13: Volcanoes and their effect on climate

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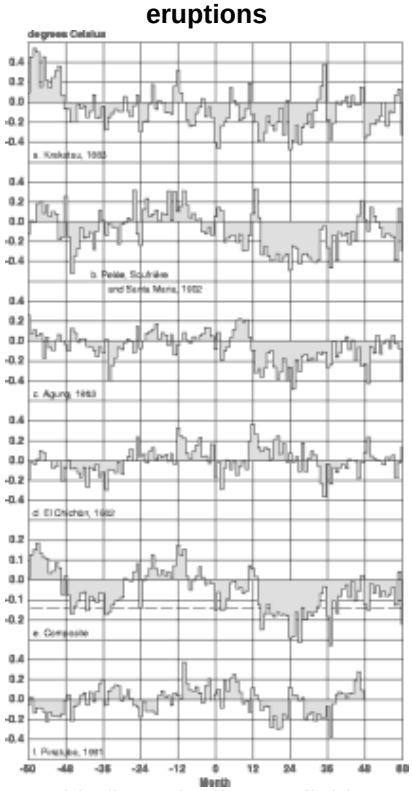
It has been known for some time that explosive volcanic eruptions can have a major influence on global and regional climate. The most well known eruption of recent times was Tambora, Indonesia, which exploded in 1815. The following summer became known as the "the year without a summer" in many parts of the Northern Hemisphere.

Only certain types of volcanic eruption will have an effect upon the climate. The eruption has to be of sufficient magnitude to emit very large quantities of material into the lower stratosphere (20-25km above the Earth's surface) and, for maximum impact, it should be in lower latitudes. With these conditions met, the particles in the lower stratosphere spread to form a "veil" over the whole planet. This veil then affects the amount of the sun's energy which reaches the Earth's surface.
Mt. St. Helens, which erupted in 1980, was large, but the main bulk of the ejected material emerged at a 45° angle rather than directly upwards, so wasn't able to enter the stratosphere. Vast amounts of material were deposited over the northern plains states of the US, but all the finer material was washed out by precipitation processes within a few weeks.

Benjamin Franklin, in 1783, first postulated that major volcanic eruptions affect climate, after the eruption of the Laki volcano in Iceland. Ironically, most of the ejected material from this eruption remained in the lower parts of the atmosphere, so Franklin had the right idea but the wrong volcano.

Figure 1 - global average temperatures before and after eruptions



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The Volcanic Effect on Climate

Past volcanic events provide a guide to the impact of major eruptions.

In the upper four panels, Figure 1 shows the effects on global average temperatures of four low-latitude eruptions between the 1880s and 1980s. Whilst the individual eruptions show a lot of variability in the timing of the cooling (partly because the eruptions occur at different times of the year) the average of the four, labelled "composite" in the fifth panel, shows significant cooling for many of the months in the subsequent three years (particularly the boreal summers).

Major eruptions in lower latitudes are more climatically effective as the veil is capable of reaching the higher latitudes of both hemispheres, because of the nature of the atmospheric circulation. Material from major eruptions in the middle-to-high latitudes of each hemisphere tends to remain poleward of the eruption latitude. Major Icelandic or Alaskan/Aleutian/Kamchatkan eruptions, therefore, only influence the higher latitudes of the Northern Hemisphere.

Figure 1 also includes a similar hemispheric temperature history for the period before and after the Pinatubo eruption in 1991. The northern summers of 1992 and 1993 were the coolest of the period from 1986 to the present.

The Spatial Patterns of Temperature Change

Whilst such large-scale averages provide good tests of climate models and of our theoretical understanding of the physical effects, forecasts like this are of little use unless we can also give some spatial detail.

