Climate Reconstruction Improvements from Iteratively Adjusted Statistics, Demonstrated Using Model SST

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SST Reconstructions

- Statistical reconstructions to analyze sparse historical SST data
  - Typically need modern dense data for statistics
- A problem: representing long-period variations
  - Modern base data too brief
  - Need to either extend statistics or use simpler methods
- Goal here: to adjust statistics to better represent the long-period variations

Long-period SST Anomaly Estimates

- How to analyze long-period variations?
  - HadISST: a global mode
    - Not defined all areas due to data limits
    - Not trained on the full reconstruction period
  - ERSST: large-scale data smoothing
    - Gives a smooth annual estimate
    - Not defined everywhere due to data limits

- Improving the long-period first guess should improve the monthly analysis
  - Iterative EOF method developed

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Testing Using CGCM SST

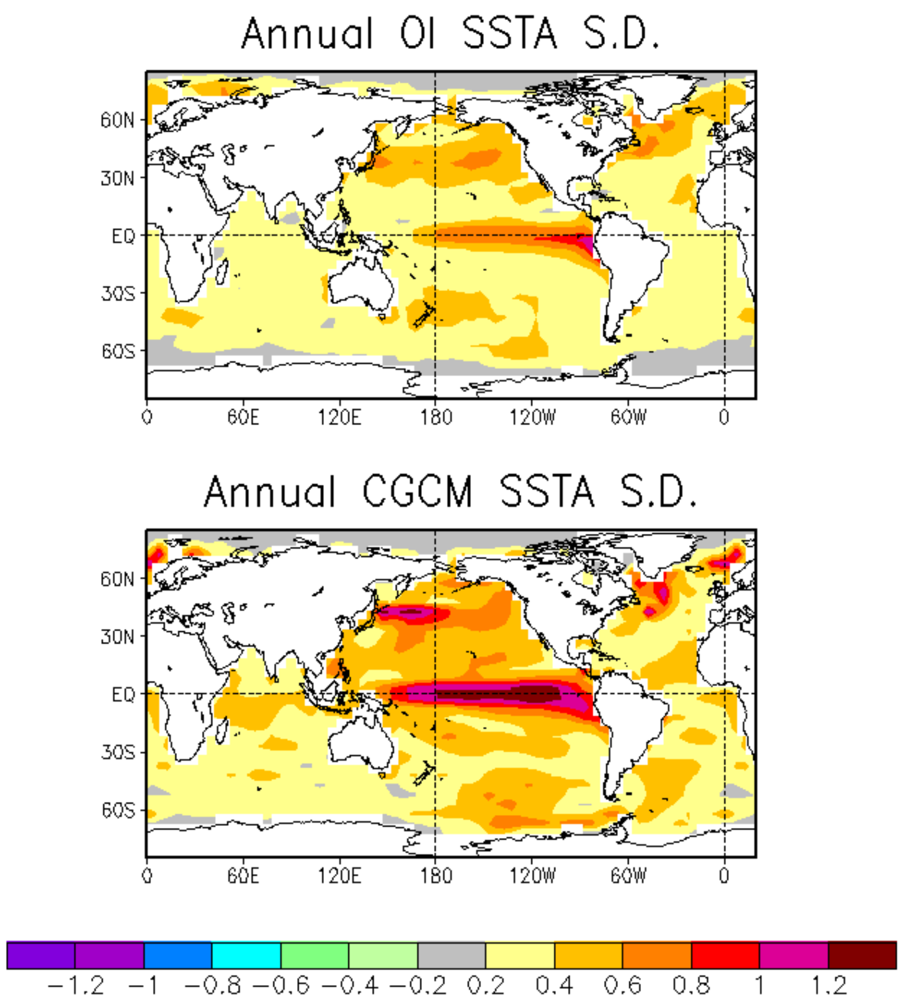
- Observed sampling & CGCM output
  - HadSST monthly, 5° sampling
  - GFDL-ESM2M historical run from CMIP5, use monthly surface temperatures averaged to 5° grid
  - Add random and partly-correlated errors to mimic observed data errors
  - Comparison to full CGCM output to test skill

- Testing of annual and long-period anomaly analysis
  - ERSST long-period method applied using the data to show differences

CGCM & OI Data

SST Anomaly Variations

- Comparison to satellite-based NOAA OI standard deviation
- Locations of relatively large and small S.D. similar in both
  - Sampling should influence both similarly
- CGCM tends to have larger S.D.



