Hydroclimate reconstructions with data assimilation

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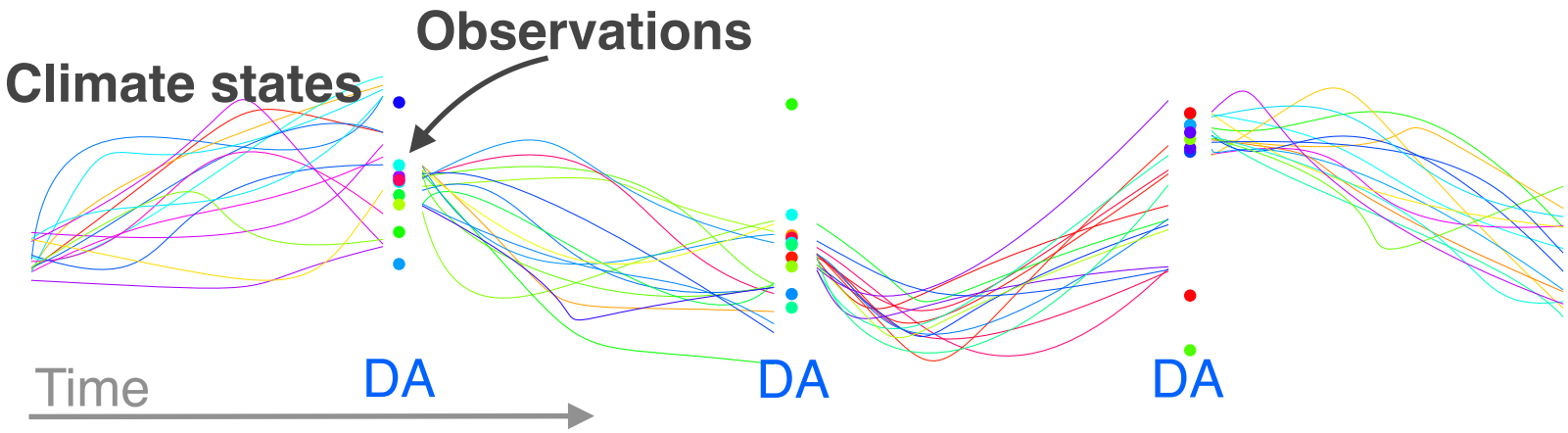
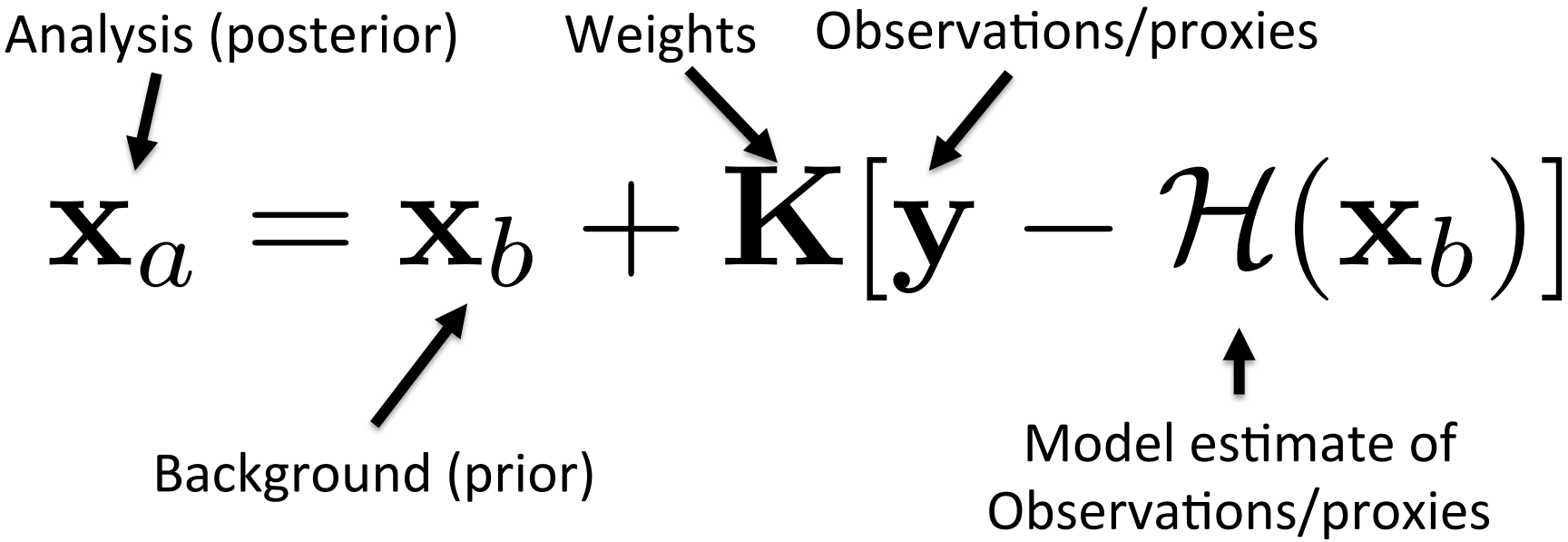
Data Assimilation (DA)

- DA: (Model + ε_m) + (Proxies + ε_p)
- Why use DA for climate reconstructions?
  - Constrains reconstructions with climate physics
  - Reconstructs any climate model variable or related quantity derivable from model variables
  - Provides mechanisms for a given climate change
  - *Can include proxy system models!*

How to imagine ensemble DA?



