



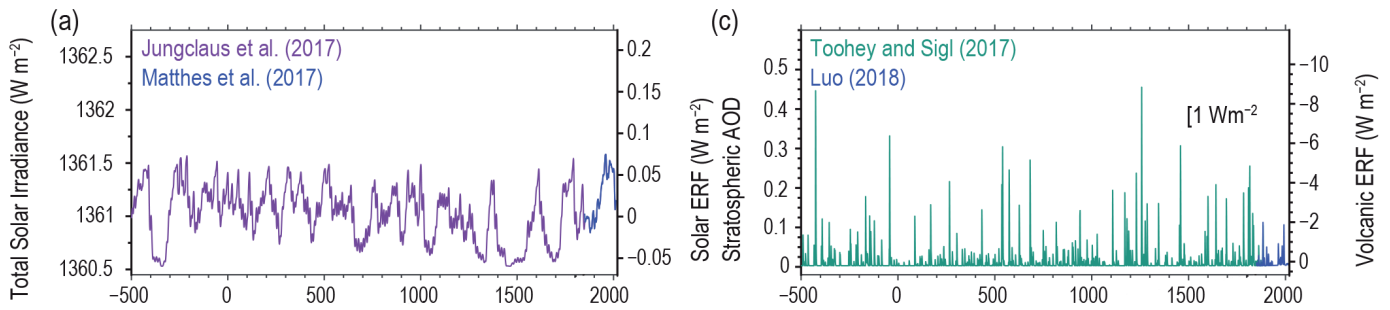
Climate Model Simulations of the Last 1,000 Years

Recent and unprecedented warming can be explained only by human-caused increases in greenhouse gases, not by natural factors.

Paleoclimate records of the last 1,000 years indicate that climate varies naturally due to factors such as solar and volcanic activity. These factors are called "forcings" because they drive or "force" the climate system to change. Could these forcings, rather than the human-caused rise in greenhouse gases, have caused global warming since the 19th century? One method to study past, present, and future effects of these forcings is to use models of the full climate system.

Climate models are computer programs that apply physical laws to calculate how climate has changed in the past and may change in the future. Models range from relatively simple ones, which represent only the most essential processes at a coarse spatial resolution, to complex ones, which include many additional important interactions between the atmosphere, ocean, sea ice, and land surface operating at regional scales. These models require input information about forcings such as solar variations, volcanic activity, and greenhouse gas concentrations, usually in the form of time series. They compute temperature, precipitation, and other climate variables. Modeling studies support the results of the proxy-based reconstructions and, more importantly, examine the contribution of higher greenhouse gas concentrations to global warming.

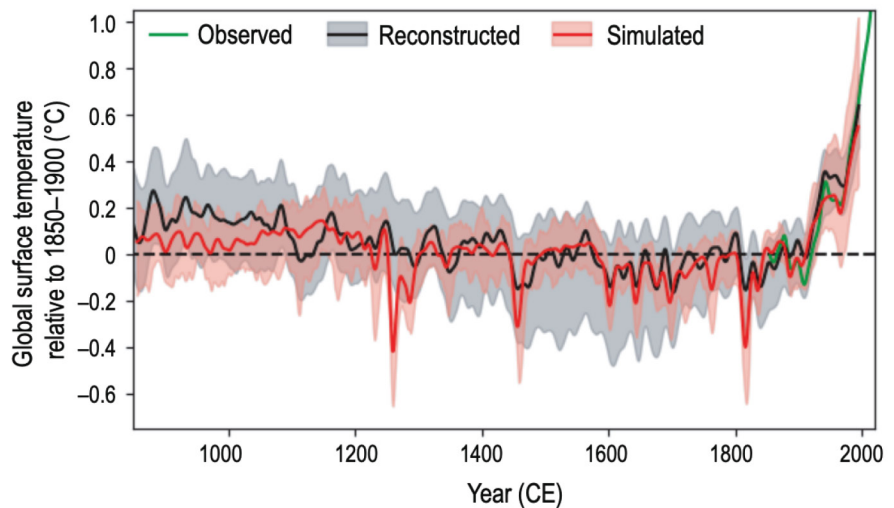
Scientists use various proxies to infer how these forcings have changed over time. The concentrations of the isotopes ^{14}C and ^{10}Be , which are preserved in tree rings and ice cores, respectively, depend on solar activity and provide a measurement of this forcing. Volcanic eruptions are preserved as layers of sulfate (SO_4^{2-}) in ice cores. The concentration of greenhouse gases, such as CO_2 , can be measured in air bubbles trapped in ice cores. The figure below shows time series of volcanic and solar forcings, expressed in terms of Watts (a flux of energy) per square meter of Earth's surface. Positive forcing warms Earth, while negative forcing cools it.



Reconstructions of total solar irradiance (10-year running average) from radiocarbon measurements before 1850 (purple) and sunspot observations after 1850 (blue) and volcanic forcing from sulfate measurements in ice cores before 1900 (green) and satellite and ground-based optical observations after 1850 (blue). ERF = Effective Radiative Forcing (an estimate of the combined effect of the forcing itself plus any follow-on adjustments by the atmosphere and surface); AOD = Aerosol Optical Depth (a measure of the amount of sunlight that is prevented from reaching the ground by aerosol particles). Graphic is from the [Intergovernmental Panel on Climate Change Sixth Assessment Report](#).

Simulations of the last 1,000 years have been completed with several different models. Although some of the details are different, they all show several similar trends in global climate: relative warmth before the 14th century followed by cold periods between the 15th and early 19th centuries.

The warming of the 20th century is, given the perspective of the previous millennium, unprecedented. These simulations are within the uncertainty bounds of temperature reconstructions the last 1,000 years, except for some short periods following major volcanic eruptions when forcings are not well-known. Differences between the time series can also be due to the unpredictability of some interactions between the atmosphere, ocean, land surface, and sea ice.



Comparison of simulated, reconstructed, and observed global surface temperature changes (10-year smoothed). Light red and gray bands show 5-95% uncertainty ranges. Graphic is from the [Intergovernmental Panel on Climate Change Sixth Assessment Report](#)

Looking at the relative contributions of these forcings to climate change over the past 1,000 years, scientists have concluded from model simulations that:

- Solar and volcanic forcings have been responsible for some of the variations in global temperature over the past 1,000 years.
- Neither solar nor volcanic forcing can explain the dramatic warming of the 20th century. Changes in these forcings during the 20th century would actually have resulted in a small cooling since 1960.
- Only by adding the human-caused increase in greenhouse gas concentrations are the models able to explain the unprecedented warmth we are currently experiencing.