1982-2005 Annual SST anomaly S.D. showing similar variations

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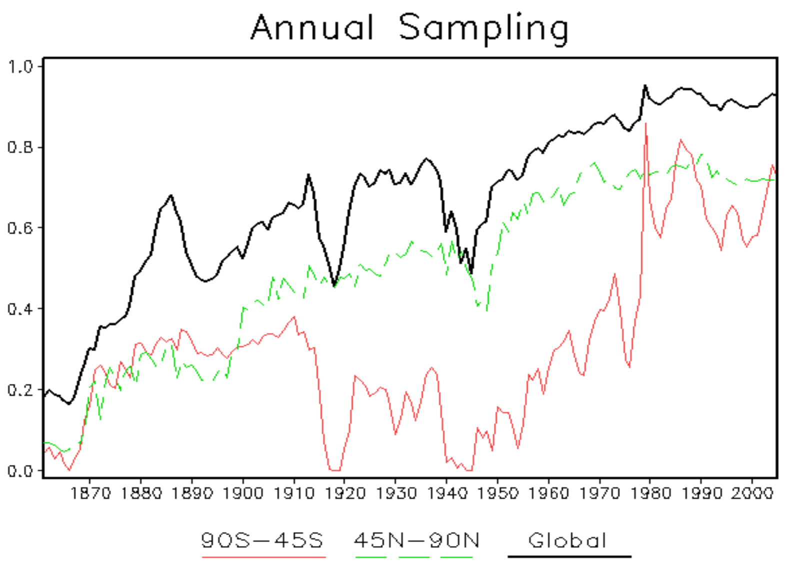
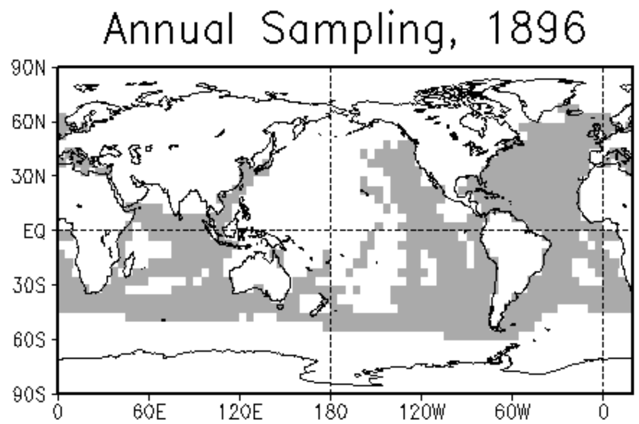
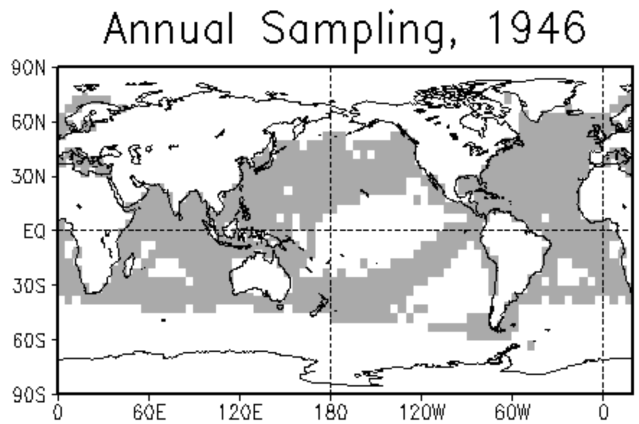
Annual HadSST Sampling

- From 5° monthly to annual
- At lease 4 months sampled
- Error estimates larger where sampling is lower







Annual sampling for 2 years . At least 4 months are sampled & errors are larger where sampling is lower.

Random Error Estimates

- Random errors as a function of the number of observations, N

- N=1 random noise/signal variance = 15
  - From earlier estimates (RS94, similar magnitudes to Kent et al. estimates)

- Scale signal/noise standard error by CGCM s.d. and a random number, R (with 0 mean, s.d. = 1)

Random noise/signal variance for N observations

$$\eta_{5d}^2(N) = \eta_0^2 / N$$

Random-error estimate added to CGCM SSTs

$$\varepsilon_R = R\sigma\eta_{5d}$$

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Correlated Error Estimates

- Based on HadSST-OI SST
  - Normalized MSD as a function of N
  - Equation fit best with r=0.7 and normalized error = 0.5 with N=1
- Make N=1 error maps
  - Randomly select a map & scale locations by N, with $r=0.7$
- Test random & partly-correlated error
- Partly-correlated errors give greater reconstruction errors

