Cosmic Ray Flux Variations Due to the Hunga-Tonga Volcano Eruption Observed with Neutron Monitor Data

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Introduction

Tonga is a country located in the Southern hemisphere at the Pacific Ocean. It comprises 169 islands, which are mainly made of magmatic rocks. Some of the islands lie along a submarine orographic feature that includes nearly a dozen of active volcanoes. It is an underwater ridge of about 500 km length and lies on the boundary between the Australian and the Pacific tectonic plates. In the southern section of this ridge is the Hunga Tonga-Hunga Ha'apai volcano, whose vent is below the sea level but it is about 2 km above the sea floor. This and the other volcanoes in the submarine ridge seem to be of relatively recent formation, and some of them have underwent eruptions with periods of 20-50 years Bryan et al. 1972.

The Hunga-Tonga Volcano

From December 2021 to January 2022 the Hunga-Tonga presented high activity with various eruptions. On January 15, 2022 at 04:14:45 UTC, it experienced an intense eruption, which generated a fumarole that reached a height of 58 km in 30 minutes and about 600 km in diameter. The coordinates of the Hunga-Tonga volcano are 20.546 S 175.390 W Dourado et al., 2022. The Hunga-Tonga eruption generated a pressure wave that traveled around the Earth during three days and, as below mentioned, the wave pressure was recorded in many different sites at several distances from the volcano, also a traveling ionospheric disturbances were observed during four days Zhang et al. 2022.

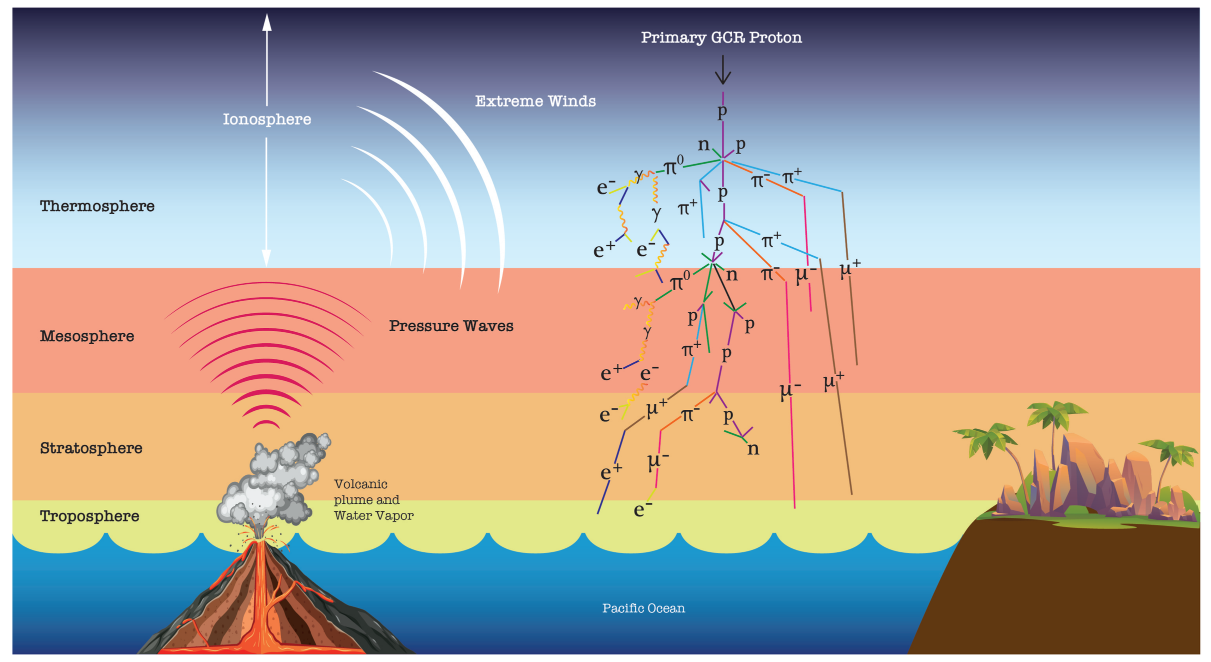

Figure 2: The Hunga Tonga-Hunga Ha'apai eruption.

