

Evidence for a Multidecadal Oscillation in Global Temperature and Its Impact on the Deduced Anthropogenic Warming Trend

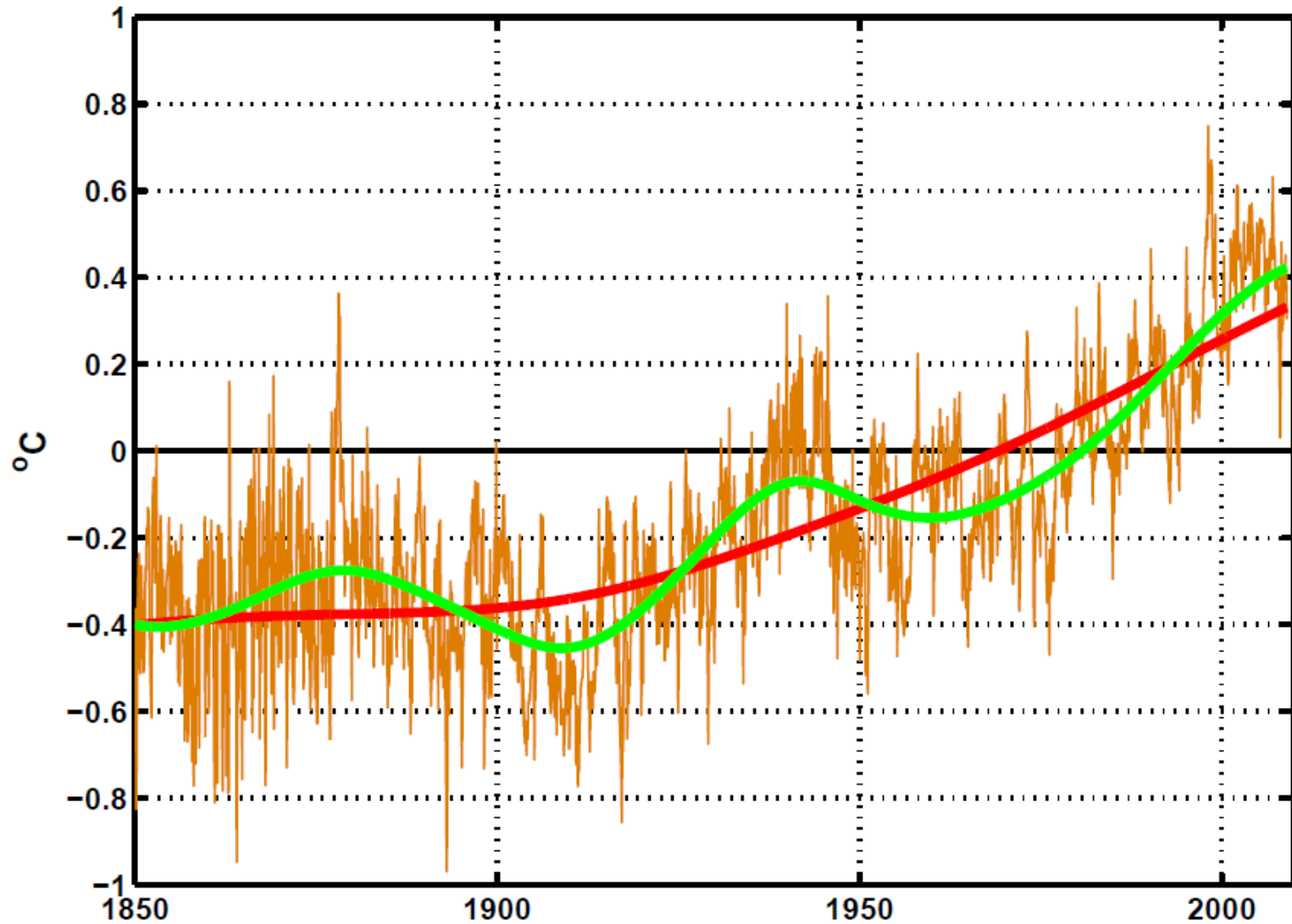
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Global-mean Surface Temperature



Wu, Huang, Wallace, Smoliak and Chen (2011): Trend + 65-year AMO mode

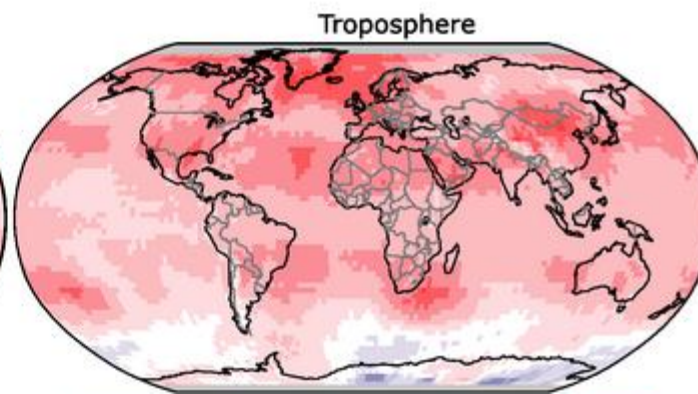
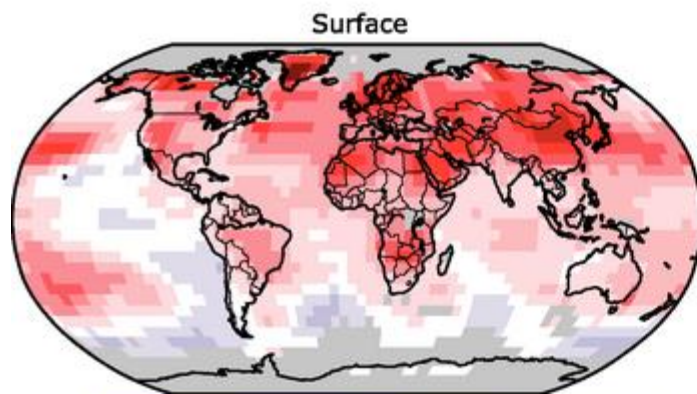
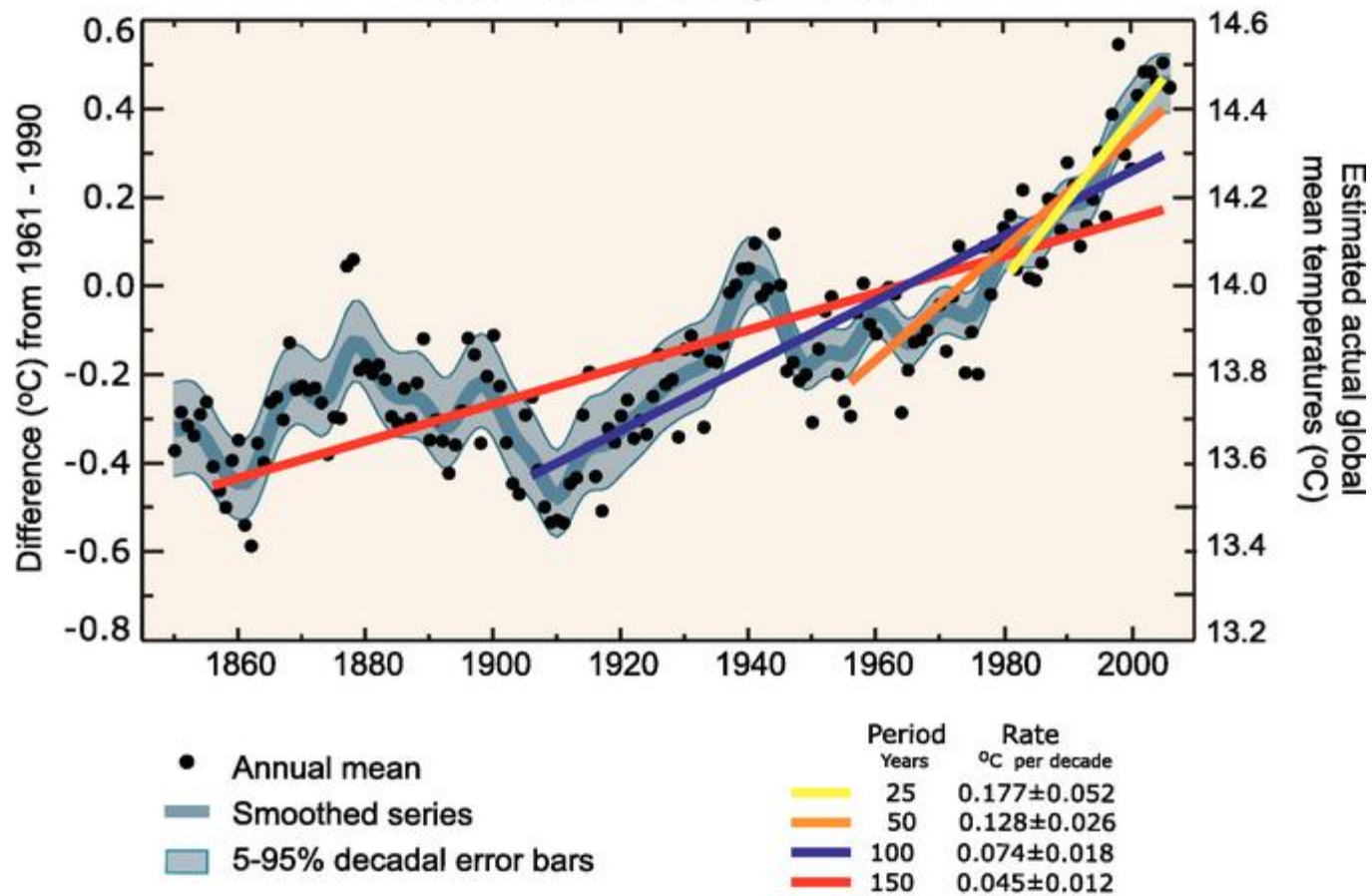
Is the observed oscillation natural or forced by
“time-varying aerosol forcing”?

- Booth et al (2012, *Nature*): HadGEM2 model:
“Aerosols implicated as a prime driver of
twentieth-century North Atlantic climate
variability”

Is the observed oscillation natural or forced by
“time-varying aerosol forcing”?