Correlated error variance as a function of N and error correlation, r

$$\eta_C^2(N) = \frac{\eta_0^2}{N}(1+(N-1)r)$$

Iterative EOF Reconstruction

1. Compute annual EOFs from annual modern satellite-era SST anomalies

2. EOF anomaly reconstruction over historical period using a limited number of modes

$$F_k(x,t) = \sum_{m=1}^{M} \psi_{k,m}(x) w_{k,m}(t)$$

3. OI reinjection of anomaly increments, I_k, to adjust historical anomalies using original SST data, D

$$I_k(x,t) = D(x,t) - F_k(x,t)$$

$$T_k(x,t) = F_k(x,t) + OI(I_k(x,t))$$

4. Update EOFs: compute using adjusted extended historical analysis, T_k

5. Repeat steps 2 to 4 until the analysis stabilizes (< 5% variance change)

Use of Iterative EOF Reconstruction

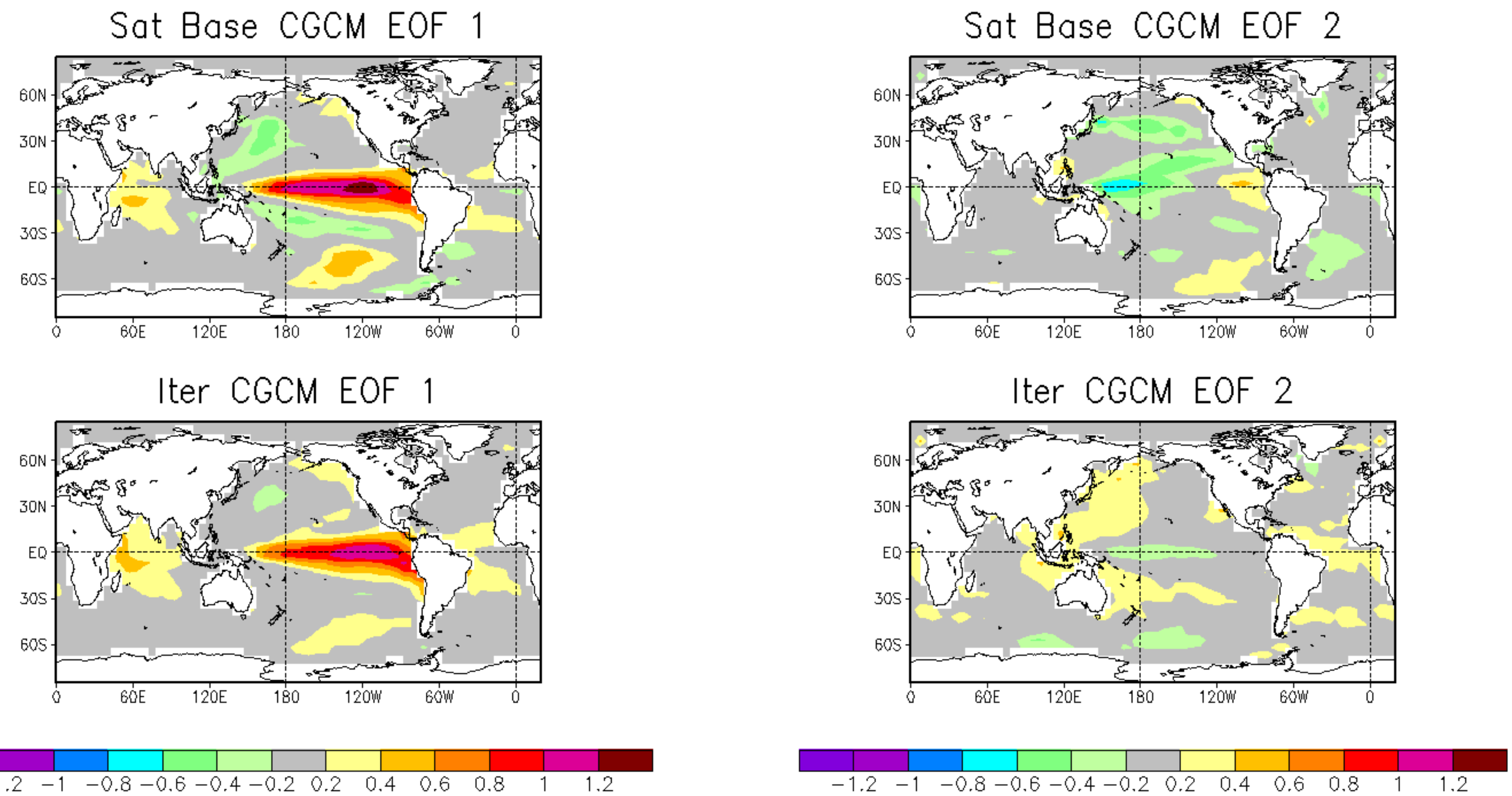
- Limit the number of EOF modes
  - Filter out isolated features from data reinjection
  - Lets reinjected data influence large-scale variation
  - For annual analysis 10 modes resolves almost all base (last 24 years) CGCM variations

- Updated EOFs resolve more large-scale historical variations
  - Need enough sampling, and annual averaging expands the sampling
  - Testing needed for sampling sufficiency

First two EOFs

Satellite-base period EOF (upper), adjusted full-period EOF (lower)

