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Impact and Inspiration of Tonga volcanic Eruption in 2022

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Abstract. People have been puzzled by the problem of volcanic eruptions since ancient times. Because volcanic eruptions are difficult to predict accurately, if people can't take some precautions in advance, sometimes volcanic eruptions will cause great injuries and deaths and hazards. In this context, this review selects the Tonga Volcano as the research object, summarizes the hazards during the eruption of the volcano and the symptom before the eruption, in order to get inspiration for predicting volcanic eruptions. This paper firstly introduces that Tonga volcano is located on the Tonga-Kermadec volcanic arc. When Tonga volcano erupted, it tended to an explosive eruption, which Surtseyan eruption dominated. Secondly, the author analyzes the impact on the capital of Tonga, the surrounding area and the world through the primary disaster, such as the collapse of crater, volcanic ash and SO_2. Then, the global impact of secondary disasters after primary disasters is analyzed, such as tsunami and climate change. Thirdly, the author concludes the pre-eruption symptoms, such as surface deformation and ionospheric anomaly. The observation of these anomalies and the establishment of a volcano monitoring system will help people to predict the next volcanic eruption. In addition, it remains to be seen how to detect the symptoms of volcanic eruption in time. Finally, this paper emphasizes that there are few practical applications of volcano monitoring system, and more volcanoes need to be monitored in time. If volcano monitoring systems were made more common around the world, people could minimize the damage caused by volcanoes.

1 Introduction

The problem of volcanic eruptions has puzzled people since ancient times. According to research, there are currently about 2,000 volcanoes on Earth, and there are at least 50 volcanic activities every year. Lava flows and eruptions of volcanic gases not only cause great damage to residential areas, but also pollute water sources and the atmosphere. Therefore, the monitoring of volcanic eruptions is extremely important. If unusual volcanic activity is detected in advance, residents can be evacuated in advance and emergency plans made. Most of the existing volcano monitoring systems have been established and managed by national monitoring agencies and are therefore focused on monitoring volcanoes located within their national political boundaries or within limited areas of interest. For example, the U.S. Geological Survey (USGS) provides global seismic information, but their volcanic disaster project monitors volcanoes in the United States, it can't monitor volcanoes all over the world [1]. In order to reduce the disaster caused by volcanoes, people should build as many volcano monitoring systems as possible in worldwide.

In recent years, global awareness of volcano monitoring and prevention has increased, but due to the large number of volcanoes and lack of funds, satellite monitoring is still mainly used, that is, to observe abnormal volcanic activities through satellite remote sensing images, but this method does not detect volcanic eruption in time. There is also the use of underwater sonar, but not for long periods of time. There are many researches on volcanic eruption both at home and abroad, which mainly focuseses on the disaster after volcanic eruption. Some articles also discuss the problems of volcanic monitoring. Some scholars have proposed to use surface deformation and ionospheric anomaly monitoring, but it is still difficult to accurately predict the eruption time and size.

This paper will discuss the Tonga volcanic eruption in 2022, its effects after the eruption and the inspiration for monitoring. The Tonga volcano is part of the highly active Tonga-Kermadec Islands volcanic arc, which was formed by the Pacific plate subducting west under the Australian plate. This volcano was built up by each eruption as time went on. Tonga started at a great depth, which cooled the water, which quickly cooled the magma that was coming out. So many underwater volcanoes start with underwater overflow eruptions, which are rarely noticed. After this volcano has had a lot of eruptions, islands form on the surface of the sea, and that's what happens when some of the eruptions cool down and turn into rocks and cover the surface of the volcano, and help the volcano get closer to the surface, and then come out of the surface and form islands.

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2 Impact of Tonga Volcanic Eruption in 2022

Since 20th December 2021, Tonga volcano had erupted underwater, and a large amount of volcanic ash was created, the public could see the volcanic ash in Tonga's capital, where is about 70 kilometers away from the Tonga volcano. By this time, it was already the precursor of the eruption on 14th January 2022. Starting from the beginning of 2022, Tonga volcano erupted less, and more water vapour and volcanic gas were produced by the volcano, despite less volcanic ash was formed. The largest scale of eruption was on 14th January 2022, it influenced a wide range of the world. During this time, Tonga volcano tended to an explosive eruption, which Surtseyan eruption dominated. Volcanic ash, water vapour and volcanic gas erupted together, therefore they caused atmospheric shock waves to propagate globally. Besides, many hazards had been generated by the eruption, such as tsunami, climate change and so on.

