Contemporary Climate Change: How do we know what we know?

1. **Detection of Climate Change**

   (a) In the reading and in lab this week we discussed the "global average temperature anomaly" (GATA). Briefly explain how this quantity is defined and how it is calculated, given measurements of temperature from thermometers at various locations on Earth.

   (b) Pointing to specific places on the graph of GATA[1] 1850–present (see figures on next pages), comment on: (i) how the methodological *uncertainty* in the estimate of the GATA has changed over time (consider for example the comparison of the values from independent groups; try to give quantitative estimates) and, (ii) why the uncertainty might have changed in this way.

   (c) Pointing to specific places on the graph, comment on: (i) the natural variability in the *value* of the Earth's temperature (Can you give a quantitative estimate for the value of this variabilty in °C?), and (ii) which features of the data cannot be explained by "natural variability."

   (d) Consider now the longer-term temperature graph — including both human thermometer measurements since 1850, and geological "temperature proxy" measurements since 25,000 years ago — comment again on the "natural variability" of Earth's temperature, and specifically how we should interpret the change in GATA since 1970.

2. **Attribution of Climate Change** Scientists in the "working group" for *the physical scientific basis of climate change*[2] within the Intergovernmental Panel on Climate Change (IPCC), have use the terminology "Detection and attribution" of climate change[3]. Problem (1.) addressed the question of detection: Has the climate changed in a statistical sense, i.e., outside of the bounds of instrumental and methodological uncertainty, and natural variation? (I think your answer to that question is "yes.") Here we consider the *attribution* question: To what can we attribute these changes; what is their cause? This is often stated more specifically as: Can the detected increase in GATA be confidently attributed to human greenhouse gas production?

   (a) Consider the information presented in the lecture slides (see "Class Slides" on Blackboard, possibly supplemented by Nadir Jeevanjee's original talk). State and briefly explain 2–3 pieces of evidence that support the argument that our warming climate can indeed be attributed to greenhouse gas (primarily CO_2) production.

   (b) Consider the 2008 Geophysical Research Letters paper by Lean et. al. [4], whose abstract and first two figures are shown on a later page. (i) What do they mean by a "robust multivariate analysis"? (ii) What is the connection between the data shown in Figure 1 and the overplotted green line on the temperature graph of Figure 2? (iii) What is the overall conclusion of this analysis?

