PROCEEDINGS OF SCIENCE

Observation of the atmospheric wave created by Hunga Tonga-Hunga Ha'apai volcano eruption using GRAPES-3 detectors

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The Hunga Tonga-Hunga Ha'apai volcano eruption on 15 January 2022 is the largest volcanic eruption after Krakatoa in 1883. This eruption triggered catastrophic events such as tsunami waves, atmospheric shock waves, and sonic booms. The eruption injected about 10% of the water vapour found in the stratosphere, which may lead to a global temperature rise. Recent studies by NASA and ESA revealed records of high-speed winds in the upper atmosphere and unusual electric currents found in the ionosphere immediately after the eruption. It is one of the most destructive events observed over the past century with a direct impact on global weather. A pressure wave created by this violent eruption circled the globe multiple times, recorded by numerous instruments around the world. The GRAPES-3 is a ground-based cosmic ray experiment consisting of an array of plastic scintillators and a large area muon telescope to record secondary cosmic rays in the extensive air showers produced by the interaction of primary cosmic rays in the atmosphere. It also monitors the local atmospheric pressure at Ooty in order to account for the impact of pressure on the count rate of secondary cosmic ray particles. Both the scintillator array and the muon telescope recorded a sudden change in the count rate that coincided with the pressure variation associated with the volcano eruption. We will present the analysis and interpretation during the conference.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

PoS(ICRC2023)530

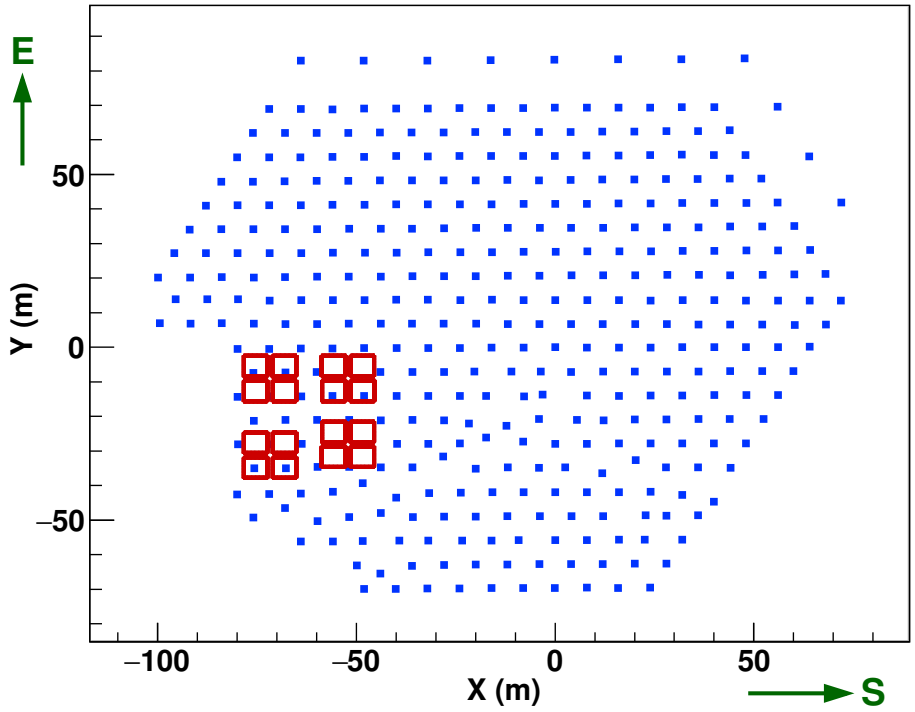

Figure 1: Layout of GRAPES-3 experiment showing (i) array of 400 plastic scintillator detectors (G3SD) and (ii) a large area tracking muon telescope (G3MT).

1. Introduction

Volcano eruptions are one of the disastrous events on Earth and that impact on climate significantly. They are also responsible for loss of several lives, disruptions in activities of several million lives, and unaccountable property damage [1]. Earth is continuously encountering volcano eruptions for many millennia. A well-documented study from 1960 suggests that there are 68±10 eruptions every year covering a range of Volcanic Explosivity Index (VEI) from 0 to 8 [2]. The Hunga Tonga-Hunga Ha'apai volcano eruption on 15 January 2022 was the most powerful eruption after Krakatoa in 1883, also the largest since the eruption of Mt. Pinatubo in 1991. This eruption was rated as VEI-5 and triggered tsunami waves, atmospheric shock waves, sonic booms, etc. Notably, the pressure wave created from the eruption circled around the Earth approximately six times. Many barometers around the world recorded this effect as sudden change in pressure. The GRAPES-3 being a ground based composite extensive air shower (EAS) experiment, it records the weather parameters on minute time scale for correction of atmospheric effects in the data. The GRAPES-3 barometers recorded an increase of ∼1.6 hPa in local pressure from its normal variations. Coincidentally, the particle detectors at GRAPES-3 recorded significant decrease in their count rates.

