The Relationship of Climate and Volcanoes

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Observations show a direct link between volcanic eruptions and the Earth's climate. What we learn from volcanic eruptions and their effect on the climate may one day soon help us to mitigate the impact of global warming from greenhouse gases.

Introduction: Volcanos and Climate

Observations show a direct link between volcanic eruptions and the Earth's climate, both in the geological record and our historical record. Scientists hypothesize that water, a major gaseous component of volcanic eruptions, in the Earth's oceans and atmosphere results from volcanic eruptions early in the Earth's history. Further, volcanologists posit that Earth's largest eruptions caused many major extinctions throughout the geological record. The Mount Toba eruption in Indonesia ~74,000 years ago is hypothesized to have caused a bottleneck in hominid evolution seen in our mitochondrial DNA (Robock et al., 2009). In 1783, Laki eruption's volcanic gases wiped out much of Iceland's population (up to 40%) and even traveled worldwide, causing a European famine that partly catalyzed the French Revolution. The 1991 Mt Pinatubo eruption injected roughly 19 million tons of SO_2 into the atmosphere causing a decrease in the Earth's surface temperature of about 0.4° C for the next couple of years. The Pinatubo eruption also caused a significant decrease in the Earth's ozone layer. Clearly, research bridging volcanology and climate science is imperative to understanding human's future.

How Eruptions of Volcanic Gases Affect the Earth's Climate:

So, what is it about volcanoes that change the Earth's climate – CO_2, Sulfur gases, ash? The major gaseous components volcanoes emit are H_2O, SO_2 and CO_2 which can all affect the climate (Figure 1). It goes without saying that abundances correlate.

CO_2 Impacts

CO_2 is one of several gasses that causes a greenhouse effect. The greenhouse effect contributes to global warming by absorbing and re-radiating infrared rays reflected from the Earth's surface (Causes). However, the injection of volcanic CO_2 into our atmosphere is insignificant compared to the anthropogenic CO_2 coming from humans burning fossil fuels. For example, volcanic CO_2 output annually is about 130 million tons per year and human output is over 30 billion tons per year and increasing. This insignificance of volcanic output compared to human output is well illustrated in the Keeling Curve (Figure 2) which shows no significant change during major eruptions such as Mt Pinatubo.

SO_2 Impacts

Arguably one of the most important, or influential gases released from a volcano is, SO_2. Volcanos' sulfate aerosols are the driving force behind any climate change induced by an explosion. The high flux of sulfate aerosols released from Toba, many times the amount released from Mt. Pinatubo, caused a decades-long volcanic winter (Figure 3). The sulfur dioxide released from volcanos subsequently oxidizes and hydrolyzes in the upper atmosphere to produce sulfuric acid (H_2SO_4). This sulfuric acid forms an aerosol which spreads throughout the stratosphere and reflects the sun's energy back into space causing a net cooling on the Earth's atmosphere (Robock et al., 2009).

Ashfall Distribution

Another physical characteristic of an explosive volcano is the ashfall. Ash fallout can cause societal complications by damaging peoples' water supply, agriculture, and transportation. The thickness of the fallout, its source's orientation, and the eruption cloud's dispersion will determine the extent of the explosion's consequences (Ashfall?).

Interaction with Ozone

Considering ozone is an important part of understanding the fluctuations of temperature caused by volcanic gases. Volcanic hydrogen chloride is a commonly emitted gas that can destroy ozone by reacting in the stratosphere. Studies show that most of the hydrogen chloride released dissolves in rain and settles out of the air in two to three years. This means that volcanoes are proven to impose only a miniscule amount of damage to the ozone. To put in perspective, "estimates suggest that volcanoes account for 1 to 5 percent of ozone damage, with 15 to 20 percent from other natural sources, and a whopping 75 to 85 percent due to human activity" (Volcano Watch). Thus, it is important to understand both humans and volcano's role in ozone depletion.

Yellowstone

Despite the many concerns from Americans both near and far from Yellowstone's vicinity, science indicates that no super volcanic eruption will likely occur in the near future. The possibility of a hydrothermal explosion with the power to blast a one-kilometer-wide crater is higher than any other volcanic hazard. So, the likelihood of a mass-panic inducing, or life-threatening eruption is extremely miniscule. While a Yellowstone volcanic eruption in our lifetime is possible, its size will be a fraction of the past super volcanic explosions. The eruption size would be more comparable to Mount Pinatubo or Mt. St. Helen's eruptions. Most notably, the USGS reports minute chances of a caldera-forming eruption happening in the next millennium, no need to worry about running from molten hot lava flows just yet (Questions).

If you would like information, a report meant to be understandable from a non-scientist perspective was written to assess Yellowstone's potential hazards (USGS Open-File Report 2007-1071).

Geoengineering

Stopping or mitigating climate change begins with the innovation geoengineering provides. Geoengineering involves solving the Earth's most pressing environmental issues such as, increasing temperatures, ocean acidification, and energy waste. One solution proposed is inserting artificial aerosols into the atmosphere to perpetrate cooling. Much like sulfur dioxide spouted from volcanoes, tiny aerosol particles would reflect sunlight away from the Earth's surface. Another method discussed includes growing mass populations of phytoplankton to convert greater amounts of CO_2 to Oxygen. A movement gaining momentum with big energy companies is the implementation of Carbon Capture Sequestration (CCS). CCS uses direct carbon capture to filter the CO2 produced from oil or gas and insert it into the ground. While each method is plausible, funding the deployment of each solution on a global scale would require united cooperation (Kulkarni, 2022).