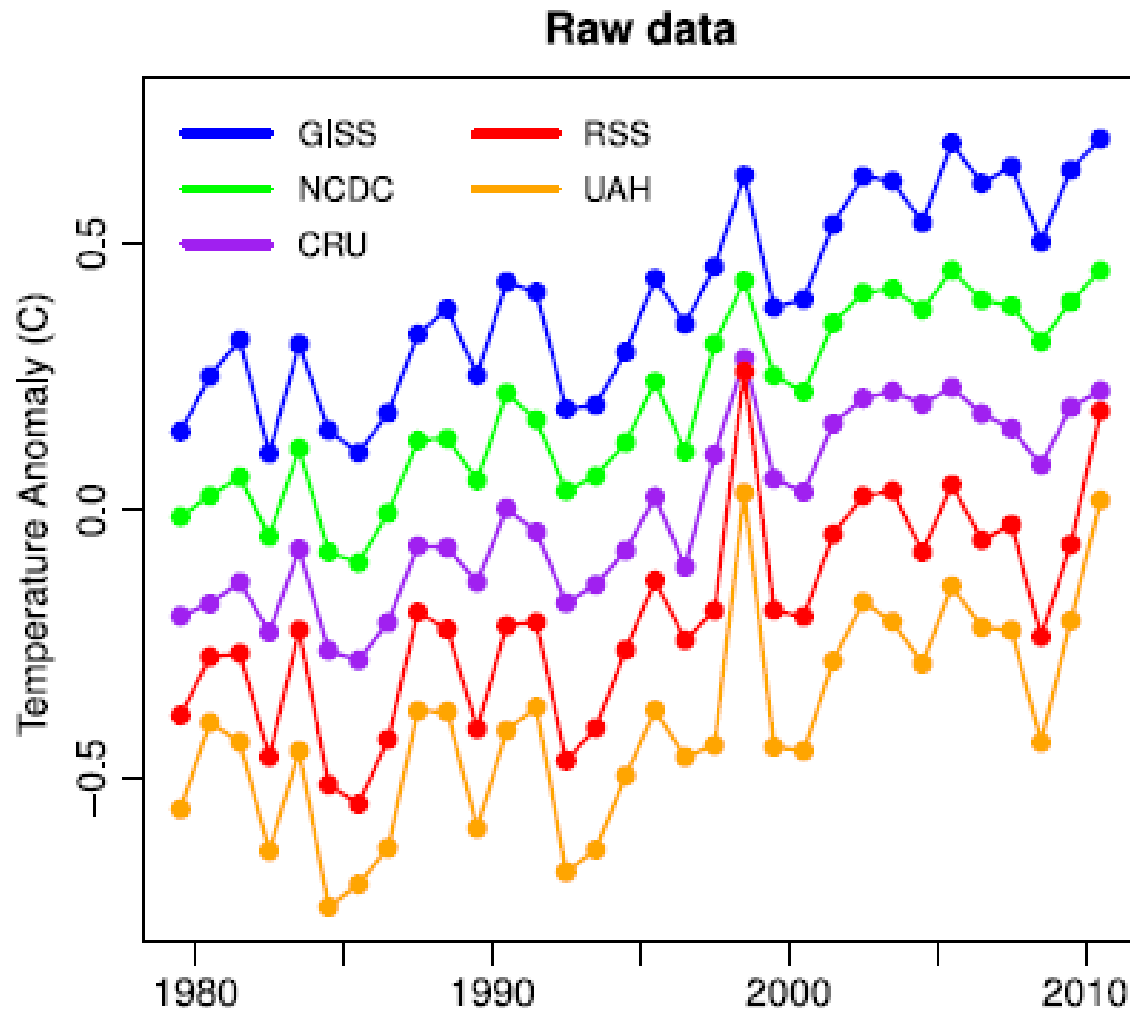
- Booth et al (2012, Nature): HadGEM2 model:
“Aerosols implicated as a prime driver of
twentieth-century North Atlantic climate
variability”
- The controversy can be resolved by examining
longer records.

Global Mean Temperature



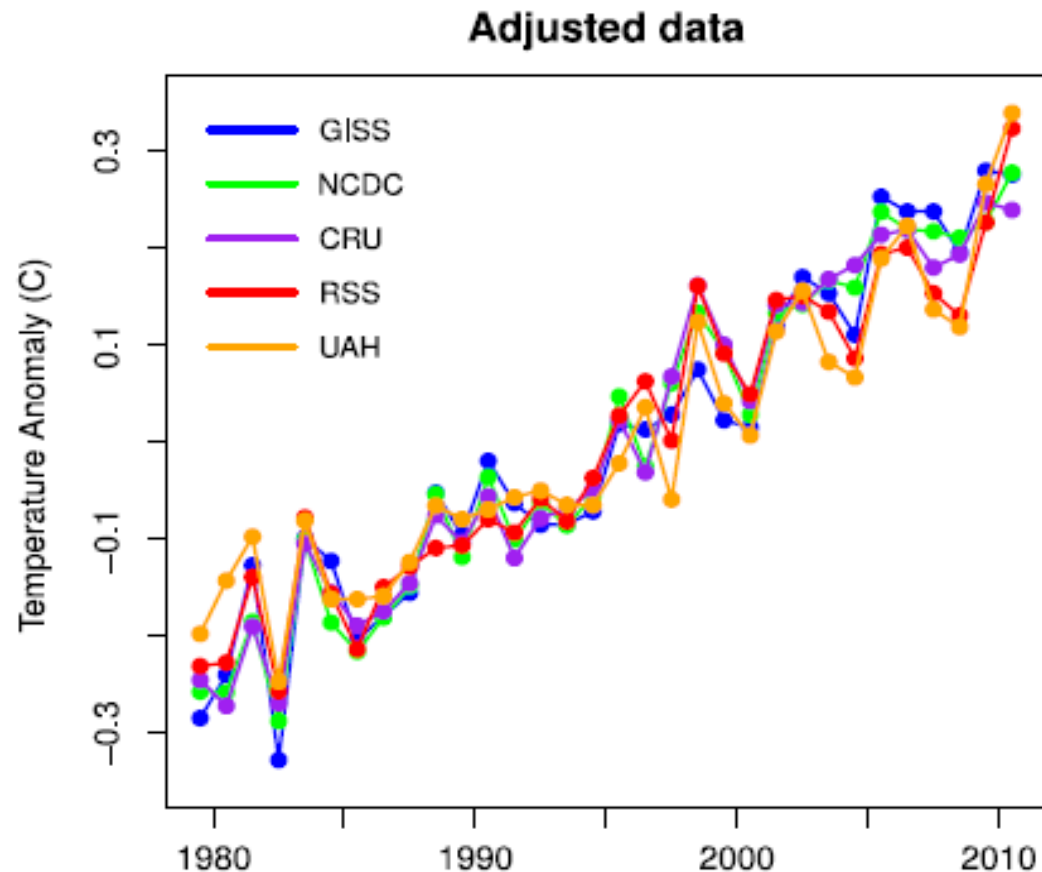
Foster and Rahmstorf (2011)

Raw data appear
to show that the
warming trend
slowed recently

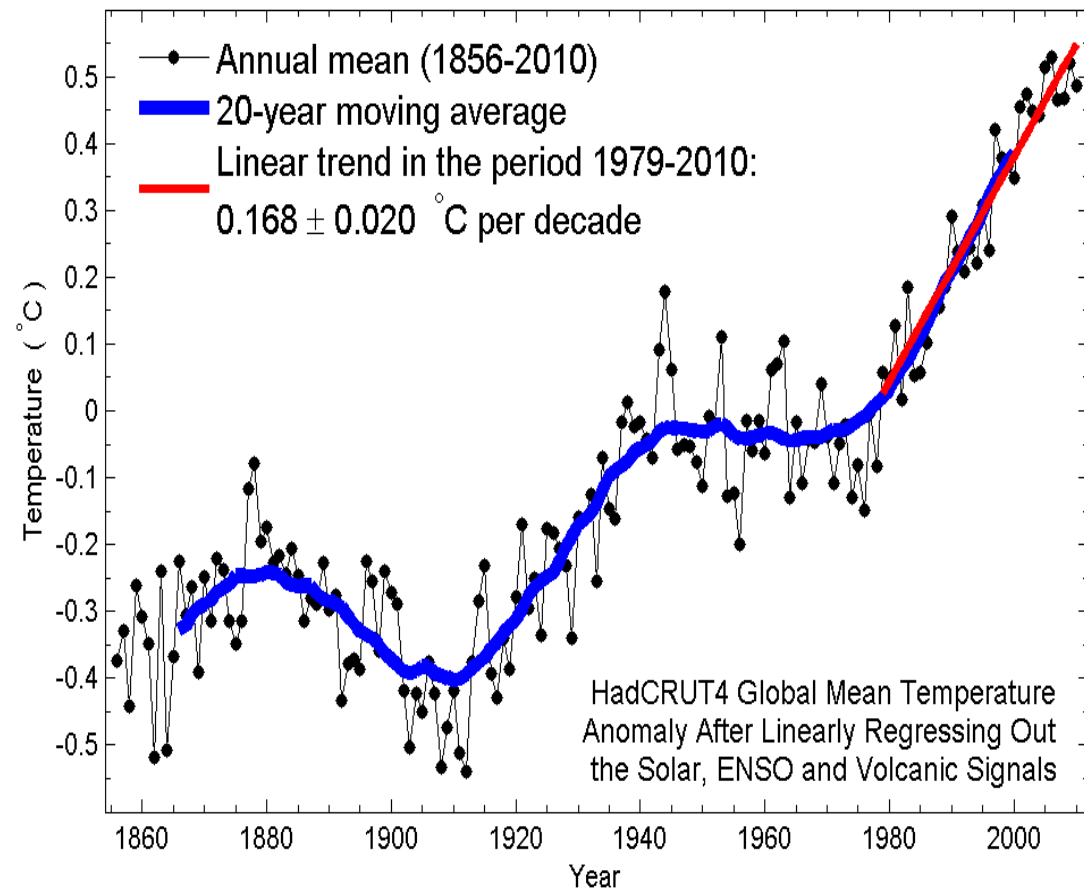


Foster and Rahmstorf (2011): When ENSO, volcano aerosols and solar variability are removed through multiple linear regression, the “true anthropogenic warming trend” is “remarkably steady” since 1979.

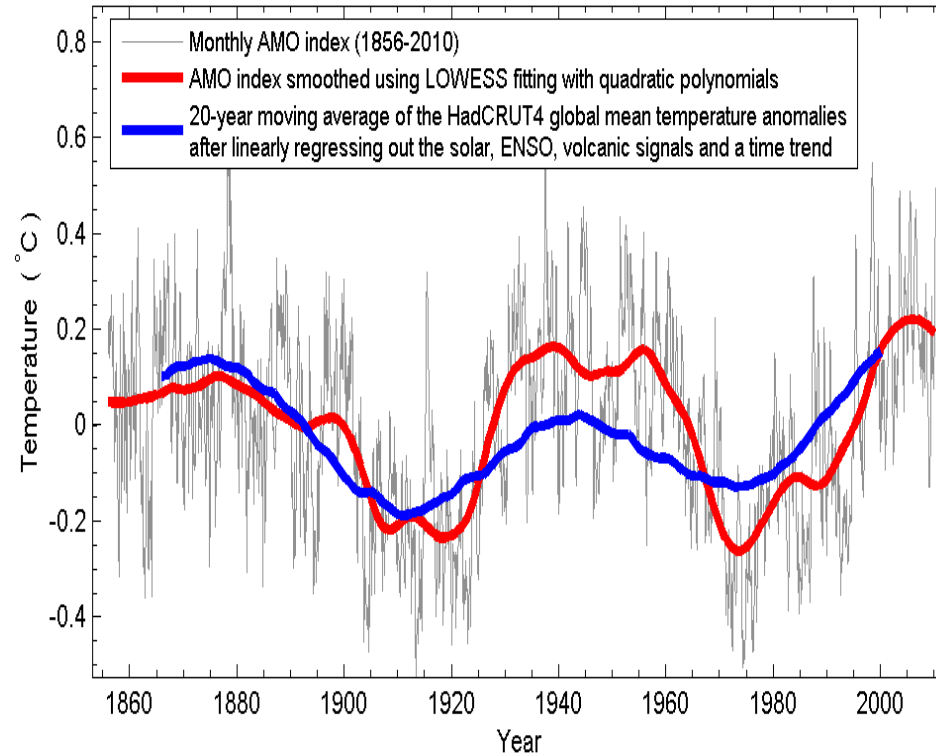
The 32-year linear trend
Is found to be
0.17 K/decade



Zhou and Tung (2012) repeated the regression analysis of Foster and Rahmstorf but used a longer data set, HadCRUT4, going back to 1850. Same 32-year trend is found but the residue contains a low-frequency oscillation, not seen previously because either the record examined was too short or the residual was never shown.