---

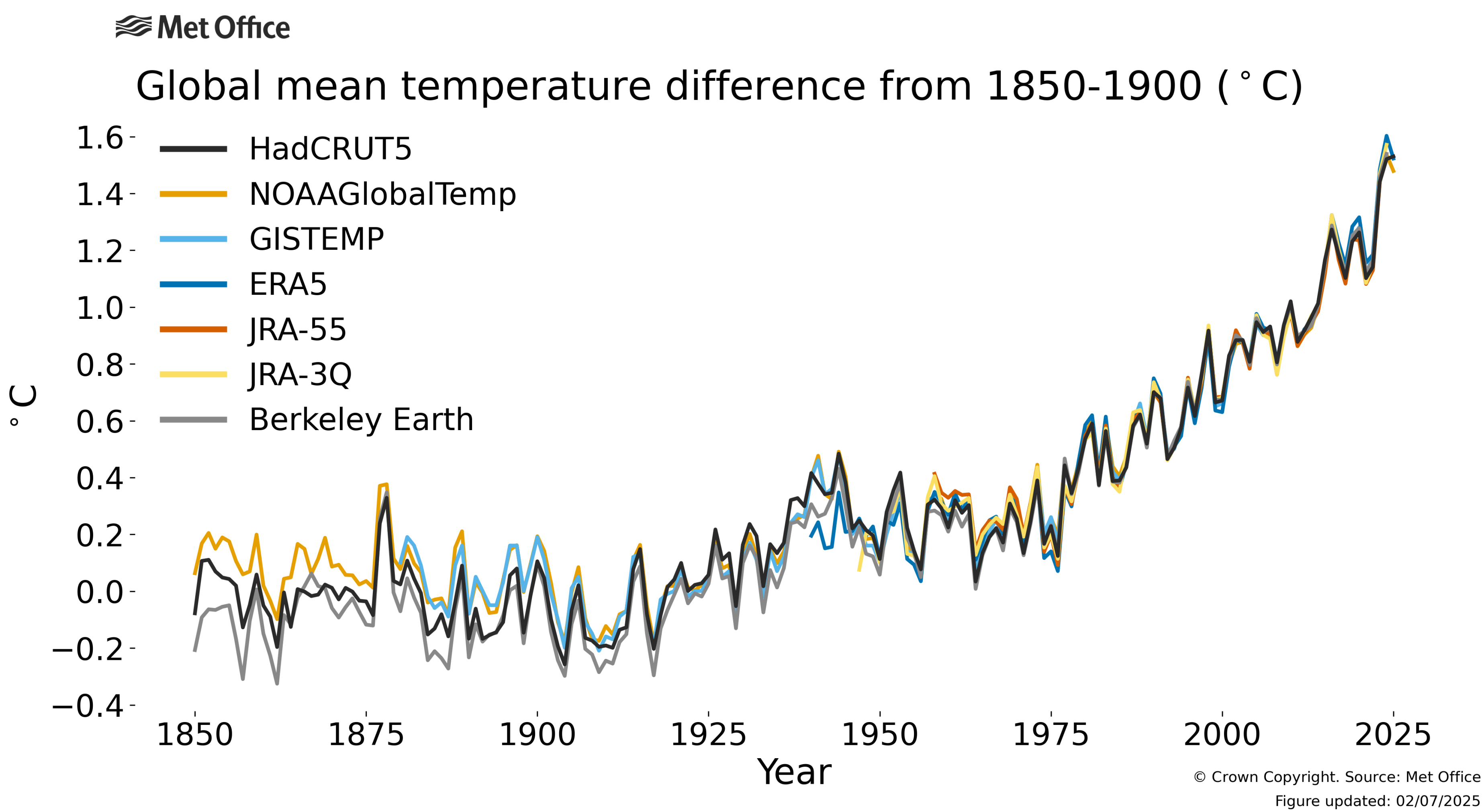
[1]In the figure it is called the "global mean temperature difference."

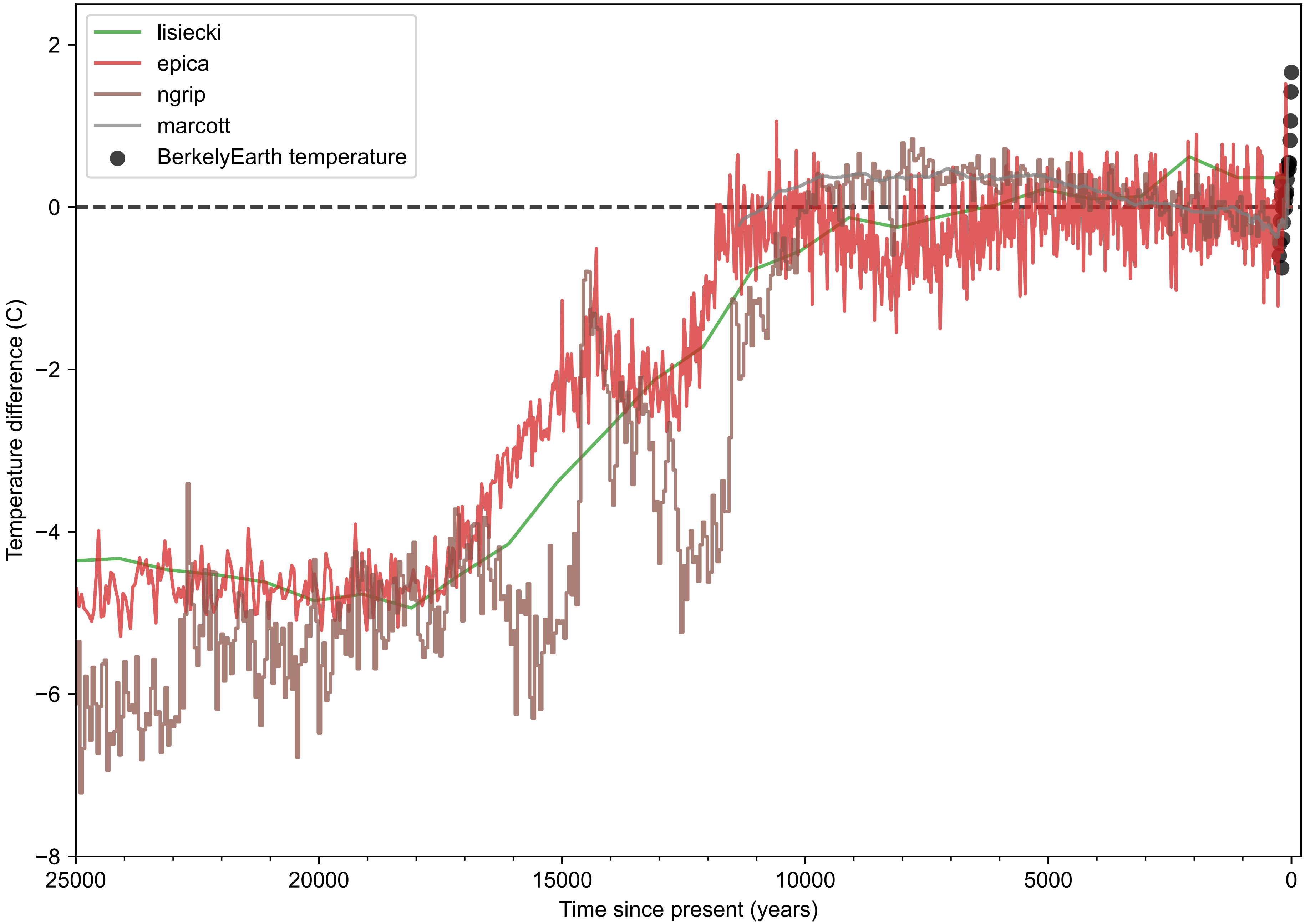
[2]There are two other working groups in the IPCC: WG2 asseses the vulnerability of socioeconomic and natural systems to the effects of climate change, and WG3 assesses options for mitigating climate change.

