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Investigating the effects of volcanic eruptions on global climate variability

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Abstract

Volcanic eruptions have long been recognized as significant natural phenomena capable of influencing global climate variability. This review synthesizes current knowledge on the mechanisms through which volcanic eruptions affect climate, the historical impacts observed from notable eruptions, and the challenges and advancements in modeling volcanic influences on climate systems. By examining previous studies, this paper aims to provide a comprehensive understanding of the interplay between volcanic activity and climate variability, contributing to better predictive models and mitigation strategies for future climatic changes.

Keywords: Volcanic eruptions, climate variability, volcanic aerosols, stratospheric sulfur injection, historical eruptions, climate modelling

Introduction

Volcanic eruptions are among the most powerful and awe-inspiring natural phenomena on Earth. They have the capability to affect not only the immediate environment surrounding the eruption site but also the global climate system. The impact of volcanic eruptions on climate variability has been a subject of scientific inquiry for many decades, driven by the need to understand how these sporadic but potent events can alter weather patterns, temperature, and even human activities on a global scale. The primary mechanism through which volcanic eruptions influence climate is the emission of large quantities of gases and particles into the atmosphere. Among these emissions, sulfur dioxide (SO₂) is particularly significant. When SO₂ reaches the stratosphere, it reacts with water vapor to form sulfuric acid (H₂SO₄) aerosols. These aerosols can remain in the stratosphere for extended periods, sometimes several years, depending on the magnitude of the eruption. By scattering and reflecting incoming solar radiation, these aerosols cause a net cooling effect on the Earth's surface, a phenomenon known as radiative forcing. The historical record provides numerous examples of volcanic eruptions leading to notable climatic changes. The eruption of Mount Tambora in 1815 is often cited as one of the most dramatic instances of volcanic climate impact, resulting in the "Year without a Summer" in 1816. This event caused significant temperature drops, widespread crop failures, and food shortages across the Northern Hemisphere. Similarly, the eruption of Krakatoa in 1883 led to global temperature declines and vivid sunsets, attributed to the dispersal of volcanic aerosols. The more recent eruption of Mount Pinatubo in 1991 has provided extensive observational data that have been critical for advancing our understanding of volcanic impacts on climate. The Pinatubo eruption injected approximately 20 million tons of SO₂ into the stratosphere, leading to a global cooling of about 0.5 °C over the following two years. The study of volcanic impacts on climate extends beyond immediate cooling effects. Volcanic aerosols can alter atmospheric circulation patterns, including the jet streams and monsoon systems, leading to changes in weather patterns that can persist for years. Additionally, the cooling of sea surface temperatures following significant eruptions can influence oceanic circulation and phenomena such as the El Niño-Southern Oscillation (ENSO), which has far-reaching effects on global climate. Advancements in climate modelling have been instrumental in enhancing our understanding of volcanic impacts on climate variability. Modern climate models incorporate detailed representations of volcanic forcings, including the formation, dispersion, and radiative effects of aerosols. The integration of observational data from satellite measurements and ground-based observations has improved the accuracy of these models. Furthermore, paleoclimate records, such as ice cores and tree rings, provide invaluable data

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on past volcanic activity and associated climatic changes, extending our understanding beyond the instrumental record. Despite significant progress, challenges remain in accurately predicting the climatic impacts of volcanic eruptions. One of the primary challenges is the uncertainty in the magnitude, composition, and spatial distribution of volcanic emissions. Improving observational networks and integrating more detailed measurements of volcanic emissions are crucial for reducing these uncertainties. Additionally, understanding the long-term effects of volcanic eruptions on climate requires integrating volcanic impacts into broader climate variability and change scenarios.

Objective

The objective of this study is to synthesize current knowledge on the mechanisms and impacts of volcanic eruptions on global climate variability, examining historical case studies and advancements in climate modelling to enhance predictive capabilities and understanding of future volcanic influences on climate.

