20CR-1815: Extending reanalysis back to Tambora

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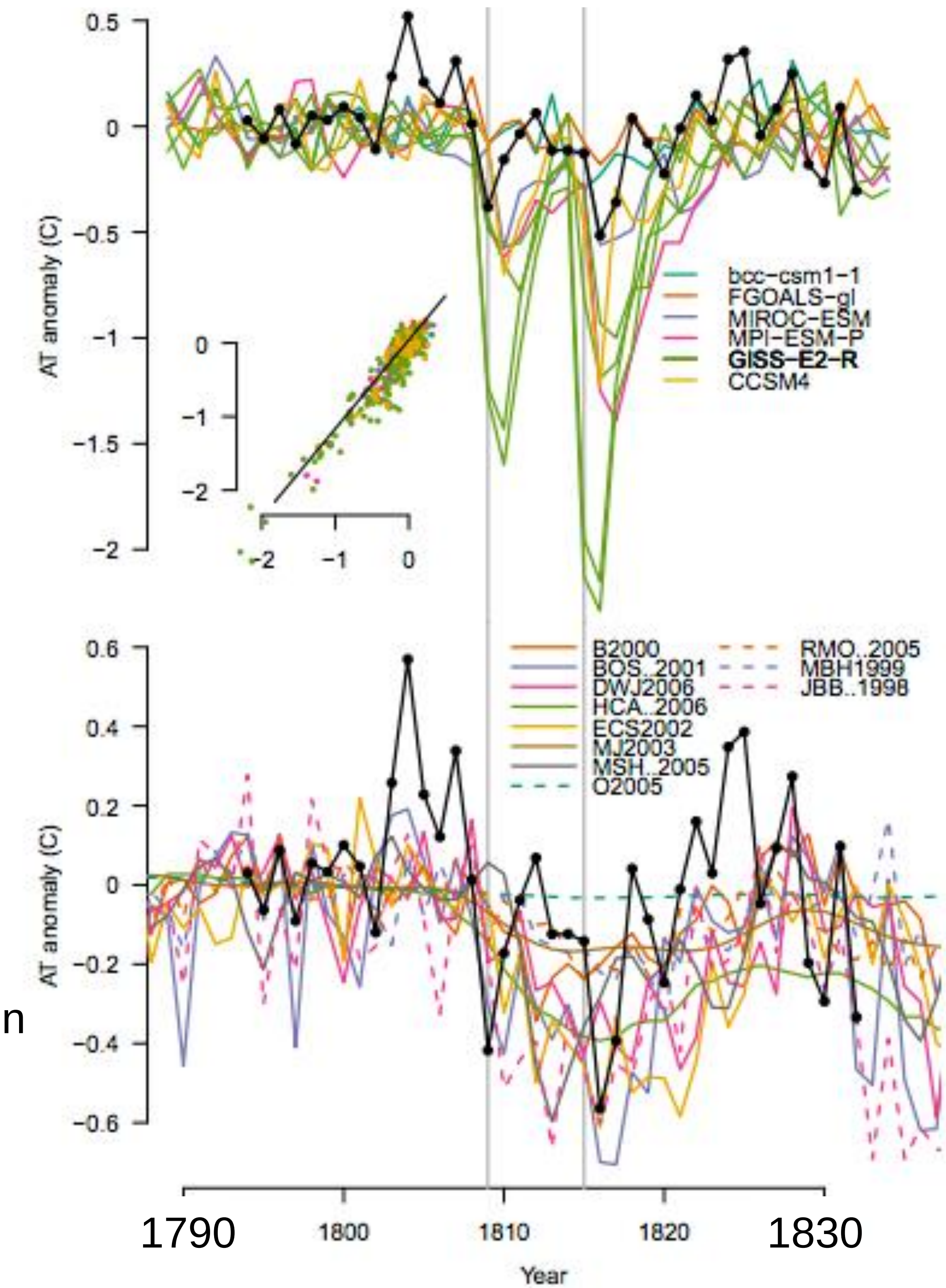
Tambora 200 Conference, Bern: 2015-04-09

Near Surface Air Temperature (1790-1835)

OBS
vs
CMIP5



Black Obs curves are the same in both panels

OBS
vs
Reconstruction

Fig. 9. Comparison of observed, simulated, and proxy-derived large-scale near-surface temperature variability over the early nineteenth century. Upper panel: tropical (observations coverage) marine temperatures from observations (black) and the CMIP5 simulations. Lower panel: Northern Hemisphere temperatures from observations (black) and proxy reconstructions. Inset: relationship between observations coverage (x) and Northern Hemisphere (y) temperature in the simulations, with best fit line (slope 1.2). All series normalised to have mean zero over 1795–1805. The grey vertical lines mark the dates of two large volcanic eruptions (1809 and 1815). Data used is listed in Table 1.

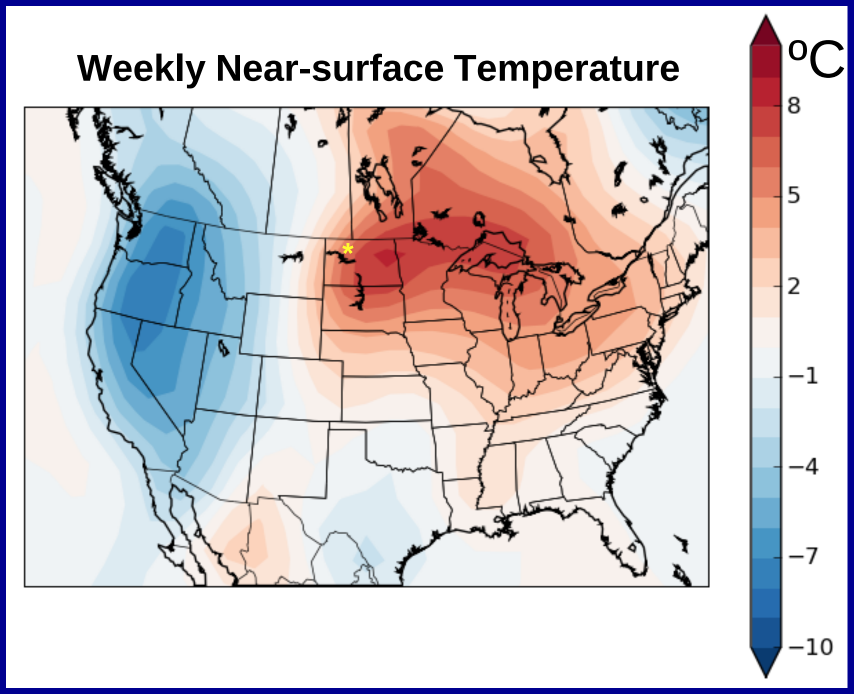
Brohan et al. 2012

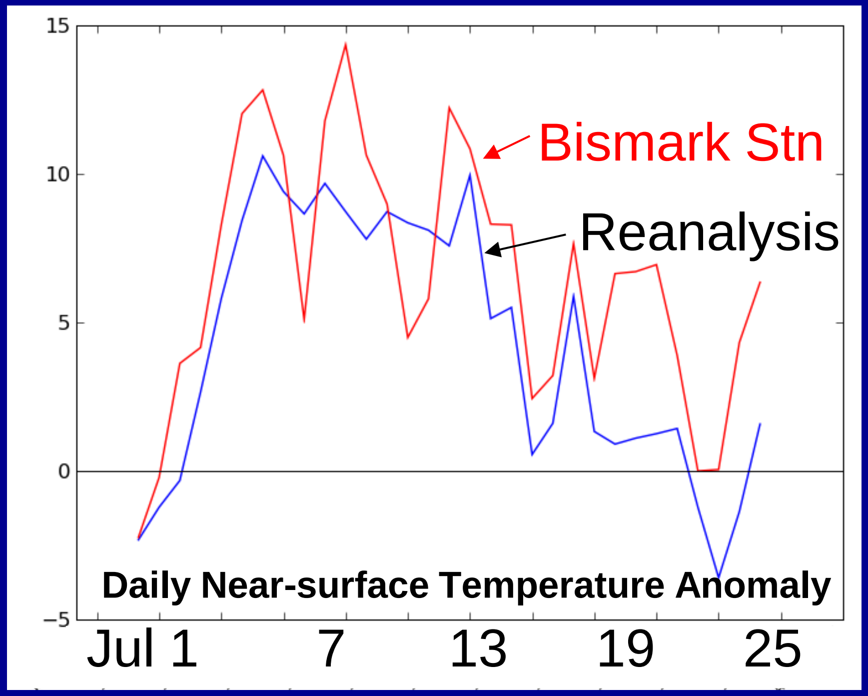
The 20th Century Reanalysis Project version 2c (1851-2011)

Summary: An international project led by CIRES and NOAA to produce *4-dimensional* reanalysis datasets for climate applications extending back to the 19th century using an Ensemble Kalman Filter and *only surface pressure observations.*

Weekly-averaged anomaly during July 1936 North American Heat Wave (> 2,000 dead during 10-day span)

Daily variations compare well with in-situ data.





The reanalyses provide:

-First-ever estimates of near-surface to tropopause 6-hourly fields extending back to the middle of the 19th century;

-Estimates of uncertainties in the basic reanalyses and derived quantities (e.g., storm tracks).

Examples of uses:

•Validating climate models.
•Determining storminess and storm track variations over the last 150 years.
•Understanding historical climate variations (e.g., 1930s Dust Bowl, 1920-1940s Arctic warming).
•Estimating risks of extreme events

go.usa.gov/XTd Compo et al. 2011

20CR: version “1815”

<u>20th Century Reanalysis "1815" implementation of Ensemble Filter Algorithm</u>

(based on Whitaker et al. 2004, Compo et al. 2006, Compo et al. 2011)

Algorithm uses an ensemble of GCM runs to produce the weight **K** that varies with the <u>atmospheric flow</u> and the <u>observation network</u> every 6 hours

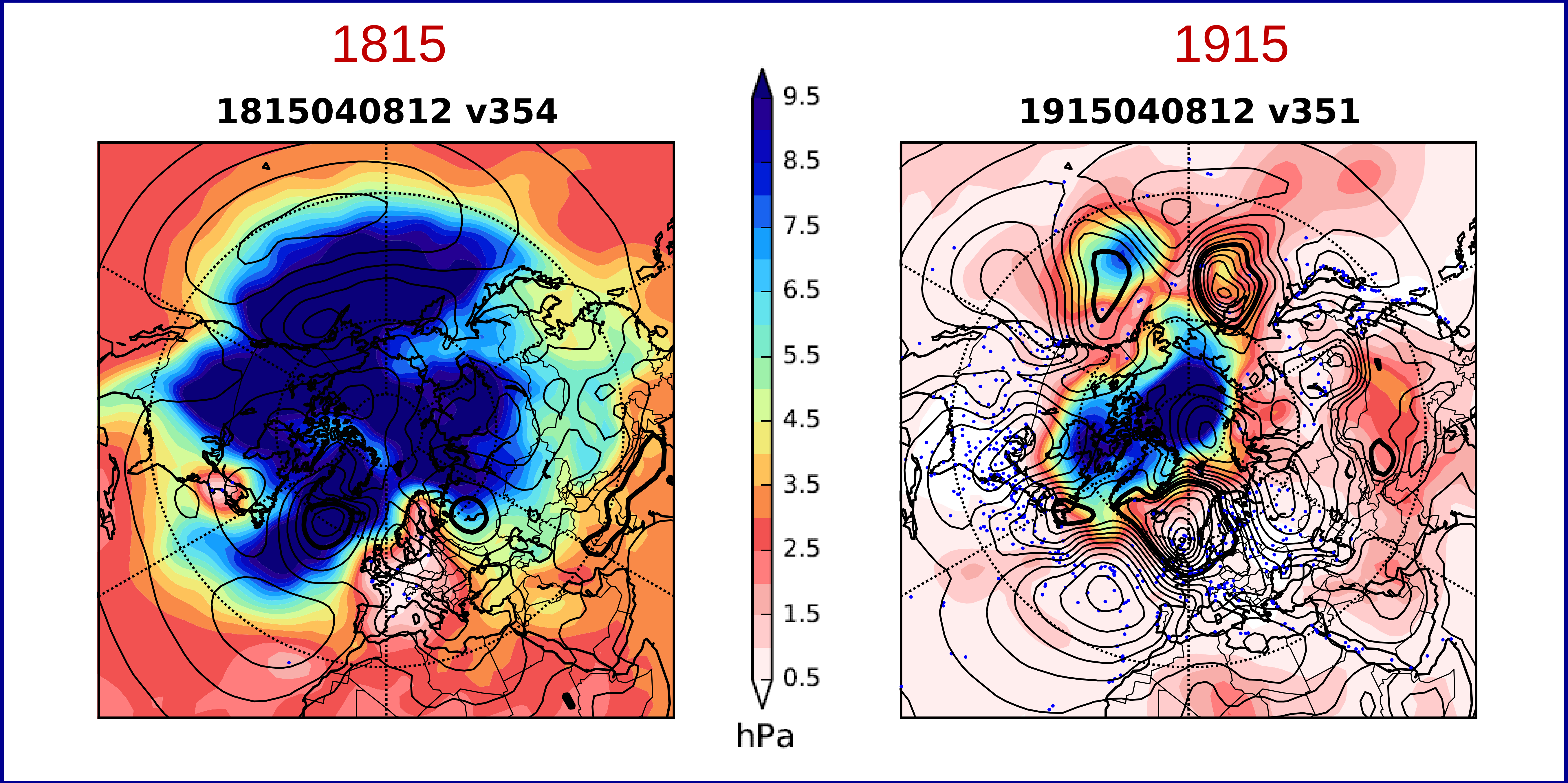
Using 56 member ensemble,
prescribed <u>1861-1890 climatological</u> boundary conditions:
COBE-SST2 <u>monthly</u> SST and sea ice concentration (*Hirahara et al. 2014*)

<u>1815-1850</u>: T62 (~200km), 28 level NCEP GFS08ex atmosphere/land model
9 hour forecasts for 6 hour centered analysis window
- time-varying CO_2 , 11 year repeating solar cycle, and

Specified monthly volcanic aerosol optical depth:
-No Aerosols, Gao et al (2008), Crowley (2008)

Every 5 years produced in parallel: 1816-1820,…, 1846-1850, after 14 month spin-up

20CR Analyses of Sea Level Pressure For 8 April 1815 and 1915



Contours-ensemble mean (ci: 4 hPa, 1000 hPa thickened)

Shading- blue: more uncertain, white: more certain

Early analyses may have value regionally. Not a simulation even in 1815.

