Last Millennium Climate Reanalysis Project

Reconstructing Climate Fields by Combining Proxies and Models

Greg Hakim, Dave Anderson, Julien Emile-Geay, David Noone, and Eric Steig

Sponsors: NOAA & NSF

LMR Motivation

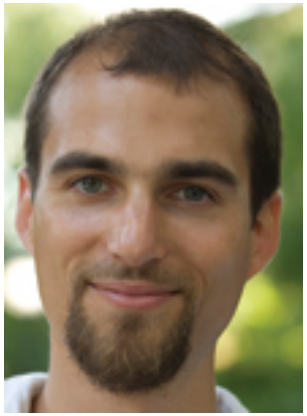
- **What is it?**
  - Paleoclimate data assimilation
  - Dynamically consistent space—time gridded fields
  - Generalizes previous reconstruction techniques (e.g. Mann et al 2009)
- **Why now?**
  - Key assimilation aspects now understood
  - Emergence of proxy system models
  - Comprehensive proxy data organization (v. heterogeneous)
- **Why do we need it?**
  - Decadal—centennial climate variability
  - Climate sensitivity
  - Climate predictability & forecast verification

LMR Goals and Deliverables

- Reconstruct climate variables for last 1K years
  - 2m air temp; 500 hPa height; precipitable water
  - SST; MOC; ocean heat content
  - Common climate indices
- Comprehensive uncertainty quantification
  - Include error from proxies, models, PSMs
  - Monte Carlo approach: O(100) realizations

The LMR Team

Dave Anderson



Julien Emile-Geay

David Noone

Eric Steig

Greg Hakim

Nathan Steiger

Kaleb Horlick

Robert Tardif

Nicole Collier

LMR Advisory Panel


Kevin Anchukaitis


Kim Cobb

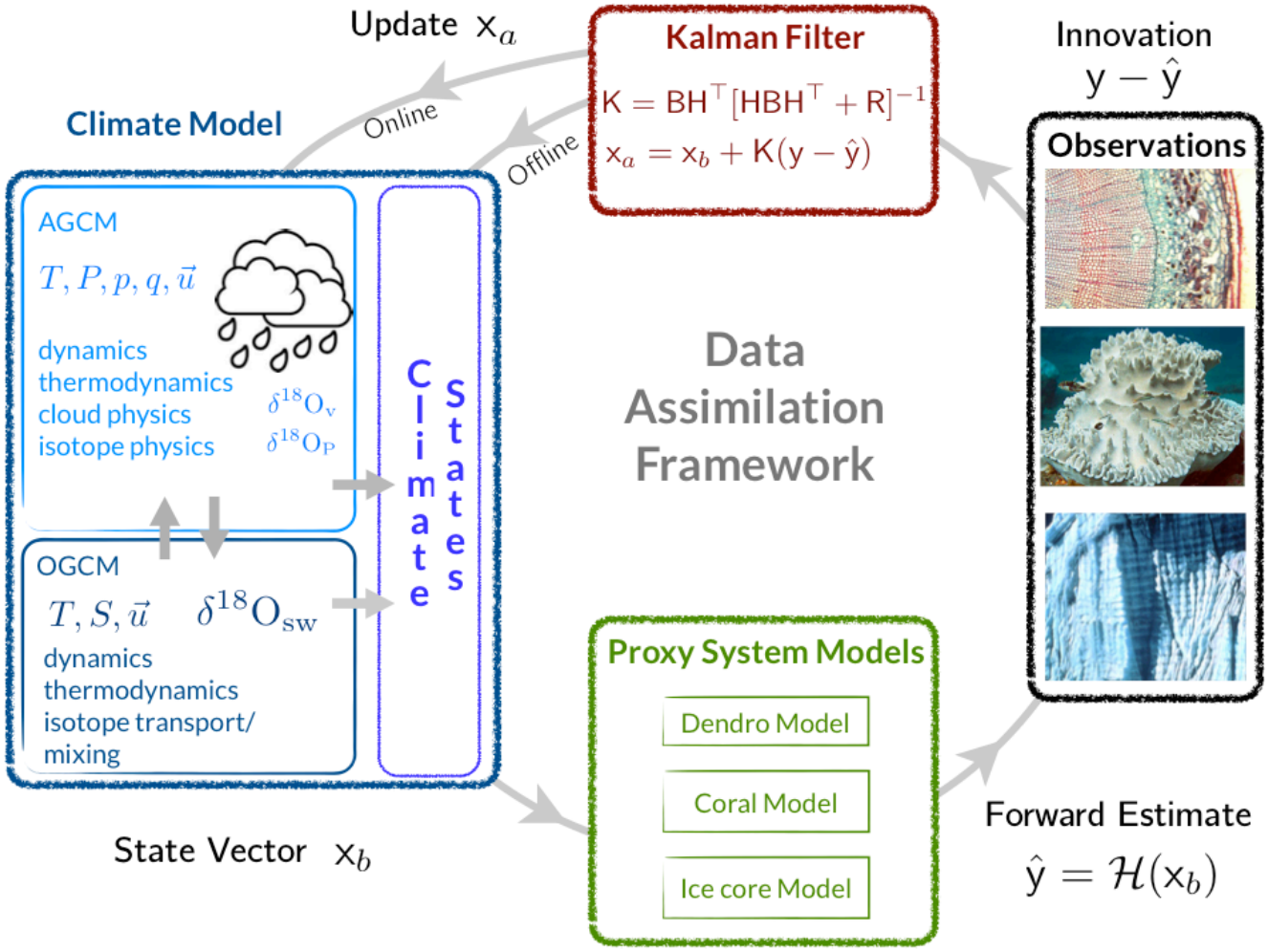

Thorsten Kiefer


Michael Evans


Gil Compo

Thank you!

