UNIVERSITÄT BERN

The ModE-RA data set

Palaeoclimate reconstruction using data assimilation

Veronika Valler, Jörg Franke, Eric Samakinwa, Elin Lundstad, Angela-Maria Burgdorf
Ralf, Hand, Yuri Brugnara, Stefan Brönnimann

Oeschger Centre and Institute of Geography, University of Bern, Switzerland

European Research Council
Established by the European Commission

Copernicus Europe's eyes on Earth

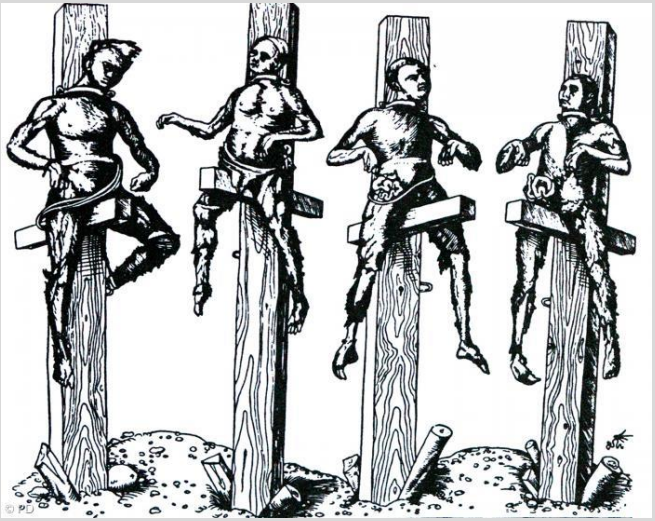
ERA CLIM

ERA CLIM 2

FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

Climate extremes

Looters, 1540



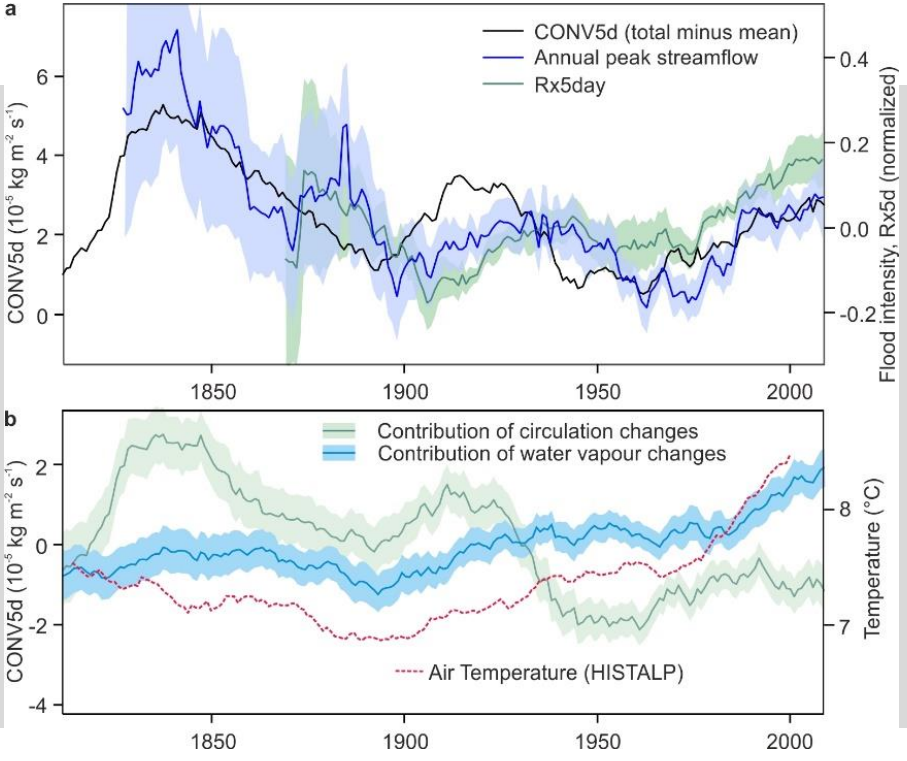
Prices, 1816

Flood, 1855

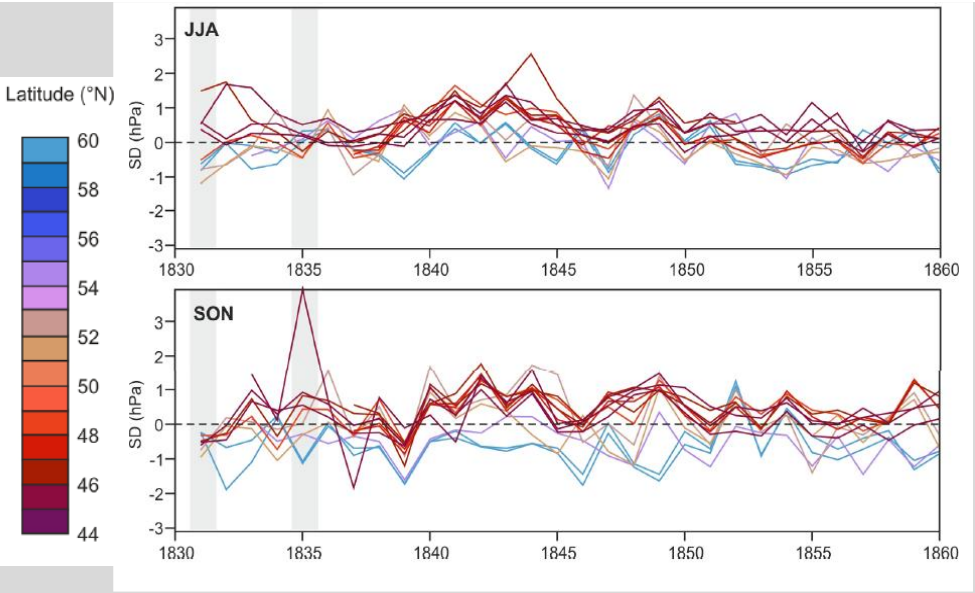
Centennial reanalyses

UNIVERSITÄT BERN