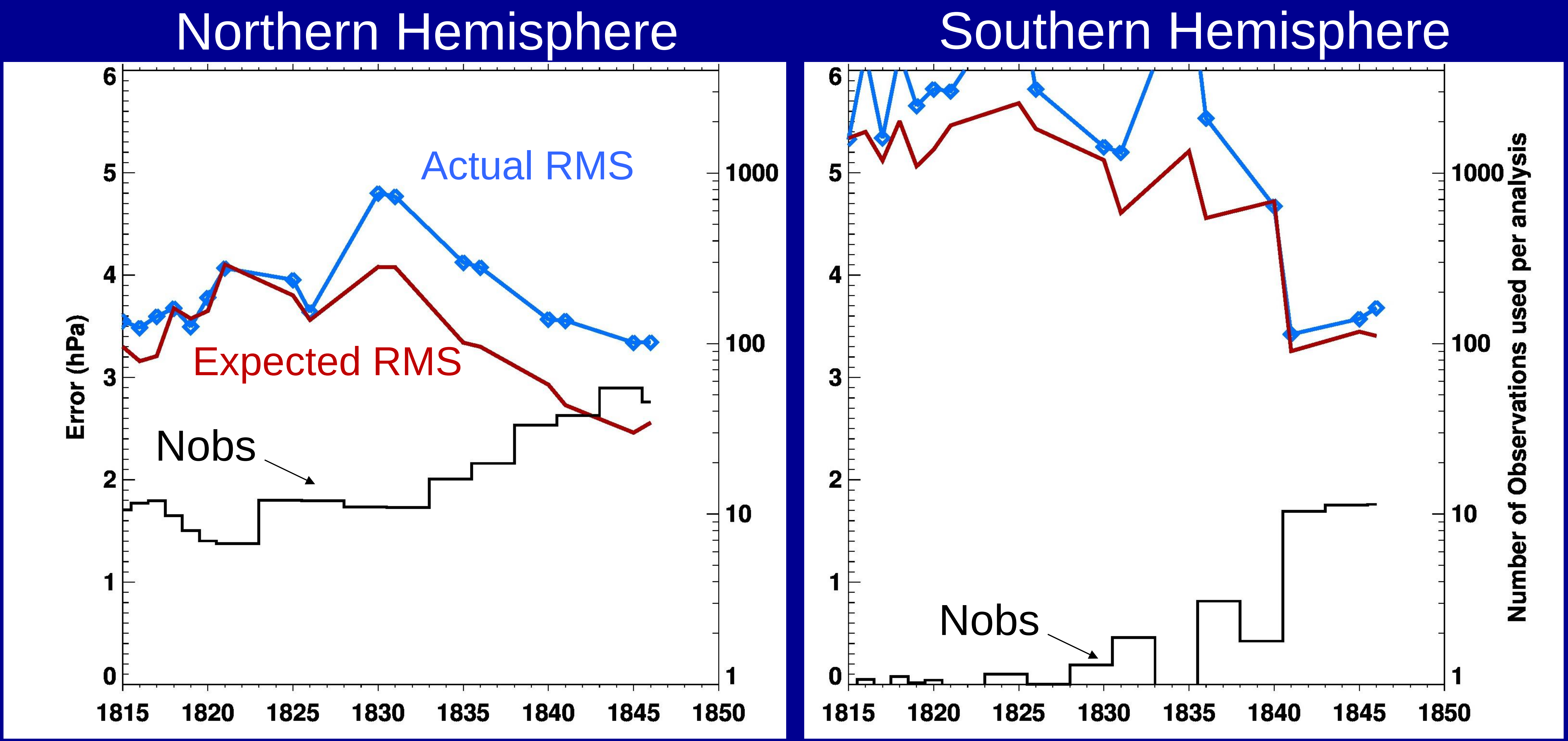
Estimate of the observed weather. Need more observations (blue dots) to improve further.

These observations exist and more need to be recovered!

20CR:1815 Surface Pressure uncertainty estimate poleward of 20(S,N)

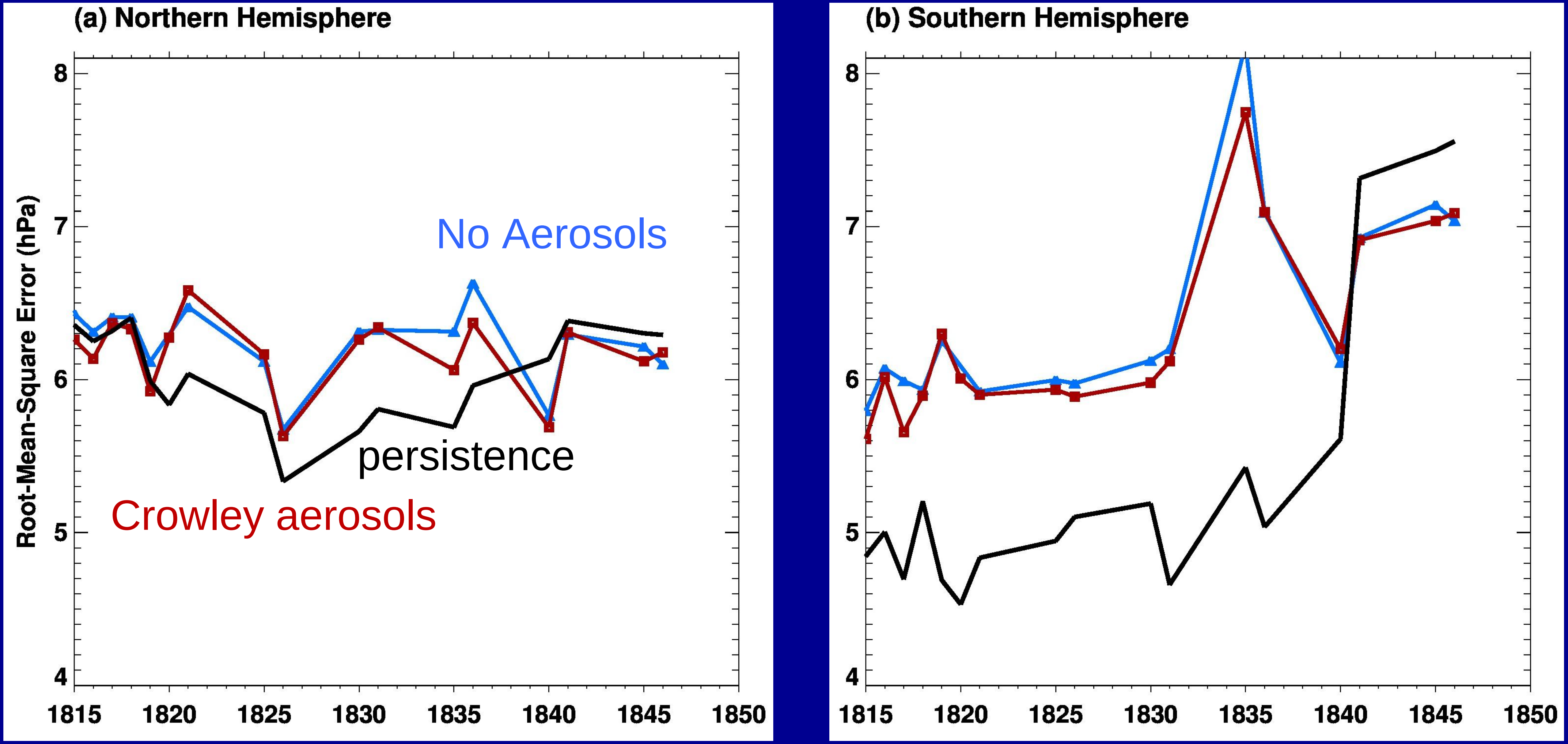
blue actual RMS difference

red expected RMS difference

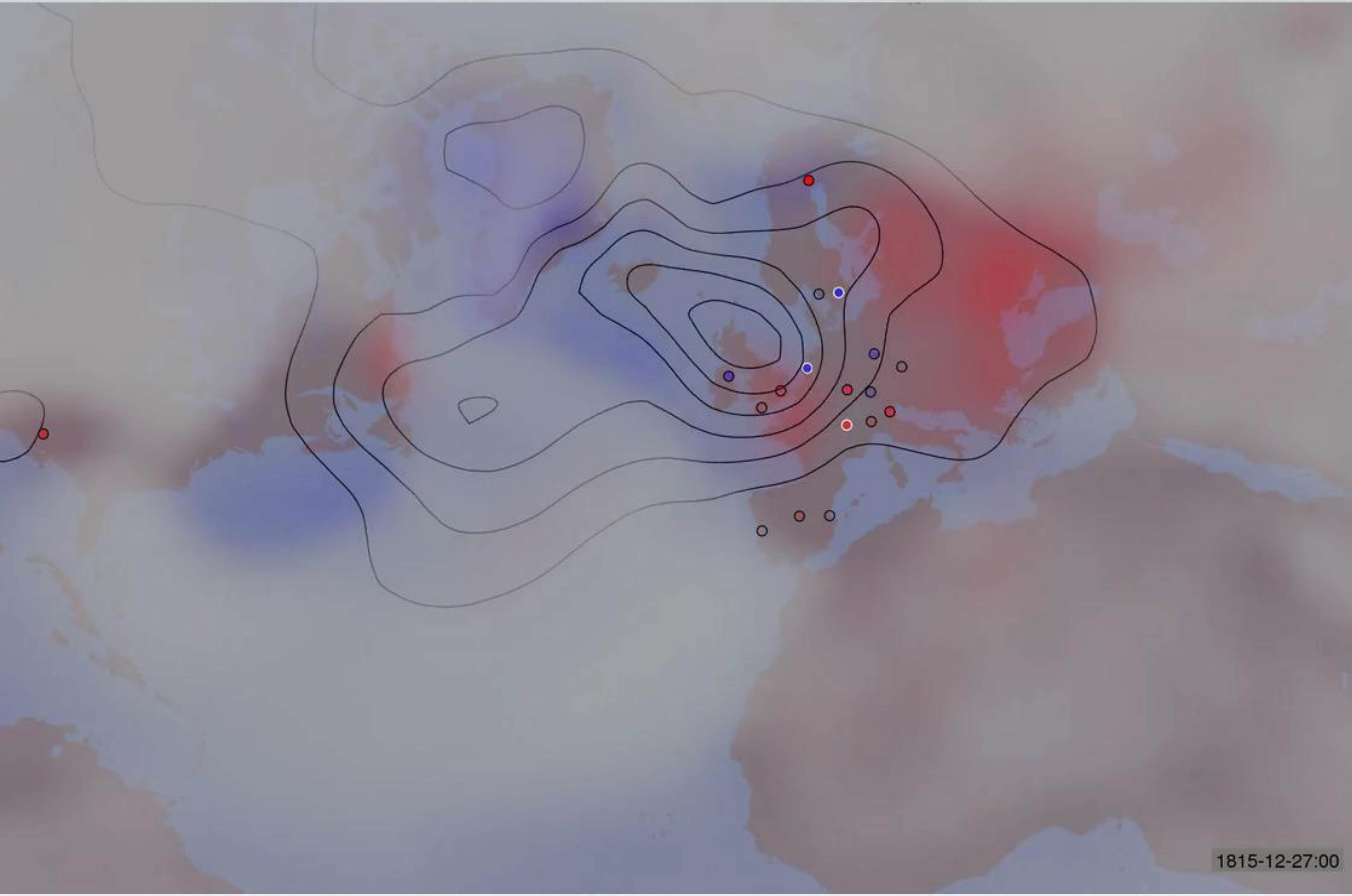


Uncertainty estimates are consistent with actual differences between first guess and pressure observations even in early 19th Century. Quantitative consistency degrades in NH after 1830s.

