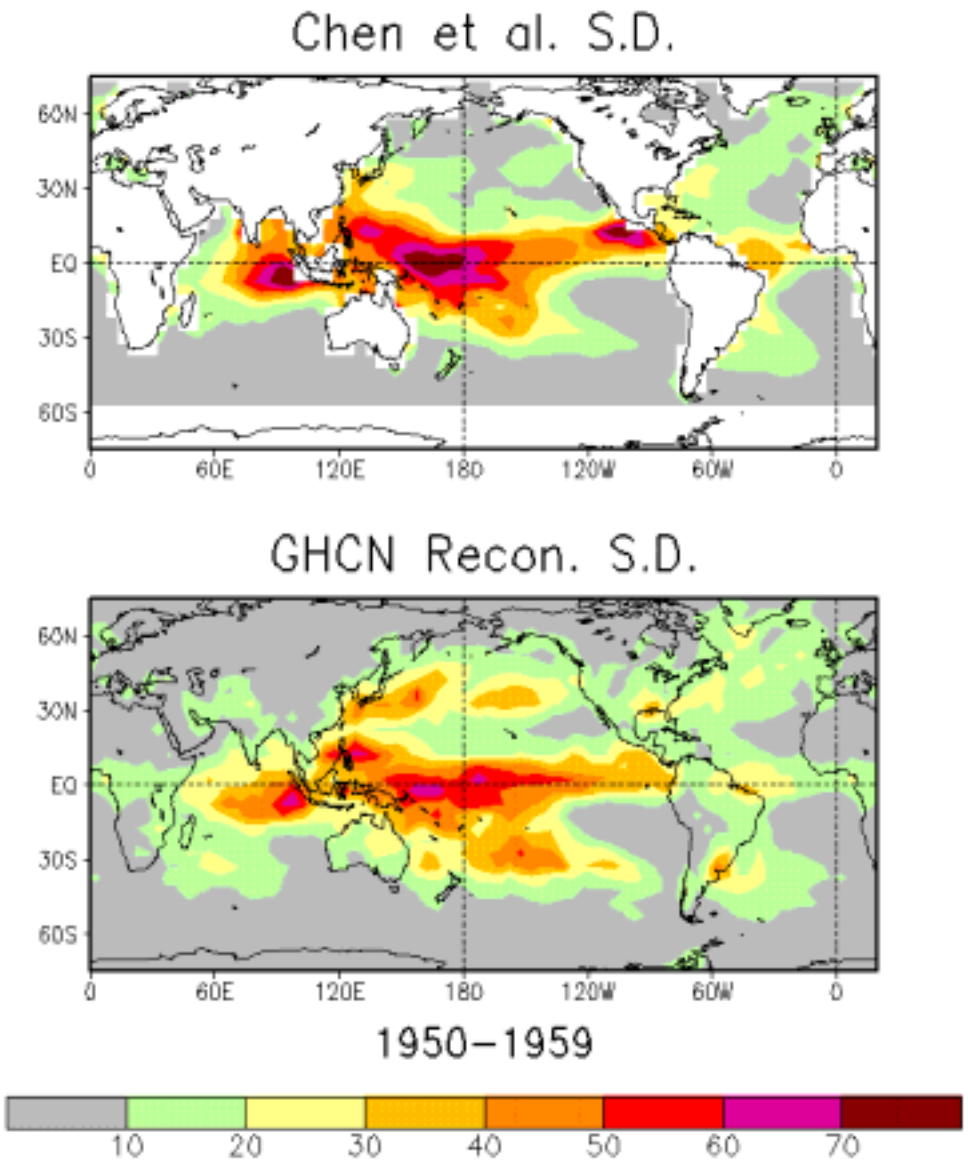
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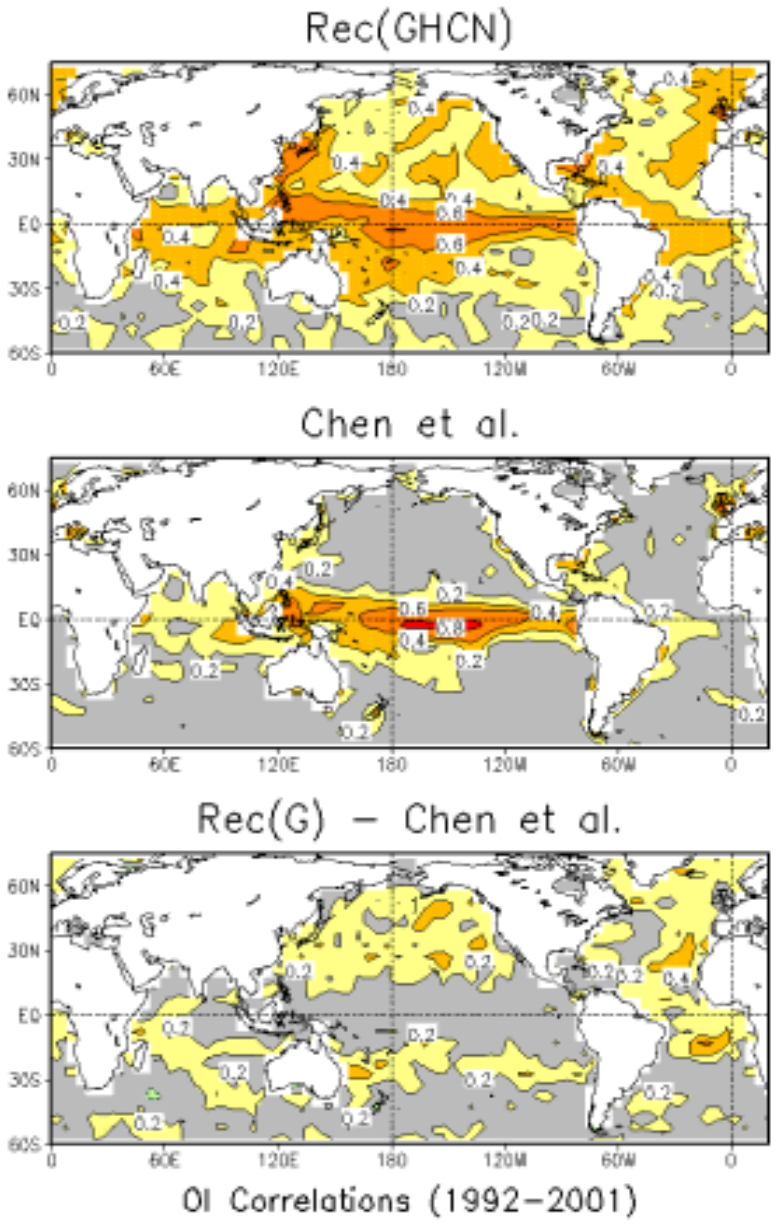
1950s Reconstruction S.D.