Brönnimann et al. 2019



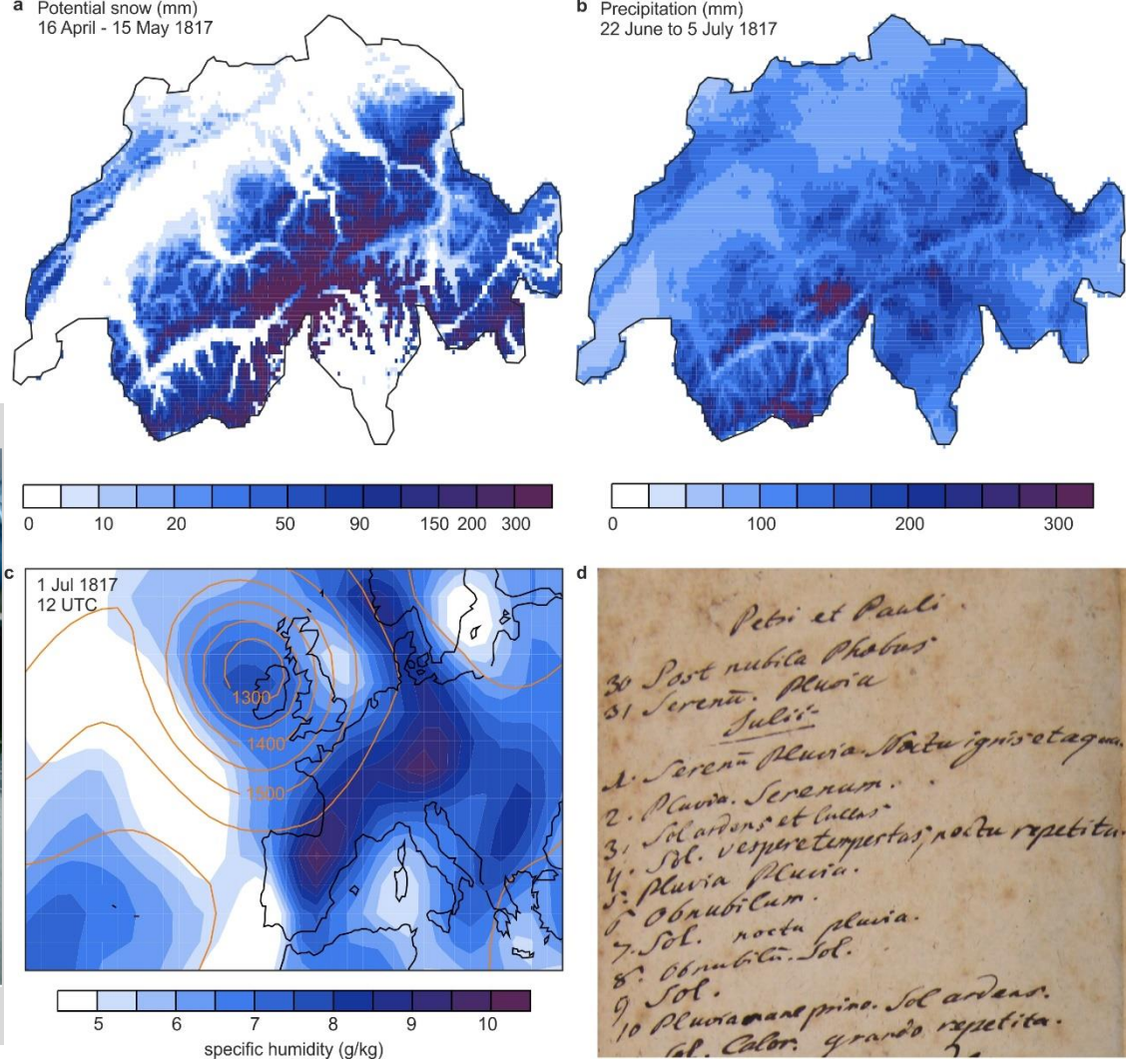
Daily observations



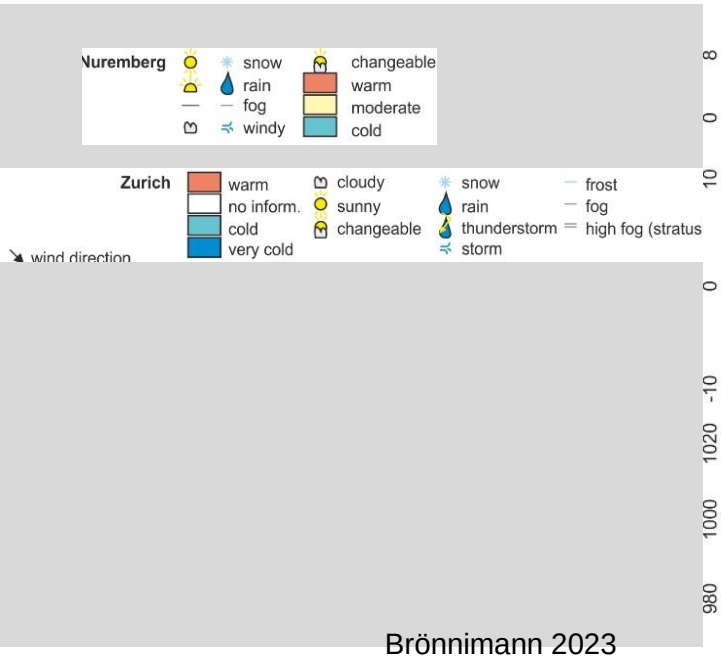
Brönnimann et al. 2019

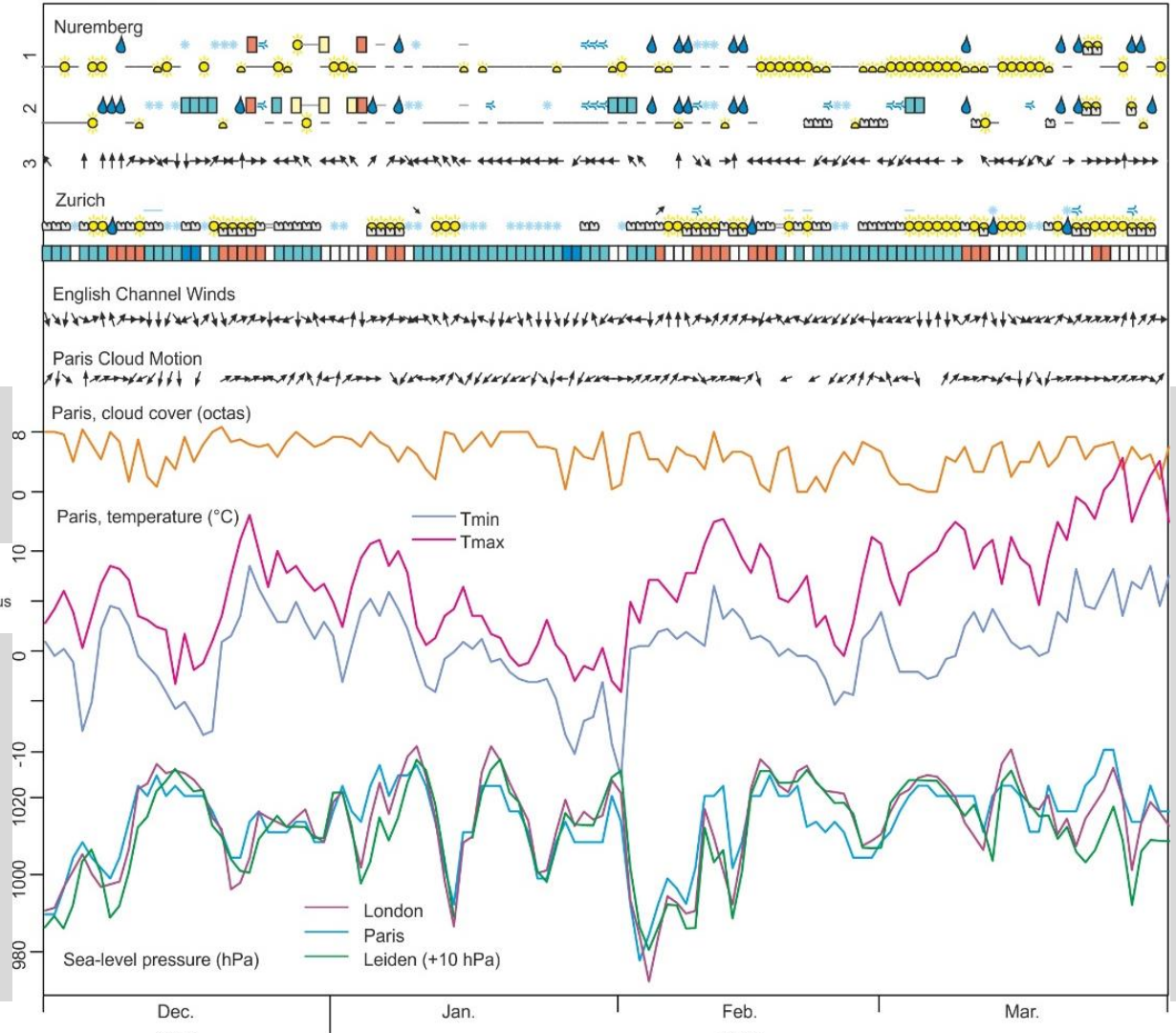
Flood 1817

Rössler and Brönnimann 2018



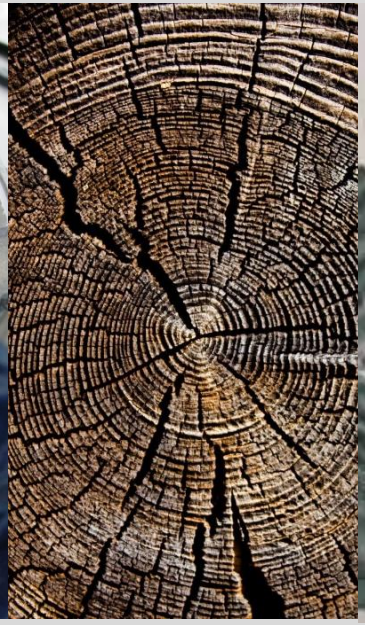
There's a limit

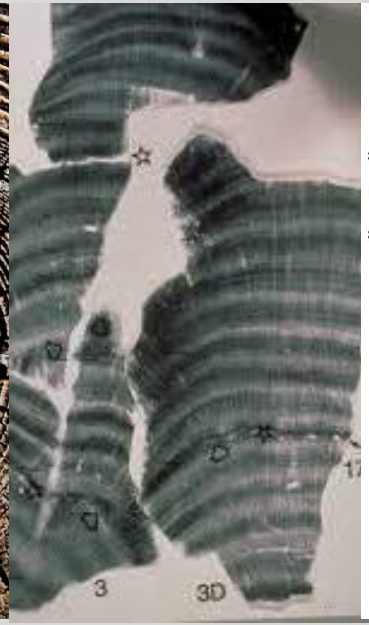


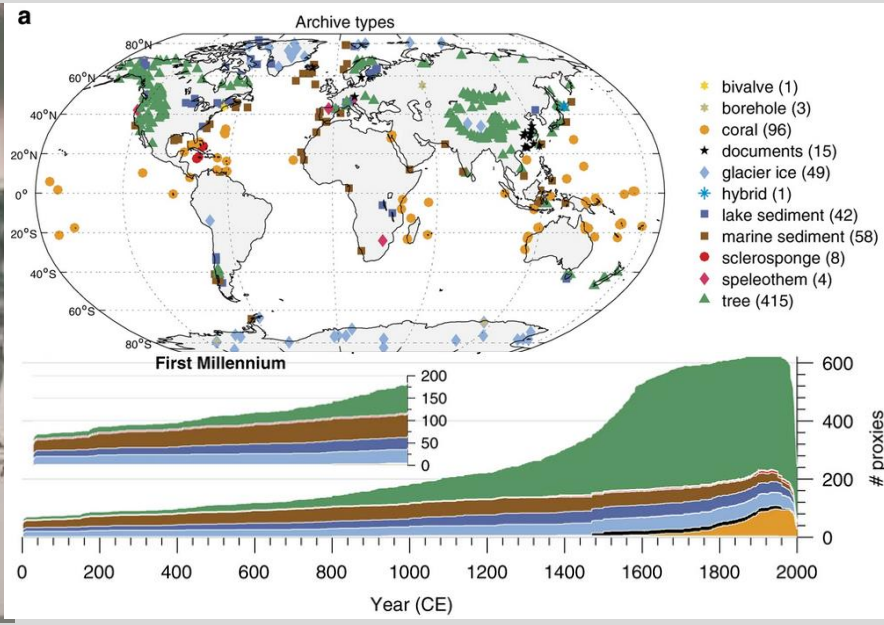


Brönnimann 2023

Annual scale: «Traditional» reconstructions





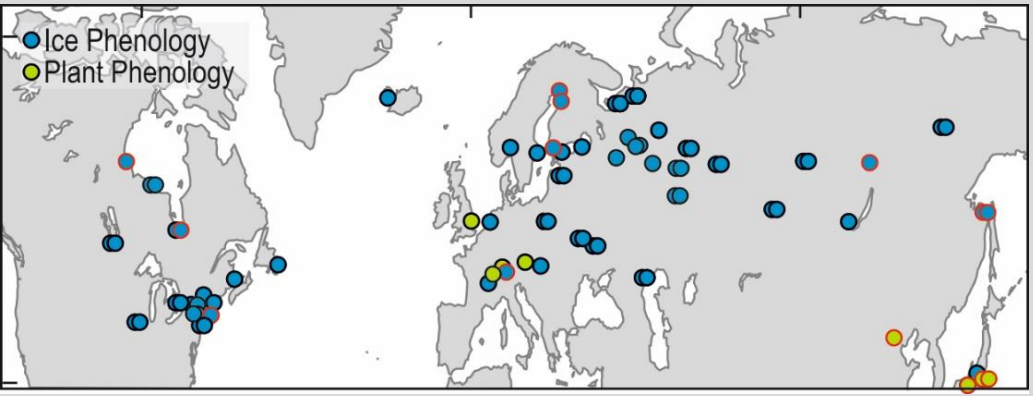


Reconstructions using data assimilation

- Use instrumental data, documentary data, climate proxies
- Off-line assimilation into an ensemble of atmospheric model simulations
- Generate monthly output (6-month assimilation window)

