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Environmental and Climatic Effects of Atmospheric Processing of Volcanic Ash vs Mineral Dust

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Abstract

This article compares volcanic ash and mineral dust in terms of their sources, atmospheric loads, deposition mechanisms, atmospheric processing, and effects on the environment and climate. It also compares their chemical and physical properties. Although there are significant differences between the histories of volcanic ash and mineral dust particles before they are released into the atmosphere, there are many similarities between how the atmosphere is processed at ambient temperatures and the effects on the environment and climate. This review paper seeks to encourage future combined research methods to advance our existing understanding through close collaboration between mineral dust and volcanic ash experts by outlining the similarities and contrasts between the processes and consequences of volcanic ash and mineral dust.

Keywords: Volcanic; Dust

Introduction

Volcanic eruptions produce a significant amount of volcanic ash. It is created by volcanic vents' surrounding rock material and magma fragmenting throughout the formation process. According to the intensity of a volcanic eruption, volcanic ash is ejected into the free troposphere or even the stratosphere, where it is carried by the dominant winds until it is eliminated from the atmosphere by gravity settling and wet deposition [1]. According to wind speed, ash size, ash density, and eruption magnitude, volcanic ash is also known to be mobilised by wind from its deposits, which have accumulated after volcanic eruptions on land along the main transport directions of the volcanic cloud, which extends over hundreds to thousands of kilometres [2]. Unlike the mineral dust in the atmosphere, numerous studies have been conducted on the global cycle of mineral dust and how it affects the Earth's climate [3]. By serving as cloud condensation or ice nuclei, mineral dust particles have an impact on the radiative forcing of the atmosphere both directly and indirectly [4]. Climate variability impacts the mineral dust load of the atmosphere through changes in precipitation, vegetation cover, and wind. In addition, mineral dust aerosols regulate ozone photochemistry and provide nutrients to marine and terrestrial ecosystems [5].

Chemical and Physical Properties

According to the "Glossary of Atmospheric Chemistry Terms," dust is made up of small, solid, dry particles that are discharged into the atmosphere by mechanical or artificial operations as well as by natural factors like wind and volcanic eruptions (e.g., crushing, milling, and shoveling). Typically, dust particles range in size from 1 to 100 m and descend slowly from the atmosphere due to gravity. Mineral dust and volcanic ash may thus make up a small portion of all dust that has been seen [6]. The following criteria are used to differentiate between mineral dust and volcanic ash: While volcanic ash is a loose, unconsolidated substance with smaller particle sizes, atmospheric mineral dust is derived from a suspension of soil minerals. Silica and oxygen, which are the primary ingredients of minerals and rocks in the Earth's crust and mantle, are found in large quantities in volcanic ash as well as in mineral dust [7]. The magma from which the volcanic ash is formed largely determines the chemical makeup of the bulk material. Three distinct forms of magma are typically used to separate them. Different viscosities, melting points, and typical volatile concentrations are present in these varieties of magma. Silica makes up between 45 and 75 weight percent of the mineral content of volcanic ash. Additionally, silicate makes up the majority of minerals, including feldspar, olivine, pyroxene, hornblende, and biotiteThese minerals are created by the successive crystallisation that occurs during cooling and decompression as magma rises from the Earth's mantle through the crust and into the conduit, then enters the volcanic plume [8]. The composition of the melt changes during the crystallisation process as outcomes of the depletion of crystallised components and enrichment of remaining components, which drives the successive production of various minerals, including ones lacking silicate, such as magnetite or ilmenite. Whether volcanic ash was formed by an explosive eruption, a phreatomagmatic eruption, or a pyroclastic density current, these processes have a significant impact on the size distribution of the ash [9]. Additionally, secondary volcanic ash clouds—which shouldn't be confused with coignimbrite clouds as we'll explain later—are the outcomes of the resuspension of volcanic ash depositions on land. Magma rising in the conduit that contains volatiles dissolves causes explosive volcanic outbursts. Gas bubbles are created as outcomes of the exsolution of volatiles and increase as a finding of coalescence, decompression, and diffusion [10]. A continuous gas stream with magma clots and clasts (known as pyroclasts) emerges from the vent explosively the farther the magma-gas combination rises because the pressure is falling as it rises, which causes the mixture to accelerate in the face of friction and gravity.