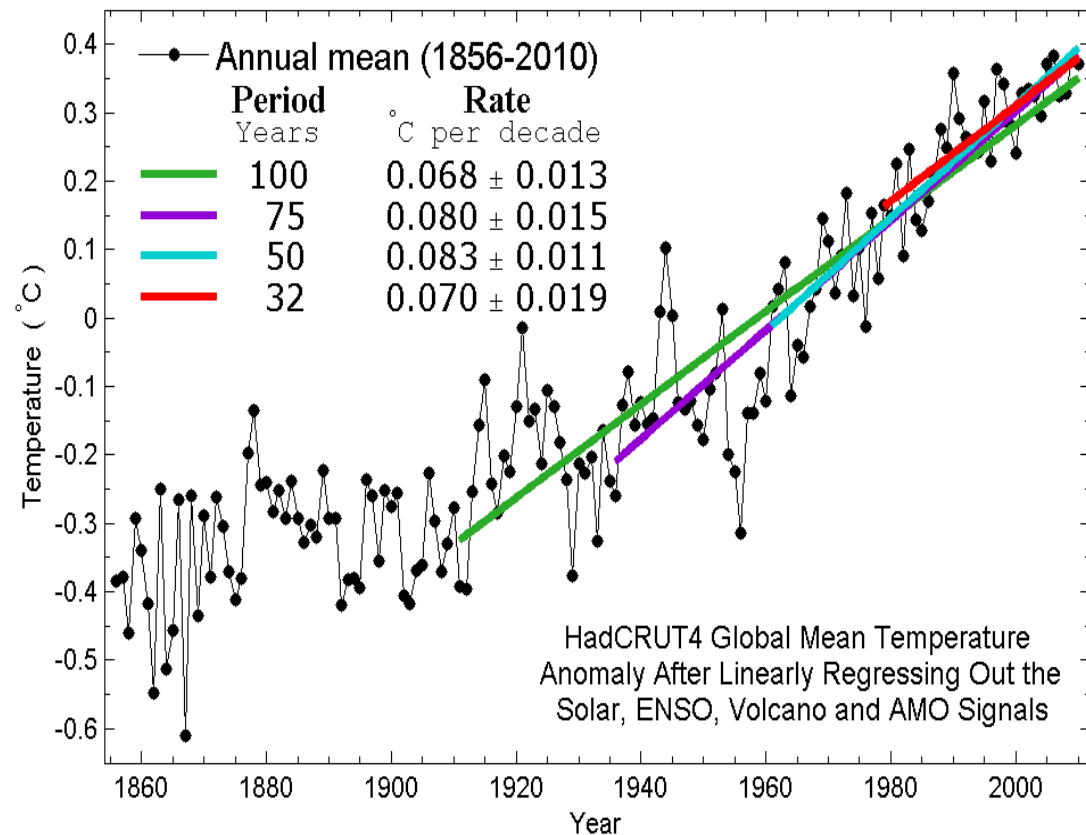


The residual follows the AMO Index



When the AMO index is included as a regressor, in addition to ENSO, volcano and solar the net anthropogenic warming trend is **steady for the past 100 years**, and is **0.07-0.08 K/decade**, less than half of the accepted values. This is controversial.

It suggests that the anthropogenic tropospheric aerosols increased along with industrialization faster than that used in current models.



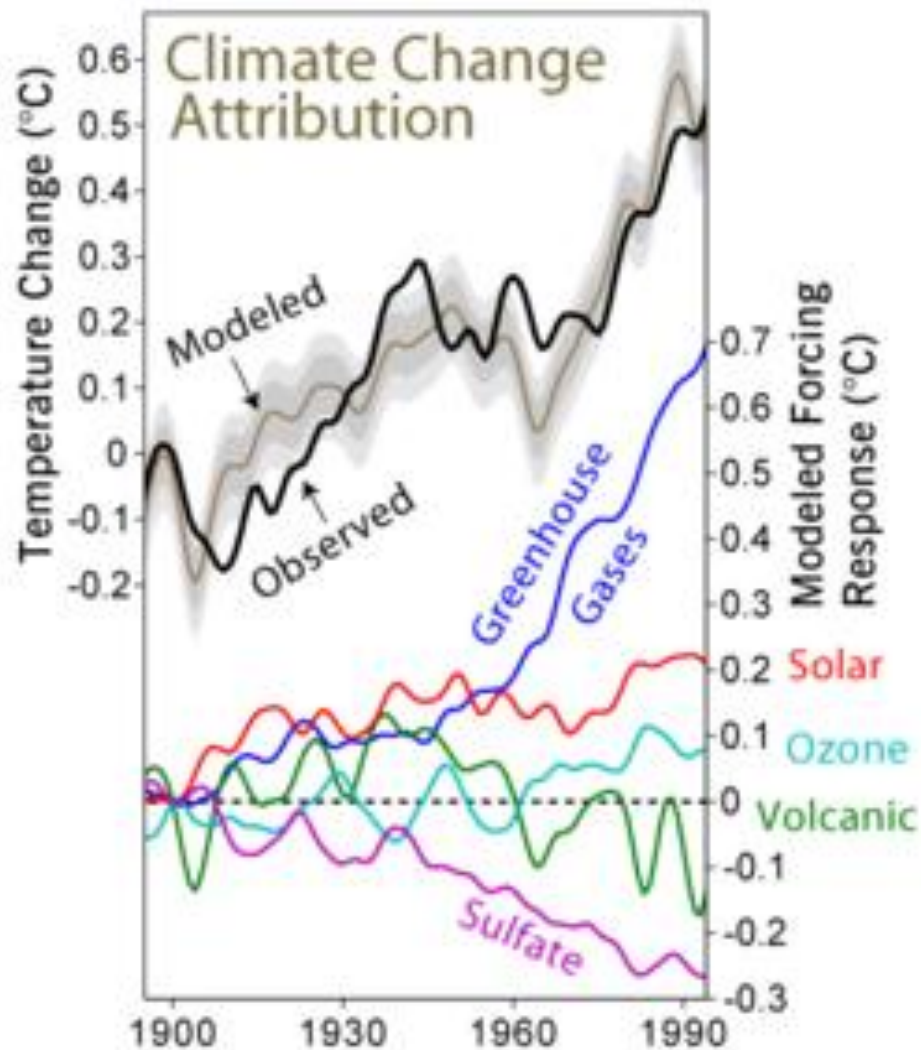
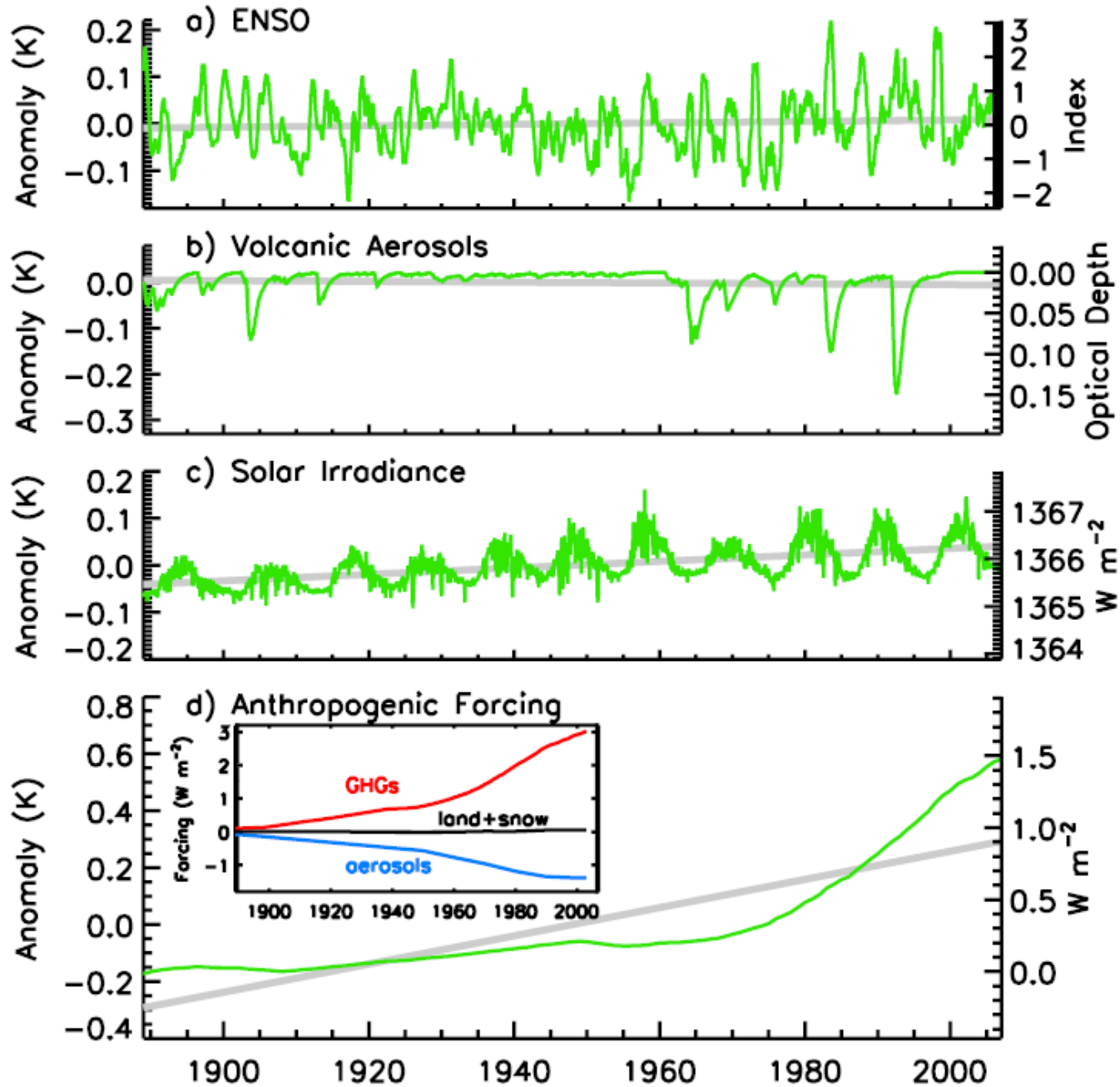


