The Global Surface Temperature Average: a history , recent changes and their context over the Late Holocene

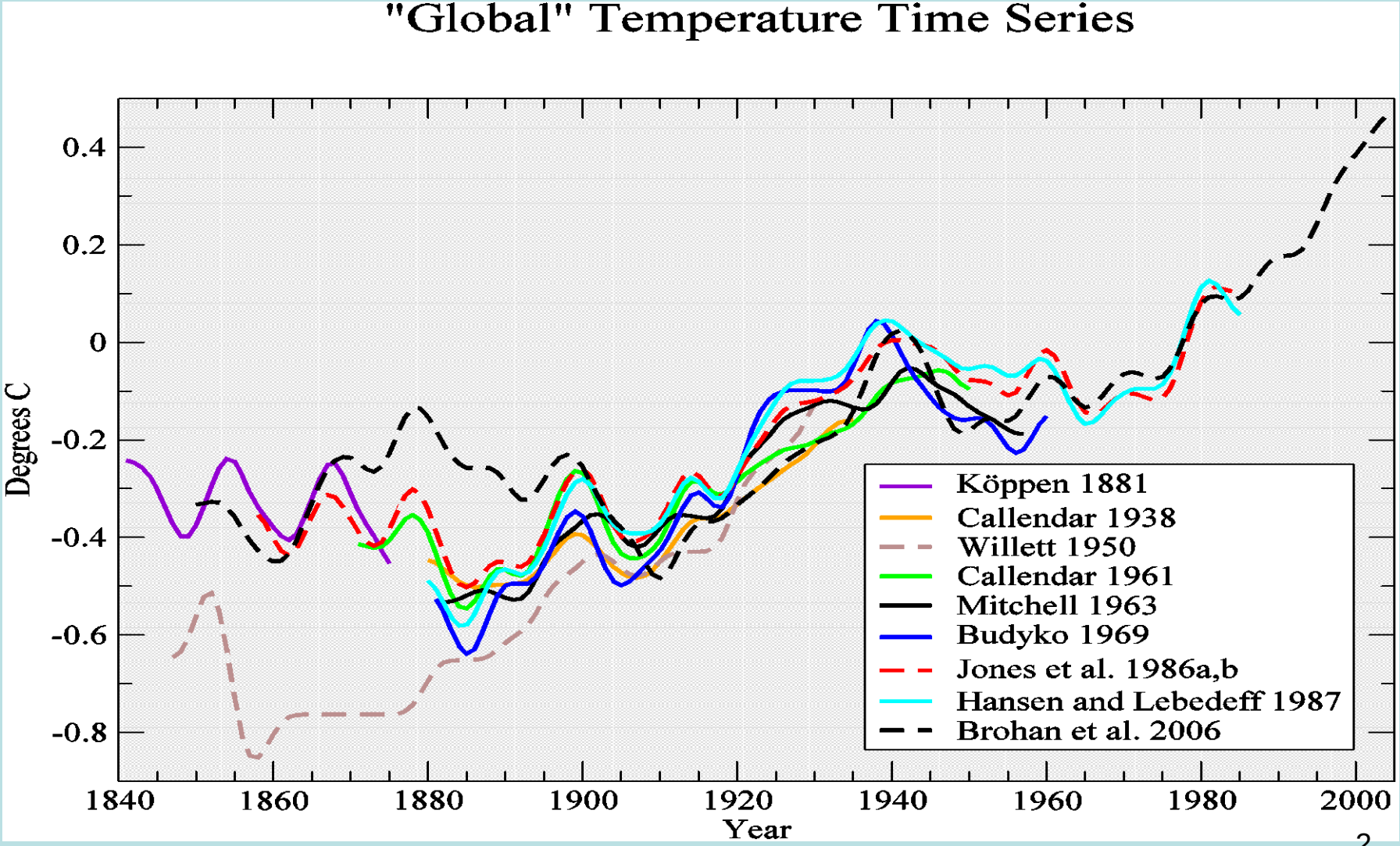
Phil Jones CRU, UEA

- History of Global Temperatures
- Problems with the data (land then marine)
- Recent Changes
- Context over the Late Holocene (last 2000 years)
- Thanks to some slides from Tim Osborn

Jones, P.D., 2016: The Reliability of Global and Hemispheric Surface Temperature Records. *Advances in Atmospheric Sciences* **33**, 269-282, doi:10.1007/s00376-015-5194-4.

(**one of the two most read papers in this journal**)

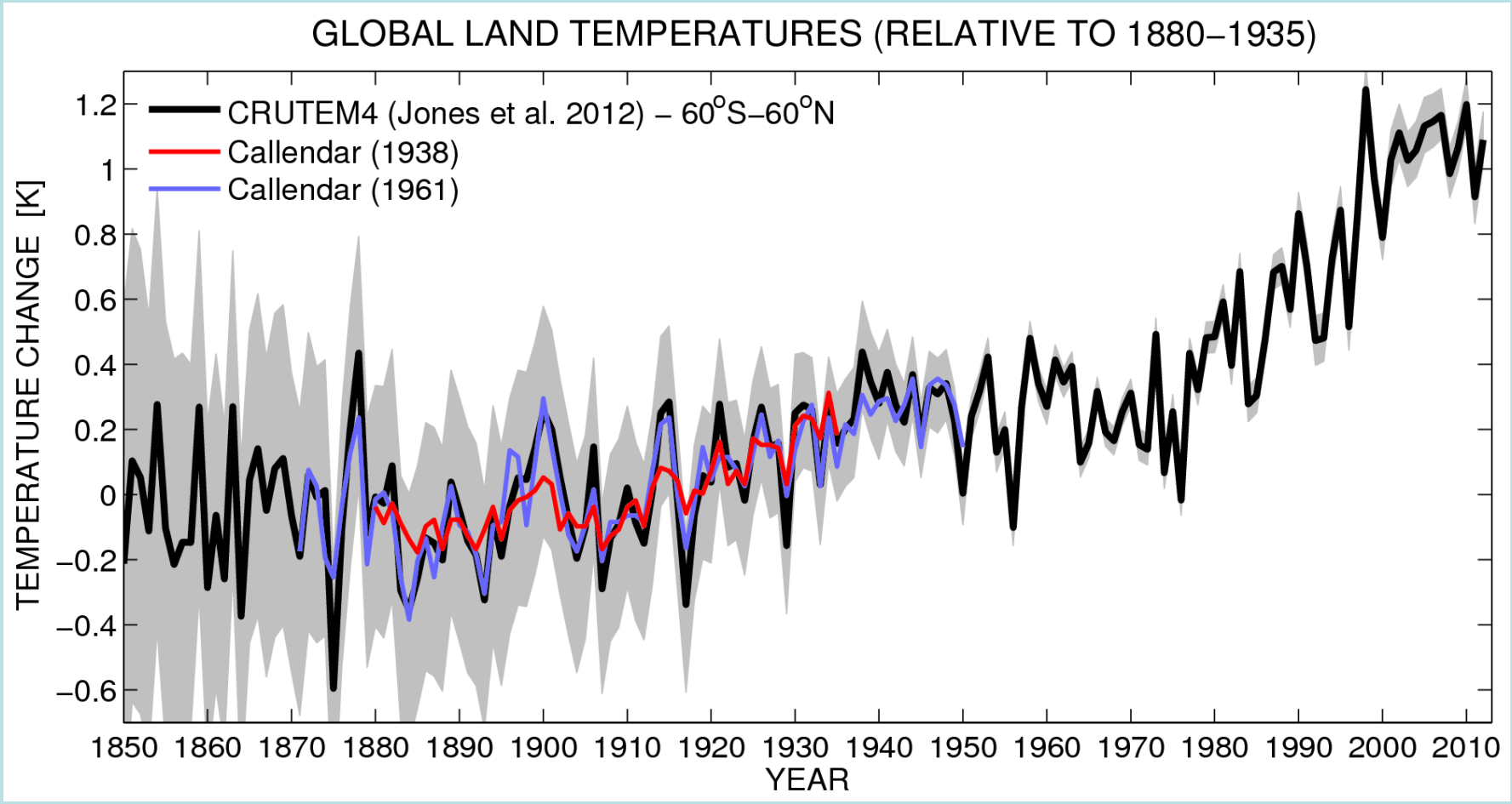
Pre-CRU land temperature series, each adjusted to have Brohan *et al* average (HadCRUT3) over their last 30 years of overlap (from Ch1 of AR4: zero line is 1961-90)



AR4 shouldn't have compared land only series with HadCRUT3!

Comparison of CRUTEM4 with papers by Callendar (1938, 1961)

Includes the error estimate ranges for CRUTEM4 developed by Morice et al (2012)
Further comparisons with earlier work in Ch 1 of WG1 from AR4



Hawkins, E. and Jones, P.D., 2013: On increasing global temperatures: 75 years after Callendar. Q. J. Royal Meteorol. Soc., 139, DOI:10.1002/qj.2178.

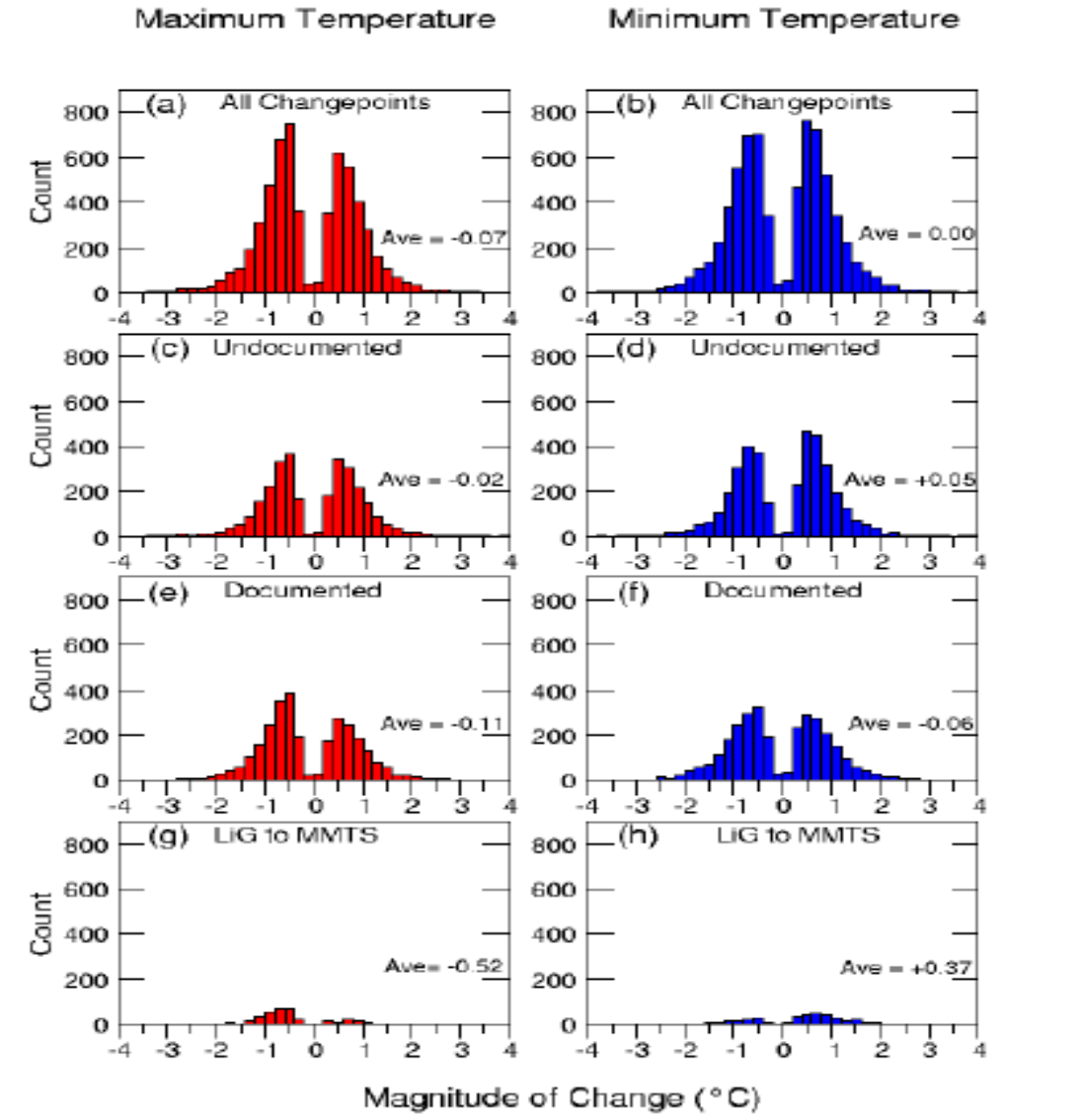
Agreement between the current land-based datasets (CRUTEM4, NCEI, GISS, Berkeley Earth)

- Station Homogeneity – Consistency of the Records
- Tends to make little difference, as issues differ from place to place
- Representativeness of individual stations

- Robustness of the record illustrated by removing large numbers of stations

- **Real issues are the biases, from consistent changes (e.g. urbanization, introduction of screens, and the most important, when combining with marine data – the change over time in the way sea-surface temperature measurements have been taken)**

Station Homogeneity Assessment – US HCN



Menne et al (2009) in BAMS

Matthew J. Menne, Claude N. Williams Jr., and Russell S. Vose, 2009: The U.S. Historical Climatology Network Monthly Temperature Data, Version 2, *BAMS*, **90**, 993-1007

Overall Station Homogeneity affects are not that important – at large scales (hemispheric averages)

Can be important locally at the grid-box scale

Representativeness of single stations

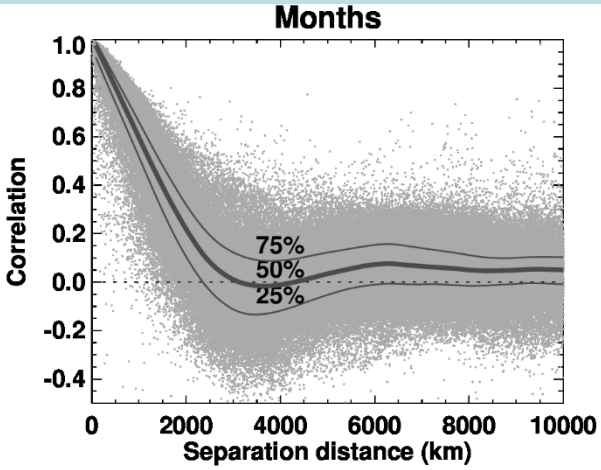
- How many stations need to calculate the global mean?
- How many stations needed to produce a gridded temperature dataset?

- Answers depend on what you want to do?
- Depends on timescale

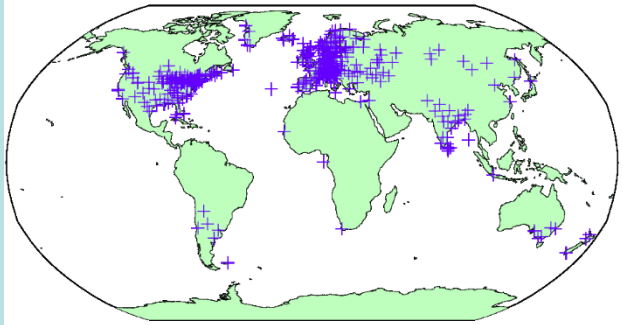
- Answer different for a variable like precipitation

- Records of Ice Ages from a couple of locations

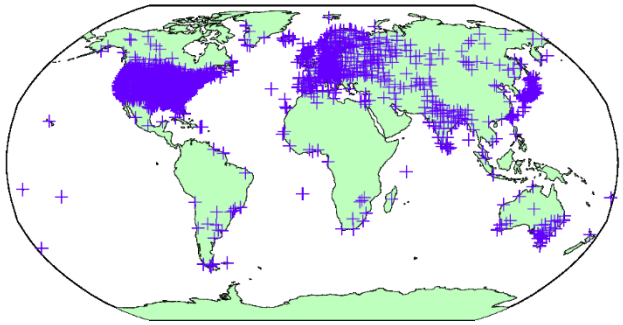
When did records start?



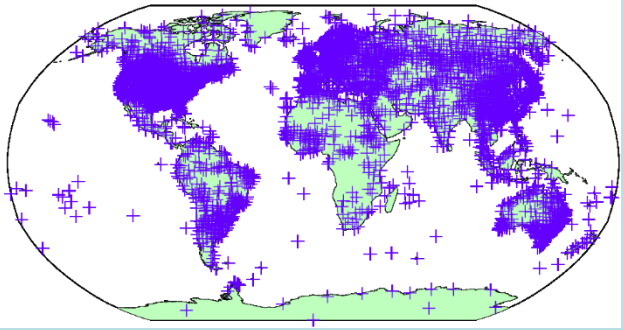
Jan 1875 land stations with data = 425



Jan 1900 land stations with data = 2075

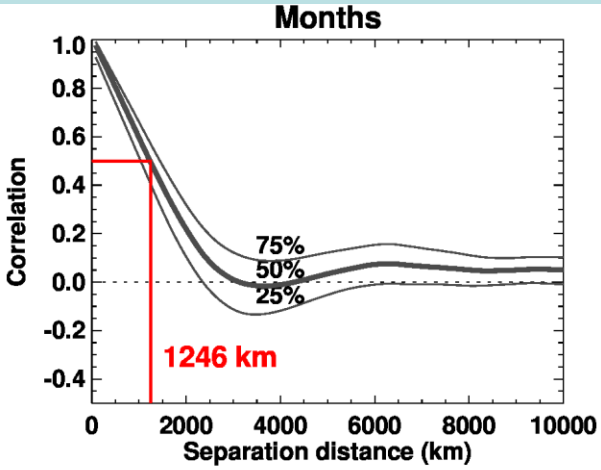


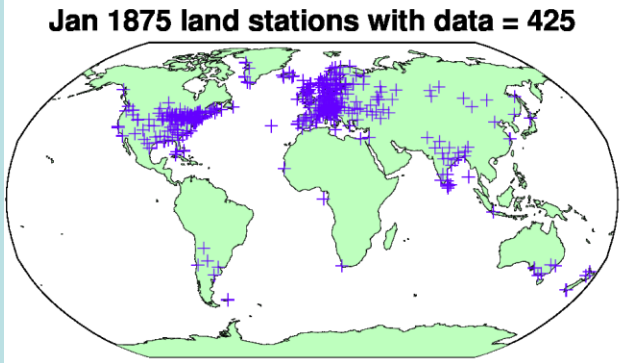
Jan 2010 land stations with data = 4719

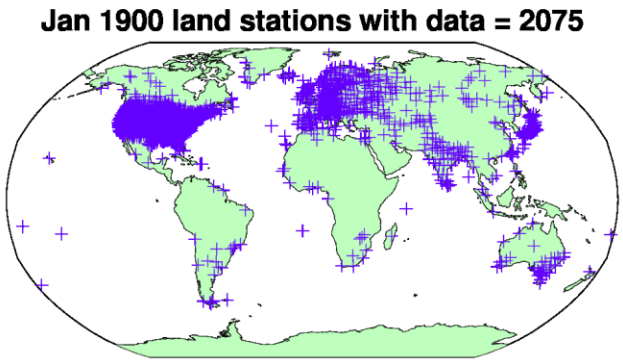


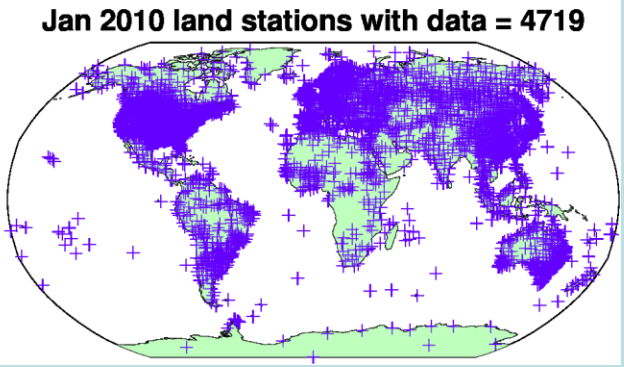
Jones, Osborn, Briffa (1997) *J. Geophys. Res.*; Osborn *et al.* (in prep.) CRUTEM5