[3]See a complete definition and explanation of the terminology in the 2007 WG1 report here, as well as the AR5 (2018) report.

[4]From Lean et. al. *How natural and anthropogenic influences alter global and regional surface temperatures: 1889 to 2006* (Geophys Res Lett 2008)

(c) There is another interesting piece of evidence that allows us to attribute warming to greenhouse gas emissions, which is often called the "human fingerprint" of temperature change. (i) Read the abstract of Santer et al (PNAS 2023) linked on Blackboard and describe what the effect is. (ii) Using Figure 1 of their paper, discuss how they have observed the effect.


Met Office
Global mean temperature difference from 1850-1900 (°C)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
°C
HadCRUT5
NOAAGlobalTemp
GISTEMP
ERA5
JRA-55
JRA-3Q
Berkeley Earth
1850
1875
1900
1925
1950
1975
2000
2025
Year
© Crown Copyright. Source: Met Office
Figure updated: 02/07/2025


lisiecki
epica
ngrip
marcott
BerkelyEarth temperature
Temperature difference (C)
2
0
−2
−4
−6
−8
25000
20000
15000
10000
5000
0
Time since present (years)

Geophysical Research Letters

Climate | Free Access

How natural and anthropogenic influences alter global and regional surface temperatures: 1889 to 2006

Judith L. Lean, David H. Rind

First published: 16 September 2008 | https://doi.org/10.1029/2008GL034864 | Citations: 280

Abstract

[1] To distinguish between simultaneous natural and anthropogenic impacts on surface temperature, regionally as well as globally, we perform a robust multivariate analysis using the best available estimates of each together with the observed surface temperature record from 1889 to 2006. The results enable us to compare, for the first time from observations, the geographical distributions of responses to individual influences consistent with their global impacts. We find a response to solar forcing quite different from that reported in several papers published recently in this journal, and zonally averaged responses to both natural and anthropogenic forcings that differ distinctly from those indicated by the Intergovernmental Panel on Climate Change, whose conclusions depended on model simulations. Anthropogenic warming estimated directly from the historical observations is more pronounced between 45°S and 50°N than at higher latitudes whereas the model-simulated trends have minimum values in the tropics and increase steadily from 30 to 70°N.