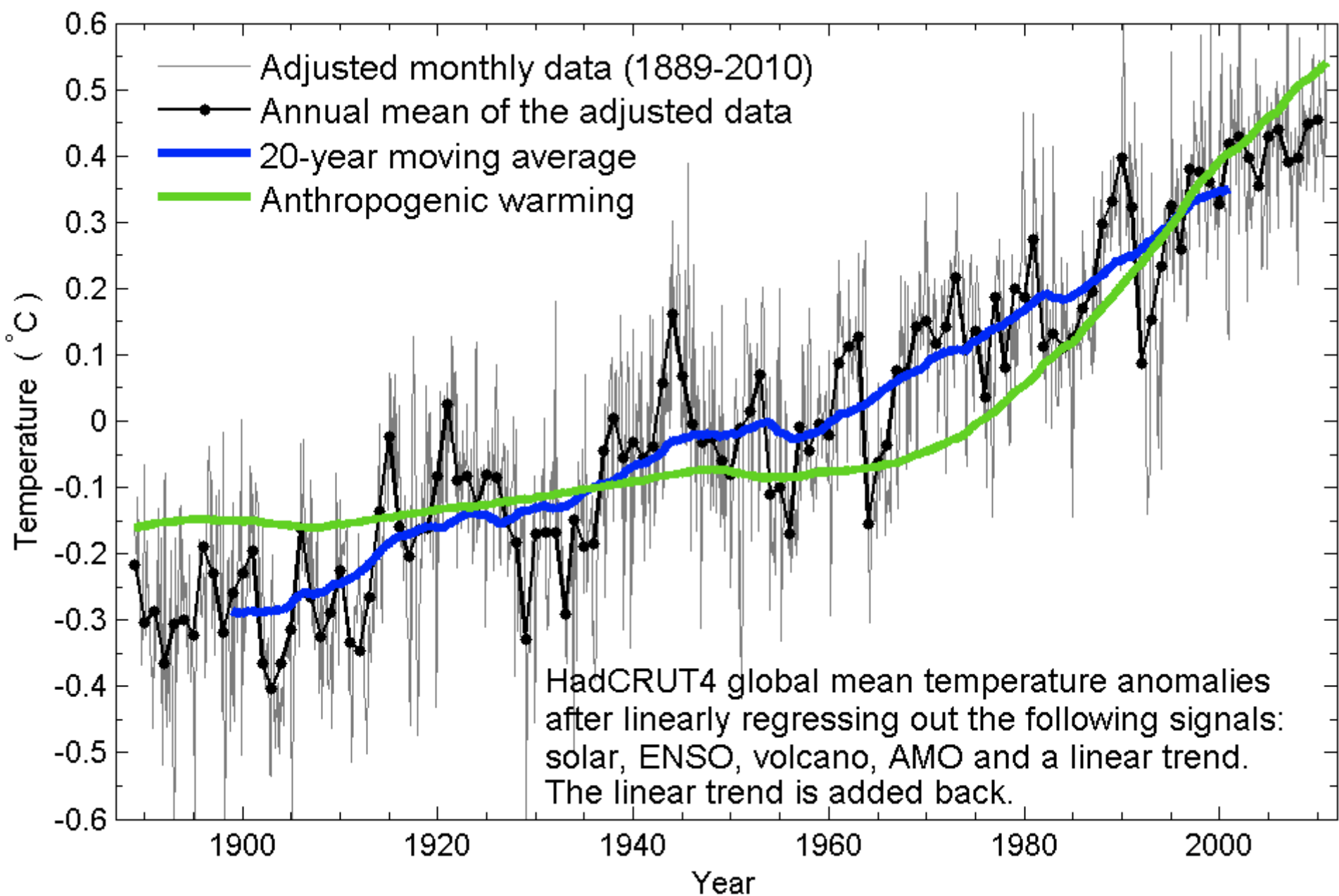
Figure taken from Wikipedia: attribution of 20th century global warming, Note: no role for multidecadal internal variability in model attribution, either because of ensemble averaging or of slab ocean in models of intermediate complexity often used for attribution. Also, the sulphate cooling could have increased more.

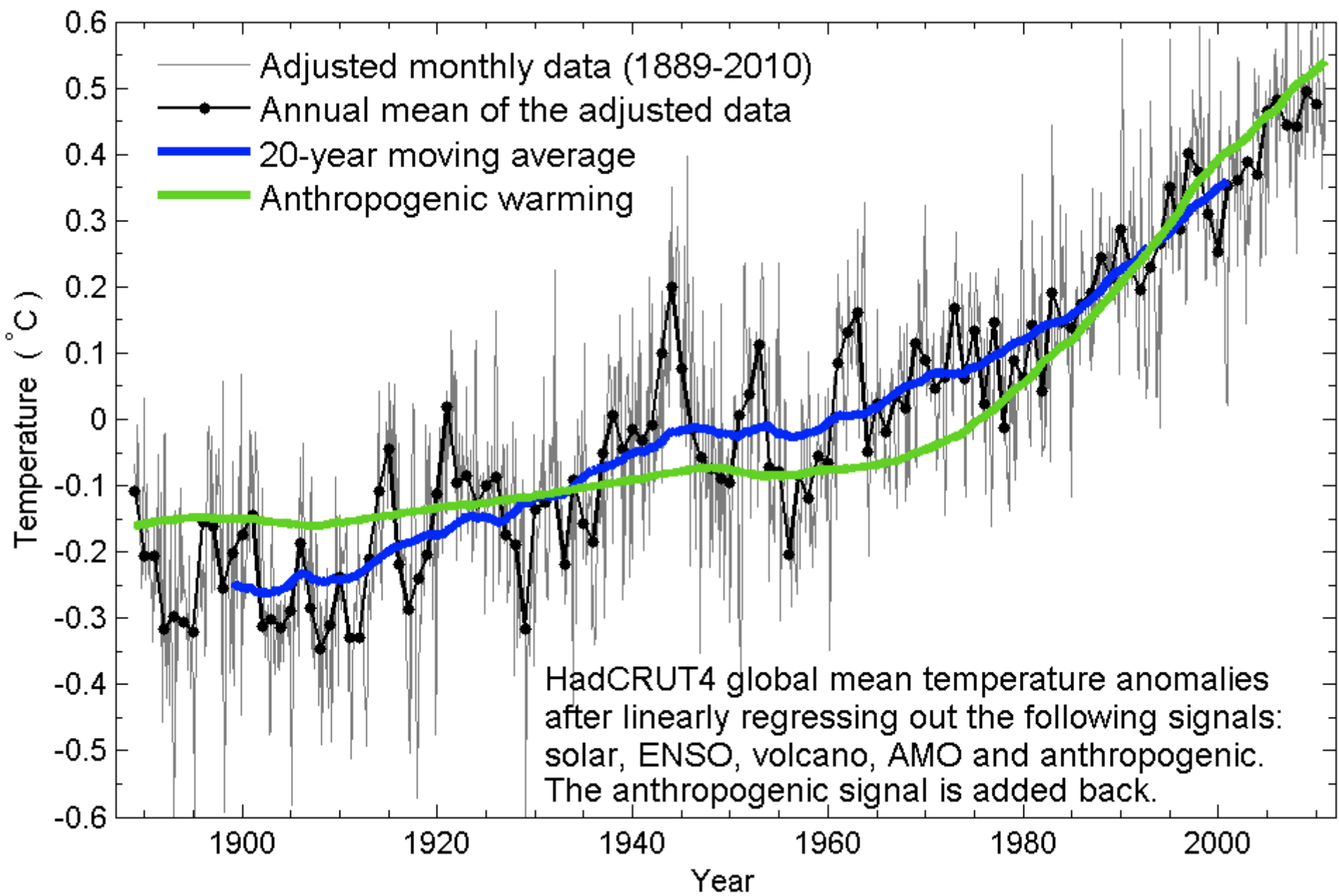
Surface Temperature Variability Components

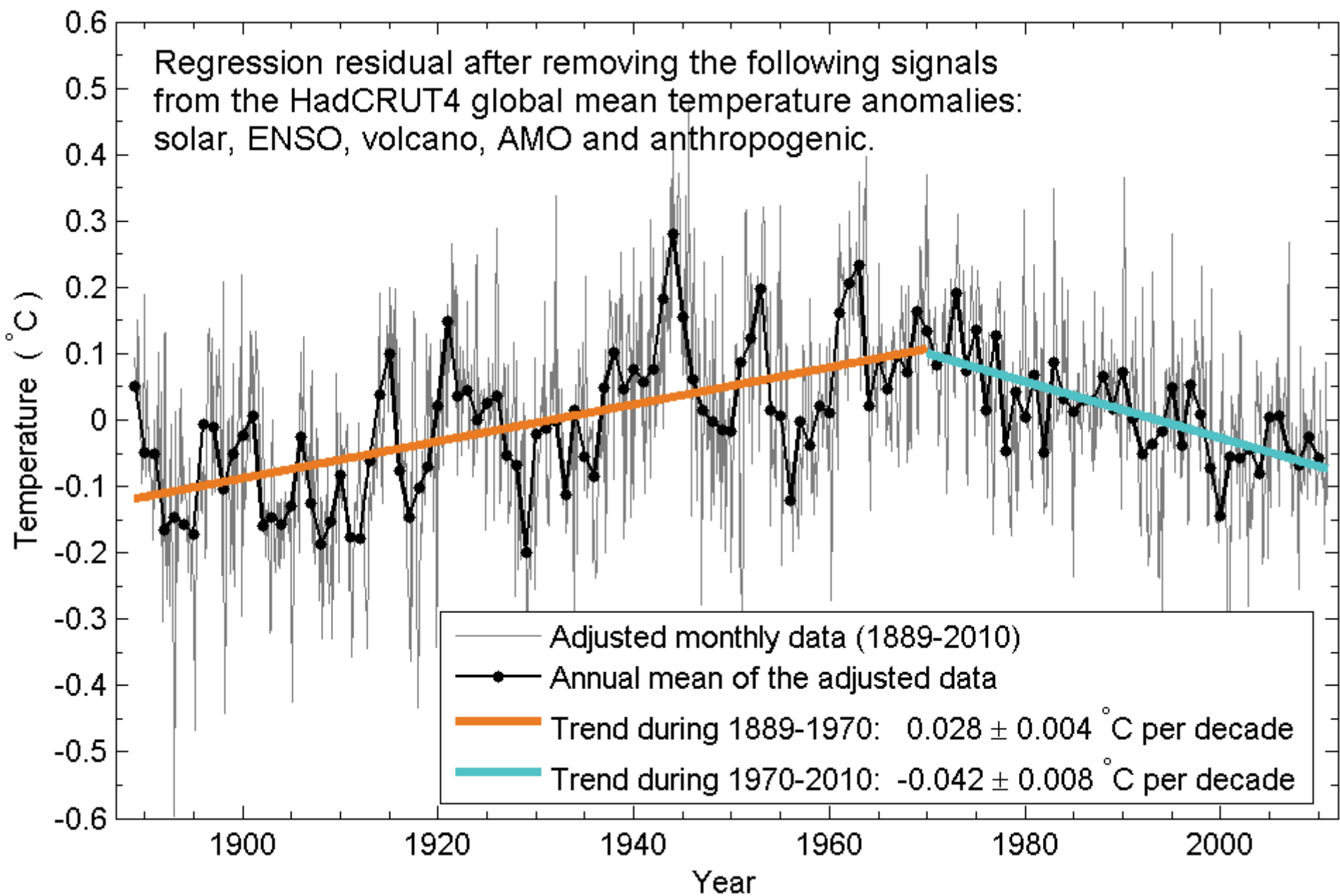


Lean and
Rind (2008)