Monthly Timescale and Representativeness



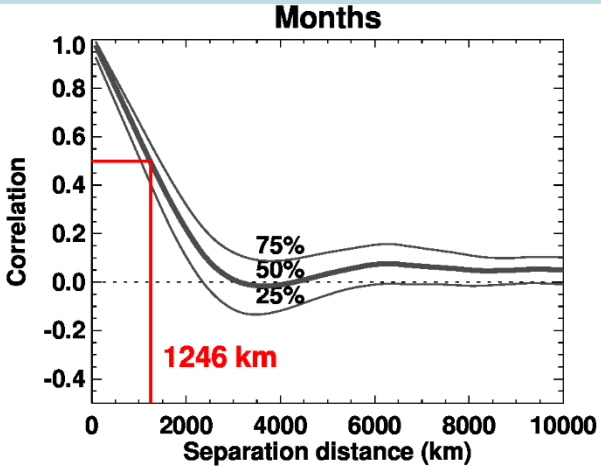




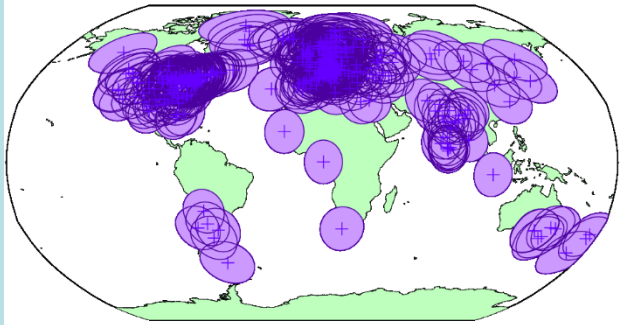


Jones, Osborn, Briffa (1997) *J. Geophys. Res.*; Osborn *et al.* (in prep.) CRUTEM5

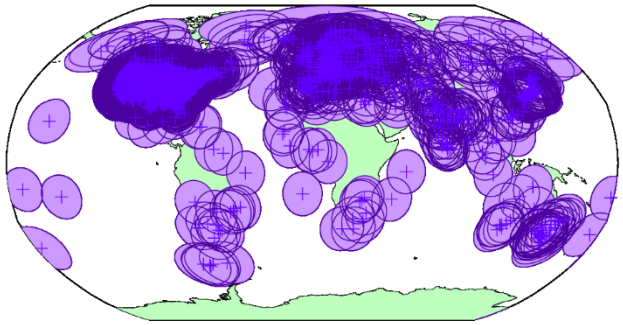
Monthly Timescale



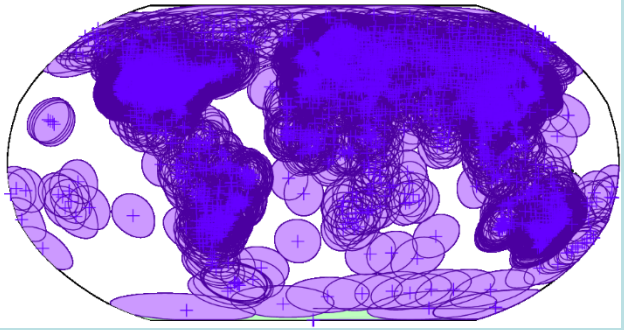
Jan 1875 land stations with data = 425



Jan 1900 land stations with data = 2075

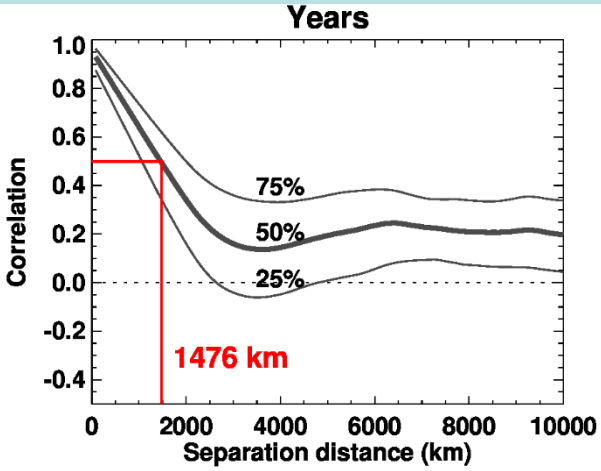


Jan 2010 land stations with data = 4719

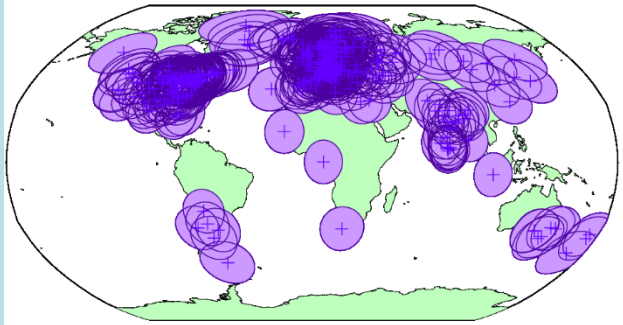


Jones, Osborn, Briffa (1997) *J. Geophys. Res.*; Osborn *et al.* (in prep.) CRUTEM5

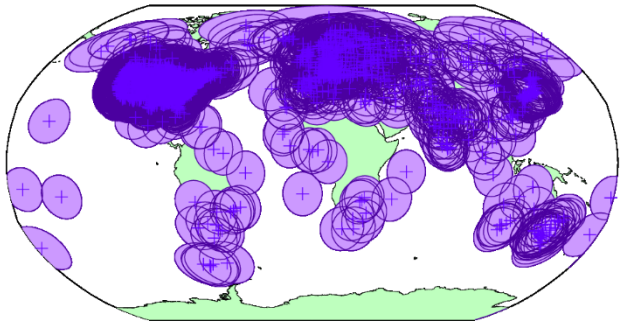
Annual Timescale



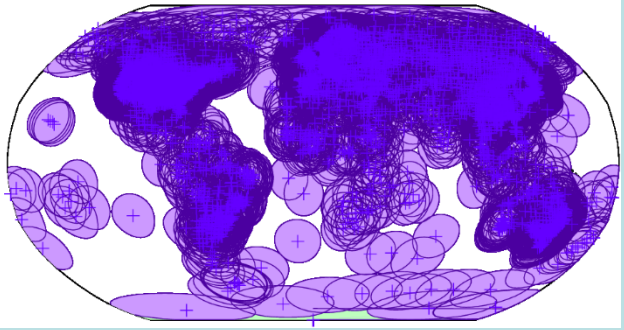
Jan 1875 land stations with data = 425



Jan 1900 land stations with data = 2075

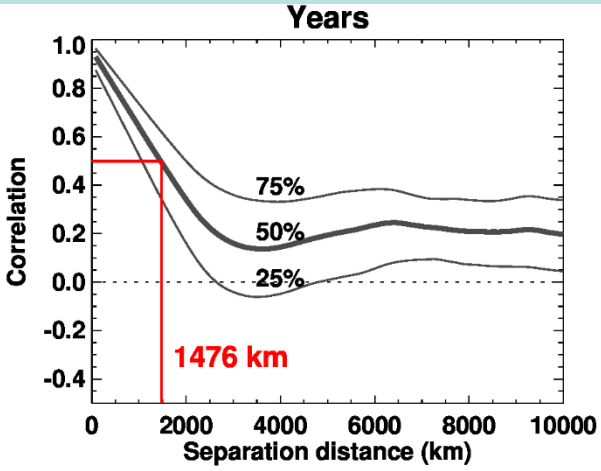


Jan 2010 land stations with data = 4719

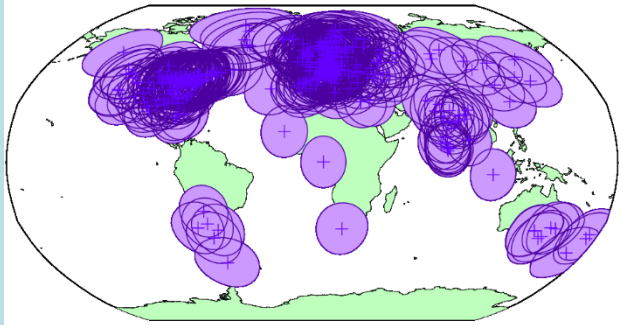


Jones, Osborn, Briffa (1997) *J. Geophys. Res.*; Osborn *et al.* (in prep.) CRUTEM5

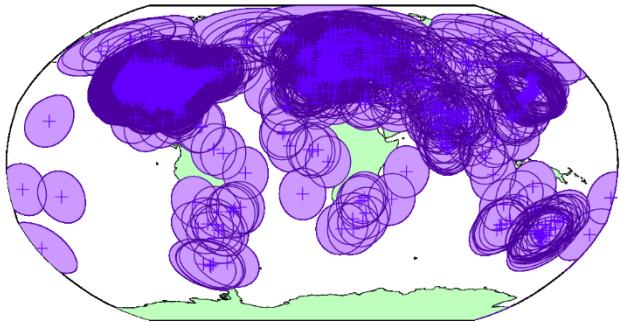
Annual Timescale



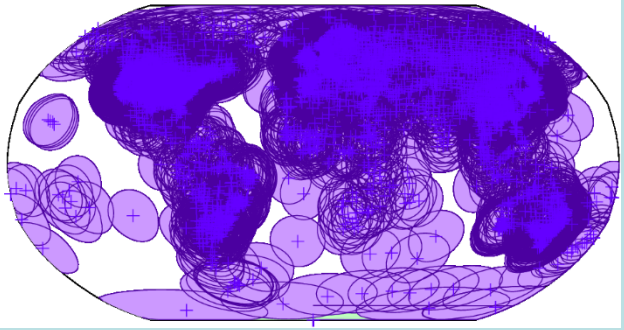
Jan 1875 land stations with data = 425



Jan 1900 land stations with data = 2075

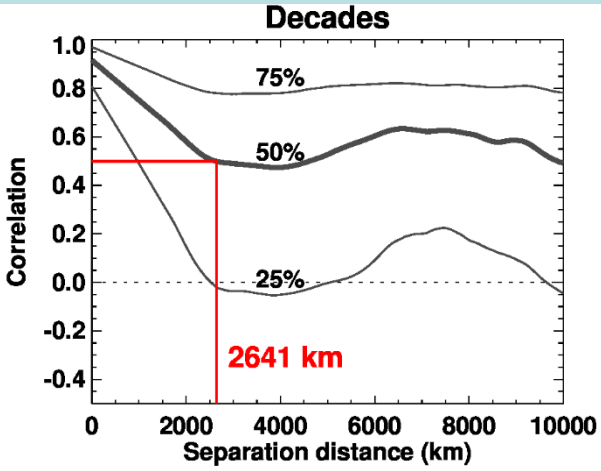


Jan 2010 land stations with data = 4719

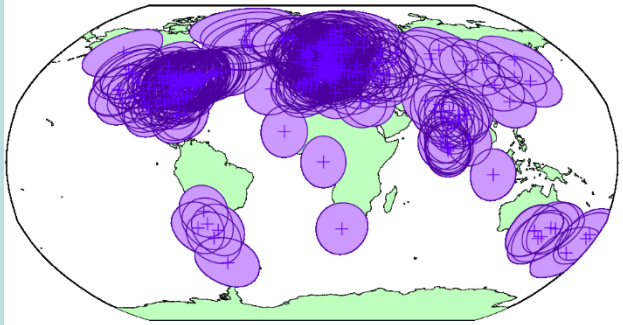


Jones, Osborn, Briffa (1997) *J. Geophys. Res.*; Osborn *et al.* (in prep.) CRUTEM5

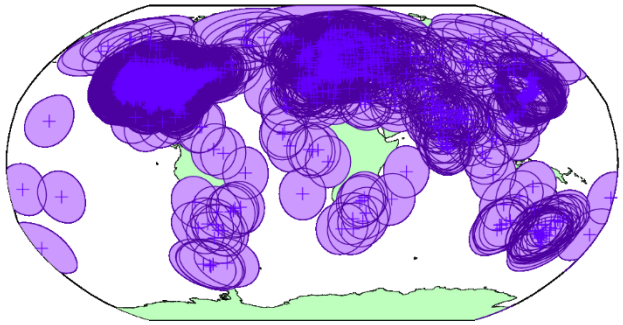
Decadal Timescale



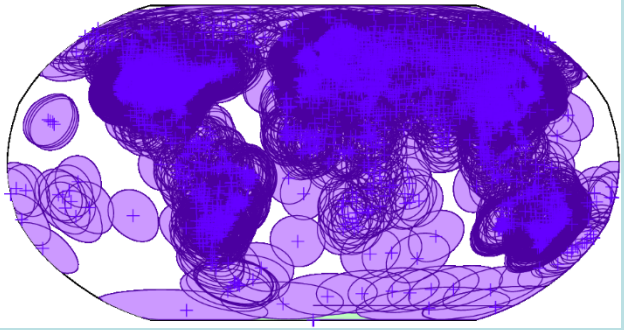
Jan 1875 land stations with data = 425



Jan 1900 land stations with data = 2075



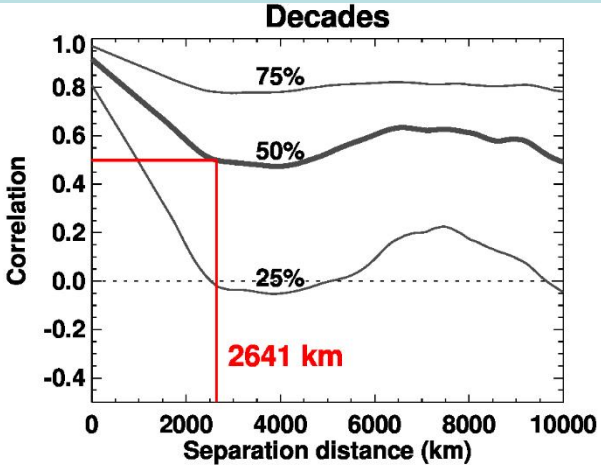
Jan 2010 land stations with data = 4719



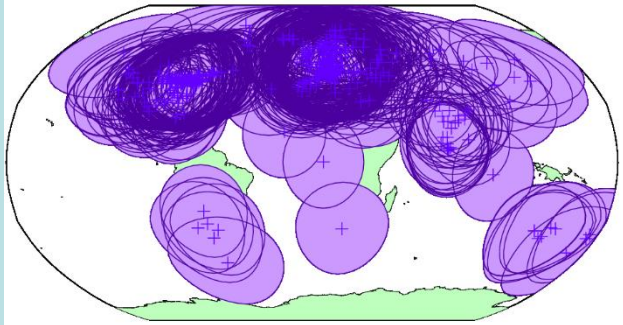
Jones, Osborn, Briffa (1997) *J. Geophys. Res.*; Osborn *et al.* (in prep.) CRUTEM5

At these timescales, the land is well covered. Important though to get the oceans in.