Root Mean Square difference of Surface and Sea Level Pressure Observations and 24 hour Forecasts from No Aerosols and Crowley Aerosols (*Jan-Dec*)



Northern Hemisphere 24 hr forecasts beat persistence even in 1815!
Southern Hemisphere has an analysis that produces forecasts comparable to persistence starting in 1840s with increased obs.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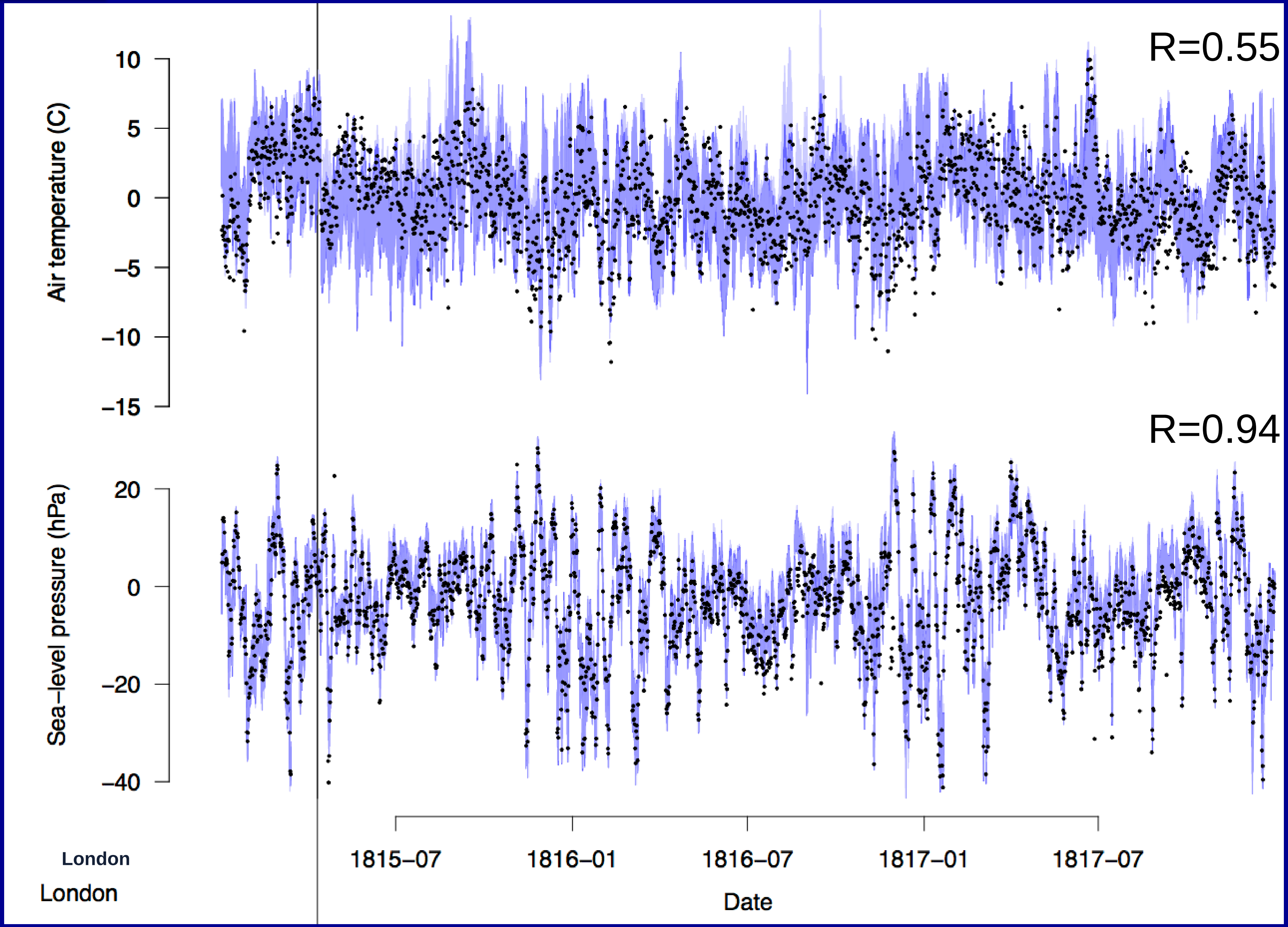
Reconstructing the effects of Tambora 1815 and the Year Without a Summer of 1816

Comparison of anomalies from

Black dots: subdaily independent Air T and assimilated SLP from London

Purple swaths: 20CR-1815 ensemble range (1815 to 1817)



~4 other N. American and ~10 European Station, and ~10 Ship Obs assimilated each day.

2-4 times more possible.

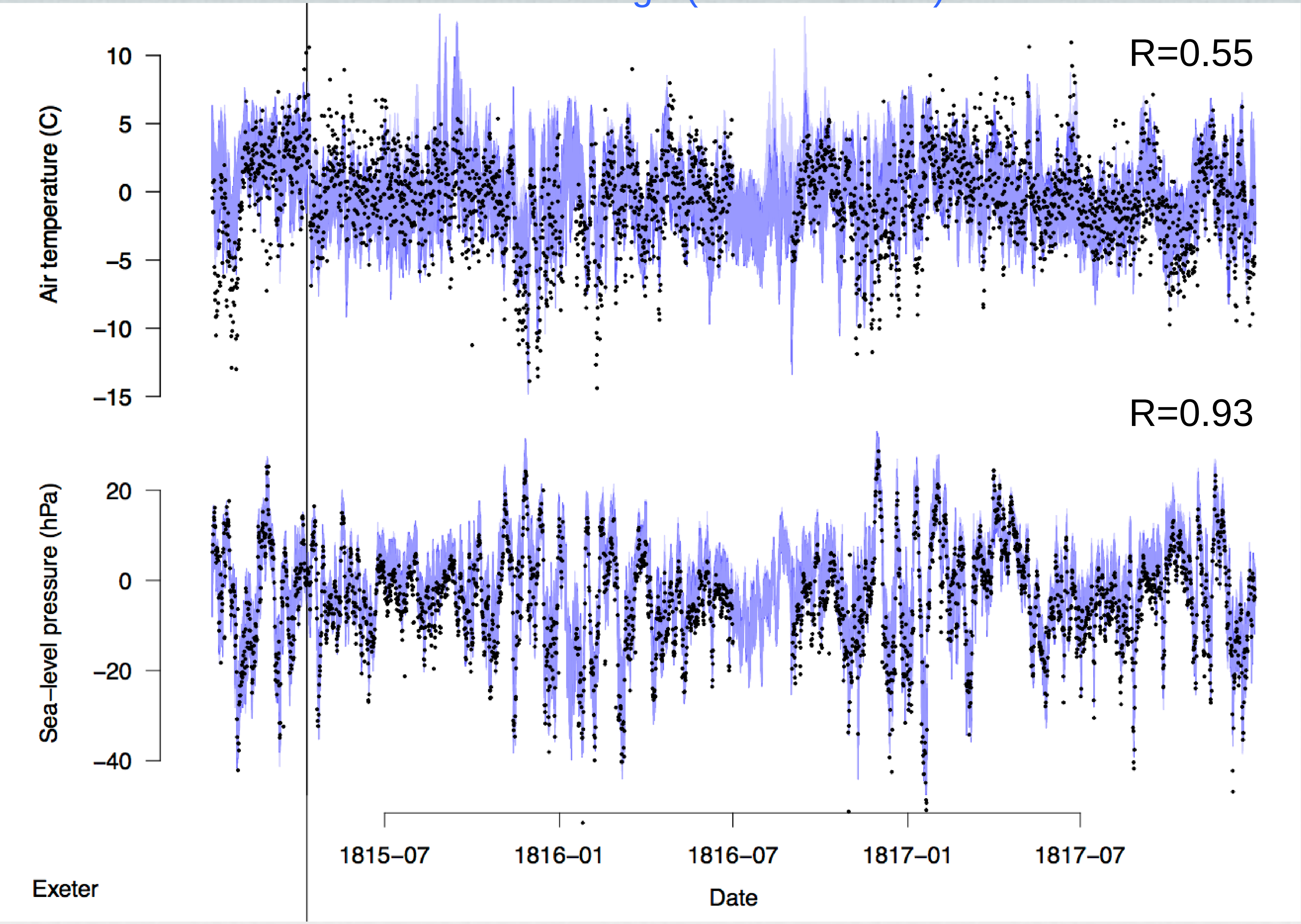
In regions such as Europe, 20CR-1815 compares well, showing skillful weather variability from the pressure observations. 1816 doesn't appear particularly anomalous in either dataset.

(Compo, Brohan, Whitaker, Broennimann, Brugnara, Allan, Sardeshmukh 2015)

Comparison of anomalies of

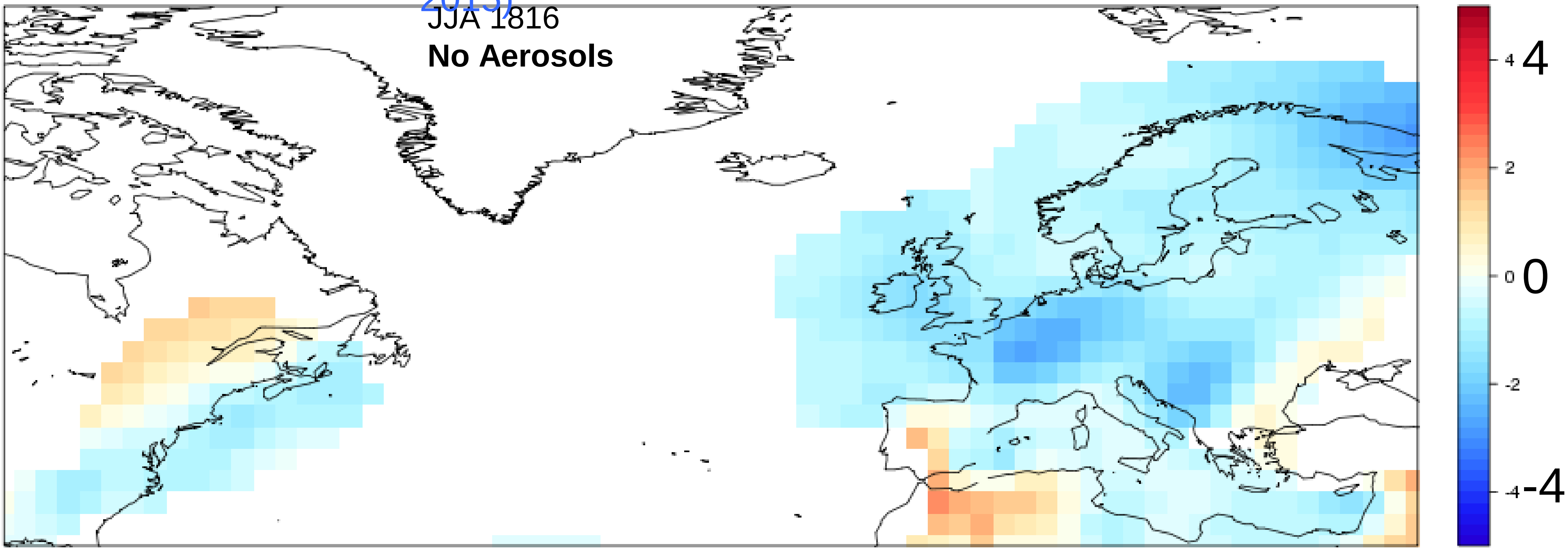
Black dots: subdaily **independent** Air T and **independent** SLP from Exeter

Purple swaths: 20CR-1815 ensemble range (1815 to 1817)

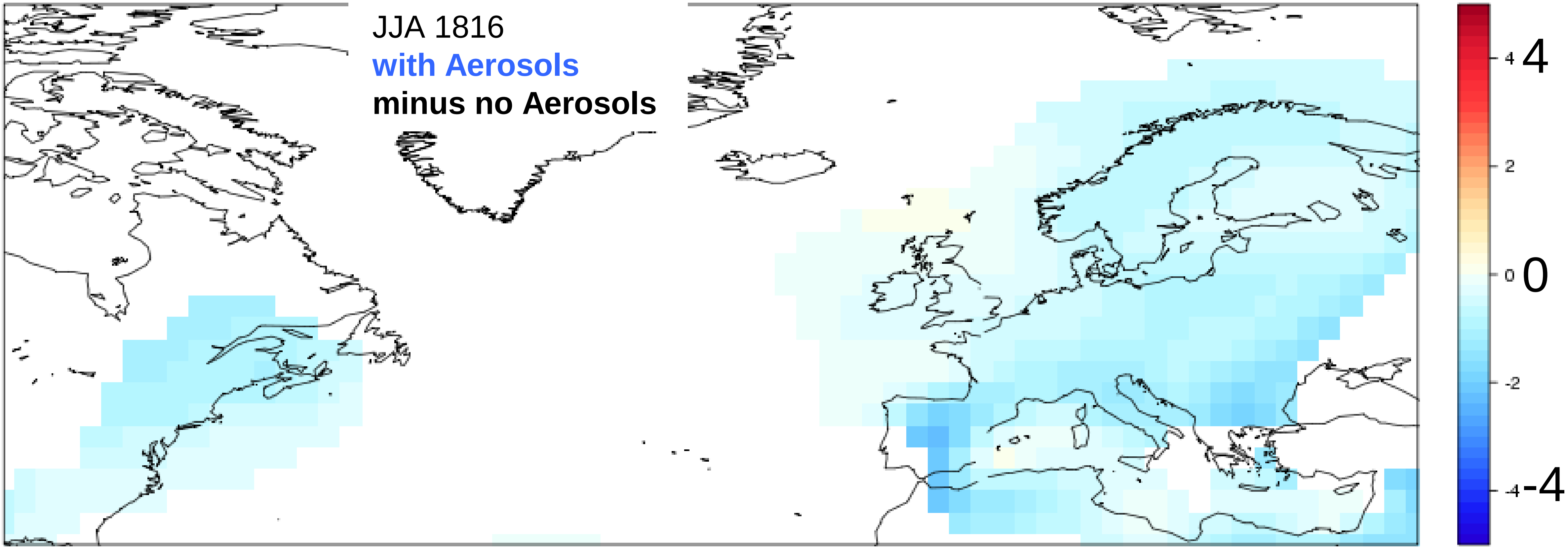


Both variables compare well, though pressure is more precise. Extreme tempe rature anomalies are muted