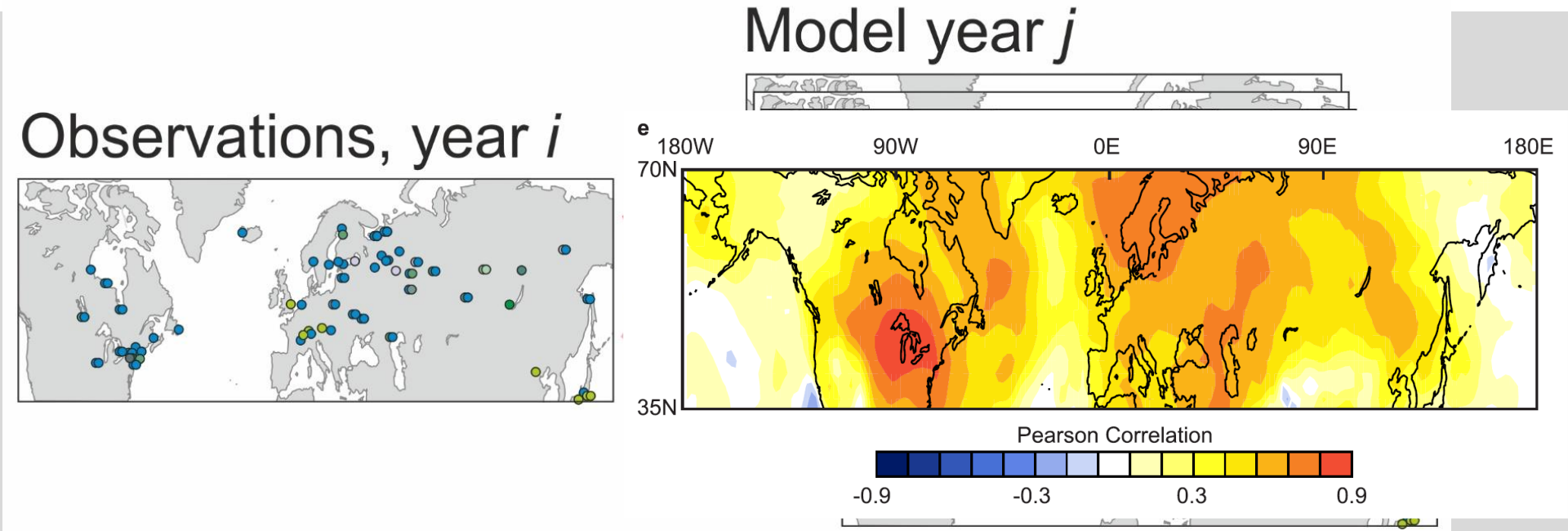
Weighted analog approach

Reconstruct Oct-May T from plant, ice phenology

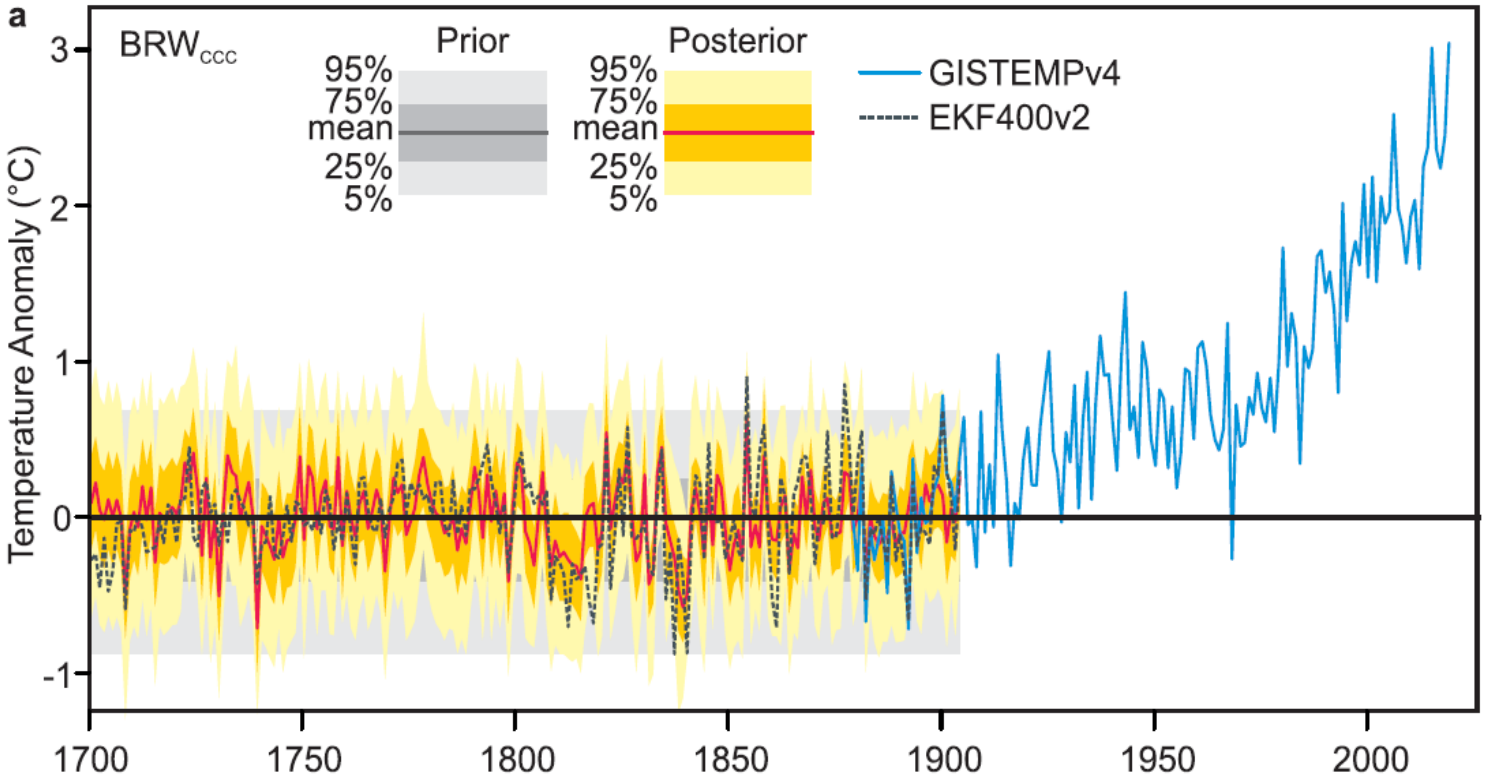


Reichen et al. 2022

Weighted analog approach



Weighted analog approach



Off-line Ensemble Kalman Filter

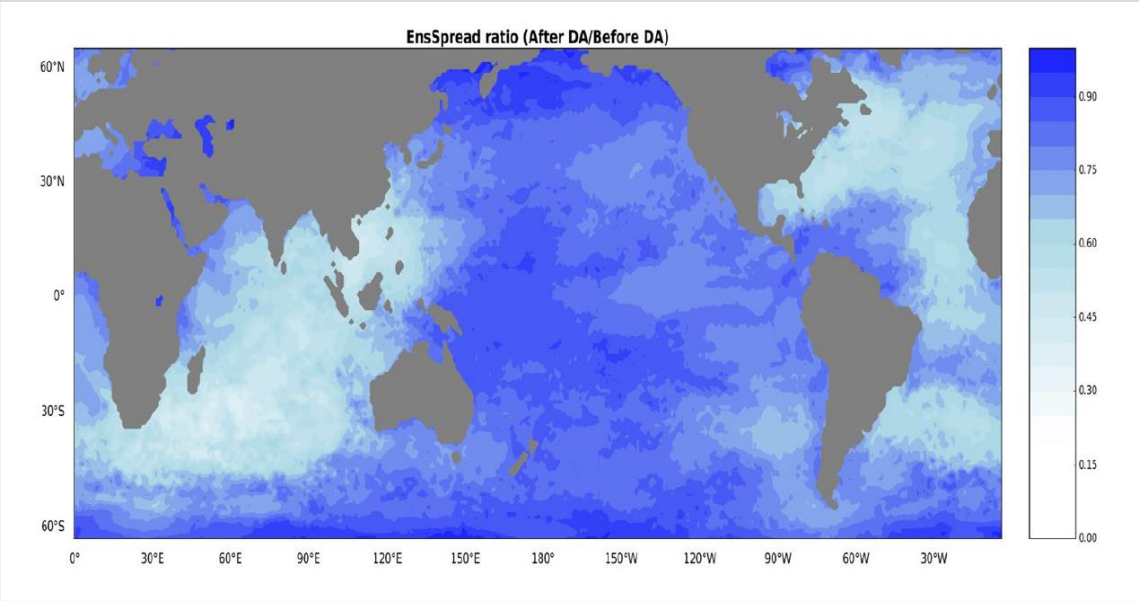
$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x_b})^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x_b}) + (\mathbf{y} - H[\mathbf{x}])^T \mathbf{R}^{-1} (\mathbf{y} - H[\mathbf{x}])$$

where **x** is the analysis,
$\mathbf{x_b}$ the background or first guess,
y the observations,
R the observation error covariance matrix,
B the background error covariance matrix,
H the observation operator

Solution: $\mathbf{x} = \mathbf{x_b} + \mathbf{B}\mathbf{H}^T(\mathbf{R}+\mathbf{H}\mathbf{B}\mathbf{H}^T)^{-1}(\mathbf{y}-H[\mathbf{x_b}])$

UNIVERSITÄT BERN

Sea-surface temperatures

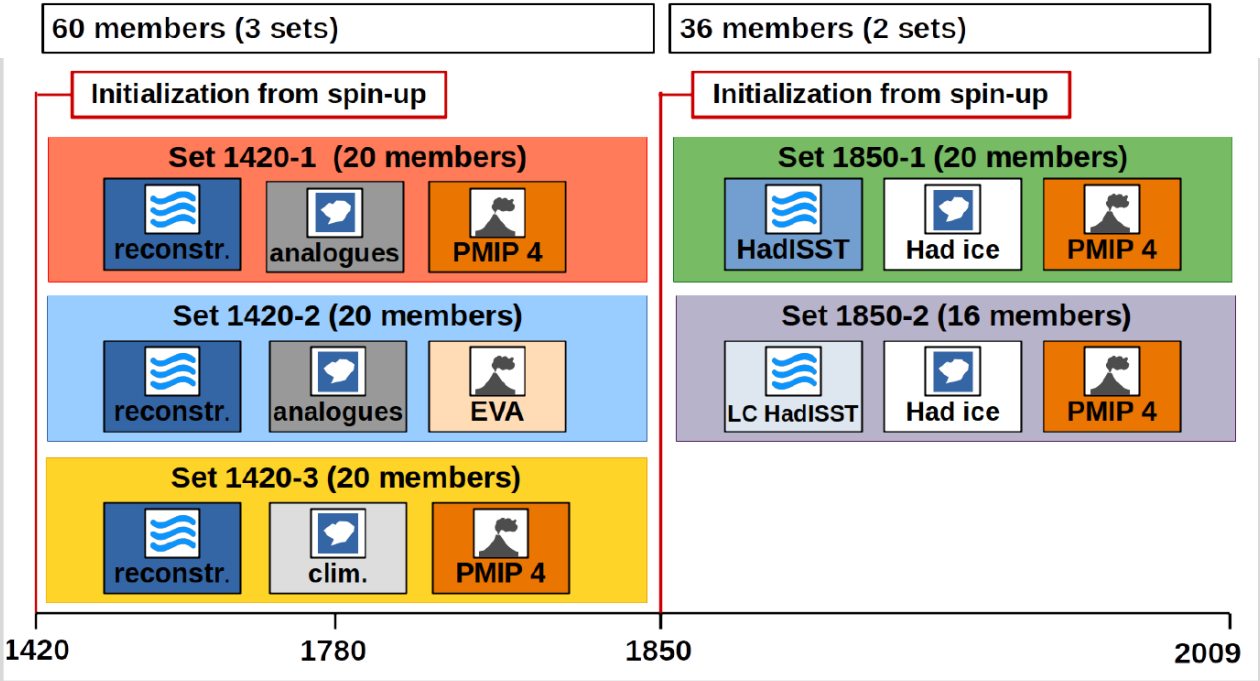


- Based on (annual) PAGES2k reconstructions (analog approach, ensemble)
- add intra-annual variability
- assimilate SST and NMAT (after ca. 1780)
- Climatological sea ice

Samakinwa et al. 2021

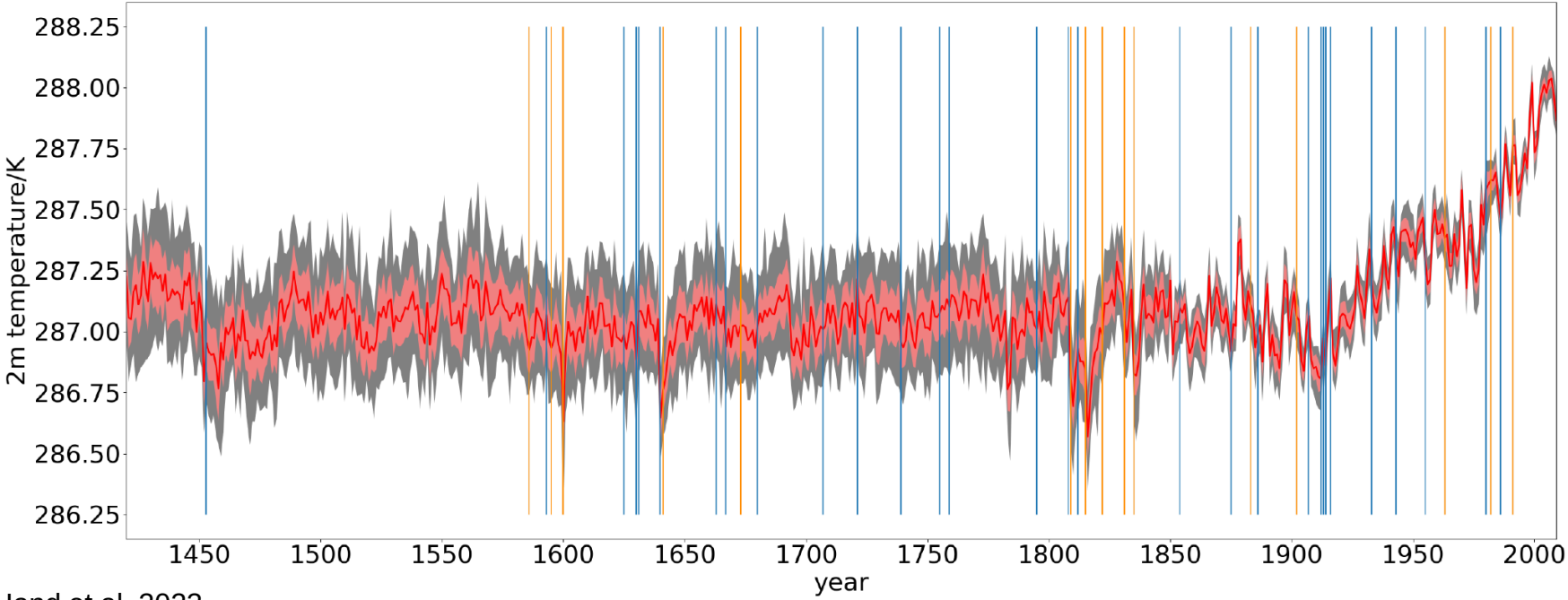
Atmospheric Model Simulations

Model: ECHAM6
Period: 1421-2009
2° x 2° resolution
36 to 60 members
(different initial conditions)
(different SSTs)
(different volcanic forcing)