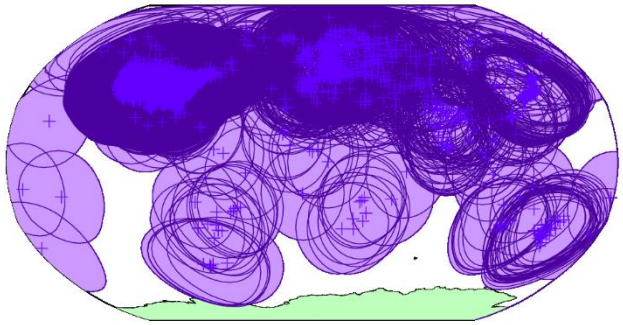
Decadal Timescale



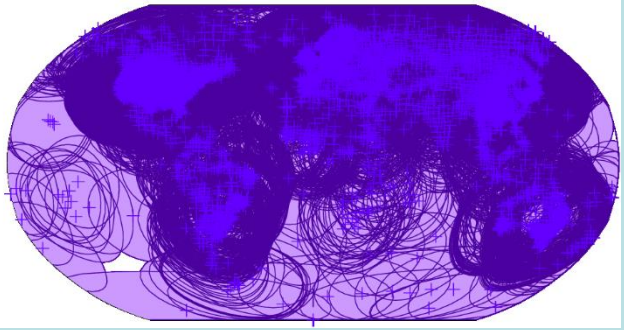
Jan 1875 land stations with data = 425



Jan 1900 land stations with data = 2075

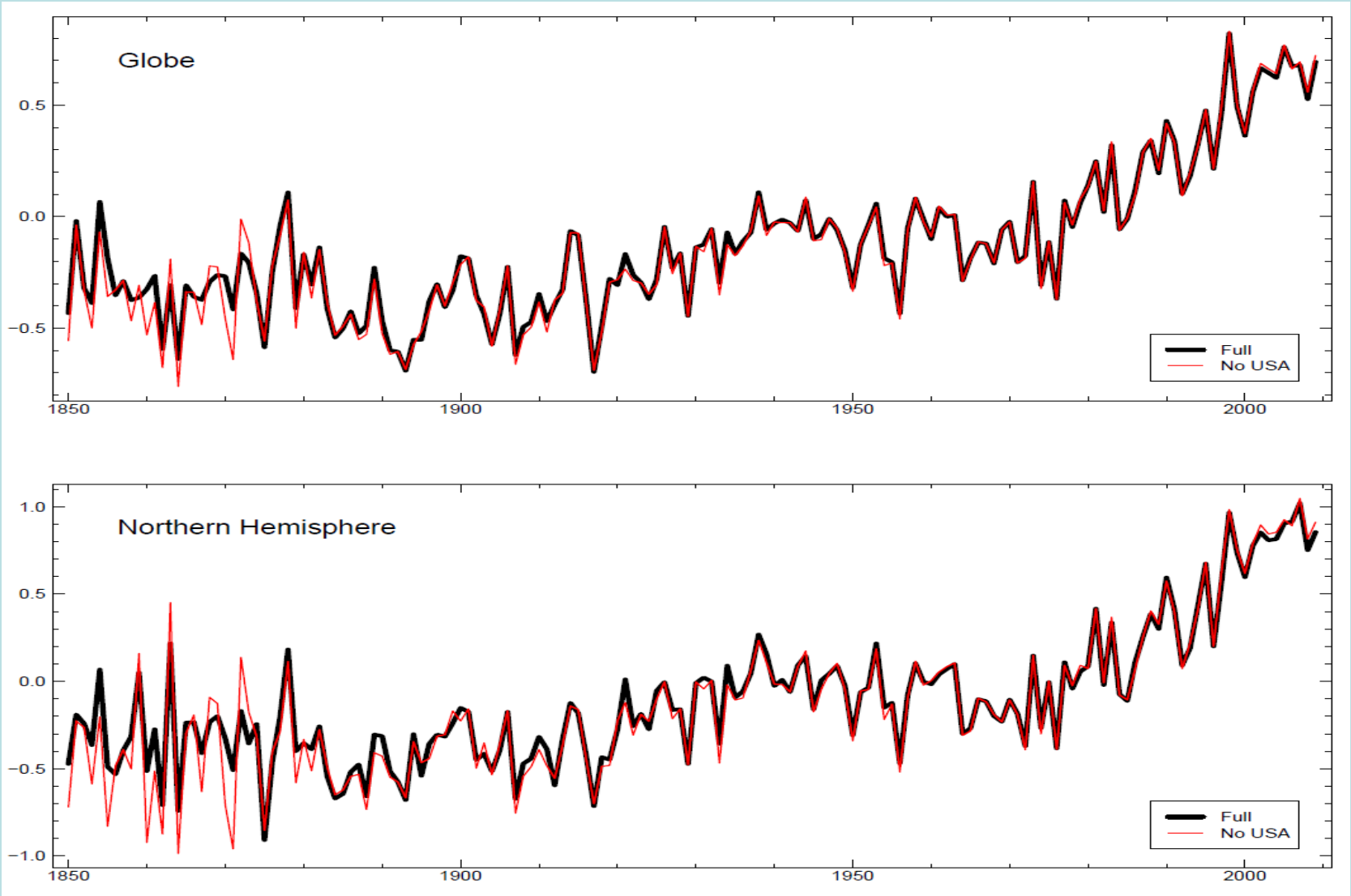


Jan 2010 land stations with data = 4719

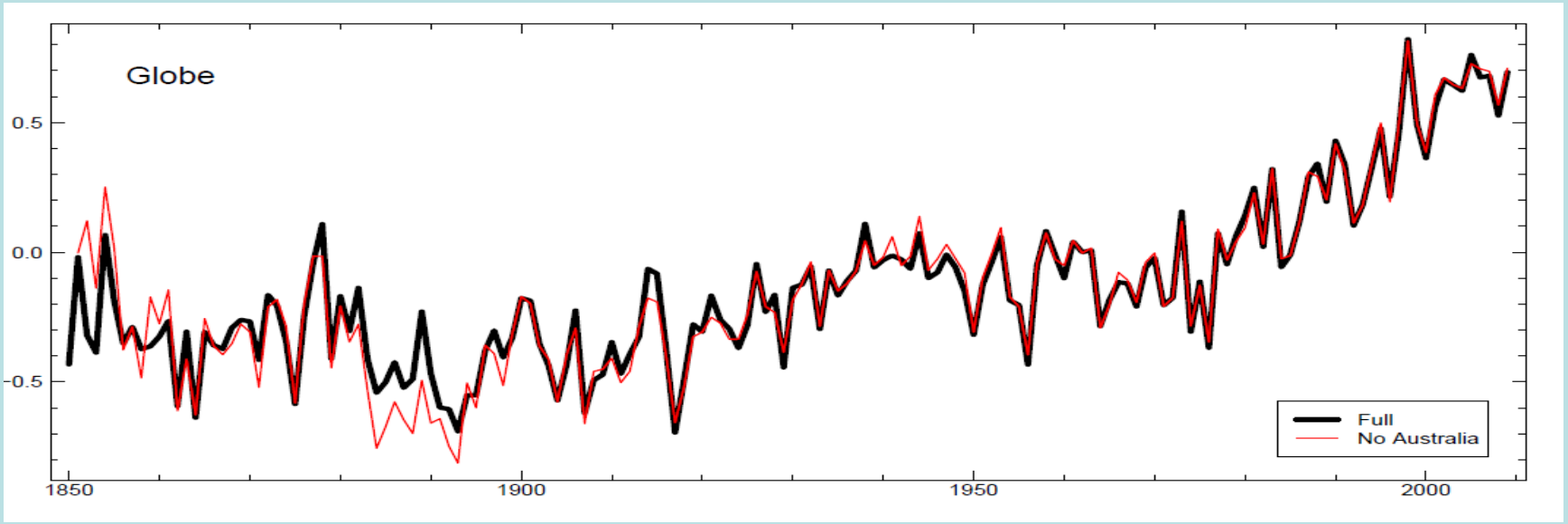


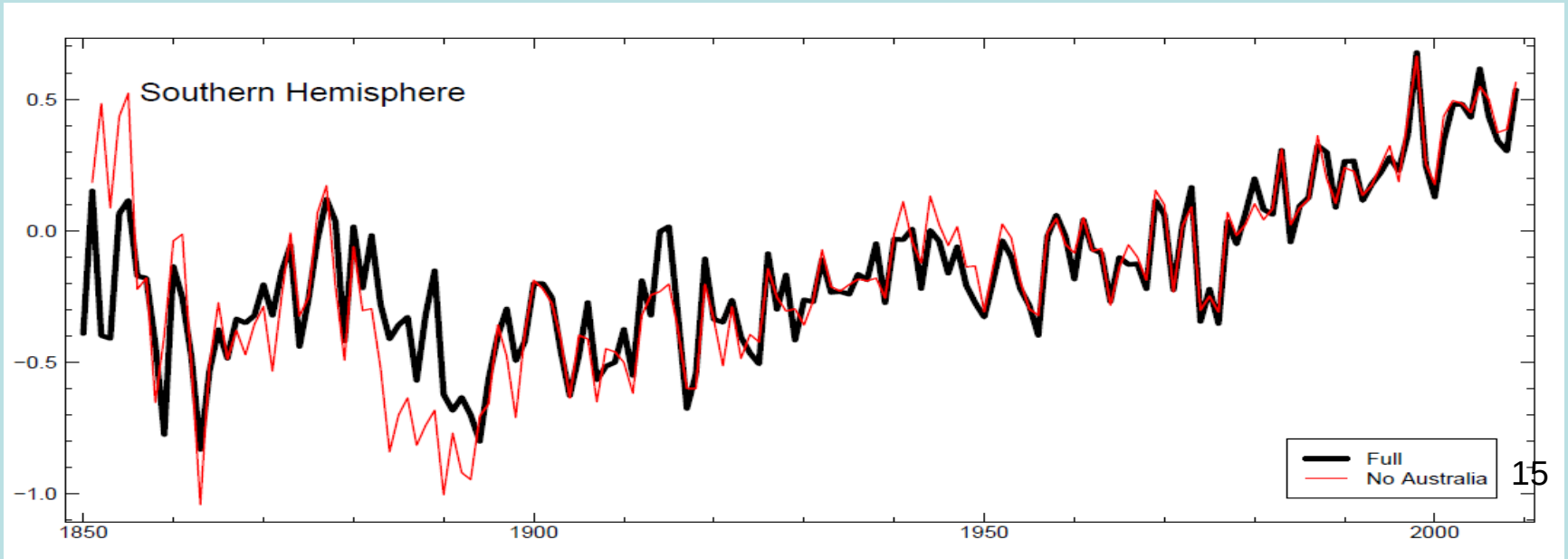
Jones, Osborn, Briffa (1997) *J. Geophys. Res.*; Osborn *et al.* (in prep.) CRUTEM5

Robustness of the global temperature record (1) removal of all stations in the contiguous United States



Removal of Australia

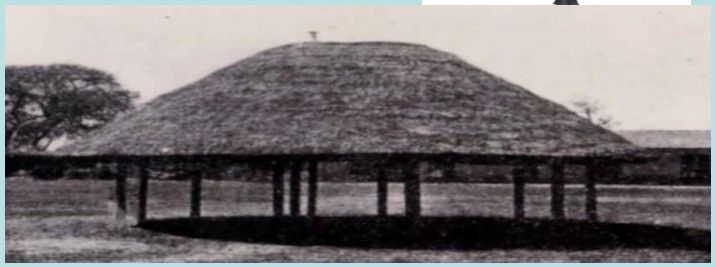




The effects of the biases

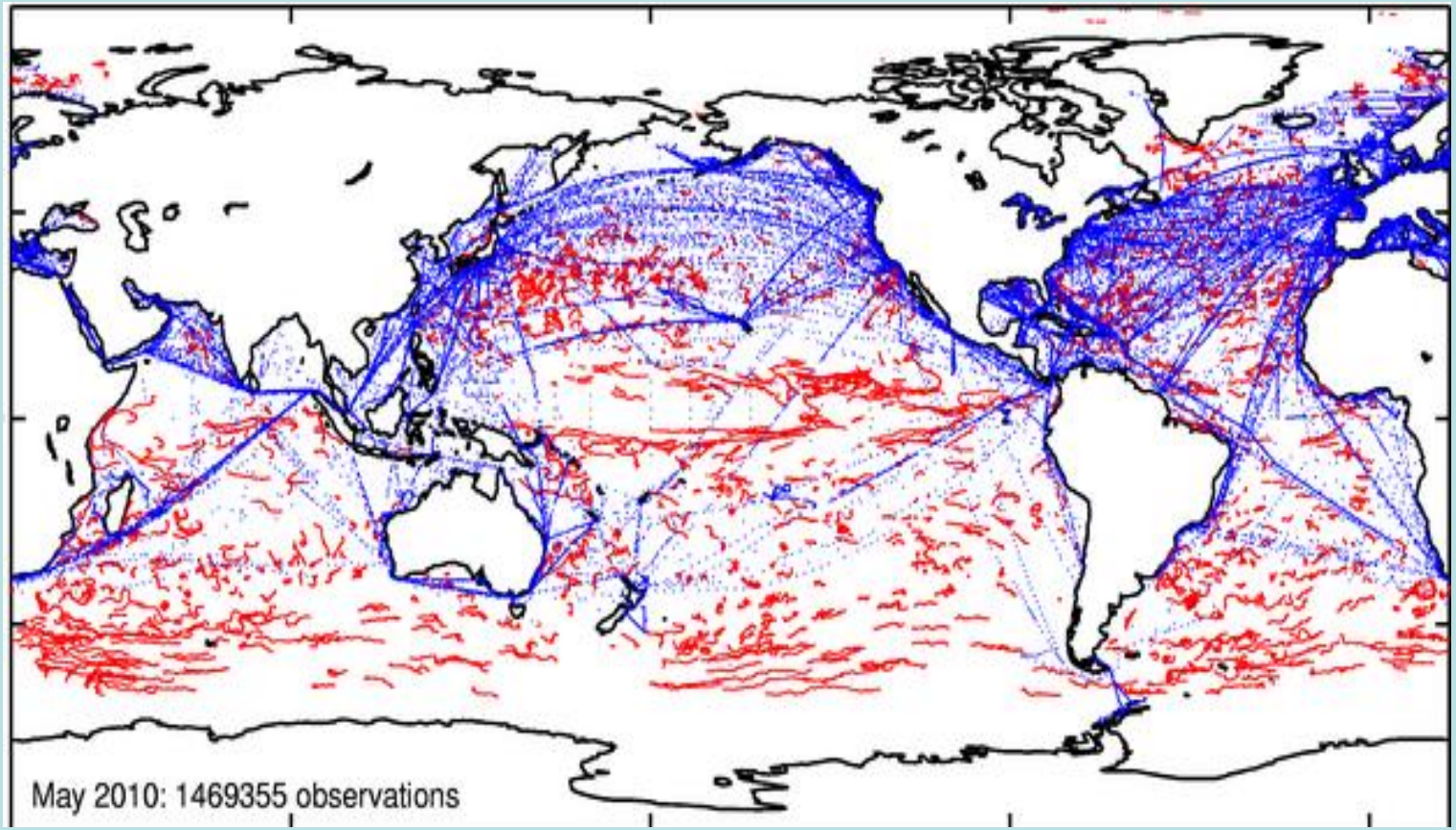
Land data: urbanisation and exposure changes

As Folland et al. (2001).



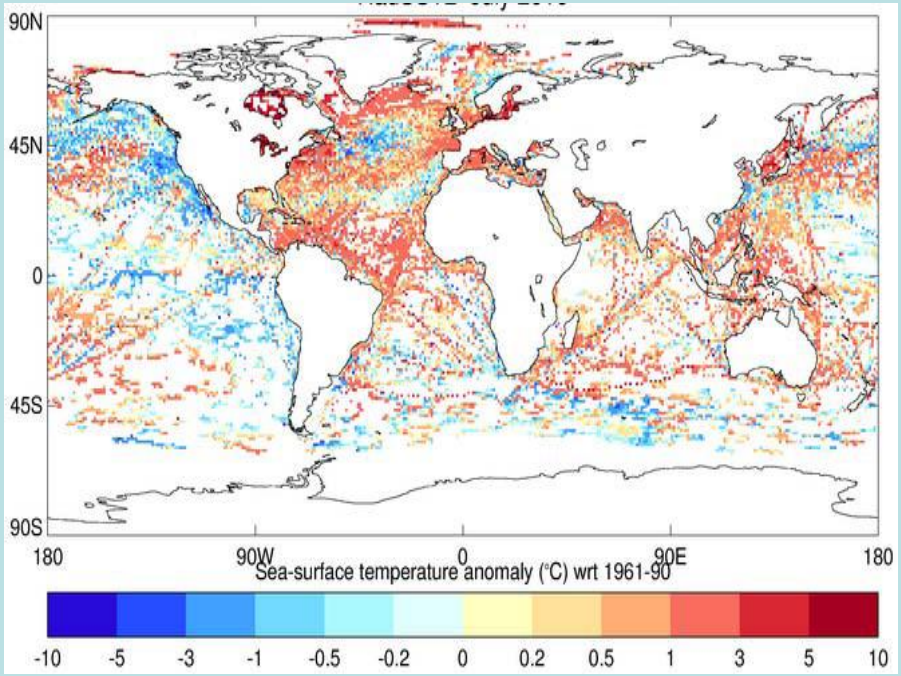
Marine data: bucket corrections (Rayner et al., 2006)

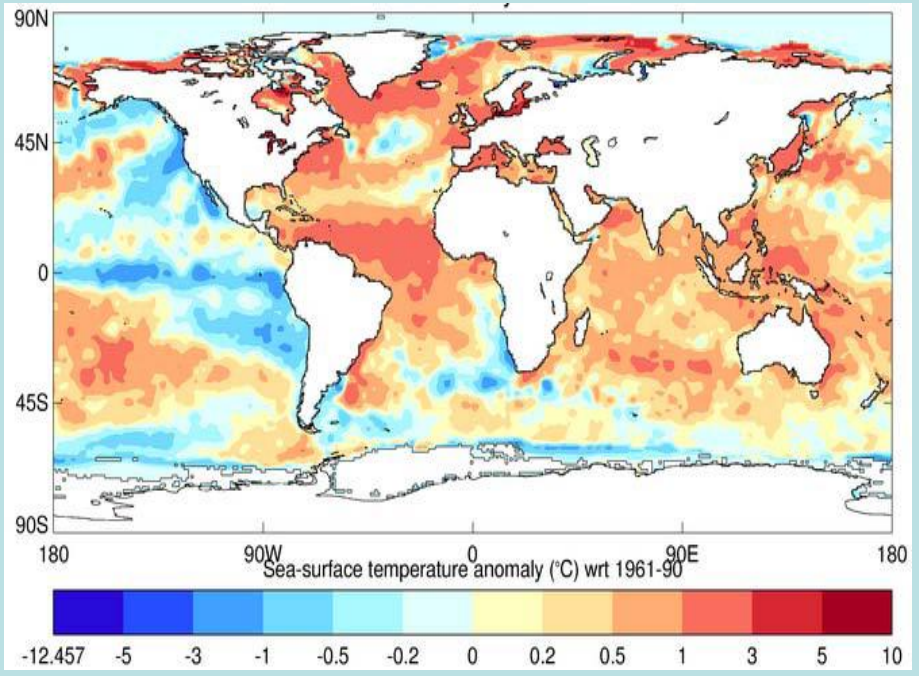
SST Observations – May 2010



Blue – ships; Red – drifting buoys; Grey – fixed buoys

SST Interpolation





Rayner, N. A., P. Brohan, D. E. Parker, C. K. Folland, J. J. Kennedy, M. Vanicek, T. J. Ansell, and S. F. B. Tett (2006), Improved analyses of changes and uncertainties in sea-surface temperature measured in-situ since the mid-nineteenth century, **J. Clim.**, *19*, 446– 469.

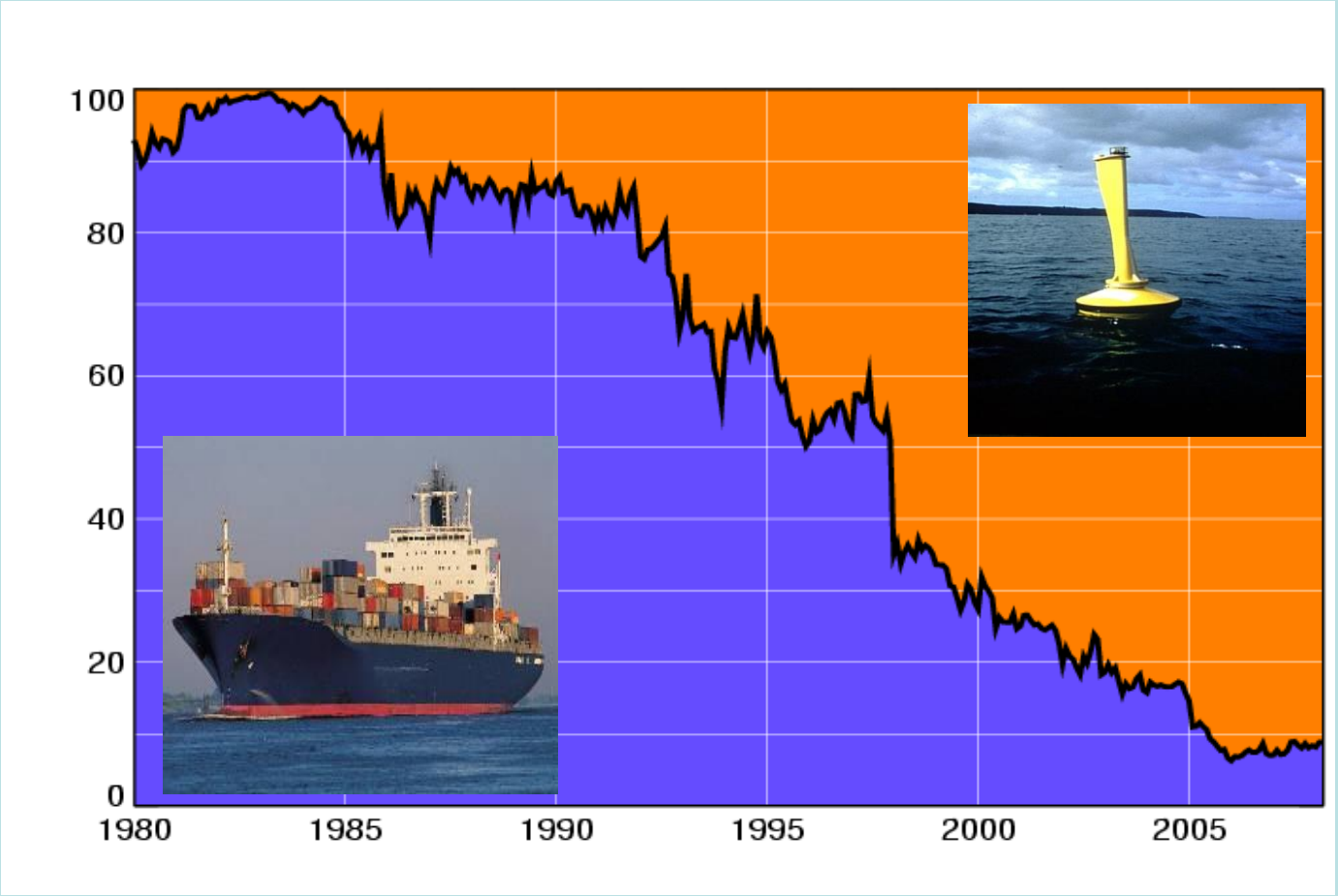
Huge change in marine observing network in the past 25 years