Paleoclimate Data Assimilation



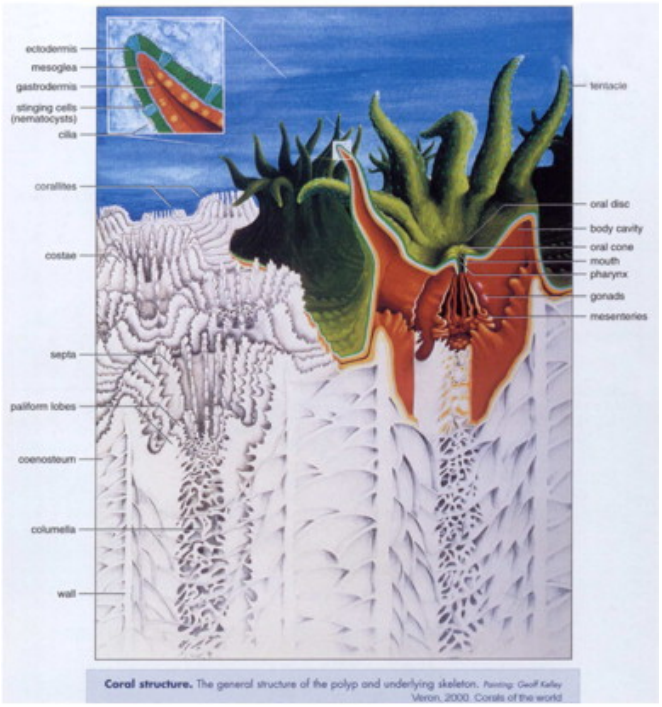
Key Differences from "Standard" Reanalysis

- Observations
  - Geochemistry on biological organisms
  - Complex forward models (PSMs)
  - Sparse network; large error (low signal/noise)
  - Time integrated (~annual and longer)
- Models
  - Climate predictability poor on proxy timescales
  - Very expensive due to timescale of interest

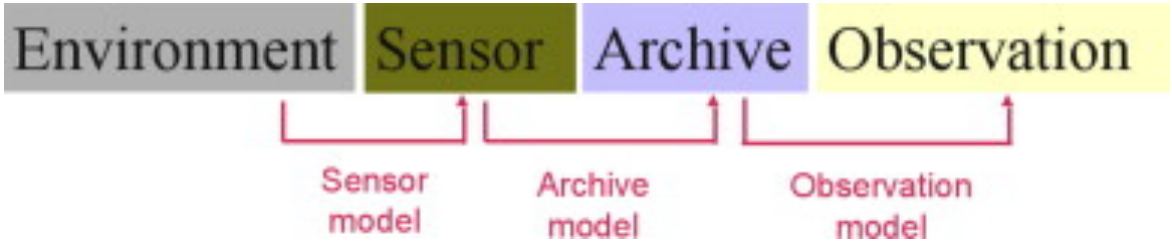
Proxy System Models

Significantly different from “typical” forward models

Sensor: Schleractinian corals



Coral structure. The general structure of the polyp and underlying skeleton. Painting: Geoff Kelley. Veron, 2000. Corals of the world



SST, SSS, chem **coral polyp** **aragonite** **d18O, Sr/Ca**

Evans et al. (2013)

Paleoclimate Data Assimilation Approach

- "Offline" Ensemble technique (no cycling)
  - Current models offer little skill on proxy timescales
    - "online" very expensive with little upside or flexibility
  - Fixed prior from existing model simulations
    - Currently "last millennium" simulations (850—1850)
  - Fast and cheap; facilitates parallelization
  - Square-root update
- Linear PSMs calibrated on instrumental period
  - Upgrade pathway available over linear "benchmark"
- Monte Carlo error approach
  - Randomly sample: proxies, priors, PSMs, dating
  - Randomly withhold proxies for independent verification

Software Framework

- **Object-oriented Python**
  - Useful methods-data bindings through classes
    - e.g., Y.psm(X_b) leaves specifics of PSM bound to proxy instance
    - Clean high-level code, burden left to class methods
  - Use inheritance to over-ride/extend class definitions
    - E.g., overload master class defaults, such as PSM, I/O, etc.
  - Deep scientific community libraries (e.g. `pyspharm`)
- **Main modules**
  - Proxy (classes for corals, trees, sediments, ice cores, etc.)
  - Prior (classes for CMIP models, reanalysis, custom, etc.)
  - Calibration (classes for GIS, CRU, MLOST, etc.)
  - Data assimilation (methods)
- **Performance**
  - MC/offline approach facilitates trivial parallelization
  - Extract bottlenecks to compiled code
    - So far, `numpy` and `scipy` beat hand-coded `f2py` experiments