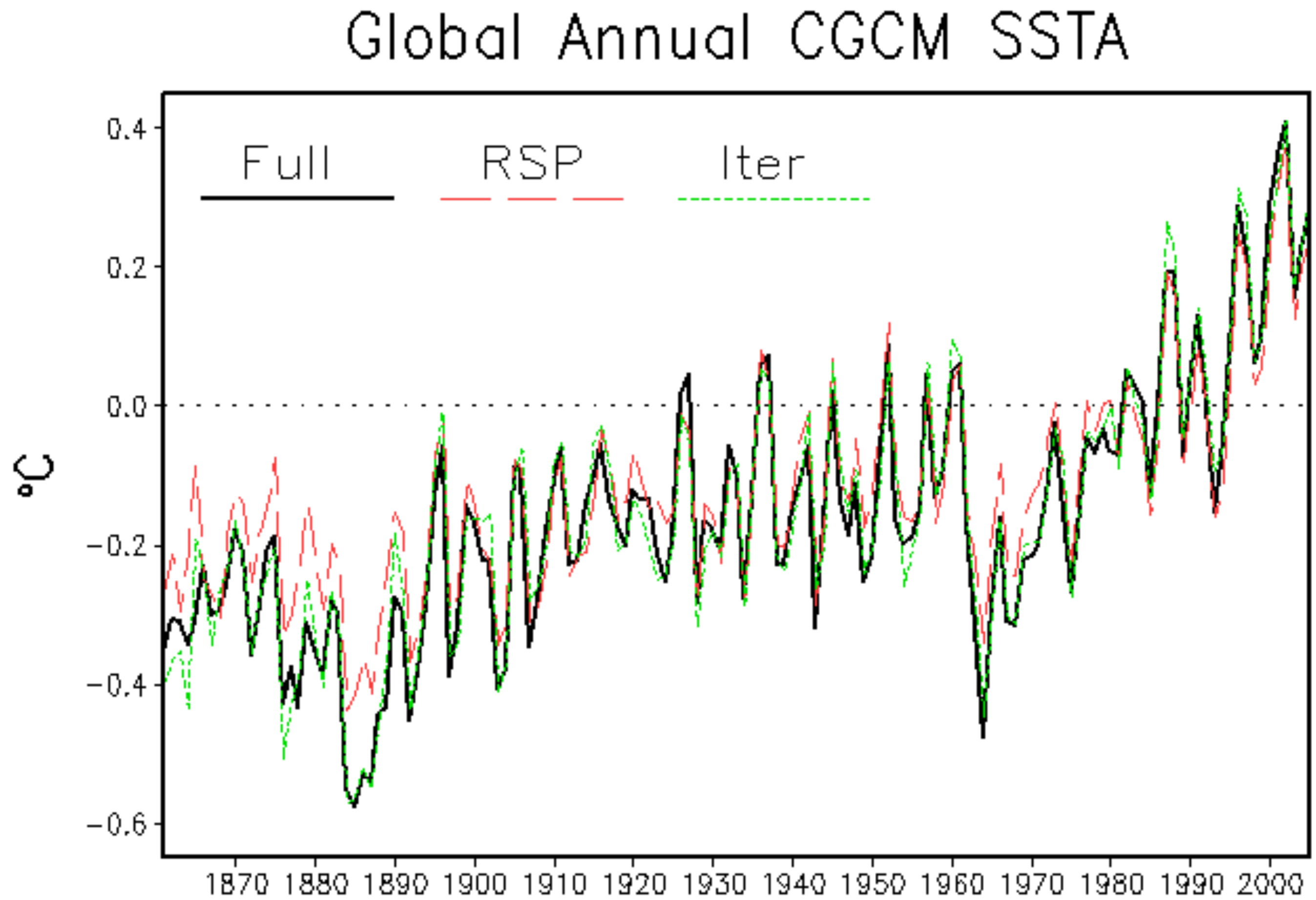
- Differences, but no bullseyes or other apparent adjustment problems
- More rearranging of variations in higher modes