- Chen et al. (XEA) stronger in tropics, too weak in extra tropics
- New method resolves extra-tropics better



Anomaly Correlation With Base OI Data

- Upper panel: new GHCN recon. correlation
  - Highest in tropics and some N.H. regions
- Middle panel: Chen et al. correlation
  - High in tropical Pacific, not as good in most other regions
- Lower panel: difference
  - Potential skill improvement for large regions

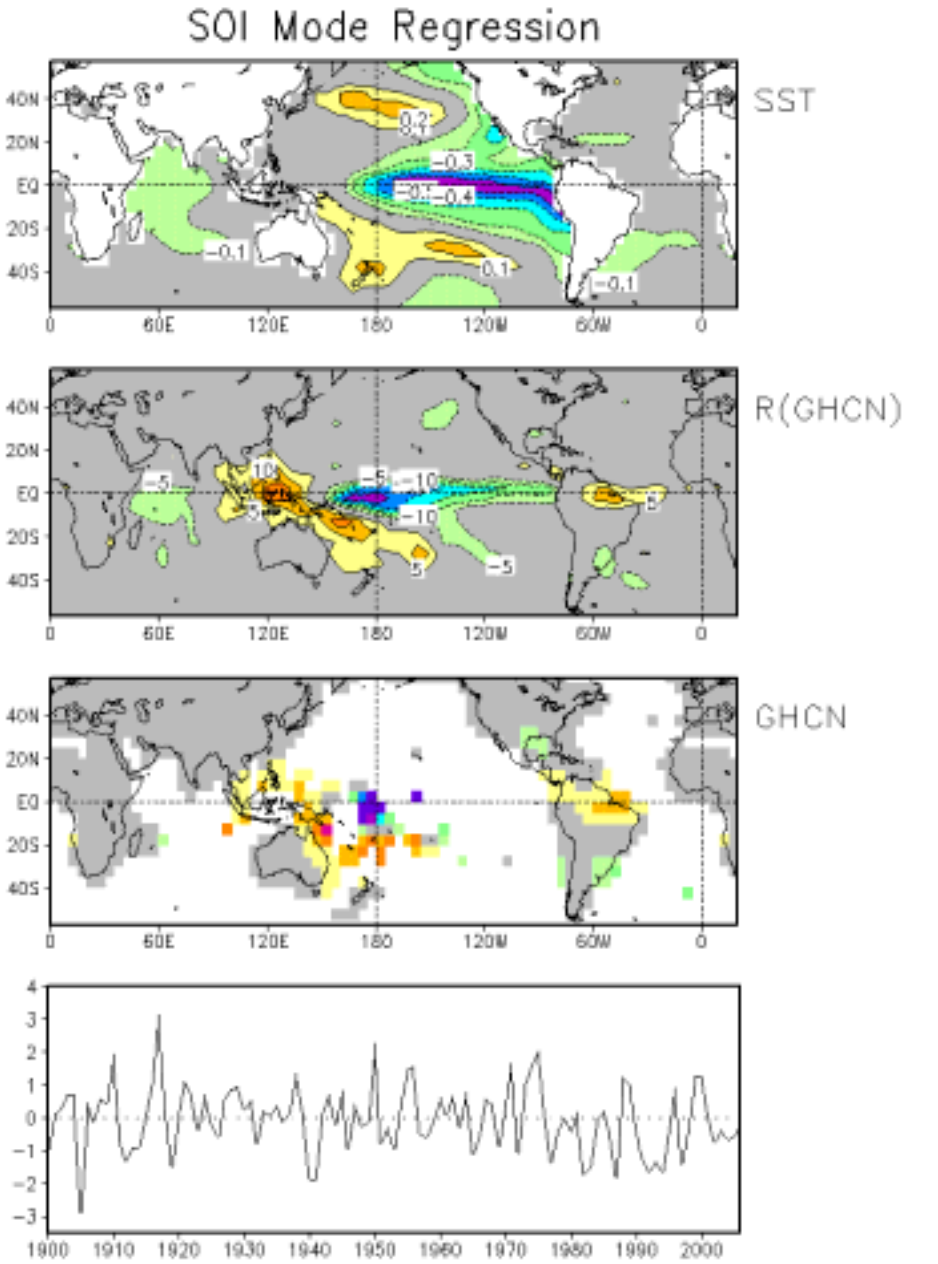


Climate Mode Regressions

- Climate modes used to monitor and predict climate anomalies
- Modes usually based on anomalies of SLP or SST
- Regressions of several modes with reconstruction values are shown