2. The GRAPES-3 experiment

Gamma **R**ay **A**stronomy at **P**eV **E**nergie**S** – phase **3** (**GRAPES-3**) is a ground based EAS experiment located at Ooty, India (11.4°N, 76.7°E, 2200 m above mean sea level). It consists of

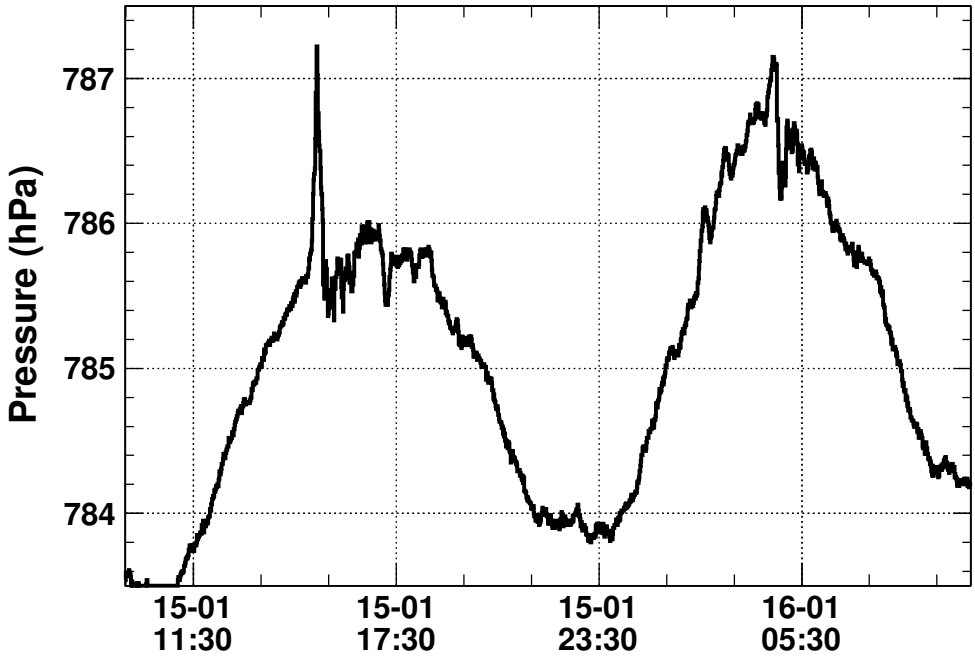

Figure 2: Arrival of pressure wave recorded by GRAPES-3 barometer (Model: Vaisala PTB220).

two detector elements namely (i) array of 400 plastic scintillator detectors (G3SD) and (ii) 560 m^2 large area tracking muon telescope (G3MT) as shown in Figure 1. The G3SD is used to record the energy deposit and relative arrival time of the secondaries (i.e. electron, gamma, muon, and hadrons) above a few MeVs produced in the EAS whereas the G3MT is used only to record the tracks of muons above a GeV. Detailed description of these detectors can be found elsewhere [4, 5].

3. Hunga Tonga-Hunga Ha'apai volcano eruption

Being one of the largest and the most powerful volcanic eruptions in the past century, this event evidently caused a lot of damages to the Earth and lives in various forms. This volcano was inactive since 2014 and started showing minor activities on 20 December 2021 and continued till early January 2022 [3]. As the activity reduced, it was declared as dormant. However, a large eruption occurred on 13 January 2022 with clouds of ashes reaching altitude as high as ~20 km. Subsequently, a second major eruption occurred on 15 January 2022 that rose to an altitude of ~60 km. The resultant explosion was even heard several thousand kilometers away. Also, this eruption poured ~150 billion litres of water into the stratosphere which is roughly 10% of its total capacity and expelled large amount of rocks and ashes in the atmosphere. These effects may raise global temperature and sadly it may take many years to dissipate. The explosion was estimated to be having an yield of more than 100 megatons of TNT, created a shock wave that was felt across the globe and circled the Earth six times. The GRAPES-3 is located ~12300 km away from the eruption and recorded this shock wave after ~11 hrs as sudden increase (~1.6 hPa) in pressure lasted for ~30 minutes as shown in Figure 2. During that period the G3SD and G3MT recorded significant decrease in the count rates. Figure 3 shows the background corrected and normalized count rates