Research Activity

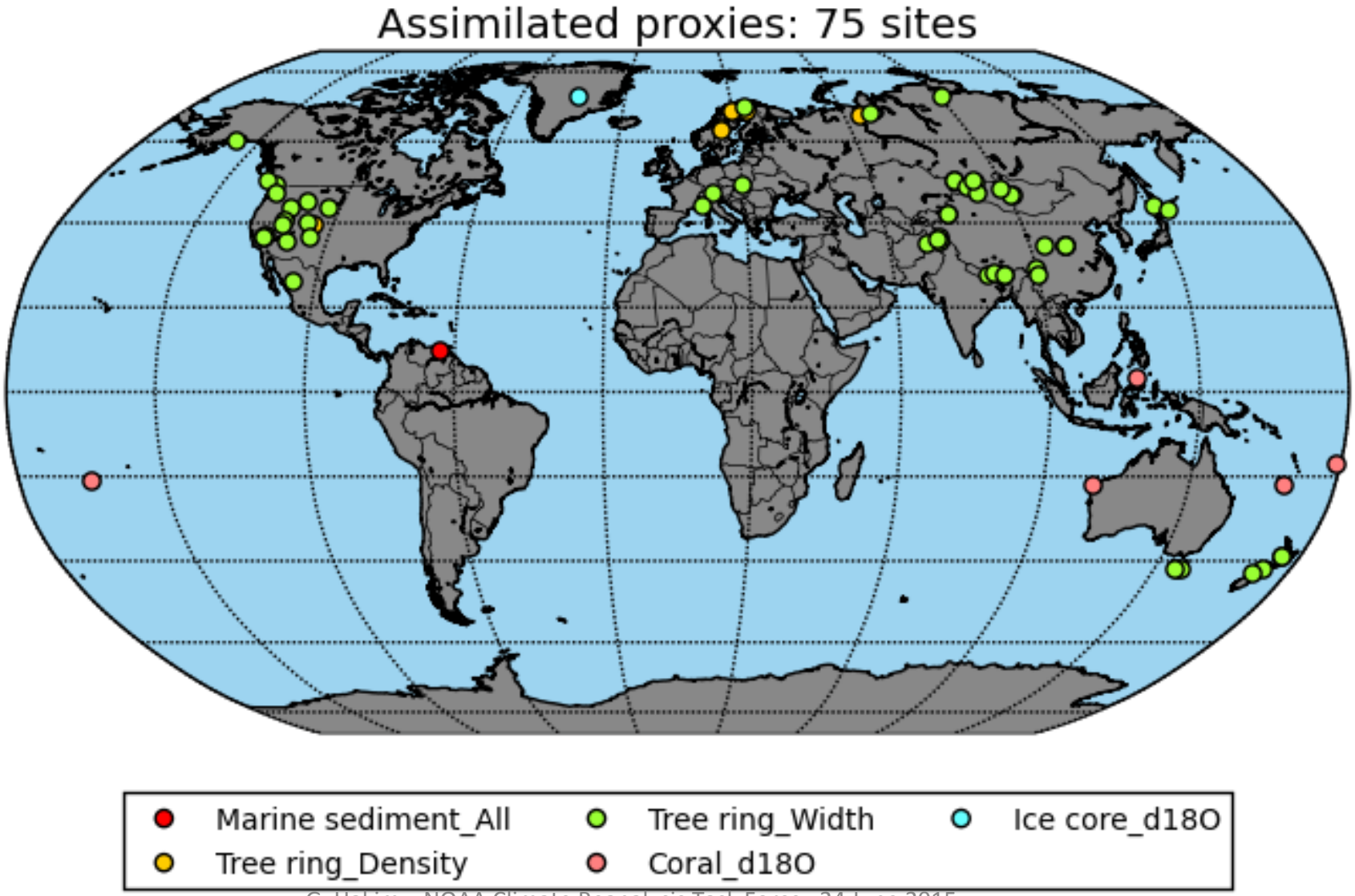
- Proxies (Anderson; Horlick; Collier; Steig)
  - Collect proxy data records
  - Uniform file format and metadata
- Proxy system models (Dee; Emile-Geay; Steig)
  - PRYSM; age models
- Climate modeling (Noone)
  - Direct modeling of water isotopes
- Data assimilation (Hakim; Tardif; Steiger)
  - Object-oriented Python codebase

Very Preliminary Results

- Linear PSMs fit on 2m air temperature
  - Calibration on GIS, BE and CRU (separate experiments)
  - Reject proxy if $r < 0.2$
- PAGES2K proxies
- 75% of proxies randomly selected
  - 104 proxies per realization
- 21 realizations (just testing MC framework)
  - 100 ensemble members per realization
  - T42 spatial truncation

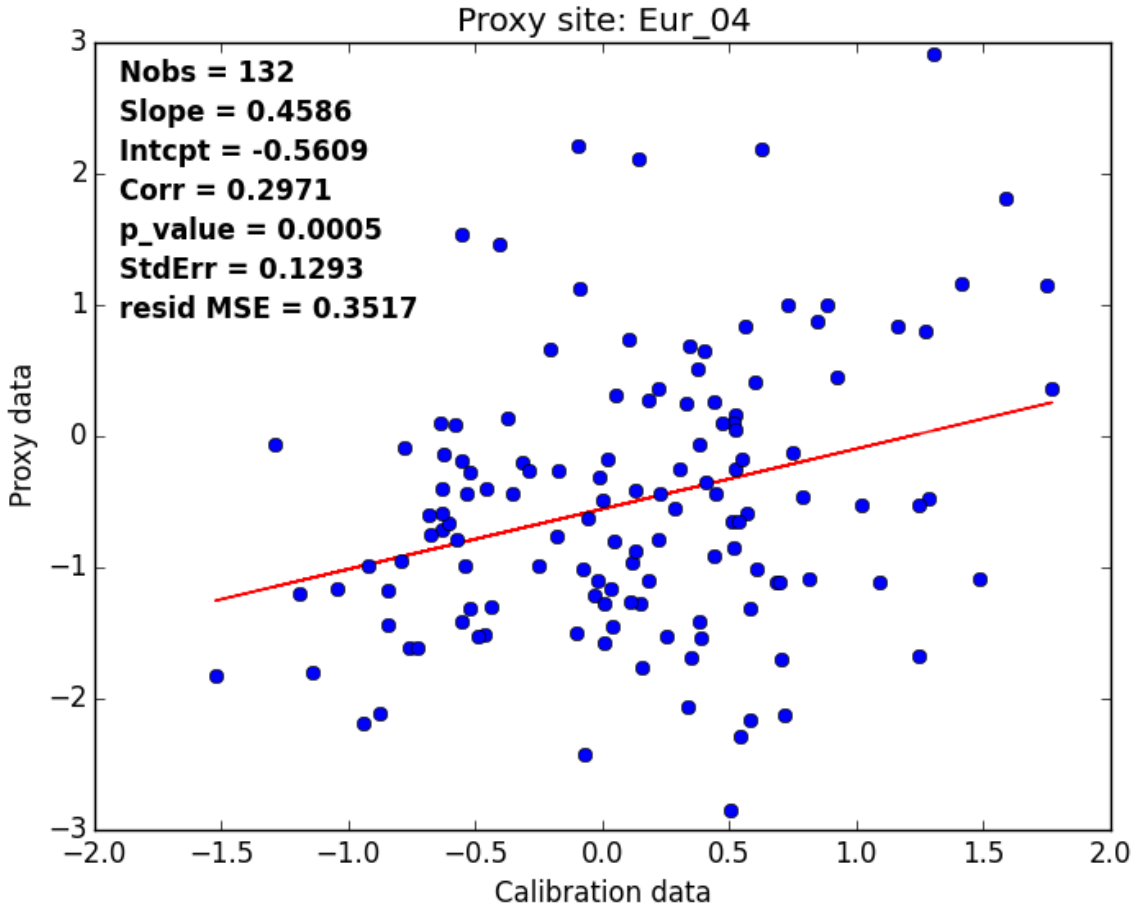
Results provide baseline for reconstruction skill