Percentage of observations coming from

DRIFTERS

and

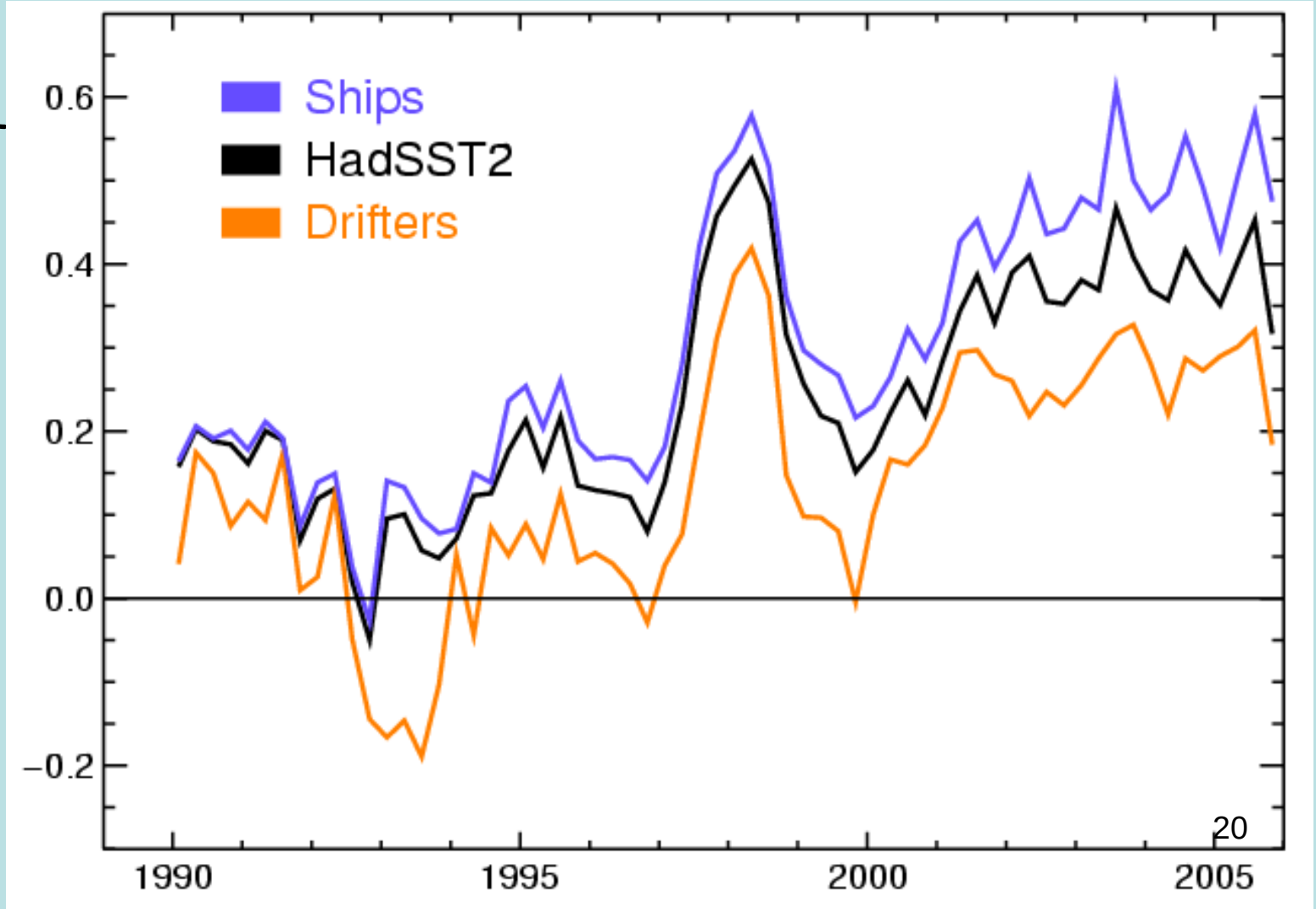
SHIPS



Drifters cause significant cooling in global average SST

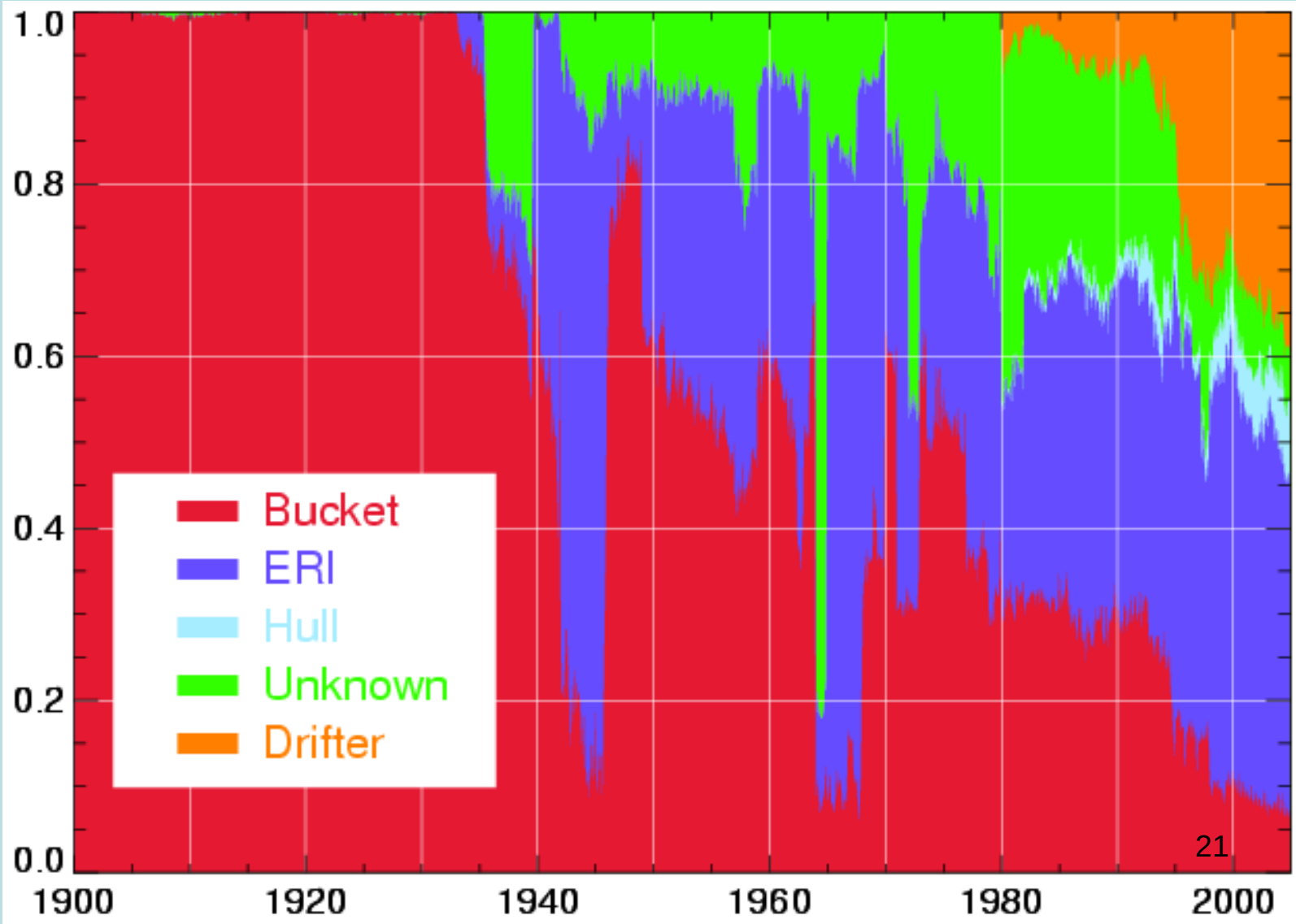
Global-average SST anomaly (°C) wrt 1961-1990

The base being based on ships – but the drifters are likely the better in an absolute sense



Time series of measurement methods (based on assumptions as of 2006)

Weight in global average



Buckets of differing types – some insulated, some not. Drifters take lots of measurements , but in limited areas

HadSST3 versus raw observations (red)

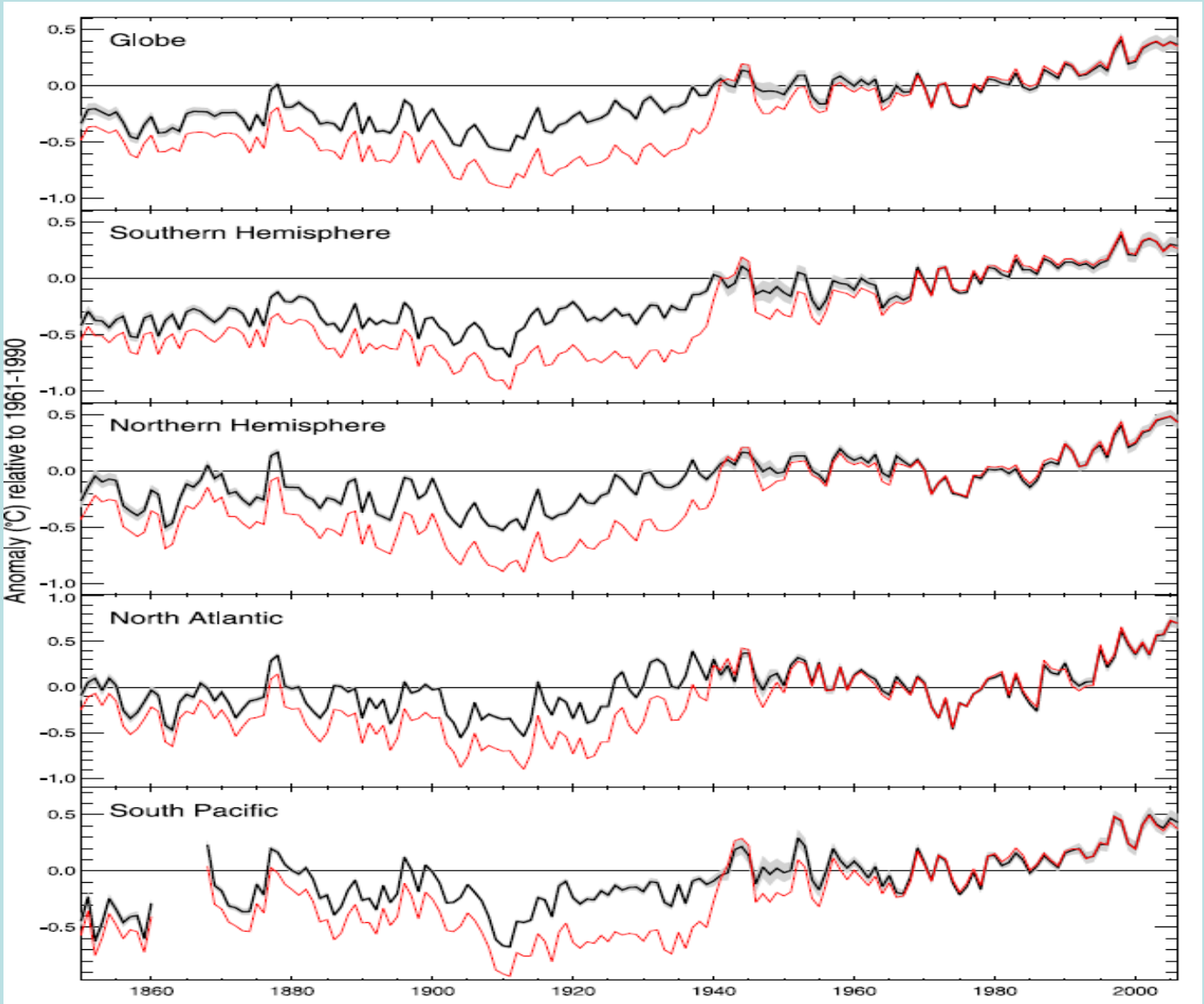
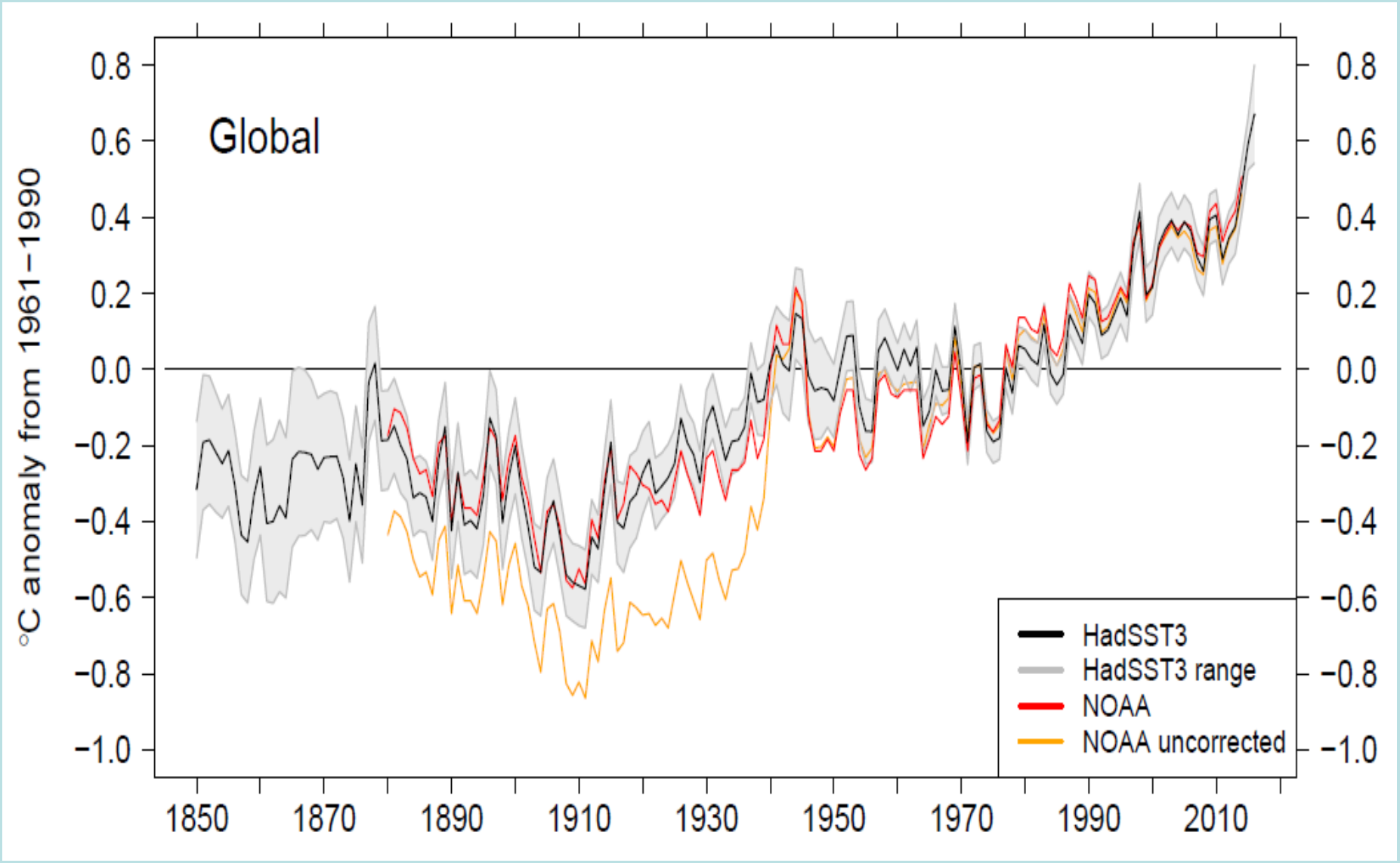


Figure 4. Regional annual average SST anomalies 1850–2006 (relative to 1961–1990) for 100 realizations of HadSST3 (black line plus 2 standard deviations grey area) and unadjusted gridded data (red line).

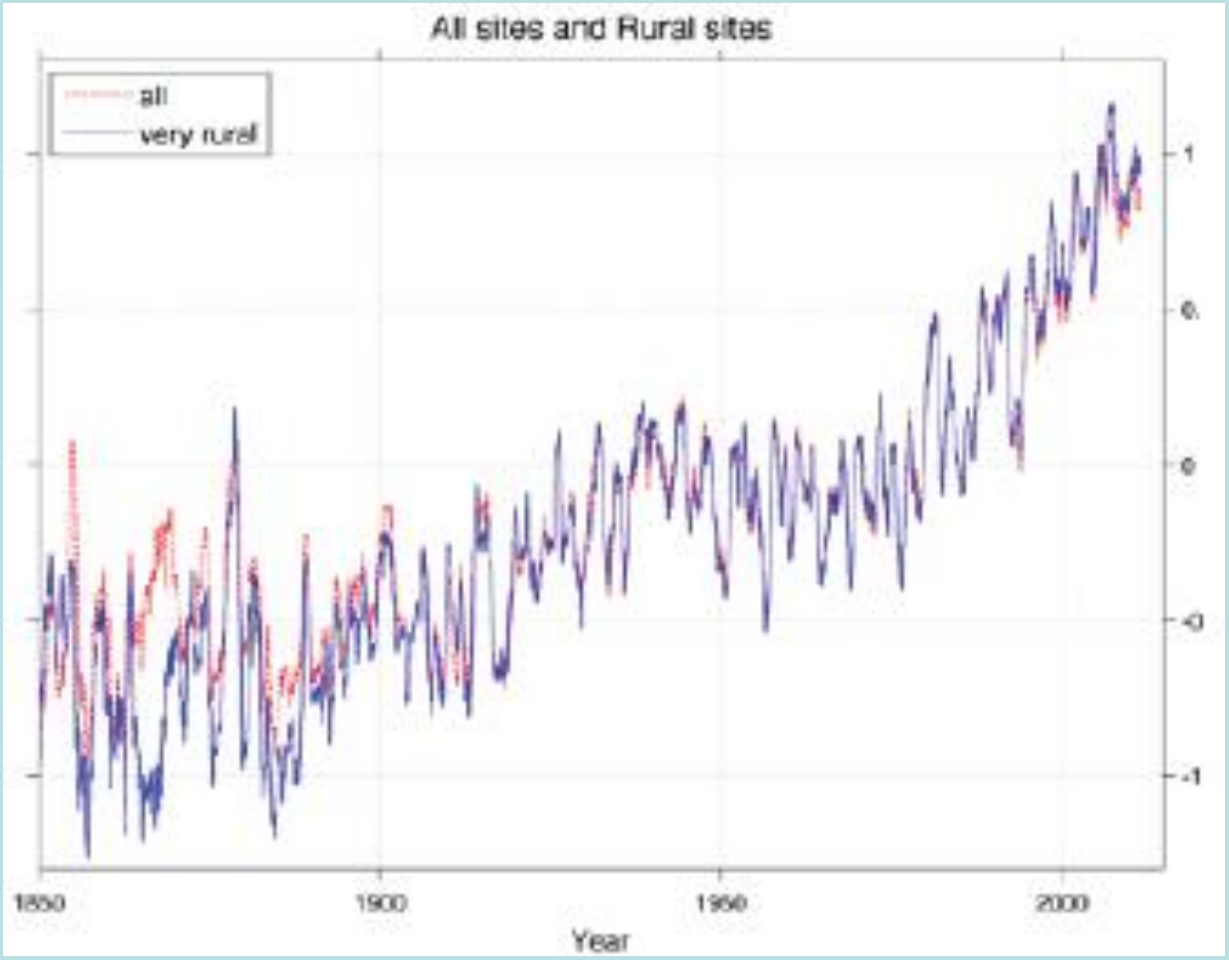
Grey band is error associated with the assumptions made

Definitions of the regions given in Kennedy *et al* (2011) in JGR



Kent, E. C., Kennedy, J. J., Smith, T. M., Hirahara, S., Huang, B., Kaplan, A., Parker, D. E., Atkinson, C. P., Berry, D. I., Carella, G., Fukuda, Y., Ishii, M., Jones, P. D., Lindgren, F., Merchant, C. J., Morak-Bozzo, S., Rayner, N. A., Venema, V., Yasui, S., Zhang, H-M., 2017: A call for new approaches to quantifying biases in observations of sea-surface temperature. *Bulletin of the American Meteorological Society*, **98**, 1601-1616, doi:10.1175/BAMS-D-15-00251.1

Large-scale urbanization influence is negligible



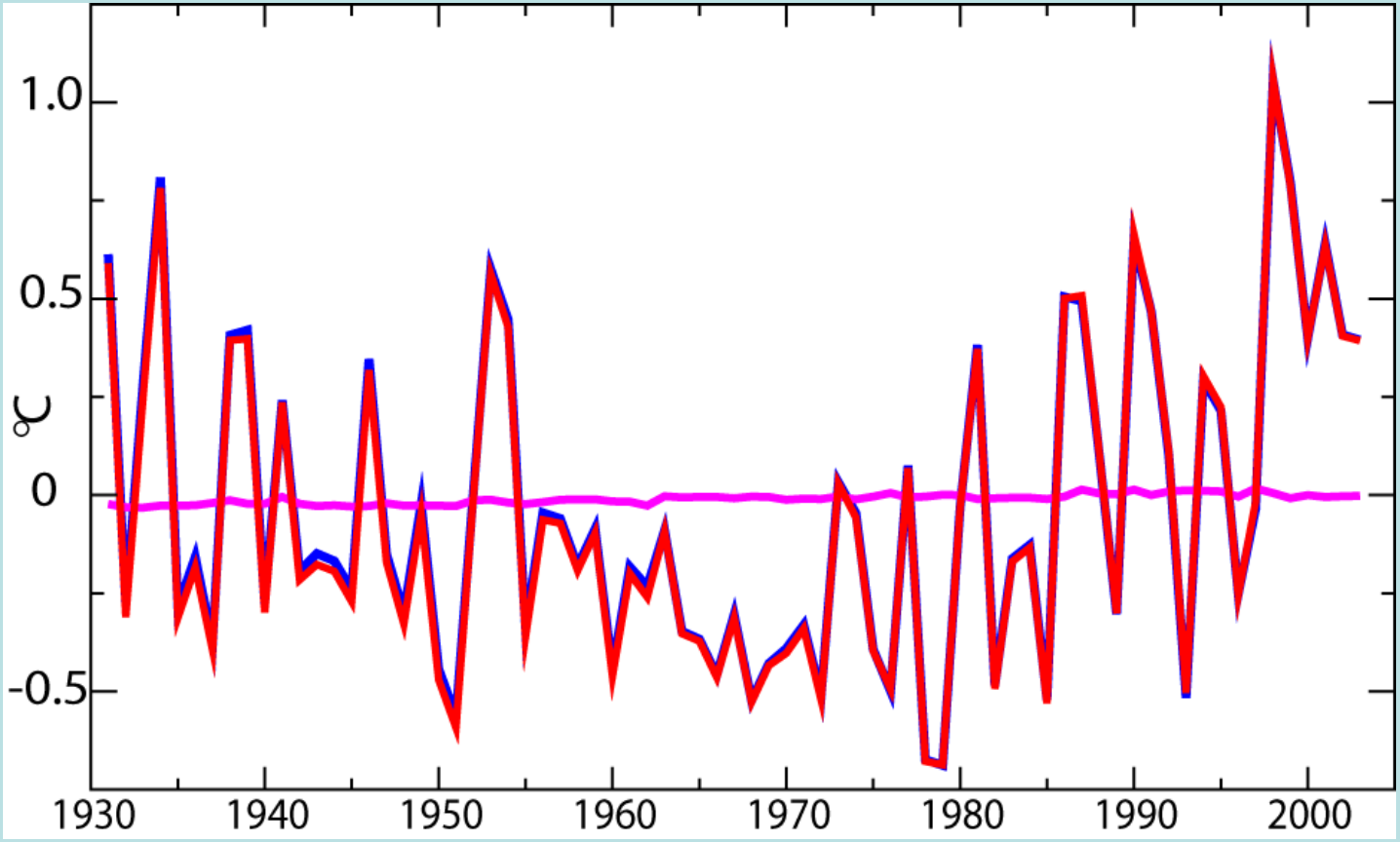
In this recent analysis by the BEST team, the very rural sites warm slightly more than the urban sites

Site category determined using satellite (MODIS) data

Wickham C, Rohde R, Muller RA, Wurtele J, Curry J, et al. (2013) Influence of Urban Heating on the Global Temperature Land Average using Rural Sites Identified from MODIS Classifications. *Geoinfor Geostat*: An Overview **1:2**. doi:10.4172/gigs.1000104

