Can SST Proxy Data Reconstruct Common Era AMOC variability?

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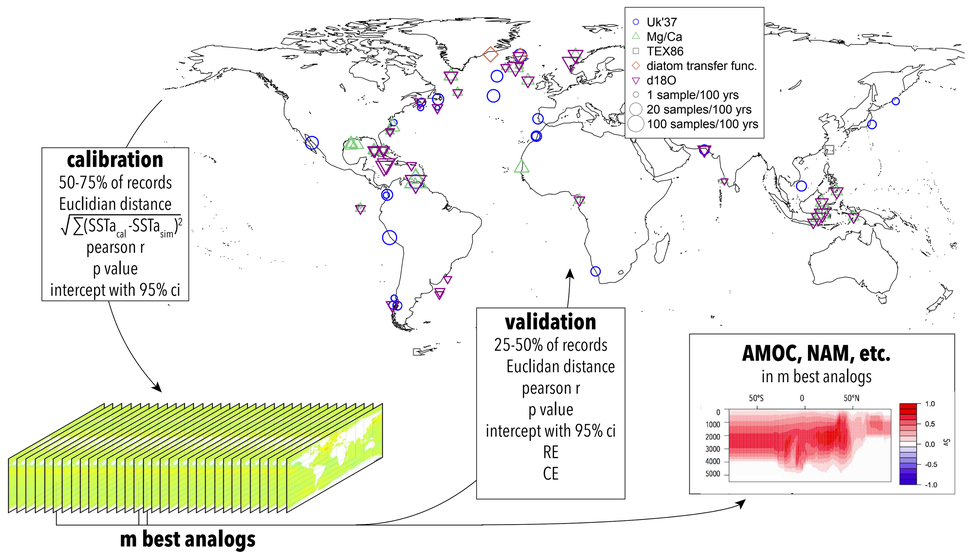
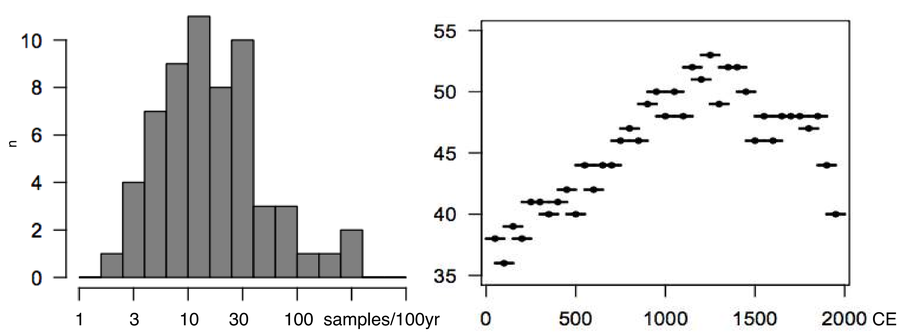
Summary: Proxy surrogate reconstructions (PSRs) combine the strengths of proxy data and climate simulations. We construct PSRs using the PAGES Ocean2K metadatabase of sea surface temperature annomalies (SSTa) and a subset of CMIP5 piControl, past1000 and historical simulations, with the goal of reconstructing Atlantic Meridional Overturning Circulation (AMOC) and quantifying reconstruction skill. Proxy data appear sufficient for centennial resolution, but greater variance than observed in simulations compromises skill. Empirical scaling of proxy data improves skill, but further work is needed to determine if such a scaling is realistic. Preliminary results suggest subtle AMOC variations of +/- 0.5 Sv over the past 2000 yrs without clear trends during the Little Ice Age or Medieval Climate Anomaly.

Proxy Surrogate Reconstructions (PSRs)

- Simulations are physically realistic, but don't necessarily track the climate's true evolution
- Proxy data record actual climate climate, but are spatially irregular and noisy.
- PSRs are an analog approach to utilize the strengths of proxy and GCM data (Graham et al. 2007)
  1. Compile a network of paleoclimate data. Here, **Ocean2K SST reconstructions +**
  2. Construct a catalog of model-based estimates of the same variable. Here, **CMIP5 historical, past1000** (CCSM4, MPI-ESM3) and **piControl** (CCSM4, MPI-ESM3, CNRM and INMC)
  3. When simulations skillfully capture proxy SST, all model variables can be accessed



What temporal resolution is possible?