Very Preliminary Results



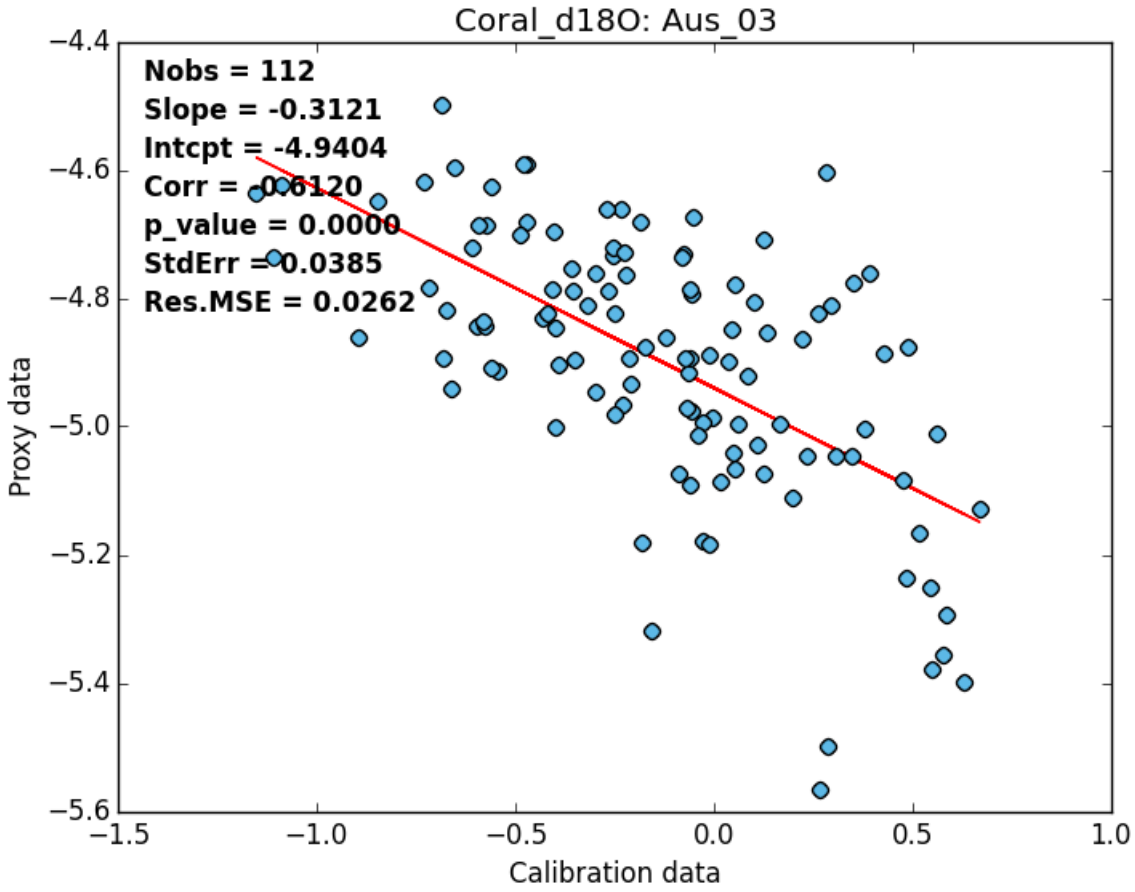
Example Linear PSM Fit

(TRW Tat12 Slovakia)

