

## Frequently Asked Questions

**FAQ 11.2 | How Do Volcanic Eruptions Affect Climate and Our Ability to Predict Climate?**

Large volcanic eruptions affect the climate by injecting sulphur dioxide gas into the upper atmosphere (also called stratosphere), which reacts with water to form clouds of sulphuric acid droplets. These clouds reflect sunlight back to space, preventing its energy from reaching the Earth's surface, thus cooling it, along with the lower atmosphere. These upper atmospheric sulphuric acid clouds also locally absorb energy from the Sun, the Earth and the lower atmosphere, which heats the upper atmosphere (see FAQ 11.2, Figure 1). In terms of surface cooling, the 1991 Mt Pinatubo eruption in the Philippines, for example, injected about 20 million tons of sulphur dioxide ( $\text{SO}_2$ ) into the stratosphere, cooling the Earth by about  $0.5^\circ\text{C}$  for up to a year. Globally, eruptions also reduce precipitation, because the reduced incoming shortwave at the surface is compensated by a reduction in latent heating (i.e., in evaporation and hence rainfall).

For the purposes of predicting climate, an eruption causing significant global surface cooling and upper atmospheric heating for the next year or so can be expected. The problem is that, while a volcano that has become more active can be detected, the precise timing of an eruption, or the amount of  $\text{SO}_2$  injected into the upper atmosphere and how it might disperse cannot be predicted. This is a source of uncertainty in climate predictions.

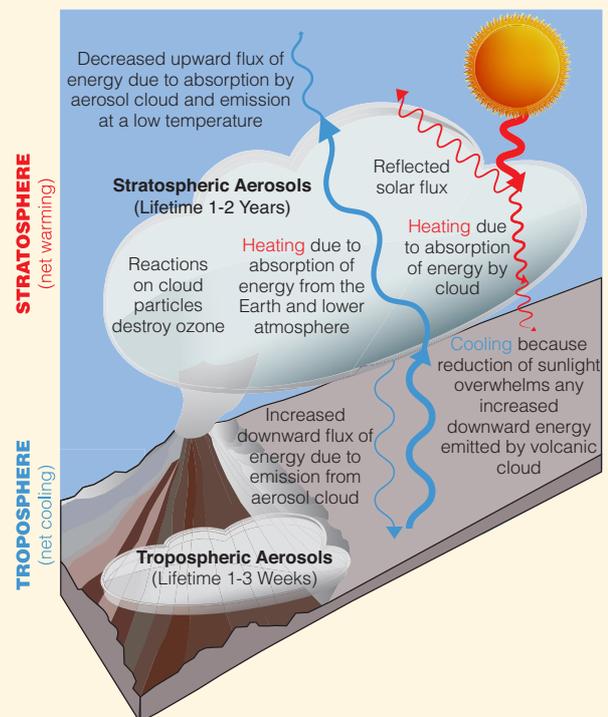
Large volcanic eruptions produce lots of particles, called ash or tephra. However, these particles fall out of the atmosphere quickly, within days or weeks, so they do not affect the global climate. For example, the 1980 Mount St. Helens eruption affected surface temperatures in the northwest USA for several days but, because it emitted little  $\text{SO}_2$  into the stratosphere, it had no detectable global climate impacts. If large, high-latitude eruptions inject sulphur into the stratosphere, they will have an effect only in the hemisphere where they erupted, and the effects will only last a year at most, as the stratospheric cloud they produce only has a lifetime of a few months.

Tropical or subtropical volcanoes produce more global surface or tropospheric cooling. This is because the resulting sulphuric acid cloud in the upper atmosphere lasts between one and two years, and can cover much of the globe. However, their regional climatic impacts are difficult to predict, because dispersion of stratospheric sulphate aerosols depends heavily on atmospheric wind conditions at the time of eruption. Furthermore, the surface cooling effect is typically not uniform: because continents cool more than the ocean, the summer monsoon can weaken, reducing rain over Asia and Africa. The climatic response is complicated further by the fact that upper atmospheric clouds from tropical eruptions also absorb sunlight and heat from the Earth, which produces more upper atmosphere warming in the tropics than at high latitudes.

The largest volcanic eruptions of the past 250 years stimulated scientific study. After the 1783 Laki eruption in Iceland, there were record warm summer temperatures in Europe, followed by a very cold winter. Two large eruptions, an unidentified one in 1809, and the 1815 Tambora eruption caused the 'Year Without a Summer' in 1816. Agricultural failures in Europe and the USA that year led to food shortages, famine and riots.