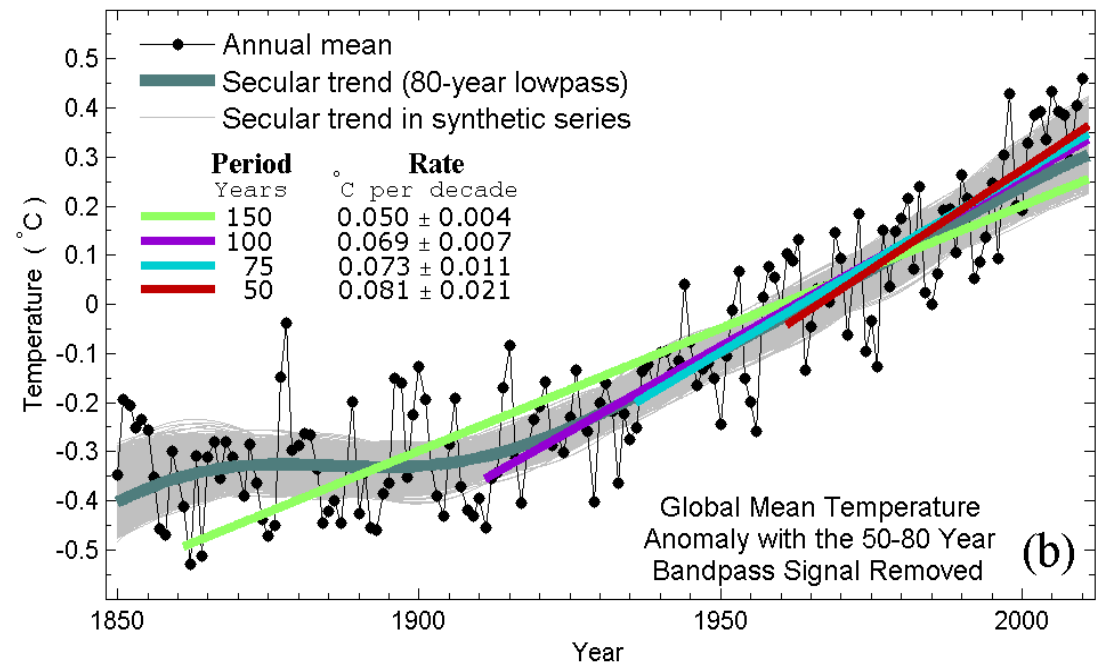
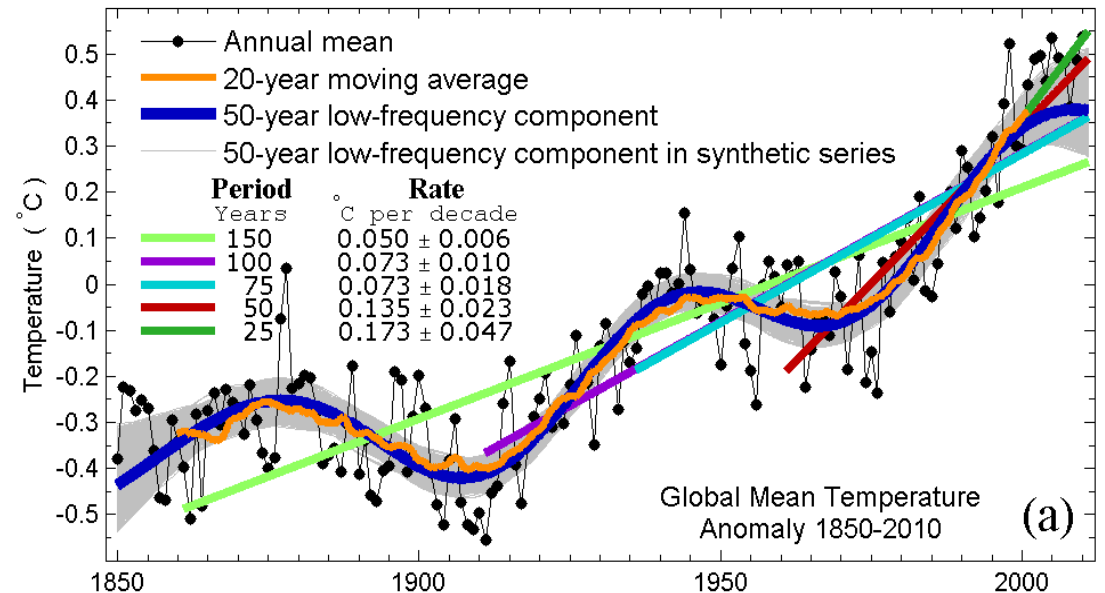
25-year trend
0.20 K/decade





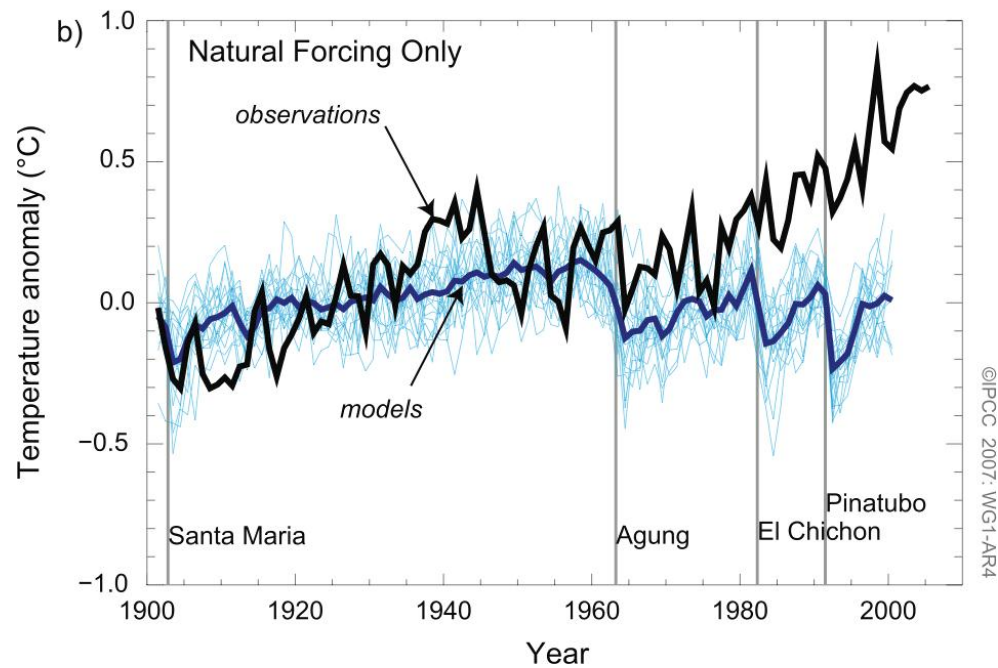
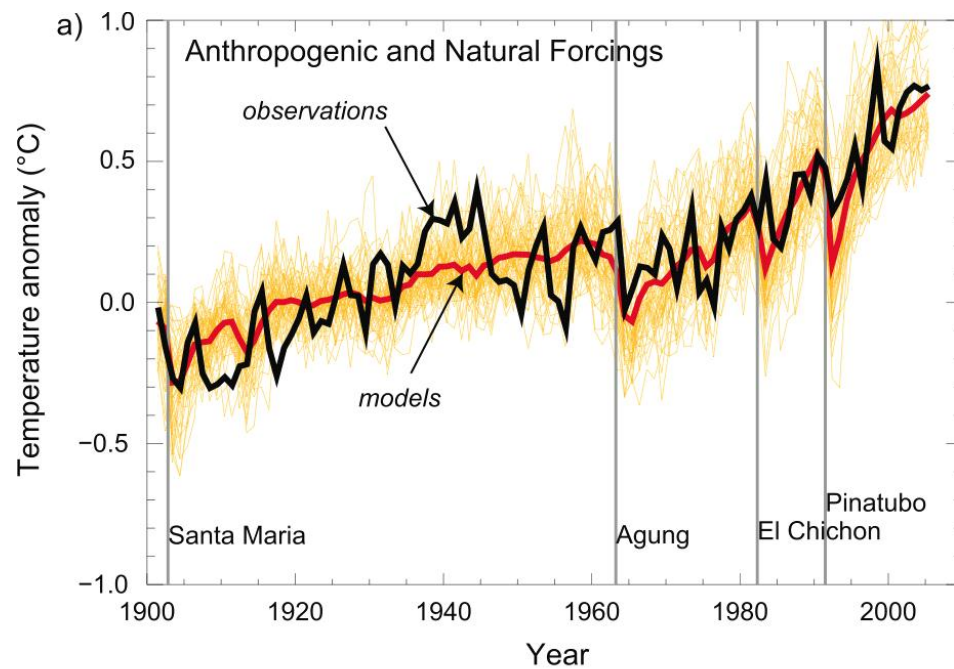


Take another look at the raw HadCRUT4 data, and see the presence of the multidecadal oscillation even with the most elementary methods: moving average and low pass filter.



Why doesn't multidecadal variability play a more prominent role in AR4 models?

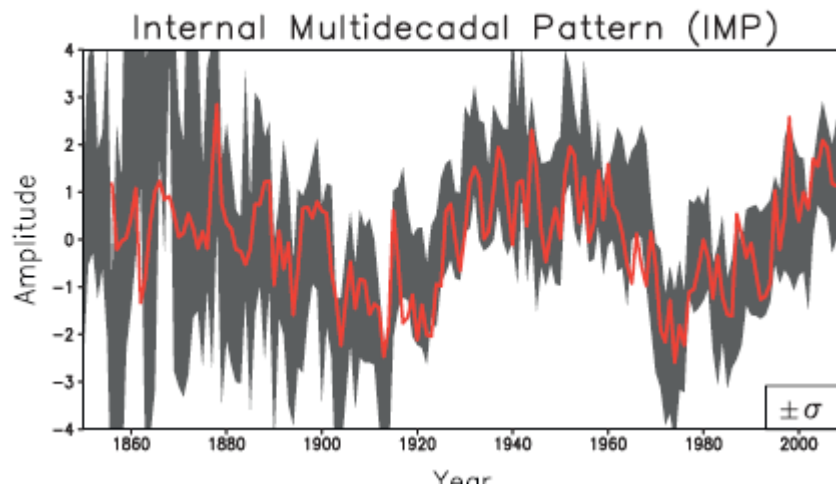
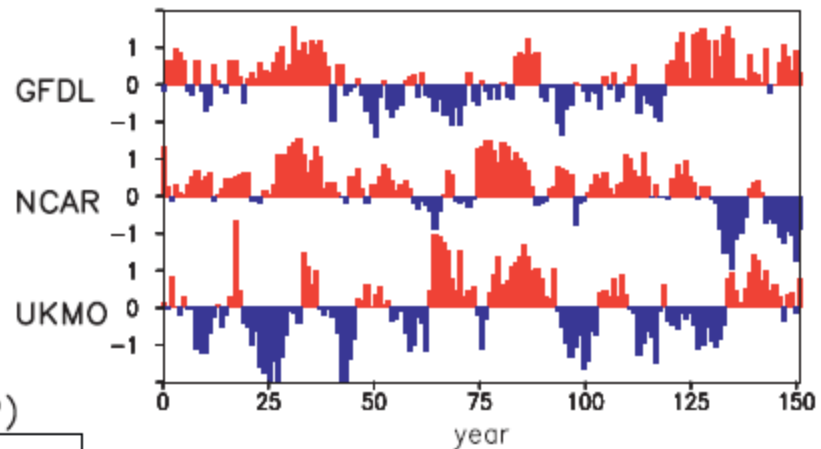
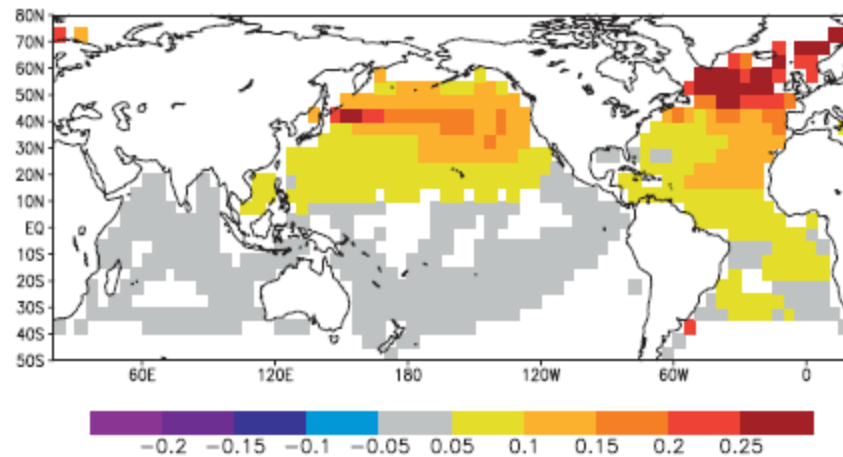
- Individual models have different periods, different phases and different amplitudes (Medhaug and Furevik (2011)). Ting et al (2009) showed that the observed North Atlantic variability is well outside the range of AR4 model uncertainty/variability.
- For the same model, not always the right phase, depending on initiation. One realization of the GFDL model got it right (Delworth and Mann (2000))
- AR4 emphasized forced response, obtained by ensemble averaging different initializations.
- AR4 conclusion: the observed temperature variation can be well simulated by **forced** response; “most” of the observed warming since mid-20th century is anthropogenic. AR4 does not have a definitive conclusion on Early Twentieth Century Warming.