Climate change and volcanoes have a directly proportional relationship. In other words, more volcanic eruptions equate to a greater climactic impact, especially super volcanic explosions. The future of volcano and climate research is continuously evolving. Such as research on water vapor's involvement with volcano's effect and mid-ocean ridge eruption as a climate valve (Tolstoy, 2015). National Aeronautics and Space Administration (NASA), the National Center for Atmospheric Research (NCAR), and the American Geophysical Union (AGU) are all working towards discovering volcano's exact implications from the past and how they will apply to future eruptions. It can truthfully be said that with volcanos and climate, there is a lot left to learn.

Conclusion: Volcanoes a Possible Answer to Anthropogenic Climate Change

Humans in our conceit, pursue the idea that we can control the effects of nature, but volcanoes pose a significant challenge to this ideal; the sheer destructive force and unpredictability make volcanoes impossible to control including their global effect on the Earth's climate. However, through the burning of fossil fuels, we have controlled our Earth's climate to our detriment. Ironically, what we are learning from volcanoes and their effect on the climate may one day soon help us to mitigate the impact of global warming from greenhouse gases.

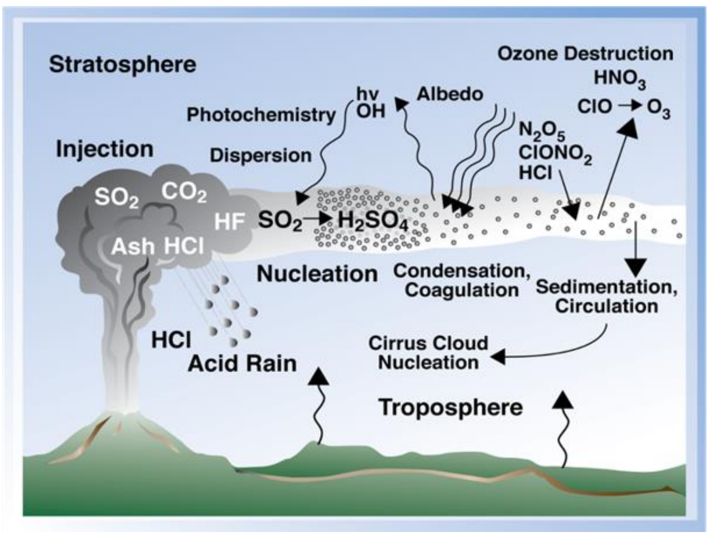

Fig. 1 The interaction of volcanic gases in the atmosphere, including sulfur dioxides effect on albedo and the destruction of ozone. (Sims Bostonian Science Museum Science Presentation as modified by Oppenheimer).

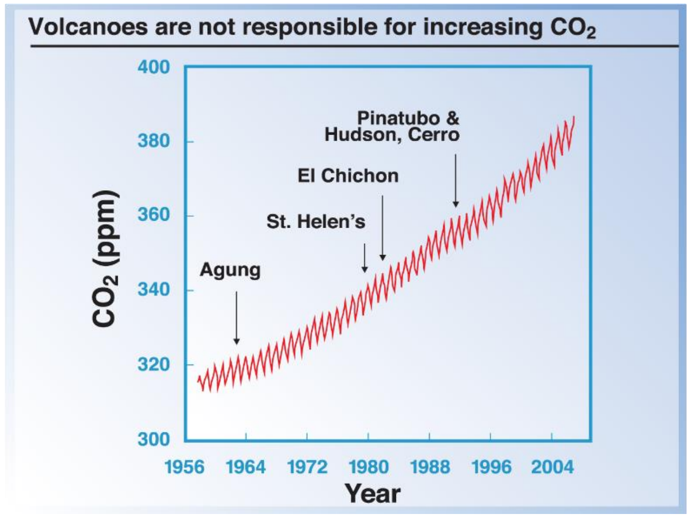

Fig. 2: The Keeling curve displays the approximate concentration of carbon dioxide in the atmosphere (Nordebo et al., 2020). Note the included dates of major eruptions showing no impact of volcanic eruptions on the CO2 content of the Earth's atmosphere.

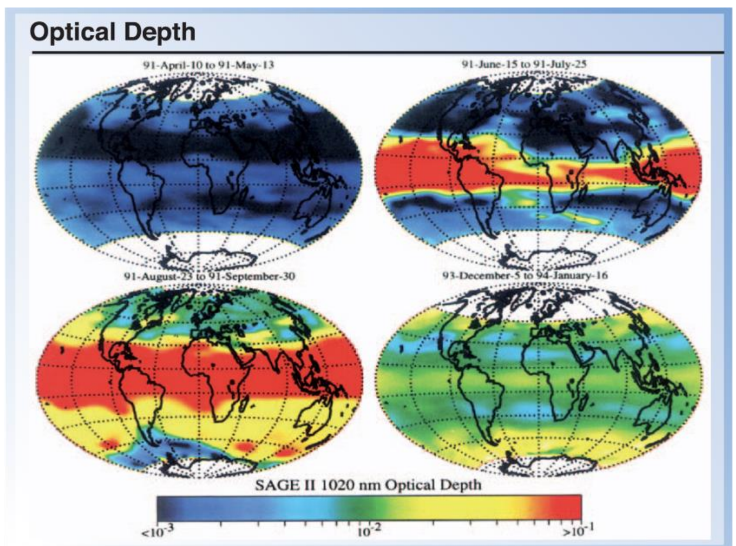

Fig. 3: Optical Depth from 1990 Pinatubo Eruption (NASA, 2001). Note the length of time that the optical depth is affected by volcanic sulfur aerosols in the atmosphere. Sulfur aerosols in the atmosphere have a half-life of approximately 18 months.

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