Global averages: Iter closer to Full CGCM

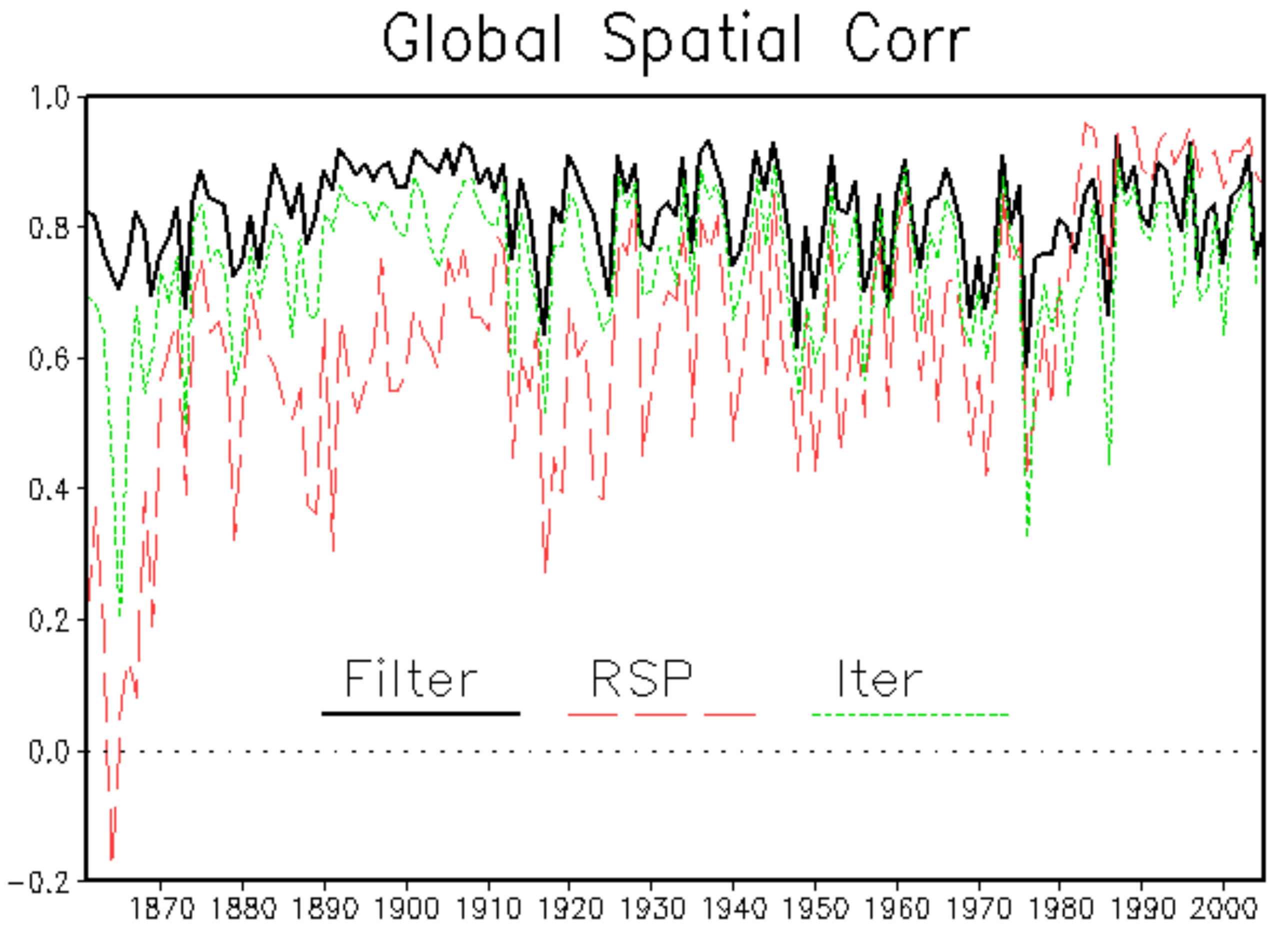
RSP: Recon using 10 satellite-base period EOFs

