Space weather related to M6+ potentially destructive seismic events recorded on a global scale between 2012 and 2021

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Abstract

Between 2012 and 2021, >1300 potentially destructive seismic events (M6+) were recorded on Earth: it is a number of earthquakes that over the past 10 years (2012-2021) followed the trend of the end of the 24th solar cycle (SC24) and the beginning of the 25th solar cycle (SC25) and, therefore, we can affirm that by macroscopically analyzing solar activity it was possible to find a general objective correlation between this and the number of potentially destructive seismic events that occur on Earth. But that is not all. By analyzing solar activity in more detail, it was possible to ascertain that the potentially destructive seismic activity recorded on a global scale between 2012 and 2021 is closely related to changes in the density of the solar ion flux.

Keywords: space weather, seismic precursors, potentially destructive seismic events, M6+, solar wind.

Introduction

Thanks to dedicated space missions, in recent decades man has managed to understand many things about the structure and electromagnetic phenomena that occur in the chromosphere, photosphere and solar corona. It is a series of phenomena and areas of the solar atmosphere responsible for the variation of the density and speed of the solar ion flux that is expelled into interplanetary space also towards the Earth. It is known that the solar ion flux is mainly composed of protons and electrons (about 95%), while the remaining 5% consists of helium nuclei with traces of nuclei of heavier elements. When this flow of electrically charged particles meets the Earth's magnetosphere, a series of (measurable) electromagnetic interaction phenomena occur through which it is also possible to quantify the extent of the impact that solar activity had on the Earth's geomagnetic field. Between 1960 and 1970 a series of correlations between solar activity and geophysical processes were observed for the first time [1-3], while years later it was possible to understand in more detail that the solar ion flux was related to the activity seismic and volcanic [4-16].
More recently, and precisely from January 1, 2012, the authors analyzed the density of the solar ion flux to understand if this was related to the potentially destructive global seismic activity (M6+). Already at the end of 2012, the conclusions of this preliminary study (which continues today) have established this hypothesis [17-53]. In this paper, the data obtained from January 1, 2012 to December 31, 2021 will be presented.

Methods and data

This study analyzed 1311 destructive seismic events recorded on Earth between 1 January 2012 and 31 December 2021 (corresponding to 99.92% of the M6+ seismic events recorded on a global scale between 2012 and 2021 (**Fig. 1**); percentage of seismic events for which it was also possible to have data relating to solar activity in the days preceding their registration). The catalog used on the potentially destructive seismic activity was that of USGS (United States Geological Survey) and the data on the M6+ activity to carry out this study were collected almost in real time and rechecked after a few days: it is however possible that in the course of longer time frames, some data have undergone updates or the number of potentially destructive seismic events has changed due to more precise analyzes carried out on the energy released by the seismic events. Having said this, the authors cross-referenced the temporal data of potentially destructive seismic events with the data relating to the solar ion flux, and in particular with the data of the density of the solar ion flux (mainly the proton flux).