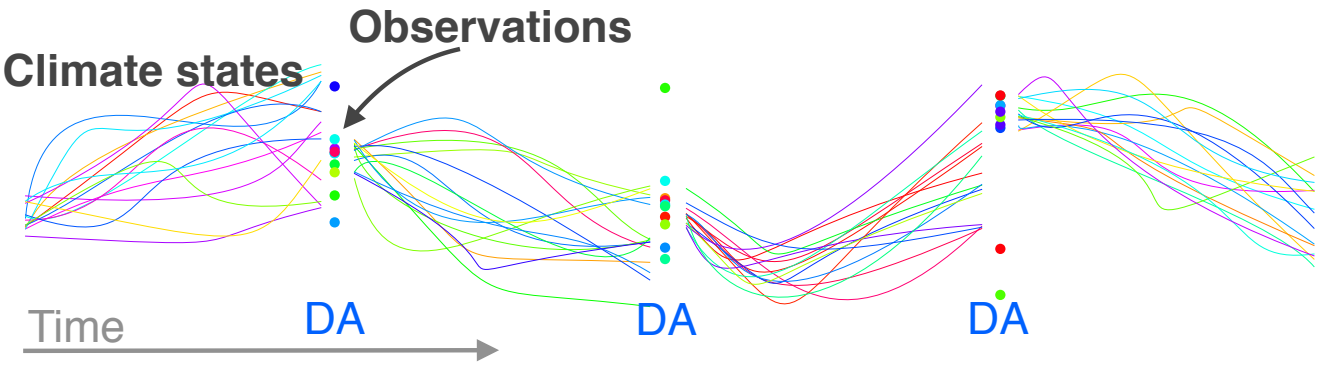
Basic equation of data assimilation



- Basically a least squares estimation
- $\mathbf{K}$ contains model and proxy error estimates as well as covariance information

How to imagine DA?

DA in time



DA in space

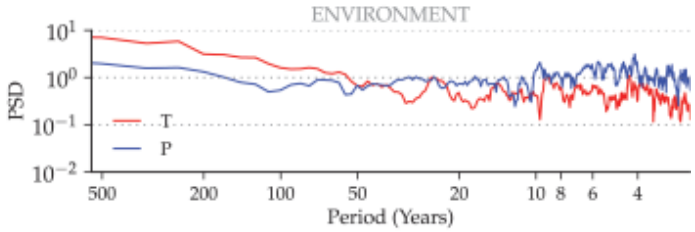
PROXY SYSTEM MODEL: ICE CORE $\delta^{18}O$

Simulated MTM spectra for each transformation, Quelccaya

Monthly

INPUTS:
temperature
precipitation

$T, P, \delta^{18}O_P$



Proxy system models link the proxies and the climate model

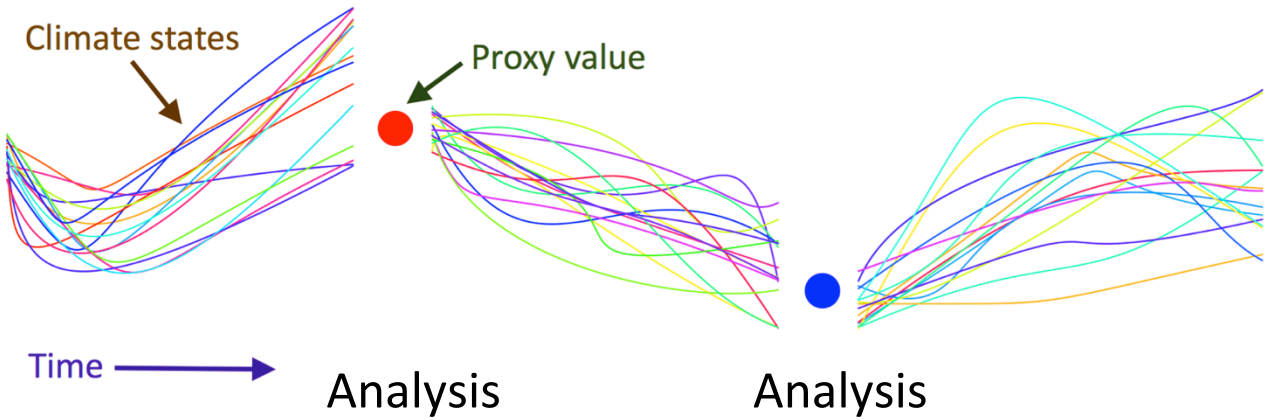
$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{K}[\mathbf{y} - \mathcal{H}(\mathbf{x}_b)]$$

New work incorporating PSMs!

