Space weather related to M6.1 Indonesia earthquake recorded on June 3, 2021

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Abstract

On June 3, 2021 a potentially destructive seismic event (M6.1) was recorded in Indonesia at 10:09:58 UTC. The authors analyzed the conditions of the space weather between May 31, 2020 and June 4, 2021 to verify if the strong earthquake was related to an increase in solar activity. The results of this study showed that the strong Indonesian earthquake was preceded by an increase in solar ion flux confirming once again that the M6+ seismic activity that is recorded on Earth is always preceded by a solar wind proton density increase.

Keywords: proton density increase, seismic precursors, solar activity, Indonesia earthquake, seismic prevision.

Introduction

The study of the solar wind has allowed the international scientific community to understand the dynamics of electromagnetic interaction between solar activity and the Earth's magnetosphere. Thanks to the technological developments made from the second half of the twentieth century to today, which followed the "space race", it has been possible to obtain ever-increasing quality data on the solar wind. Currently these data are mainly used to predict the weather conditions of space; for example: to understand if a coronal mass ejection is directed towards the Earth (dangerous situation for artificial satellites and for the international space station), or to understand if a high-class solar flare may occur on the surface of the Sun triggering malfunctions of terrestrial electrical equipment. But these aren't the only uses researchers make of space weather. In the 1920s, a correlation between Earth's seismic activity and the number of sunspots was observed for the first time [54].

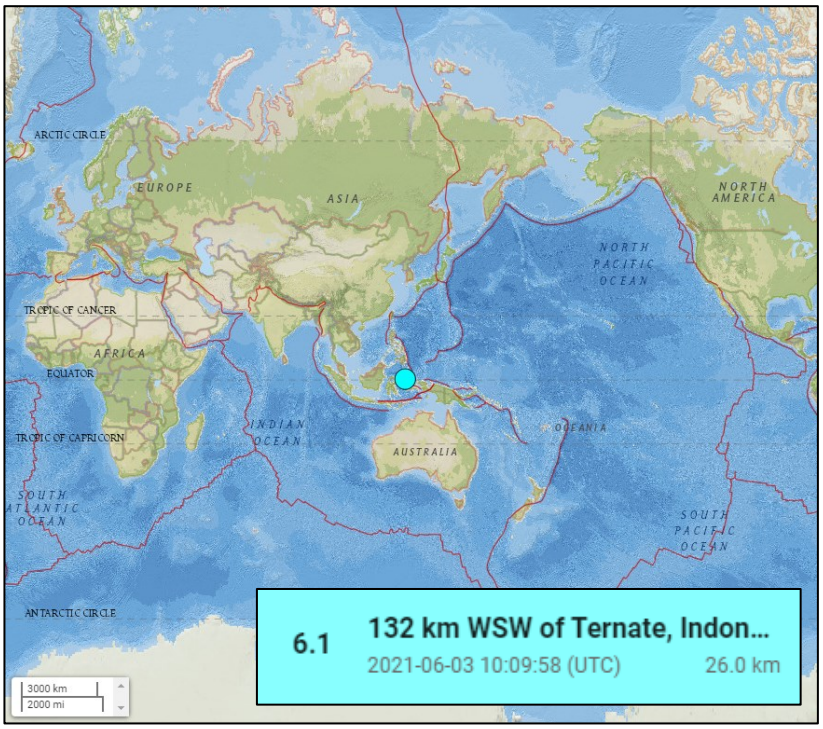

Fig. 1 – Seismic epicenter of M6.1 Indonesian earthquake recorded on June 3, 2021. In the image above is visible the seismic epicenter of the M6.1 earthquake recorded in Indonesia on June 3, 2021 at 10:09:58 UTC. Credits: USGS, Radio Emissions Project.

In 1998, a study was published that closely correlated the seismicity of the Vesuvian area (Italy) with the solar flux and variations in the Earth's magnetic field [55]. In the wake of these studies, starting from 2010 and 2011, the authors analyzed the characteristics of the solar wind (speed, density, dynamic pressure, temperature, magnetic field strength) and found that all potentially destructive earthquakes (M6+) were closely related to the solar activity. In 2012 the authors identified increases in the proton density of the solar wind as the phenomenon most closely related to M6+ global seismic activity [5-7] [9-15] [17-19] [21] [22] [25] [32] [39] [41] [43] [45-52]. In this work, the authors will present the results of the analysis conducted on space weather with respect to the Indonesian earthquake M6.1 recorded on June 3, 2021 at 10:09:58 UTC (**Fig. 1**).