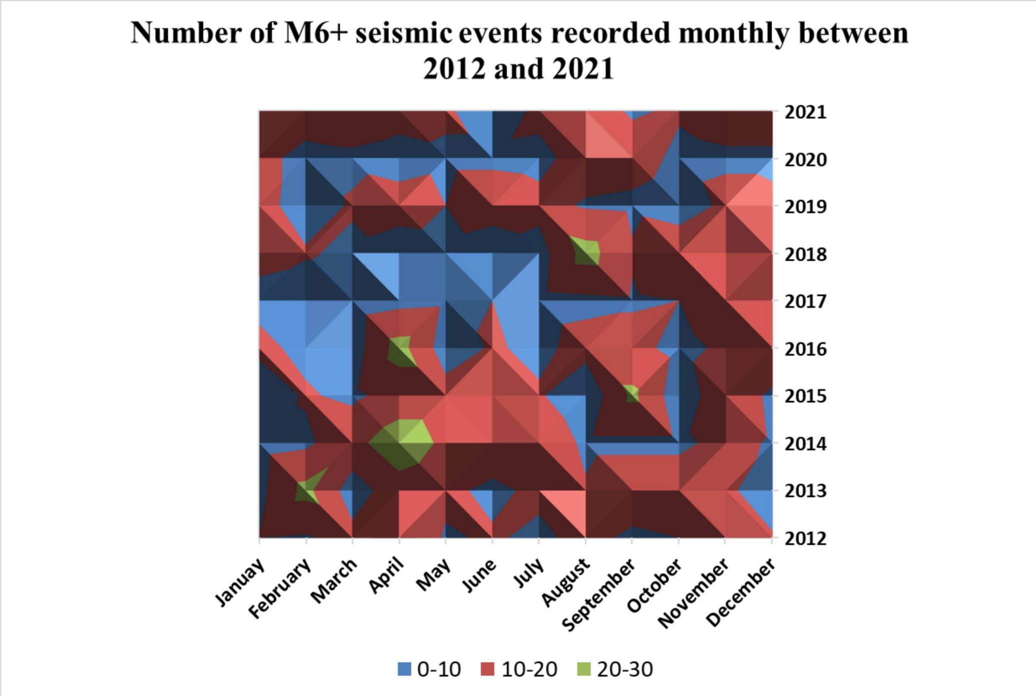

Fig. 1 – Monthly distribution of potentially destructive seismic events (M6+) recorded on a global scale between 2012 and 2021*. The graph shows the monthly distribution of potentially destructive earthquakes recorded on a global scale between 2012 and 2021. Credit: Radio Emissions Project, USGS.*

Considering the limits introduced by the technological resources used to measure the density of the solar ion flux in the Lagrangian orbit (instruments sensitivity deterioration, malfunction, etc.), the authors proceeded to measure the density of the solar ion flux by analyzing both the data provided by the Advanced Composition Explorer (ACE) Satellite, and from the Deep Space Climate Observatory (DSCOVR) Satellite. This solution was necessary to have a greater coverage of the data on the solar ion flux since during the solar minimum because the EPAM instruments equipped with ACE Satellite, relative to the proton fractions analyzed (visible below), did not always prove capable of highlighting increases of proton flows in the Lagrangian orbit L1; which instead occurred by analyzing the quantity of protons per cm^3 through the sensors of the DSCOVR Satellite:

ACE Satellite:

- differential proton flux 1060-1900 keV (p/cm^2-sec-ster-MeV);
- differential proton flux 761-1220 keV (p/cm^2-sec-ster-MeV);
- differential proton flux 310-580 keV (p/cm^2-sec-ster-MeV).

DSCOVR Satellite:

- proton density (p/cm^3).

During the solar minimum recorded at the end of SC24 and the initial phase of SC25, the measurement of the solar proton flux carried out with only the instruments equipped on the ACE Satellite was not profitable. Here, therefore, that the authors have decided to also use the readings provided by the Satellite DSCOVR to integrate them into the correlation study. In fact, this solution made it possible to verify the presence of increases in the density of the solar ion flux that otherwise would not have been identified. The monitoring of the modulation of the density of the solar ion flux has in fact the function of identifying the alternation of the phases of which the proton variation curve has been ideally divided (**Fig. 2**) allowing to identify the beginning of each single proton increase and its terminal phase: data that are necessary to subsequently calculate the time intervals related to the potentially destructive seismic activity related to the proton increment.