Results 2

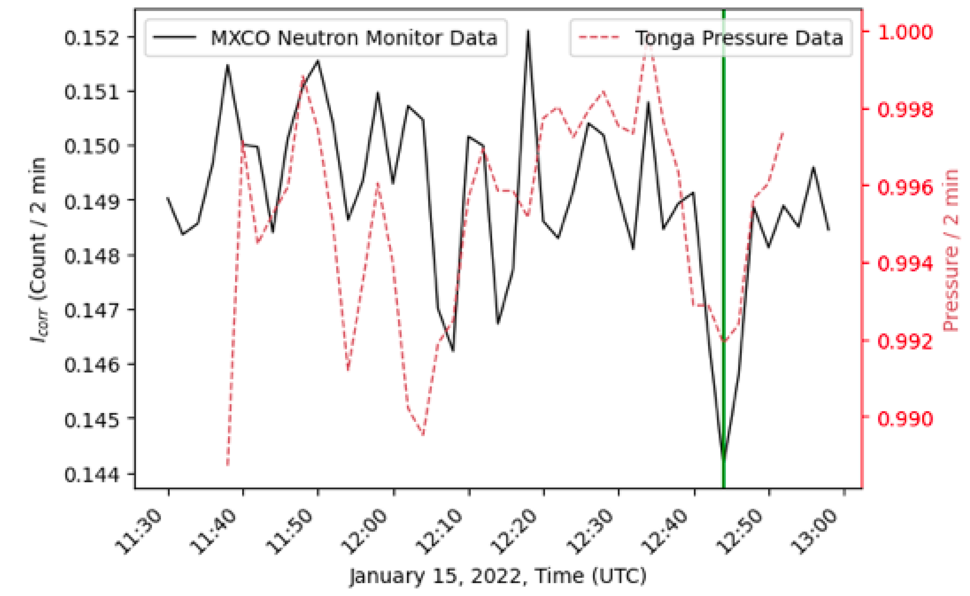

Figure 3: Corrected cosmic ray intensity rate observed by Mexico neutron monitor as a function of time from January 15, 2022.

The Effect of Atmospheric Pressure on Cosmic Rays

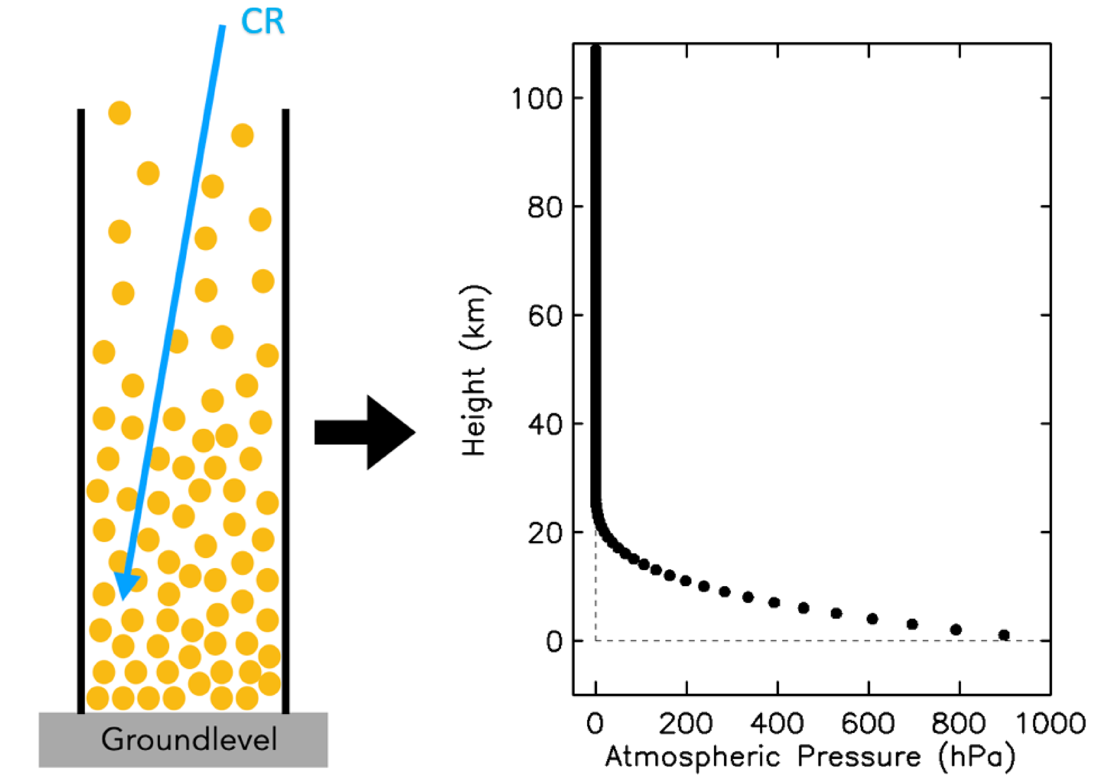

Figure 1: The effect of atmospheric pressure on cosmic rays.