Dee et al. 2015

“Off-line” vs “on-line” DA

If your model has predictive skill



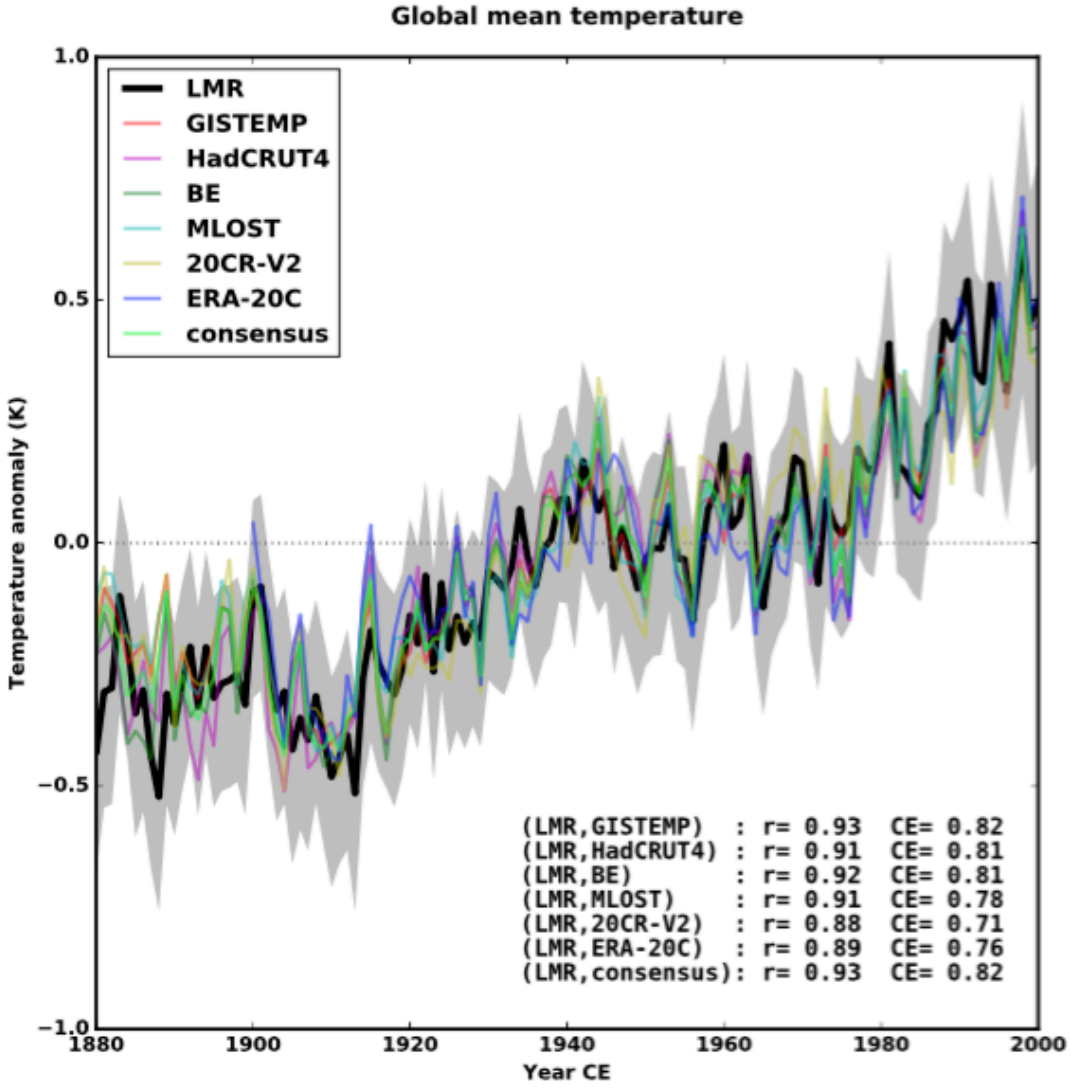
Can skip running the model real-time
Huge computational savings!

Recent DA-based reconstructions: Last Millennium Reanalysis

- Goal: produce an reanalysis-like product over the past millennium (or two) by assimilating proxies
- Time scale of the reconstructions are currently annual
- *"PSMs" are simply linear fits of proxies with temperature*
- Prior = several "past1000" simulations
- "Off-line" DA