2.1 Primary Hazards

The earliest hazard in all kinds of hazards is called primary hazard. Since volcanic eruptions are accompanied by the production of volcanic ash, lava flow, etc., they are primary hazards. Generally, all of them have profound influences, and some of them can produce secondary hazards. In this eruption, a large amount of magma erupted after the crater collapsed and reacted violently with sea water, creating hundreds of explosions that exacerbated the hazard of primary hazards.

2.1.1 Pyroclastic rock and crater collapse

Pyroclastic rocks are rocks formed by short distance transport or deposition of various detrital materials produced by volcanic eruption. According to the satellite images, the area of Tonga increased at first. This is because the tephra accumulated around the volcano. After the eruption on 14th and 15th January 2022, part of Tonga volcano above the sea level and the crater collapsed (Fig. 1). There are two possible reasons for the collapse of the crater of Tonga volcano: (i) Intermittent eruptions since December 2021 have kept the magma channel open and a large amount of sea water has flooded into the magma system, and the explosive eruption on 14th January 2022 caused the crater to collapse; (ii) Prior to the major eruption on 15th January 2022, due to upwelling of magma supply and deformation of the cone, the landslide of the volcanic cone resulted in decompression of the upper part of the volcanic mechanism, which induced the volcanic eruption [2]. The exact cause of the collapse of the crater is not yet known, it still needs further exploration.

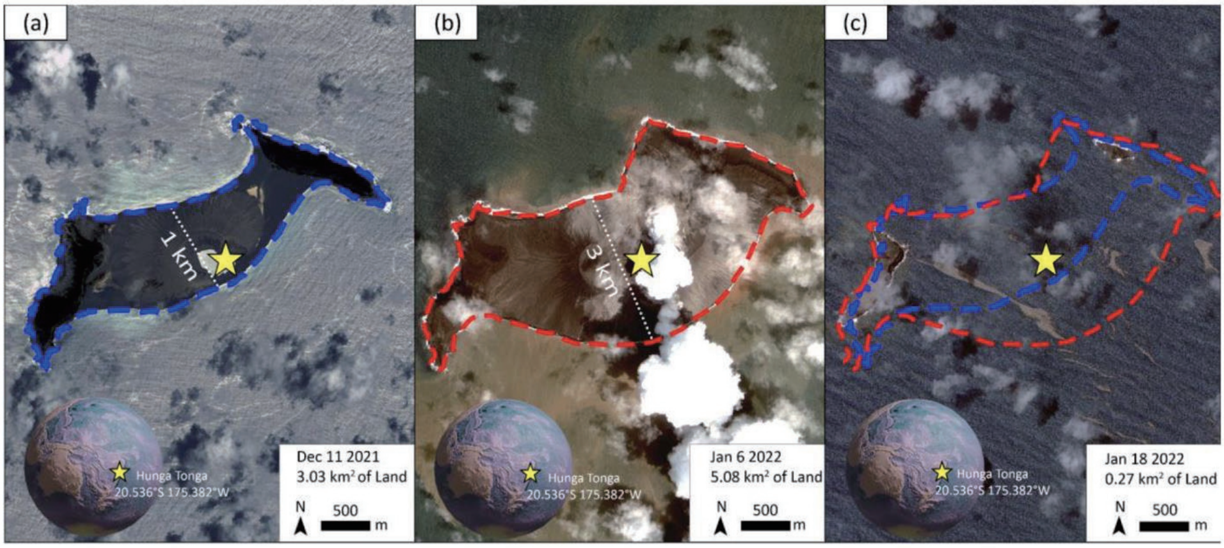

Fig. 1. Satellite photos of Tonga Tonga [3]https://assets.researchsquare.com/files/rs-1377508/v1_covered.pdf?c=1663272662

2.1.2 Volcanic ash

Volcanic ash can have a serious impact on air quality, and on the day of the Tonga volcanic eruption, people were urged to wear face masks to prevent breathing in air contaminated by volcanic ash. Particles among the sizes of millimeters and less than 1 μm make up the volcanic ash that is directly produced during volcanic eruptions, as well as the sulfate aerosols that are created by the photochemical reactions of the sulfide that are also released at the same time [4]. Nuku'alofa, Tonga's capital, was greatly influenced by the ash. The buildings and main port facilities in Nuku'alofa were covered by the ash (Fig. 2). Agriculture, Tonga's mainstay industry, had been buried by the ash. On 18th January 2022, satellite images released by the Australian Weather Bureau showed that the ash was moving west at 92 kilometers per hour and floating 3,000 kilometers over northeastern Australia.

