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

\[
D(x,t) = a(x,t) - \mu(x,t)
\]

\[
\mu = \text{1st guess}
\]

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

\[
\psi_m = \text{mode } m \text{ spatial pattern}
\]
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

\[
\sum_{m=1}^{M} w_m(t) \sum_{x=1}^{K} \psi_m(x) \psi_n(x) \delta_x \cos \phi_x
\]
\[
= \sum_{x=1}^{K} D(x,t) \psi_n(x) \delta_x \cos \phi_x, \quad \text{for } n = 1, 2, \ldots, M
\]

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

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

Zonal Average Anomalies: Sea only

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

- Over oceans, OI and GPCP close

- Over land comparisons are not as good
  - GPCP uses gauges
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 (80°S-20°S, 30°S-30°N, and 20°N-80°N) the cumulative % variance explained by the given number of modes.

<table>
<thead>
<tr>
<th>Number Modes</th>
<th>1</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>11</th>
<th>12</th>
<th>15</th>
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<tbody>
<tr>
<td>20°N-80°N</td>
<td>7.4</td>
<td>18.6</td>
<td>30.4</td>
<td>39.6</td>
<td><strong>44.7</strong></td>
<td>47.1</td>
<td>53.2</td>
</tr>
<tr>
<td>30°S-30°N</td>
<td>17.0</td>
<td>30.2</td>
<td>40.2</td>
<td>47.1</td>
<td>50.9</td>
<td><strong>52.4</strong></td>
<td>56.8</td>
</tr>
<tr>
<td>80°S-20°S</td>
<td>9.6</td>
<td>23.1</td>
<td><strong>36.1</strong></td>
<td>45.4</td>
<td>50.7</td>
<td>53.0</td>
<td>58.9</td>
</tr>
</tbody>
</table>
Mode 1 EOFs and Weights

Mode 1 EOFs and Weights based on 1992-2001 anomalies

Correlations

<table>
<thead>
<tr>
<th></th>
<th>NH</th>
<th>TR</th>
<th>SH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>0.83</td>
<td>0.89</td>
<td>0.70</td>
</tr>
</tbody>
</table>
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
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
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 similar**
  - 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