

## Frequently Asked Questions

**FAQ 5.1 | Is the Sun a Major Driver of Recent Changes in Climate?**

*Total solar irradiance (TSI, Chapter 8) is a measure of the total energy received from the sun at the top of the atmosphere. It varies over a wide range of time scales, from billions of years to just a few days, though variations have been relatively small over the past 140 years. Changes in solar irradiance are an important driver of climate variability (Chapter 1; Figure 1.1) along with volcanic emissions and anthropogenic factors. As such, they help explain the observed change in global surface temperatures during the instrumental period (FAQ 5.1, Figure 1; Chapter 10) and over the last millennium. While solar variability may have had a discernible contribution to changes in global surface temperature in the early 20th century, it cannot explain the observed increase since TSI started to be measured directly by satellites in the late 1970s (Chapters 8, 10).*

The Sun's core is a massive nuclear fusion reactor that converts hydrogen into helium. This process produces energy that radiates throughout the solar system as electromagnetic radiation. The amount of energy striking the top of Earth's atmosphere varies depending on the generation and emission of electromagnetic energy by the Sun and on the Earth's orbital path around the Sun.

Satellite-based instruments have directly measured TSI since 1978, and indicate that on average,  $\sim 1361 \text{ W m}^{-2}$  reaches the top of the Earth's atmosphere. Parts of the Earth's surface and air pollution and clouds in the atmosphere act as a mirror and reflect about 30% of this power back into space. Higher levels of TSI are recorded when the Sun is more active. Irradiance variations follow the roughly 11-year sunspot cycle: during the last cycles, TSI values fluctuated by an average of around 0.1%.

For pre-satellite times, TSI variations have to be estimated from sunspot numbers (back to 1610), or from radioisotopes that are formed in the atmosphere, and archived in polar ice and tree rings. Distinct 50- to 100-year periods of very low solar activity—such as the Maunder Minimum between 1645 and 1715—are commonly referred to as grand solar minima. Most estimates of TSI changes between the Maunder Minimum and the present day are in the order of 0.1%, similar to the amplitude of the 11-year variability.

How can solar variability help explain the observed global surface temperature record back to 1870? To answer this question, it is important to understand that other climate drivers are involved, each producing characteristic patterns of regional climate responses. However, it is the combination of them all that causes the observed climate change. Solar variability and volcanic eruptions are natural factors. Anthropogenic (human-produced) factors, on the other hand, include changes in the concentrations of greenhouse gases, and emissions of visible air pollution (aerosols) and other substances from human activities. 'Internal variability' refers to fluctuations within the climate system, for example, due to weather variability or phenomena like the El Niño-Southern Oscillation.

The relative contributions of these natural and anthropogenic factors change with time. FAQ 5.1, Figure 1 illustrates those contributions based on a very simple calculation, in which the mean global surface temperature variation represents the sum of four components linearly related to solar, volcanic, and anthropogenic forcing, and to internal variability. Global surface temperature has increased by approximately  $0.8^\circ\text{C}$  from 1870 to 2010 (FAQ 5.1, Figure 1a). However, this increase has not been uniform: at times, factors that cool the Earth's surface—volcanic eruptions, reduced solar activity, most anthropogenic aerosol emissions—have outweighed those factors that warm it, such as greenhouse gases, and the variability generated within the climate system has caused further fluctuations unrelated to external influences.

The solar contribution to the record of global surface temperature change is dominated by the 11-year solar cycle, which can explain global temperature fluctuations up to approximately  $0.1^\circ\text{C}$  between minima and maxima (FAQ 5.1, Figure 1b). A long-term increasing trend in solar activity in the early 20th century may have augmented the warming recorded during this interval, together with internal variability, greenhouse gas increases and a hiatus in volcanism. However, it cannot explain the observed increase since the late 1970s, and there was even a slight decreasing trend of TSI from 1986 to 2008 (Chapters 8 and 10).

Volcanic eruptions contribute to global surface temperature change by episodically injecting aerosols into the atmosphere, which cool the Earth's surface (FAQ 5.1, Figure 1c). Large volcanic eruptions, such as the eruption of Mt. Pinatubo in 1991, can cool the surface by around  $0.1^\circ\text{C}$  to  $0.3^\circ\text{C}$  for up to three years. *(continued on next page)*