Atmospheric Load, Subsequent Deposition, and Atmospheric Emissions [11]

The term "emission" refers to the discharge of material into the atmosphere from a location outside the atmosphere, which serves

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as the atmosphere's source. Mineral dust source sites are typically found in semiarid or arid regions with minimal vegetation and dry surfaces. The wind can gather and move fine-grained particles into the atmosphere in this area. In most cases, dust emission zones are determined by numerical models for mineral dust mobilisation using factors including soil moisture, soil texture, and vegetation influences. The emission of mineral dust into the atmosphere is a complicated, nonlinear function of both the soil surface qualities and the weather. Mineral dust emissions from an erodible surface occur when the wind friction velocity exceeds a threshold value, dependent on the soil properties. Explosive volcanic eruptions, phreatomagmatic eruptions, or pyroclastic density currents all produce volcanic ash. Around 20 volcanoes erupt worldwide at any given time, 50–70 volcanoes erupt annually, and at least one big eruption with a Volcanic Explosivity Index of at least 4 takes place each year. Small volcanic eruptions with VEI 4 account for the majority of eruptions, and their combined emissions of volcanic ash into the troposphere are estimated to be 20 Tg/yr, or 10 km3, assuming a particle density of 2000 kg/m3. These volcanic ash emissions, however, are often quickly evacuated from the atmosphere and only have local significance in the region of the volcanoes up to a radius of around 100 kilometres.

There is a lot of temporal and spatial variation in the concentrations of volcanic ash and mineral dust in the atmosphere. Mineral dust load in the atmosphere is largely influenced by seasonal fluctuation, such as rainy and dry seasons, whereas volcanic ash load is primarily influenced by the occurrence of sporadic and typically unpredictable volcanic eruptions. Gravitational settling, turbulent dry deposition, and wet deposition—wet scavenging by rain—all serve to remove mineral dust and volcanic ash from the sky. By definition, the removal processes of dry and wet deposition include the dry and wet aggregation of volcanic ash. They are treated individually afterwards, though, due to their area of expertise. According to estimations from mineral dust models, the amount of wet deposition over the ocean varies greatly from 30% to 95% of the overall amount of mineral dust deposition, with the ratio of dry to wet deposition. The distribution and magnitude of deposition fluxes serve as a convenient way to summarise all uncertainties associated with the global mineral dust cycle, including emissions and movement through the atmosphere [12].

Environmental Processing

The volcanic eruption plume, which is extending vertically into the atmosphere from the vent to the level of neutral buoyancy, experiences tremendous temperature gradients in extremely short periods of time before atmospheric processing occurs at ambient temperatures. Along with the fragmentation processes occurring here, quenching is a crucial step in the formation of the minerals created by incomplete crystallisation reactions and the glass material found in volcanic ash. Due to vertically divided zones of negatively and positively charged volcanic ash particles, intense lightning is a frequently observed phenomenon in the volcanic eruption plume. The charged volcanic ash particles may have an impact on how volcanic ash aggregates. The chemical makeup of volcanic ash has only recently been studied in relation to temperature and ionising effects of lightning. Without taking into account lightning, the literature discusses a number of potentially significant processes for physical-chemical alterations of volcanic ash surfaces, as summarised below. The different homogeneous and heterogeneous chemical and microphysical alterations on the ash surfaces are caused by the cooling of volcanic eruption plumes, which rise from roughly 1000°C at the vent to ambient temperature [13]. Volatiles—which are gases released into the atmosphere along with volcanic ash—occur in significant quantities during volcanic eruptions. It is hypothesised that soluble compounds are produced on the surfaces of volcanic ash, scavenging up to 30%–40% of the sulphur and 10%–20% of the chlorine released from volcanic eruptions through the interaction between these gases and secondary aerosols produced from these gases with volcanic ash within the eruption plume.

Climate Change and Environmental Effects

Human Health [14]

Due to the elevated air concentrations, aeolian dust outbreaks pose a serious threat to human health. Because of its tendency to combine with pollution aerosols in urban areas of Asia, mineral dust episodes are becoming a significant threat to the wellbeing of people and ecosystems. Asthma, allergic alveolitis, eye irritations, and common chronic respiratory and lung disorders have all been linked to increased levels of exposure. Similar health consequences to those caused by mineral dust may be experienced by anyone exposed to large levels of volcanic ash. Small ash particles do, however, have extra mechanical impacts due to their sharp surface patterns. For instance, in windy conditions, they can abrade the front of the eye and, in the worst case scenario, cause silicosis.

Aviation

Due to limited vision, strong mineral dust storms primarily hinder takeoff and landing of aircraft. Aircraft can, however, fly in areas with large concentrations of mineral dust without experiencing any engine issues. When mineral dust is fed into jet engines, which generally melts at temperatures of roughly 1700°C, it does not melt. However, due to the melting temperatures being at or below the working temperatures of high-performance jet engines, which are roughly 1400°C, volcanic ash may cause issues for jet engines. When temperatures rise over their glass transition point, the molten material that is deposited on the cooler parts of the engines can produce flame-outs, which can also be brought on by glass shards. Volcanic ash interfered with 129 flights throughout the course of the last 60 years.