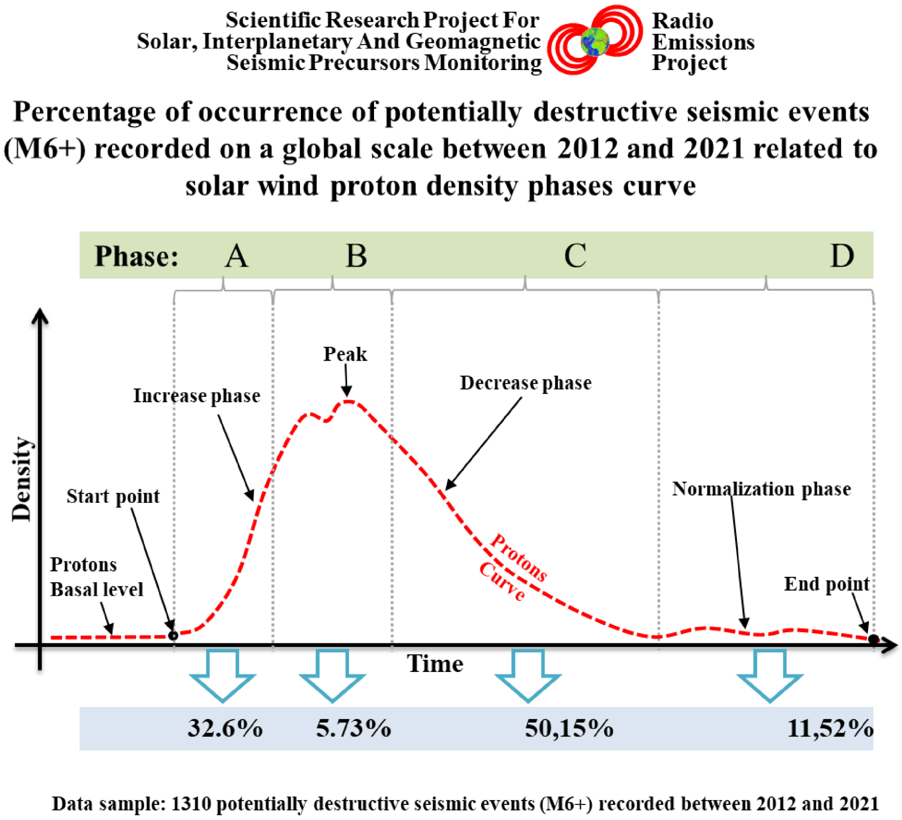

Fig. 2 – Distribution of potentially destructive seismic events (M6+) recorded on a global scale with respect to the proton variation curve. *In the graph above the typical proton curve of a "gradual" type event has been reproduced. The authors divided the variation curve into four distinct phases to simplify the description in relation to the correlation data with the M6+ global seismic activity provided by the study. Credit: Radio Emissions Project.*

By analyzing the variation curve present in **Fig. 2** it is possible to understand that the first phase is that identified with the letter "A": it corresponds to the increase in the density of the solar proton flux recorded in the Lagrangian orbit L1 when it arrives with a density higher than baseline (start point). Then the "B" phase takes over: the moment in which (± 6 hours) the density of the solar proton flux reaches its maximum variation. After this phase the proton density begins to decrease as the interplanetary bubble is moving beyond the Lagrangian point L1: thus begins the phase "C" which will end when the basal proton density level is almost reached. In the last phase (the "D") the proton density, now reduced to the minimum values, undergoes some small oscillations at the end of which (end point) the pre-increase basal values are definitively reached. Certainly, the identification of these single phases does not always happen easily: the Sun continuously emits ionic bubbles in the interplanetary medium which, due to the radial distancing, can overlap other increases already in progress, complicating the identification of each single increase. To facilitate the analysis and identification of each individual proton curve, it is essential to follow the temporal evolution of the solar ion flux in real time: this procedure allows for early identification of any overlap of secondary ion fluxes. To make this procedure even easier, it is possible to simultaneously analyze the data on the solar ion flux provided by two or more artificial satellites present in the L1 Lagrangian orbit. The authors use this procedure to identify in detail the characteristics of the various phases of increase and/or decrease of the solar ion flux that crosses the Lagrange point L1. This is also accompanied by the analysis of data relating to the variation of the Earth's geomagnetic field. In summary, the data that the authors examined to carry out this study are provided by iSWA, (Community Coordinated Modeling Center, NASA) and are:

- solar ion flux density data provided by Advanced Composition Explorer (ACE) Satellite;
- solar ion flux density data provided by Deep Space Climate Observatory (DSCOVR) Satellite;
- solar wind dynamic pressure;
- Interplanetary Magnetic Field (IMF) variations provided by GOES Satellite;
- solar ion flow rate and temperature provided by DSCOVR Satellite;

- variation of the dynamic pressure of the solar wind, distribution of electronic clouds on the Earth's orbital plane and variation of the speed of the solar wind provided by WSA-Enlil Solar Wind Prediction and Nowcast;
- Windmi (low-dimensional model of the energy transfer from the solar wind through the magnetosphere and into the ionosphere);
- ASAP flare monitor;
- ASSA detect filaments and coronal holes;
- SOHO and SDO images;
- data on the variation of the Earth's geomagnetic indices.