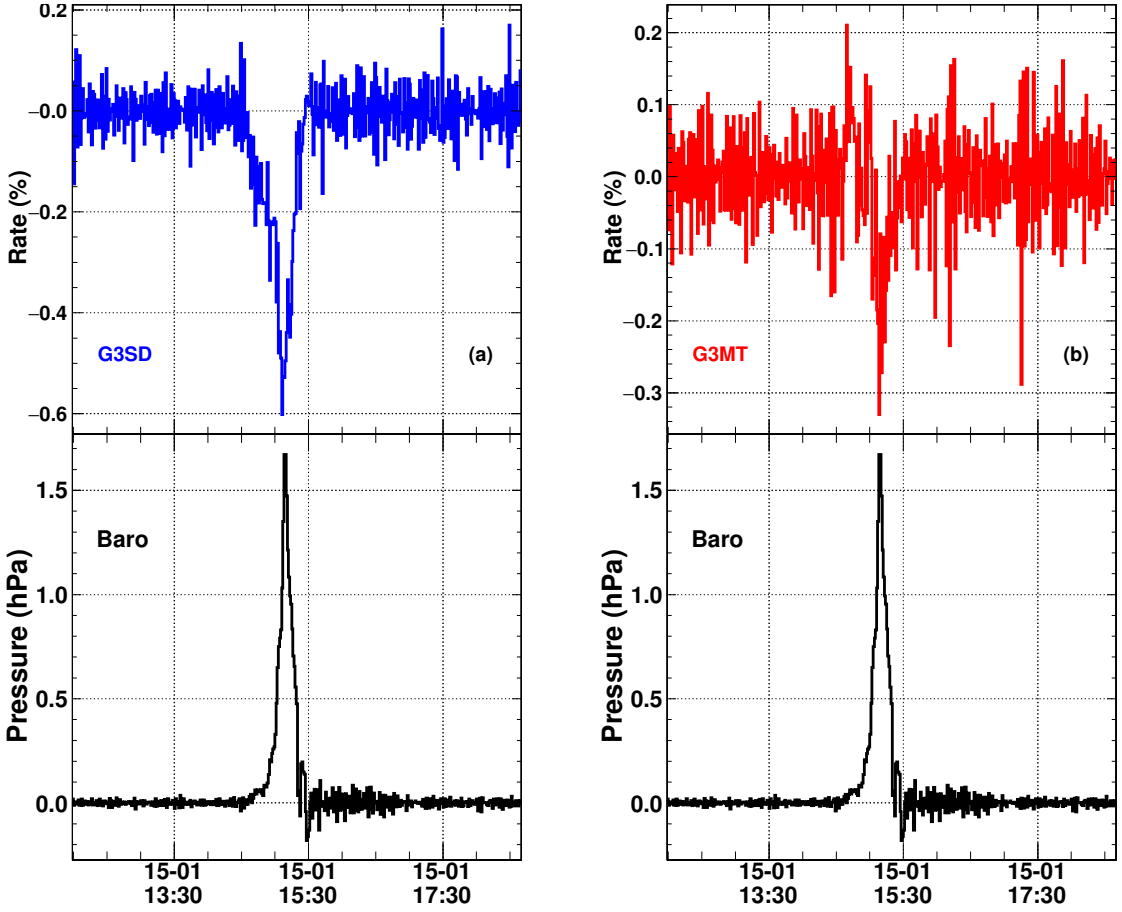

Figure 3: Percentage rate variation of (a) G3SD and (b) G3MT.

of G3SD and G3MT in comparison with the change in local pressure. The G3SD recorded a peak deficit of –0.6% for the pressure increase of 1.6 hPa. The total deficit in G3SD was estimated to be 25 σ significance with a correlation coefficient (CC) of –0.84. Similarly, the G3MT recorded a peak deficit of –0.3%, with a significance of 8 σ having a CC of –0.68. The anti-correlation of cosmic ray secondaries with atmospheric pressure is a well-known effect [6–8]. However, it is important to under the difference in the amplitudes recorded in G3SD and G3MT. The G3SD records electron, gamma, muon, and hadron above a few MeVs. In contrast, the G3MT records only muons above a GeV. This could possibly be the reason for the difference is amplitudes recorded in both the instruments. Similar observations were reported by HAWC experiment in compliance with GRAPES-3's observation [9].

4. Conclusion

The Hunga Tonga-Hunga Ha'apai volcano eruption is one of mast disastrous events occurred in the recent era. The aftereffects of such events may last for several years. On the positive note, the ground based cosmic ray detectors could record the variations in particle density caused by the

pressure wave precisely, despite being located several thousands of kilometers away. They could provide additional information for volcanic studies.

5. Acknowledgements

We are grateful to D.B. Arjunan, A.S. Bosco, V. Jeyakumar, S. Kingston, N.K. Lokre, K. Manjunath, S. Murugapandian, S. Pandurangan, B. Rajesh, R. Ravi, V. Santhoshkumar, S. Sathyaraj, M.S. Shareef, C. Shobana, and R. Sureshkumar for their role in efficient running of the experiment. We acknowledge support of the Department of Atomic Energy, Government of India, under Project Identification No. RTI4002. This work was partially supported by grants from Chubu University, Japan.

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