The largest eruption in more than 50 years, that of Agung in 1963, led to many modern studies, including observations and climate model calculations. Two subsequent large eruptions, El Chichón in 1982 and Pinatubo in 1991, inspired the work that led to our current understanding of the effects of volcanic eruptions on climate.

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**FAQ 11.2, Figure 1 |** Schematic of how large tropical or sub-tropical volcanoes impact upper atmospheric (stratospheric) and lower atmospheric (tropospheric) temperatures.

## FAQ 11.2 (continued)

Volcanic clouds remain in the stratosphere only for a couple of years, so their impact on climate is correspondingly short. But the impacts of consecutive large eruptions can last longer: for example, at the end of the 13th century there were four large eruptions—one every ten years. The first, in 1258 CE, was the largest in 1000 years. That sequence of eruptions cooled the North Atlantic Ocean and Arctic sea ice. Another period of interest is the three large, and several lesser, volcanic events during 1963–1991 (see Chapter 8 for how these eruptions affected atmospheric composition and reduced shortwave radiation at the ground).

Volcanologists can detect when a volcano becomes more active, but they cannot predict whether it will erupt, or if it does, how much sulphur it might inject into the stratosphere. Nevertheless, volcanoes affect the ability to predict climate in three distinct ways. First, if a violent eruption injects significant volumes of sulphur dioxide into the stratosphere, this effect can be included in climate predictions. There are substantial challenges and sources of uncertainty involved, such as collecting good observations of the volcanic cloud, and calculating how it will move and change during its lifetime. But, based on observations, and successful modelling of recent eruptions, some of the effects of large eruptions can be included in predictions.

The second effect is that volcanic eruptions are a potential source of uncertainty in our predictions. Eruptions cannot be predicted in advance, but they will occur, causing short-term climatic impacts on both local and global scales. In principle, this potential uncertainty can be accounted for by including random eruptions, or eruptions based on some scenario in our near-term ensemble climate predictions. This area of research needs further exploration. The future projections in this report do not include future volcanic eruptions.

Third, the historical climate record can be used, along with estimates of observed sulphate aerosols, to test the fidelity of our climate simulations. While the climatic response to explosive volcanic eruptions is a useful analogue for some other climatic forcings, there are limitations. For example, successfully simulating the impact of one eruption can help validate models used for seasonal and interannual predictions. But in this way not all the mechanisms involved in global warming over the next century can be validated, because these involve long term oceanic feedbacks, which have a longer time scale than the response to individual volcanic eruptions.

### 11.3.6.3 Synthesis of Near-term Projections of Global Mean Surface Air Temperature

Figure 11.25 provides a synthesis of near-term projections of global mean surface air temperature (GMST) from CMIP5, CMIP3 and studies that have attempted to use observations to quantify projection uncertainty (see Section 11.3.2.1). On the basis of this evidence, an attempt is made here to assess a *likely* range for GMST in the period 2016–2035. Such an overall assessment is not straightforward. The following points must be taken into account:

1. No likelihoods are associated with the different RCP scenarios. For this reason, previous IPCC Assessment Reports have only presented projections that are conditional on specific scenarios. Here we attempt a broader assessment across all four RCP scenarios. This is possible only because, as discussed in Section 11.3.6.1, *near-term* projections of GMST are not especially sensitive to these different scenarios.
2. In the near term it is expected that increases in GMST will be driven by past and future increases in GHG concentrations and future decreases in anthropogenic aerosols, as found in all the RCP scenarios. Figure 11.25c shows that in the near term the CMIP3 projections based on the SRES scenarios are generally cooler than the CMIP5 projections based on the RCP scenarios. This difference is at least partly attributable to higher aerosol concentrations in the SRES scenarios (see Section 11.3.6.1).
3. The CMIP3 and CMIP5 projections are ensembles of opportunity, and it is explicitly recognized that there are sources of uncertainty not simulated by the models. Evidence of this can be seen by comparing the Rowlands et al. (2012) projections for the A1B scenario, which were obtained using a very large ensemble in which the physics parameterizations were perturbed in a single climate model, with the corresponding raw multi-model CMIP3 projections. The former exhibit a substantially larger *likely* range than the latter. A pragmatic approach to addressing this issue, which was used in the AR4 and is also used in Chapter 12, is to consider the 5 to 95% CMIP3/5 range as a '*likely*' rather than '*very likely*' range.
4. As discussed in Section 11.3.6.2, the RCP scenarios assume no underlying trend in total solar irradiance and no future volcanic eruptions. Future volcanic eruptions cannot be predicted and there is *low confidence* in projected changes in solar irradiance (Chapter 8). Consequently the possible effects of future changes in natural forcings are excluded from the assessment here.