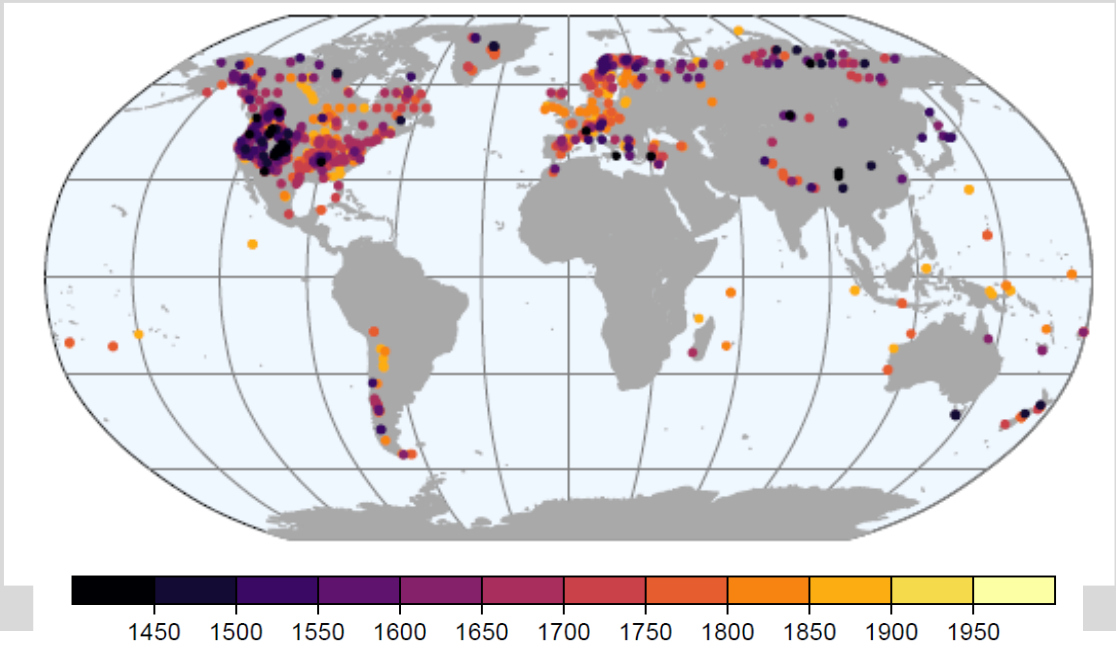
Hand et al. 2023

Atmospheric Model Simulations



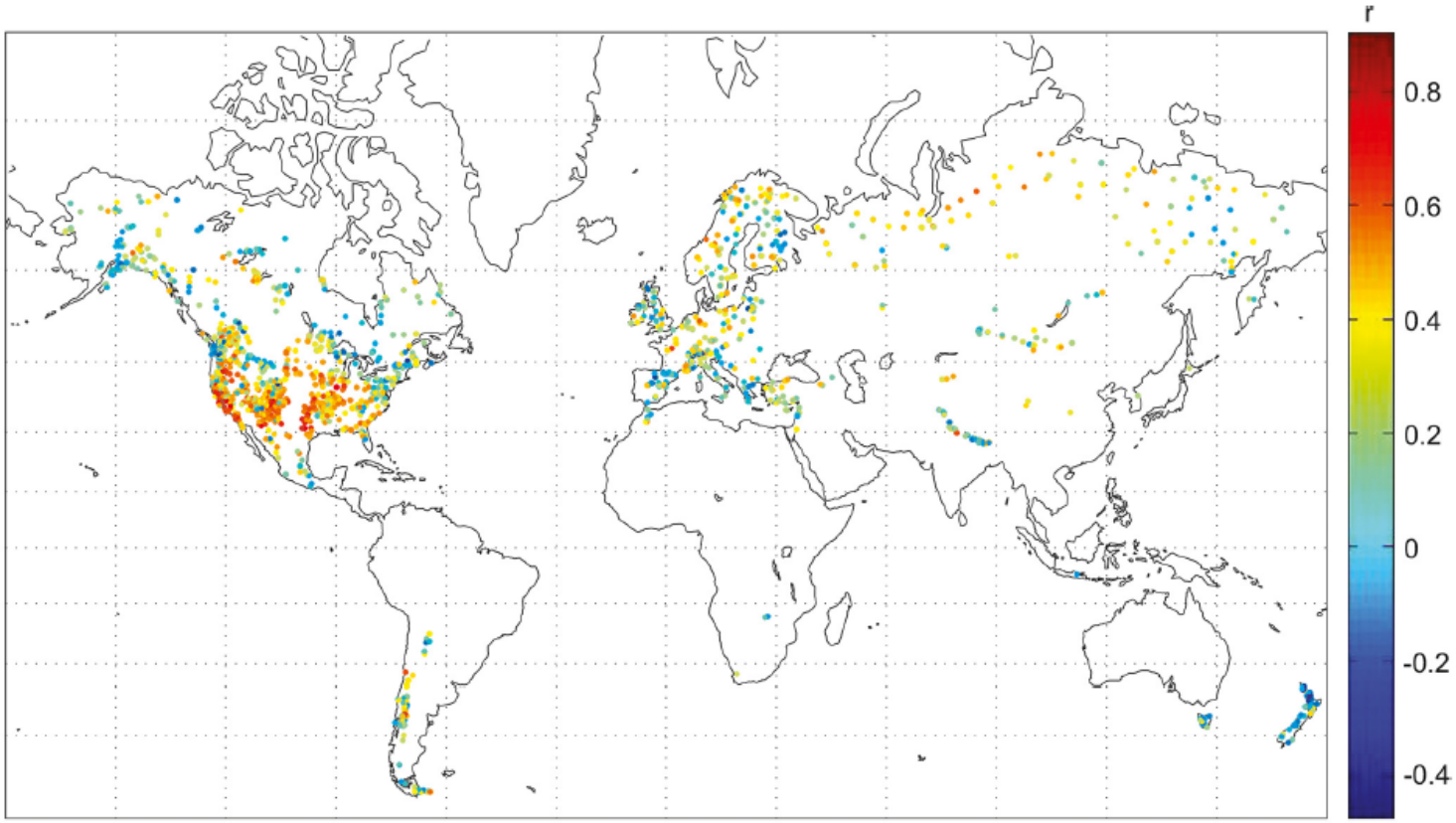
Hand et al. 2023

Natural proxies



Valler et al. (revised)

Proxy forward models

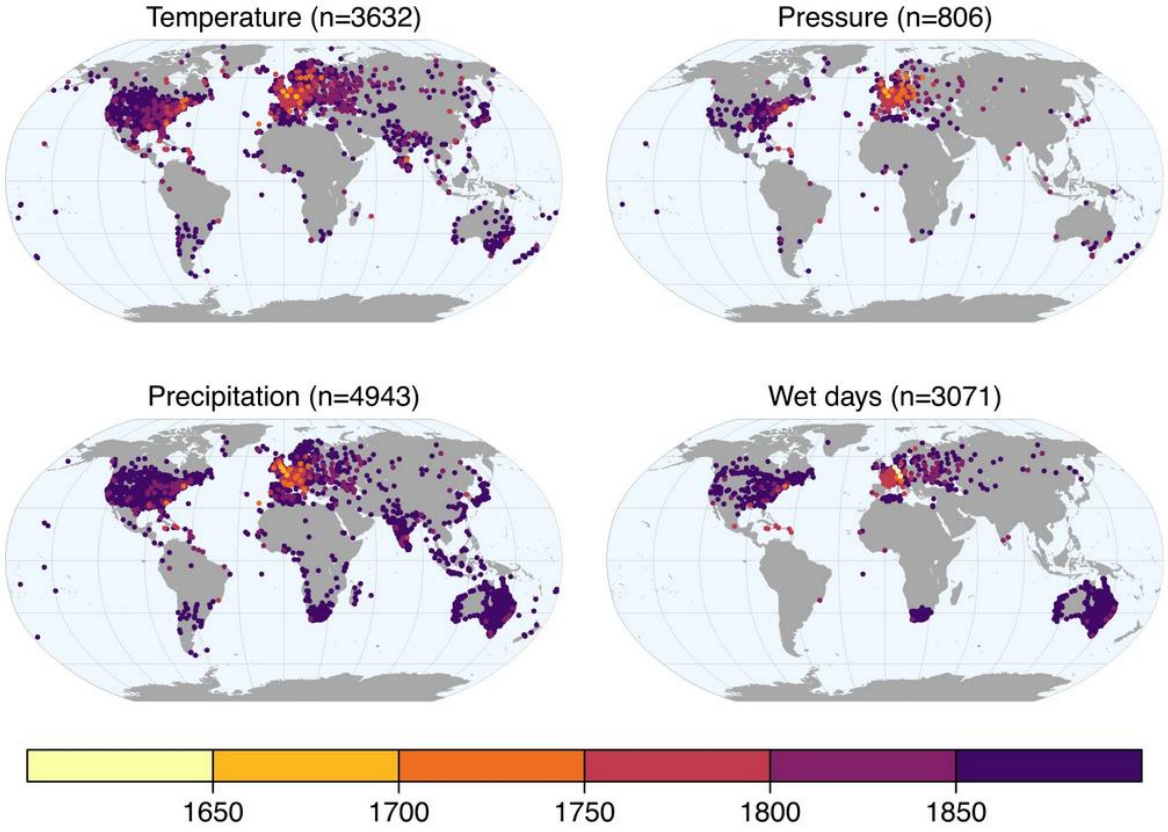


Correlation of modelled tree ring width

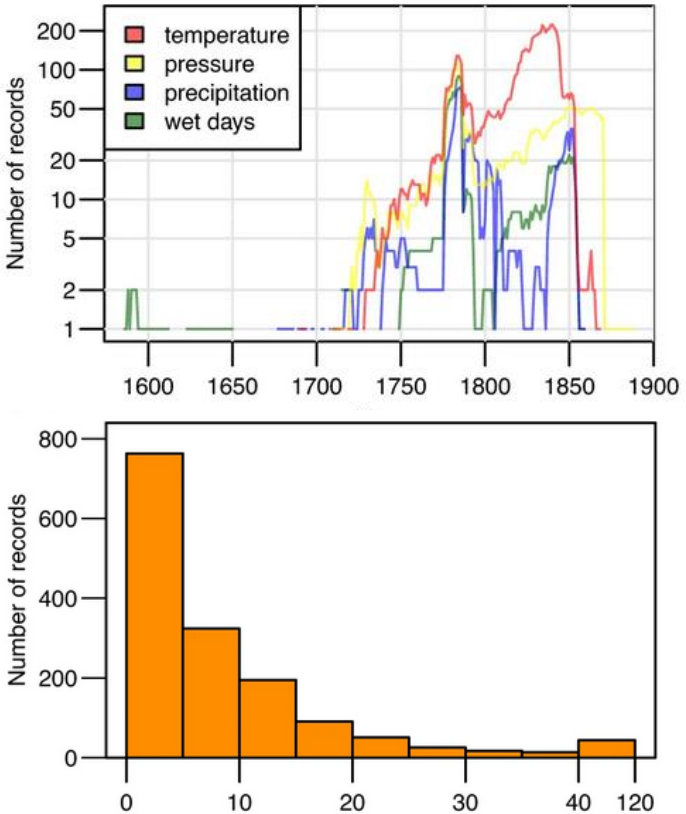
Breitenmoser et al. 2014

UNIVERSITÄT BERN

Instrumental Observations (Land)