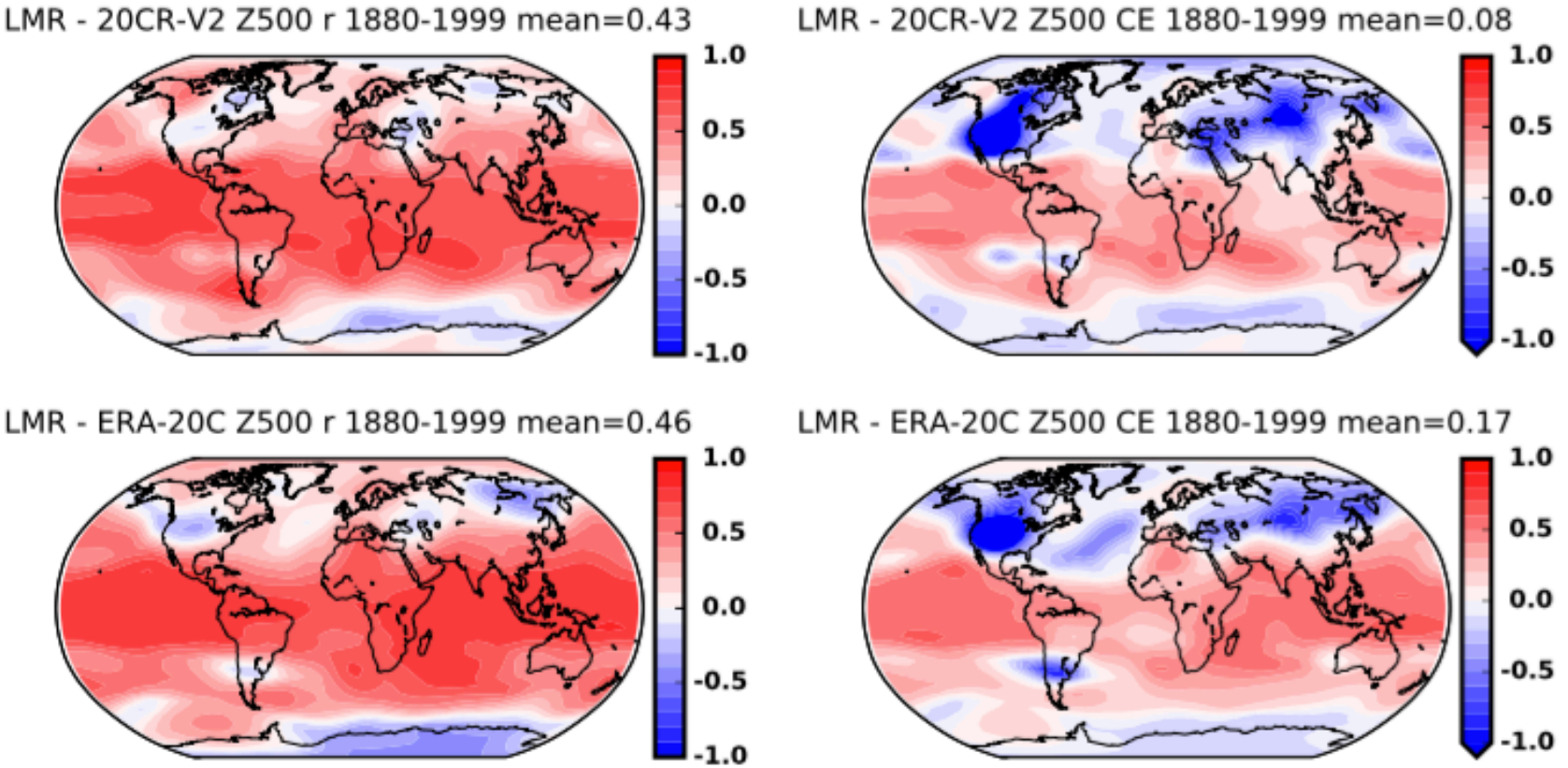
Hakim et al. 2016

Recent DA-based reconstructions: Last Millennium Reanalysis



Hakim et al. 2016

Recent DA-based reconstructions: Last Millennium Reanalysis

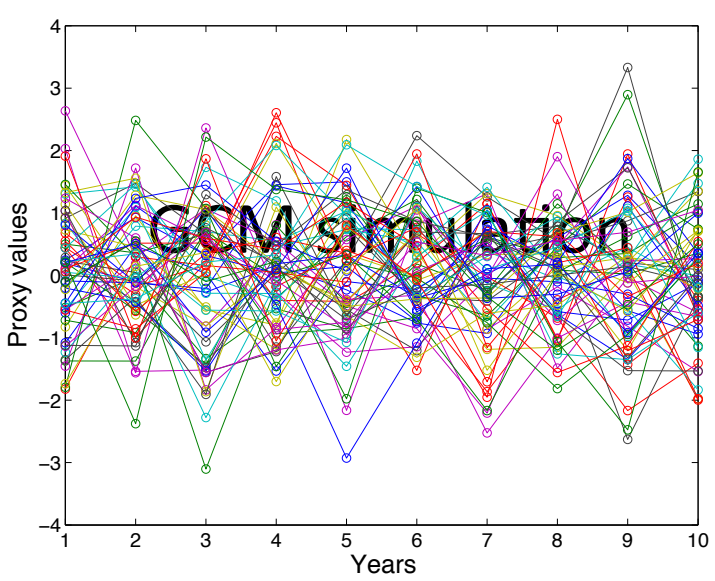


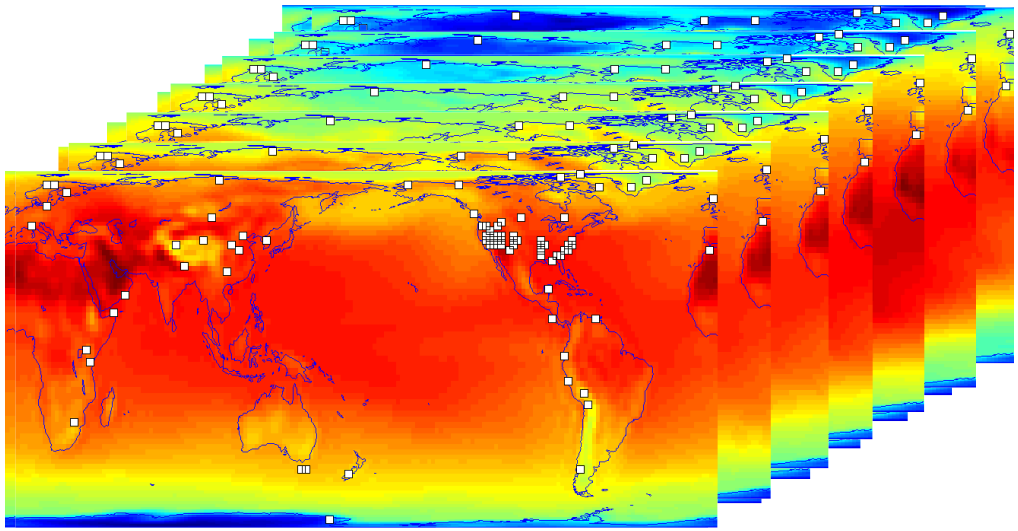
Hakim et al. 2016

Ice core-based reconstructions using real PSMs

- Goal: what can ice cores tell us about past climate over annual and decadal time scales?
- Prior = ECHAM5-wiso & iCESM (both forced with historical SST and sea ice, 1871-2011)
- PSM = $\delta^{18}O$ of precip (from the GCMs) + compaction and diffusion (Dee et al. 2015)
- Both pseudoproxy and real proxy reconstructions