Returning to **Fig. 2**, after having identified the start of the proton increase (start point), a resumption of the global seismic activity M6+ is expected: this occurs on average 103.1 hours after the start of the proton increase and the temporal deviations are distribute as indicated in the lower part of **Fig. 2**:

- Phase A = 32,6%
- Phase B = 5,73%
- Phase C = 50,15%
- Phase D = 11,52%

It is not known to the authors why the majority of potentially destructive earthquakes (M6 +) that occur on a global scale are mainly distributed on phase A (increase) and phase C (decrease) but it can be agreed that these two phases represent the moments in which the solar wind proton density variation does not remain stable but tends to vary.
The authors measured the rate of change of the proton density from the moment in which the "start point" increase begins (**Fig. 2**) up to the maximum density level reached before the recording of the M6+ earthquake (which in some cases may coincide precisely with the time of the earthquake). The distribution of the rate of increase can be seen in **Fig. 3**.

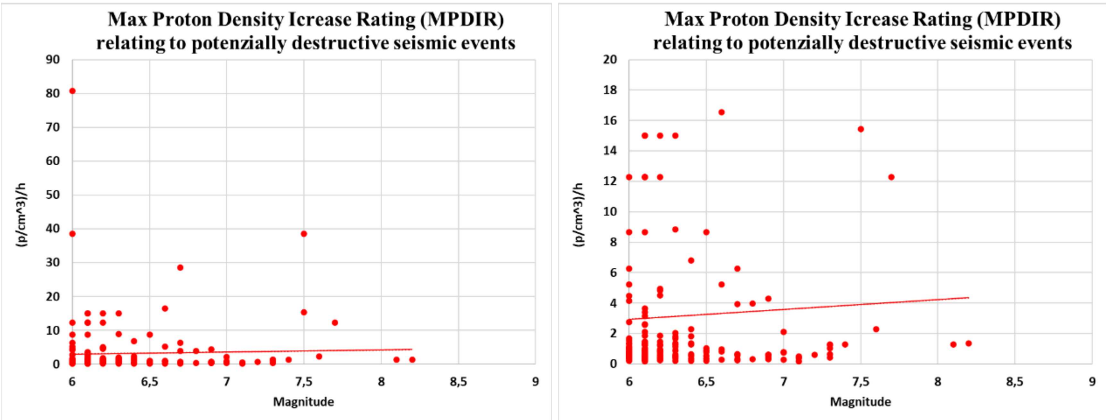

Fig. 3 – Maximum rate of increase in the proton density of the solar wind related to potentially destructive seismic activity (M6 +)*. The graphs above show the distribution of the "Max Proton Density Icrease Rating" (MPDIR) relating to potentialially destructive seismic events, calculated between September 7, 2020 and January 11, 2022 through the data provided by the DSCOVR Satellite. The graph on the right shows a "zoom" of the data represented in the graph on the left. Credits: Radio Emissions Project, USGS, iSWA.*

From the first data obtained by analyzing 186 destructive seismic events (M6+) recorded between September 7, 2020 and January 11, 2022 it was shown that the rate of increase of the proton velocity (p/cm^3)/h undergoes a slight increase as it increases the magnitude of the M6+ related earthquake. Another interesting fact that confirms this trend was obtained by measuring the proton density of the solar wind in the instants preceding the start of the proton increase (start point) (**Fig. 3**).

