

# Solar and Earth's geomagnetic activity related to M6+ earthquakes recorded between 15 and 21 September 2024

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**Abstract.** Between 15 and 21 September 2024, three strong seismic events were recorded on our planet (M6.5 earthquake recorded in Canada on September 15, 2024 at 22:22 UTC; M6.3 earthquake recorded in Mariana Islands on September 16, 2024 at 11:36 UTC; M6.0 earthquake recorded in Argentina on September 21, 2024 at 21:24 UTC). The analysis of solar activity and the Earth's geomagnetic activity has allowed us to establish that the three earthquakes were preceded by an increase in the density of the solar ion flux which determined an increase in the Earth's geomagnetic activity.

**Key Word:** space weather, seismic precursors, M6+, geomagnetic activity, proton density.

## Introduction

It was 2011 when the Authors observed for the first time a correlation between solar activity and global M6+ seismic activity. At that time, the three researchers had noticed that some potentially destructive earthquakes were preceded by a disturbance of the interplanetary magnetic field (IMF). Through a large-scale study conducted in 2012 on the physical and technical parameters of the solar wind (velocity, proton and electronic density, temperature, chemical composition, intensity of the interplanetary magnetic field, particle energy, characteristics of the Parker spiral, deflection angle, dynamic pressure) it was possible to establish that all the M6+ seismic events recorded during 2012 were all preceded by an increase in the proton density of the solar ion flux that could also determine an increase in the Earth's geomagnetic activity. This trend has been verified every year, up to today [1-50].

Solar wind data is continuously provided by:

- Advanced Composition Explorer (ACE) Satellite.
- DSCOVR Satellite.
- SOHO Satellite.

By analyzing the characteristics of the solar wind, it is possible to establish on average about 98.4 hours in advance when it is possible to expect a resumption of potentially destructive seismic activity on our planet.

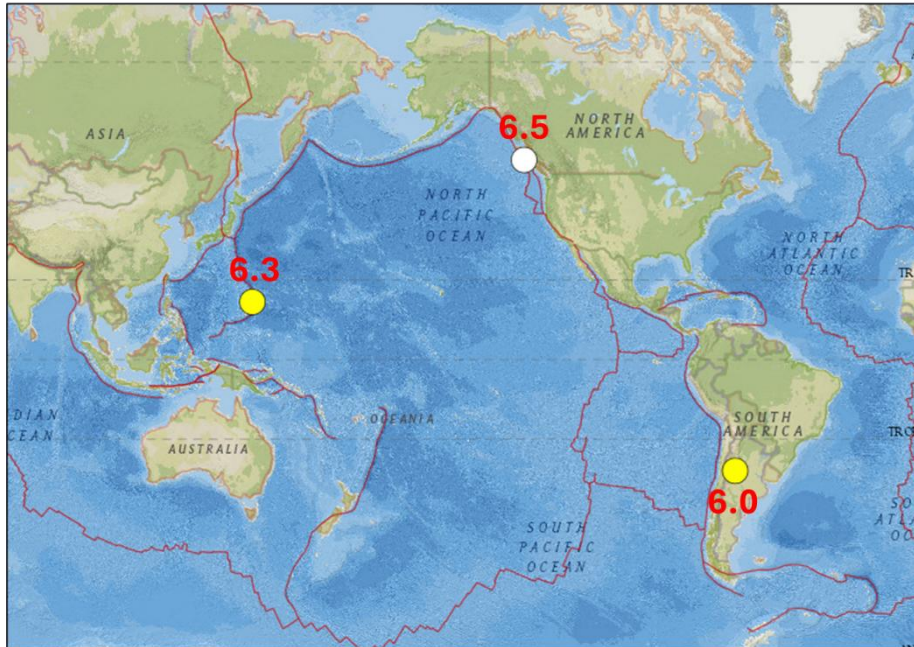
Between September 15 and 21, 2024, three strong seismic events were recorded on Earth (**Fig. 1**):

- M6.5 earthquake recorded in Canada on September 15, 2024 at 22:22 UTC;
- M6.3 earthquake recorded in Mariana Islands on September 16, 2024 at 11:36 UTC;
- M6.0 earthquake recorded in Argentina on September 21, 2024 at 21:24 UTC.

In this study, the authors analyzed solar activity and Earth's geomagnetic activity to verify the existence of a close correlation between the potentially destructive seismic activity recorded between 15

and 21 September 2024 and the solar proton flux and to establish whether Earth's geomagnetic activity is also correlated to seismic activity.

### Seismic Epicenters



**Fig. 1** Seismic Epicenters. The image above shows the seismic epicenters of three strong earthquakes recorded between September 15 and 21, 2024: M 6.5 earthquake recorded in Canada on September 15, 2024 at 22:22 UTC; M 6.3 earthquake recorded in Mariana Islands on September 16, 2024 at 11:36 UTC; M 6.0 earthquake recorded in Argentina on September 21, 2024 at 21:24 UTC. Credits: USGS, Radio Emissions Project.