Iter: Recon using 10 iterative adjusted EOFs



Global spatial correlation: Iter close to Filter

Filter: CGCM filtered using 10 EOFs from the full period full CGCM



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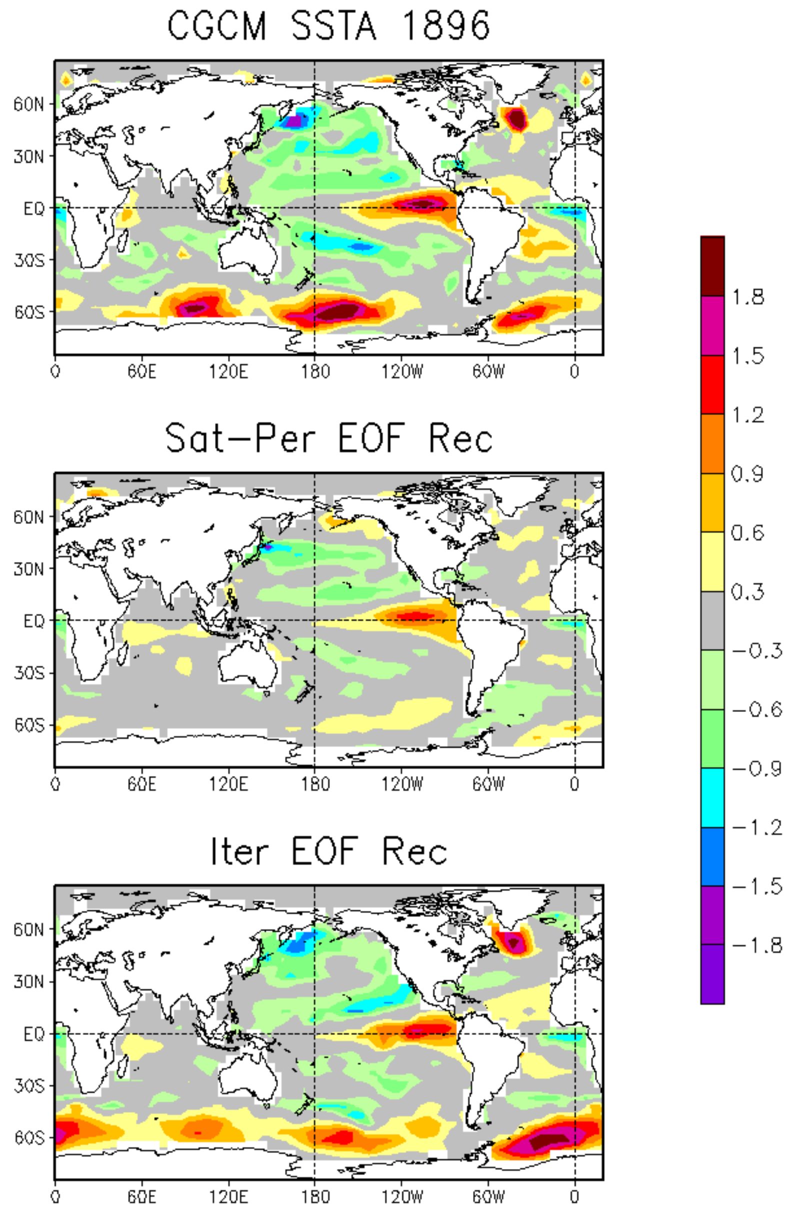
Example Anomaly Recon: 1896

Full CGCM (upper, model warm ENSO), Satellite-period EOF recon (middle), and Iterative-EOF recon (lower)

Biggest improvements from Iterative EOFs in the extra tropics and high latitudes

Southern Ocean anomalies much better wi Iterative EOFs



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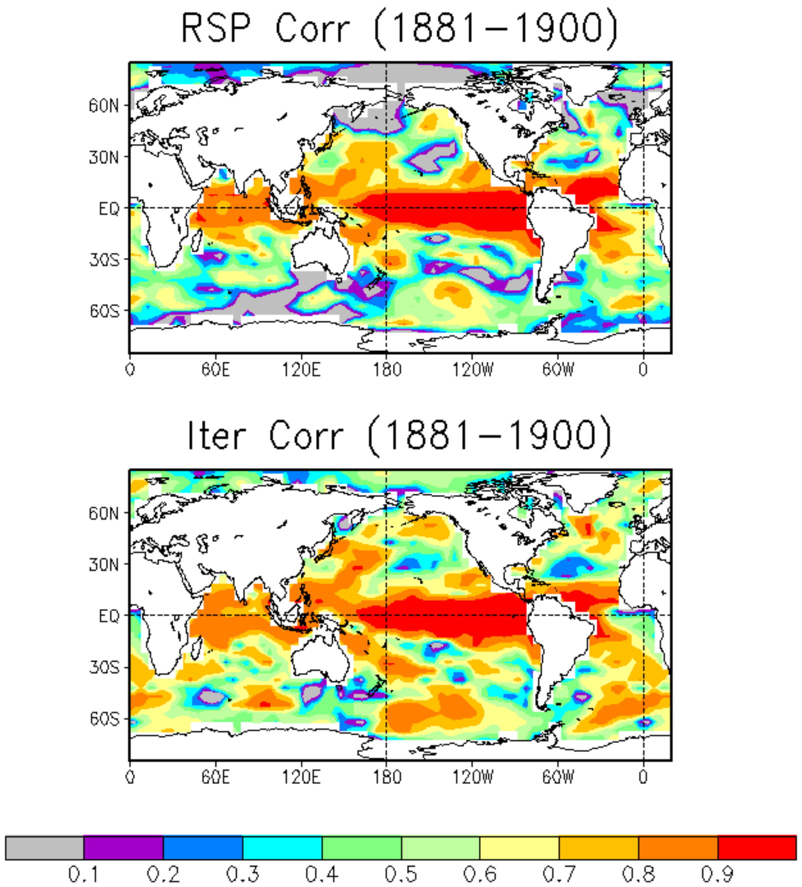
Correlations with full CGCM: 1881-1900

Satellite-period EOF recon good in tropics (RSP)