(Compo, Brohan, Whitaker, Broennimann, Brugnara, Allan, Sardeshmukh 2015)



20CR JJA 1816 2m temperature anomaly (C) - **No Aerosols**



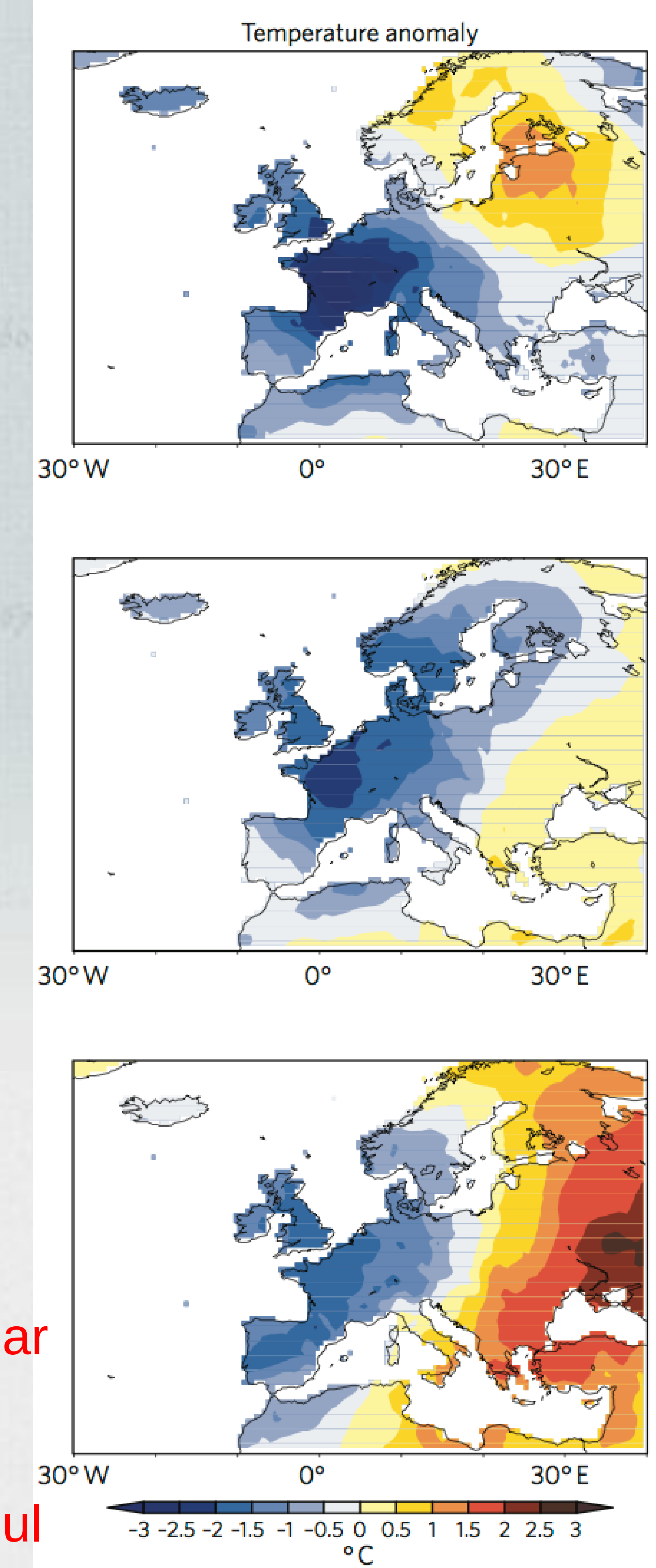
Additional cooling effect of adding Crowley aerosols is moderate but detectable.

1816 Near-Surface
Air Temperature Anomaly
(climo 1951-1980)

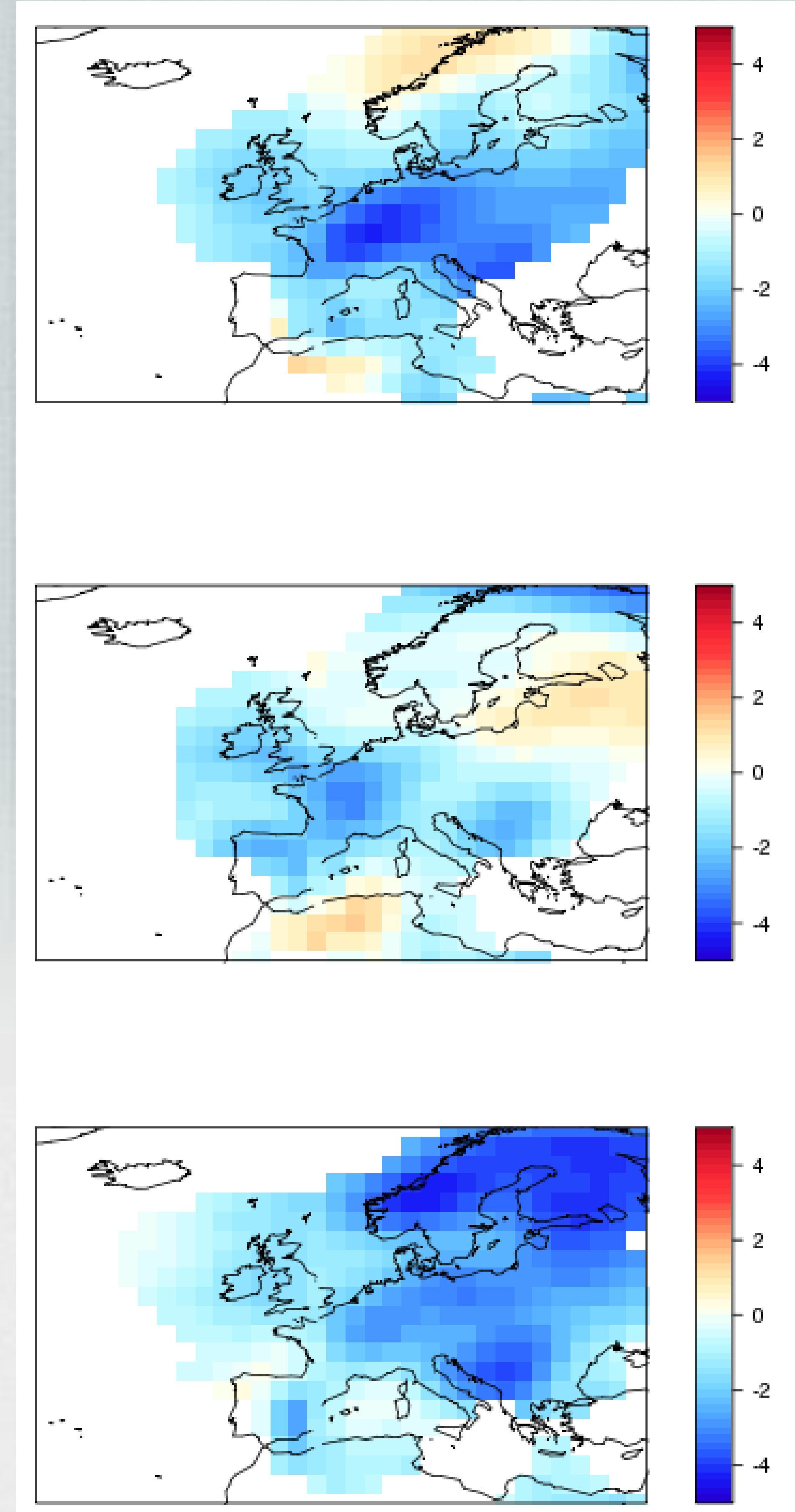
June 1816

July 1816

August 1816

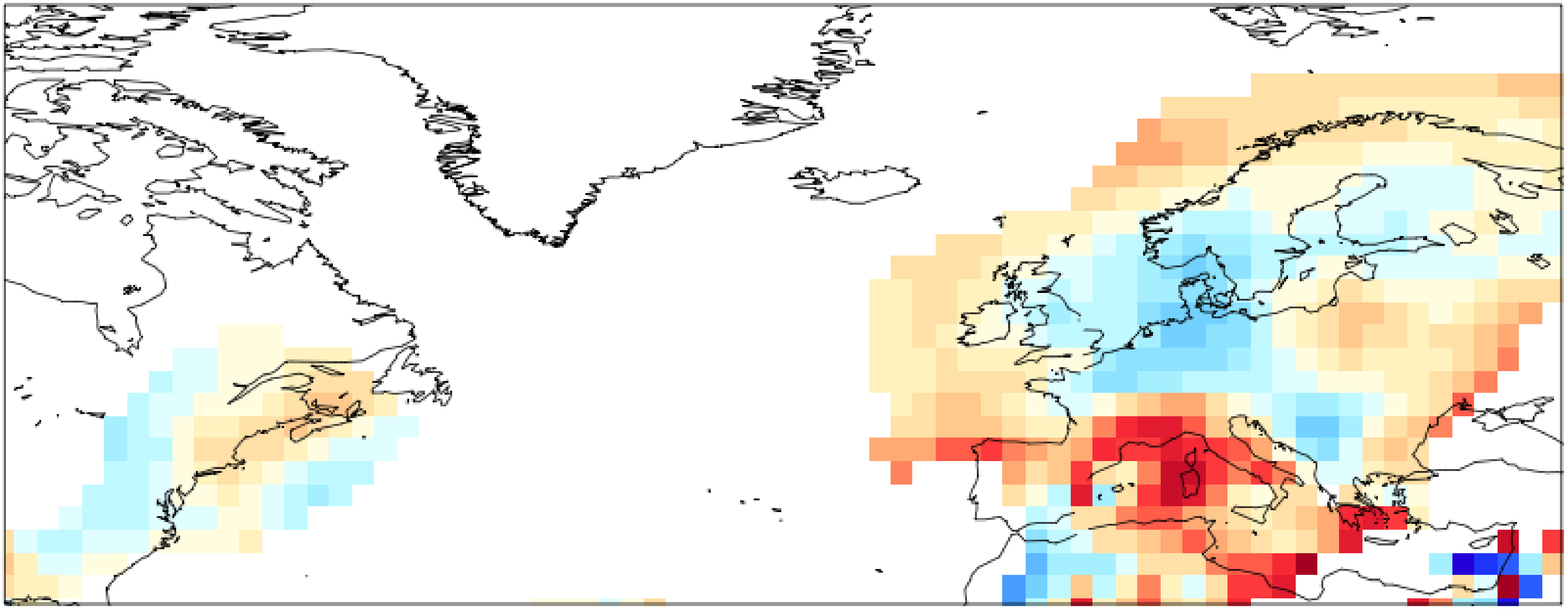


Luterbacher & Pfister 2015

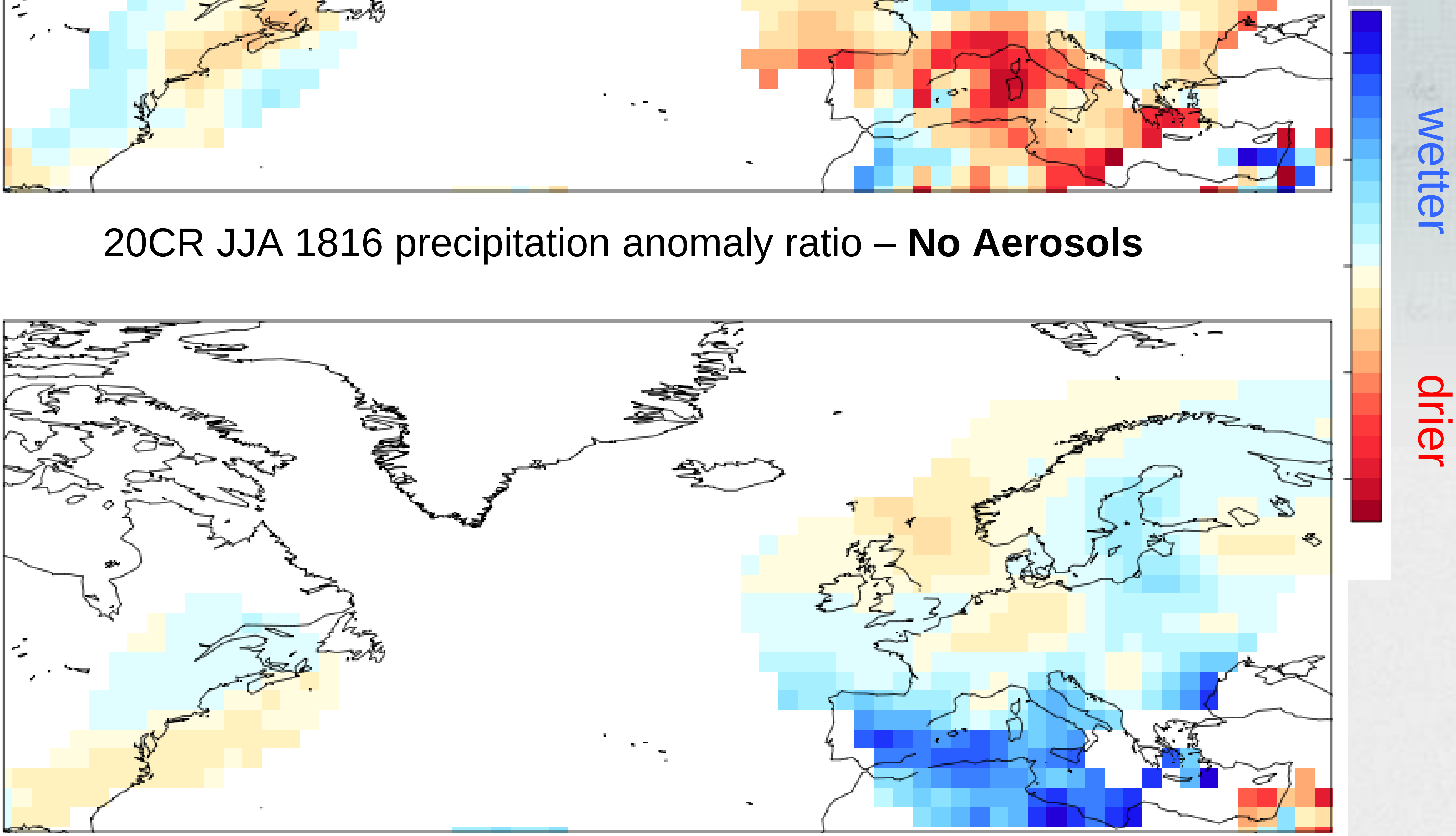


20CR: Crowley aerosols

Reanalysis anomalies are lar
ger
than LP reconstruction.
Some agreement in June, Jul
y,
less in August.