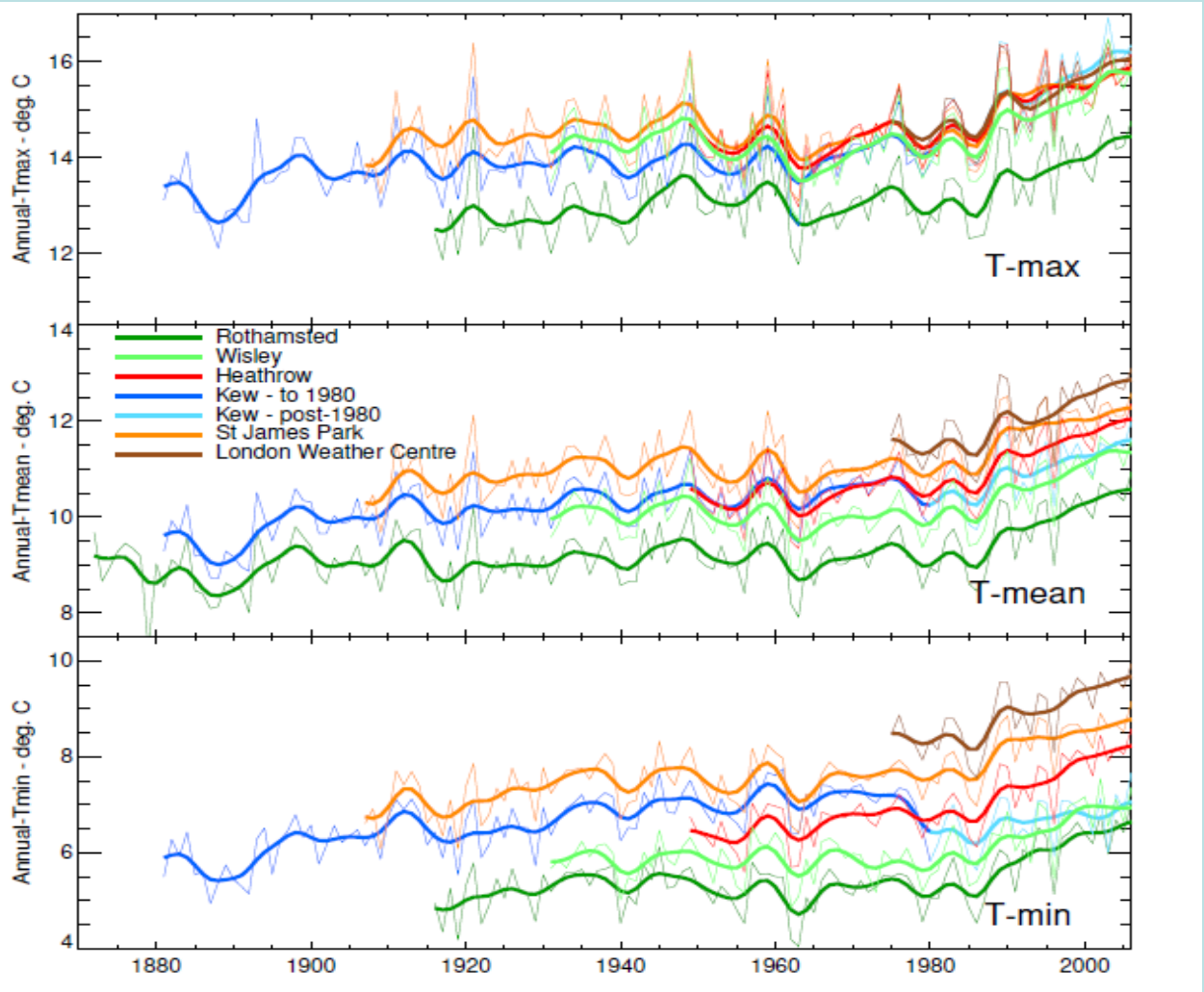
Need to look at global land areas: not individual sites and not on extreme days

Urban effects in the US Temperature Record



Anomaly (°C) of full USHCN data (red), the USHCN data without the 16% of the stations with populations of over 30,000 within 6 km in the year 2000 (blue). The full USHCN set minus the set without is in magenta.

Urbanization – Example of London



UHI greater for Tn than Tx. Central London sites always warmest at night, but warmer during day west of London

London has an Urban Heat Island (UHI), but no urban-related warming since at least 1900. In other words, the centre got warmer earlier

Jones, P.D. and Lister, D.H., 2009: The Urban Heat Island in Central London and urban-related warming trends in Central London since 1900. *Weather* **64**, 323-327.

Early exposure issues

- Europe affected, before the development of Stevenson screens (~1870s/1880s)
- Solution has come about from modern parallel measurements (in Austria where old screens are still in use, together with new ones at one site)
- Modern parallel measurements taken today with old equipment to estimate the effect (in Spain and also in the Netherlands)
- Effect is annually ~0.4°C, with most series too warm by up to 0.7°C in June
- Issue important as it is the summers that calibrate the natural and documentary proxies

Exposure Issues pre-screens Kremsmünster - Austria

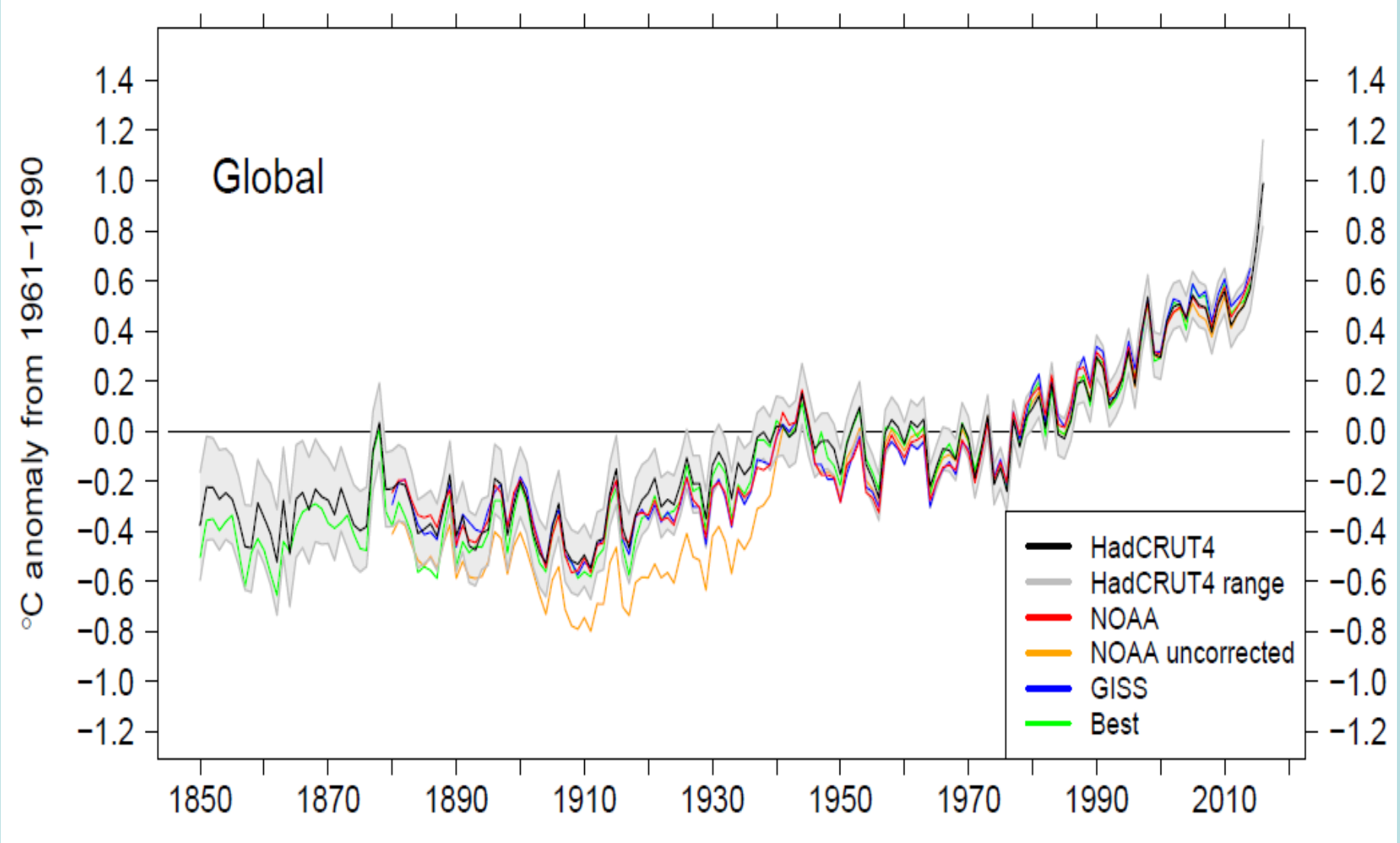
Böhm, R., Jones, P.D., Hiebl, J., Frank, D., Brunetti, M. and Maugeri, M:, 2010: The early instrumental warm-bias: a solution for long Central European temperature series, 1760-2007. *Climatic Change* **101**, 41-67.

Kremsmünster - Austria

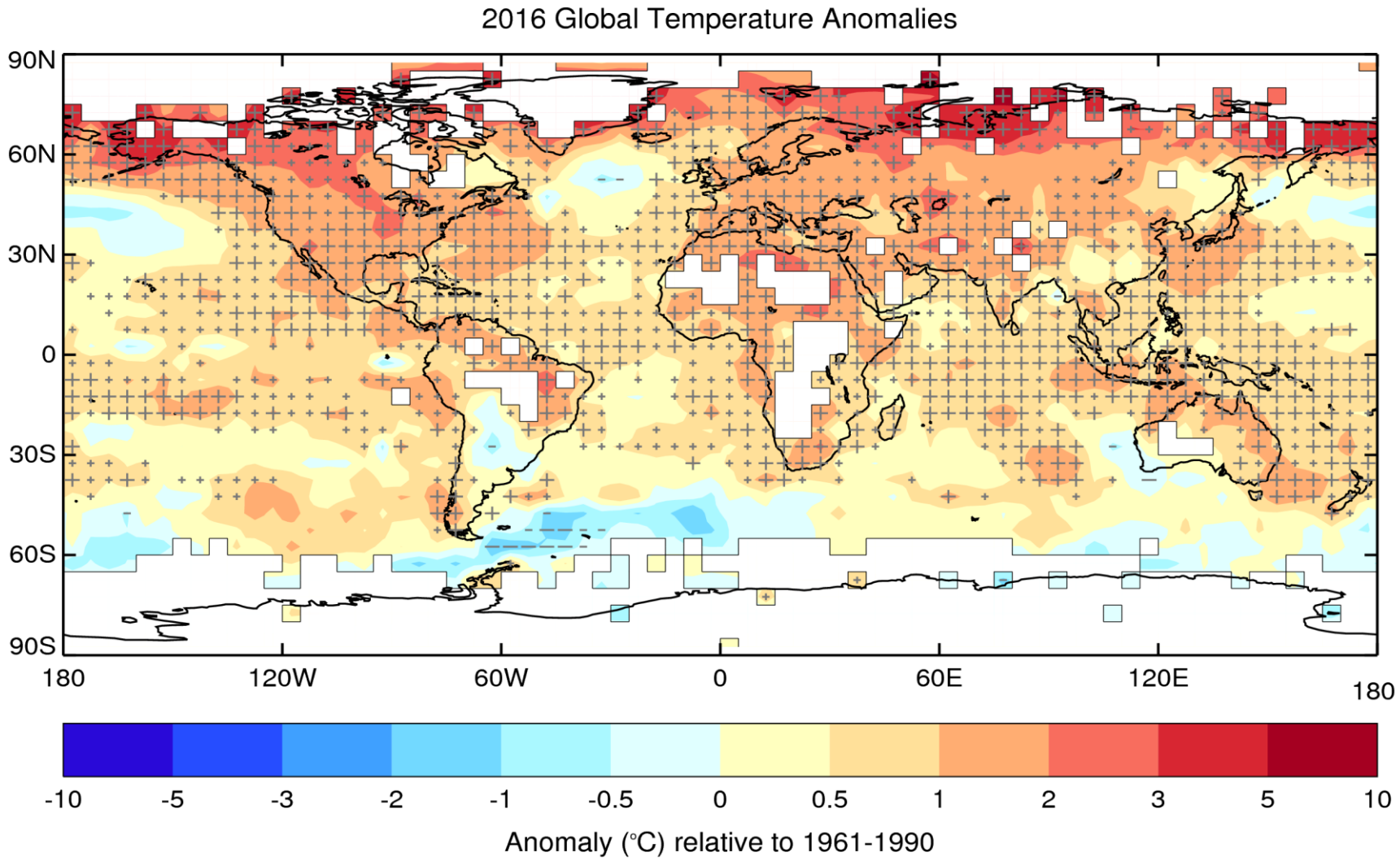
When built in the 1770s, this monastery was the tallest in Europe for the time

Experiment beginning in the Netherlands
The Pagoda screen is how measurements were made by KNMI (Dutch Met Service) at De Bilt (nr Utrecht).
This will take several years of measurements before anything can be reported.
Another earlier screen to the right of the Pagoda is also being tested.

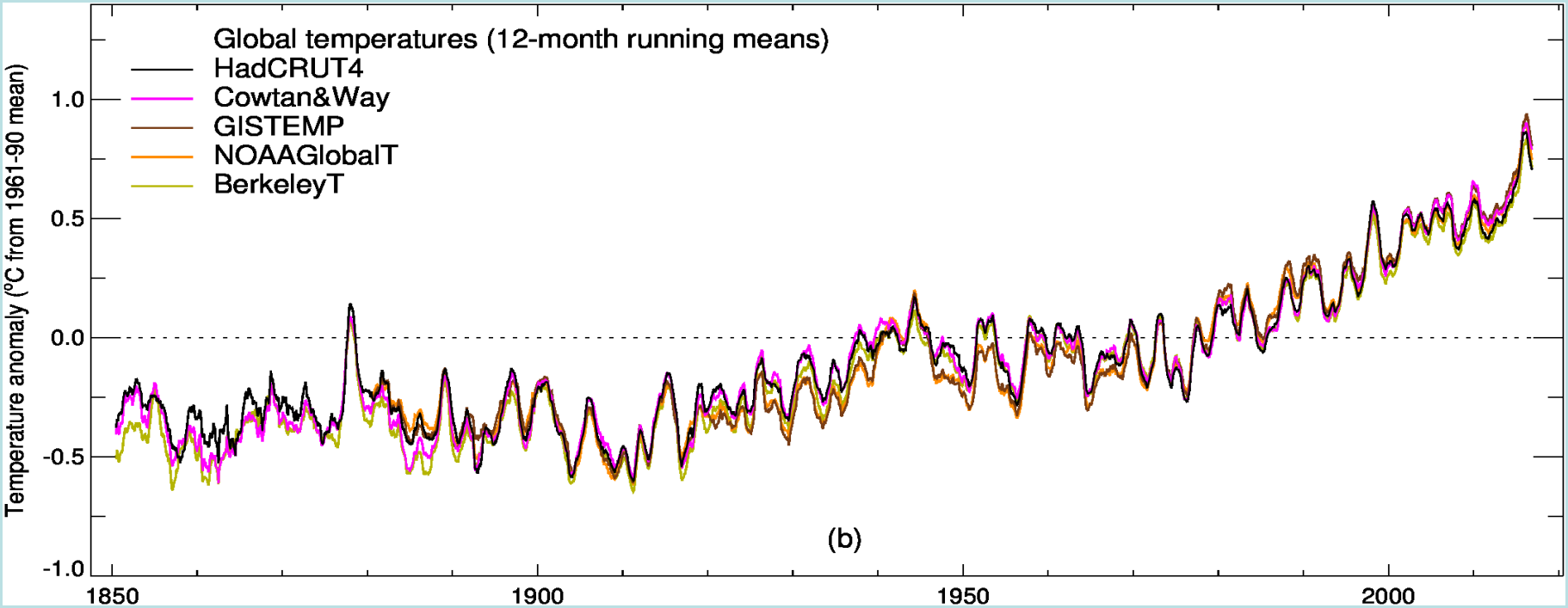
Global Temperatures – Land+Marine (without any adjustments for NOAA series)



BEST more similar to HadCRUT4 as they have HadSST3 in common.
Using unadjusted data would lead to greater warming.

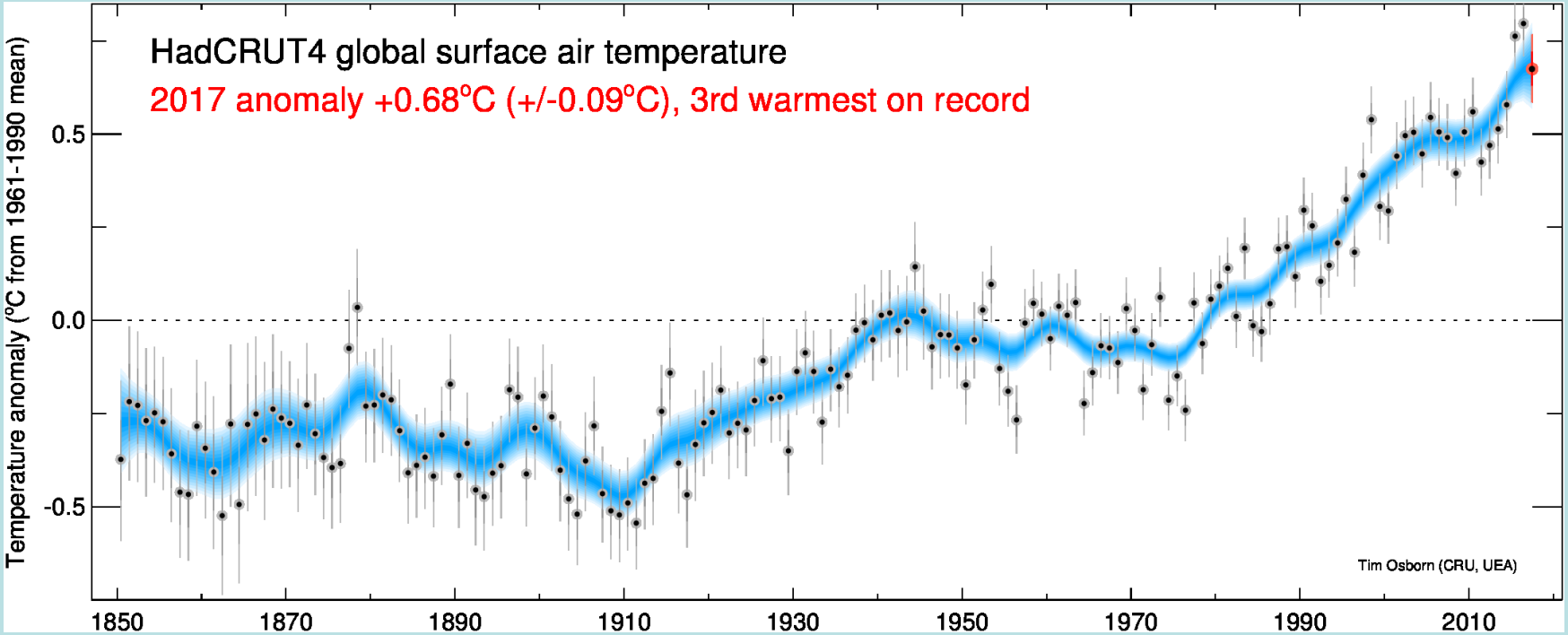

2016 Global Temperature Anomalies
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
-10
-5
-3
-2
-1
-0.5
0
0.5
1
2
3
5
10
Anomaly (°C) relative to 1961-1990

Recent Years but with 12-month running means, and no error ranges 1961-90 average and the Pre-Industrial Period



2017 was the third warmest year. 2017 cooler than 2016 and 2015, warmer than 2014 (the warmest year before 2015). The 4 warmest years will be 2014 to 2017, with 2015-2017 about 0.15 to 0.20 warmer than 2014. 2015-2017 just under 0.8 deg C warmer than 1961-90 average, or about 1.05 above the pre-industrial average (Hawkins et al., 2017). 2018 will probably be 4th warmest.