SOI Mode

- Regressions against normalized SOI index (lower panel)
  - Annual averages for all
- Upper panel: Reconstructed SST anomalies
  - Typical ENSO SST anomaly patterns
- 2nd panel: Reconstructed precipitation anomalies
  - Pattern similar to that obtained from satellite data
- 3rd panel: GHCN precipitation gauge data
  - Shading the same as in 2nd panel
  - Data and reconstruction consistent



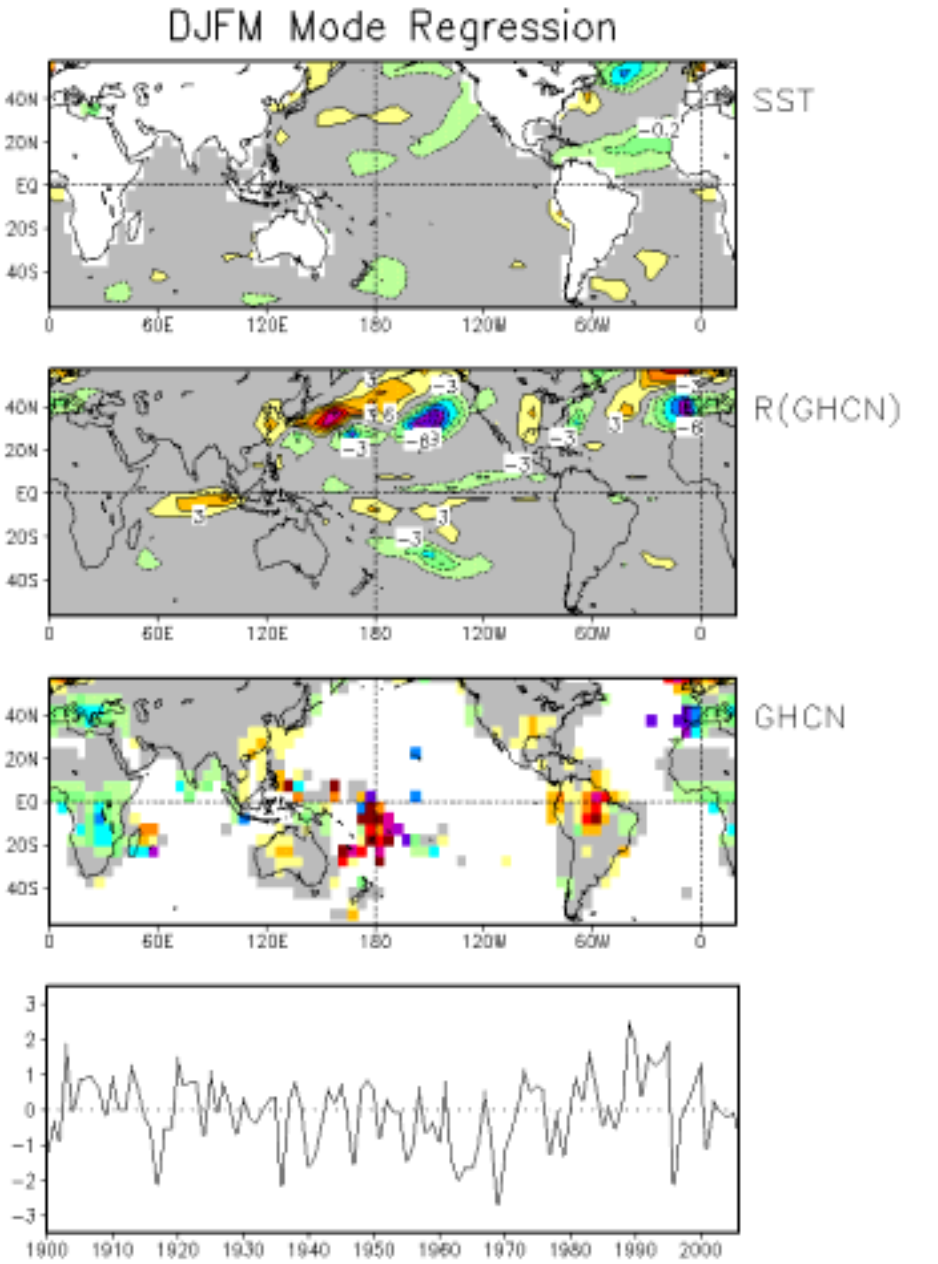
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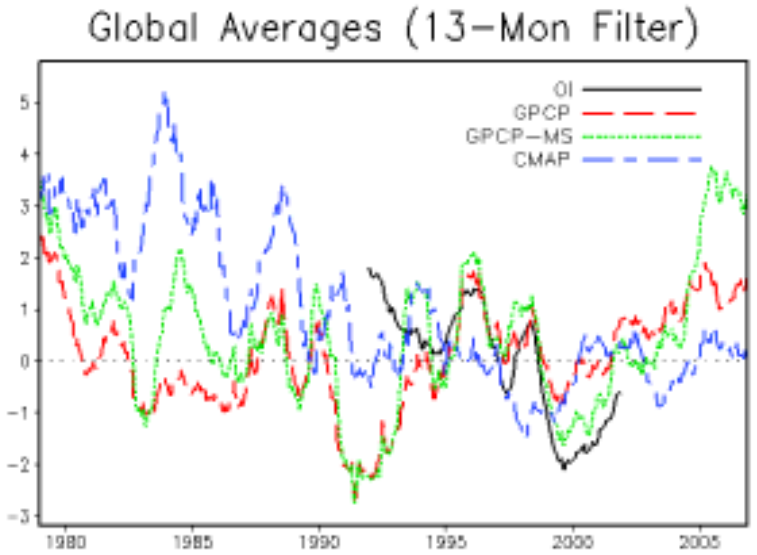
NAO Regression

