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GUEST EDITORIAL

## Are volcanic eruptions causing the current global warming?

At the December 2015 Paris meeting, the international community not only acknowledged the seriousness of climate change, but also unanimously agreed to limit global mean warming 'below 2°C' by the year 2100. Recall, the planet has already warmed by ~1°C since the pre-industrial period. While it is unclear how this can be achieved as the voluntary pledges made by world governments could lead to a 3°C warming by the end of this century, there is still hope, as the pledges would be revisited every 5 years. One may believe that the debate on anthropogenic climate change is settled in favour of the 'believers', but there are still 'deniers', who believe that the current climate change is due to natural causes such as solar radiation variations or volcanic-CO<sub>2</sub> fluxes. Let me focus on volcanism here.

Volcanoes have long been implicated as a possible cause for weather and climate. The most recent volcanic eruption that made headlines in the press was the May 2011 Grímsvötn eruption in Iceland. The ash from the eruption caused major disruption to air traffic in Europe between 22 and 25 May 2011. This Icelandic eruption was a *minor* one, as the eruption was mostly limited to the troposphere. As the *turbulent tropospheric rainfall processes* removed the volcanic ashes within two weeks, the impact disappeared, once the eruption ceased on 26 May.

However, dramatic cooling can result from *major volcanic eruptions* that reach stratospheric heights (20–50 km). In such cases, the aerosols from the eruption could stay in the *stable stratosphere* for a couple of years and block the solar radiation. The last major volcanic eruption was the 1991 Mount Pinatubo (Philippines) eruption. The planet cooled by 0.5°C in 1992 and it gradually warmed up as the aerosols fell out of the stratosphere in the following years. The last 250 years have witnessed about 12 such major volcanic eruptions<sup>1</sup>.

Major volcanic eruptions cool the planet on seasonal to inter-annual timescales. Some eruptions could prove to be devastating, as the planet-wide cooling could disrupt agriculture and food production. For instance, the 1815 Mount Tambora eruption in Indonesia with an eruption column height of 45 km, caused global cooling for the next three years and world-wide crop failures in 1816. In India, the eruption disrupted the monsoon and caused three successive failed harvests and the infamous Bengal famine. The year 1816 is sometimes known as the 'year without a summer' or the 'poverty year'.

Major volcanic eruptions cause cooling, because the eruptions release SO<sub>2</sub> into the stratosphere where it is oxidized to form sulphate aerosols, which scatter solar radiation back to space and reduce the amount that reaches the surface. These aerosols are carried by atmospheric winds and the aerosol cloud can circle the globe in about 2 weeks. The amount of SO<sub>2</sub> released by Pinatubo and Tambora eruptions are estimated as 20 and 50–60 megatonnes respectively. Though anthropogenic emissions of sulphate aerosols are much larger at 110 megatonnes of SO<sub>2</sub> per year, they are mostly emitted into the troposphere, where their residence time is only a couple of weeks. *Hence, the cooling effects of anthropogenic sulphate aerosols would disappear in two weeks if their emissions are halted.*

Volcanism affects the climate system in two distinct ways: short-term cooling due to stratospheric volcanic-aerosols followed by long-term warming caused by volcanic-CO<sub>2</sub>. Volcanic eruptions release CO<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub>, H<sub>2</sub>, SO<sub>2</sub> and many other gases. The sulphates formed by oxidation of SO<sub>2</sub> cool the planet for a few years and are removed by wet/dry deposition followed by sedimentation during this period. Only volcanic-CO<sub>2</sub> stays in the atmosphere for a longer period of thousands of years (10% of the CO<sub>2</sub> stays in the atmosphere even after 10,000 years<sup>2</sup>). *Since CO<sub>2</sub> is a greenhouse gas, the long-term effect of volcanic eruptions is a warming.*

This long-term warming effect of volcanism has played an important role in regulating the climate of the earth. On million plus year timescales, the climate of the planet is regulated by the so-called 'silicate weathering thermostat' mechanism: a delicate balance between the volcanic emissions of CO<sub>2</sub> and the removal of this CO<sub>2</sub> by weathering. Weathering is basically chemical reaction affecting silicate rocks and atmospheric CO<sub>2</sub>. Weathering rates are larger in warmer and wetter climates. On long timescales, if volcanic activity increases, atmospheric CO<sub>2</sub> goes up leading to a warmer world and an accelerated hydrological cycle. The warmer and wetter climate causes increased weathering rates which pulls down the atmospheric CO<sub>2</sub> level and thus cooling or stabilizing the climate. Under reduced volcanism, the chain of events is reversed and thus climate is again stabilized.