## FAQ 5.1 (continued)

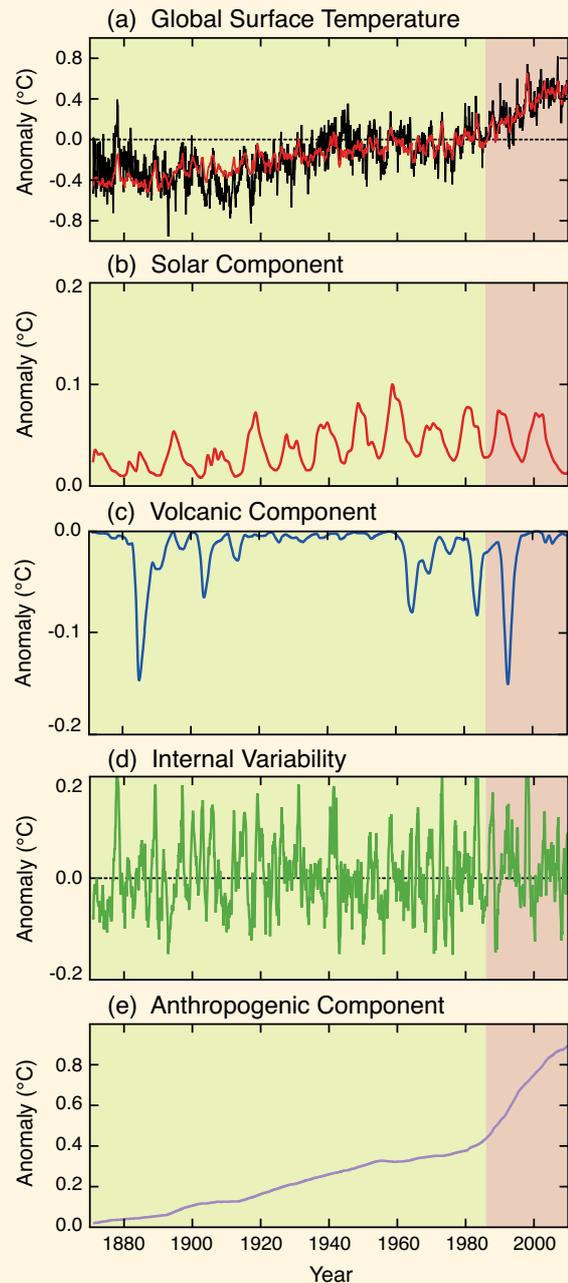
The most important component of internal climate variability is the El Niño Southern Oscillation, which has a major effect on year-to-year variations of tropical and global mean temperature (FAQ 5.1, Figure 1d). Relatively high annual temperatures have been encountered during El Niño events, such as in 1997–1998.

The variability of observed global surface temperatures from 1870 to 2010 (Figure 1a) reflects the combined influences of natural (solar, volcanic, internal; FAQ 5.1, Figure 1b–d) factors, superimposed on the multi-decadal warming trend from anthropogenic factors (FAQ 5.1, Figure 1e).

Prior to 1870, when anthropogenic emissions of greenhouse gases and aerosols were smaller, changes in solar and volcanic activity and internal variability played a more important role, although the specific contributions of these individual factors to global surface temperatures are less certain. Solar minima lasting several decades have often been associated with cold conditions. However, these periods are often also affected by volcanic eruptions, making it difficult to quantify the solar contribution.

At the regional scale, changes in solar activity have been related to changes in surface climate and atmospheric circulation in the Indo-Pacific, Northern Asia and North Atlantic areas. The mechanisms that amplify the regional effects of the relatively small fluctuations of TSI in the roughly 11-year solar cycle involve dynamical interactions between the upper and the lower atmosphere, or between the ocean sea surface temperature and atmosphere, and have little effect on global mean temperatures (see Box 10.2).

Finally, a decrease in solar activity during the past solar minimum a few years ago (FAQ 5.1, Figure 1b) raises the question of its future influence on climate. Despite uncertainties in future solar activity, there is *high confidence* that the effects of solar activity within the range of grand solar maxima and minima will be much smaller than the changes due to anthropogenic effects.



**FAQ 5.1, Figure 1** | Global surface temperature anomalies from 1870 to 2010, and the natural (solar, volcanic, and internal) and anthropogenic factors that influence them. (a) Global surface temperature record (1870–2010) relative to the average global surface temperature for 1961–1990 (black line). A model of global surface temperature change (a: red line) produced using the sum of the impacts on temperature of natural (b, c, d) and anthropogenic factors (e). (b) Estimated temperature response to solar forcing. (c) Estimated temperature response to volcanic eruptions. (d) Estimated temperature variability due to internal variability, here related to the El Niño-Southern Oscillation. (e) Estimated temperature response to anthropogenic forcing, consisting of a warming component from greenhouse gases, and a cooling component from most aerosols.