Effects of volcanism on climate

Paul Withers – 2000.02.18
Dave Kring’s volcanology class
Early volcanism-climate relations

- Etna, 44BC
- Laki, Iceland, 1783, and Franklin
- Tambora, Indonesia, 1815, Year without Summer, *Frankenstein*, and Turner’s sunsets
- Krakatoa, Indonesia, 1883, lots of optical effects
Figure 2 Excess visual optical depth at northern latitudes as a function of time reckoned from the date of the 1815 Tambora eruption. The plotted point for 9–10 June 1816 is only the lower limit to the true value (after Stothers 1984a).
Contents of volcanic plumes

- Ash, irrelevant (cf Kuwait)
- Gases – 80% H₂O, 10% CO₂, 5% SO₂, traces of halogens
- Entrained air
Figure 2. Atmospheric transport of tephra or volcanic ash from explosive volcanic eruptions. The diagram shows grain diameter (μm) versus distance along the down-wind axis (km). Note the much greater dispersal of tephra from eruptions during glacial stages, as compared to the two Holocene events. This may be attributed to increased atmospheric vigor during glacial stages, as column heights of, for example, the Campanian and Minoan Mediterranean volcanic events are similar. In case of the Toba eruption (75 ka), data is shown for the mean grain size and the maximum grain size observed down-wind (Ninkovich and others, 1978). The equation gives the exponential relation of grain size and distance for the maximum component of the Toba fallout. Data for the Campanian eruption in Italy (38 ka) show the grain size of the coarse mode of the bimodal deposit (Cornell and others, 1983). Data for the Minoan (3,500 B.P.) and Mount St. Helens (1980) events are also for the coarse modes of the bimodal fallout (Sparks and Huang, 1980; Carey and Sigurdsson, 1982).
Sulphur

- 75% $\text{H}_2\text{SO}_4$ – 25% $\text{H}_2\text{O}$ liquid aerosols, submicron size
- Injected into stratosphere with month-long residence times
- Interacts with radiation to give tropospheric cooling and stratospheric heating
- Surfaces provide reaction sites for chemistry
Lower stratosphere temperature anomalies, 85S-85N, 1982-1991 base period
Figure 1  Composite plot of the temperature departure for the Northern Hemisphere in the four years immediately before and after some large nineteenth and twentieth century eruptions (after Self et al 1981).
Figure 18.2  Theoretical models of climate forcing by a stratospheric aerosol layer (after Lacis et al. 1992). (a) Shows the change of solar flux, $\Delta F_{\text{sol}}$ (cooling), and infrared thermal flux, $\Delta F_{\text{IR}}$ (warming), at the tropopause, as a function of aerosol radius, caused by adding a stratospheric aerosol layer at 20–25 km altitude, with an optical depth $\tau = 0.1$. (b) Shows the change of the net radiative flux, $\Delta F_{\text{net}}$, at the tropopause for an aerosol optical depth $\tau = 0.1$, as a function of aerosol radius, and for three values of effective variance or width of the particle size distribution, $V_{\text{eff}}$. Multiplying $\Delta F_{\text{net}}$ by 0.3 yields $\Delta T$ (°C), the equilibrium air temperature change at the Earth's surface.
Figure 18.3 The effect of aerosol composition on (a) the net radiative flux, $\Delta F_{\text{net}}$, in watts per square metre, and (b) the change in temperature in the stratospheric aerosol layer, as a function of effective aerosol radius, for optical depth $\tau = 0.1$ (after Laca et al. 1992). Sulphuric acid is representative of a typical volcanic aerosol. A basalt dust layer is representative of the optical properties of glassy particles from most explosive volcanic eruptions. The large difference in the temperature change of an aerosol layer with desert dust in (b) is due to its strong absorption of solar radiation (a large real refractive index).
Figure 18.6 The cumulative fallout time (seconds) for sulphuric acid aerosols (the upper of each pair of curves) and volcanic glass particles, in the range 0.01, 0.1, 1 and 10 μm radius, as a function of altitude in the stratosphere, down to the tropopause (c. 10 km). These settling times are calculated for an initial aerosol injection at 30 km altitude, from the data of Kasten (1968) for a 1962 US standard atmosphere.
Important factors

- Eruption volume
- Magma sulphur content (1 ppm to 1 wt%, more mafic, more sulphur)
- Eruption style (injection into stratosphere)
- Volcano location (global wind patterns)
- $T_{\text{decrease}} = 6e-5 \ (S/\text{grams})^{1/3}$ roughly…
Figure 5. Yield of sulfur to the atmosphere (difference between glass inclusion concentration and sulfur concentration in degassed matrix glass) during volcanic eruptions, plotted as a function of SiO$_2$ content of the magma. Note the high sulfur yield during basaltic and trachyandesite eruptions, in contrast to the low yield for eruptions of rhyolite or other silicic magmas. Data from Palais and Sigurdsson (1989) and Devine and others (1984).
Figure 6. The observed relation between sulfur yield to the atmosphere during large volcanic eruptions and the Northern Hemisphere temperature decrease following the event. Sulfur-yield data from Sigurdsson (1982), Devine and others (1984), and Palais and Sigurdsson (1989). Climatological data from Rampino and Self (1982). The equation describes the best fit to the data, with a correlation coefficient of 0.92.
FIG. 4 Global mean ozone in Dobson units (DU) from the total ozone mapping spectrometer (TOMS) measurements as a function of time. Light green line, TOMS/NIMBUS 7 measurements for 1992; red line, TOMS/METEOR 3 measurements for 1993. These two lines are superimposed on the range of TOMS-observed global (65° N–65° S) mean ozone between 1979 and 1990 (dark blue line). The dark green line is the average total ozone for this period. TOMS data show a notable decrease in column ozone amounts beginning in early 1992 and persisting to the end of 1993. The loss reached as much as 6% of the column mean in April 1992\textsuperscript{72,73}.\textsuperscript{72,73}
Figure 4. Sulfur solubility relations in silicic magmas, as a function of FeO* total content. Solid symbols show sulfur content in glass inclusions in phenocrysts from 1985 Nevada del Ruiz rhyolacite tephra (Sigurdsson and others, 1990). Crosses are results of hydrothermal experiments on sulfur solubility in Mount St. Helens 1980 dacite starting composition (after Carroll and Rutherford, 1985), at reduced oxygen fugacities (graphite-methane and quartz-magnetite-fayalite buffer curves) and 1 to 2 kbar, with P_{total} = P_{fluid}. The equation is a best-fit regression through the data, with a coefficient of correlation of 0.95.