- Since cosmic rays interact with atoms present in the different atmospheric layers, it is also expected that their intensity presents variations related to atmospheric phenomena at the ground level.
- Simply, we can describe the barometric effect through an absorption process of cosmic rays by the atmosphere. As a cosmic particle moves towards the ground, the greater the atmospheric pressure acting on it.

$$\frac{dI}{I} = \beta \cdot dP \tag{1}$$

Results 1

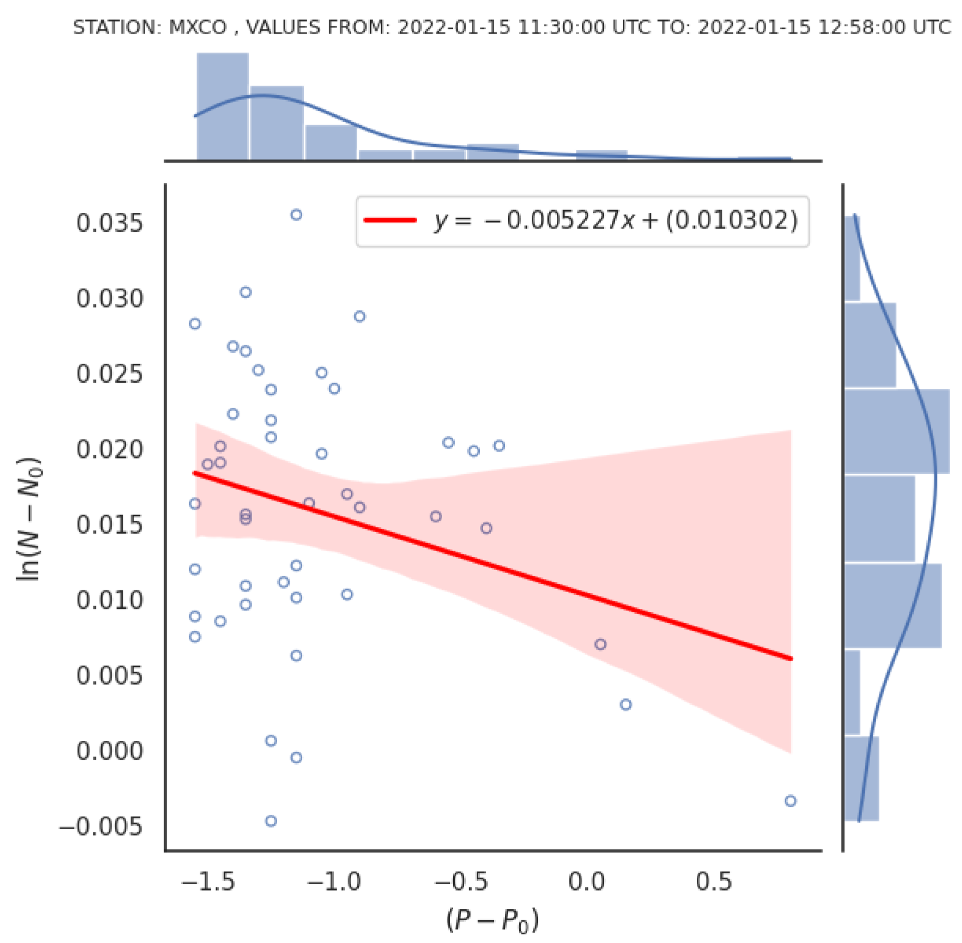

Figure 5: Correlation diagram of the cosmic ray intensity and the pressure variation for synchronous measurements during the passage of the first pressure wave from the Hunga explosion as recorded by the Mexico neutron monitor.