- ENSO & other tropical variations sufficiently sampled

Iterative EOF recon better at mid and high latitudes

- Likely that multi-decadal variations (e.g., PDO-like) need longer base periods
- Full global coverage with adjusted base EOFs



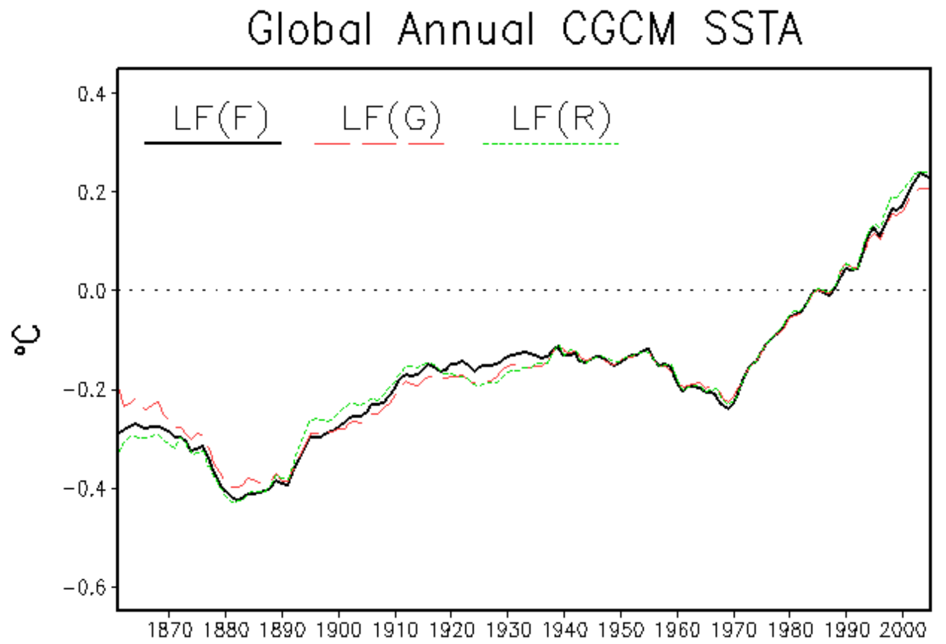
Impact on ERSST First Guess

- ERSST annual first guess: filtering 15-years of SST anomalies
  - Compute annual anomalies averaging over months and 15° spatial areas, where enough data are available
  - First guess is 15-year centered median of annual averages

- Compute 15-year medians using CGCM anomalies
  - Full-data, no error added
  - ERSST-method, gapped data & errors added
  - Iter analysis 15-year median

Comparisons to ERSST low-frequency

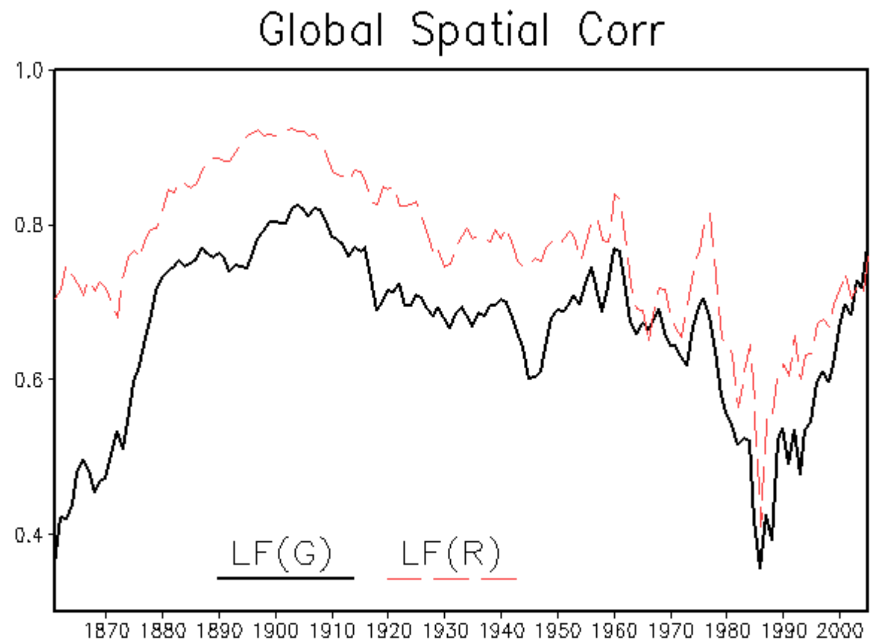
LF(F) 15-year filtered full CGCM
LF(G) ERSST 15-year filtered method using gapped data
LF(R) 15-year filtered iterative-EOF recon



Global averages similar from different estimates: influence on the global first-guess error small

Comparisons to ERSST low-frequency

LF(F) 15-year filtered full CGCM
LF(G) ERSST 15-year filtered method using gapped data
LF(R) 15-year filtered iterative-EOF recon