Newly digitised:



UNIVERSITÄT BERN

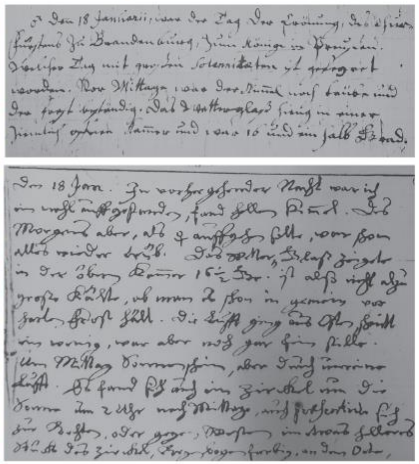
Documentary Records

Freezing/thawing dates

Blossom dates

Harvest dates

Documentary sources

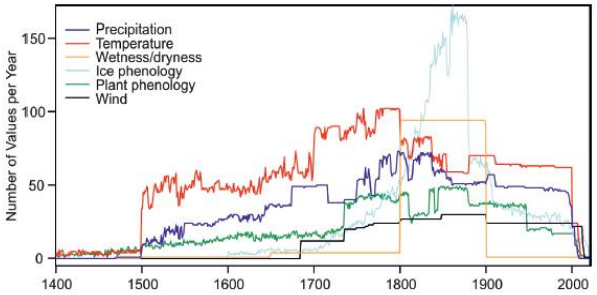


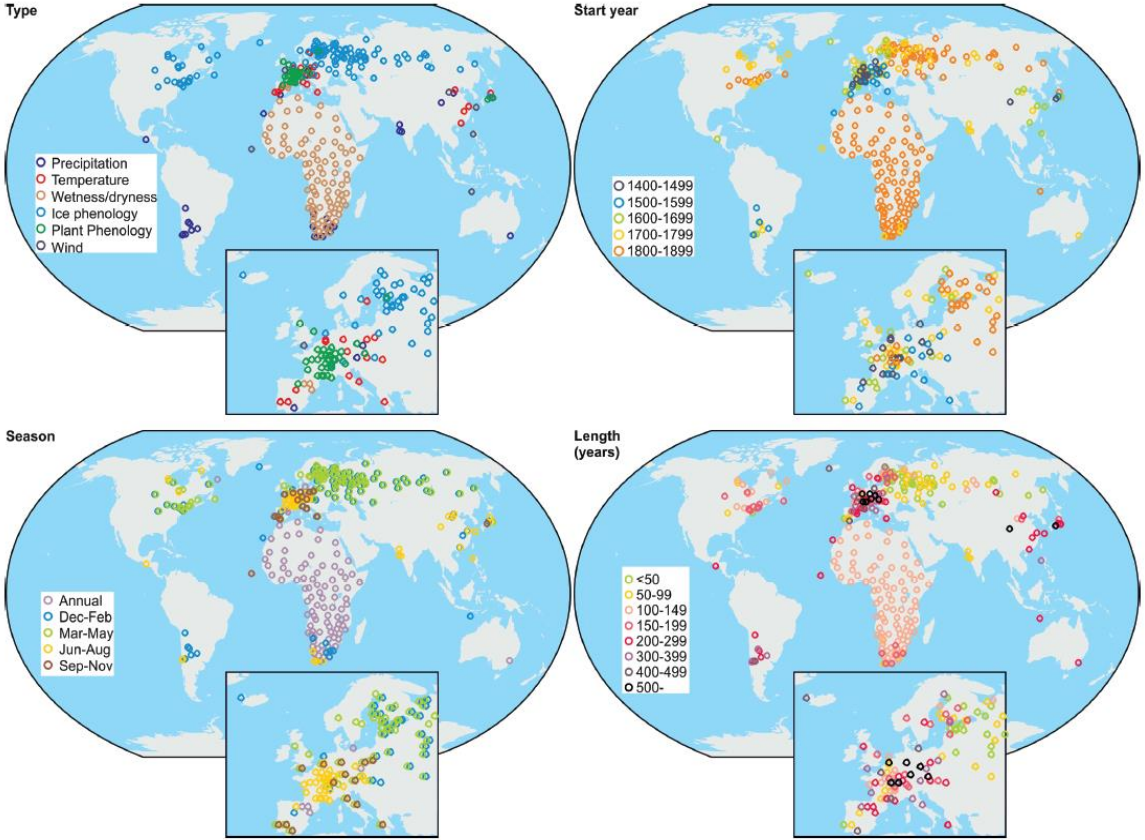
479 series compiled
142 series digitised
DOCU-CLIM = 621 series

