Important research questions on volcanic eruptions and climate

Alan Robock

While we understand much about how the climate system responds to volcanic eruptions, there are still a number of outstanding research questions, including on aerosol microphysics, observational capabilities, and climate responses on seasonal to century time scales.

On the 200th anniversary of the largest volcanic eruption of the past 500 years, that of Mt. Tambora in Indonesia, it might be useful to summarize what we still do not know about the impacts of volcanic eruptions on climate. That the April 10, 1815 Tambora eruption was responsible for the 1816 "Year Without a Summer" is well accepted, as large volcanic eruptions produce stratospheric sulfate aerosol clouds that reflect sunlight and cool Earth. Lord Byron wrote *Darkness*, Mary Shelley wrote *Frankenstein*, and John Pollidori wrote *The Vampyre* that summer, inspired by the cold, gloomy weather in Geneva. As I pondered in a review (Robock 1994) of the book by Harington (1992, The Year Without a Summer? World Climate in 1816), "The purpose of the book reviewed here is to address the question of whether Shelley and Byron were making too much of the weather that summer. The summer in New England that year also had extreme weather. Was 1816 truly a 'Year Without a Summer' globally or just a local European and New England phenomenon? What were the causes of these extreme climate anomalies? Were they the result of the Tambora volcanic eruption in April 1815, in Indonesia, or caused by solar variations, El Niño/Southern Oscillation (ENSO) events, or random weather variations?"

Many of these details are still unknown. What exactly is the spatial and temporal pattern of response to a large volcanic eruption, and how well will we be able to predict that response in the seasons and years to come once the next one erupts? How well will our current observing system measure the important parameters needed to make this prediction, as well as to understand the important processes? These and many of the questions presented in Robock (2002) are still unanswered. So if you are looking for a Ph.D. dissertation topic or an important scientific question for your next proposal, in addition to the questions above, here are my candidates:

Are stratospheric sulfate aerosols larger following large SO_2 injections? This is important because it determines their lifetime and their impact on radiation per unit mass, both of which make larger aerosols have a smaller negative radiative forcing and climate impact. Size also determines their ability to destroy ozone, which would be less for larger particles. This mechanism is also important to understand for evaluating proposals for stratospheric geoengineering. Pinto et al. (1989) provided the theoretical explanation for this process, which was used by Crowley (2000) and Crowley and Unterman (2013) to convert ice core records of sulfate deposition into volcanic radiative forcing, and a number of recent papers have assumed that this theory is true. However, there are no observations to support this theory. How can it be verified?

Did volcanic eruptions at the end of the 13th Century, reinforced by the 1452 Kuwae eruption, produce the Little Ice Age? Miller et al. (2012) used observations of ice sheet persistence on Baffin Island and general circulation model (GCM) simulations to propose a mechanism whereby feedbacks between large volcanic cooling and oceanic energy transport into the Arctic Ocean resulted in a colder climatic state after a series of large eruptions. But this mechanism depended on the initial state of the climate model and does not occur in some simulations. So how robust is this mechanism and what are the details of the climate system response?

Why was the summer of 1783 so warm in Europe? Was it caused by the Laki eruption in Iceland? Was it just a coincidence that it was so warm in Europe during the summer of 1783? If it was caused by the Laki eruption, what was the mechanism? Was it radiative, or did the radiative forcing produce a strong southerly advection? How?

Why do climate models have such a hard time producing winter warming over Northern Hemisphere continents after large tropical eruptions? As Stenchikov et al. (2006) and Driscoll et al. (2012) have shown, GCMs have a hard time simulating the observed winter warming (Robock and Mao 1992) following large tropical volcanic eruptions. Why?

Are we ready to monitor the next big volcanic eruption, or geoengineering outdoor experiments or implementation? Specific scientific questions that can be addressed include the size distribution of sulfate aerosol particles, how the aerosols will be transported throughout the stratosphere, and how temperatures change in the stratosphere as a result of the aerosol interactions with shortwave (particularly near IR) and longwave radiation. What observational needs must be met to provide information that would help us produce seasonal and decadal forecasts? Is the total SO_2 enough, or do we need more precise measurements of altitude, or the small tephra particles and subsequent sulfate aerosol clouds? If there is an influence on cirrus and other clouds as the sulfate leaves the stratosphere, do we have good enough observations of potential indirect effects on tropospheric clouds? Do we have enough measurements to evaluate changes in the chemical composition of the atmosphere?

How much seasonal, annual, and decadal predictability is possible following a large volcanic eruption? How large does an eruption have to be to produce a detectable response, and how does this depend on the location and time of year of the eruption? Are the amplitudes of global cooling patterns, winter warming, and summer monsoon precipitation reductions linear with respect to stratospheric aerosol loading?

There are still many interesting research questions with respect to volcanic eruptions and climate, and answering them will allow us to be prepared to address the impacts of the next large eruption, and to better separate natural and anthropogenic climate responses from each other.

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REFERENCES

Crowley TJ (2000) Science 289: 270-277

Crowley TJ, Unterman MB (2013) Earth Sys Sci Data 5: 187-197

Driscoll S et al. (2012) J Geophys Res 117, doi:10.1029/2012JD017607

Harington CR (1992) The Year Without a Summer? World Climate in 1816, Canadian Museum of Nature, 576 pp

Miller GH et al. (2012) Geophys Res Lett 39, doi:10.1029/2011GL050168

Pinto JR et al. (1989) J Geophys Res 94: 11165-11174

Robock A (1994) Clim Change 26: 105-108

Robock A (2002) EOS 83: 472

Robock A, Mao J (1992) Geophys Res Lett 19: 2405-2408

Stenchikov G et al. (2006) J Geophys Res 111, doi:10.1029/2005JD006286