A testbed for climate reconstruction methods: **pseudoproxy experiments**



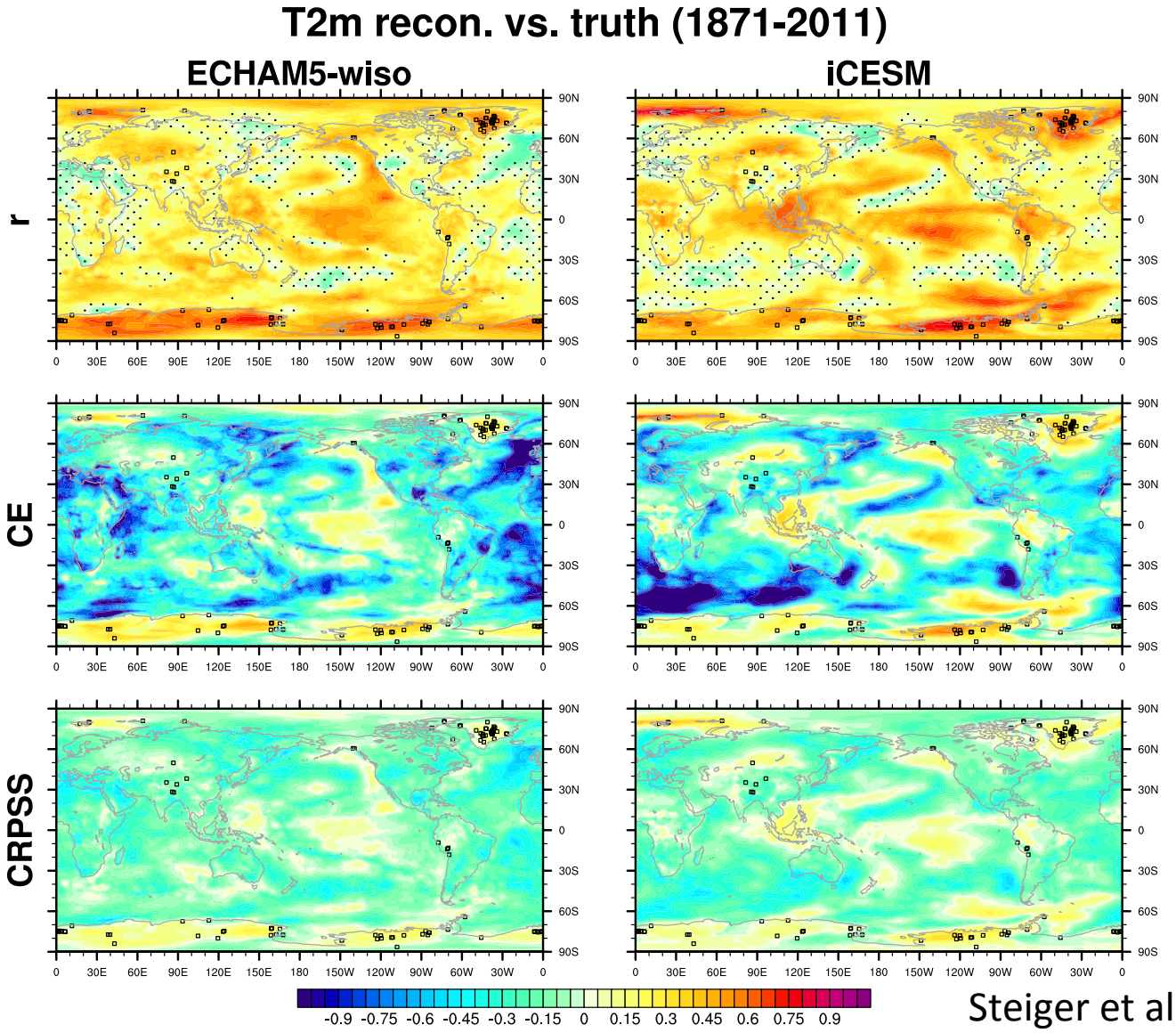


→ Generate pseudoproxies with GCM data at typical proxy locations (use the same PSM to both generate and estimate the proxies)

→ Perform reconstructions within this model world

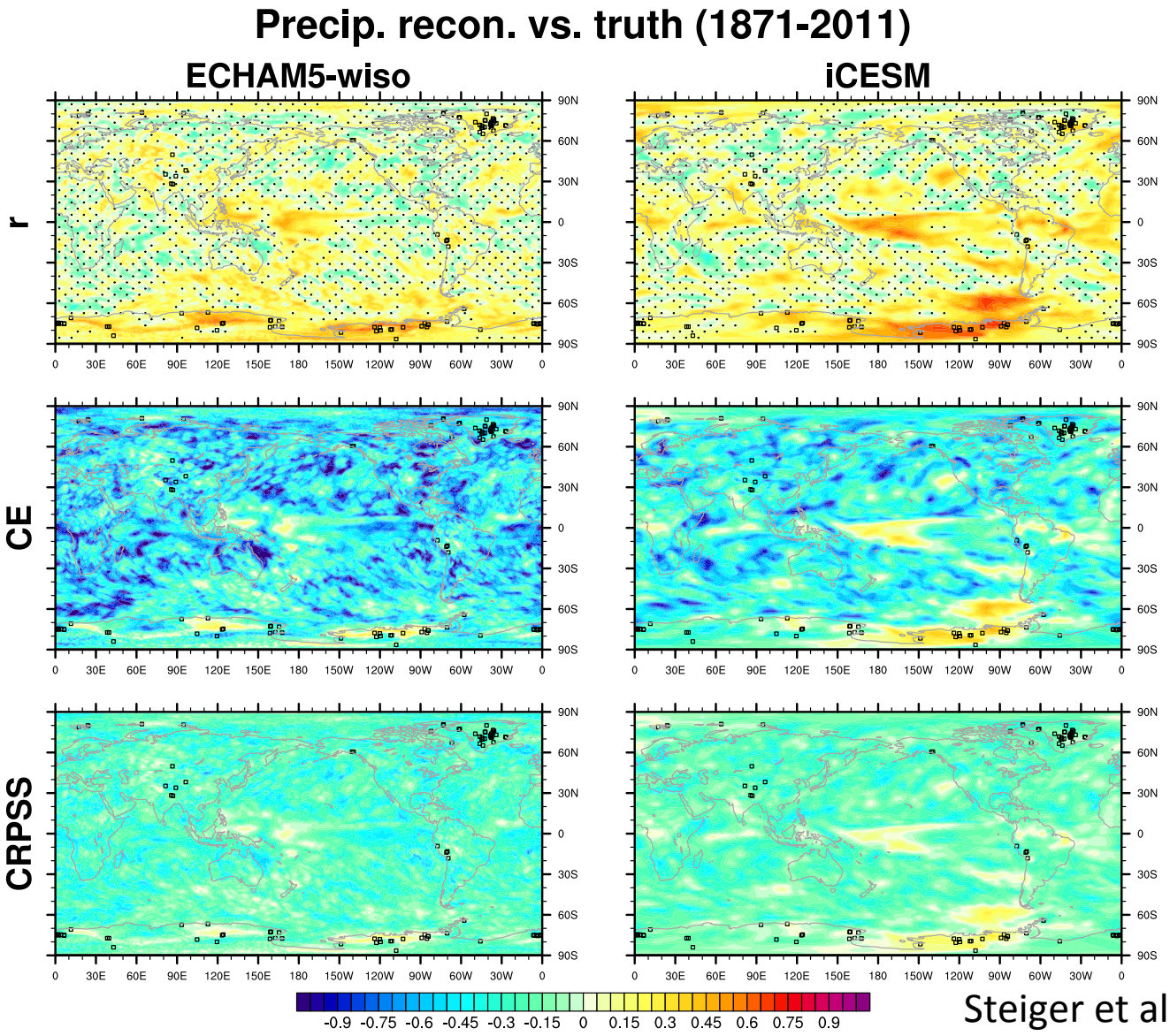
→ *Controlled experiments where the answer is known*