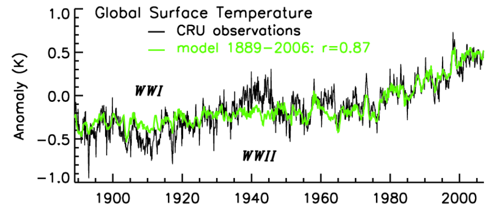


Figure 1. Compared with the CRU monthly mean global temperature time series (hadcrut3vcgl) is an empirical model obtained from multiple regression for the period from 1889 to 2006, inclusive. The value of r is the correlation coefficient for the global temperature observations and empirical model. Largest differences occur at the times of the two World Wars when observations were sparse.

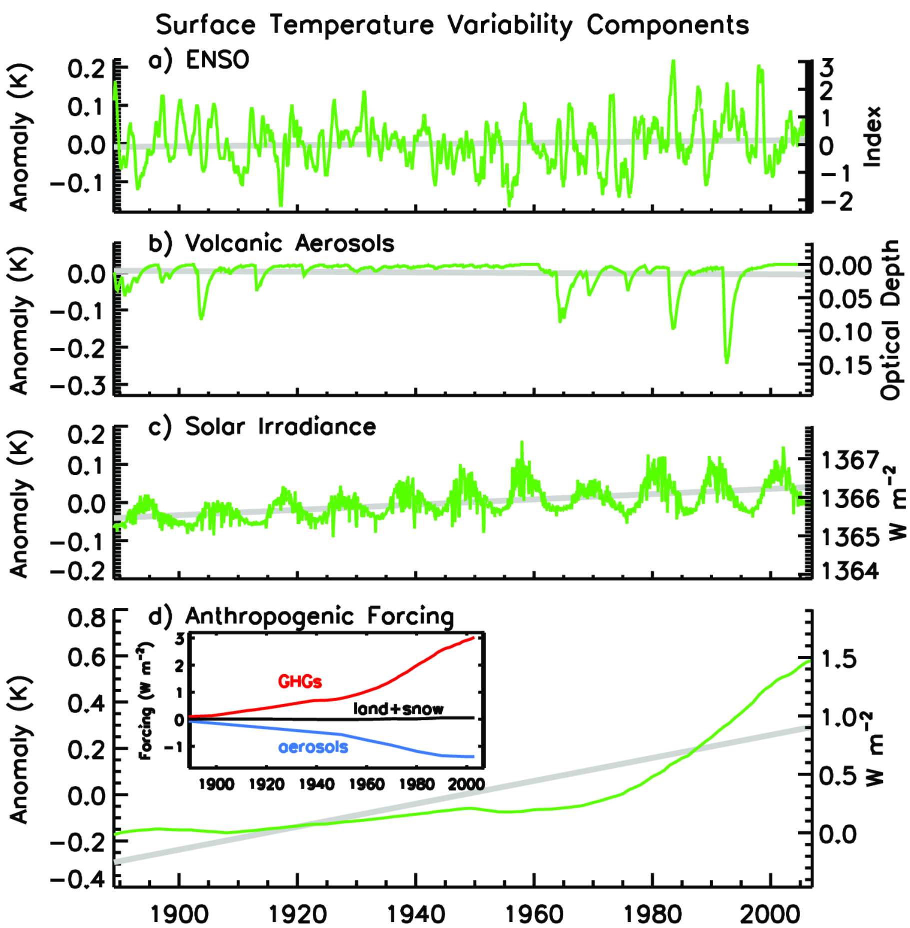


Figure 2. Reconstructions of the contributions to monthly mean global surface temperatures by individual natural and anthropogenic influences (at appropriate lags) are shown. The right hand ordinates give the native scales of each influence and the left hand ordinates give the corresponding temperature change determined from the multiple regression analysis. The grey lines are trends for the whole interval. The inset in Figure 2d shows the individual greenhouse gases, tropospheric aerosols and the land surface plus snow albedo components that combine to give the net anthropogenic forcing.