Hawkins, E., Ortega, P., Suckling, E., Schurer, A., Hegerl, G., Jones, P.D., Joshi, M., Osborn, T.J., Masson-Delmotte, A., Mignot, J., Thorne, P. and van Oldenborgh, G.J., 2017: Estimating changes in global temperature since the pre-industrial period, *Bulletin of the American Meteorological Society*, **98**, doi:10.1175/BAMS-D-16-0007.1 **First time the pre-industrial period estimated.**



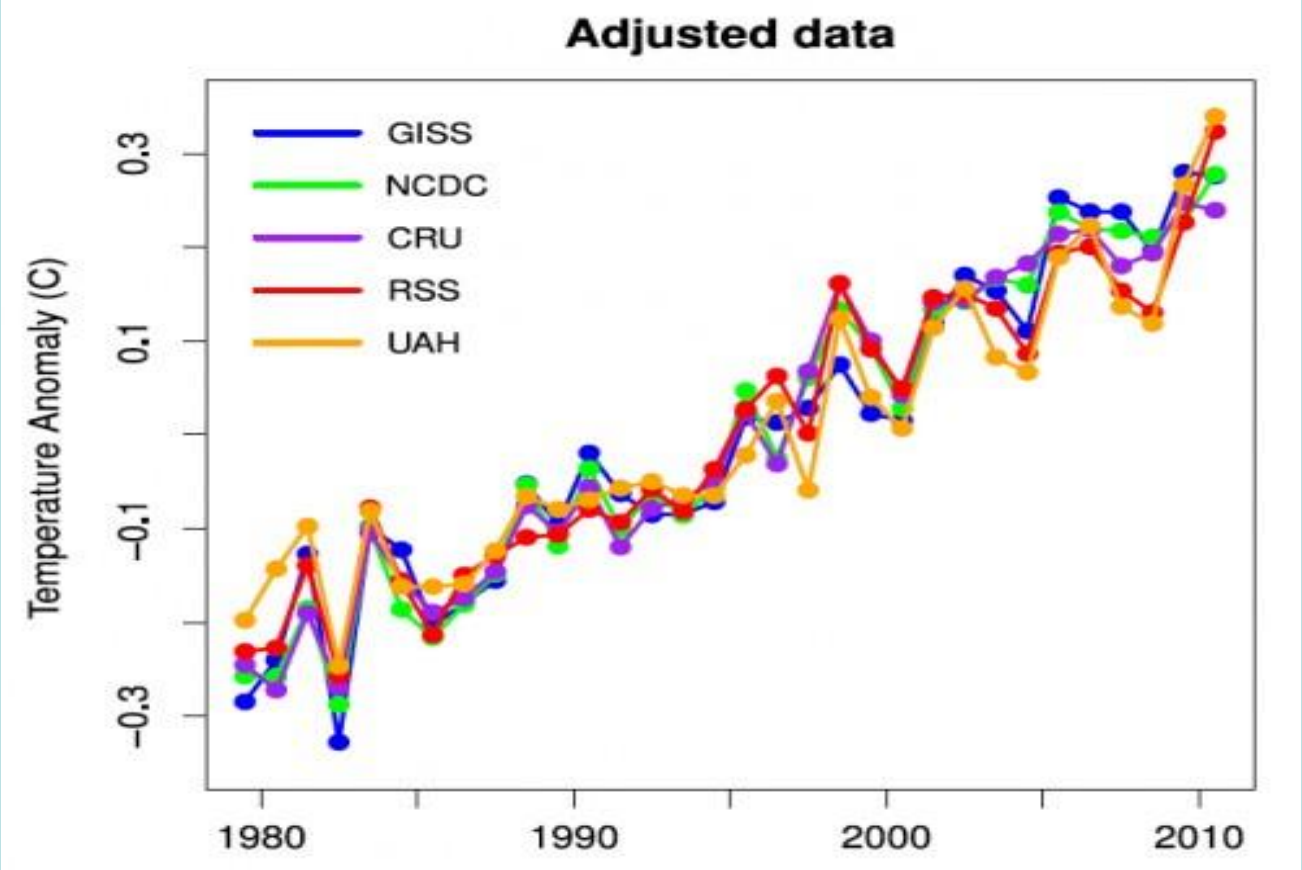
High-frequency influences – ENSO events, Volcanoes, Other Natural?

Lower-frequency influences – GHGs, Solar Variability, Natural/Oceans, Land-use changes

Since about 1985, several papers have taken out the influences of the higher-frequency factors

Next slide is one of the latest

Global temperatures factoring out the effect of ENSO, volcanoes , the Sun

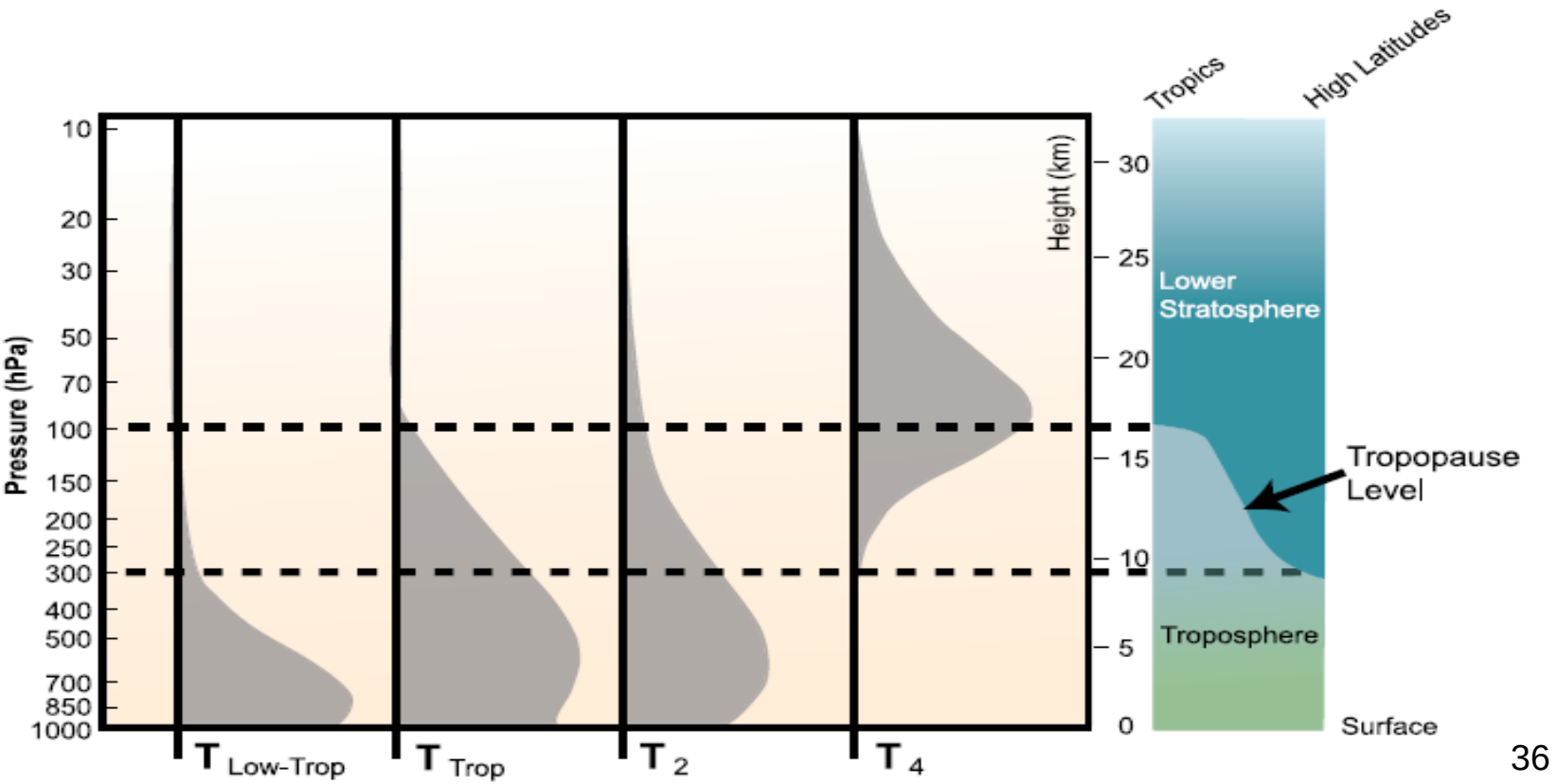


Grant Foster and Stefan Rahmstorf 2011 *Environ. Res. Lett.* **6** 044022
doi:10.1088/1748-9326/6/4/044022

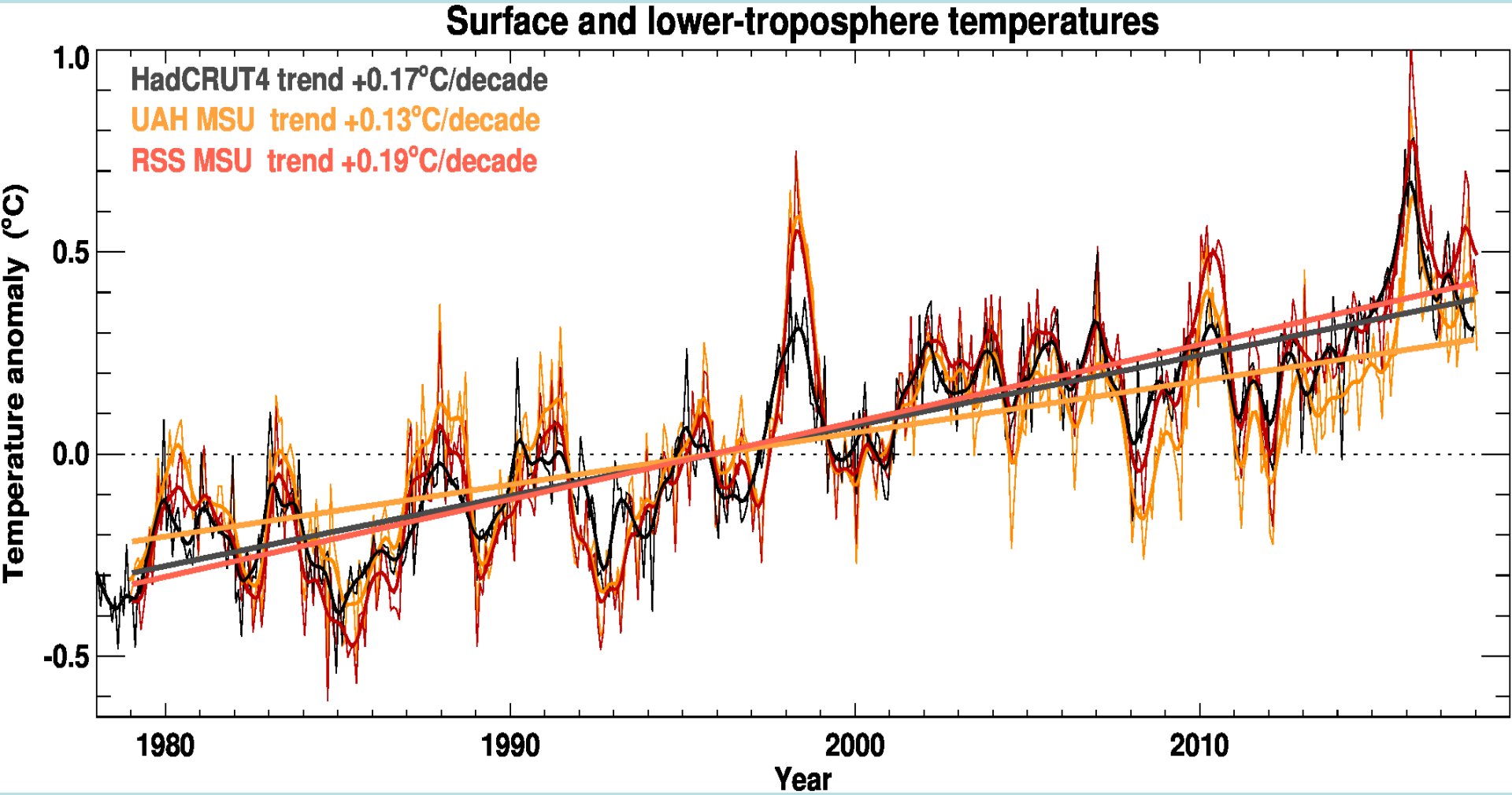
Uses a more modern base period than 1961-90. Probably 1981-2010.

MSU Weighting Functions - Satellite Temperature Data

- Satellites don't measure surface are temperature, but at about 650hPa, 4km above the surface
- Need numerous adjustments for changes to satellite orbits (timings of overpasses and heights of orbits)

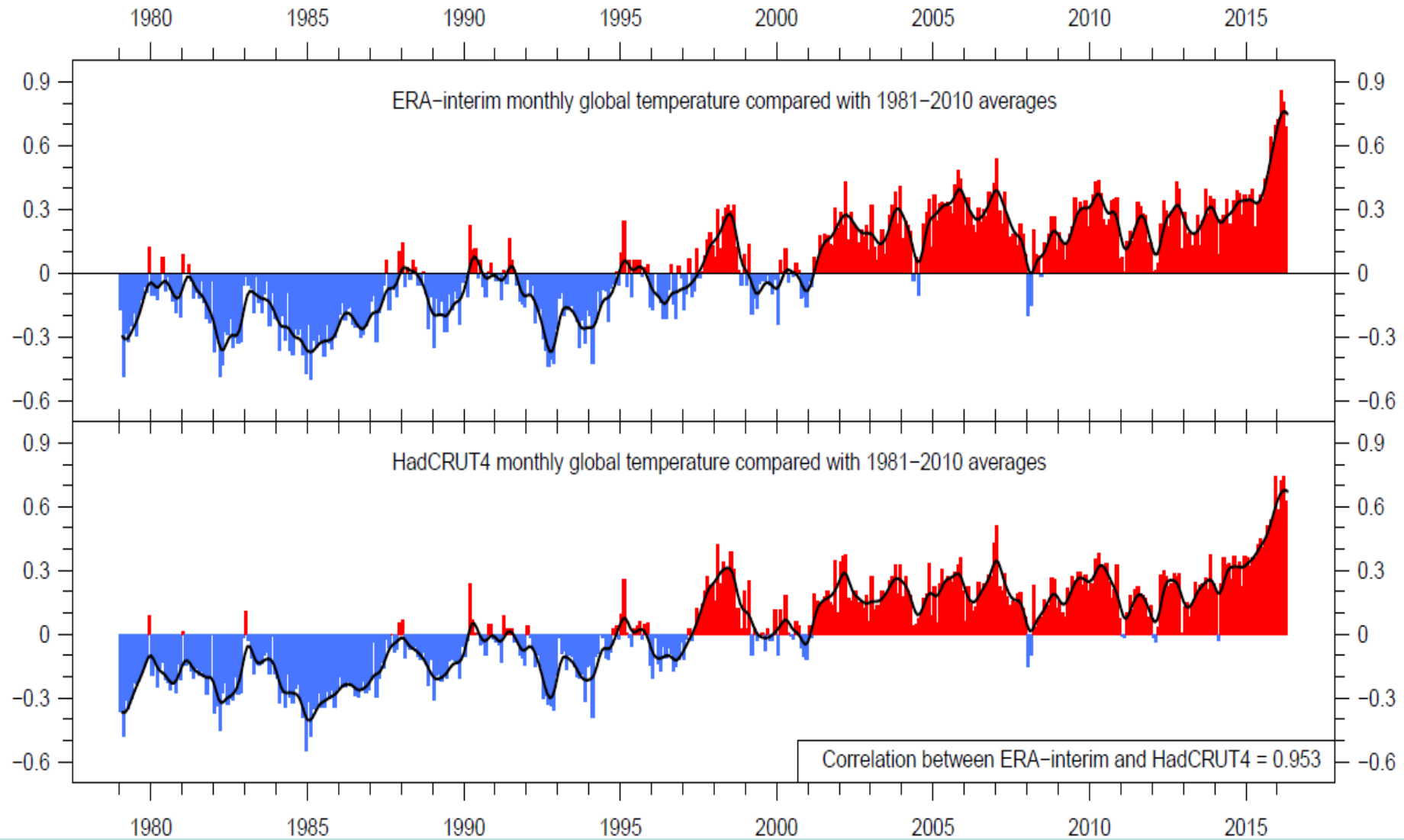


Surface vs Satellite



Surface and satellite records of temperature AGREE!!
Two satellite records don't agree with one another on the long-term trend.
Skeptics always use UAH, but RSS has markedly fewer adjustments.

Reanalyses are from ERA-Interim, the first dataset of surface temperatures to report each month. Comparison with HadCRUT4



In ERA-Interim, 2015/16 El Niño event clearly warmer than 1997/98

Context for the Late Holocene

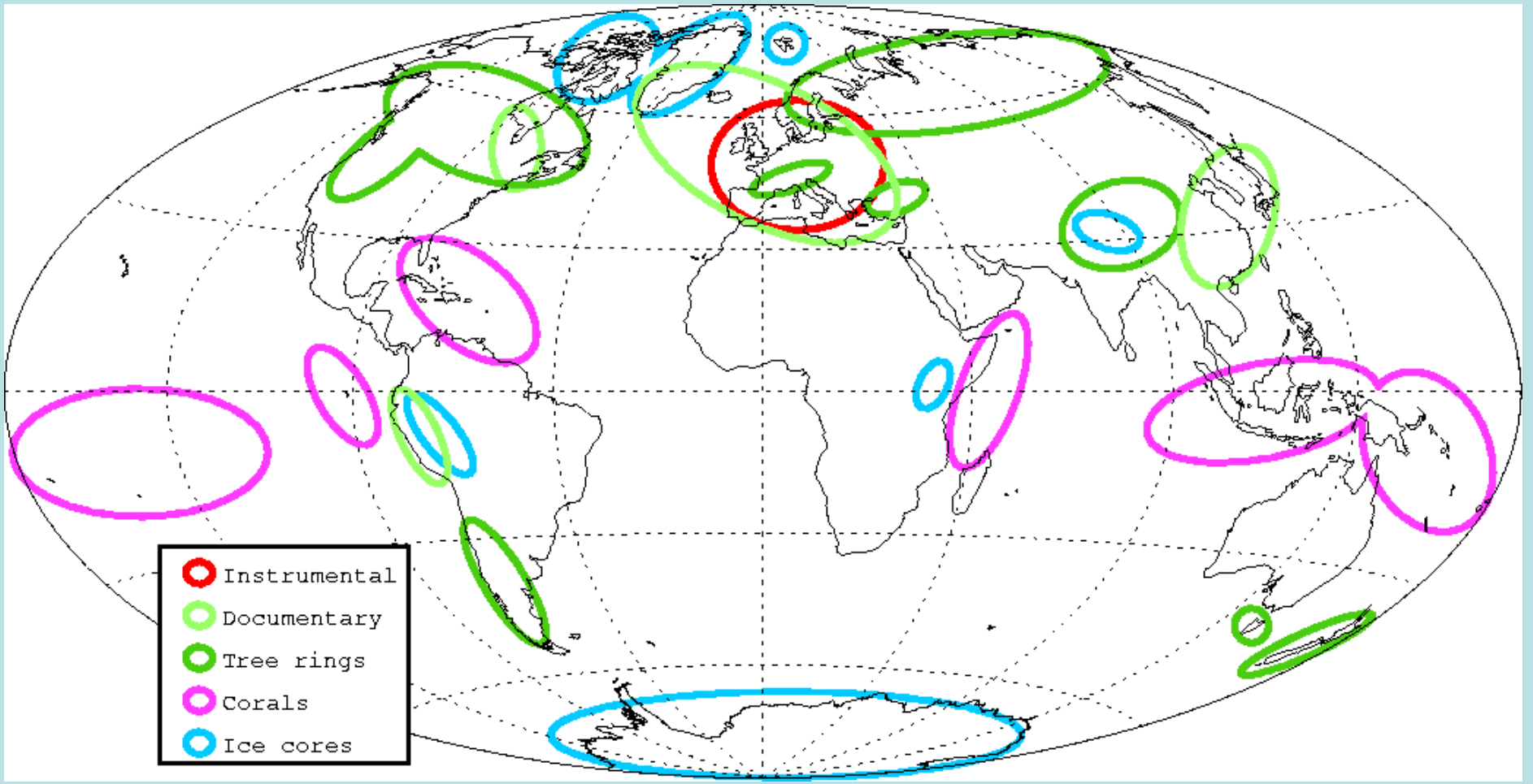
- Around 1980, it was believed that the period from AD 900-1200 was warm and called the Medieval Warm Period/Epoch. It is now referred to as the Medieval Climate Anomaly

- The world then cooled into the Little Ice Age (AD 1550-1850) as glaciers in many NH mountainous regions advanced

- Since 1980, we now have at 3-4 orders of magnitude more data than then, so why does everything have to be portrayed in the context of the MWP and the LIA? This is not just the climate skeptics, but many paleoclimate scientists as well. Often they discuss how their new piece of evidence compares with the 'accepted' wisdom of the MWP and LIA

- Also most assume that the four seasons all follow the 'annual' average, yet most proxy data tells us about summers. The MWP could have had warmer summers, and the LIA colder winters.