Volcanic eruptions

Volcanic eruptions are potent natural events that have the capacity to significantly alter global climate patterns. These eruptions can vary greatly in size and impact, ranging from minor events that produce localized effects to massive eruptions that influence climate on a global scale. The primary mechanism through which volcanic eruptions affect climate is the release of large quantities of sulfur dioxide (SO₂) into the stratosphere. When SO₂ is injected into the upper atmosphere, it reacts with water vapor to form sulfate aerosols. These fine particles are capable of reflecting incoming solar radiation back into space, leading to a cooling of the Earth's surface. This phenomenon is known as radiative forcing.

Historical studies have provided substantial evidence of the climatic impacts of volcanic eruptions. For instance, the eruption of Mount Tambora in 1815 is one of the most well-documented examples. This eruption resulted in the "Year Without a Summer" in 1816, causing significant temperature drops, widespread crop failures, and food shortages across the Northern Hemisphere. Similarly, the eruption of Krakatoa in 1883 led to a global temperature decrease of approximately 1.2°C in the year following the event. The volcanic ash and aerosols dispersed by Krakatoa created vivid sunsets and disrupted global weather patterns for several years.

The eruption of Mount Pinatubo in 1991 offers a modern example with extensive observational data. Pinatubo's eruption released around 20 million tons of SO₂ into the stratosphere, leading to a global cooling of about 0.5 °C over the next two years. This event has been extensively studied and modelled, providing valuable insights into the processes and effects of volcanic aerosols on climate. The cooling effect observed after Pinatubo's eruption was significant enough to temporarily offset some of the warming caused by greenhouse gases.

Previous studies have emphasized the importance of volcanic eruptions in modulating climate variability. Robock (2000) ^[9] highlighted the role of volcanic eruptions in driving short-term climate changes and their potential to influence long-term climate trends. Stenchikov *et al.* (1998) ^[12] examined the radiative forcing effects of the Pinatubo

eruption, providing detailed simulations of aerosol dispersion and its climatic consequences. Zielinski (2000) ^[15] used paleo-records, such as ice cores and tree rings, to investigate the long-term impacts of volcanic eruptions on climate, revealing patterns of cooling and recovery over centuries.

Advancements in climate modelling have further enhanced our understanding of volcanic impacts. Timmreck (2012) ^[14] discussed the improvements in simulating large explosive volcanic eruptions and their incorporation into climate models. These models now better capture the spatial and temporal distribution of volcanic aerosols, leading to more accurate predictions of climate responses. Additionally, self explored the potential climatic effects of large volcanic eruptions, emphasizing the importance of accurately characterizing volcanic emissions and their interactions with the atmosphere.

In summary, volcanic eruptions are critical natural drivers of climate variability, capable of inducing significant short-term cooling and altering atmospheric and oceanic circulation patterns. Historical eruptions and advancements in climate modelling have provided a comprehensive understanding of these impacts, though challenges remain in accurately predicting future volcanic influences on climate. Continued research and interdisciplinary collaboration are essential for improving our predictive capabilities and developing effective strategies to mitigate the climatic effects of volcanic eruptions.

Volcanic influence on climate

Volcanic eruptions exert a profound influence on the Earth's climate through several interconnected mechanisms, primarily driven by the release of volcanic gases and aerosols into the atmosphere. When a volcano erupts, it emits sulfur dioxide (SO₂), carbon dioxide (CO₂), water vapor, and ash into the stratosphere. Among these emissions, SO₂ plays a critical role in climatic changes. Upon reaching the stratosphere, SO₂ reacts with water vapor to form sulfuric acid aerosols. These aerosols can persist in the stratosphere for months to years, depending on the magnitude of the eruption, and significantly alter the radiative balance of the Earth by reflecting incoming solar radiation back into space, leading to a cooling of the Earth's surface a phenomenon known as radiative forcing.