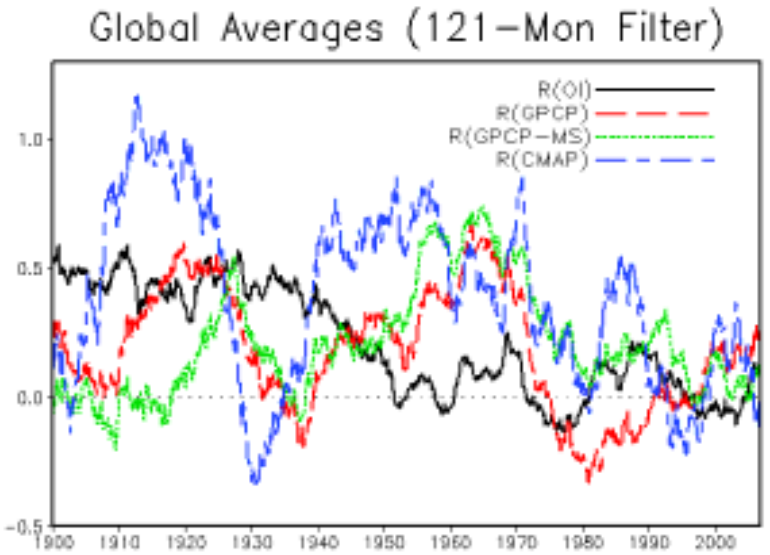
- Regression against normalized NAO index
  - All averaged Dec-Mar
- Reconstruction SST anomaly strongest in Atlantic
- Oceanic reconstructed P anomaly
  - Strong in Atlantic and Pacific
  - Variations extend to tropics
- Oceanic data generally consistent
  - Data anomalies stronger
  - Data alone not sufficient to show oceanic climate patterns



Global Averages

- Upper panel: satellite-based analyses
- Lower panel: Reconstructions using GHCN gauges and the indicated base data for modes
- Large differences in reconstruction global averages
  - Some differences from different length of OI and other base analyses
  - Models suggest that global warming should increase precipitation
  - May need a first guess for the reconstruction to better resolve these variations





Summary of Reconstruction by Fitting Gauge Data to Modes

- Much of the climate-scale variance can be reconstructed from sparse irregular historical sampling
  - Dense modern data are needed to define spatial functions
  - Testing is needed to see how much sampling is needed

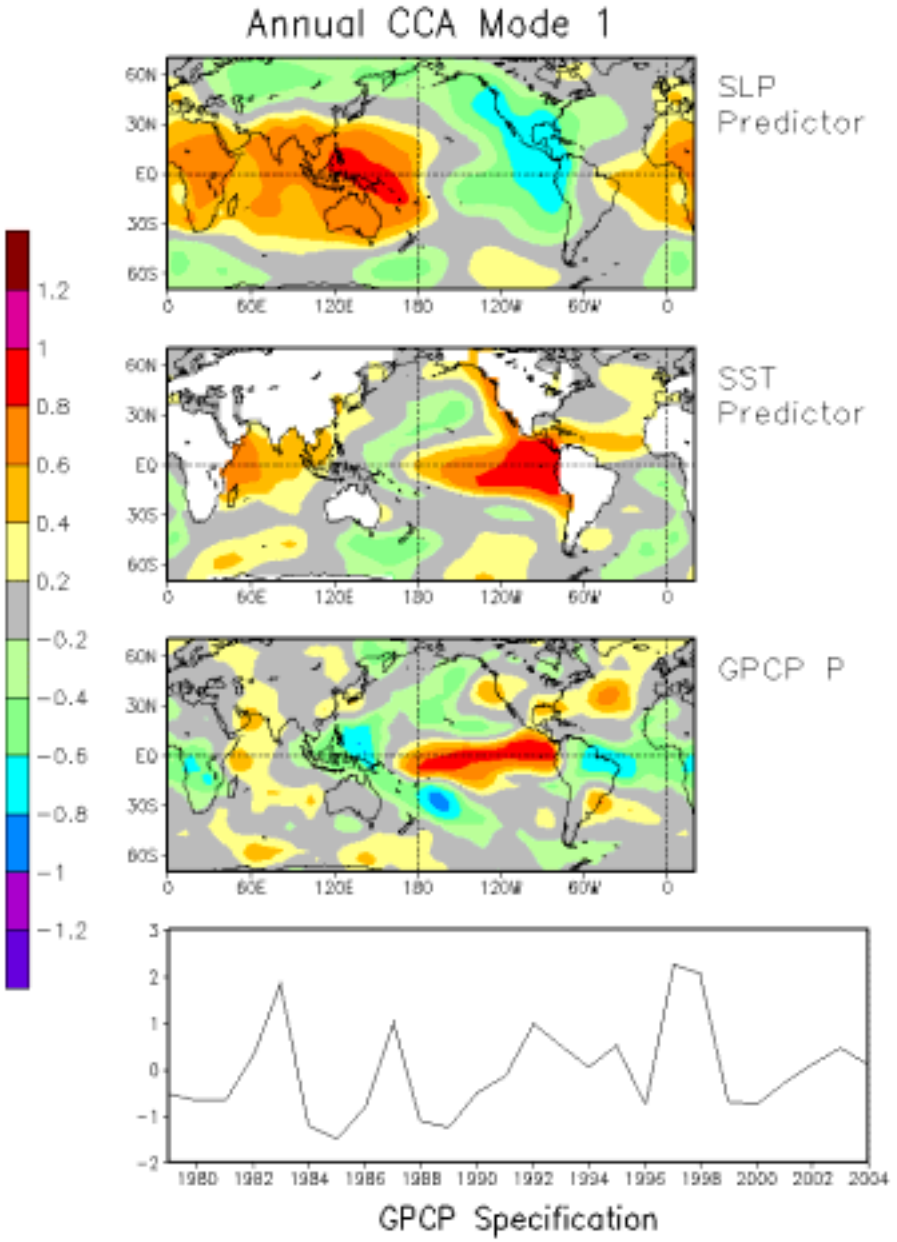
- Global or multi-decadal averages may not be resolved as well