Figure 2 - spatial pattern of cooling

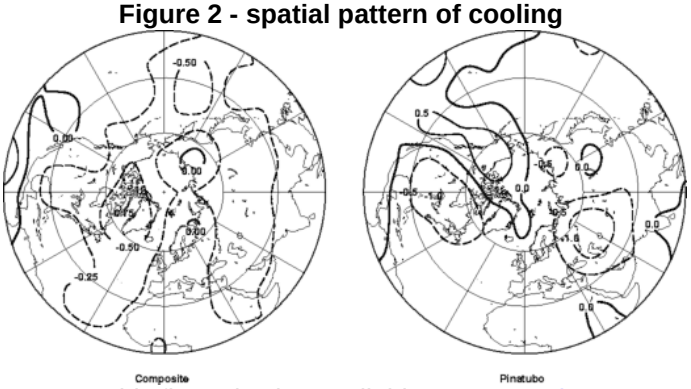

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Figure 2 shows the spatial pattern of the cooling for the two extended summer seasons (March-October) following each eruption (i.e. the two years after each eruption). One plot is for the same four-volcano composite, the other for Pinatubo. Cooling tends to be most marked over the continents and at middle-to-high latitudes, with the greatest effects over eastern North America and northern and central Asia. Both Figures 1 and 2 are discussed in more detail in Kelly et al. (1996).

Have Volcanic Eruptions Occurred More Frequently Recently?

The 20th century has only seen five major tropical eruptions. Another five have occurred at higher latitudes, giving a large climate-shaping eruption about every ten years. The eruptions have, however, not occurred at regular intervals. They all took place before 1915 or after 1956. The in-between years were devoid of major eruptions and this has probably been a contributing factor to the global warming early this century, between 1920 and 1945 - though volcanic effects can only be a part of the reason as northern hemispheric cooling began at least 10 years before the eruption frequency increased after 1956.

Was the 20th Century Unusual for Eruptions?

We have records back many centuries in some regions - millennia for Italy and Japan because of the existence of written records - but in many regions such as the North Pacific and large parts of the tropics direct evidence is limited. Fortunately, the material in the veils eventually falls to Earth and an excellent record is preserved on the ice caps of Greenland and Antarctica. We may not know where the eruption occurred but the frequency can be compared over several millennia.

These data show that the 20th century has seen more eruptions than some centuries of this millennium but less than in the 16th/17th/19th centuries. Volcanoes have probably, therefore,

made a contribution to the cooler temperatures of these centuries, relative to the 20th century (see The Millenial Temperature Record).

The Eruption of Mt Pinatubo, Philippines, June 1991

The eruption of Mt. Pinatubo in the Philippines in June 1991 provided an excellent opportunity to study the response of the climate system to a major volcanic event.

Earlier work, from the 1960s onwards, suggested that when eruption clouds reach the lower stratosphere (about 20-25km aloft) the dust spreads around over subsequent months forming a veil over the Earth. The veil slightly reduces the amount of incoming solar radiation reaching the surface, causing a cooling. The effects in the Northern Hemisphere are greatest in the summer season because, then, the sun's radiation levels are at their maximum. Cooling is most pronounced over land regions because the thermal inertia is much smaller than over the oceans. The effects in the Southern Hemisphere are less and tend to spread out over a longer period.

Shortly after the eruption, when it was clearly evident that the eruption was of sufficiently large magnitude to eject material into the lower stratosphere, scientists, led by Jim Hansen at NCAR in the US, ran several model integrations from the period just before the eruption to about 5 years later.

The results showed good agreement with average surface temperatures over the Northern Hemisphere, highlighting the cooling in the northern summers of 1992 and 1993. After that time, both the model and the observations returned to normal levels, continuing the slight upward trend of temperatures over the 1980-2000 period.

In many respects, this study can be considered as the first long-term forecast several seasons ahead.

Impact apart, the importance of volcanic events is that forecasts can be tested relatively quickly over the subsequent few years. Other natural (e.g. solar output changes) and anthropogenic (increases in greenhouse gases and sulphate aerosols) operate on decadal-to-century timescales and any changes over short timescales are very difficult to distinguish from the natural variability of the climate system. Volcanic-induced forcing is sufficiently large to be clearly seen and provides a good test of climate model performance.

References

- Kelly, P.M., Jones, P.D. and Jia Pengqun, 1996: "The spatial response of the climate system to explosive volcanic eruptions." *International Journal of Climatology* 16(5), 537-550

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