Data analysis

Between May 31, 2021 and June 4, 2021, the DSCOVR Satellite (located in Lagrangian orbit L1) detected a solar wind proton density increase which reached its maximum density (45.87 p/cm^3) on June 3, 2021 at 00:40 UTC (**Fig. 2**) causing an increase in the Earth's geomagnetic field between June 2, 2021 and June 3, 2021 (**Fig. 3**).

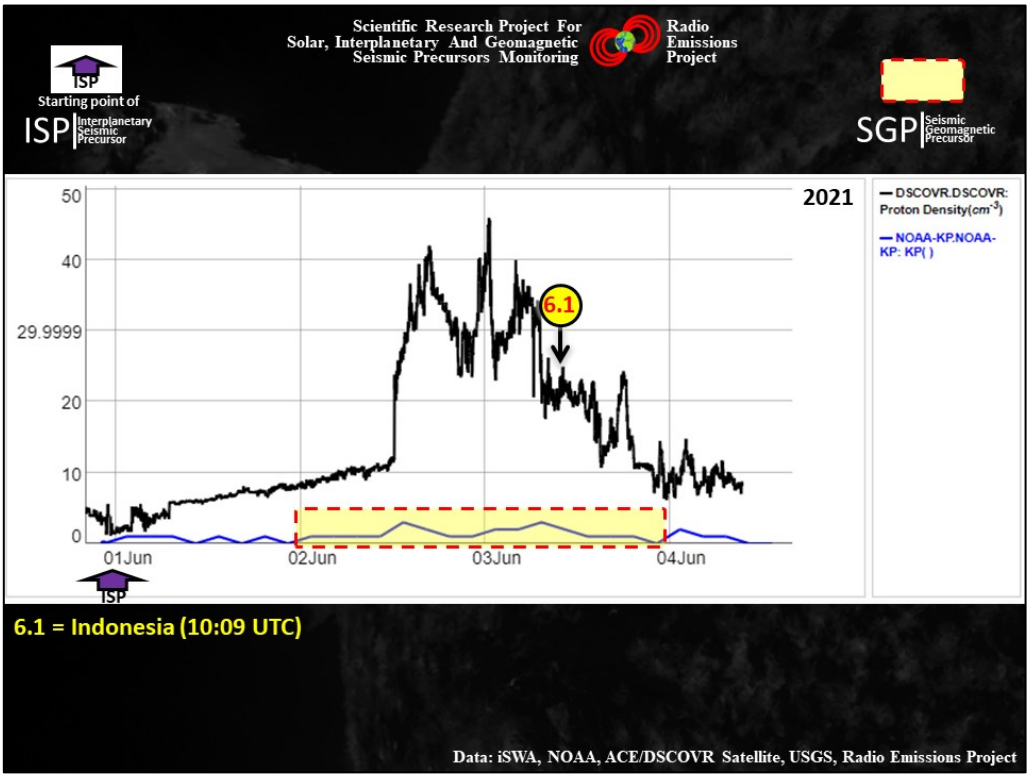

Fig. 2 – Variation in solar ion flux and Earth's geomagnetic activity related to the M6.1 Indonesia earthquake recorded on June 3, 2021. The graph above shows the time marker of M6.1 Indonesia earthquake recorded on June 3, 2021 at 10:09:58 UTC (black vertical arrow). Analyzing the data in the graph it is evident that the Indonesian earthquake was preceded by a solar wind proton density increase (Interplanetary Seismic Precursor; black curve) and by some increases of Kp Index (Seismic Geomagnetic Precursor; blue curve highlighted by the yellow area) whose maximum value was recorded on June 2, 2021 (Kp = 3) and june 3, 2021 (Kp = 3). The purple arrow indicates the start of solar wind proton density increase. Credits: iSWA, USGS, Radio Emissions Project.