Ice core-based reconstructions



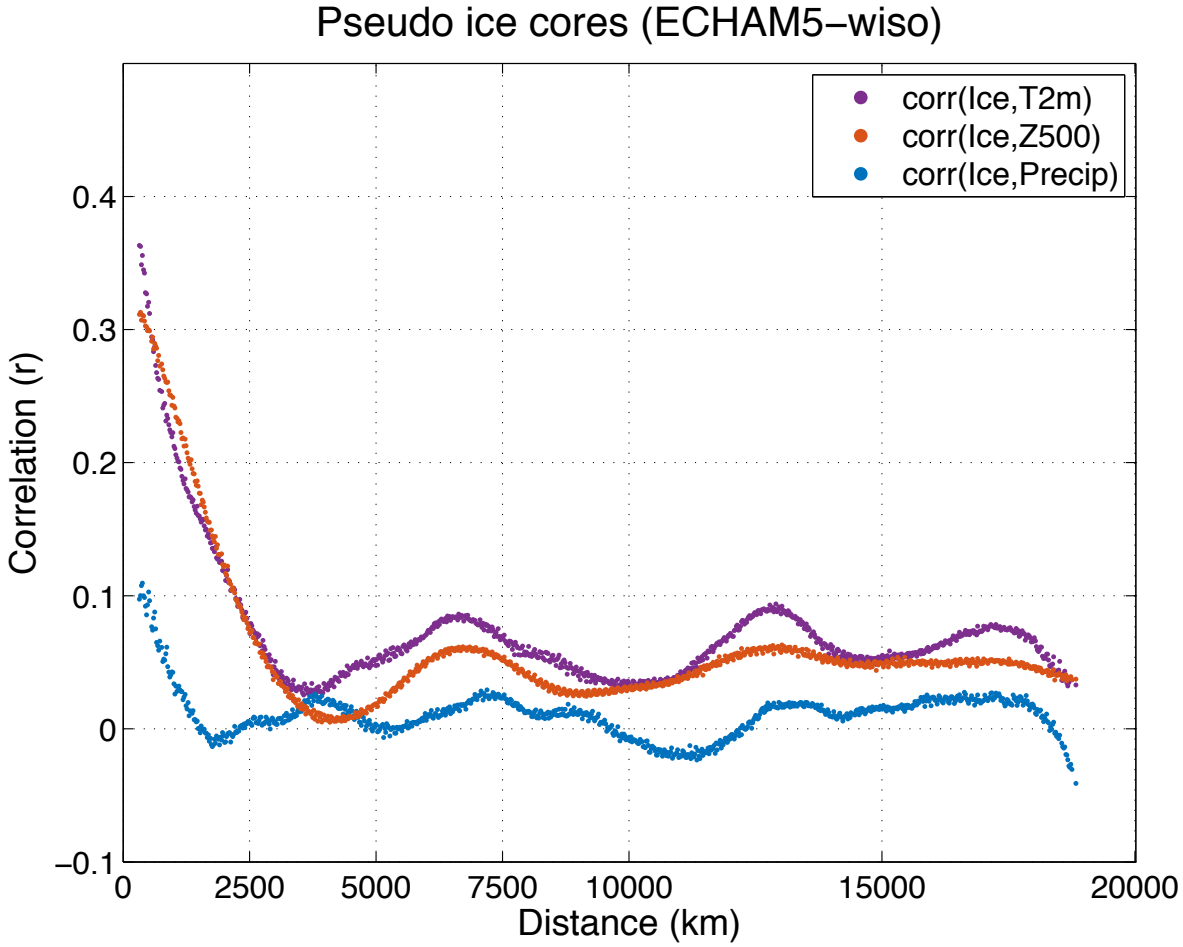
Steiger et al. 2016, sub.

Ice core-based reconstructions



Steiger et al. 2016, sub.

Why can't we reconstruct precipitation with ice core $\delta^{18}O$?