©IPCC 2007: WG1-AR4

Figure TS.23

DelSole et al (2011):
Examined 14 models
in CMIP3



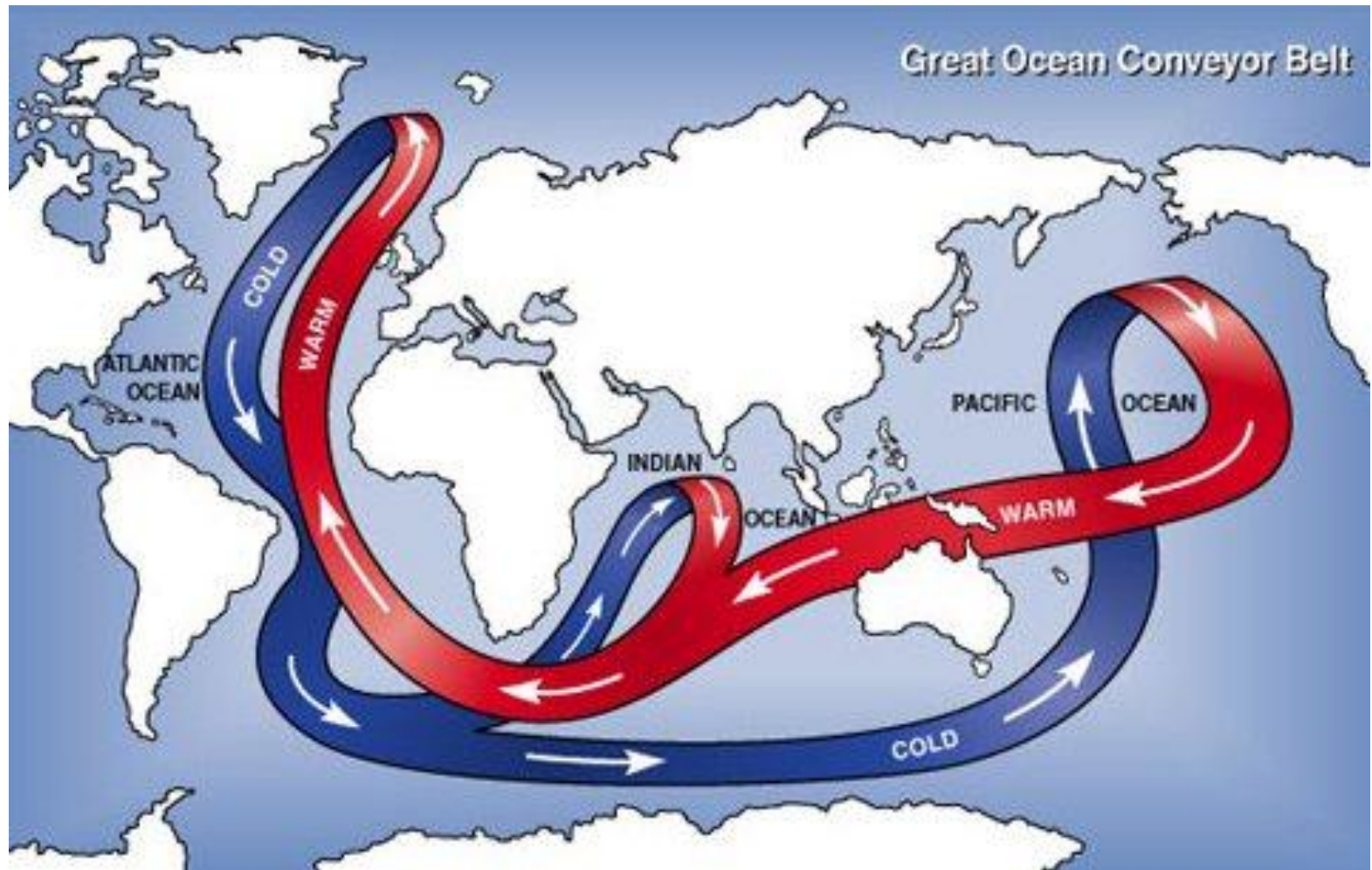
Projected observed data onto the
model pattern. Compare with AMO
Index in red.

Mechanisms for the AMO

- Related to the Thermohaline Circulation (THC) in the Atlantic, specifically its SST variability.
- Delworth and Greatbatch (2000): stochastic atmospheric forcing of the ocean; primarily an ocean variability.
- Why 70-year period when the time scale of THC is $O(1000 \text{ years})$?
- Dima and Lohmann (2007); Latif et al (2004); Semenov et al (2010)

Negative feedbacks involving the THC, its SST transport, and Arctic ice melt.

Great Ocean Conveyor Belt



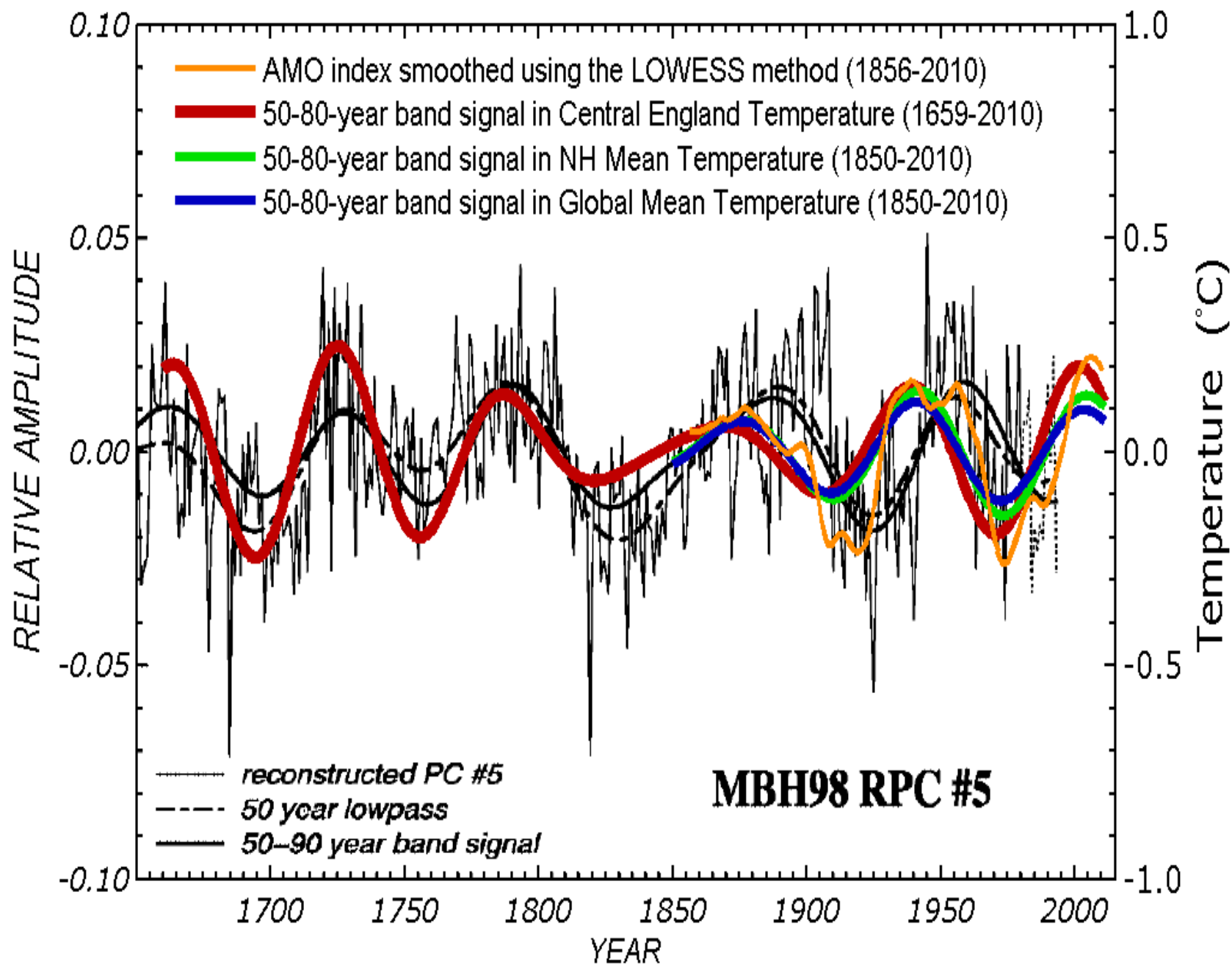
Mechanisms responsible for the ~70-year period of the AMO

- Consider a slightly stronger THC. After a lag of several years makes North Atlantic SST warmer; increased Arctic ice melt; reduced deep water formation.
- Takes about 20 years to slow down the THC a little.
- A slower THC has decreased SST transport with a delay of several years.
- Half cycle of ~35 years.
- A colder Arctic has less ice melt.....

Atlantic Multidecadal Oscillation

A brief history

- Phrase coined by the *Science* writer Kerr (2000), who attributed the discovery to Delworth and Mann (2000).
- Schlesinger et al (2000) disputed the attribution, and claimed that the credit should go to Schlesinger and Ramankutty (1994), who found two cycles with period 65-70 years.
- Actually it should be Folland et al (1984), who found a worldwide temperature fluctuation of 0.6 K with power at 83 years for the period 1856-1981.
- In reply Kerr said two cycles did not constitute the discovery of an oscillation. Preferred “half a dozen or more” cycles
- Delworth and Mann studied a 330-year multi-proxy record and found 4.5 cycles of the AMO.
- It was not pointed out previously that the multi-proxy AMO does not agree with the instrumental AMO.