The increase in proton flow started on May 31, 2021 at 23:45 UTC; the basal level of proton density before the increase reached 1.38 p/cm^3, after which it began to increase regularly for about 36 hours, exceeding 10 p/cm^3. Between June 2, 2021 at 12:00 UTC and June 3, 2021 at 20:00 UTC the proton density underwent a rapid increase and then began to decrease. During the proton density reduction phase the M6.1 Indonesian earthquake was recorded. This data confirms the trend observed between 2012 and 2019: most of the potentially destructive seismic events (49.57%) are recorded during the phase of reduction of the proton density. (**Fig. 4**). The increases in the density of the solar proton flux and the increases in the Earth's geomagnetic field are the result of the electromagnetic interaction that occurs between the solar wind and the terrestrial magnetosphere: the increase in the Earth's geomagnetic field always follows the increase in the solar ion flux in how much this interacts with the Earth's magnetic field perturbing it. But

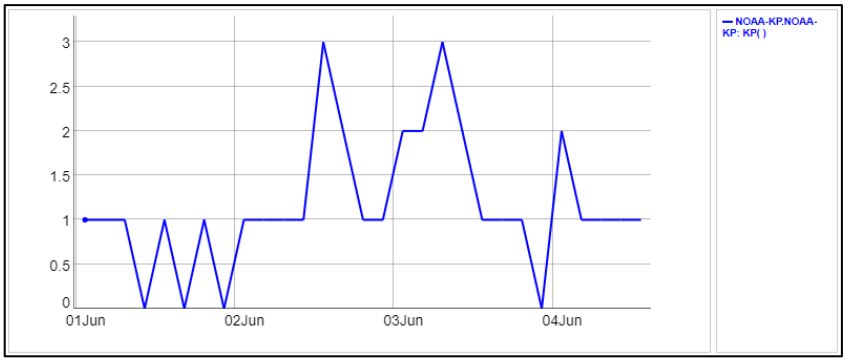

Fig. 3 – Variation of Kp-index related to the M6.1 Indonesia earthquake recorded on June 3, 2021. The graph above shows the variation of Kp-index recorded between June 1, 2021 and June 4, 2021. Credits: iSWA, Radio Emissions Project.

that is not all. The studies of the authors have shown that both of these phenomena are closely related to M6+ global seismic activity and therefore, should be considered seismic electromagnetic precursors: the first were defined by the authors as "Interplanetary Seismic Precursors" or ISPs (the whose temporal characteristics are visible in **Fig. 4**); the second "Seismic Geomagnetic Precursors" or SGPs.

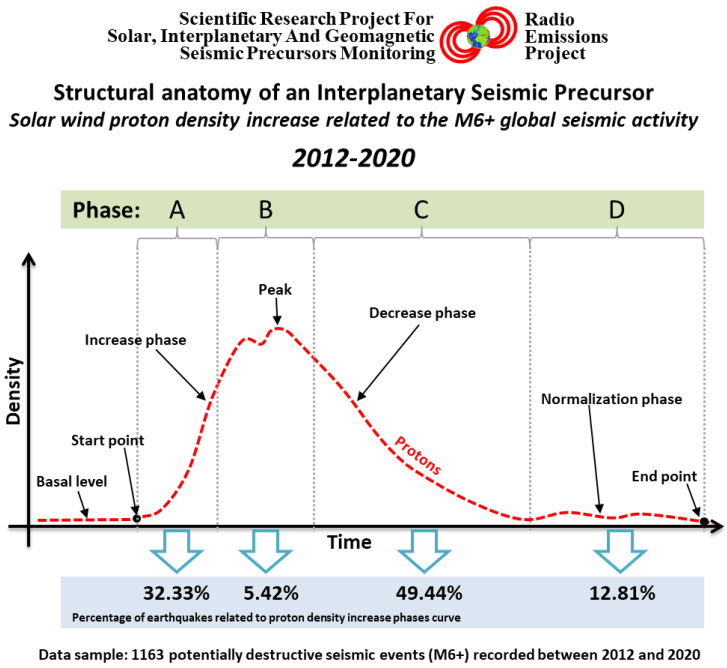

Fig. 4 – Distribution of the number of potentially destructive earthquakes with respect to the variation curve of the proton density. The graph above shows the percentage (at the bottom of the image) of potentially destructive seismic events related to the solar wind proton variation curve. The graph was created by analyzing a sample of 1051 M6+ seismic events recorded between 2012 and 2020 (100% of the potentially destructive earthquakes recorded between 2012 and 2020). The "Phase A" indicates the initial phase of the proton increase; the "Phase B" indicates the moment in which the proton density reaches its maximum value (± 6 hours); the "Phase C" indicates the phase of reduction of the proton density; the "Phase D" represents the time span in which the proton density settles to basal values. Credits: Radio Emissions Project.