Schematic of potential coverage of pre-1800 temperature information



Much better to get long time series from natural proxies

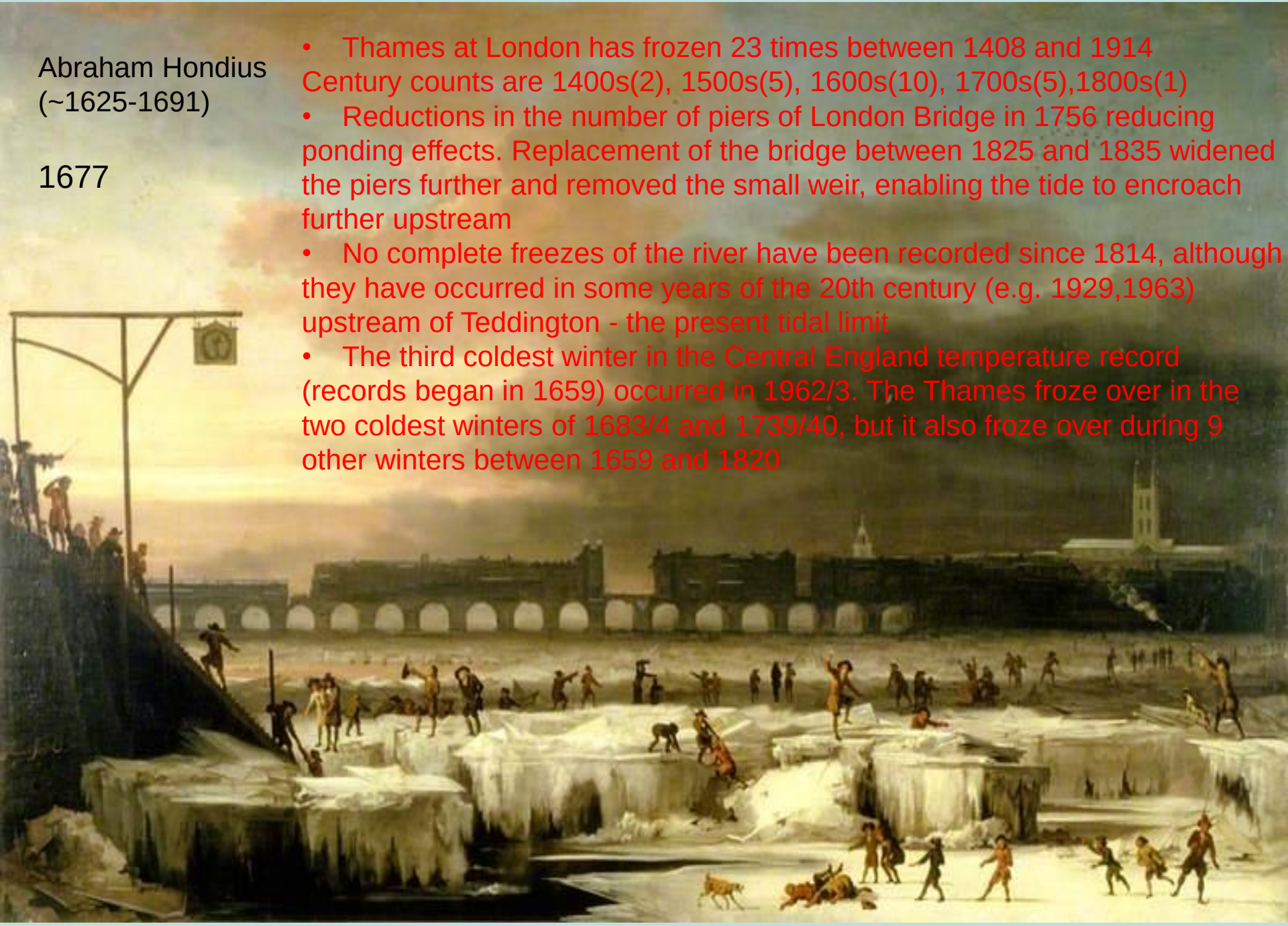
Different ellipses if this was showing regions to reconstruct precipitation/drought

Jones, Osborn and Briffa (2001) Science

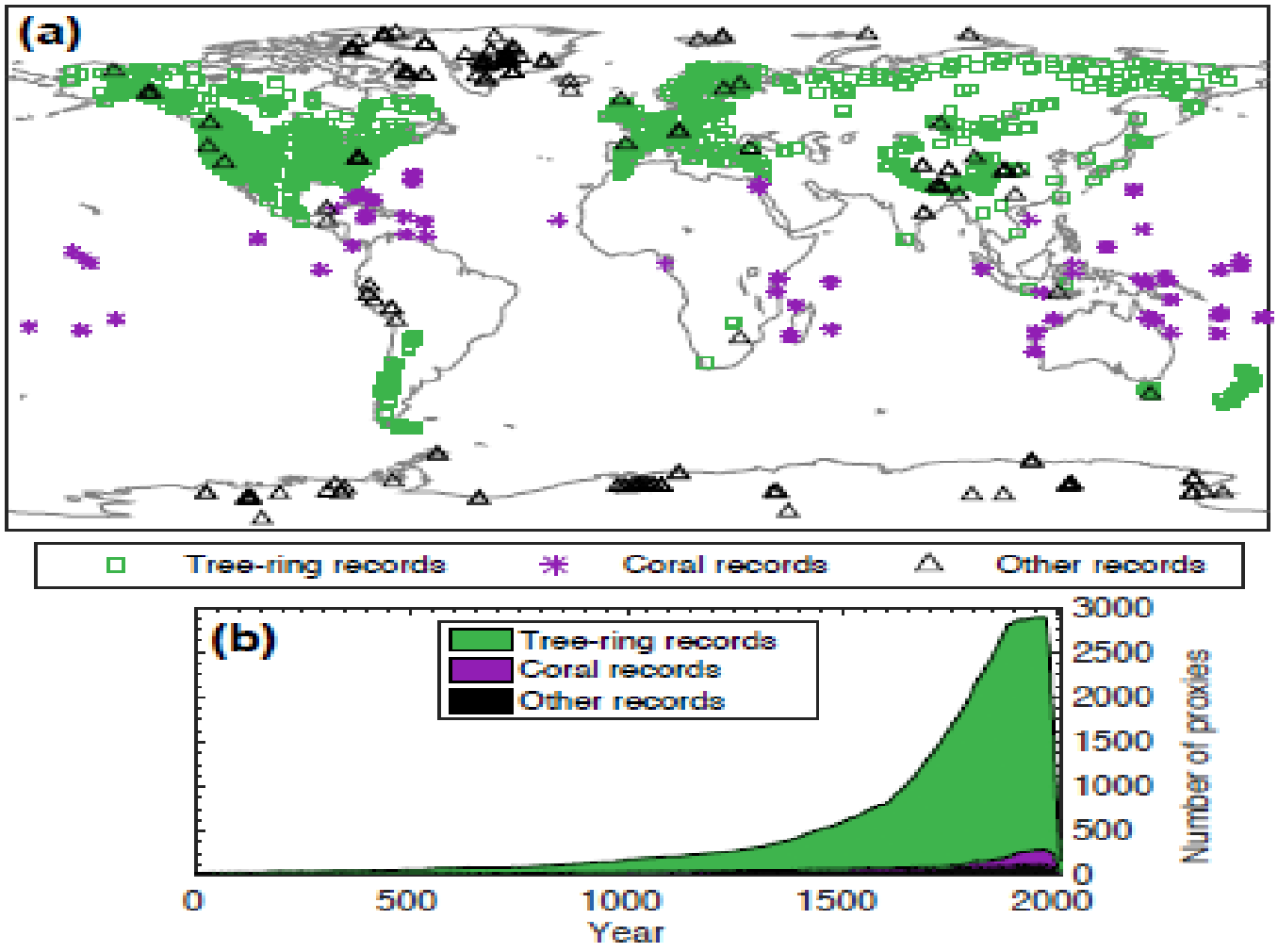
Abraham Hondius
(~1625-1691)

1677

- Thames at London has frozen 23 times between 1408 and 1914 Century counts are 1400s(2), 1500s(5), 1600s(10), 1700s(5),1800s(1)
- Reductions in the number of piers of London Bridge in 1756 reducing ponding effects. Replacement of the bridge between 1825 and 1835 widened the piers further and removed the small weir, enabling the tide to encroach further upstream
- No complete freezes of the river have been recorded since 1814, although they have occurred in some years of the 20th century (e.g. 1929,1963) upstream of Teddington - the present tidal limit
- The third coldest winter in the Central England temperature record (records began in 1659) occurred in 1962/3. The Thames froze over in the two coldest winters of 1683/4 and 1739/40, but it also froze over during 9 other winters between 1659 and 1820

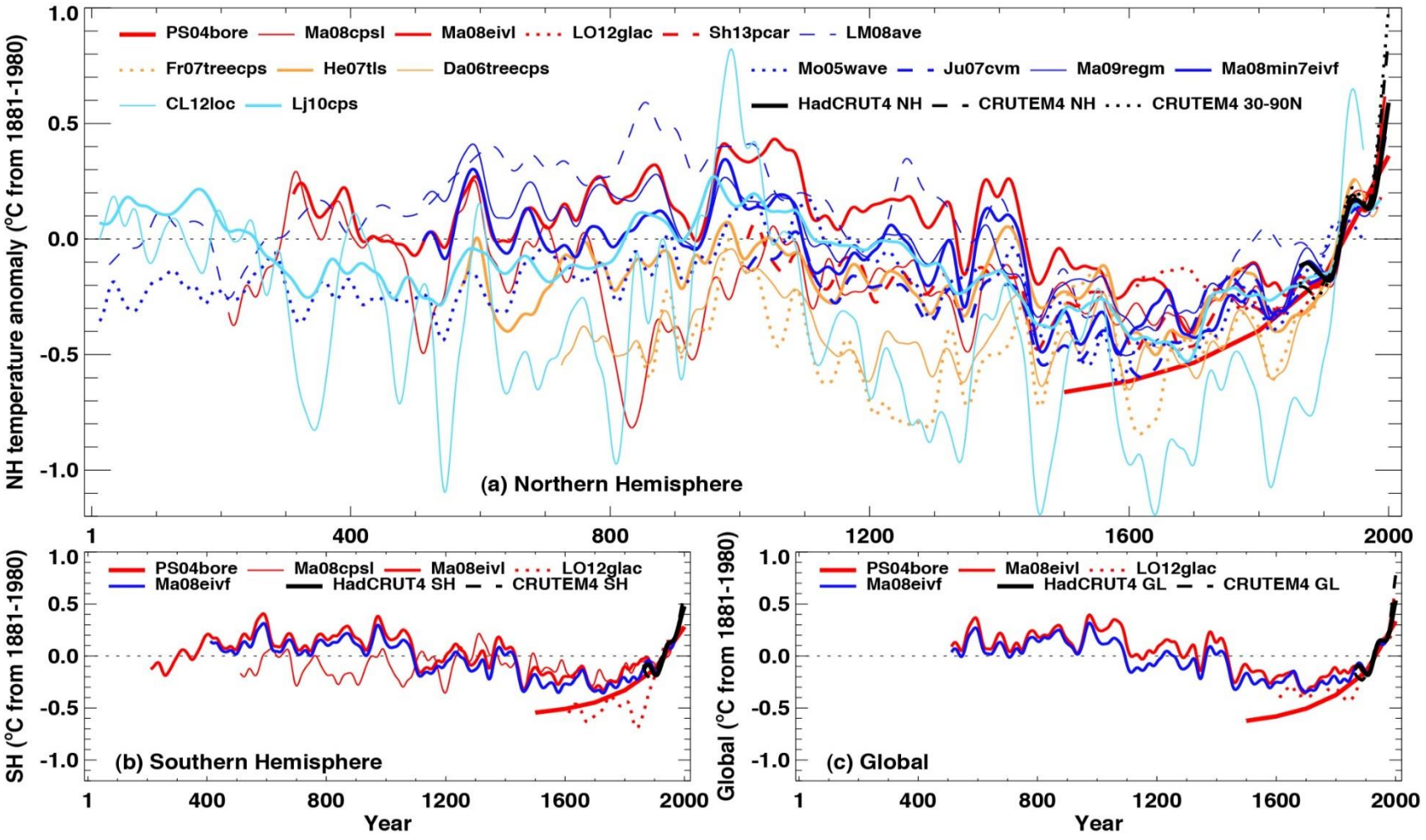


Increase in Proxy Evidence



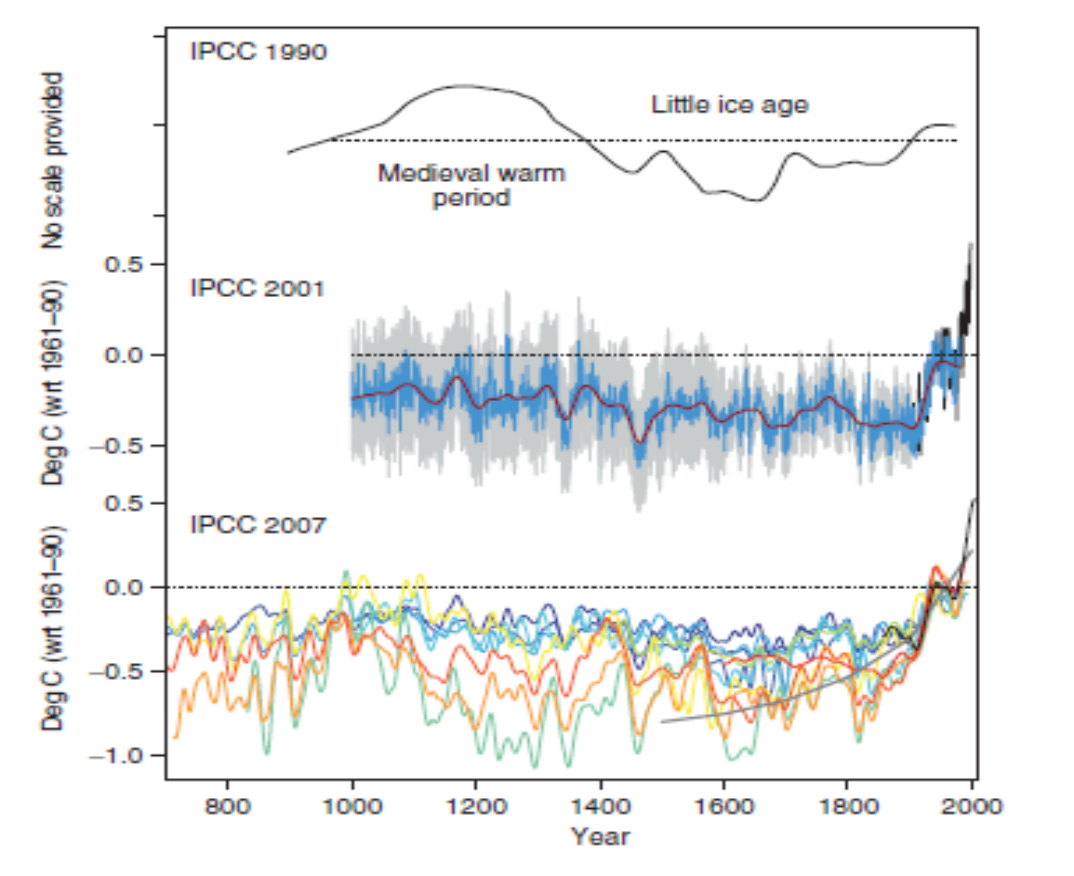
From a paper recently accepted in Nature Scientific Data

IPCC AR5 (2013) Reconstructions of the last 2000 years



Base period here is 1881-1980. This is only about 0.1 deg C warmer than the pre-industrial period discussed earlier.

The 1990, 2001 and 2007 IPCC Reports for the last Millennium

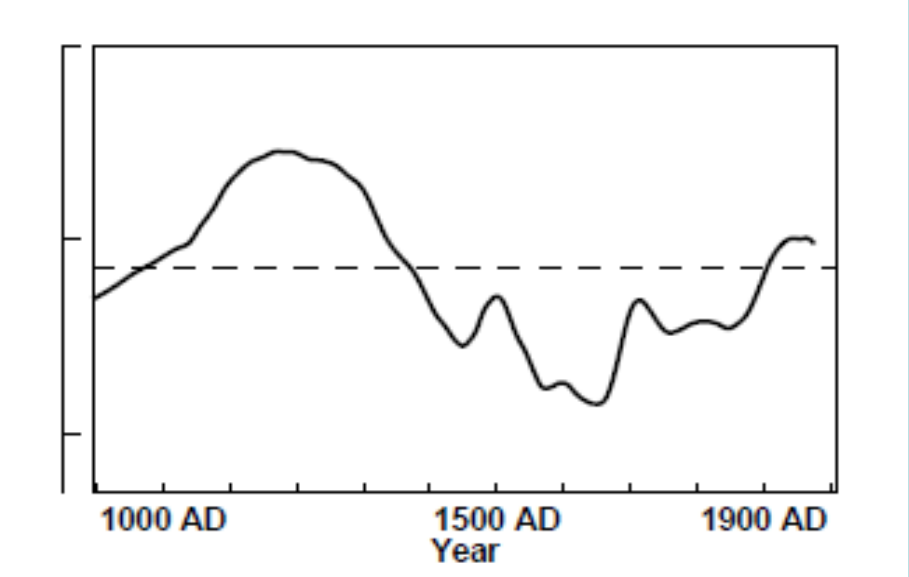


Frank et al (2010) WIREs Climatic Change

Q Why does everybody forget the 1995 IPCC Report, which only went back to 1400?

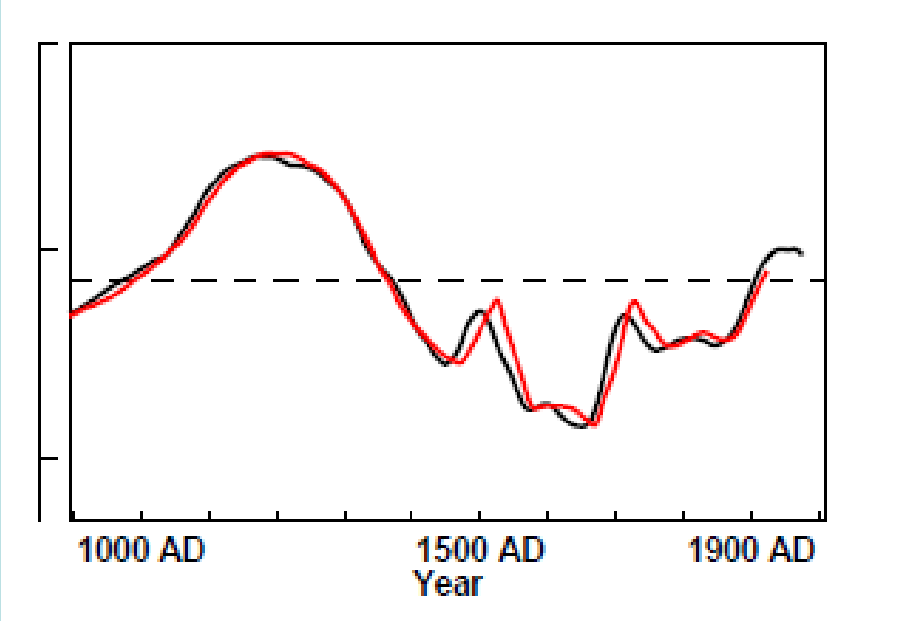
Q Why should paleoclimatology have to use a curve that was based on <1% of what we now know about the past 1000 years?

IPCC in 1990 – referred to this 'Schematic'



IPCC didn't refer to the source of the diagram as it was just a **Schematic**. Despite this some have digitized the curve believing it to a **realistic** depiction of what happened, particularly as it shows a prominent MWP

IPCC 1990 – Red is a reconstruction of Central England Temperatures produced by Hubert Lamb in 1965

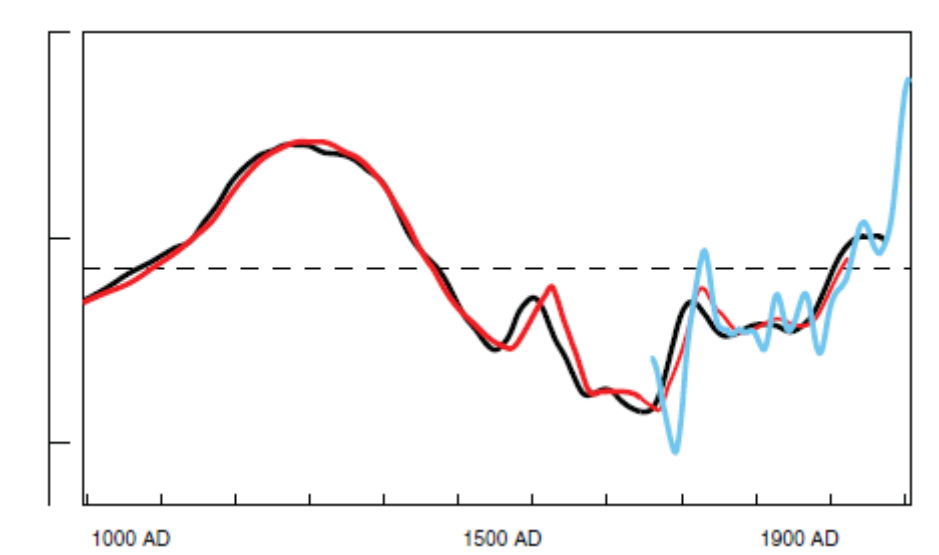


The red curve shows that the 1990 IPCC curve was based on Lamb's CET reconstruction, so it isn't global nor NH.