CCA Precipitation Reconstruction

- Predictors: Annual averages of SST & SLP normalized anomalies
  - SST from NOAA gridded analysis
  - SLP from Hadley Centre analysis
- Analyze annual average precipitation
  - Training precipitation from GPCP (longer record than OI)

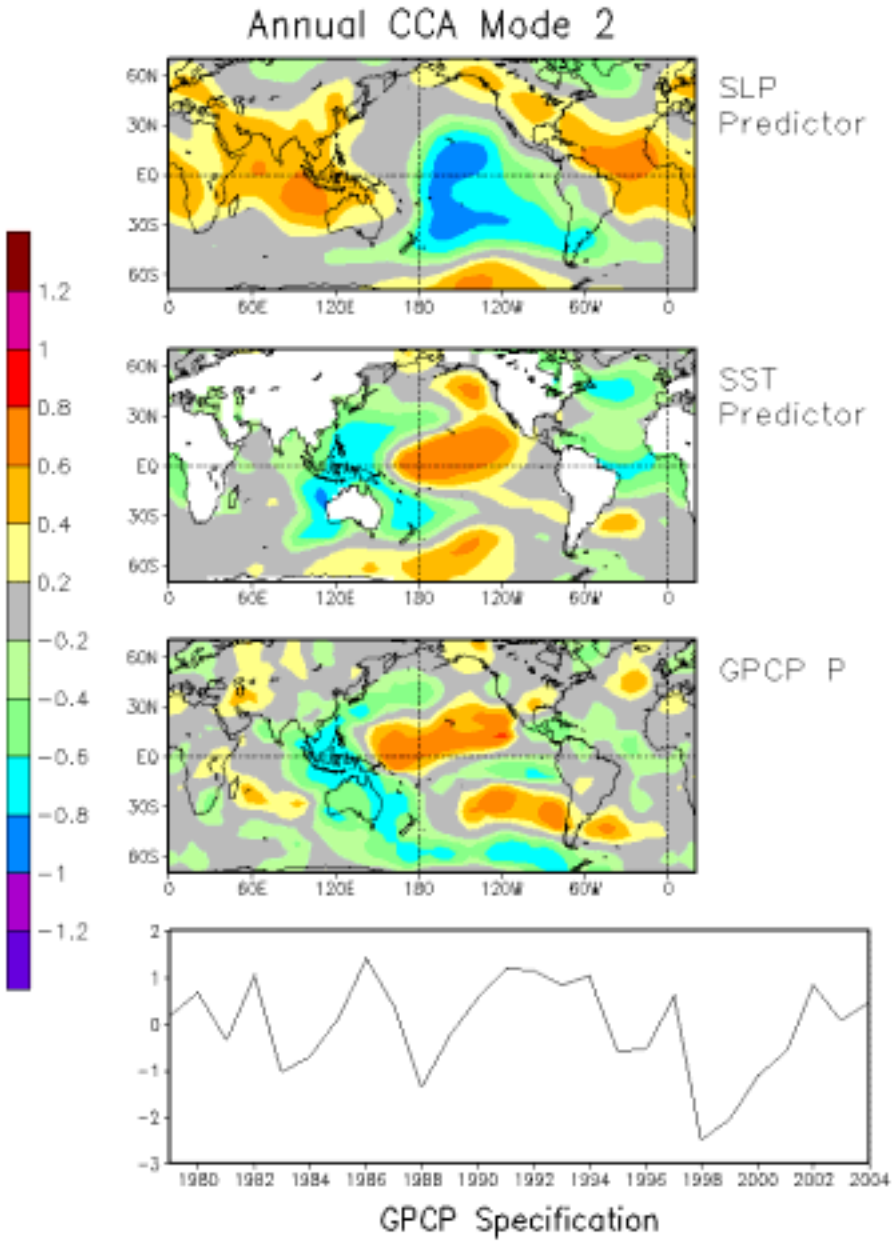
Annual-mean ENSO CCA mode

- CCA decomposes fields into modes
- 1979-2004 annual averages for base data
- ENSO is the dominant mode