20CR JJA 1816 precipitation anomaly ratio – **No Aerosols**



Additional effect of adding Crowley aerosols

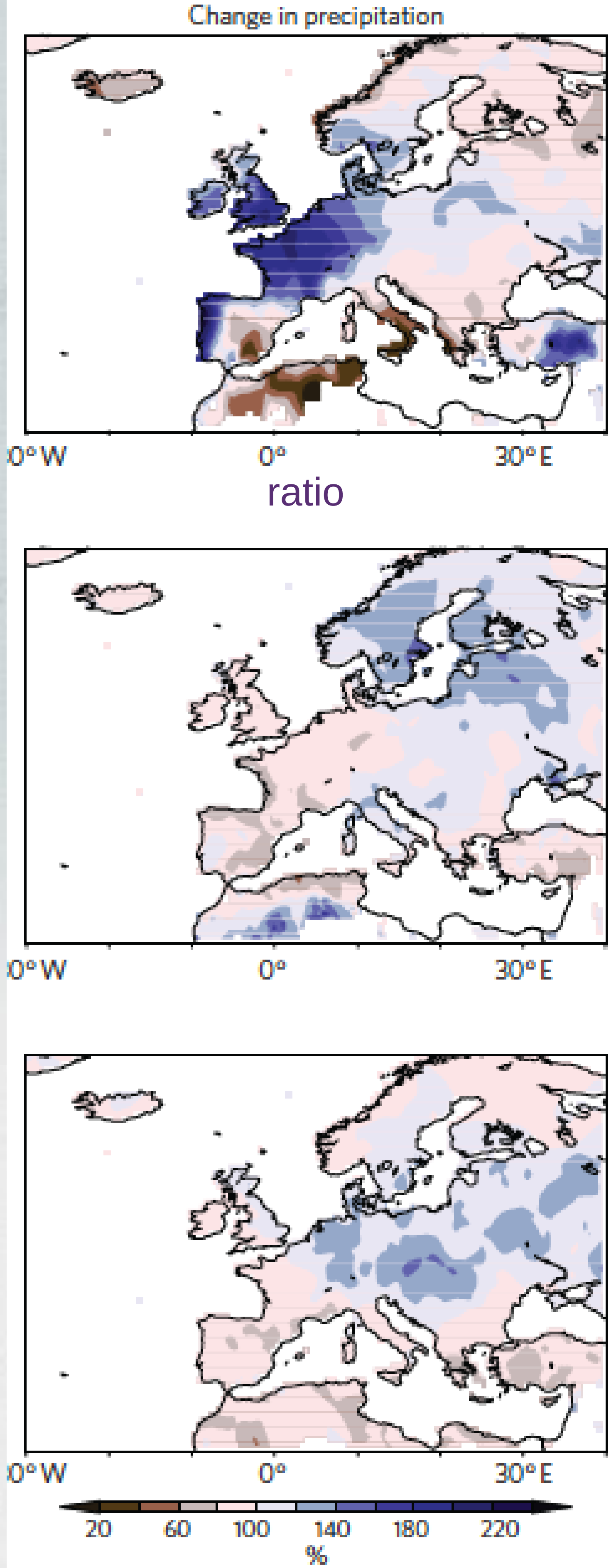
1816 Precipitation
(climo 1951-1980)

June 1816

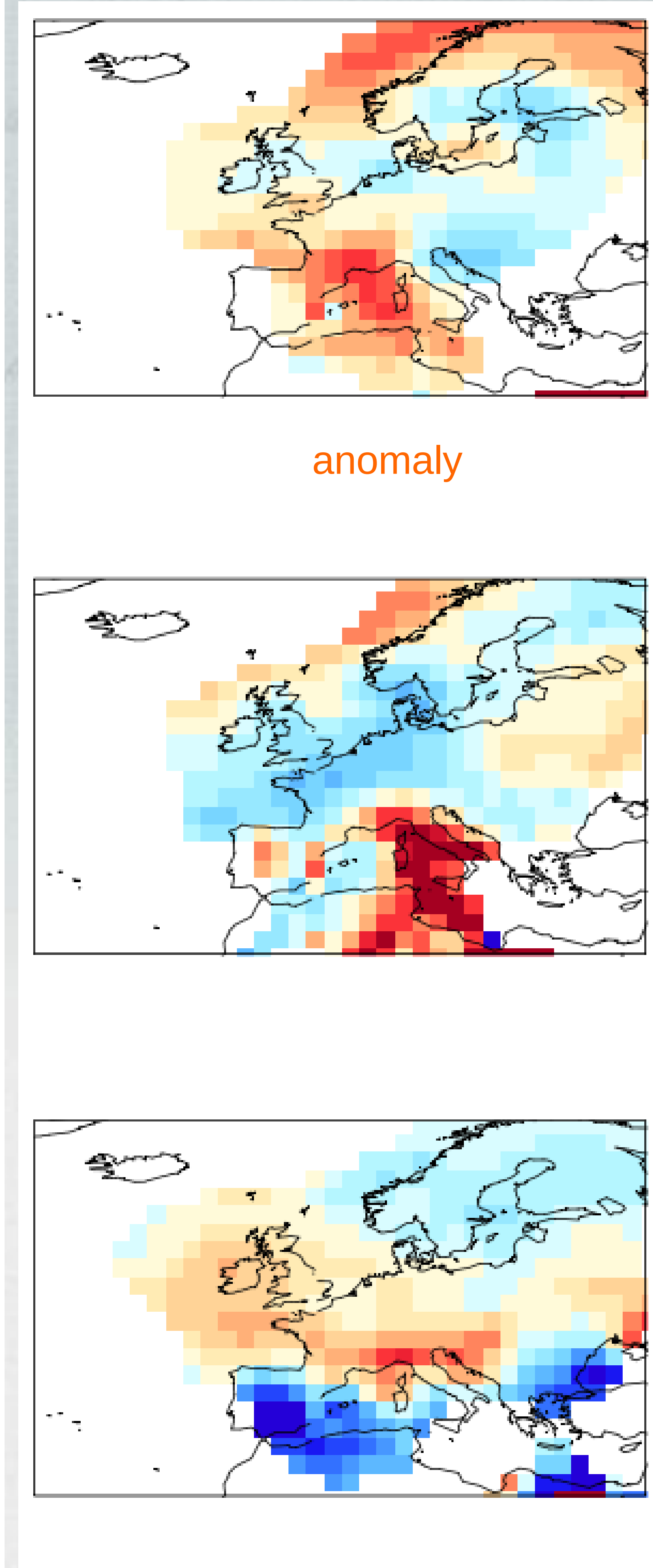
July 1816

August 1816

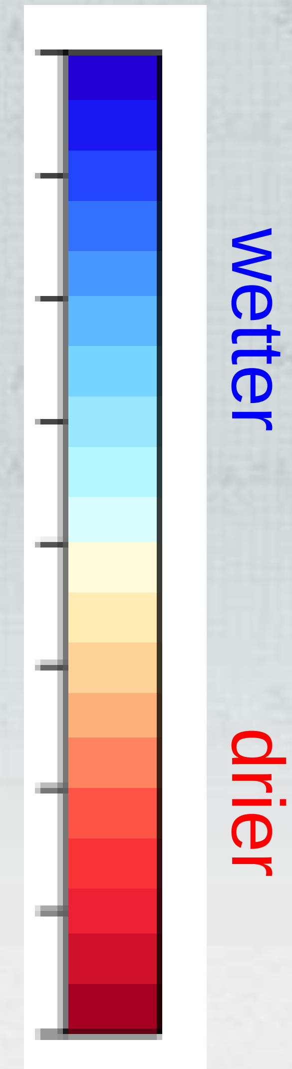
Precipitation is hard.



Luterbacher & Pfister 2015



20CR: Crowley aerosols



Conclusions

Can we do it? Yes we can.
- Useful skill in Europe and some of America
- Reanalysis from pressure obs. alone produces good agreement with observed temperatures.

Resolved some of the major arguments:
- Impacts in 1816 were mostly associated with major shifts in circulation, not directly a large-scale radiatively-forced temperature change.
- Modest large-scale annual mean reconstructed anomalies are consistent with known large impacts.

Year Without a Summer can still be blamed on the volcano:
- Minor but important part of temperature anomalies can be attributed directly to aerosol-induced radiative cooling.
- Forecast statistics are improved by adding aerosols - indicates that circulation changes may be volcanically forced.

To Do:

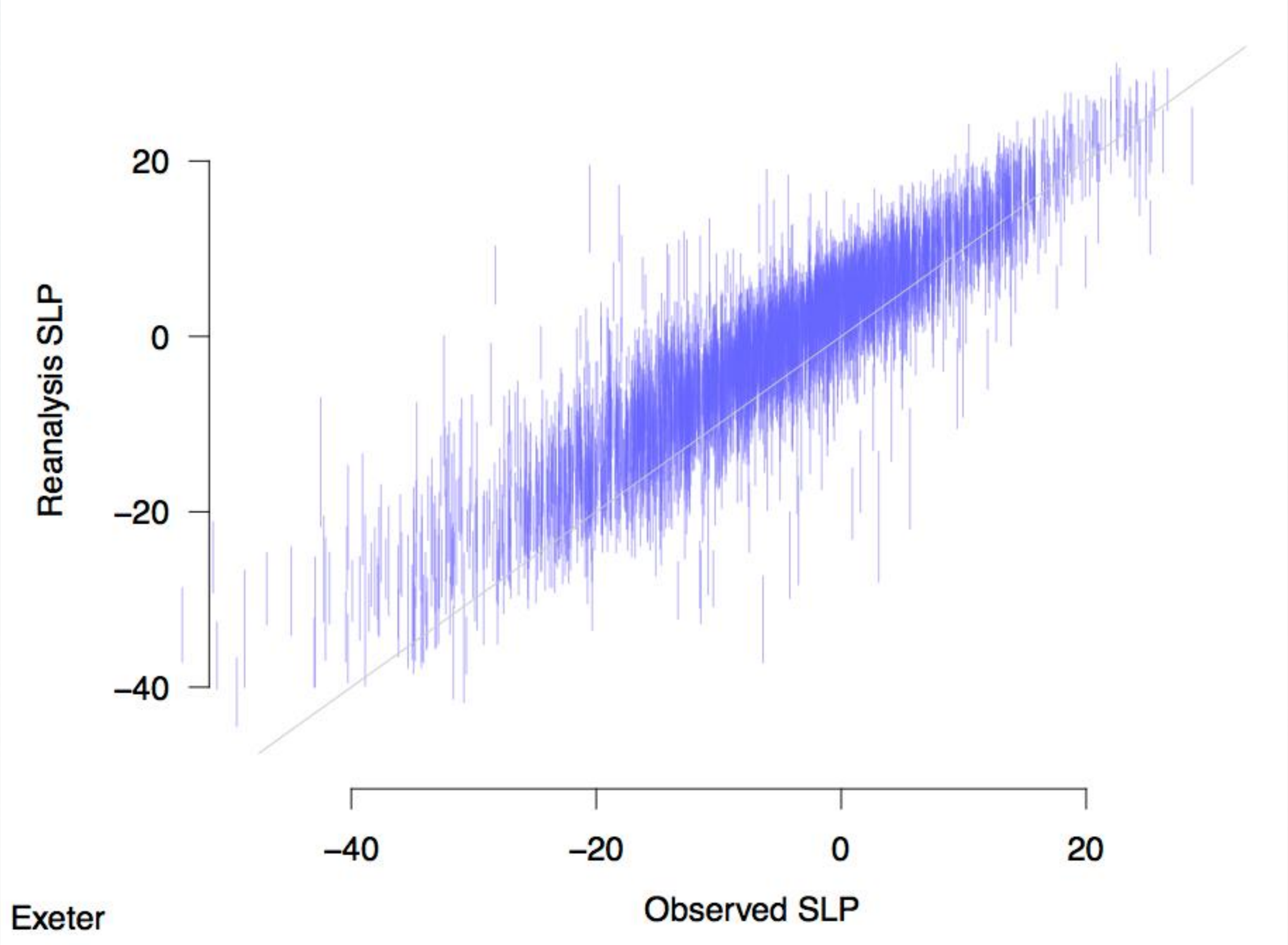
Rescue more observations: could add at least north Atlantic, north America, maybe India.

Temperature variance at stations > in reanalysis > in reconstructions. Why?