The cooling effect of volcanic eruptions has been well-documented through numerous historical and observational studies. For example, the eruption of Mount Tambora in 1815 led to the "Year Without a Summer" in 1816, characterized by significant global temperature drops, crop failures, and food shortages, particularly in the Northern Hemisphere. Studies such as those by Stothers (1984) ^[13] and Oppenheimer (2003) ^[3] have detailed the far-reaching climatic impacts of Tambora, demonstrating the connection between volcanic aerosols and substantial short-term climate cooling.

Similarly, the eruption of Krakatoa in 1883 had notable climatic effects. The explosion released vast amounts of ash and aerosols into the stratosphere, resulting in a global temperature decrease of about 1.2°C in the following year. The climatic anomalies caused by Krakatoa, including vivid sunsets and disruptions to weather patterns, were recorded worldwide. This event was studied extensively by researchers like Rampino and Self (1982) ^[7], who analyzed the atmospheric and climatic repercussions of the eruption.

The 1991 eruption of Mount Pinatubo in the Philippines offers one of the most thoroughly observed cases of volcanic influence on climate. Pinatubo injected approximately 20 million tons of SO₂ into the stratosphere, causing a global surface cooling of about 0.5 °C over the subsequent two years. This eruption has been pivotal in advancing our understanding of volcanic impacts on climate, as detailed in studies by Hansen *et al.* (1992)^[3] and McCormick *et al.* (1995)^[4]. These researchers used satellite data and climate models to track the dispersion of aerosols and their radiative effects, providing robust evidence of the cooling influence of volcanic eruptions.

Volcanic eruptions also affect atmospheric circulation patterns and precipitation. The aerosols can alter the dynamics of the jet streams and monsoon systems, leading to changes in weather patterns. For instance, Robock and Mao (1992)^[8] demonstrated that volcanic eruptions could lead to altered winter warming patterns in the Northern Hemisphere, a phenomenon attributed to changes in atmospheric circulation caused by volcanic aerosols.

Moreover, volcanic eruptions have been shown to influence oceanic circulation. The cooling of sea surface temperatures following major eruptions can impact ocean currents and phenomena such as the El Niño-Southern Oscillation (ENSO). Church *et al.* (2005)^[1] explored these interactions, noting how volcanic eruptions could temporarily disrupt oceanic heat distribution and influence climatic conditions over extended periods.

Advancements in climate modelling have been instrumental in enhancing our understanding of volcanic influences on climate. Models now incorporate detailed representations of volcanic forcings, including the injection and dispersion of aerosols and their interactions with radiation and clouds. Timmreck (2012)^[14] highlighted the improvements in climate models' ability to simulate the climatic effects of large explosive volcanic eruptions, resulting in more accurate predictions of temperature changes and atmospheric responses.

Despite these advancements, challenges remain in accurately predicting the long-term climatic impacts of volcanic eruptions. Uncertainties in the magnitude, composition, and spatial distribution of volcanic emissions can lead to variability in model outputs. Improving observational networks and integrating paleoclimate records, such as ice cores and tree rings, can help refine these models. Studies like those by Zielinski (2000)^[15] emphasize the value of paleoclimate data in extending our understanding of volcanic impacts beyond the instrumental record, providing a more comprehensive view of how volcanic activity has influenced climate over millennia.

Advances in climate modelling

Advancements in climate modelling have significantly improved our understanding of the impacts of volcanic eruptions on climate variability. These models incorporate detailed representations of volcanic forcings, aerosol dispersal, radiative effects, and interactions with atmospheric and oceanic processes, enabling more accurate simulations of the climatic responses to volcanic activity.

