

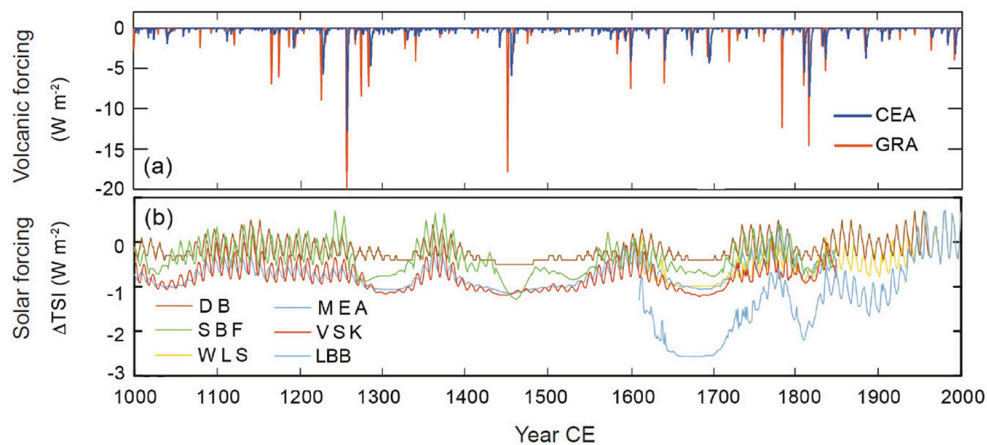
Climate Model Simulations of the Last 1,000 Years

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.

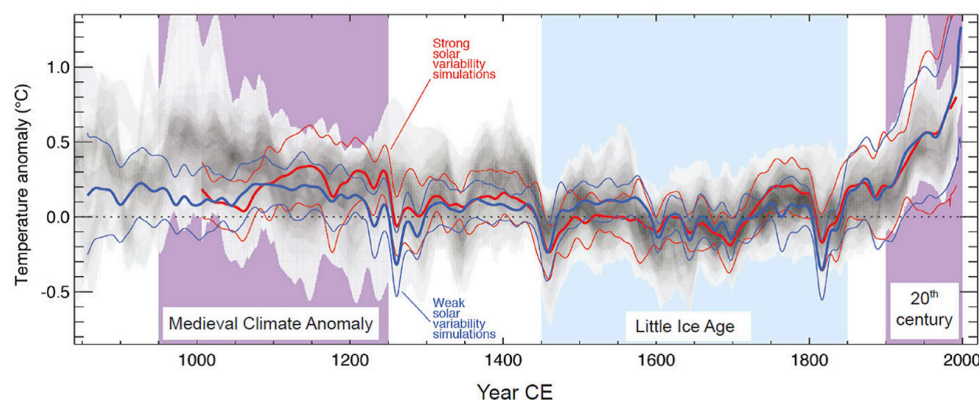
Climate models are computer programs that apply physical laws to calculate how climate has changed in the past and may change in the future. Models range from relatively simple ones, which represent only the most essential processes at a coarse spatial resolution, to complex ones, which include many 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. Proxies do not record these forcings perfectly, and differences between the time series are a result of our inexact knowledge.



Reconstructions of volcanic forcing and total solar irradiance from proxies. Time series sources: CEA = [Crowley and Untermann \(2013\)](#); GRA = Gao et al. (2012); DB = [Delaygue and Bard \(2011\)](#); SBF = [Steinilber et al. \(2009\)](#); WLS = Wang et al. (2005); MEA = [Muscheler et al. \(2007\)](#); VSK = [Vieira et al. \(2011\)](#); LBB = [Lean et al. \(1995\)](#). Graphic from the [Intergovernmental Panel on Climate Change Fifth 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 Northern Hemisphere 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 closely match the paleoclimate record of temperature for the last 1,000 years. Differences between the time series are due to several factors, including uncertainties in the forcing time series, for example whether strong or weak solar forcing is used, and the unpredictability of some interactions between the atmosphere, ocean, land surface, and sea ice.



Comparisons of simulated and reconstructed Northern Hemisphere temperature changes. Simulations are shown by colored lines, thick lines showing the mean of multiple model simulations (using, e.g., models such as [ECHAM](#) and [CSIRO](#)) and thin lines showing the 90% confidence range of this mean. Red lines show models forced by stronger solar variability and blue lines show models forced by weaker solar variability. Reconstructed temperatures are shown by gray shading. All data are expressed as anomalies from their 1500–1850 mean and smoothed with a 30-year filter. Graphic from the [Intergovernmental Panel on Climate Change Fifth 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 Northern Hemisphere 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.