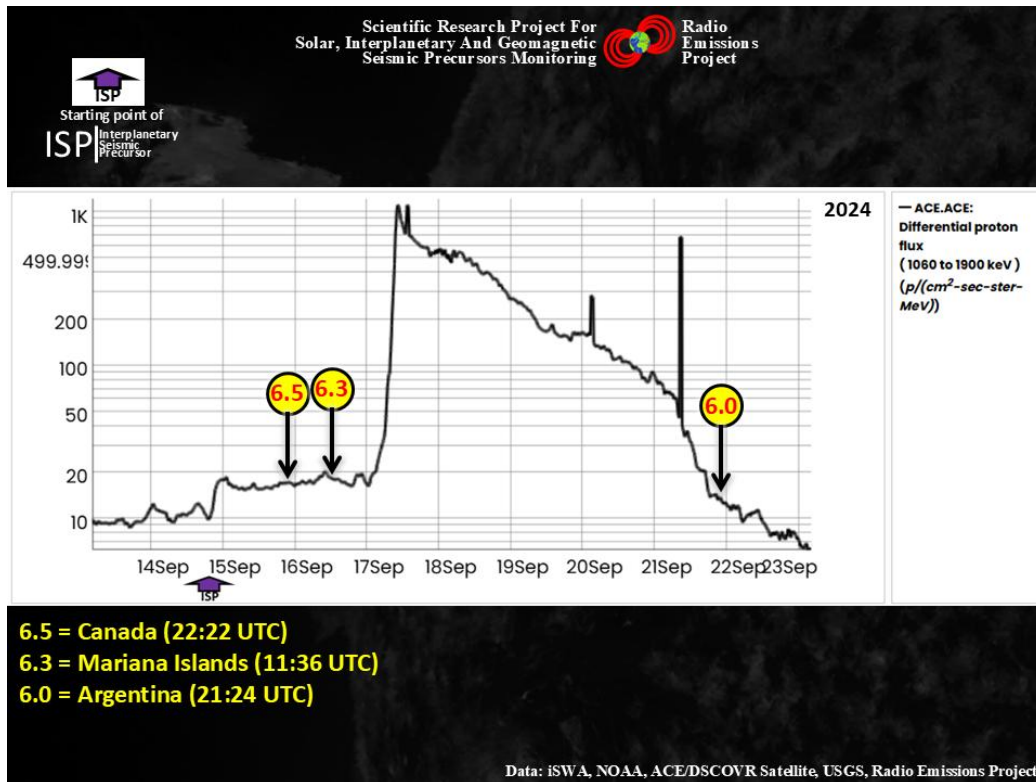
### Method and Data

The data used for this study were provided by the iSWA – Integrated Space Weather Analysis System. In particular, the authors analyzed the modulation of the solar ionic flux with energy between 1060 and 1900 keV in the time frame between September 13 and 23, 2024 (**Fig. 2**). Data on the solar proton flux density (provided by the Advanced Composition Explorer Satellite, placed in Lagrangian orbit L1) were then compared with data from the M6+ seismic events recorded between 15 and 21 September 2024 (**Fig. 2**). As was evident to be expected, thanks to the studies that the authors have conducted from 2012 to today [1-50], the three seismic events of strong intensity recorded between 15 and 21 September 2024 had been preceded by an increase in the solar wind proton flux started on September 14, 2024 at 19:40 UTC and ended on September 23, 2024 (**Fig. 2**). The maximum proton density was recorded on September 17, 2024 at 10:50 UTC. Some impulsive increases were recorded on September 20, 2024 at 03:20 UTC and on September 21, 2024 at 08:40 UTC (**Fig. 2**).

It is important to specify that the authors had noticed the beginning of the proton increase recorded on September 14, 2024 and expected a resumption of M6+ seismic activity that began a few dozen hours later. The time intervals, expressed in hours ( $\pm 30$  minutes), were the following:

- M6.5 earthquake recorded in Canada on September 15, 2024 at 22:22 UTC  $\approx 27$ .
- M6.3 earthquake recorded in Mariana Islands on September 16, 2024 at 11:36 UTC  $\approx 40$ .
- M6.0 earthquake recorded in Argentina on September 21, 2024 at 21:24 UTC  $\approx 170$ .