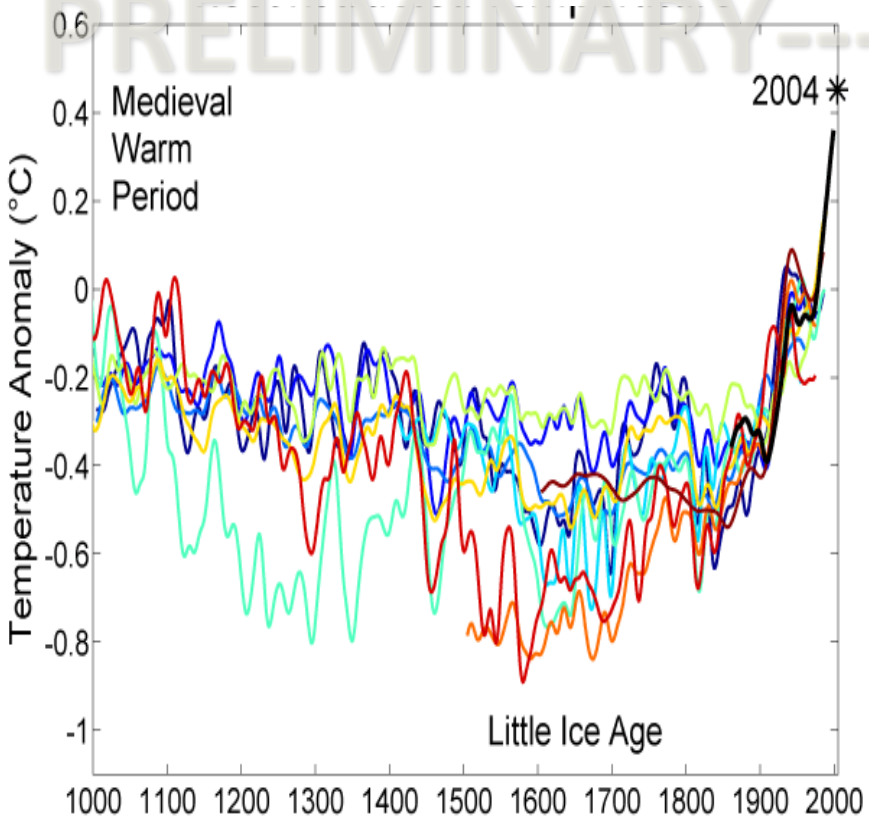


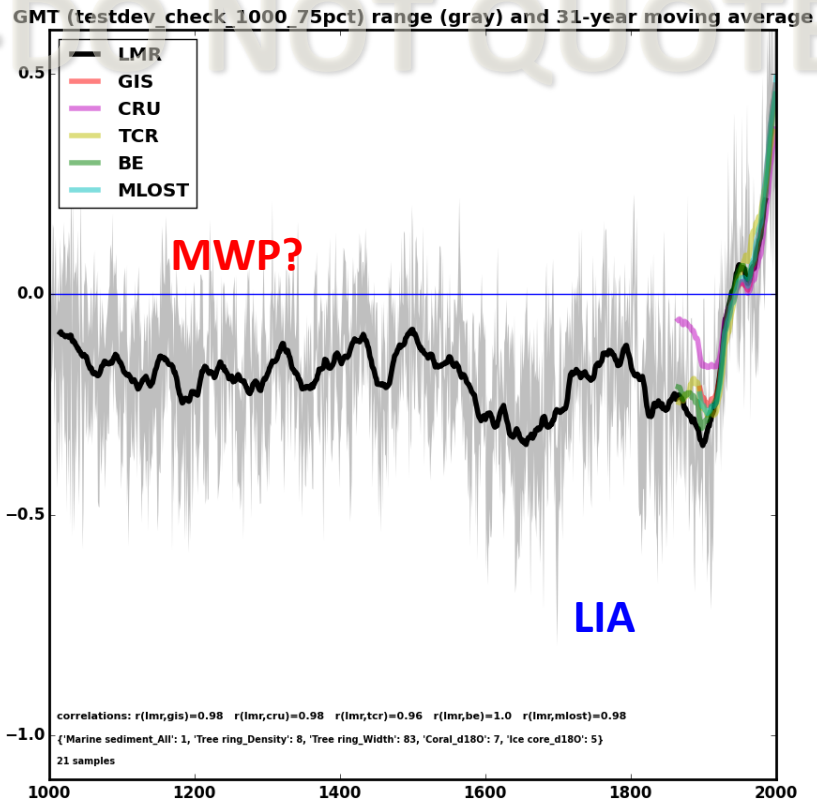
Example Linear PSM Fit

(Coral d18O Palmyra)