97% of proxy data has average sampling resolution of 1 sample/100 years or higher.
100 year binned averages, shifted every 50 years yields 36-53 records per bin

Other important considerations and what we've learned

Absolute SST vs. anomalies:

- *Absolute SST:* Strong statistics just capture climatology
- *Best choice*: Use anomalies

Time period for anomalies:

- *1200-1400CE*: Maximum data density, but spurious statistics because proxy/model are "told" to equal each other
- *0-2000CE*: Fixes problem above, but excludes most records
- *Best choice*: Calculate anomalies over a proxy record's entire interval. This is unique for each record and requires individualized catalogs of simulations with anomalies calculated in the same way (for past1000).

Seasonality:

- *Annual only:* Assume seasonal anomalies will be very similar to mean annual at 100 year intervals
- *Annual, Spring and Summer*: Include MAM and JJA in simulation catalog searched for PSR
- *Best choice:* Individualized catalog uses seasonality re ported by original publication

Skill metrics:

- *calibration/validation r >0*
- *calibration/validation p < 0.1*
- *intercept within error of 0*
- *validation RE > 0*
- *validation CE > 0*
- *Best choice: We adopt 3 highest RE, but are open to ideas.*

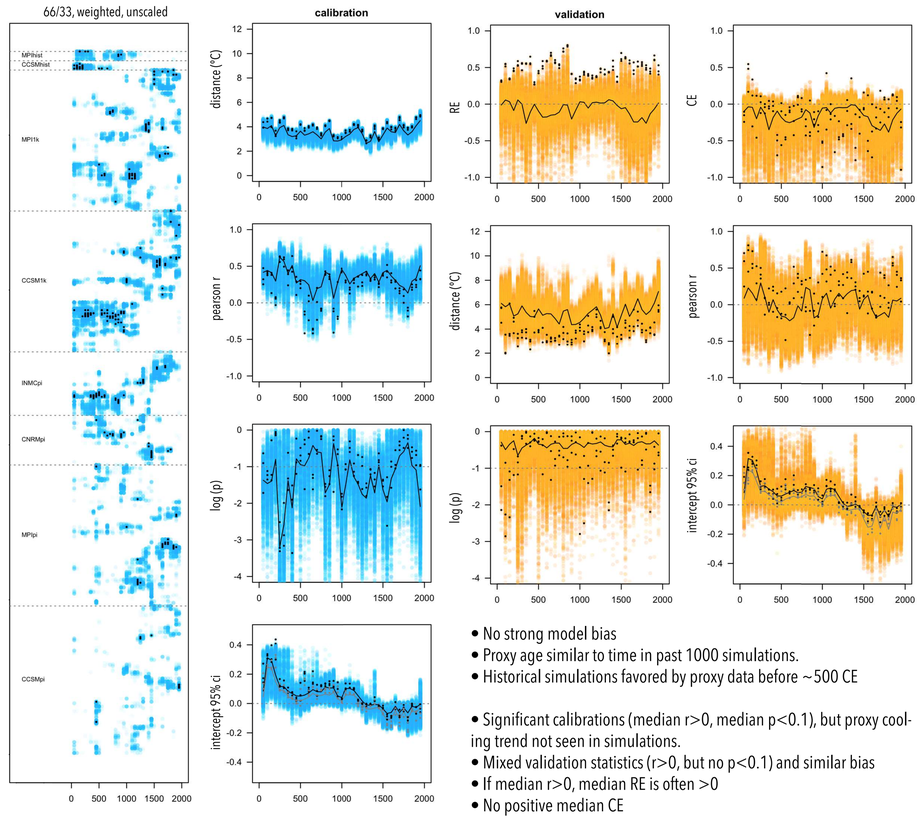
Calibration/validation ratio:

- Appears largely insensitive to 50/50, 66/33 and 80/20

Weighting:

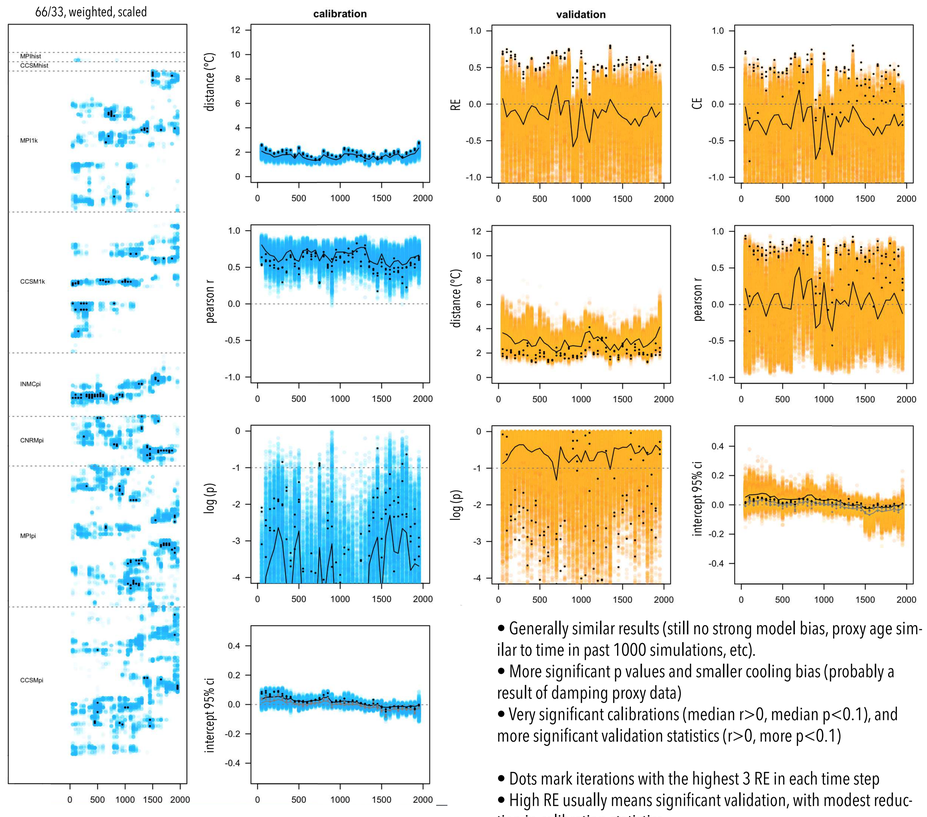
- Appears largely insensitive to no weight vs. 1/s.d.

Calibration/Validation:



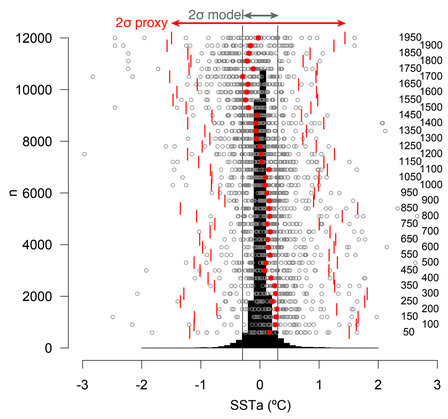
- No strong model bias
- Proxy age similar to time in past 1000 simulations.
- Historical simulations favored by proxy data before ~500 CE

- Significant calibrations (median r>0, median p<0.1), but proxy cooling trend not seen in simulations.
- Mixed validation statistics (r>0, but no p<0.1) and similar bias
- If median r>0, median RE is often >0
- No positive median CE



- Generally similar results (still no strong model bias, proxy age similar to time in past 1000 simulations, etc).
- More significant p values and smaller cooling bias (probably a result of damping proxy data)
- Very significant calibrations (median r>0, median p<0.1), and more significant validation statistics (r>0, more p<0.1)

- Dots mark iterations with the highest 3 RE in each time step
- High RE usually means significant validation, with modest reduction in calibration statistics



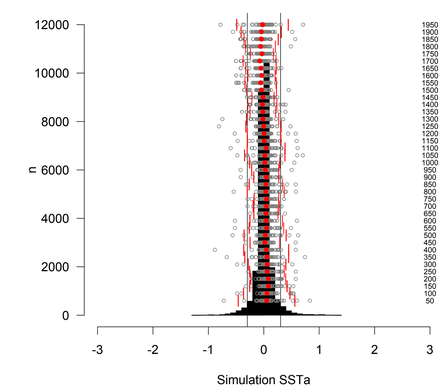
- Median proxy SSTa data in each time bin (red circles) overlaps with SSTa variance in simulation catalog (black histogram).

- Individual proxy records (open grey circles) can show appreciably larger variance, with SSTa values that don't have an analog in simulation catalog.

Marginal validation likely related to much larger variance in proxy data than in simulations.

- Local scale processes not captured by simulations
- Changes in proxy seasonality
- Non-temperature effects on proxy data

What if proxy data were dampped so each proxy record had the same variance as its simulation grid point?
See below...