Lamb, H.H. 1965: The earlier medieval warm epoch and its sequel. *Palaeogeography, Palaeoclimatology, Palaeoecology* 1, 13–37.

(Numbers given in the paper for 50-year averages – non-overlapping)

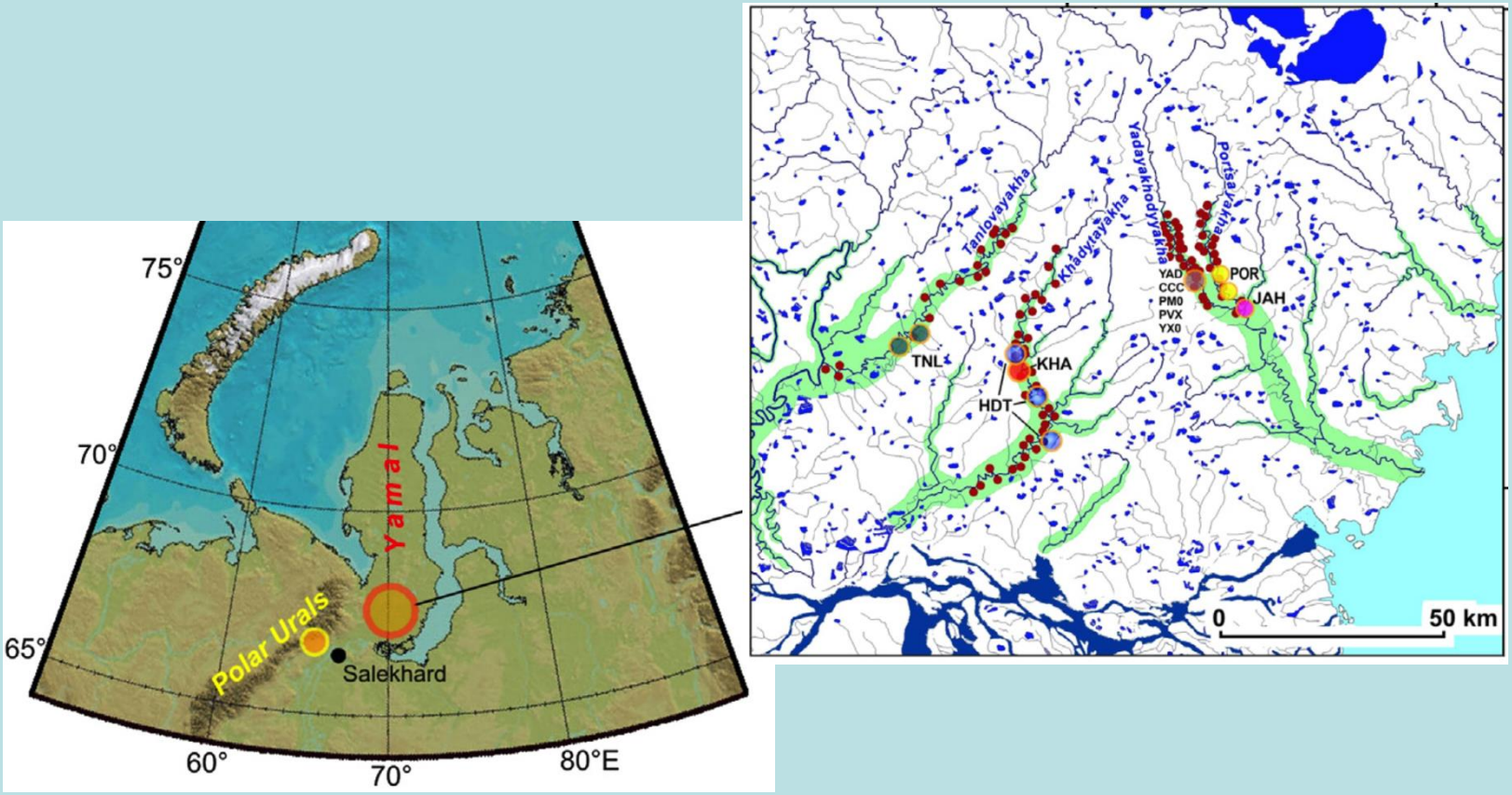
From a paper in 2009 – Blue is CET series for 1659-2009



The blue series is instrumental data for Central England, updated to 2009

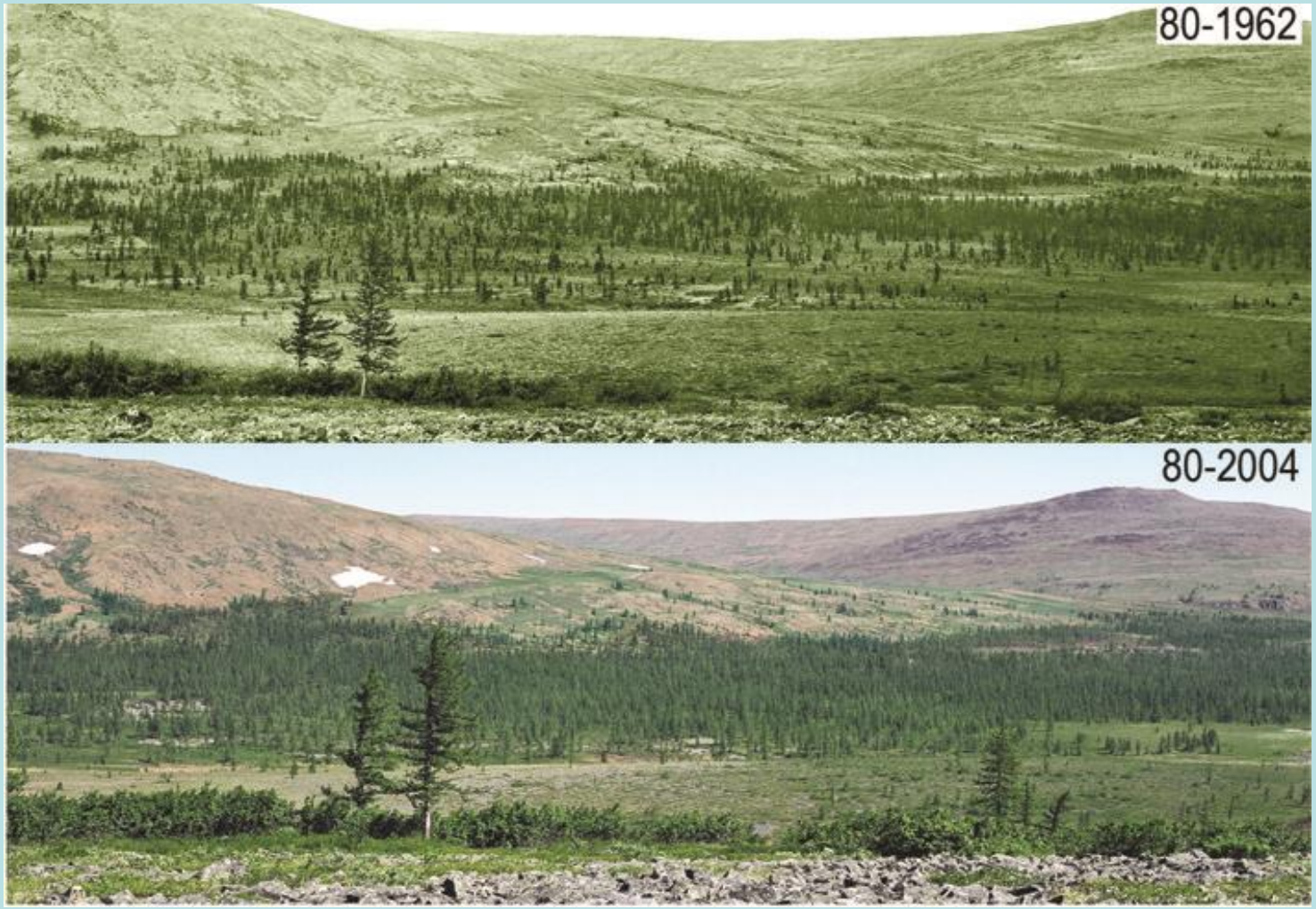
- Jones, P.D., Briffa, K.R., Osborn, T.J. et al., 2009: High-resolution paleoclimatology of the last millennium: a review of current status and future prospects, *Holocene* **19**, 3-49.

The YAMAL Peninsula



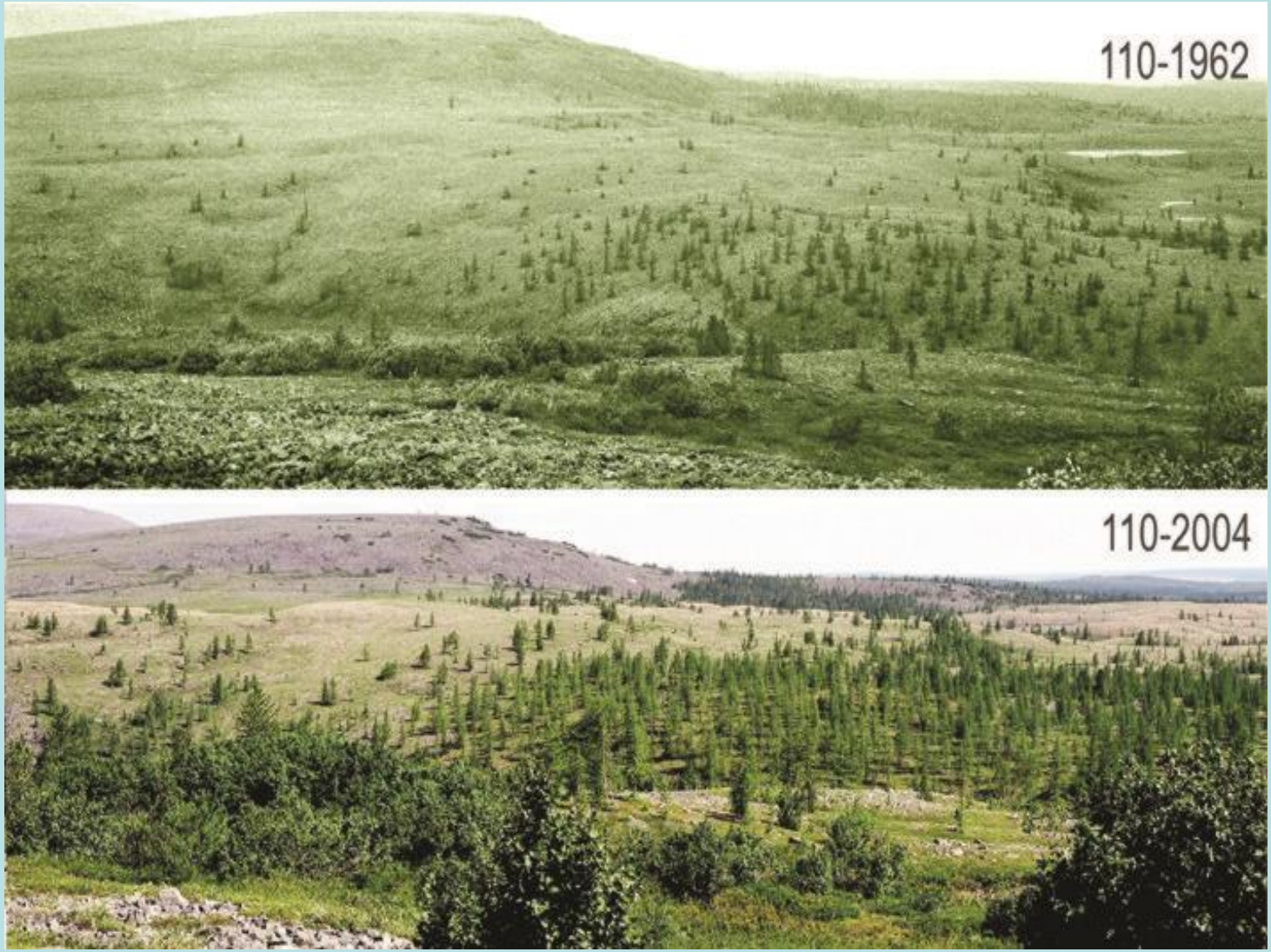
Photos from 1962 and again in 2004
Trees take a time to respond to warming

Yamal Peninsula – Northwestern Siberia



Skeptic claim here was that recent growth wasn't unprecedented and also that this one location affected many multiproxy reconstructions for the last 1000 years. Latter claim can be shown to be wrong (as it wasn't produced till 2002). The above shows dramatic recent changes at the location

Pictures taken at roughly the same time in the two years



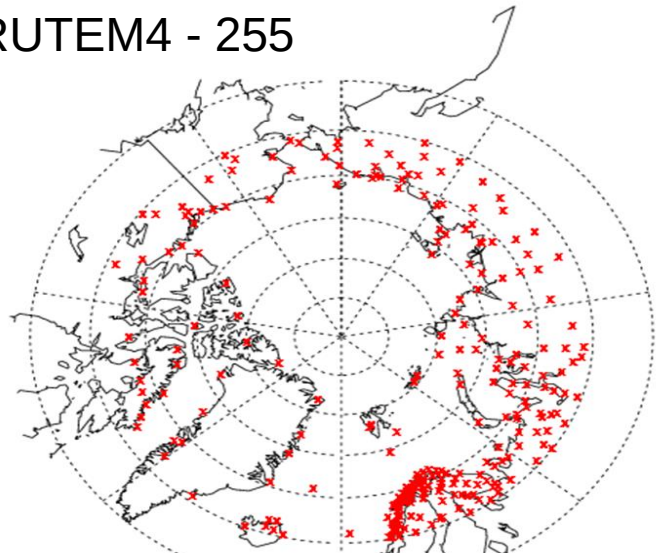
Somewhere else in the Yamal Peninsula

Conclusions

- 5 warmest years are 2016, 2017, 2015, 2018 and 2014
- Four different groups monitoring surface temperatures agree
- Important issues with the measurements relate to three biases (the way SSTs are taken, introduction of screens and urbanization). Without adjustments the world the warming would appear greater
- Warming also evident in satellite record and in the latest and best Reanalysis (ERA-Interim)
- The global average can be produced from a limited number of series (< 100 spread evenly around the world)
- If this wasn't the case, we wouldn't be able to reconstruct temperatures during the Holocene and during the Ice Ages
- Current temperatures are about 1.05 deg C above the pre-industrial average

Arctic Coverage (>65N)

CRUTEM4 - 255

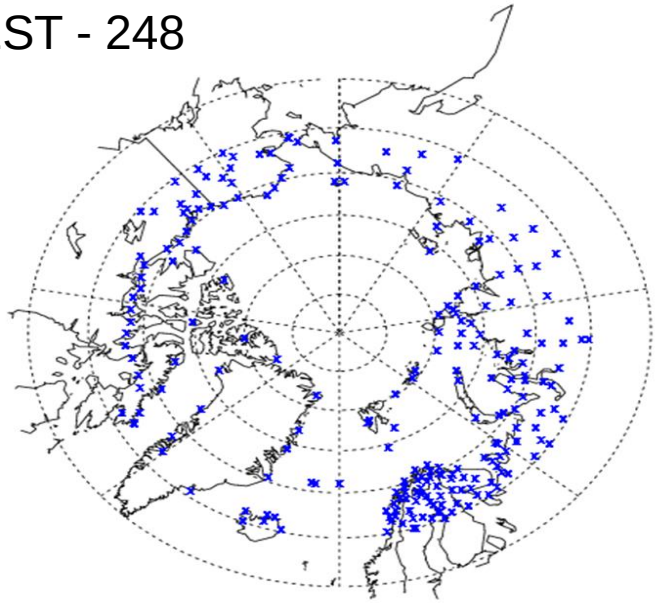


Stations plotted when they have at least 30-years of data

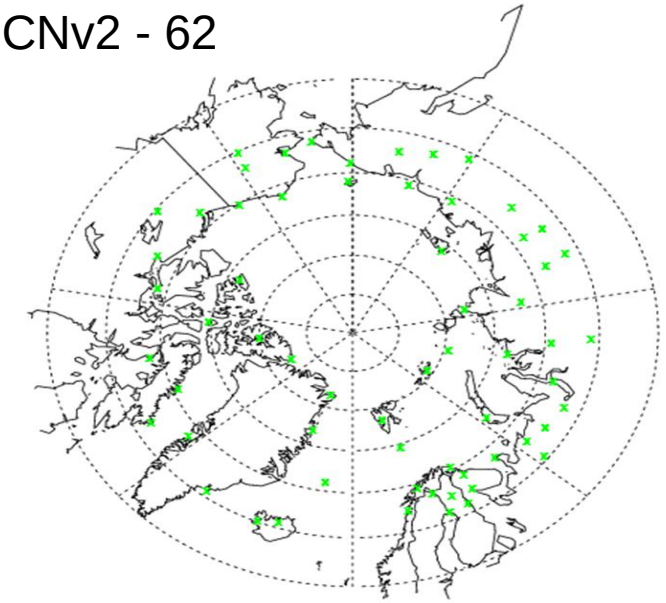
So CRU does not have less data!
Plots of station locations are useless, without any idea of record length

With CRUTEM4's 5 by 5° lat/long grid-box size, there are some missing boxes, but temperature variability is much higher here

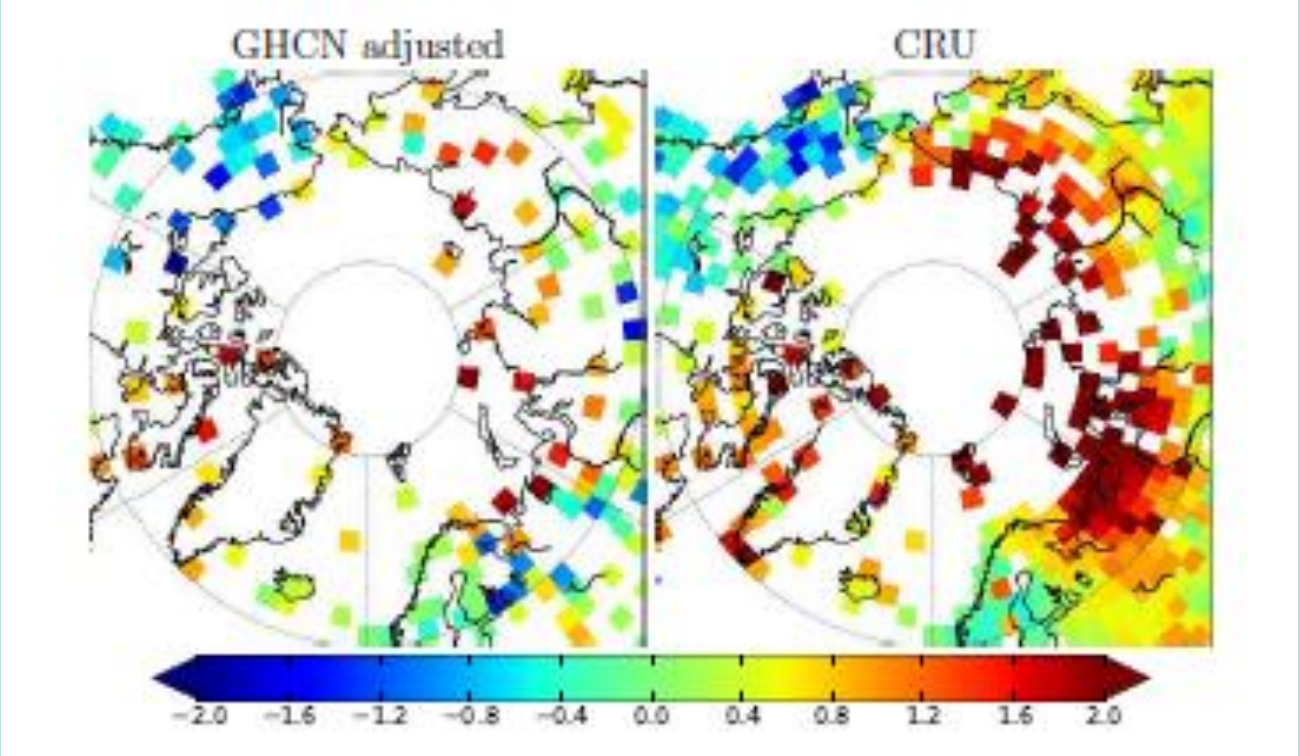
BEST - 248



GHCNv2 - 62



Arctic Data used
Trends over 1997-2012



Left is NCDC (and also GISS) based on GHCN-Monthly, Right is CRUTEM4 **GHCN/GISS infill, but CRUTEM4 leaves the gaps**. Lack of data in GHCN-Monthly will get resolved when they move to GHCNv4. GHCN-Monthly has not updated its station monthly data since 1992, except through adding data for stations they had. New version GHCN (v4) will incorporate many more stations in the Arctic.

Diagram comes from later Cowtan and Way work

Long European regional temperatures