Climate

While long-term effects take place in a more diluted environment, short-term consequences like mineral dust storms, volcanic eruptions, and volcanic ash resuspension events significantly impair visibility and sun irradiation reaching the Earth's surface. An increase in atmospheric optical depth, greater solar and thermal radiation absorption and/or scattering, and changes in surface temperature are all indicators of these impacts. In the ash-affected area downwind of Mount St. Helens, it was noted that during the first two days after the 1980 eruption, a daytime surface temperature fall of 8°C was caused by volcanic ash absorbing solar radiation. Volcanic ash's colour plays a significant influence in this situation; low-Si, high-Fe ash tends to produce a dark brown and black colouring. Mineral dust's direct radiative effects have been thoroughly researched. compared the Ejyafjallajökull eruption's volcanic ash's visual characteristics to those of Saharan dust. Although volcanic ash and mineral dust have optical characteristics that are largely identical, mineral dust exhibits less absorption and larger dips between the blue and red regions of the spectrum than volcanic ash does. Volcanic ash showed slightly stronger forward and lower backward scattering in terms of polarisation properties, which is another distinction in optical characteristics. These distinctions enable, for instance, lidar measurements to distinguish between volcanic ash and mineral dust. Although more research is required, atmospheric processing may alter the radiative characteristics of both mineral dust and volcanic ash.

If there are more aerosols available to act as cloud condensation nuclei, then a greater number of cloud droplets are created, often with smaller sizes. High concentrations of cloud droplets slow the formation of diffusional droplets. As a outcoming, droplet sizes needed for effective growth through droplet collision cannot be attained. Therefore, modifications to CDNC can have an impact on cloud albedo, cloud duration, and precipitation generation. In the tropics, it is particularly important to alter how precipitation forms in deep convective clouds. Precipitation may be stifled as a finding of the local influence near the aerosol source regions [15]. However, as more liquid water and water vapour remain in the sky, precipitation will occur elsewhere, increasing the likelihood of erosion and flooding. Another external source of iron that is usually ignored is the oceanic deposition of volcanic ash. Its relevance and influence on the climate, however, have long been seen as insignificant. It is generally accepted that the main climate-changing impact of volcanic eruptions outcomes from the reduction of solar radiation caused by volcanic sulphate aerosols. Volcanic ash, as opposed to volcanic gases and aerosols, leaves the atmosphere significantly more quickly following an eruption. Recent research has however demonstrated that volcanic ash changes the biogeochemical processes in the surface ocean, directly altering climate. Volcanic ash carried by the air may release trace species when it comes into contact with seawater and settles on the ocean's surface. Thus, volcanic ash, despite its intermittent discharge, may function similarly to mineral dust.

Discussion

Mineral dust and volcanic ash particles have very different histories before they are released into the atmosphere, but they also have a lot in common when it comes to how the atmosphere is processed at ambient temperatures and how it affects the environment and the climate. Therefore, the goal of this review is to encourage increased collaboration among the scientific community looking into the atmospheric chemical effects and changes of volcanic ash and mineral dust. Model parameterizations for the mobilisation of mineral dust from on-land deposits of volcanic ash are based on these techniques. Due to the restricted availability of ash in its deposits, new techniques will be required to take into account mass conserving parameterizations, where the movement of deposits is also taken into account. Researchers who study mineral dust may also be interested in such parameterizations. An difficulty that has prevented a comprehensive understanding of the critical processes up to this point is the extraordinary circumstances for multiphase chemistry present in volcanic plumes with regard to temperature and the gradients associated with it, acidity, lightning, and particle load. Despite these challenges, the multiphase chemistry of volcanic plumes under extreme conditions offers the potential to shed light on mechanisms that may be crucial for mineral dust atmospheric chemical processing under less extreme circumstances. The production of bioavailable iron on mineral dust and volcanic ash surfaces for ocean fertilisation is highlighted in this article in particular. Especially from leaching trials, collaborative experimental and modelling research initiatives between mineral dust and volcanic ash researchers could significantly advance our current, insufficient understanding. In order to better understand the processes affected by freezing temperatures, such as IN formations or Fe mobilisation, and their effects on the climate, more systematic research should be done. During volcanic eruptions, ash particles are easily injected into atmospheric regimes where freezing temperatures are prevalent. Wet deposition of volcanic ash and mineral dust from the atmosphere is associated with the creation of CCN and IN. In terms of volcanic ash, there is an urgent need for better understanding of aggregation, a deposition process that reduces the amount of ash for long-range transport. All ash dispersion models don't adequately account for this phenomenon. a collaboration between the meteorological and volcanic communities to understand the basic principles of ash aggregation.

Conclusion

To more accurately analyse the climate impacts of volcanic ash vs mineral dust during the geological past, sediment cores from ice, peat, sea, and ocean sediments for mineral dust and volcanic ash deposition must be constructed for paleoclimate. However, until we have a thorough grasp of current processes, we won't be able to effectively address these processes in the palaeo-records or with regard to the potential effects of mineral dust on the climate in the future, as opposed to volcanic ash.

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Conflict of Interest

The author has no known conflicts of interested associated with this paper.

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