Global Mean Temperature



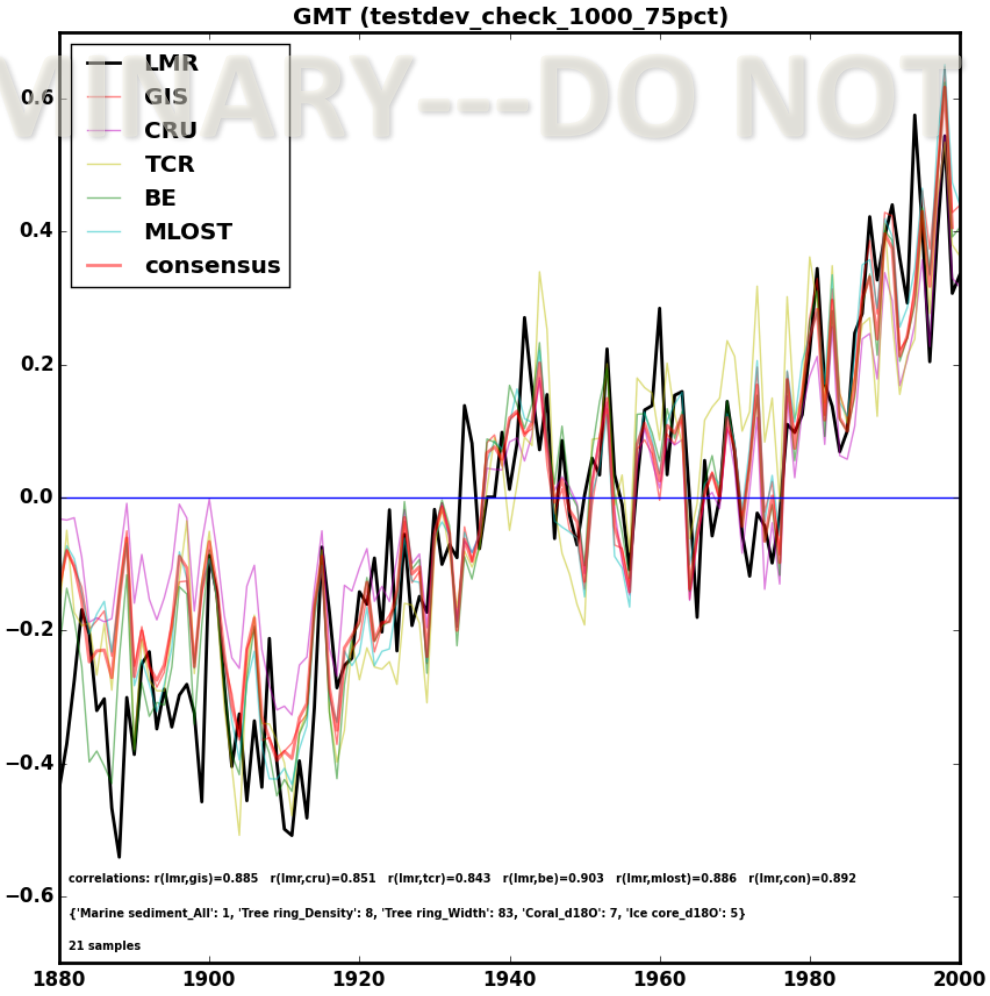


Src: Wikipedia

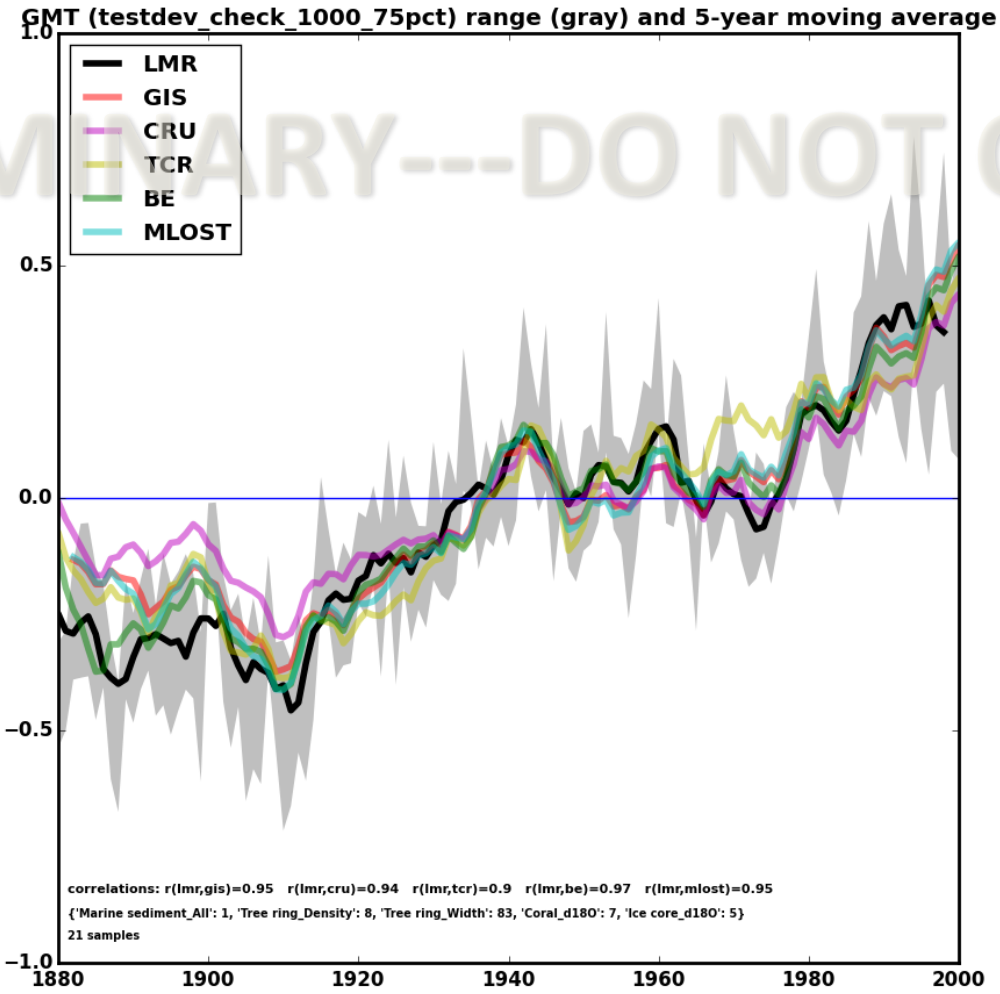
Anomalies relative to 20th century mean

TEST

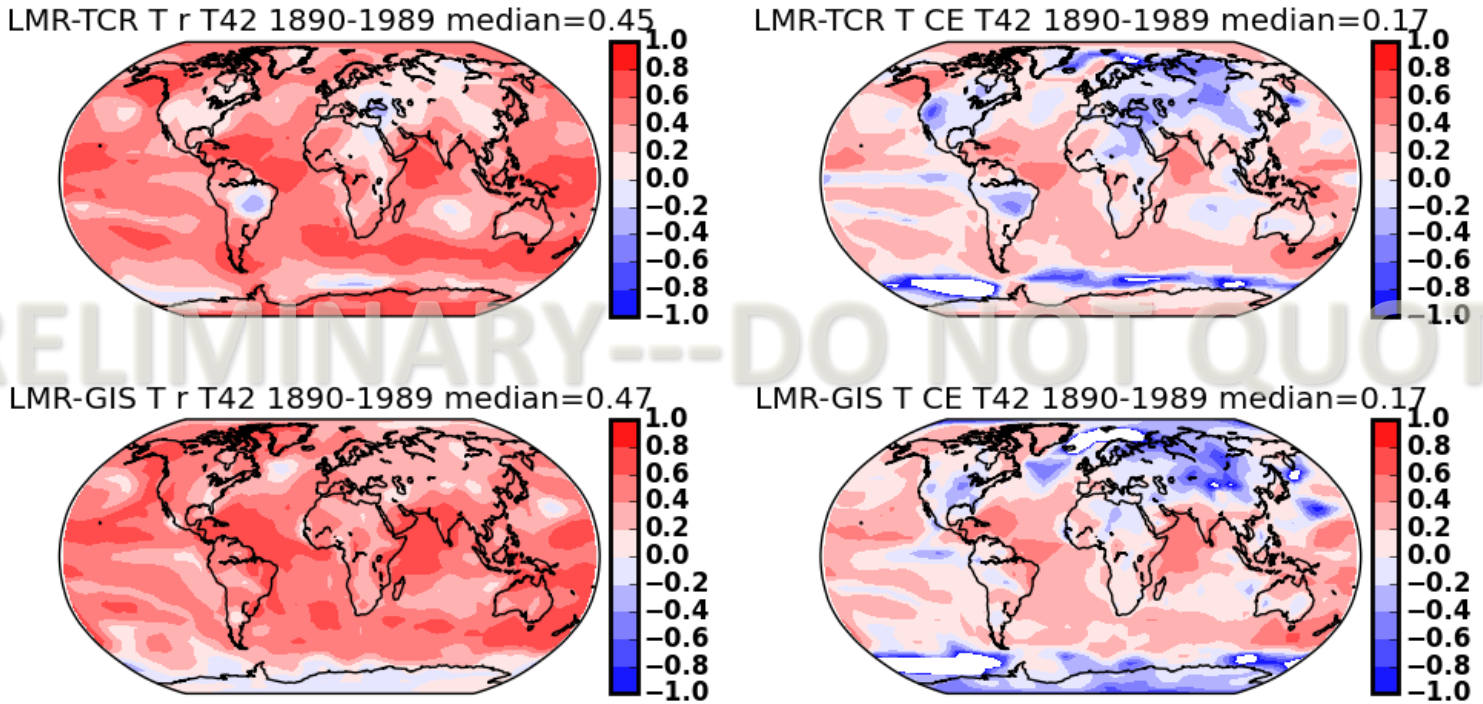
Global Mean Temperature