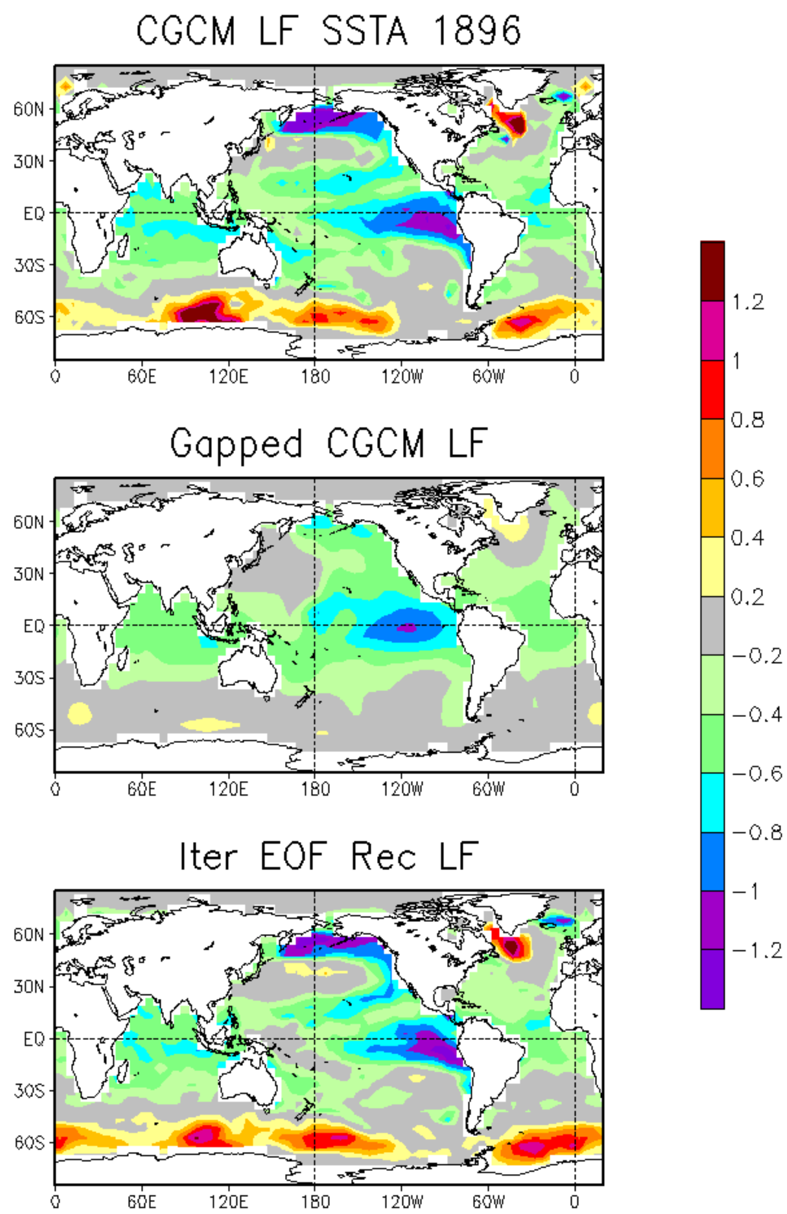


Global spatial correlations with LF(F): improvements from iterative-EOF recon

Note: Base-period correlations lower because 15-year anomalies are near 0 (lower signal, not more noise)

Example 15-year filtered

- Full CGCM filtered (upper)
- ERSST method with gapped data (middle)
- Iterative-EOF recon filtered (lower)
  - Helps most at mid and high latitudes, as with annual analysis
  - Gives better spatial resolution of LF signal at all latitudes



Comparisons over regions with and without sampling

No sampling degrades RSP

Iter always better

LF(R), from Iter, better than ERSST method

LF(R) corr higher with no sampling

- Better in high-variance areas with low sampling (e.g., southern oceans)

Spatial correlation with CGCM, 1861-2005 averages, for regions with historical sampling (Sampl) and without (No Sampl). For the LF correlations sampling of the center year is used.

	Sampl	No Sampl
Ann RSP	0.64	0.51
Ann Iter	0.73	0.71
LF(G)	0.66	0.65
LF(R)	0.73	0.80

Summary and Conclusions

- An iterative-EOF reconstruction method gives improved representation of historical variations
- Improvements are greatest in extra tropics and poorly sampled regions
- Both HadISST and ERSST first-guess analyses can be improved
  - HadISST first guess does not fill everywhere because it needs historical data to compute modes
  - ERSST first guess needs data so it is damped to 0 anomaly in persistently under-sampled areas
- New analysis can improve understanding of regional and high-latitude historical variations