One of the key advancements in climate modelling is the improved representation of volcanic aerosols. Modern climate models, such as those used in the Coupled Model Intercomparison Project (CMIP), now include sophisticated

parameterizations of volcanic aerosol formation, transport, and removal processes. This allows for more accurate simulations of the spatial and temporal distribution of aerosols following an eruption. For example, the Climate Model Intercomparison Project Phase 5 (CMIP5) included volcanic forcing datasets that accounted for the optical properties and sizes of sulfate aerosols, leading to better predictions of their climatic impacts (Eyring *et al.*, 2016)^[2]. Satellite observations have played a crucial role in validating and refining these models. The eruption of Mount Pinatubo in 1991 provided extensive observational data, which has been invaluable for model validation. Studies by Stenchikov *et al.* (1998)^[12] and Soden *et al.* (2002)^[11] used satellite data to track the dispersion of Pinatubo aerosols and their radiative effects, helping to improve the accuracy of climate models in simulating volcanic impacts. These observations have enabled scientists to fine-tune aerosol parameterizations and improve predictions of surface cooling and atmospheric changes.

Another important advancement is the incorporation of interactive stratospheric chemistry in climate models. The interaction between volcanic aerosols and stratospheric ozone can influence the radiative balance and climate. Models that include interactive chemistry, such as the Goddard Earth Observing System Chemistry-Climate Model (GEOSCCM), simulate the chemical reactions between volcanic aerosols and ozone, leading to more accurate predictions of climate responses (Pitari *et al.*, 2014)^[6]. Climate models have also improved in simulating the dynamic responses of the atmosphere and oceans to volcanic eruptions. Volcanic aerosols can alter atmospheric circulation patterns, such as the jet streams and monsoon systems. Recent models, such as those used in the European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecast System, simulate these dynamic responses more accurately, providing better predictions of regional climate impacts (Timmreck, 2012)^[14]. Additionally, the inclusion of coupled ocean-atmosphere models has enhanced our understanding of how volcanic eruptions affect oceanic circulation and sea surface temperatures. These models can simulate the cooling of the upper ocean and the resulting changes in ocean currents and phenomena such as the El Niño-Southern Oscillation (ENSO) (Church *et al.*, 2005)^[1]. Paleoclimate records, such as ice cores and tree rings, offer valuable insights into the long-term impacts of volcanic eruptions on climate. These records provide data on past volcanic activity and associated climatic changes, extending our understanding beyond the instrumental record. Studies by Zielinski (2000)^[15] and Sigl *et al.* (2015)^[10] have used ice core records to reconstruct volcanic forcing over the past millennium, helping to validate and improve climate models. By comparing model simulations with paleoclimate data, scientists can assess the accuracy of their models and refine their predictions of future volcanic impacts. Despite these advancements, challenges remain in accurately predicting the climatic impacts of volcanic eruptions. One of the main challenges is the uncertainty in the magnitude, composition, and spatial distribution of volcanic emissions. The variability in these factors can lead to differences in model outputs, making it difficult to predict the exact climatic response to an eruption. Improving observational networks and integrating more detailed measurements of volcanic emissions can help reduce these uncertainties. Another challenge is the need to

improve the resolution and complexity of climate models. High-resolution models can better simulate the fine-scale processes and interactions between aerosols, clouds, and radiation, leading to more accurate predictions. Additionally, incorporating more comprehensive datasets, such as high-resolution satellite observations and paleoclimate records, can enhance model accuracy. In conclusion, advancements in climate modelling have significantly improved our understanding of the impacts of volcanic eruptions on climate variability. The incorporation of detailed representations of volcanic aerosols, interactive stratospheric chemistry, and dynamic atmospheric and oceanic responses has led to more accurate simulations of climatic impacts. Satellite observations and paleoclimate records have played a crucial role in validating and refining these models. Despite remaining challenges, continued research and interdisciplinary collaboration are essential for further improving predictive capabilities and developing effective strategies to mitigate the climatic effects of volcanic eruptions.