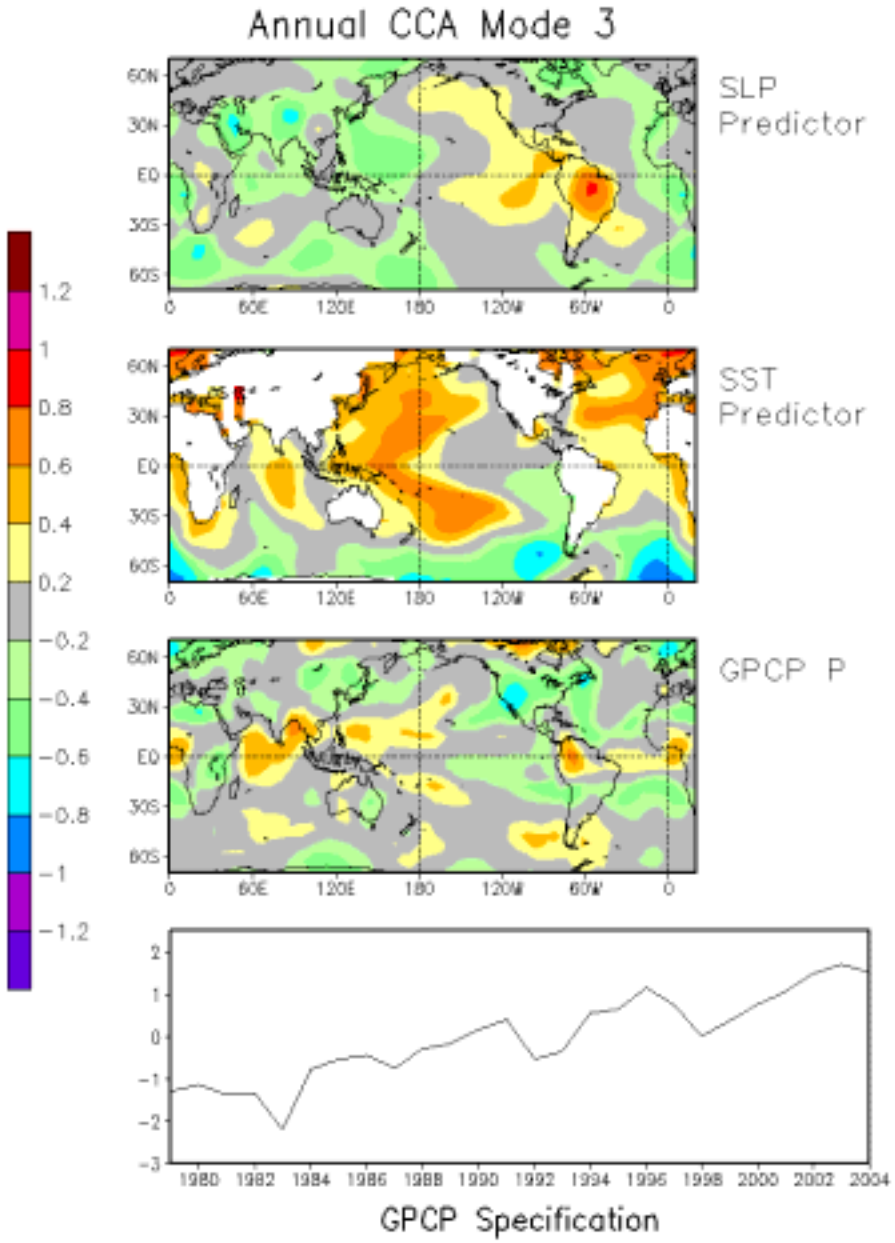
Secondary ENSO mode

- Mode modifies the ENSO-related precipitation
- 7 CCA modes used for analysis



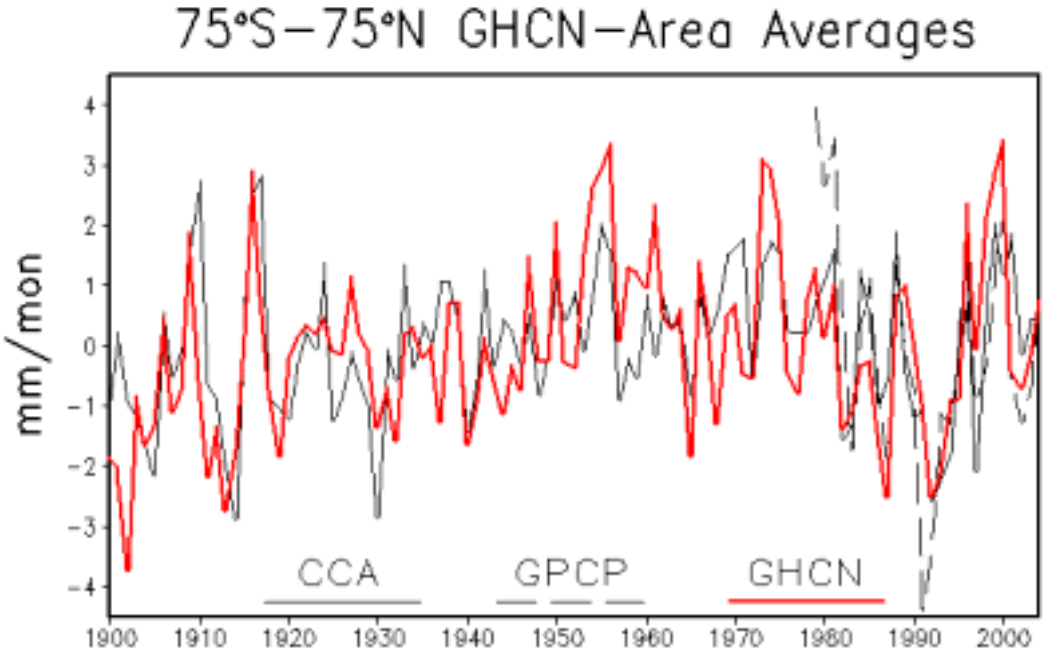
Multi-decadal mode

- SLP increasing over eastern Pacific & South America, decreasing over south Asia & western Pacific
- SST increasing over most regions, with decreases in Southern Ocean
- Precip increasing
  - Tropical Indian, western Pacific, parts of S. America across to western Africa
- Precip decreasing
  - East Africa, East Asia, Australia, N. America, northern Europe