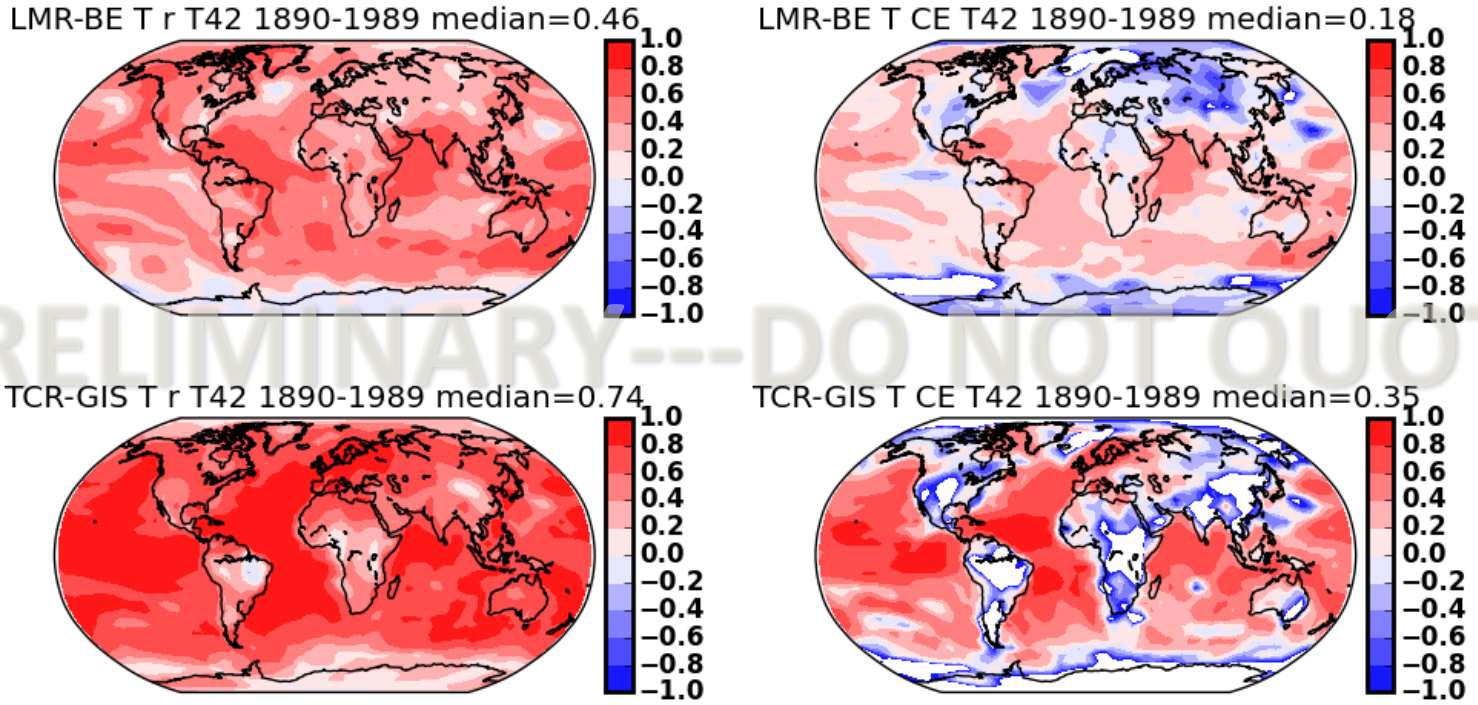
Global Mean Temperature



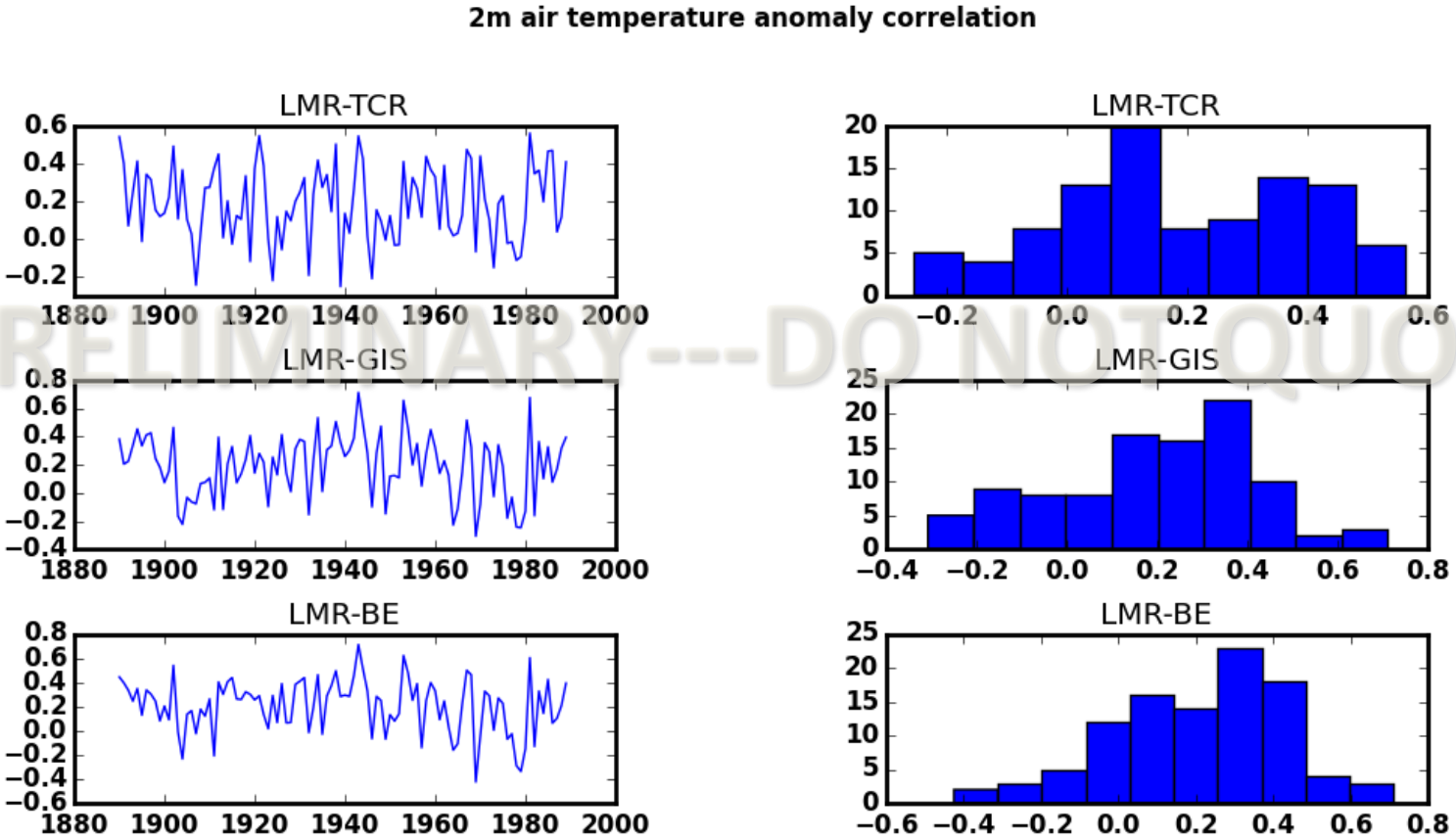
Spatial Verification



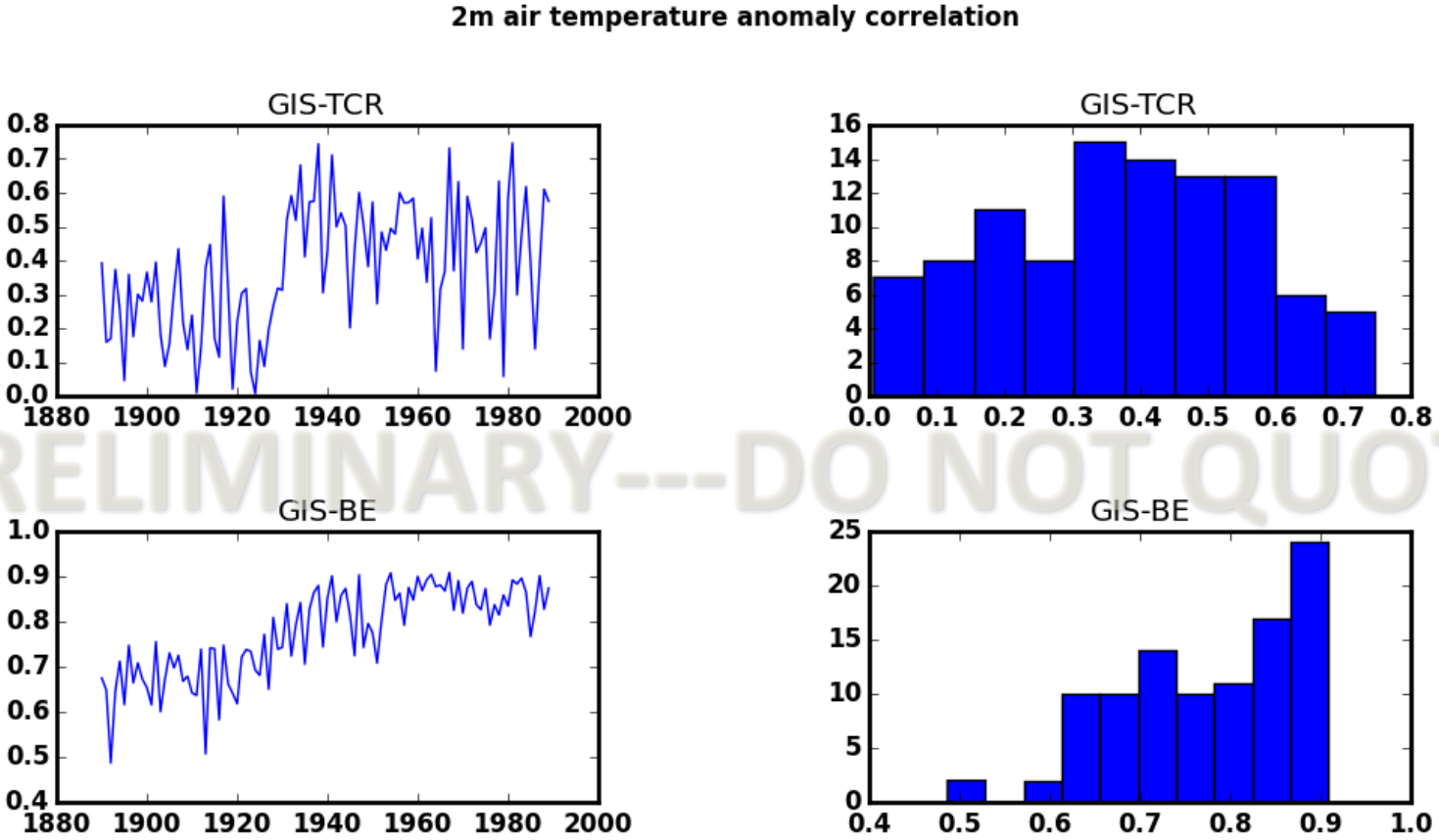
Spatial Verification



Spatial Verification



Spatial Verification



Summary

- LMR: fusion of proxies and climate model data
- Uncertainty quantification is central
  - Instrumental validation
  - Verification against withheld proxies
- On track for initial results after project year one
- Clear upgrade pathway as new proxies & PSMs become ready for testing