Thank you to organizations contributing observations to ISPD:

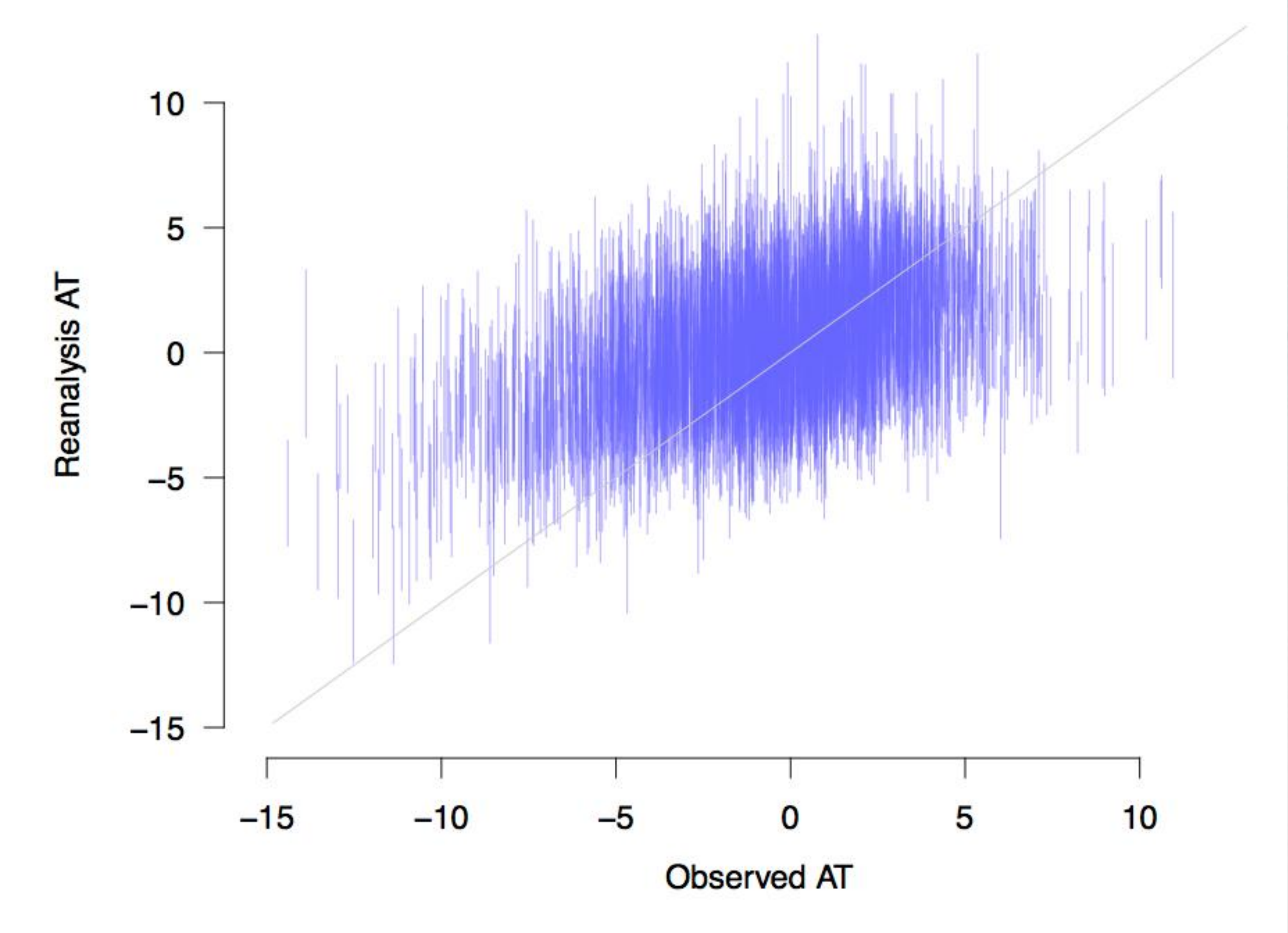
All Russia Research Institute of Hydrometeorological Information WDC
Atmospheric Circulation Reconstructions over the Earth (ACRE)
Australian Bureau of Meteorology
Australian Meteorological Association, Todd Project Team
British Antarctic Survey
Canadian Volunteer Data Rescue Project
Cook Islands Met Service
Danish Meteorological Institute
Deutscher Wetterdienst
EMULATE
Environment Canada
ERA-CLIM
ETH-Zurich
European Reanalysis and Obs for Monitoring
GCOS AOPC/OOPC WG on Surface Pressure
GCOS/WCRP WG on Obs Data Sets
Hong Kong Observatory
Icelandic Meteorological Office
IBTrACS
ICOADS
IEDRO
JAMSTEC
Japan Meteorological Agency
Jersey Met Dept.
Lamont-Doherty Earth Observatory
KNMI
MeteoFrance
MeteoFrance – Division of Climate
Meteorological and Hydrological Service, Croatia
National Center for Atmospheric Research
Nicolaus Copernicus University
Niue Met Service
NIWA
NOAA Climate Database Modernization Program
NOAA Earth System Research Laboratory
NOAA National Climatic Data Center
NOAA National Centers for Environmental Prediction
NOAA Northeast Regional Climate Center at Cornell U.
NOAA Midwest Regional Climate Center at UIUC
NOAA Pacific Marine Environmental Laboratory
Norwegian Meteorological Institute
Oldweather.org
Ohio State U. – Byrd Polar Research Center
Portuguese Meteorological Institute (IM)
Proudman Oceanographic Laboratory
SIGN - Signatures of environmental change in the observations of the Geophysical Institutes
South African Weather Service
UK Met Office Hadley Centre
U. of Bern, Switzerland
U. of Colorado-CIRES/Climate Diagnostics Center
U. of East Anglia-Climatic Research Unit
U. of Giessen –Dept. of Geography
U. of Lisbon-Instituto Geofisico do Infante D. Luiz
U. of Lisbon-Instituto de Meteorologia
U. of Mebourne
U. of Milan-Dept. of Physics
U. of Porto-Instituto Geofisca
U. Rovira i Virgili-Center for Climate Change
U. of South Carolina
U. of Toronto-Dept of Physics
U. of Washington
World Meteorological Organization - MEDARE
ZAMG (Austrian Weather Service)

Comparison of anomalies from
Subdaily independent SLP observations from Exeter vs.
Reanalysis (20CR-1815) 2*ensemble spread (1815 to 1817)



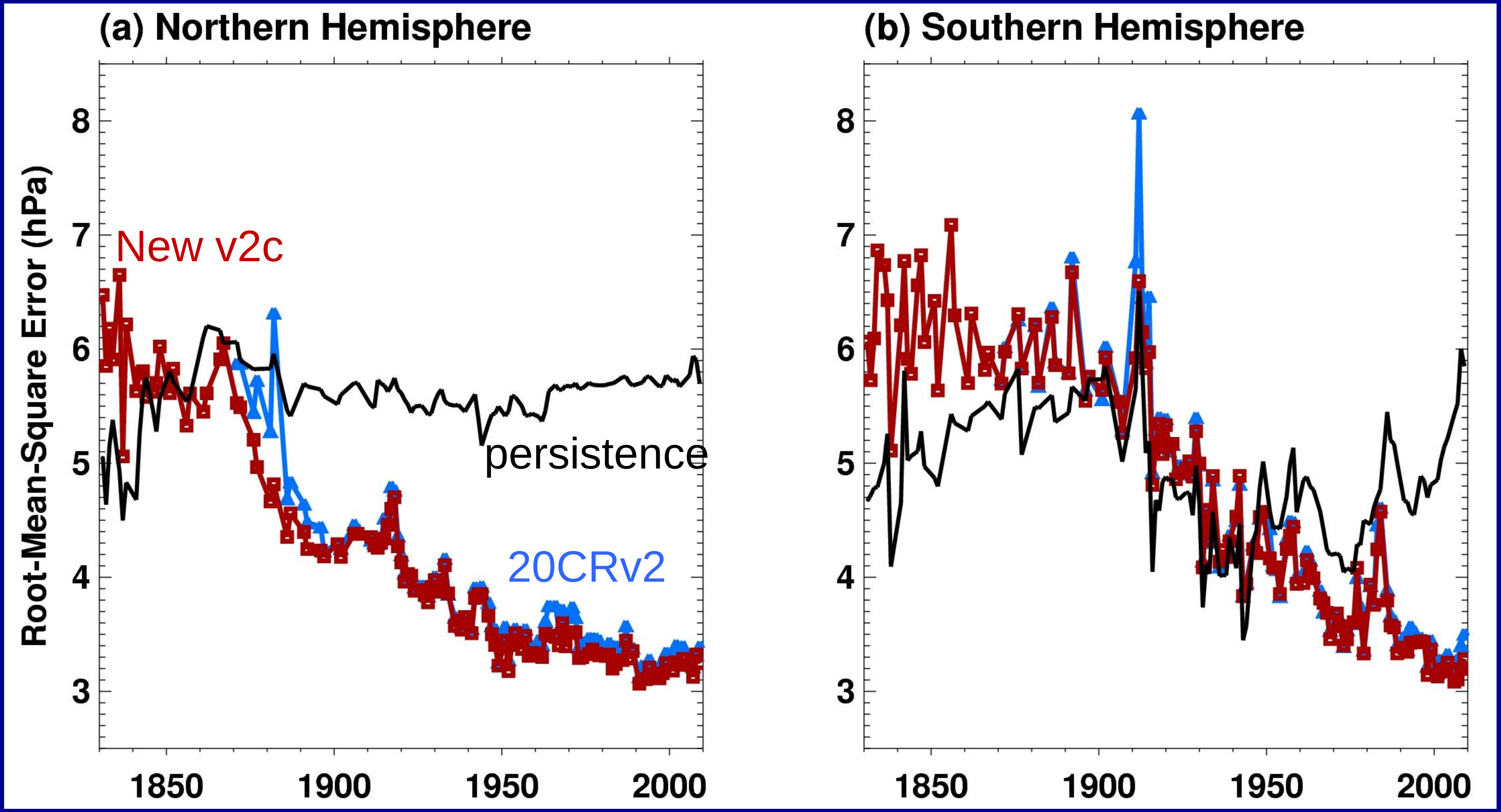
Low pressure extremes are muted, but otherwise pressure successfully predicted at t
independent station.

Comparison of anomalies from
Subdaily independent air temperature observations from Exeter vs.
Reanalysis (20CR-1815) 2*ensemble spread (1815 to 1817)



Reanalysis still has a good correlation with observations. But not as good as at London (where the pressures are assimilated) and even less variance. Why?

Root Mean Square difference of Surface and Sea Level Pressure Observations and 24 hour Forecasts from 20CRv2 and v2c (*Jan-Dec*)

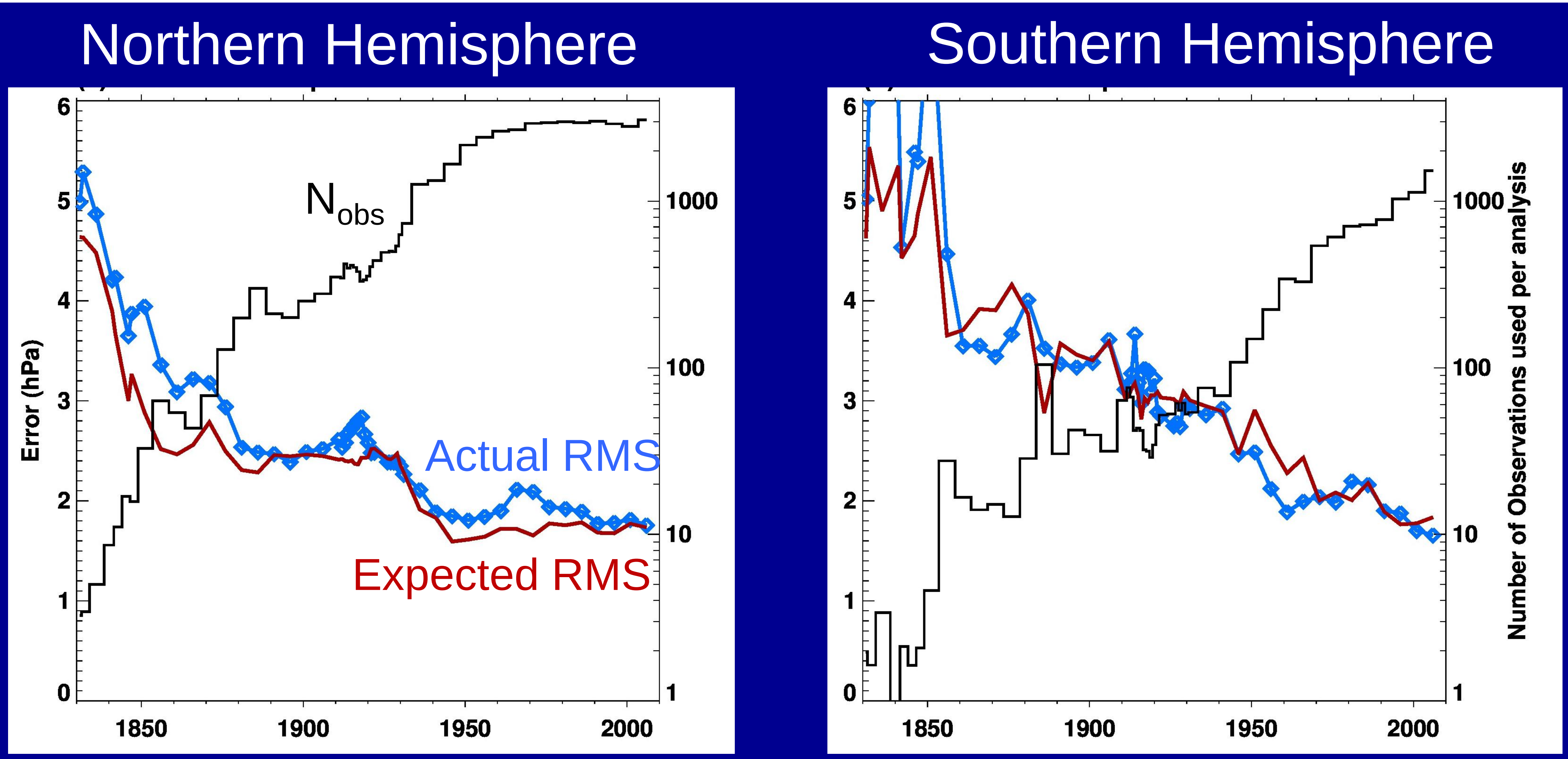


Northern Hemisphere 24 hr forecasts beat persistence even in 1850s. Southern Hemisphere has an analysis that produces forecasts comparable to persistence starting in 1900s. New v2c is an improvement.

v2c Surface Pressure uncertainty estimate poleward of 20(S,N)

blue actual RMS difference

red expected RMS difference



Uncertainty estimates are consistent with actual differences between first guess and pressure observations even as the network changes by three orders of magnitude over more than 150 years! (*This is not tuned*).