Fig. 2 Buildings in Nuku'alofa (upper); Port facilities in Nuku'alofa (lower) [5]https://link.springer.com/article/10.1186/s40677-023-00232-x#citeas

2.1.3 SO_2 and its propagation

SO_2 is a colorless gas with a pungent smell, and it's one of the major pollutants in the atmosphere. When sulfur dioxide dissolves in water, it forms sulfites. If sulfites is further oxidized, sulfuric acid is quickly and efficiently produced. When volcano erupts, it will generate a lot of SO_2. On 14th January 2022, SO_2 was mainly located in 170°W-180°W region, showing by EMI-2 observations. Five days later, it reached approximately 110°E, having already crossed Australia. In a nutshell, the spatial distribution from the EMI-2 showed a westward transport of the principal part of the SO_2 plume from this eruption [6]. As a result, the SO_2 propagated rapidly, the public needed to prevent the secondary hazards, acid rain. It would seriously affect the drinking water source.

2.2 Secondary Hazards

Many natural disasters, especially after the occurrence of high grade and high intensity natural disasters, often induce a series of other disasters. The disasters induced by the primary disasters are called secondary disasters, such as tsunami, acid rain and climate change. These hazards have a great influence of the world, especially in Tonga volcanic eruption.

2.2.1 Tsunami

According to USGS, the shock waves speed reached 300 m/s (670 mph), and pushing sea water at a similar speed. Therefore, the tsunami was created, with the high speed of the movement of sea water. The tsunami wave was detected in the Pacific, Atlantic, Indian, and Mediterranean oceans in the same day after the eruption. Moreover, the tsunami caused an oil spill off in the waters of Peru, which heavily hit the fishing industry. And the fibre-optic cable was destroyed by the tsunami, it temporarily cut off communications in Tonga.

The Antarctic ice tongue was also affected by the tsunami. The tsunami struck the coast of Victoria Land in Antarctica after traveling more than 6000 kilometers. After the tsunami hit, the rift at the calving front started to propagate quickly. After the arrival of the tsunami, images acquired more than 3.5h show the calving of an iceberg from the terminus. Then, the iceberg started to drift the following day [7].

2.2.2 Climate change

When SO_2 dissolves in water vapor, sulphuric acid aerosols will float in the air, reflecting some solar radiation and cooling global temperatures. According to estimates from the Institute of Atmospheric Physics of the Chinese Academy of Sciences, the global average surface temperature dropped by only 0.004°C the following year. Australia and parts of South America saw temperatures drop by more than 0.01°C [8]. Also, Tonga volcano has a relative lower sulphur content. In conclusion, a single Tonga volcanic eruption is not enough to have a huge impact on the climate.

3 Eruption Symptom and Monitoring Inspiration of Tonga Volcano

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There are some characteristics before the volcano erupt, but most of the time these features are not easily noticed. In other words, it is not yet clear whether these symptoms represent a small or huge eruption on the horizon, so it is still hard to deal with the hazards in time.

3.1 Characteristic of Surface Deformation

According to the images (Fig. 3), the changes in surface deformation become clear. The crater was moving downwards, and the island surrounded the crater, which became more and more visible. Red is a negative value, which represents the distance from the satellite along the satellite radar line of sight (LOS). The blue is positive, and it's approaching the satellite along LOS. The results show that during the observation time before the eruption, the volcanic mountain has obvious subsidence phenomenon and the deformation field is similarly to the semi-ring shape of the volcanic surface, and the displacement rate gradually decreases in the direction of the crater to the bottom of the mountain [9].