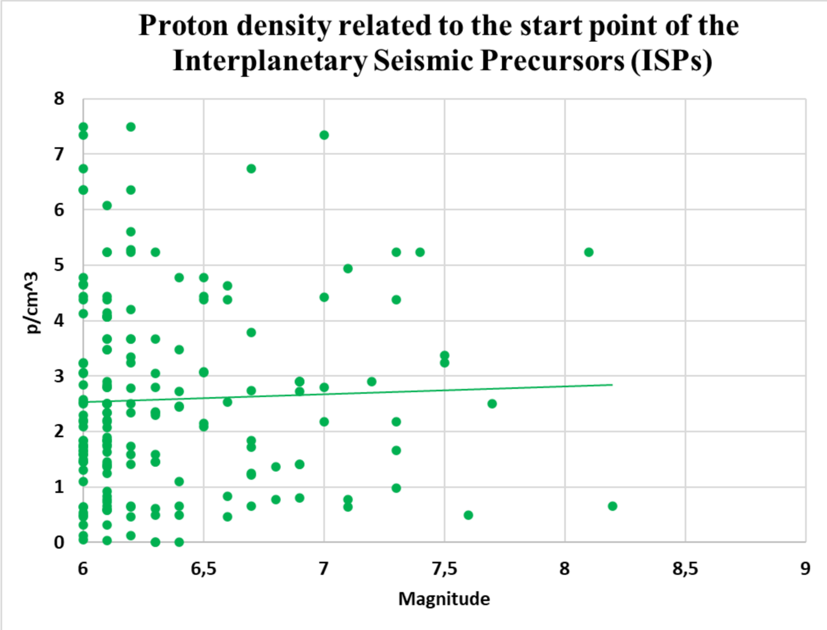

***Fig. 4 – Proton density level of the solar wind measured in the instants preceding the proton increase related to potentially destructive seismic activity (M6 +)**. The graph above shows the distribution of the basal proton density recorded in the L1 Lagrangian orbit by the DSCOVR Satellite between September 7, 2020 and January 11, 2022. Credits: Radio Emissions Project, USGS, iSWA.*

The type of correlation that was identified by the authors by analyzing data on solar activity and potentially destructive seismic activity (M6+) between 2012 and 2021 is very close: increases in the proton density of the solar wind always precede a resumption of potentially destructive seismic activity (M6+) occurring on a global scale. For this reason, the authors have defined the proton increments with the term "Interplanetary Seismic Precursors" or ISPs. Another data that emerges from the study is the maximum level of proton density reached by the solar wind before the seismic event related to it (**Fig. 5**).

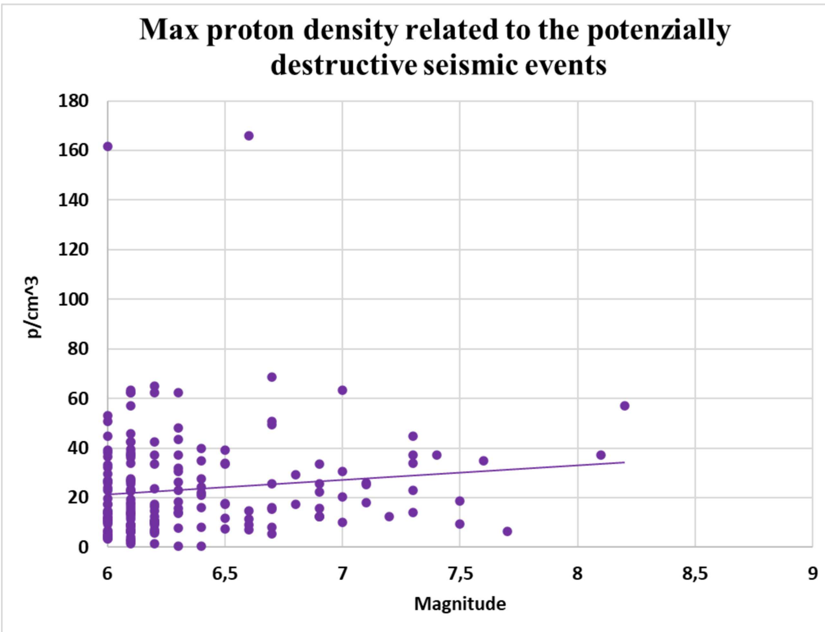

***Fig. 5 – Maximum level of proton density recorded in the interplanetary medium related to the potentially destructive seismic event (M6 +)**. The graph above shows the distribution of the maximum proton density recorded in the Lagrangian orbit L1 by the DSCOVR Satellite between September 7, 2020 and January 11, related to the seismic event. Credits: Radio Emissions Project, USGS, iSWA.*