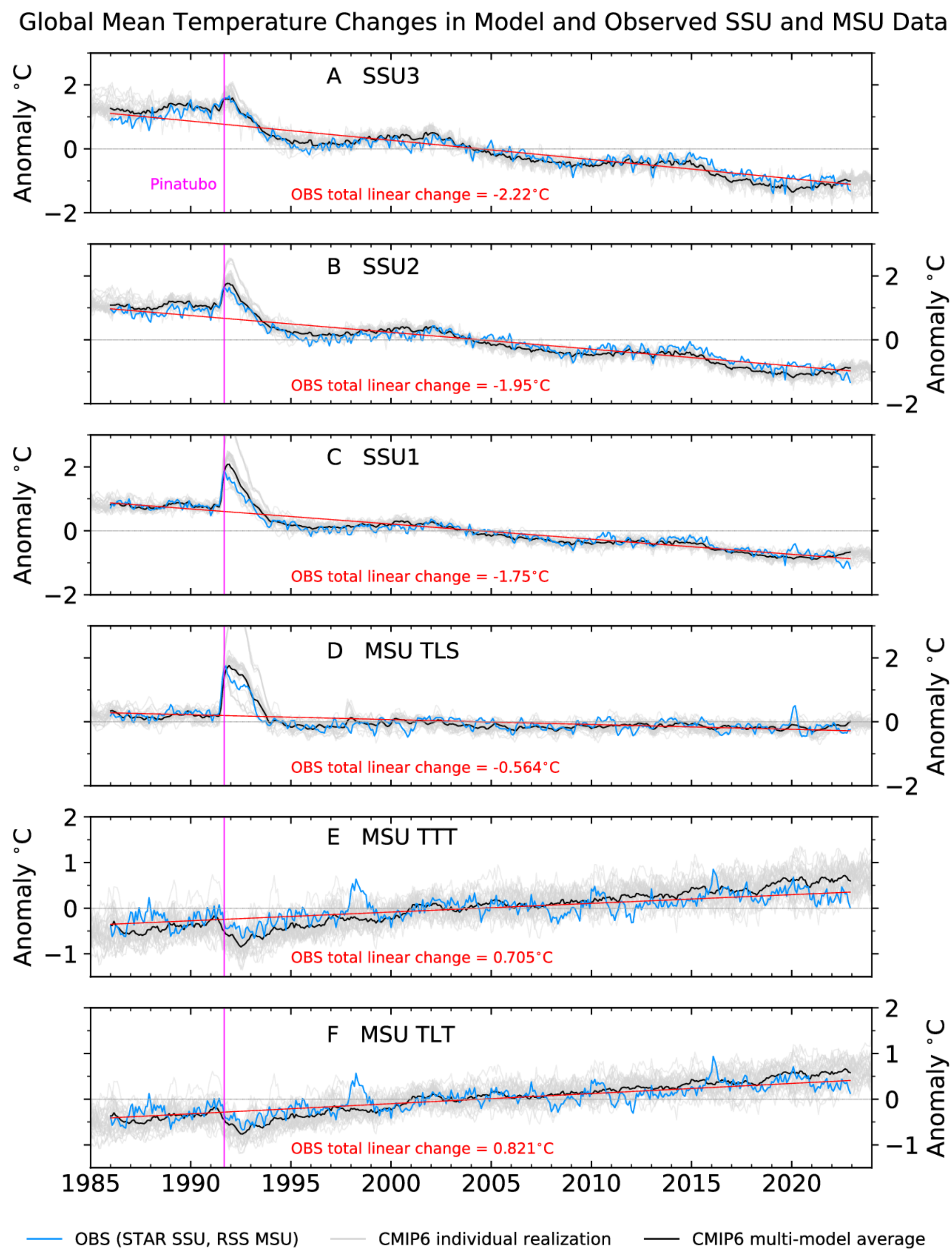


Fig. 1. Observed and simulated changes in global-mean monthly mean temperature in six atmospheric layers. Results are temperatures from channels 3, 2, and 1 of the Stratospheric Sounding Unit (SSU; panels *A*–*C*) (27), lower stratospheric temperature from the Microwave Sounding Unit (MSU TLS; panel *D*), MSU total tropospheric temperature (TTT; panel *E*), and MSU lower tropospheric temperature (TLT; panel *F*) (25). The peaks of the weighting functions for these six layers are at *ca.* 45, 38, 30, 19, 5.6, and 3.1 km above the Earth's surface (respectively). Results are anomalies relative to climatological monthly means over 1986 to 2022. Model simulations are from nine different CMIP6 models and a total of 32 realizations of historical climate change (*Methods* and *SI Appendix*).