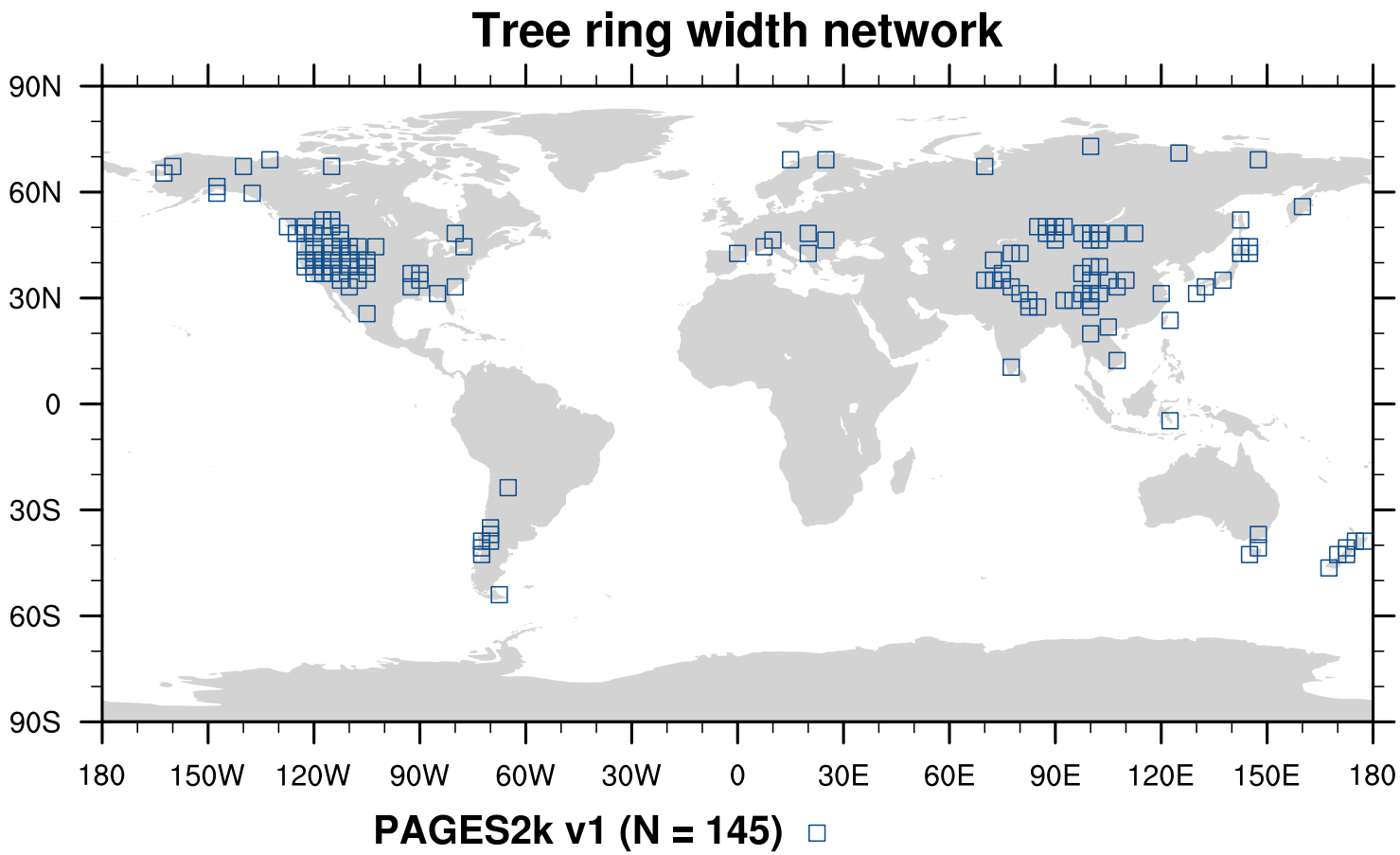
Steiger et al. 2016, sub.

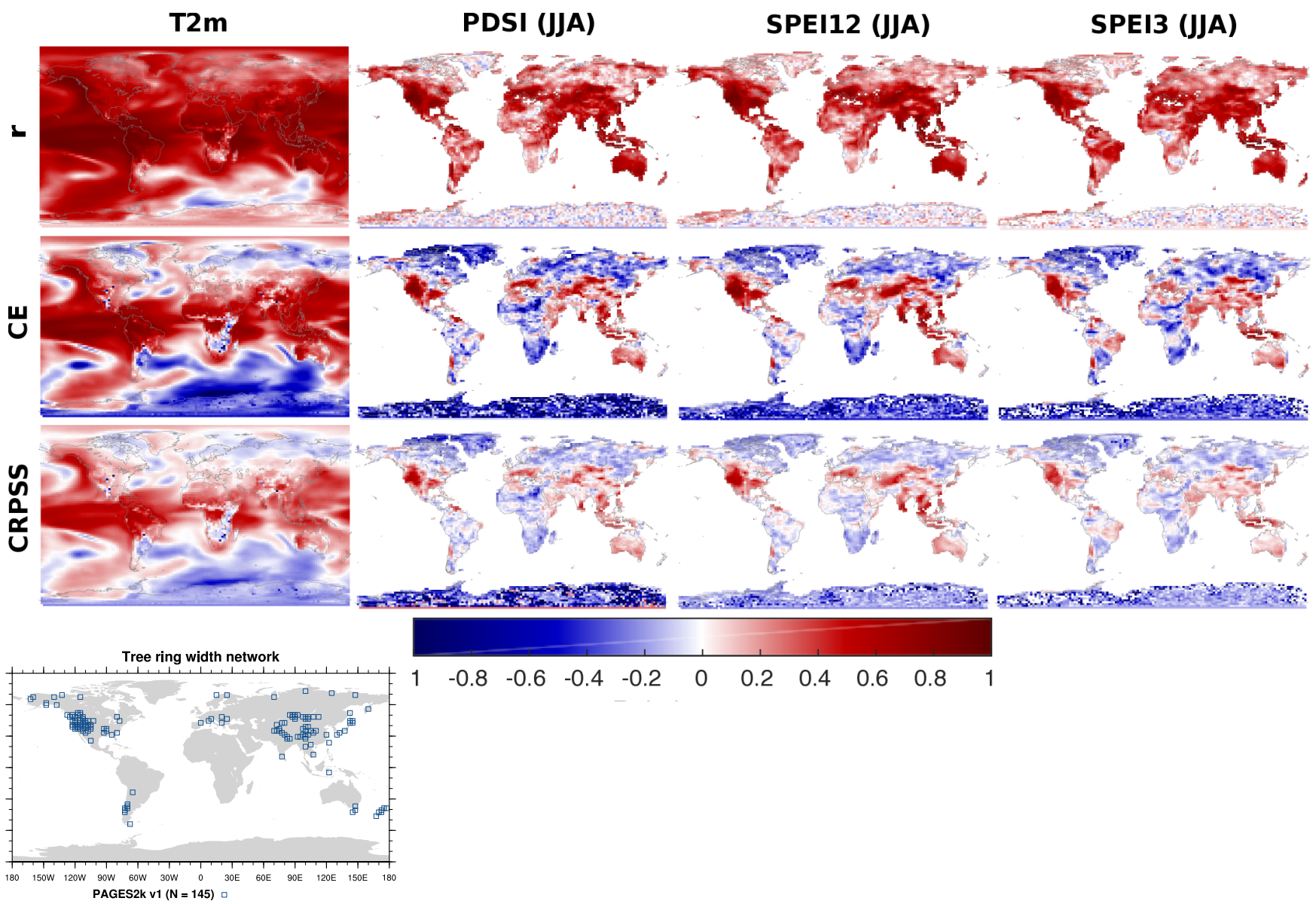
Some initial motivating questions for hydroclimate reconstructions