As volcanoes inject CO<sub>2</sub> into the atmosphere, is the current CO<sub>2</sub> increase caused by increase in volcanic activity? Can weathering pull down the atmosphere CO<sub>2</sub>

levels, so we do not need to take any action on climate change? To answer these questions, the rate of volcanic CO<sub>2</sub> emissions and weathering should be considered. The average volcanic CO<sub>2</sub> flux is ~0.1 PgC (Peta grams of carbon) per year, while the current anthropogenic emissions from fossil fuel burning and deforestation are about 10 PgC per year<sup>3</sup>. Thus, the volcanic flux is two orders of magnitude smaller and hence its greenhouse effect is negligible when compared to anthropogenic CO<sub>2</sub>.

The weathering rate is of the same order of magnitude as the volcanic-CO<sub>2</sub> flux rate and hence it could take ~10,000 years for natural weathering to remove a century of anthropogenic emissions. Obviously, on human timescales, the warming effect from volcanoes and the cooling from weathering are too small when compared to anthropogenic climate change and therefore volcanism is not important for current climate change. It is the larger rate of anthropogenic CO<sub>2</sub> emissions relative to volcanism (10 versus 0.1 PgC yr<sup>-1</sup>) and the consequent speed of increase in CO<sub>2</sub>, planetary temperatures and ocean acidification that are causing concern among climate scientists today. The large CO<sub>2</sub> increase and warming projected by the end of this century may have taken millions of years in the geologic history of our planet.

Volcanism may not be important for the ongoing centennial-timescale global warming, but they do affect the climate system on multiple timescales. As discussed above, major volcanic eruptions cause cooling on the timescale of 2–5 years as evident from the cooling that followed the 1991 Mount Pinatubo eruption. Minor volcanoes, but too many of them over decadal timescales could produce significant cooling trends. Recent studies have partly attributed such volcanic activity in the last decade to the current ‘hiatus’ in global warming<sup>4</sup>. Conversely, some studies have attributed the rapid warming during 1912–1963 to the relative absence of volcanism during that 50-year period. It is now believed that volcanic eruptions and solar variations were the important causes for climate change during the *Little Ice Age*. All these suggest that the impact of anthropogenic CO<sub>2</sub> and aerosols must be carefully evaluated against a background of continued natural forcing from volcanic activities and solar variations. *Climate scientists have performed such evaluations meticulously in the last three decades, using climate models and ‘detection and attribution’ techniques, and have confirmed the anthropogenic origin of the current climate change.*

The well-known climate effects of volcanic eruptions include cooler summers, because of reduced surface solar radiation and stratospheric heating as the volcanic aerosols absorb IR radiation. Other effects of volcanic eruptions include ozone depletion in the stratosphere<sup>1</sup>. Volcanic eruptions can have remote effects too. For instance, Asian and North African monsoon regions receive less rainfall whenever major eruptions take place in high latitudes of the Northern Hemisphere (NH). Nile River records provide evidence for this: extremely low flows were recorded following the 1783–84 Laki eruption in

Iceland. The basic mechanism for the reduced rainfall in North Africa after the Laki eruption is that the large cooling in NH high latitudes moved the Inter-Tropical Convergence Zone (ITCZ) away from NH and caused reduced rainfall in all NH monsoon regions<sup>5</sup>. The drought in Egypt due to the Laki eruption was so severe that by 1785, nearly 1/6th of the population of Egypt had either perished or left the country.

In recent years, volcanic eruptions are often cited as analogues for ‘nuclear winter’ and stratospheric aerosol geoengineering that has been proposed to reverse global warming<sup>6</sup>. The nuclear winter theory predicts massive injection of soot aerosols into the stratosphere following a nuclear holocaust. As in the case of volcanic eruptions, these aerosols would reflect solar radiation and cool the surface. The aerosol geoengineering idea proposes to inject carefully estimated amounts of sulphate aerosols into the stratosphere to offset the warming caused by greenhouse gases<sup>6</sup>. As the nuclear theory could not be tested in the real world and geoengineering is still a controversial idea, volcanic eruptions are used as analogues to support them.

From the above discussion, it is clear that volcanic eruptions play an important role in shaping the climate on multiple space and time scales, but they have little role in the recent increase of atmospheric CO<sub>2</sub> and global warming. Human activities, mainly fossil fuel burning, are causing CO<sub>2</sub> to rise at a rate that is unprecedented in the last several million years. For India, potential damages from global warming could be in the form of heat waves, extreme rainfall, sea level rise, reduced crop yields, etc. Hence, as a precautionary measure, it would be prudent to move away from the current fossil-fuel based global energy system to one based on renewables in the coming decades. Simultaneously, active research into cost-effective technologies that remove atmospheric CO<sub>2</sub> on a large scale and store it in permanent geological reservoirs should be pursued.

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