Burgdorf et al. 2023

UNIVERSITÄT BERN

Documentary Records

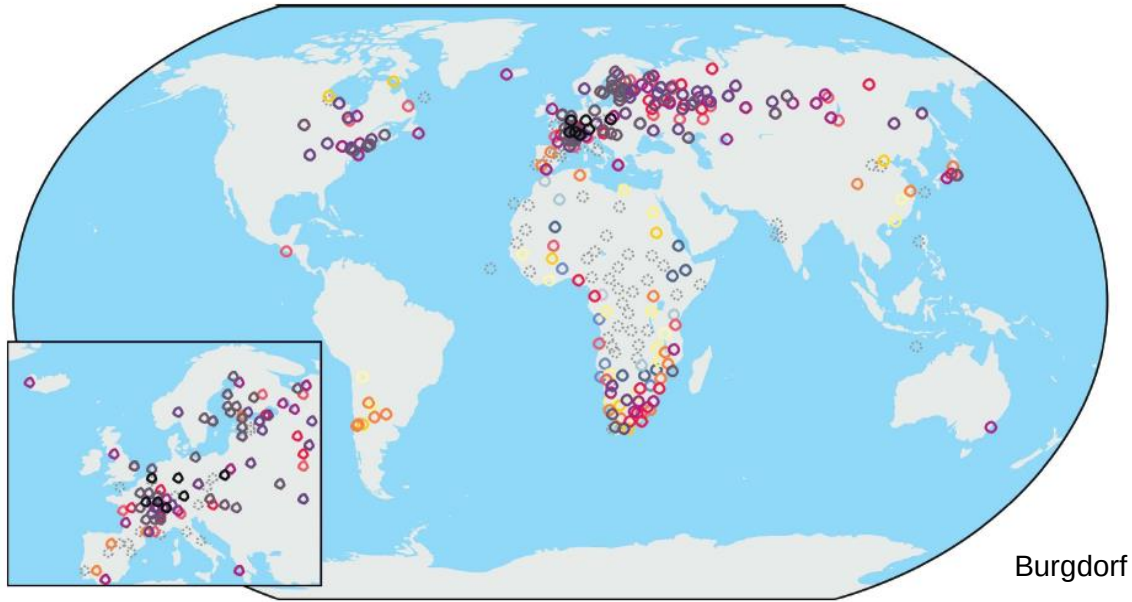


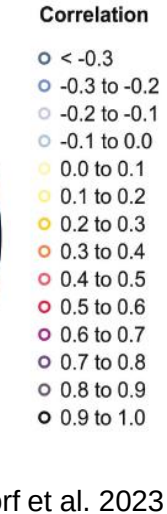


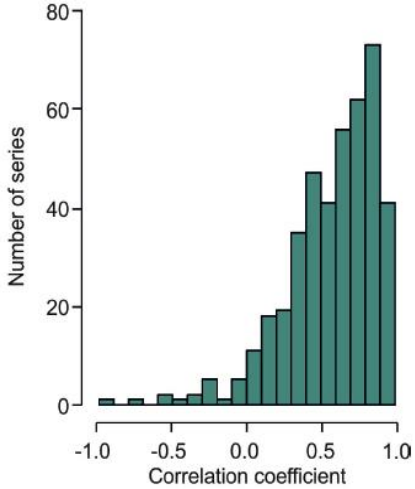
Burgdorf et al. 2023

UNIVERSITÄT BERN

Documentary Records



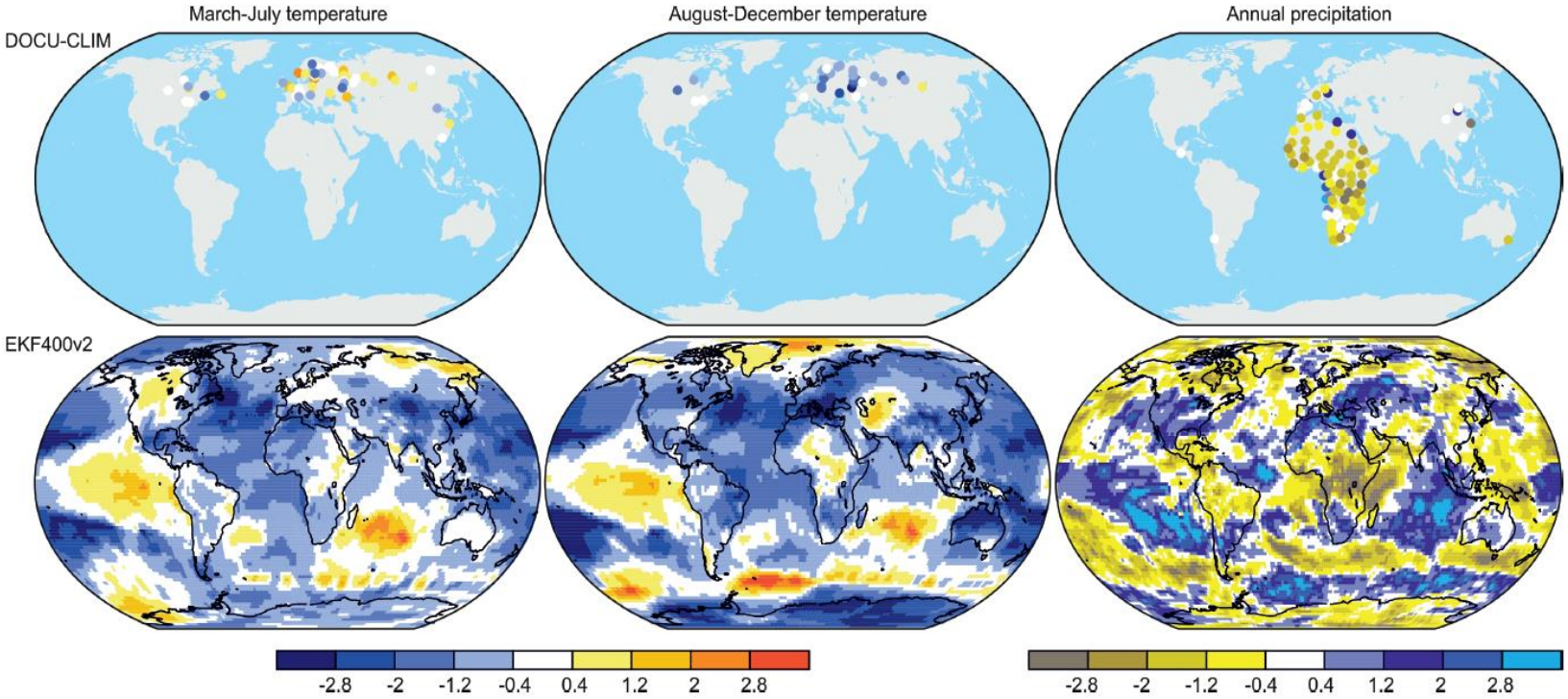




Burgdorf et al. 2023

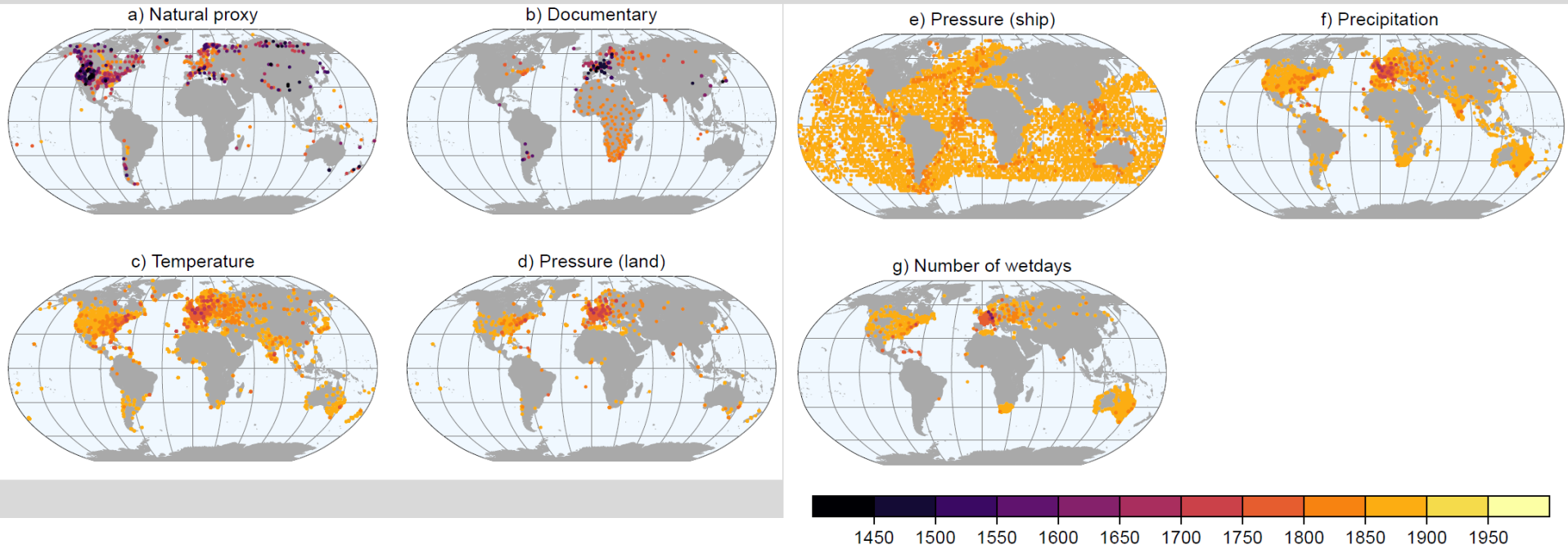
UNIVERSITÄT BERN

Documentary Records

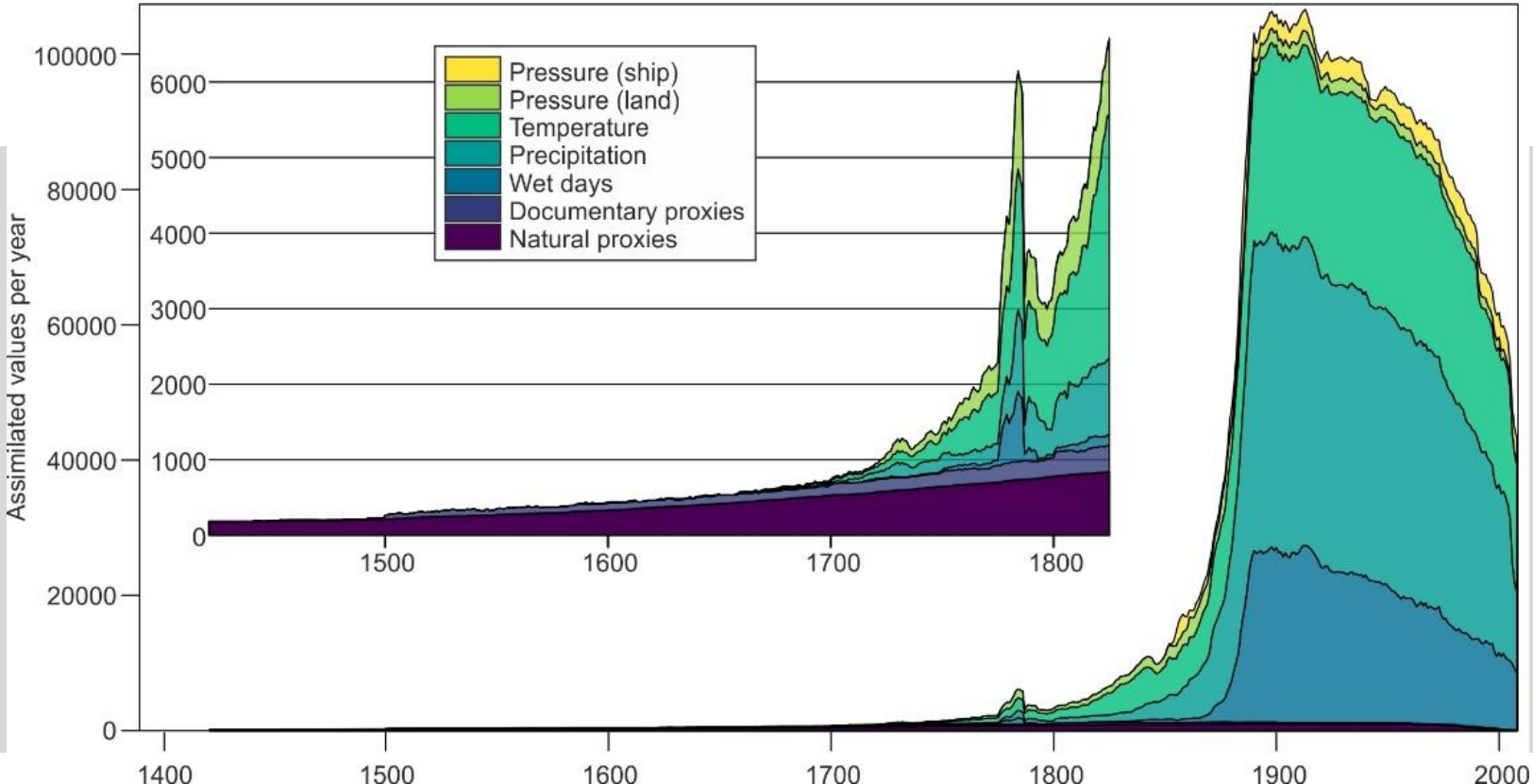


UNIVERSITÄT BERN

All records



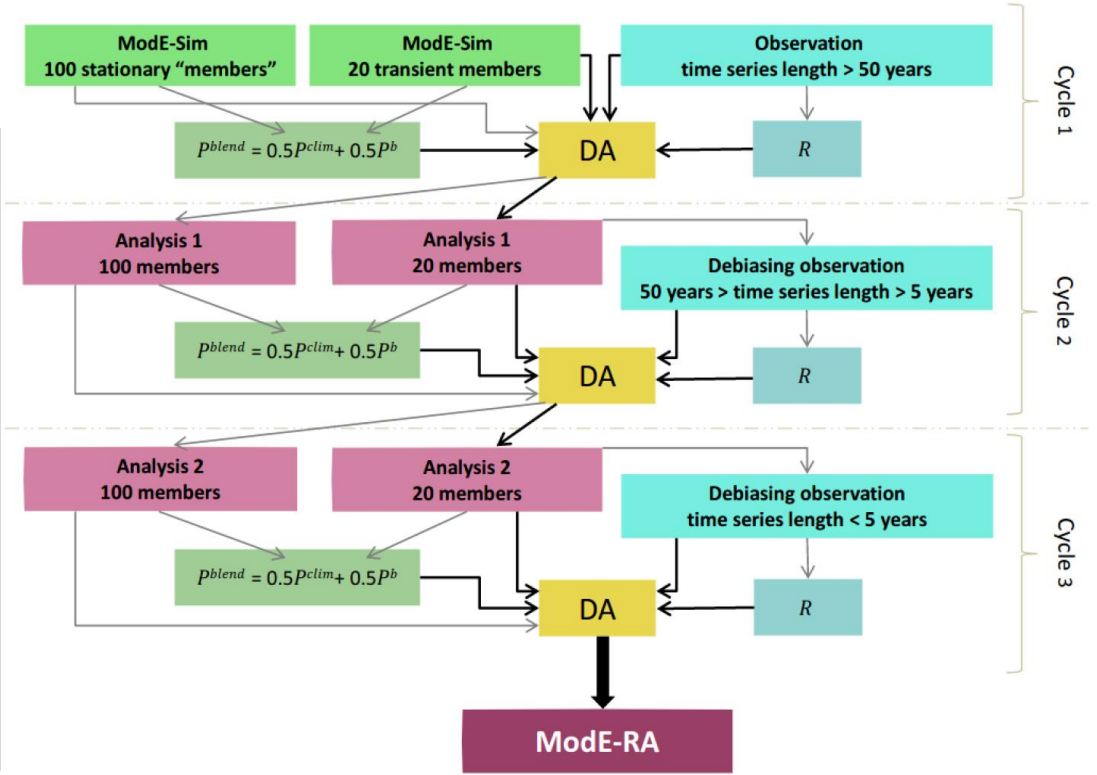
All records


Assimilated values per year
100000
80000
60000
40000
20000
0
1400
1500
1600
1700
1800
1900
2000
6000
5000
4000
3000
2000
1000
0
1500
1600
1700
1800
Pressure (ship)
Pressure (land)
Temperature
Precipitation
Wet days
Documentary proxies
Natural proxies

UNIVERSITÄT BERN

Assimilation scheme

- Anomalies from 71-yr moving average
- Three cycles
- Hybrid **B**
- Observation Feedback archive