- Given the many different indicators of hydroclimate,
  - → Which are the most important?
  - → Which are most robustly reconstructed?
- *What are the climate dynamics associated with drought?*

Hydroclimate pseudoproxy experiment

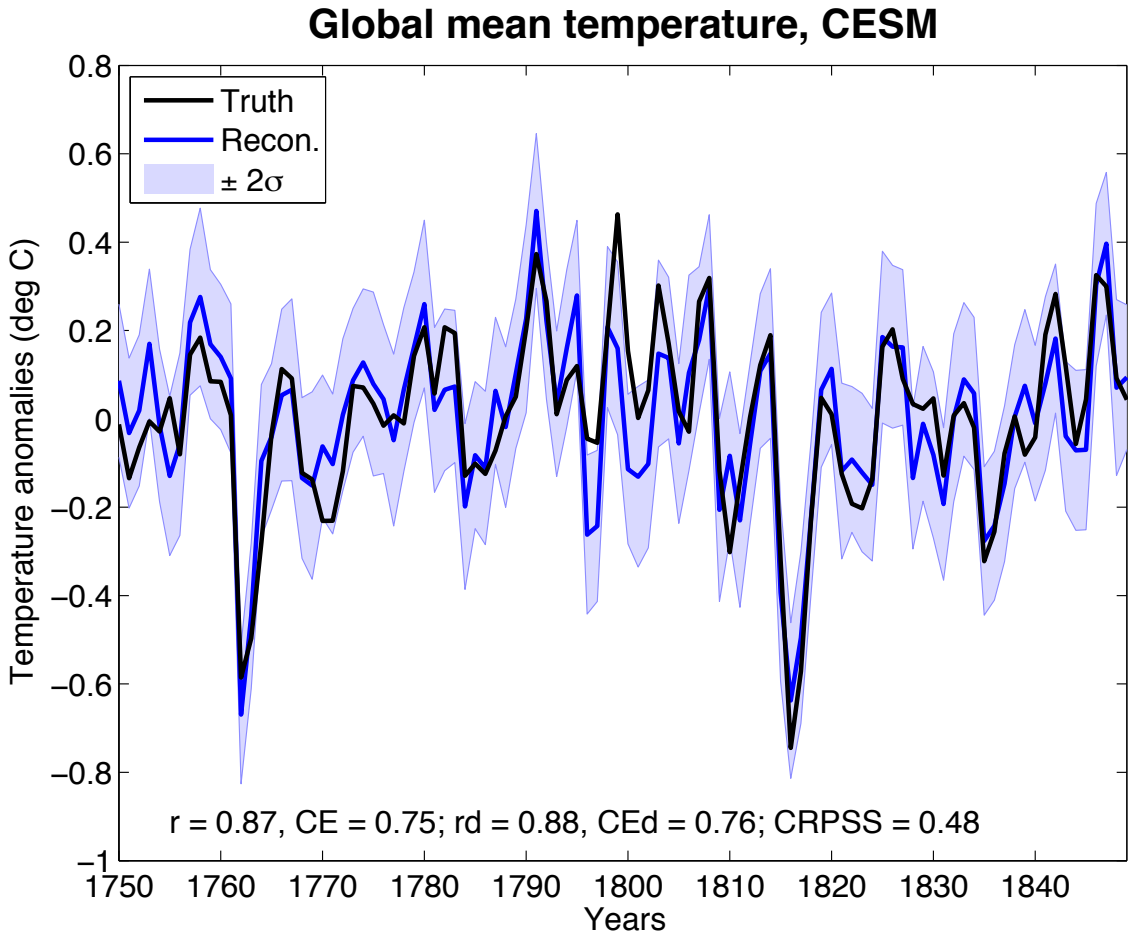
- Use one Last Millennium Ensemble member simulation to reconstruct another (draw 500 year prior from ensemble #9, reconstruct ensemble #10)
- PSM = VS-lite (Tolwinski-Ward 2011) for tree ring width
  - Takes *monthly* inputs of temperature and precipitation (models moisture balance and tree ring growth)
  - Trees can be temperature or moisture limited
- Reconstruct: temperature, PDSI, SPEI12 and SPEI3 (with Gaussian weights)


Tree ring width network
90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
PAGES2k v1 (N = 145)


T2m
PDSI (JJA)
SPEI12 (JJA)
SPEI3 (JJA)
r
CE
CRPSS
1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Tree ring width network
90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
PAGES2k v1 (N = 145)

Conclusions and future directions

- DA + PSMs have promise but they're not without challenges
- Reconstructing precipitation is probably hopeless except in a few locations
- Hydroclimate variables appear to be reconstructable in a DA framework
- Future: dynamical variables associated with drought


Global mean temperature, CESM
Truth
Recon.
± 2σ
Temperature anomalies (deg C)
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
1750
1760
1770
1780
1790
1800
1810
1820
1830
1840
Years
r = 0.87, CE = 0.75; rd = 0.88, CEd = 0.76; CRPSS = 0.48