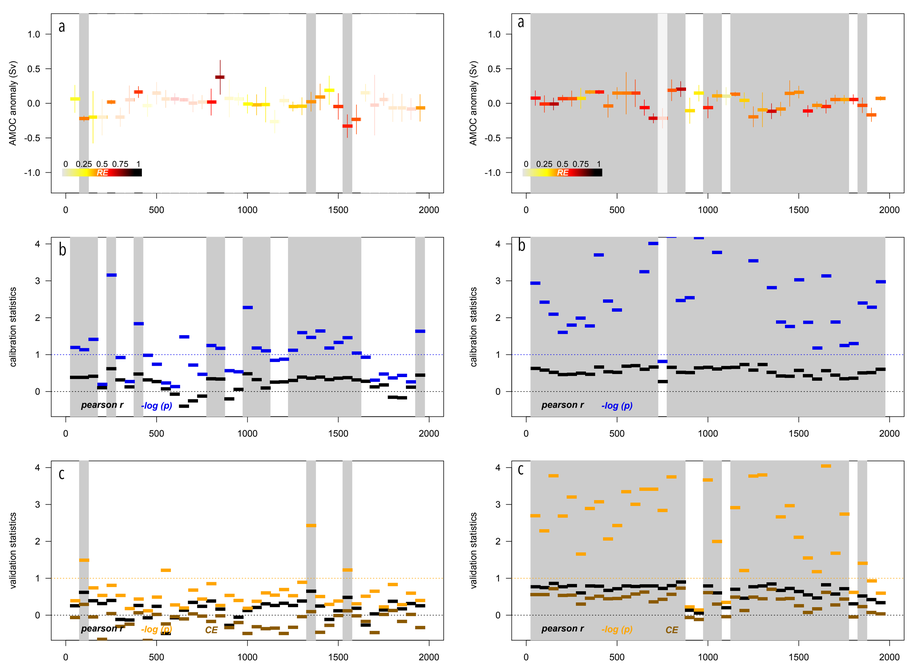
- As in histogram above, but with proxy data scaled to have the same variance as simulation in the closest 1°x1° gridbox

- (Unsurprising) better agreement with few (if any) no analog cases.

TOWARD AMOC RECONSTRUCTIONS

- Use the 3 highest RE in a timestep to derive AMOC
- Balances over calibrating and under validating
- Gives similar distances for calibration and validation
- Each of the 3 highest RE values is based on the mean of 3 iterations.
- Median AMOC in 9 simulations (replicates are possible)

AMOC reconstructions



AMOC reconstruction for unscaled PSR. a) median AMOC anomaly (+/- 1s.d.) for 3 highest RE iterations (color bar). Grey bars note time steps where validation r>0, p < 0.1. Intervals where calibration r <0 and p>0.1 are masked. **b)** calibration r (black) and -log p (blue). Dashed lines note r>0 and p<0.1. **c)** as in b for validation r (black) and -log p (orange). CE (brown) is also shown.

AMOC reconstruction for scaled PSR. As in panel at left.

- Results suggest a relatively stable AMOC with centennial scale anomalies of +/- 0.5 Sv that are smaller than the ~3 Sv suggested from Florida Straits transport (i.e. Lund et al., 2006).
- 1900-2000 AMOC does not appear anomalous, but does not validate well.

Conclusions

- PAGES, Ocean2K proxy data has spatial and temporal coverage that seems suitable for centennial scale PSRs based on SST anomalies during the past two millennia
- Calculating simulation anomalies relative to the same time frame and season appears reasonable.
- Higher variance in proxy data relative to simulations creates no-analog cases that may reflect local scale dynamics not captured by coarse simulations, proxy vital effects, or other processes
- Empirical scaling of proxy data improves PSR skill, but is it realistic?
- Reconstructed AMOC shows subtle anomalies of +/- 0.5 Sv. Unscaled reconstruction hints at a MCA to LIA reduction, but is less obvious in scaled data.

Future work

- Construct PSRs from higher spatial resolution simulations that capture local scale dynamics (e.g. eddies)
- Add additional CMIP simulations
- Incorporate oxygen isotope data and isotope enabled simulations
- Compare piControl, single forcing and multiple forcing simulations for detection/attribuition
- Pseudoproxy experiments of how proxy data variance affects AMOC, and where new proxy data has largest impact.

Acknowledgments: This work was supported by NSF-OCE award 1536418 to CPS and MNE. We appreciate fruitful discussions with Greg Hakim, Nathan Steiger, Wei Cheng and Nick Graham

References:

Graham, N.E. et al. 2007: Tropical Pacific - mid-latitude teleconnections in medieval times. Climatic Change 83, 241-285.

Lund, D.C. et al. 2006: Gulf Stream density structure and transport during the past millennium. Nature. 444, 30, 601-604.