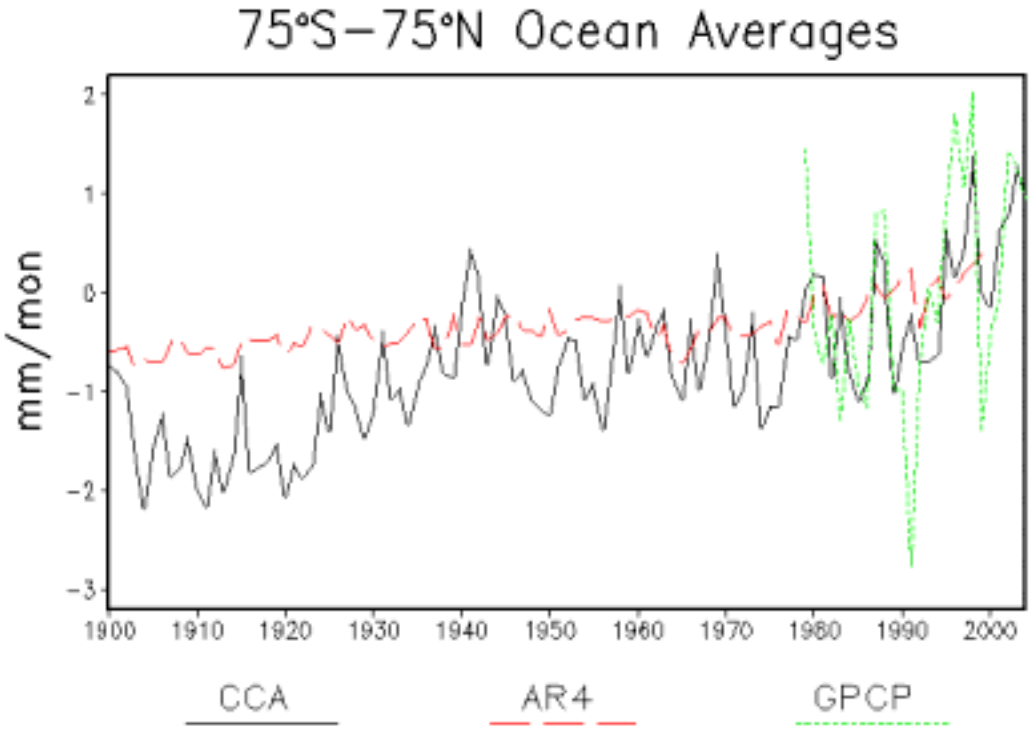
Near-Global Averages: Land

- Average at gauge locations
  - GHCN gauges, thick red line
- CCA resolves most large-scale multi-decadal variations
  - Gauges in GPCP training data since 1979
  - No gauge information in historical CCA
  - Correlation CCA and GHCN = 0.6



Near-Global Averages: Oceans

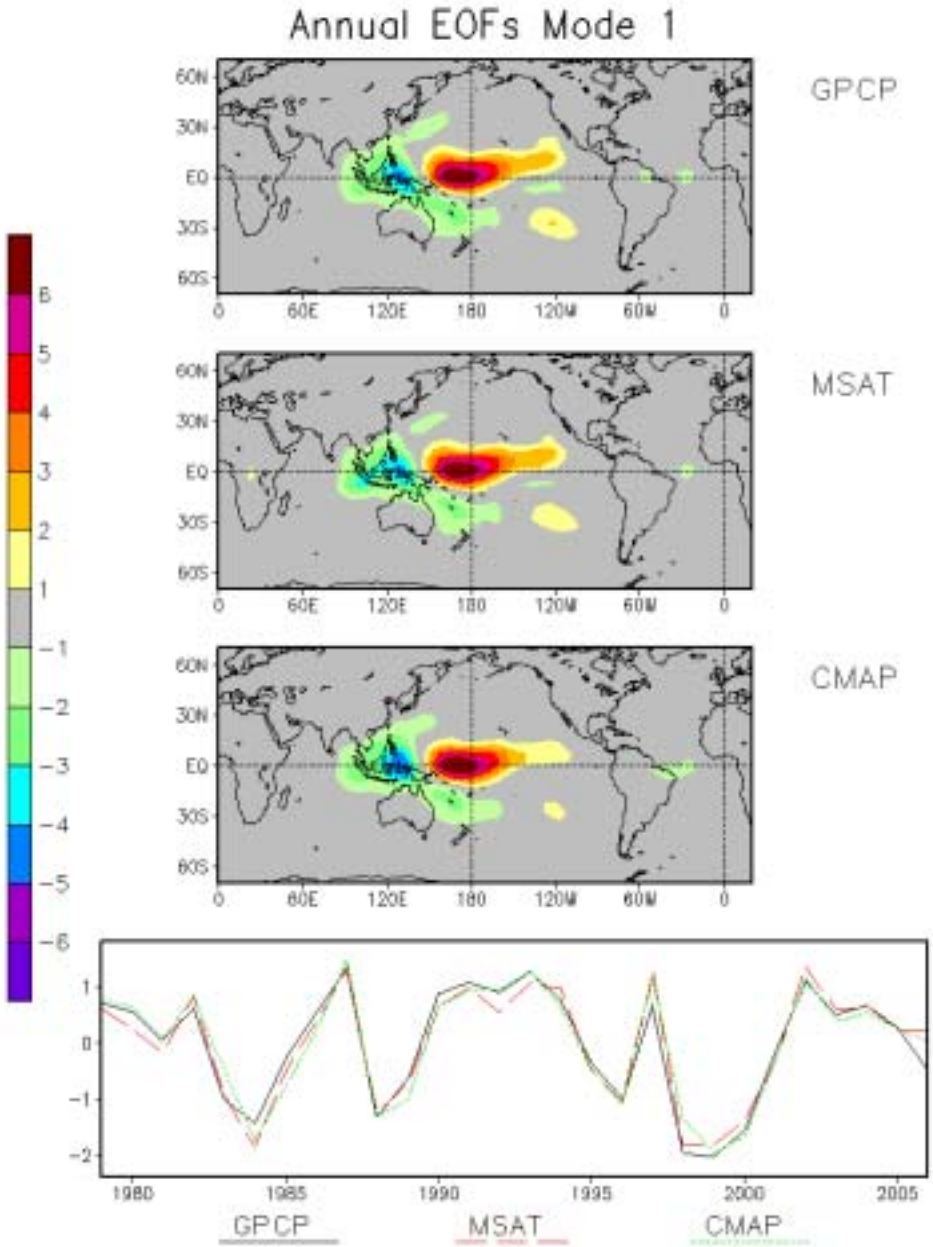
- CCA & GPCP
  - Consistency for overlap period
  - CCA tendency similar to global SST tendency
- CCA & AR4
  - Ensemble climate model mean, IPCC AR4
  - Both increase correlated with global SST (0.9 and 0.7)
  - Correlation with each other is 0.6
- All-area averages smilar
  - CCA & GPCP increase about 2% per degree temperature increase
  - AR4 increase less than 1%/deg