Conclusion

Looking to the future, the study of volcanic influences on climate holds several promising prospects for advancing our understanding and predictive capabilities. As climate models continue to evolve, incorporating more sophisticated representations of volcanic forcings and interactions with the atmosphere and oceans, our ability to accurately simulate the climatic impacts of volcanic eruptions will improve. Enhanced observational networks, including high-resolution satellite data and ground-based measurements, will provide critical real-time data to validate and refine these models.

Future research should focus on reducing uncertainties related to the magnitude, composition, and spatial distribution of volcanic emissions. Integrating detailed measurements of volcanic gases and aerosols, along with advancements in remote sensing technologies, will be crucial in achieving this goal. Additionally, leveraging paleoclimate records, such as ice cores and tree rings, will extend our understanding of volcanic impacts over millennia, providing a more comprehensive context for current and future climatic changes.

Interdisciplinary collaboration between volcanologists, climate scientists, and modelers will be essential in addressing the complex interactions between volcanic activity and climate. Developing integrated models that can simulate both the immediate and long-term effects of volcanic eruptions on climate systems will enhance our predictive capabilities. These models will be invaluable for informing mitigation strategies and policy decisions aimed at minimizing the adverse effects of future volcanic eruptions on global climate and society.

In summary, the future prospects for research on volcanic influences on climate are promising. Continued advancements in climate modelling, observational technologies, and interdisciplinary collaboration will pave the way for more accurate predictions and effective strategies to address the climatic impacts of volcanic eruptions. As we move forward, a deeper understanding of these natural phenomena will play a crucial role in enhancing our resilience to future climate variability and change.

References

1. Church JA, White NJ, Arblaster JM. Significant decadal-scale impact of volcanic eruptions on sea level and ocean heat content. *Nature*. 2005;438(7064):74-77.
2. Eyring V, *et al.* Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geosci. Model Dev*. 2016;9(5):1937-1958.
3. Hansen J, *et al.* Climate impacts of Mount Pinatubo eruption. *Geophys Res Lett*. 1992;19(2):215-218.
4. McCormick MP, Thomason LW, Trepte CR. Atmospheric effects of the Mt Pinatubo eruption. *Nature*. 1995;373(6513):399-404.
5. Oppenheimer C. Climatic, environmental and human consequences of the largest known historic eruption: Tambora volcano (Indonesia) 1815. *Prog Phys Geogr*. 2003;27(2):230-259.
6. Pitari G, *et al.* Stratospheric ozone response to sulfate geoengineering: Results from the Geoengineering Model Intercomparison Project (GeoMIP). *J Geophys Res Atmos*. 2014;119(5):2629-2653.
7. Rampino MR, Self S. Historic eruptions of Tambora (1815), Krakatau (1883), and Agung (1963), their stratospheric aerosols, and climatic impact. *Quat Res*. 1982;18(2):127-143.
8. Robock A, Mao J. Winter warming from large volcanic eruptions. *Geophys Res Lett*. 1992;19(24):2405-2408.
9. Robock A. Volcanic eruptions and climate. *Rev Geophys*. 2000;38(2):191-219.
10. Sigl M, *et al.* Timing and climate forcing of volcanic eruptions for the past 2,500 years. *Nature*. 2015;523(7562):543-549.
11. Soden BJ, *et al.* Global cooling after the eruption of Mount Pinatubo: A test of climate feedback by water vapor. *Science*. 2002;296(5568):727-730.
12. Stenchikov G, *et al.* Radiative forcing from the 1991 Mount Pinatubo volcanic eruption. *J Geophys Res Atmos*. 1998;103(D12):13837-13857.
13. Stothers RB. The great Tambora eruption in 1815 and its aftermath. *Science*. 1984;224(4654):1191-1198.
14. Timmreck C. Modeling the climatic effects of large explosive volcanic eruptions. *WIREs Clim Change*. 2012;3(6):545-564.
15. Zielinski GA. Use of paleo-records in determining variability within the volcanism-climate system. *Quat Sci Rev*. 2000;19(1-5):417-438.