UNIVERSITÄT BERN

Products

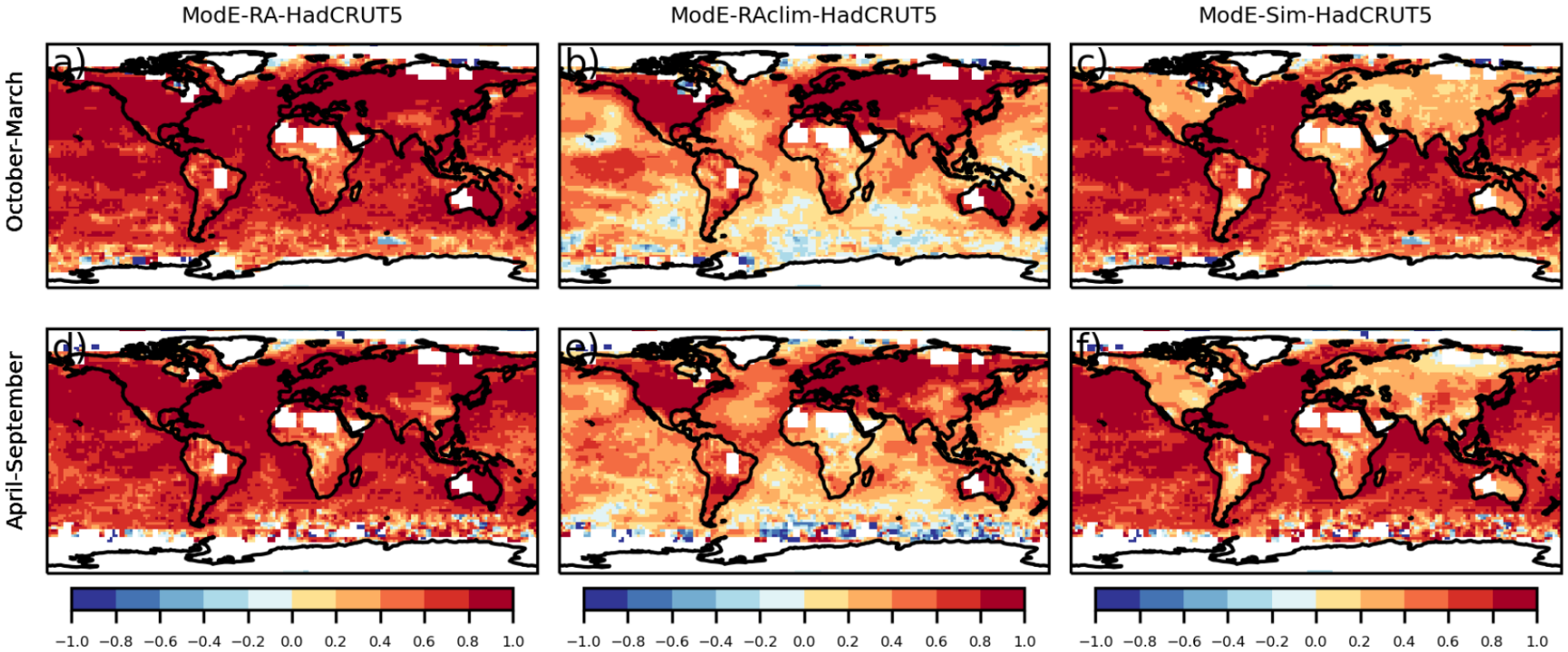
ModE-RA: Full assimilation
20 members, transient prior, hybrid **B** (50% climatological/50% transient)

ModE-Sim: Simulations
20 members, no assimilation

ModE-RAclim: Time invariant prior
100 members, climatological **B**

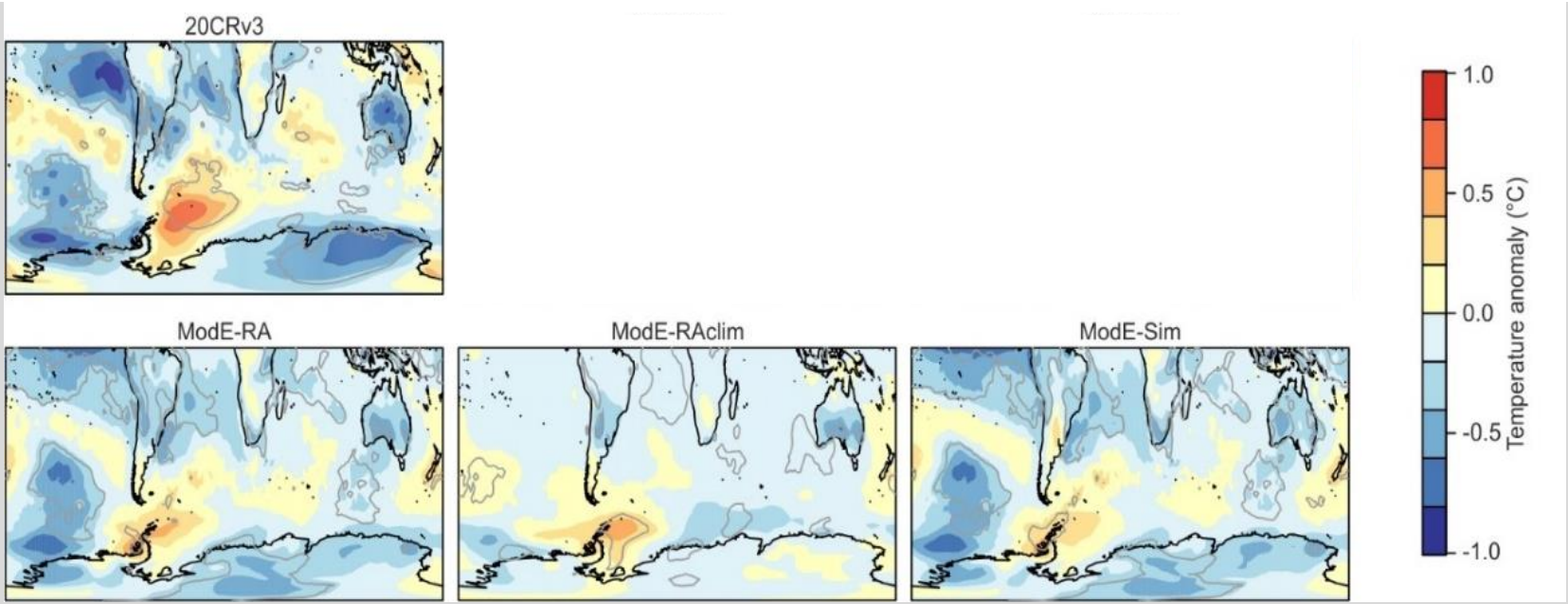
UNIVERSITÄT BERN

Evaluation: Surface air temperature

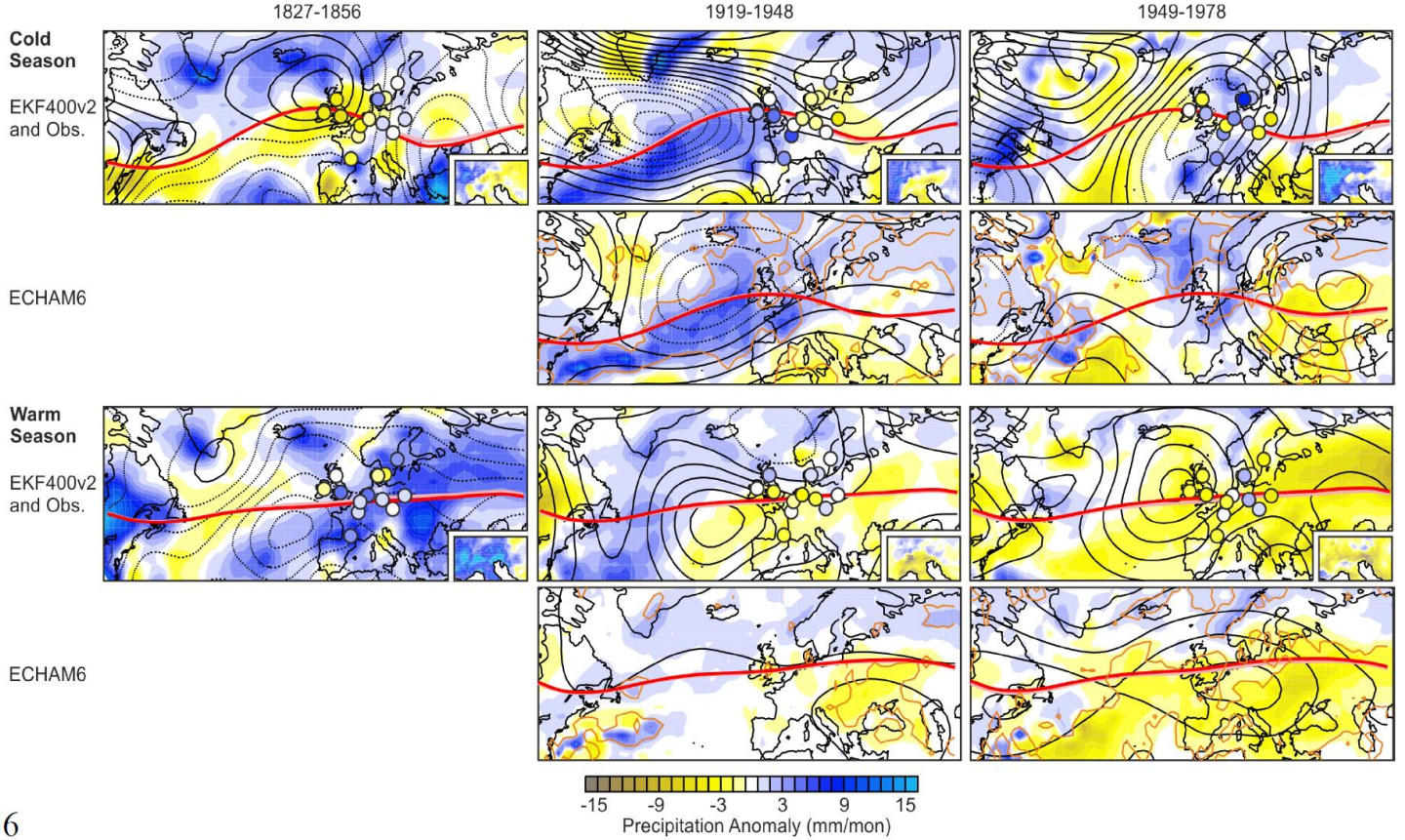


UNIVERSITÄT BERN

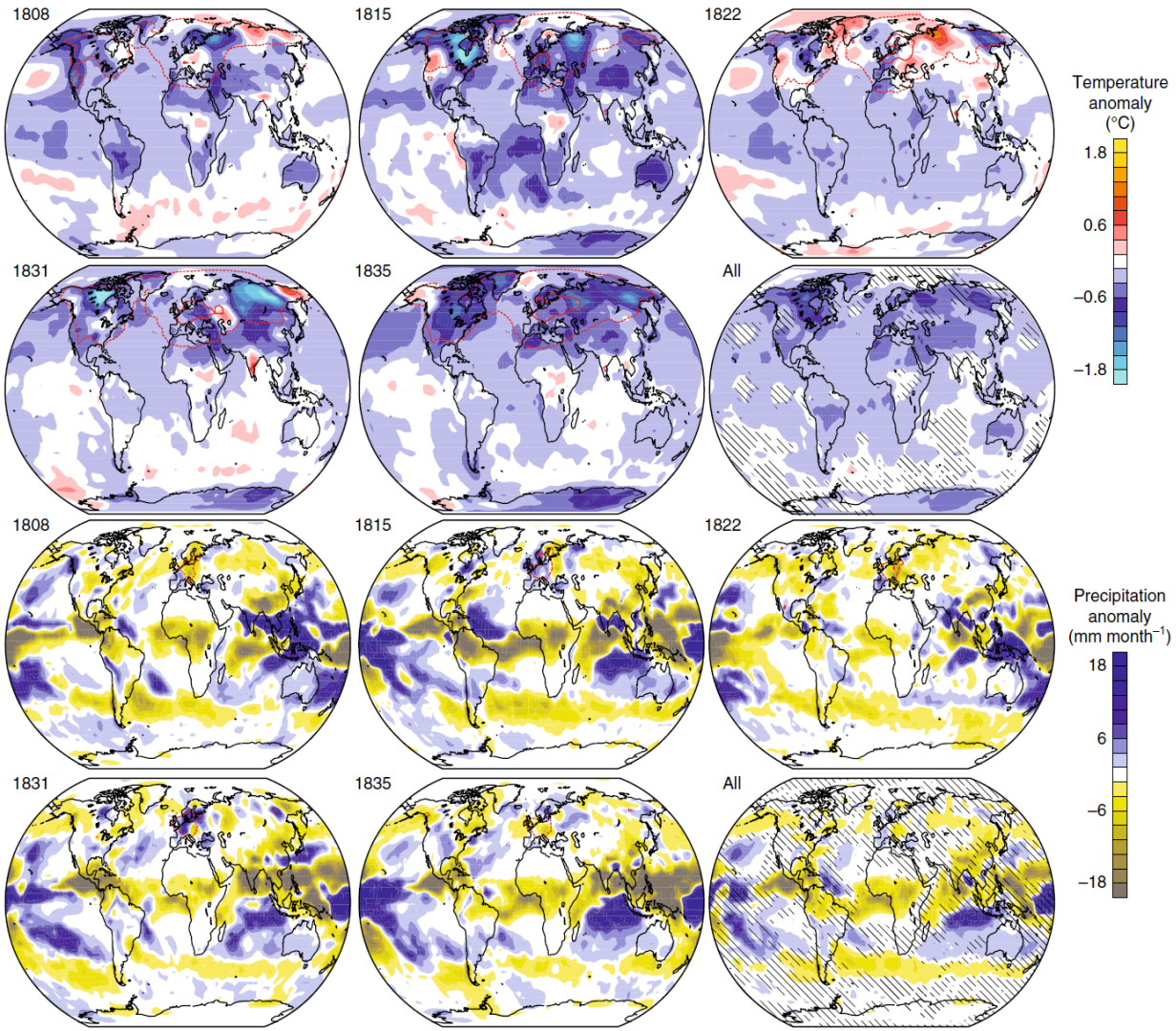
Temperature anomaly 1908-1911



Examples: EKF400v2



Examples: EKF400v2



ClimeApp

UNIVERSITÄT BERN

Data sets on DKRZ (revised)