Base Data Rotated EOFs

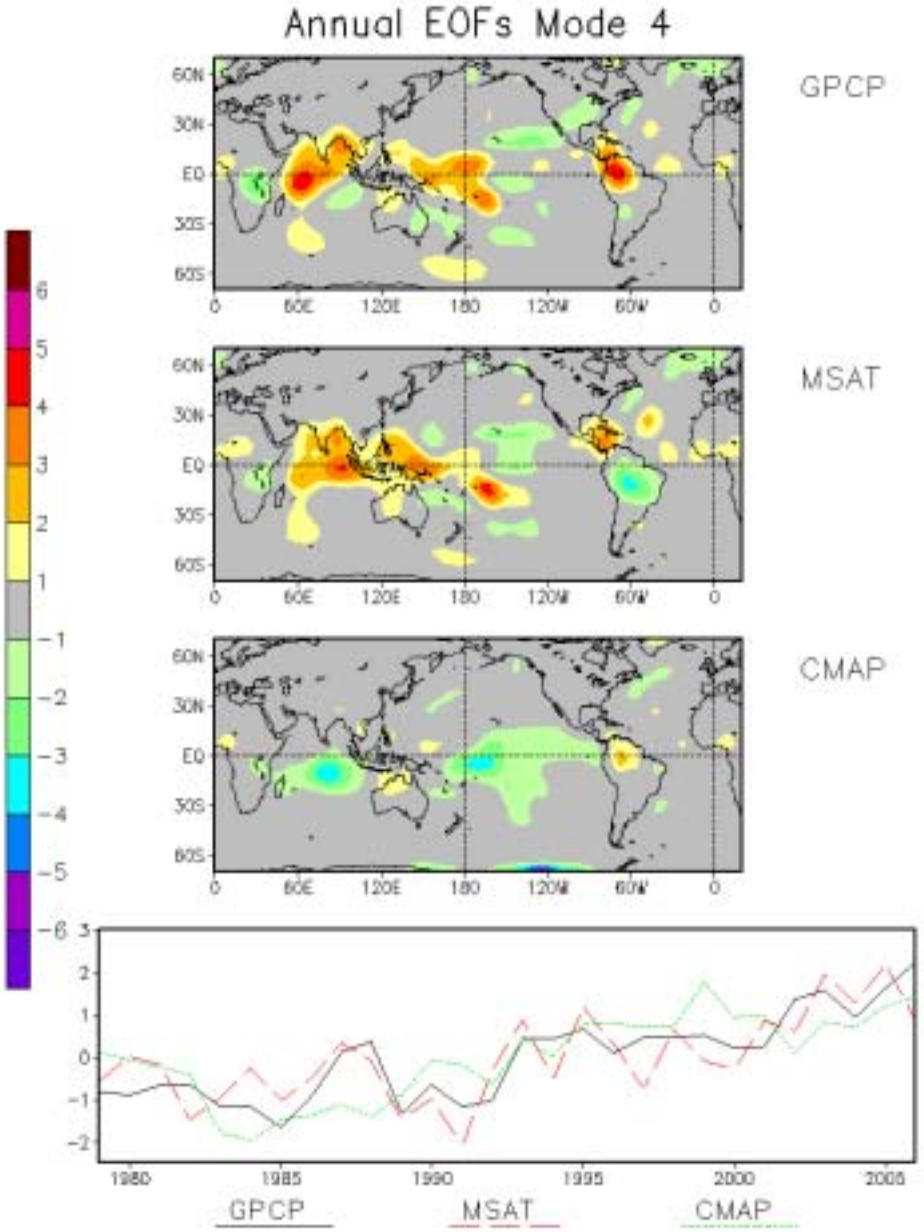
- Compare GPCP, GPCP-multi satellite only, and CMAP
- Mode 1: ENSO
  - Patterns and time series all similar

Modes 2 & 3 also similar



REOF 4: Multi-Decadal

- GPCP and MSAT similar over oceans
  - Same data over oceans
  - GPCP uses gauges over land
- CMAP multi-decadal has a different sign
  - Adjustment to island gauge stations can distort tropical ocean signal



Summary of CCA Reconstruction

- CCA can reconstruct multi-decadal precipitation from SST and SLP
  - Errors in SST and SLP and base precipitation affect precipitation reconstructions

- The best possible base precipitation analysis is critical for multi-decadal reconstruction
  - Some modern analyses developed for analyzing shorter-period variations

Next Steps

- Develop a 30-year OI using IR satellite and ERA-40 estimates for base data
- Use best base data, develop CCA for multi-decadal signal and gauge-based reconstruction for shorter periods
- Combine CCA and gauge-based reconstructions
- Compare to estimates from climate-models & model-based reanalyses for oceanic regions