The analysis of the characteristics of the solar ion flux allowed the authors to identify that the maximum level of proton density recorded in the interplanetary medium in the Lagrangian orbit L1 increases with the increase in the magnitude of the potentially destructive earthquake (M6+) correlated to the increase itself. Therefore, the authors ascertained that the magnitude of earthquakes related to a given proton increase in the solar wind tends to be supported both by an increase in the basal density of the solar wind, and by an increase in the maximum proton density reached by the solar wind before the associated seismic event (which in some cases corresponds to the time when the seismic event is recorded). This data underlines that the density of the solar ion flux has an influence on the magnitude of potentially destructive earthquakes (M6+) recorded on Earth. This could explain why the number of seismic events recorded on Earth every year seems to follow the course of the solar cycle (**Fig. 6**).

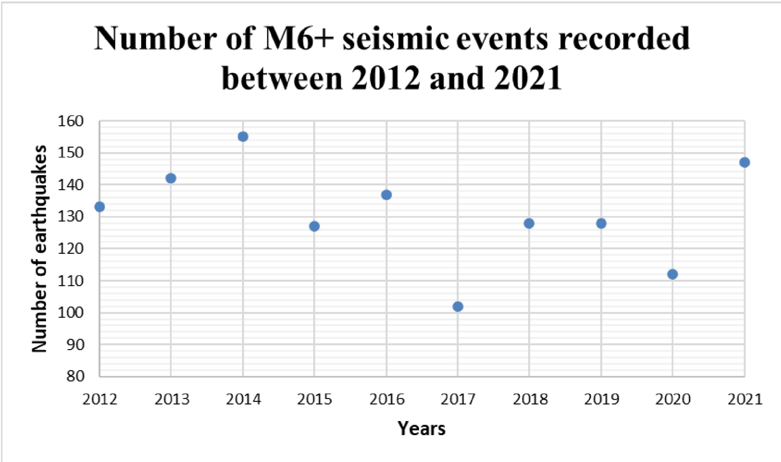

Fig. 6 – Number of potentially destructive seismic events (M6 +) recorded between solar cycle 24 (SC24) and solar cycle 25 (SC25)*. The graph above shows the number of seismic events recorded annually from 2012 to 2021. Credits: Radio Emissions Project, USGS.*

Fig. 6 shows the number of potentially destructive seismic events recorded on a global scale between 2012 and 2021. If we consider that the end of solar cycle number 24 (SC24) and the beginning of solar cycle number 25 (SC25) coincide with the date of December 2019, it is possible to observe that the number of potentially destructive seismic events recorded between 2012 and 2021 on Earth follows the trend of the end of SC24 and the beginning of SC25: in practice, the number of M6+ seismic events recorded on a global scale follows the trend of solar activity. This is a significant data that confirms, in fact, the correlation observed by the authors also for decidedly more detailed time scales, such as those in which it is possible to analyze in detail the variation of the proton density of the solar wind. [17-53].

Conclusions

The conclusions of this study confirm that the potentially destructive seismic activity (M6 +) that is recorded on a global scale is correlated to solar activity both if analyzed through macroscopic scales corresponding to annual periods, and if analyzed through decidedly smaller scales, corresponding to hourly fractions. This data emerged mainly by analyzing the proton density levels of the interplanetary medium through artificial satellites in the L1 Lagrangian orbit (ACE, DSCOVR). The analysis of these data shows that potentially destructive seismic events (M6+) are preceded by increases in the density of the solar proton flux and that the basal density level (start point, **Fig. 2**) and the maximum (preceding the seismic event M6 +; **Fig. 4-5**) increase with the increase in the magnitude of the earthquake.

The study also clarified that in the context of the research conducted on the so-called “Interplanetary Seismic Precursors” or ISPs close to the solar minimum, it is more convenient to perform an analysis of the solar ion flux by measuring the flux density through instruments capable of detecting its volume expressed in p/cm^3 (Deep Space Climate Observatory Satellite): this solution allows to identify proton increments that the EPAM of ACE Satellite instruments cannot detect.

Credits

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