The previous figure

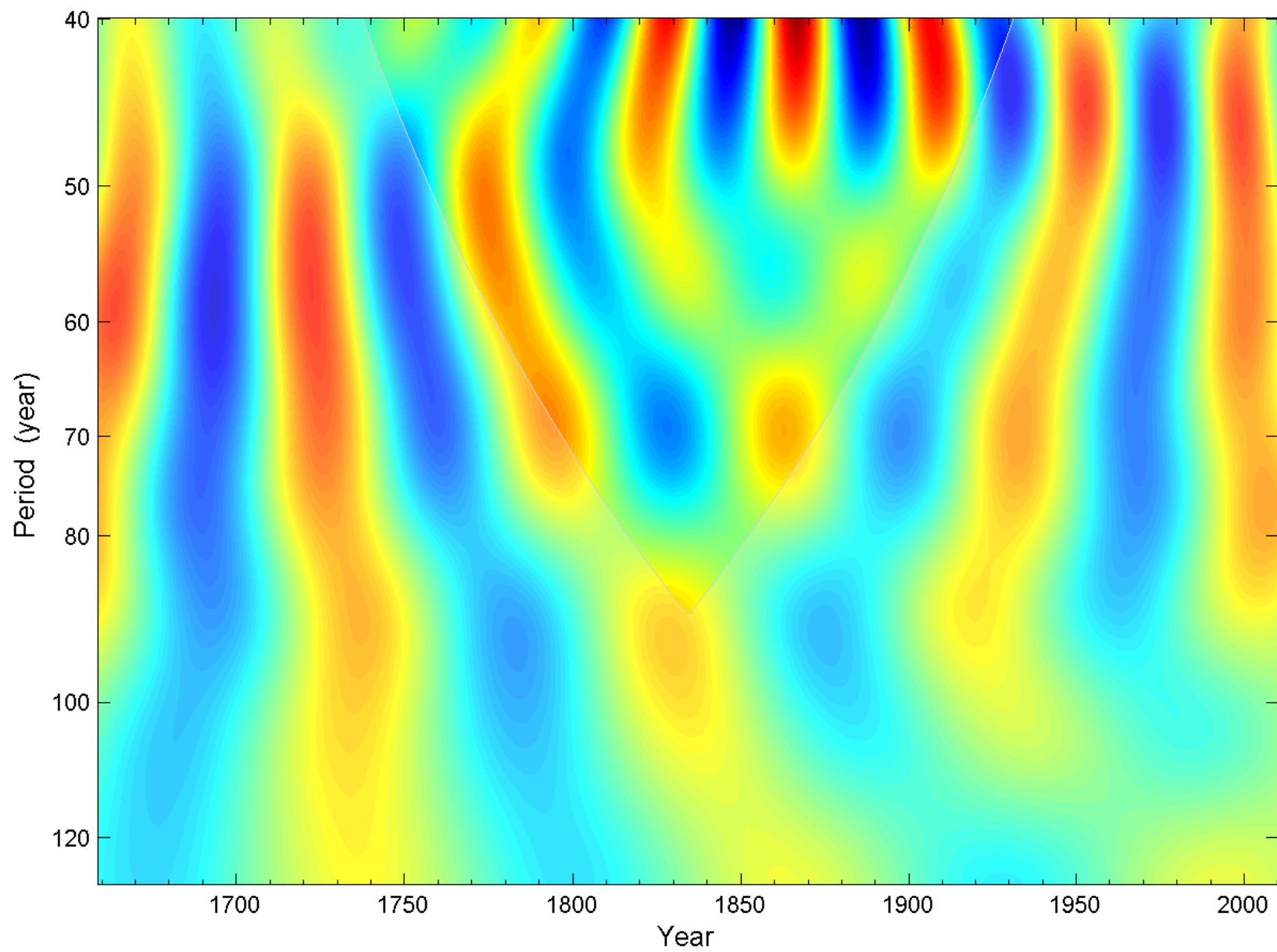
- The **red** curve was obtained using Wavelet transform of the 352-year Central England Temperature (to be discussed later).
- Same wavelet transform is done to the HadCRUT4 global mean temperature (**blue**) and the NH mean (**green**).
- The **orange** curve is the AMO Index: detrended N. Atlantic mean SST.
- The thin black curve is the multi-proxy data: the 5th PC!
- Multi-proxy AMO does not agree with the instrumental data. CET does.

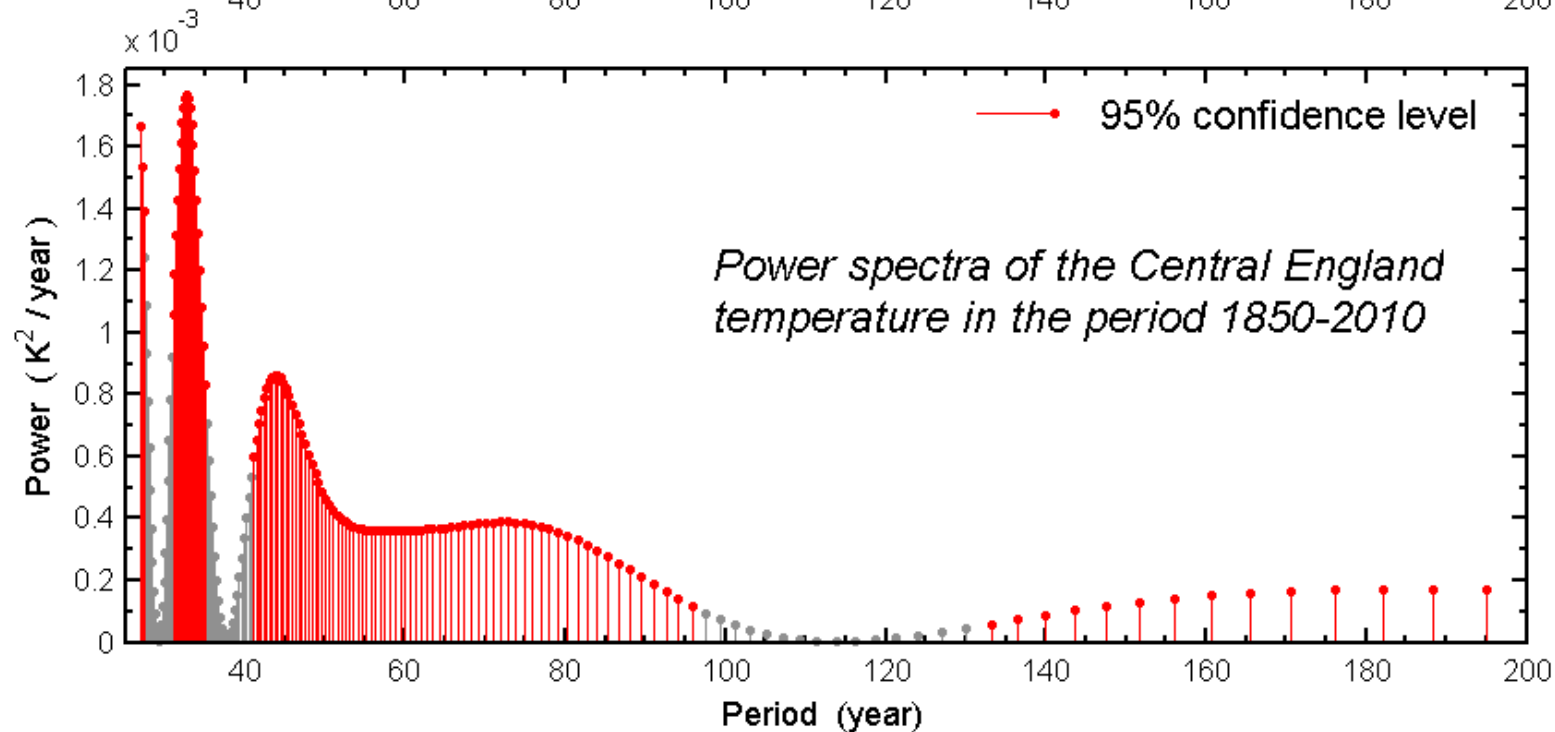
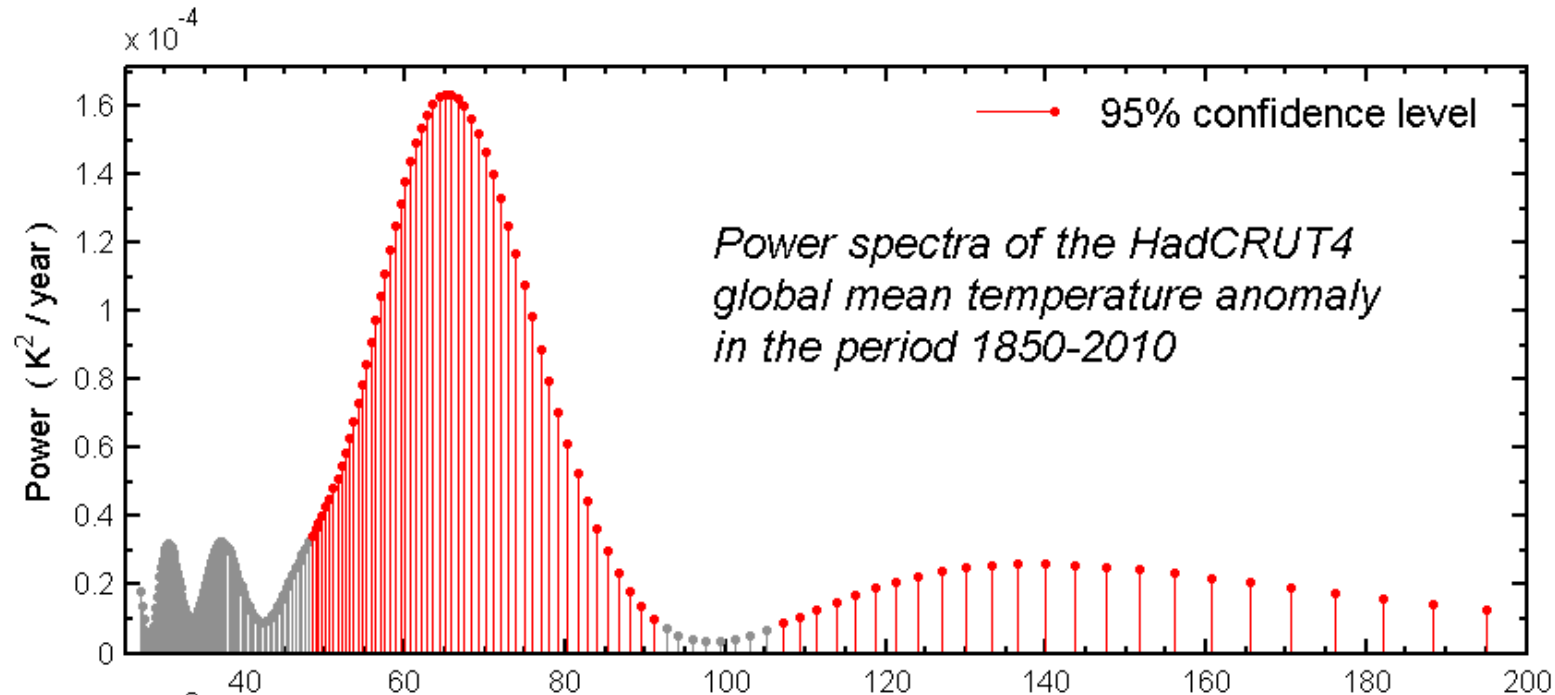
Any record longer?

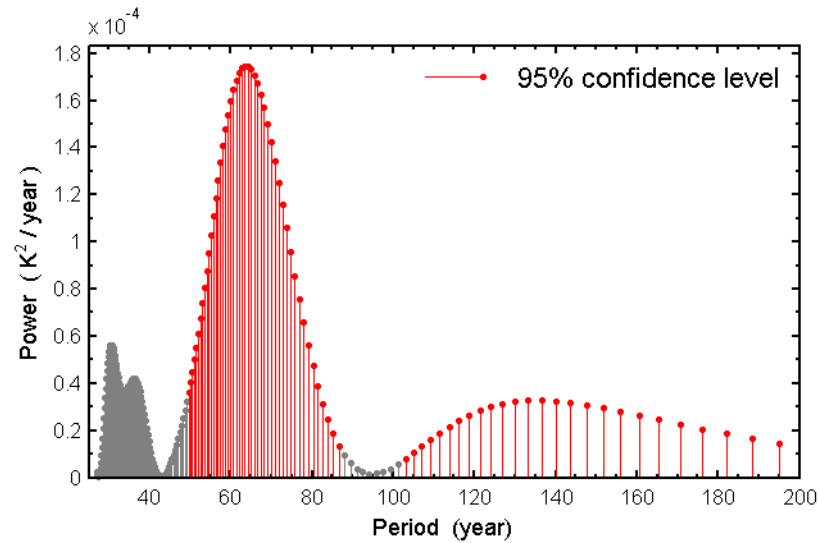
- The previous longest instrumental record analysis was Wood et al (2010): 200-year surface air temperature from 4 stations in the Atlantic-Arctic boundary: not an oscillation.
- Gray et al (2004) considered tree-ring based reconstruction of AMO back to 1567, one cycle earlier, but that cycle was probably contaminated by the severe cooling of the Little Ice Age, caused by volcanic aerosols.
- Chylek et al (2011) examined 5 ice-core dataset over the period 1303-1961 and reported two time scales for the AMO, a 20-year and a 45-85-year oscillation. The 20-year oscillation was statistically significant, but the longer oscillation was not. The use of the Hamming spectral filter may have significantly reduced the 50-60 year spectral peak.
- Broecker (1975) extracted two cycles, 1800-1975, from 800-year Camp Century ice core in Greenland. He used a combination of two harmonics, of 80-year and 180-year period.