With reference to the two seismic events recorded before the evident proton peak recorded on September 17, 2024, it should be specified that these are related not to the maximum proton increase



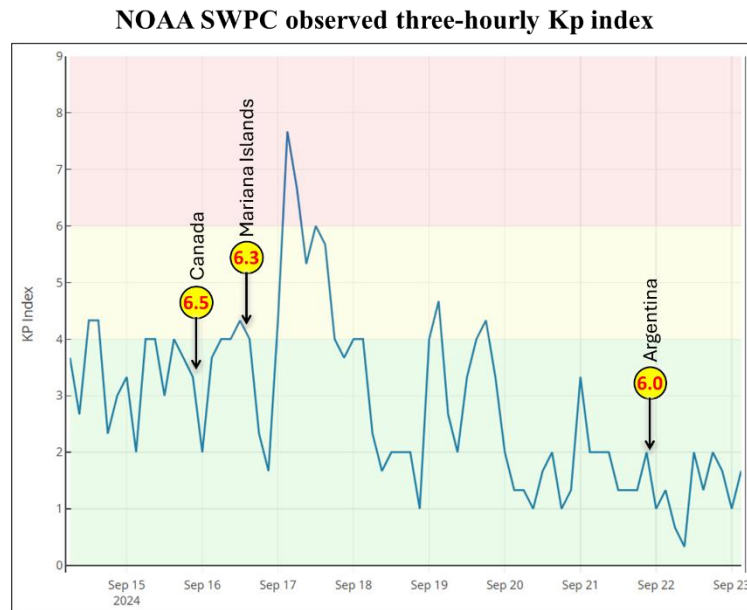
**Fig. 2** M6+ seismic sequence correlated to the protonic increase recorded between September 15 and 21, 2024. In the upper graph, the distribution of potentially destructive seismic events recorded between September 15 and 21, 2024, correlated to the increase in solar proton flux density recorded between September 13 and 23, 2024, is visible. The vertical black arrows identify the time markers of the potentially destructive seismic events recorded between September 15 and 21, 2024. Credits: iSWA, Radio Emissions Project.

(peak) but to the proton increase in its entirety, taking as a reference the beginning of the proton increase recorded on September 14, 2024. This is because every seismic event of high magnitude (M6+) is always related to increases in the solar proton flux. In relation to this last statement, the authors analysed the distribution of seismic events with respect to the variation curve of the proton density of the solar wind, finding that the greatest number of seismic events are observed during the phase of increase and decrease of the proton density of the solar wind (about 82 percent) while the rest occurs during the maximum peak reached by the proton density and during the phase in which this density returns to basal levels. The "correlation", therefore, between proton increases and potentially destructive seismic events occurs along the entire increase curve and not only after reaching the maximum peak.

Since increases in solar ion flux have a significant impact on Earth's geomagnetic activity, the authors analyzed the Kp index to understand whether the three strong seismic events recorded between 15 and 21 September 2024 were also related to an increase in Earth's geomagnetic activity. The data on the Kp index were provided by NOAA (National Oceanic and Atmospheric Administration) (**Fig. 3**). Indeed, during the proton increase, an increase in Earth's geomagnetic activity was superimposed (**Fig. 3**). More precisely, a geomagnetic storm of degree 3 (G3, at 03:00 UTC) was observed, recorded on September 17, 2024, which progressively reduced over the course of the same day, recording degree G2 (12:00 UTC), G1 (~15:30 UTC) and then returning to normal levels only at 18:00 UTC (**Fig. 3**).

## Discussion

As has been known for some time now [1-50], potentially destructive seismic activity is closely



**Fig. 3 Kp index variations.** The graph above shows the variation of the Kp index recorded between 13 and 22 September 2024. The Kp index, or planetary K index, is a numerical index that measures the level of global geomagnetic activity on Earth. It is a fundamental parameter used to describe the variations of the Earth's magnetic field caused by the interaction with the solar wind and the Earth's magnetosphere. The vertical black arrows represent the time markers of the M 6+ earthquakes recorded between 15 and 21 September 2024. Credits: iSWA, NOAA, Radio Emissions Project.

related to increases in solar proton flux. Analyzing the proton variation curve in Fig. 2, it is very clearly observed that the M6+ seismic events recorded between 15 and 21 September 2024 were recorded during the phase of increase and decrease in the proton density of the solar wind, just as the studies conducted by the authors have already ascertained in 2012. To date, the percentage of potentially destructive seismic events that are recorded on a global scale, in fact, is distributed specifically with respect to the increase curve: more than 83% of potentially destructive seismic events occur during these two phases [48]. At the current state of knowledge, the reasons for the close correlation that exists between potentially destructive seismic activity and solar activity are not known, but it is likely that a form of electromagnetic interaction may link increases in solar proton flux to seismogenesis, also considering geomagnetic perturbations.

## Conclusion

In this study it has been proven again that there is a close correlation between the variation of the solar wind proton density, the geomagnetic activity and the potentially destructive seismic activity that occurs on a global scale. This phenomenon has been observed consistently by the authors since 2012. The authors propose to use these data to improve the current seismic forecasting methods by integrating the impact that solar activity has on the resumption of M6+ global seismic activity.

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