Explore ModE-RA in ClimeApp (Beta)

http://climeapp-modera.unibe.ch:3838/

Clime App (Beta)

Welcome | Average & anomaly | Composites | Correlation | Regression

Creating absolute mean or anomaly values

Choose a variable to plot: Temperature

Choose a mode: (•) Anomaly ( ) Absolute

Select the range of years (1422-2000): 1698 to 1698

Select the range of months: ( ) Annual ( ) DJF ( ) MAM ( ) JJA ( ) SON (•) Custom

Select custom months: December (prev.) – March – December

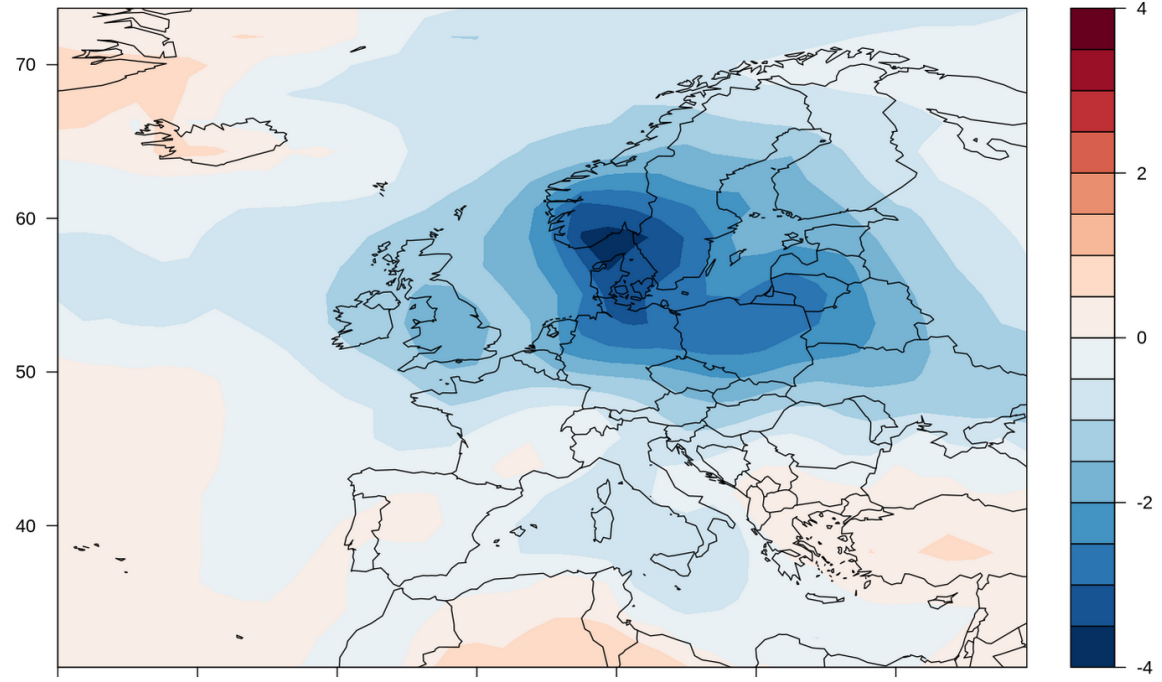
Reference period: 1651 to 1680

Map | Time series | Map data | Time series data | ModE-RA sources | Downloads

DJFM Temperature Anomaly 1698-1698

Ref. = 1651-1680

°C



Clime App (Beta)

Welcome | Average & anomaly | Composites | Correlation | Regression

Creating absolute mean or anomaly values

Choose a variable to plot: Temperature

Choose a mode: (•) Anomaly ( ) Absolute

Select the range of years (1422-2000): 1698 to 1698

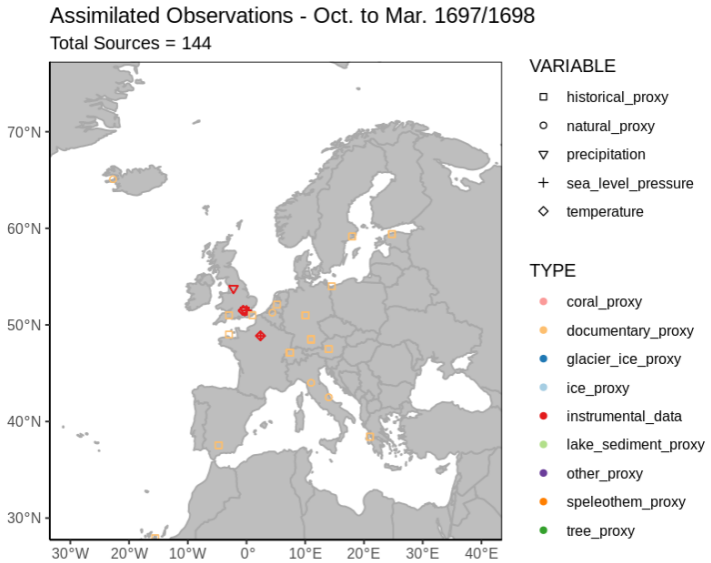
Select the range of months: ( ) Annual ( ) DJF ( ) MAM ( ) JJA ( ) SON (•) Custom

Select custom months: December (prev.) — March — December

Reference period: 1651 to 1680

Map | Time series | Map data | Time series data | ModE-RA sources | Downloads

Year: 1698



Clime App (Beta)

Welcome | Average & anomaly | Composites | Correlation | Regression

Map | Time series | Map data | Time series data | ModE-RA sources | Downloads

Creating composite mean or anomaly values

Choose a variable to plot:

Precipitation

Choose a mode:

(•) Fixed anomaly ( ) Anomaly compared to X years prior
( ) Absolute

Enter or upload a list of years:

(•) Manual ( ) Upload

Enter your list of years, separated by commas:

1809, 1816, 1835

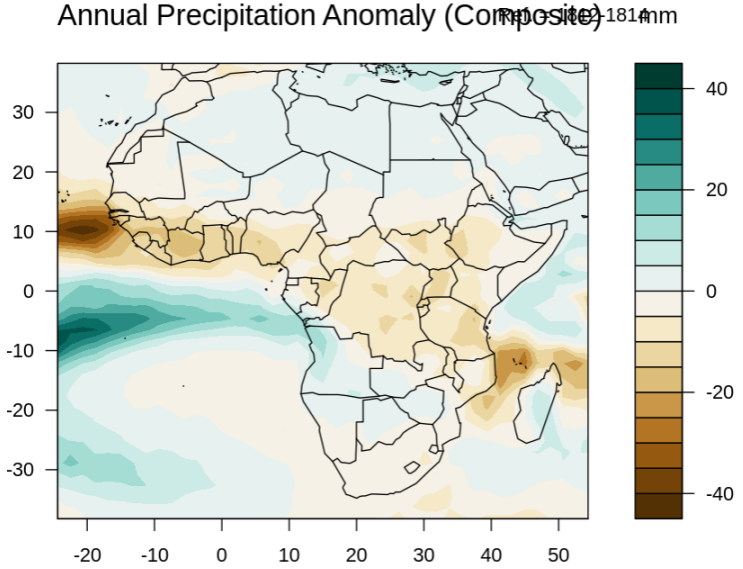
Select the range of months:

(•) Annual ( ) DJF ( ) MAM ( ) JJA ( ) SON ( ) Custom

Reference period:

List of chosen composite years:

1809 1816 1835



Clime App (Beta) Welcome Average & anomaly Composites Correlation Regression

Creating composite mean or anomaly values

Choose a variable to plot:

Precipitation

Choose a mode:

Fixed anomaly | Anomaly compared to X years prior | Absolute

Enter or upload a list of years:

Manual | Upload

Enter your list of years, separated by commas:

1809, 1816, 1835

Select the range of months:

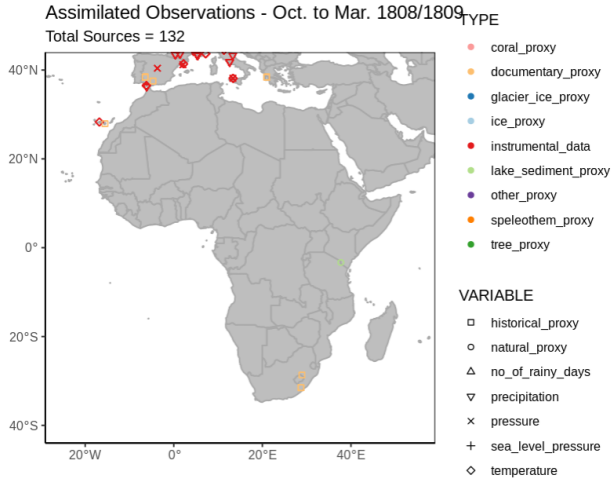
Annual | DJF | MAM | JJA | SON | Custom

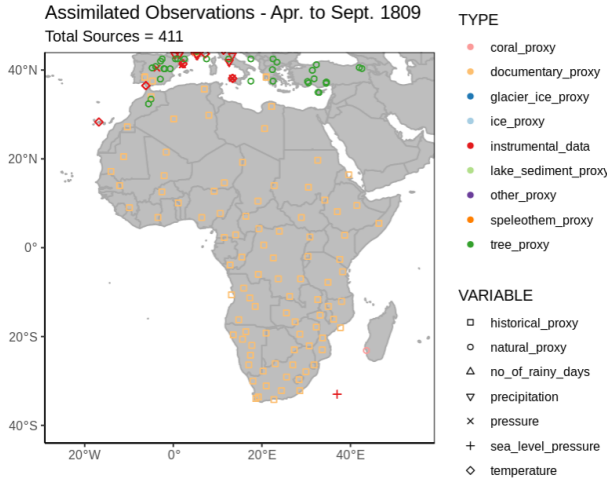
Reference period:

Map | Time series | Map data | Time series data | ModE-RA sources | Downloads

Year

1809





Conclusions

- ModE-RA: Global monthly 3D reconstruction back to 1421
- Comprehensive collection of observations
- Comprehensive observation feedback archive
- Centennial variability from model, shorter from observations
- ModE-RA, ModE-RAclim, ModE-Sim
- Explore in ClimeApp (Beta)