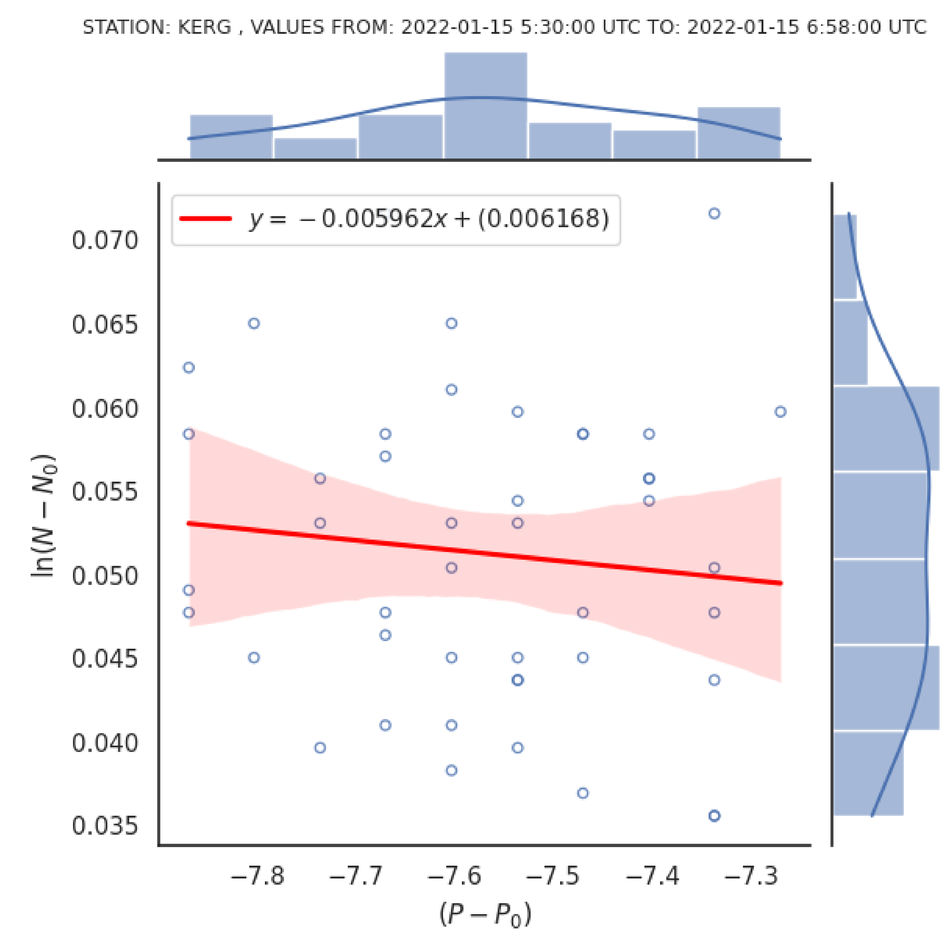

Figure 6: Correlation diagram of the cosmic ray intensity and the pressure variation for synchronous measurements during the passage of the first pressure wave from the Hunga explosion as recorded by the Kerguelen neutron monitor.

Surface Pressure Data Show Evidence of Multiple Subsequent Explosions

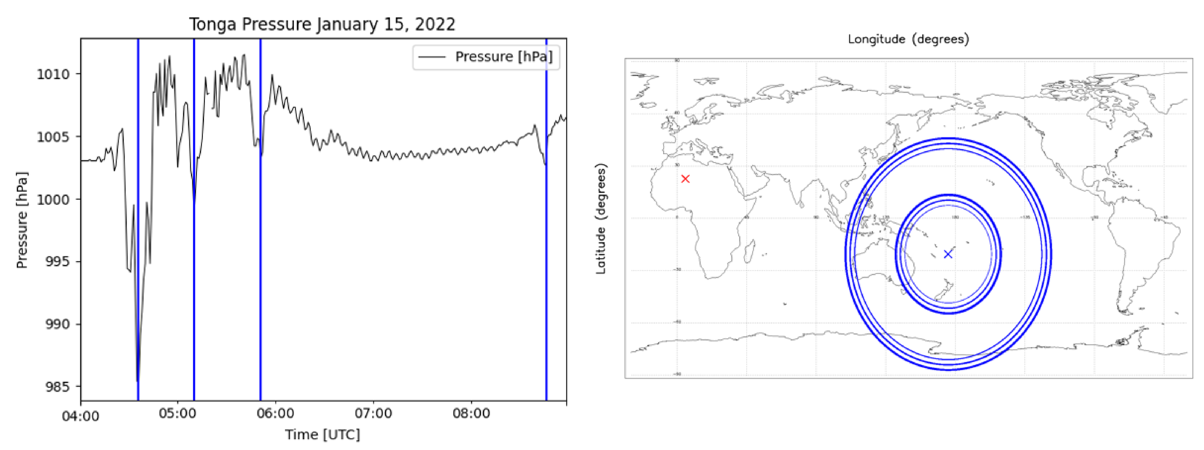

Figure 4: Left panel: Real time pressure as a function of time of the first four main pressure features. Right panel: The blue circles represent two locations of the pressure wave produced during the eruption. The red cross at Africa represents the antipodal point of the volcano location.

- In strong explosive eruptions, shock waves may be produced at the atmosphere. They travel at velocities larger than the sound speed Morrissey and Chouet, 1997. However, shock waves are not common Morrissey and Mastin, 2000 and after traveling large distances from the volcanic vent, they loss energy, decaying to a sonic wave and further traveling at the sound speed.

Conclusion

It has been seen that cosmic ray (CR) flux variations, observed at the Earth, are well correlated to trend variations (of the order of a month) of local meteorological parameters, in particular of the pressure. This allows one making corrections to the observed flux of CR due to this influence, leaving variations due to other causes (as interplanetary or galactic origin). In addition, the mitigation of the influence of the local meteorological trend, on the CR flux, makes the corrected values more sensitive to variations of transient character. On the other hand, even though the local meteorological conditions (at the Earth surface) are important to determine the flux, also the conditions at the different altitudes of the atmosphere play a role in the resulting flux. It means the integrated effect of the atmosphere on the CR paths results in the observed flux at the surface. In the present work, we explore the viability of using CR flux to identify the pass of the pressure wave thought different locations at the Earth.

References

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