Adapted from Compo et al. 2011

Ensemble Filter Algorithm (Whitaker and Hamill, 2002)

Ensemble mean analysis

$$\overline{\mathrm{x}}_j^{\mathrm{a}} = \overline{\mathrm{x}}_j^{\mathrm{b}} + \mathrm{K}\left(y^{\mathrm{o}} - \overline{y}_j^{\mathrm{b}}\right),$$

Ensemble analysis deviations

$$\mathrm{x}_j{}'^{\mathrm{a}} = \mathrm{x}_j{}'^{\mathrm{b}} - \tilde{\mathrm{K}}\left(y_j{}'^{\mathrm{b}}\right),$$

Sample Kalman Gain

$$\mathrm{K} = \mathrm{P^b H^T}(\mathrm{H P^b H^T} + R)^{-1}$$
$$= \frac{1}{n-1}\sum_{j=1}^{n} \mathrm{x}_j{}'^{\mathrm{b}} y_j{}'^{\mathrm{b}} \left(\frac{1}{n-1}\sum_{j=1}^{n} y_j{}'^{\mathrm{b}} y_j{}'^{\mathrm{b}} + R\right)^{-1}$$

Sample Modified Kalman Gain

$$\tilde{\mathrm{K}} = \left(1 + \sqrt{\frac{R}{\mathrm{H P^b H^T} + R}}\right)^{-1} \mathrm{K},$$

R=observation error variance

$\mathbf{x}_j$ is pressure, air temperature, winds, humidity, etc. at all levels and gridpoints, every six hours.

y^o is only observations of hourly and synoptic **surface pressure**,

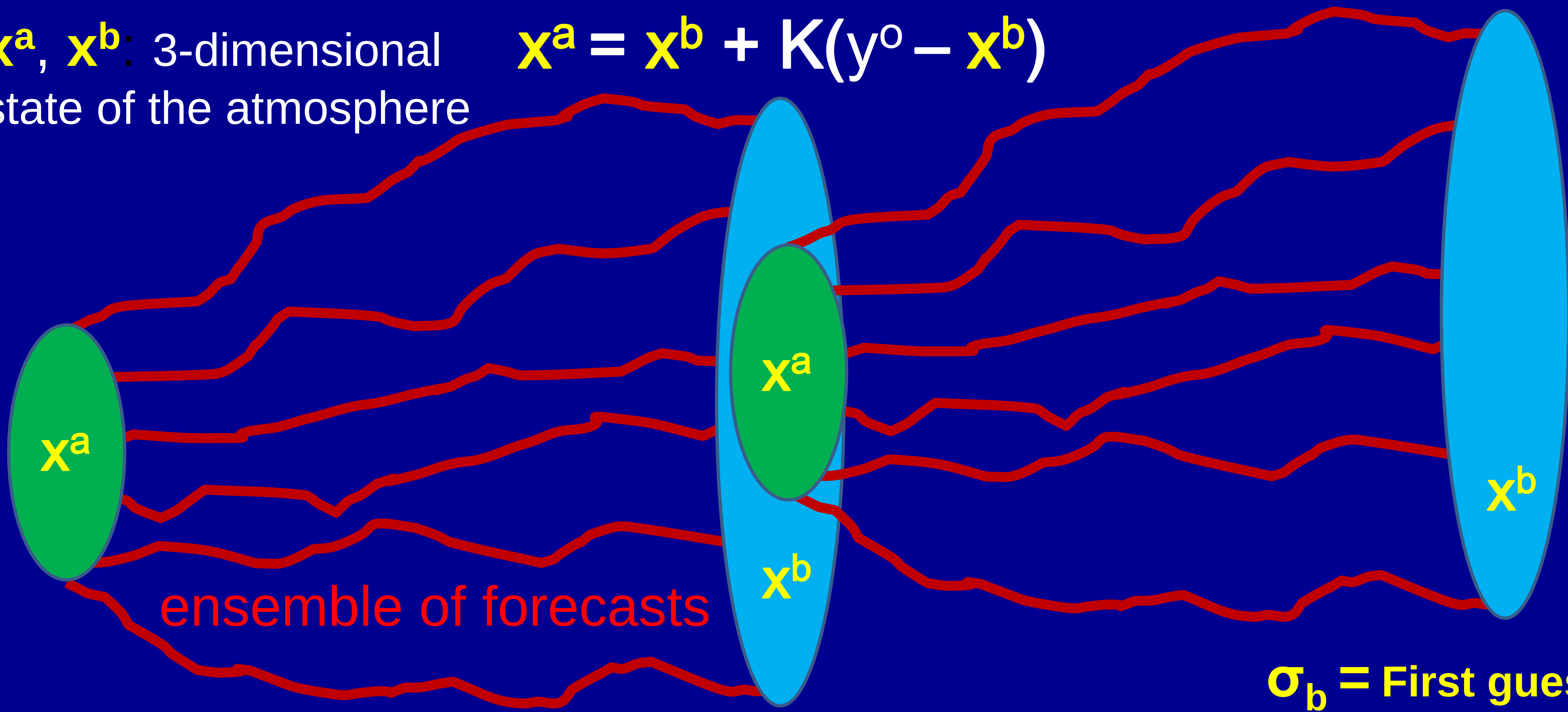
$\mathbf{y}^{\mathbf{b}}\mathbf{=H}\mathbf{x}^{\mathbf{b}}$ is guess surface pressure

Ensemble Data Assimilation (Whitaker and Hamill, 2002)

20CR analysis x^a is a weighted average of the first guess x^b and pressure observation y^o. Each observation is assimilated serially.

x^a, x^b: 3-dimensional state of the atmosphere

$$x^a = x^b + K(y^o - x^b)$$



σ_a = analysis uncertainty

σ_b = First guess uncertainty

the weight **K** varies with the atmospheric flow and the observation network

analysis time (0Z) **analysis time (6Z)** **analysis time (12Z)**

20th Century Reanalysis v2c implementation of Ensemble Filter Algorithm

(Whitaker et al. 2004, Compo et al. 2006, Compo et al. 2011)

Algorithm uses an ensemble of GCM runs to produce the weight **K** that varies with the atmospheric flow and the observation network every 6 hours

Using 56 member ensemble, new prescribed boundary conditions:

SODAsi.2c 18 member pentad SST and

COBE-SST2 monthly sea ice concentration (corrects sea ice error in v2)

(*Giese et al. 2015*, *Hirahara et al. 2014*)

1851-2011: T62 (~200km), 28 level NCEP GFS08ex atmosphere/land model

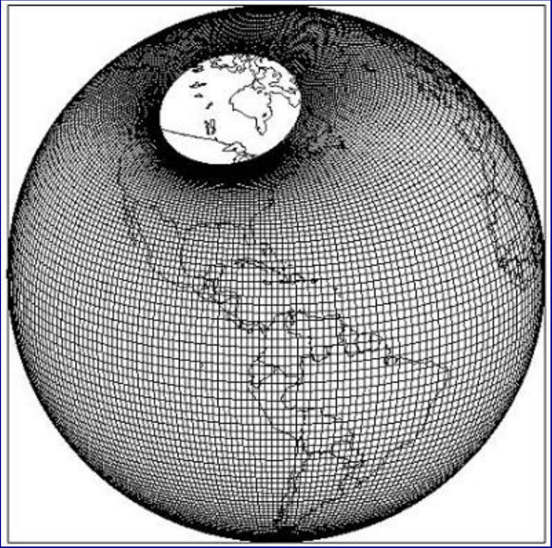
9 hour forecasts for 6 hour centered analysis window

- time-varying CO_2, solar and volcanic radiative forcing (Sato et al.)

Every 5 years produced in parallel: 1851-1855,…, 1881-1885, …,1996-2000, .., 2006-2011 after 14 month spin-up

http://go.usa.gov/XTd Compo et al. 2011, doi:10.1002/qj.776

SODA sparse input v2 (1846-2011)



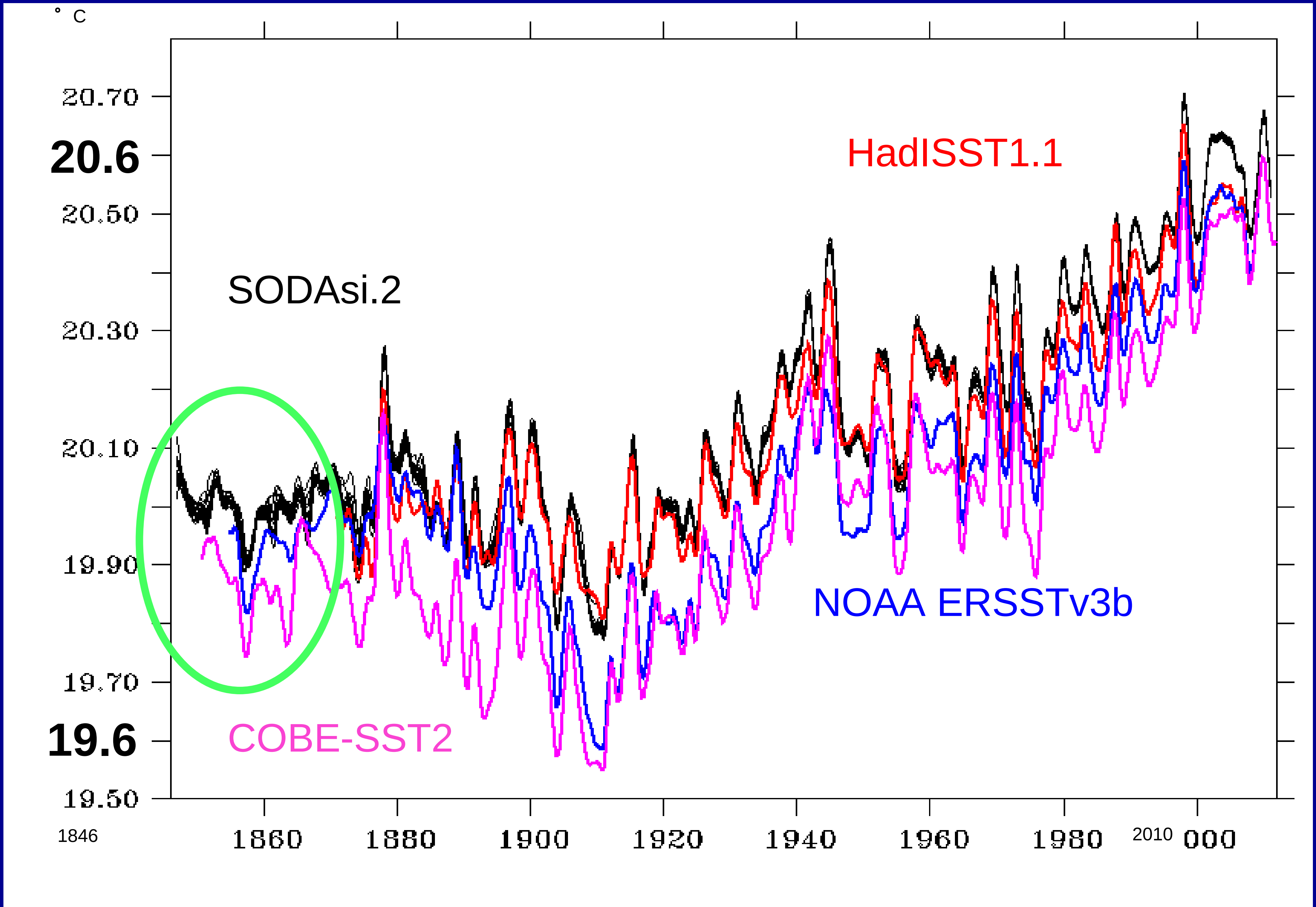
Giese et al. 2015

- **18 Ensemble Members**
- **Parallel Ocean Program v2.0.1**
  - **0.4° longitude x 0.25° to 0.4° latitude with 40 levels**
- **Winds**
  - 20CRv2 ensemble member daily stress (1949 – 2011)
  - 20CRv2 system with ISPDv3.2.4 and HadISST1.1 (1871-1948)
  - with ISPDv3.2.4 and climatological SST (1846-1870)
- **Heat and Salt fluxes**
  - Bulk formulae using 20CRv2 daily variables
- **SODAsi Observations**
  - Only ICOADS 2.5 SST data with Hadley Bucket Correction

Simple Ocean Data Assimilation sparse input v2

Global Ocean Annual Average (60N-60S)

Climo SST in 20CR 1846 to 1870 but variation in SODAsi



SODAsi trends and decadal variability are consistent with statistical reconstructions. Generates interannual variations in late 1850s even when 20CR forcing had climatological SST.