Analyzing CET data

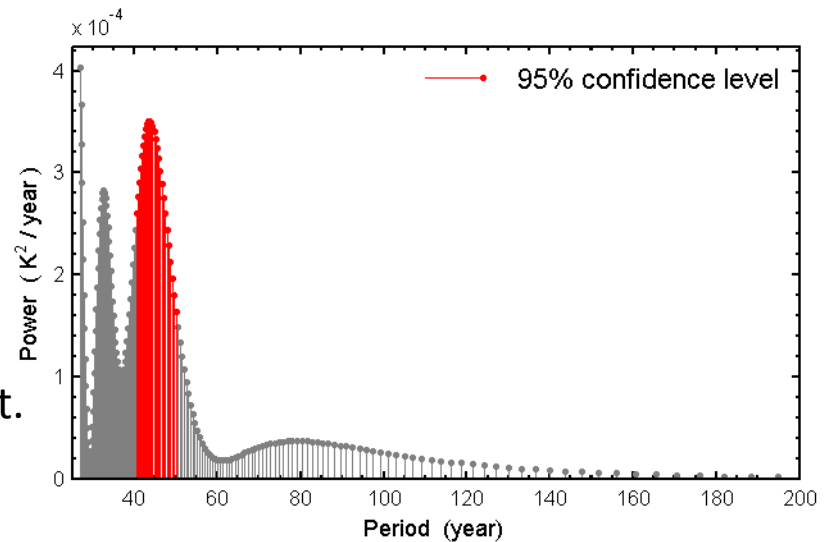
- CET is continuous instrumental data 1659-2011; 352 years, slightly longer than the 330-year multi-proxy data; no divergence problem as that between proxy and instrumental data.
- Previously studied by Plaut et al (1995) focusing on interdecadal variability up to 25-year period, by Karoly and Stott (2006) on its variance up to 50-years.

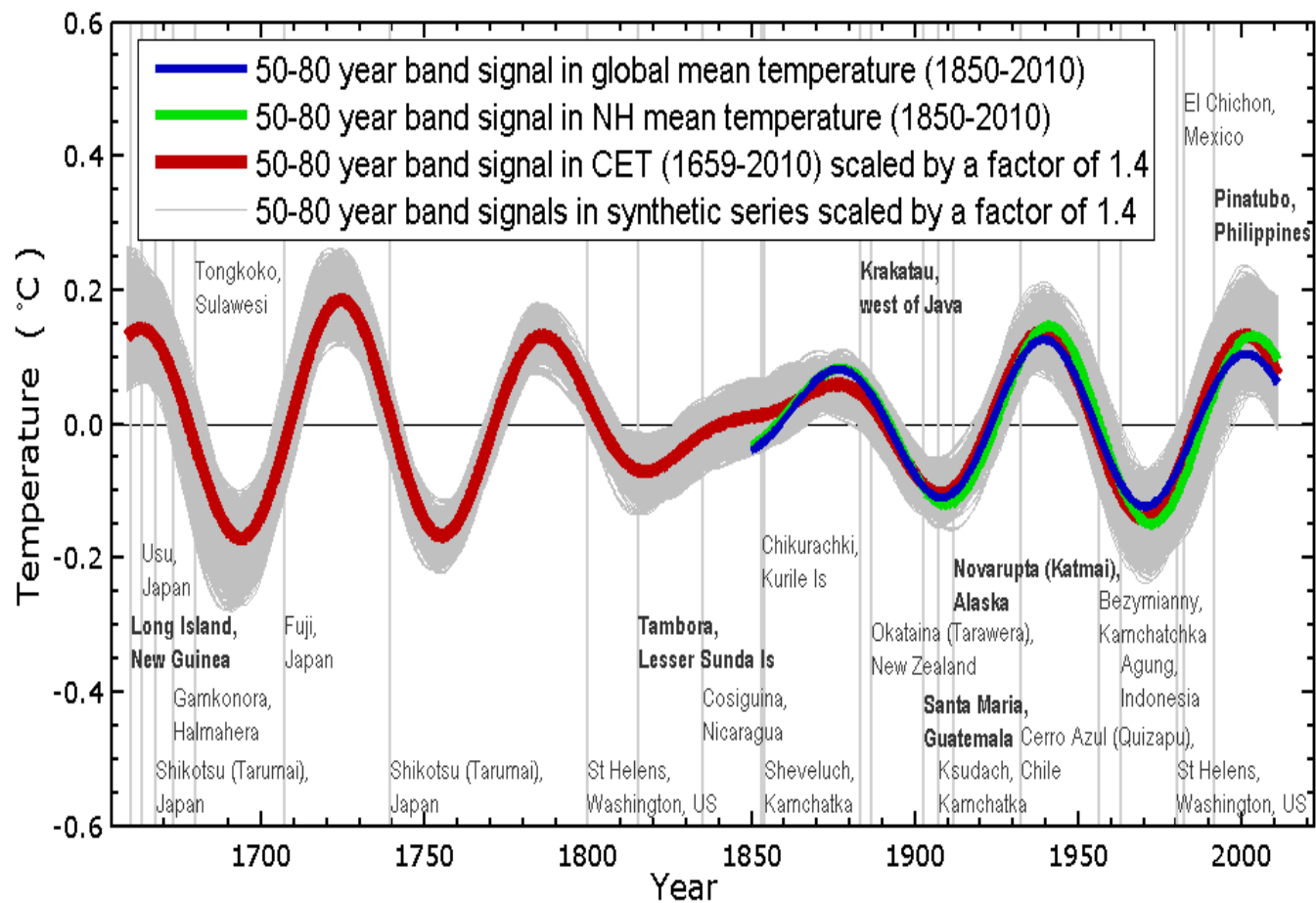


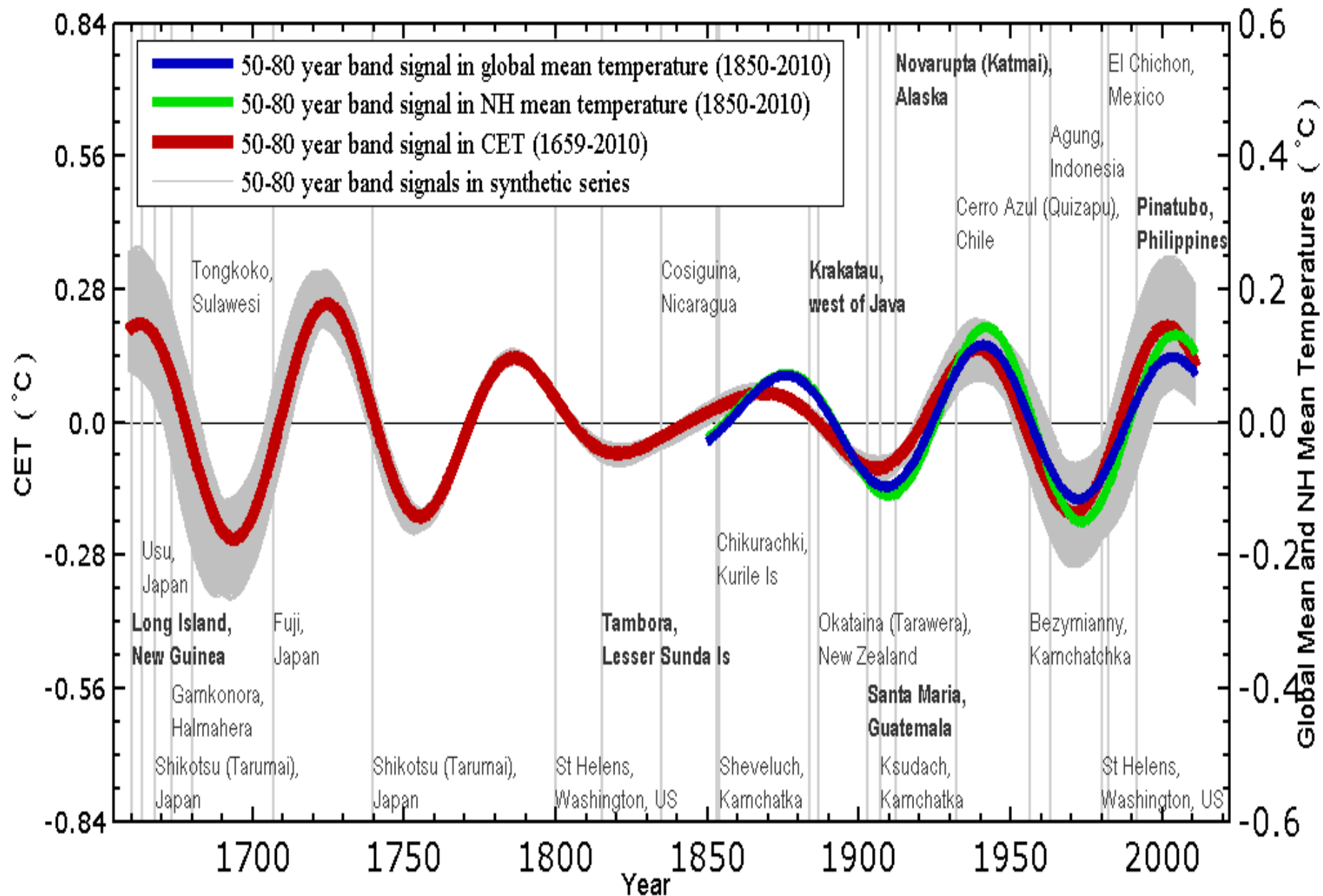




Difference spectrum
between CET and global mean
during overlap.
40-year peak has no global counterpart.







The previous figure

- The grey curves are from random synthetic time series of much longer span. The range quantifies edge-effect errors.
- Not aligned with volcano eruptions.
- Middle cycle small.

Conclusion

- The 2.5 cycles of the multi-decadal oscillation that were found in the global mean temperature is likely part of a recurrent oscillation extending at least to the Little Ice Age, is likely natural, and quasi-periodic with 70-year period.
- The observed episodes of warming and cooling in history can now be explained (next two slides).
- A more controversial conclusion: the anthropogenic warming rate during the early 20th century can be detected and it is no different than during the second half. The increasing anthropogenic aerosols likely masked the true greenhouse warming rate during the second half.

Conclusion (conti.)

- Accepting that the AMO is real and recurrent allows a more consistent and coherent explanation of many observed multidecadal episodes of warming and cooling in history. Previously different explanation is given for each episode:

Recent “stalling” of warming of last 20 years: Kauffmann et al (2011): coal burning in emerging China. Solomon et al (2010): increase in stratospheric water. Solomon et al (2011): variable background stratospheric aerosol. Swanson and Tsonis (2009): climate regime shift.

Early 20th Century Warming: Scafetta and West (2005): solar forced. Wood et al (2010): A singular event of internal variability.

Cooling period in the 70s and 80s: Rind and Overpeck (1993): enhanced aerosols.

Similarly for preindustrial episodes, such as the Dalton Minimum...

This is our last argument: the Occam’s razor argument

EEMD: Low-frequency component (last 3 IMFs)