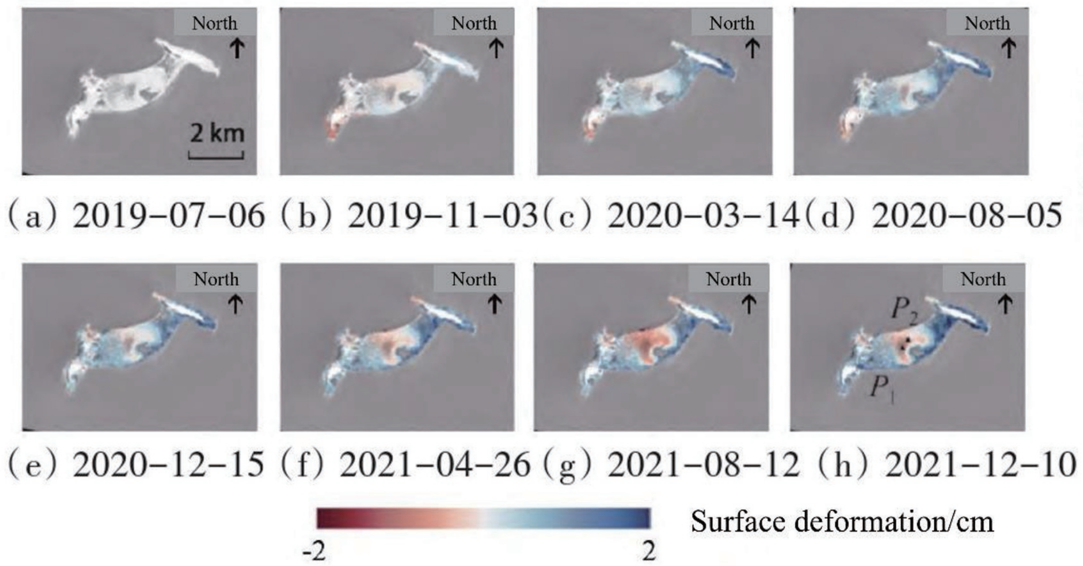

Fig. 3 Characteristic of surface deformation
[9]https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7ioT0BO4yQ4m_mOgeS2ml3UGVXTGXcoUzuMymUC55NWuesDmPp8WAdPTw99rL32cQJ&uniplatform=NZKPT

3.2 Ionospheric Anomaly Analysis

When a volcano erupts, the Earth's crust releases a lot of energy, which affects the ionosphere and upper atmosphere. The total electron content (TEC) is an important parameter to describe the morphology and structure of the ionosphere. The total electron content unit (TECU) is the unit of TEC. By observing the ionospheric anomaly, some pre-eruption symptoms can be obtained. On the 22-27 days before the eruption, large-scale positive anomalies occurred in TEC, with some anomalies more than 10 TECU. On the 11-12 days before the eruption, there were slight negative anomalies, with some anomalies less than 5 TECU [10]. At 0 o 'clock on the 24th day before the occurrence of the volcano, a wide range of TEC abnormal disturbance appeared all over the world, among which the most obvious was in the range of 25°~65° in dimension and 60°W~180° in longitude, and the TEC anomaly exceeded 15 TECU to a maximum. A wide range of TEC anomalies also appeared in the corresponding southern hemisphere. With the passage of time, the global TEC anomalies gradually moved eastward, and the intensity and scope of the anomalies were gradually reduced. By 24:00 UTC, most of the global TEC anomalies were distributed on the northeast, north and northwest sides of the volcanic eruption site, with an intensity of about 5 TECU (Fig. 4) [10]. Fig. 4a-I are 09:00-24:00 UTC respectively, and the time interval is 2h. The location of the five stars is the center of the eruption.