The proton increase started on May 31, 2021 preceded the Indonesian earthquake by about 59 hours, and it took about 49 hours to reach its maximum density (45.87 p/cm^3). Recent studies conducted by the authors have shown that the basal level of the proton density of the solar wind which is recorded just before the proton increase and the maximum level of proton density reached by the solar wind before the seismic event associated with it is directly proportional to the magnitude of the potentially destructive earthquake. Instead, it seems that the speed rate of the proton density increase is not significantly correlated to the magnitude of the earthquake: this is the result of an analysis conducted by the authors on the solar ion flux from September 7, 2021.

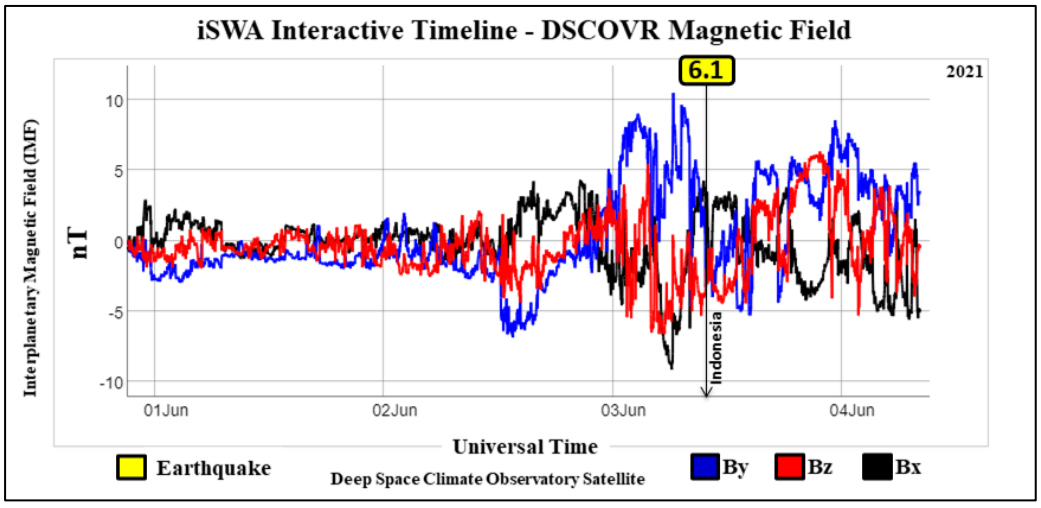

Fig. 5 – Solar wind magnetic field perturbation correlated to M6.1 Indonesian earthquake recorded on June 3, 2021. The chart above shows the variation of the interplanetary magnetic field (IMF) recorded through the Deep Space Climate Observatory (DSCOVR) Satellite in orbit at L1 Lagrange point. The recording was done on 3 axes (By, Bx, Bz). Analyzing the variation curves it is evident that the M6.1 earthquake recorded in Indonesia has been preceded by a perturbation of the interplanetary magnetic field (IMF) whose greater intensity was recorded between 2 and 3 June 2021. The long black vertical arrow represents the temporal marker of M6.1 earthquake. Credits: iSWA, USGS, Radio Emissions Project.

To confirm the existence of the interplanetary electromagnetic perturbation, it is possible to observe **Fig. 5**: the solar ion flux composed mainly of protons and electrons also carries with it the extension of the solar

magnetic field which, once it reaches interplanetary space, is called “Interplanetary Magnetic Field” or IMF. The intensity of the IMF is directly proportional to the density and speed of the solar ion flow that supports it. Analyzing the variation curve of the Interplanetary Magnetic Field on the three spatial axes as a function of the temporal data of the Indonesia M6.1 earthquake, it is evident that this was recorded after an important variation of the Interplanetary Magnetic Field. The authors first identified this correlation in 2010 thanks to some studies conducted on environmental and geomagnetic radiofrequency started in 2009 [1] [7] [31] [43] which subsequently made it possible to study the peri-seismic radio admissions [16-18] [20] [31] [43] and the implementation of RDF technology in the context of seismic prediction [24] [26-31] [33-38] [40] [42-44] [53]. Also in this case we are faced with a potentially destructive seismic event that was recorded after a series of electromagnetic phenomena of solar and geomagnetic origin [2-8] [13-15] [19] [21] [22] [25] [39] [41] [43] [45-52].

Conclusions

In this last decade, the authors have proved that there is an evident correlation between potentially destructive earthquakes and solar activity. This scientific evidence has important influences on scientific research dedicated to seismic prediction and these data cannot be ignored for a long time as they have the potential to improve current predictive methods. The monitoring of solar activity and geomagnetic activity are currently two essential activities to understand when a resumption of M6+ seismic activity is expected on Earth.

Credits

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