International Surface Pressure Databank version 3.2.9 (ISPD)

Subdaily observations assembled in partnership with

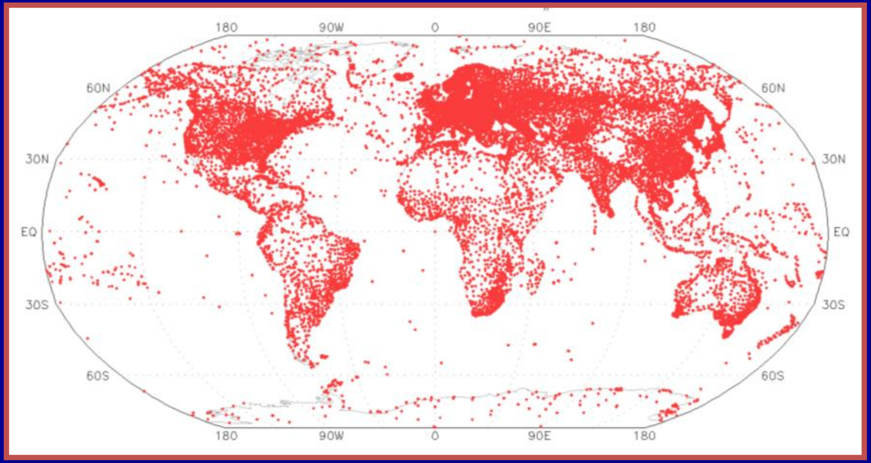
GCOS AOPC/OOPC Working Group on Surface Pressure

GCOS/WCRP Working Group on Observational Data Sets for Reanalysis

Atmospheric Circulation Reconstructions over the Earth (ACRE)

Land data Component: merged by NOAA NCDC, NOAA ESRL, and CU/CIRES

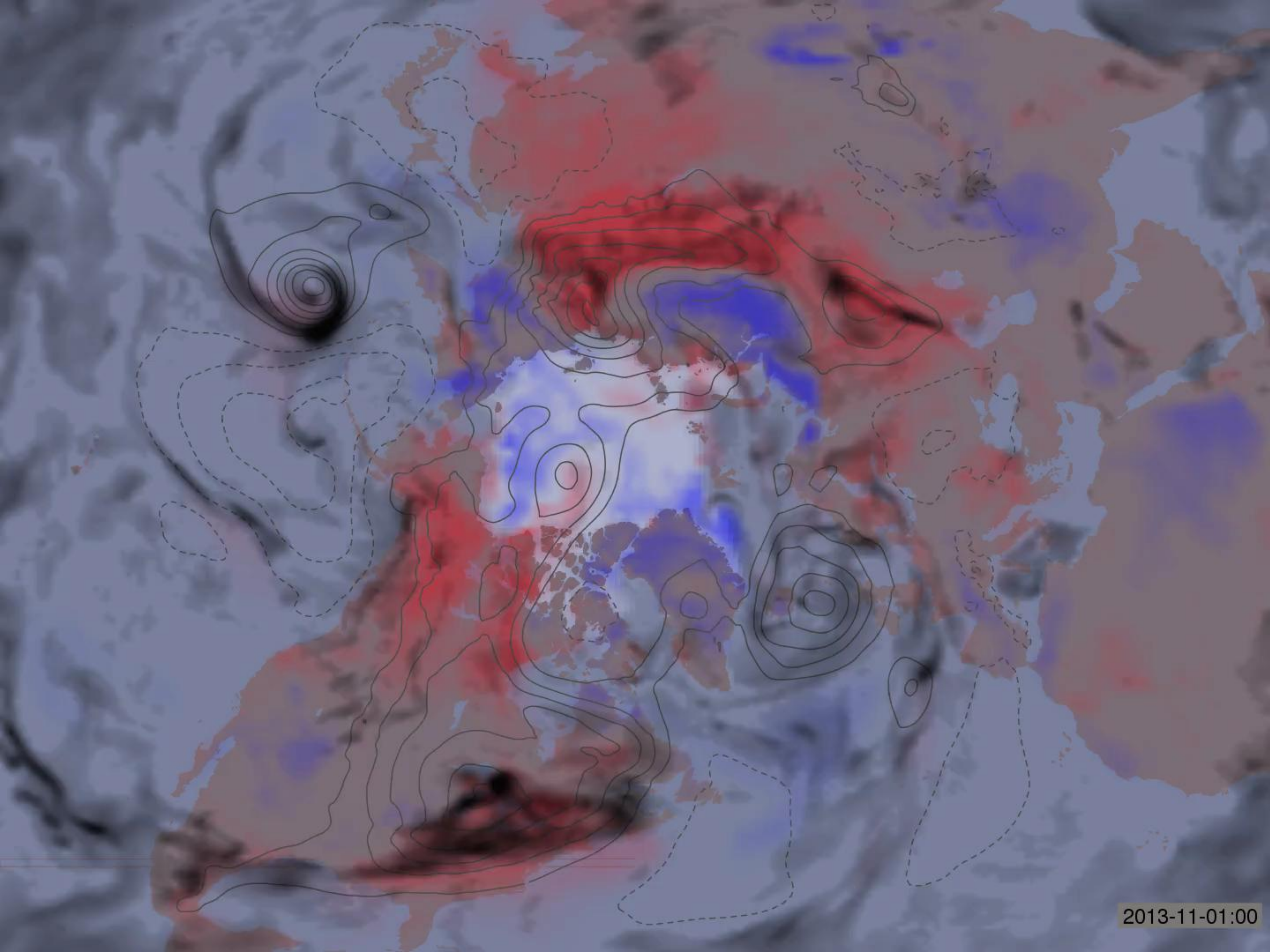
– **63 data sources**
– **40,000+ stations**
– **2.1 billion obs**
– **1755 - 2013**



Marine data component: **Oldweather.org, ACRE expeditions**, **ICOADSv2.5** merged by NOAA ESRL, NCDC, and NCAR

Tropical Cyclone Best Track data component: **IBTrACS** merged by NOAA NCDC

DATA ACCESS soon: rda.ucar.edu/datasets (T. Cram, NCAR DSS; C. McColl CIRES)
Reanalyses.org/observations/surface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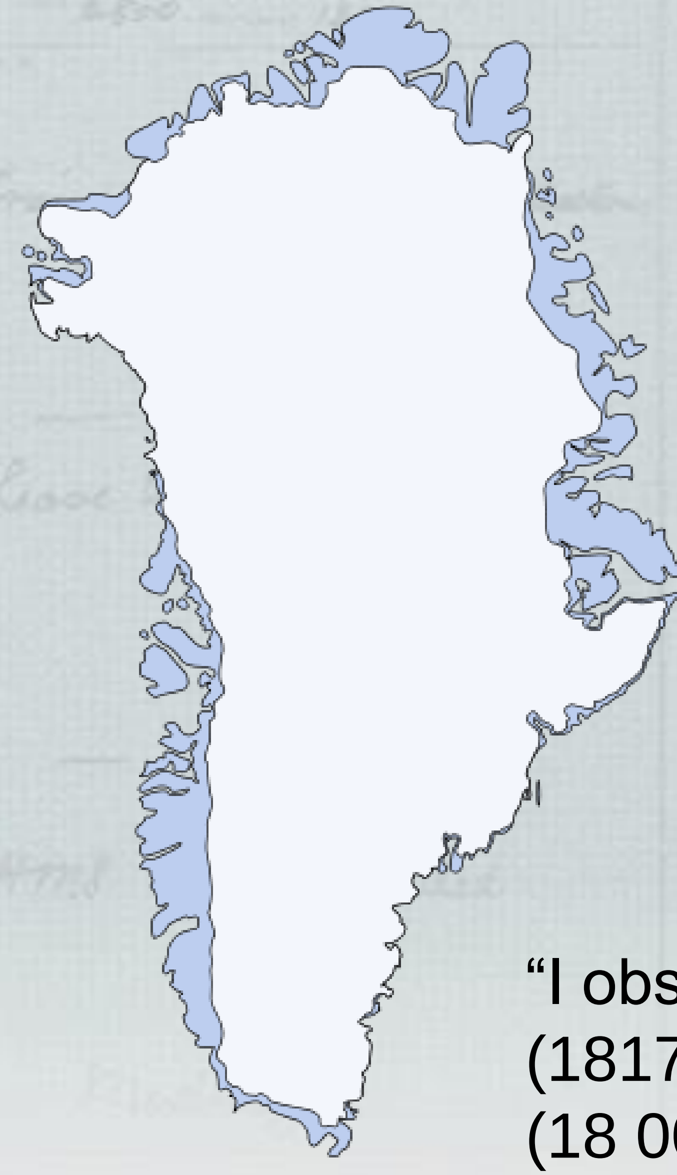
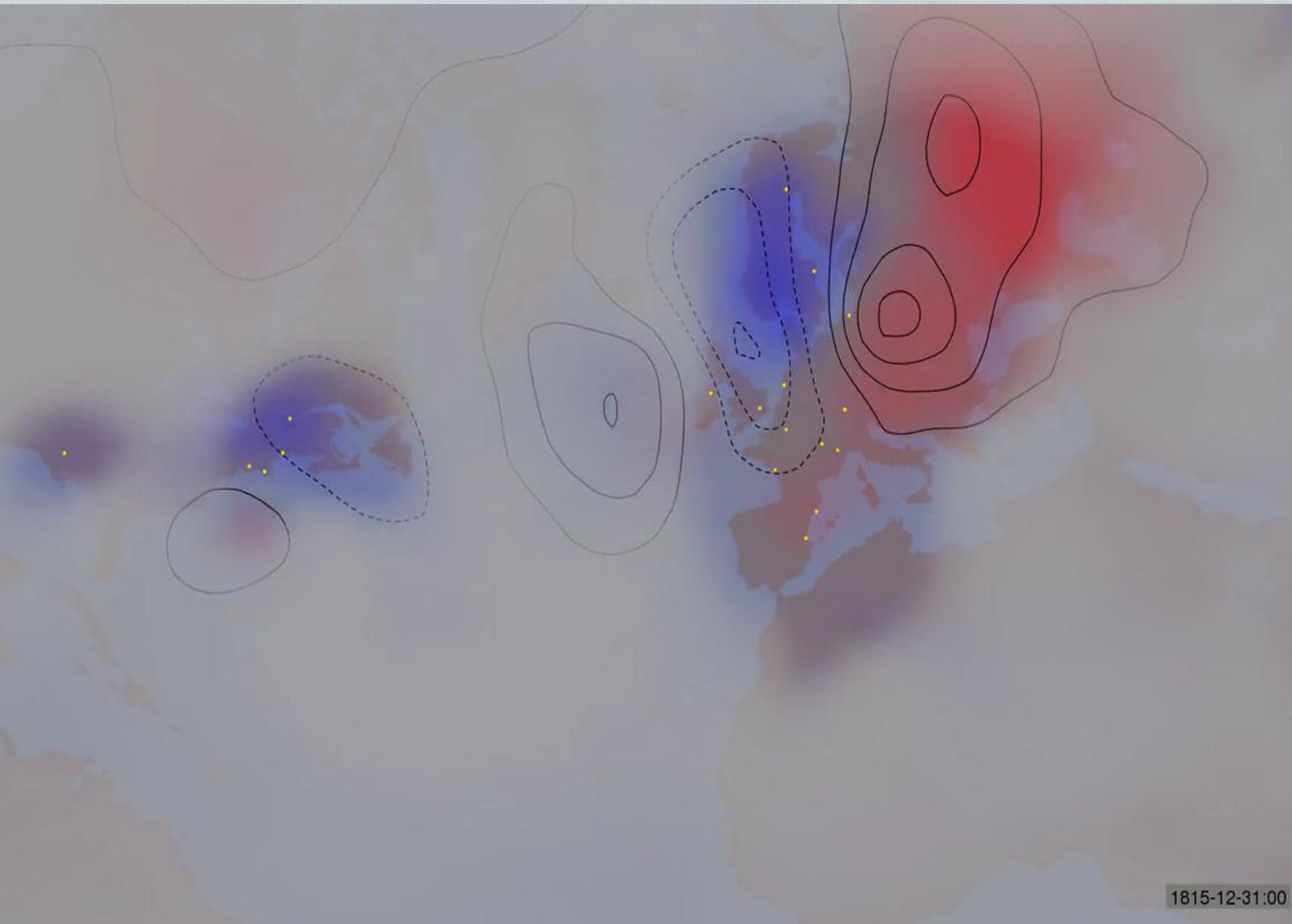


"… in 1816 open ice lingered more than one month later than present-day ice dates in Hudson Bay to the northwest of the Belcher Islands and also in the northern half of James Bay.
… the most severe summer ice conditions in this region [Labrador coast north of 55] throughout the nineteenth century occurred in 1816."

Catchpole & Faurer, 1985

"I observed on my last voyage (1817) about 2000 square leagues, (18 000 square miles) of the surface of the Greenland seas, included between the parallels of 74 and 80, perfectly void of ice, all of which disappeared within the last two years"

Letter: William Scoresby (Whaler) to Sir Joseph Banks (Royal Society)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