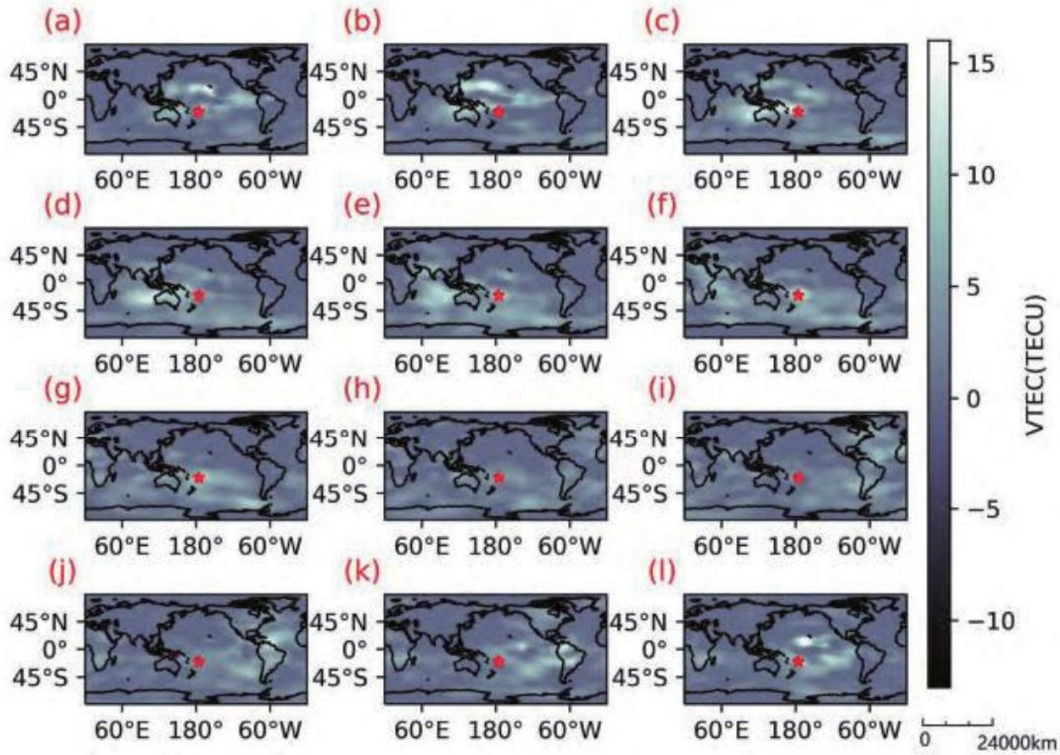

Fig. 4 Global TEC anomaly distribution on the 24th day before the eruption [10]https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7ioT0BO4yQ4m_mOgeS2ml3UIkJbIMXKRKN6YDmmDahdFldQKrK33nCQAakM5kDBgyd&uniplatform=NZKPT

3.3 Monitoring Inspirations

According to the above, people can find that there were some traces of the volcano before the eruption, such as surface deformation and ionospheric anomaly. By these traces, to some extent, people can prevent the disaster caused by volcanic eruption and reduce their own losses. In the future, countries would better establish more volcano monitoring stations. More developed countries could update the monitoring machines and have a complete volcano warning system as far as possible. Managers in volcano monitoring stations shall strengthen monitoring and early warning work.

4 Conclusion

Volcanic eruptions are closely related to crustal movements and pollutants such as volcanic ash produced by volcanic eruptions are also natural sources of air pollution. Ash and volcanic gases floating in the atmosphere can linger in the atmosphere for a long time and have an impact on the climate. Tongan volcanoes have erupted in 1912, 1937, 1988, 2009, 2014, 2015, 2019 and 2021, but these have all been small eruptions. The last major eruption occurred in 1100 AD, 920 years ago. As a result, the Tonga volcanic eruption of 2022 was difficult to predict. Signs of an eruption were observed, but its size could not be determined. More often, they are just small eruptions underwater. After this huge volcanic eruption, due to the collapse of the crater, Tonga volcano is not expected to have another major eruption, but after a period of stability, a small eruption is still possible. Therefore, long-term monitoring of the Tonga volcano, the volcanoes around it and the potential for future volcanic eruptions under the sea is still needed. This paper summarizes the effects of the Tonga volcanic eruption and the symptoms before the eruption. The main impact of volcanic eruption is that the eruption will produce a lot of pyroclastic, volcanic ash and SO_2, which will pollute the atmosphere. The volcano that erupted this time had an impact on the climate, albeit a small one. Huge volcanic eruptions can also cause tsunamis, such as the Tonga volcano in 2022, and even cause the collapse of the Antarctic ice tongue. These effects are hard to intervene against. At present, there may be some measures to reduce the extent of the impact of the eruption, but the impact on the area around the eruption is relatively large. Therefore, the prediction of pre-eruption signs, such as ionospheric anomalies and surface deformation around the volcano, can be used to minimize the proportion of human casualties and the damage caused by the eruption. In the future, people should establish volcano monitoring and early warning systems in active volcanoes as much as possible to monitor the surface deformation, volcanic gas and volcanic earthquake before the eruption of the volcano, respond to the eruption of the volcano in time, carry out crowd evacuation, etc.

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