[https://doi.org/10.69646/bbbs2403]
Invited Lecture

Analysis of possible relationship between earthquakes and Solar flare events during Solar cycle 24

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Abstract: Earthquakes pose a significant threat to the population, causing harm to individuals and also impacting modern infrastructure. Prediction of earthquakes as a subfield of seismology aims to address questions and problems related to forecasting of earthquakes. An area of research that could contribute to this matter is the field of space weather specifically related to the impact of the sun on Earth. This brief communication presents a statistical analysis of occurrences of solar flares and earthquakes during the 24th solar cycle. Overall, the findings indicate that it is unlikely to attribute solar flares as a trigger factor for earthquake events; however, the analysis reveals a limited number of intriguing instances that warrant further research.

Keywords: space weather, earthquake prediction, statistical analysis.

Introduction

Earthquakes (EQs) are natural occurrences in which seismic waves emitted from a hypocenter propagate outward through surrounding geological structures. During an EQ, a significant amount of energy is released, resulting in potentially catastrophic effects on the population. Consequently, significant endeavors have been undertaken throughout history to assess potential precursors of EQs and to statistically ascertain them. However, predictions of EQs are still with minimal success.

This brief communication presents a statistical analysis of solar flares (SFs) as a potential trigger of EQs on the Balkan peninsula during the 24th solar cycle (SC). A multitude of literature studies have proposed correlations between different space weather parameters and EQs. For instance, solar wind (Straset et al. 2014; Cataldi et al. 2016; Marchitelli et al. 2020) and SFs (Novikov et al. 2020; Takla, Samwel, 2023) have been linked to EQs. However, there are also literature findings that raise serious questions about the predictability of EQs as a whole (Rhoades, Evison, 1987; Geller et al. 1997; Kagan, 1997; Hough, 2010). However, conducting a statistical analysis of the strongest (X-class) SFs and EQs registered in the region of the Balkan Peninsula is advantageous in order to verify possible the correlation between SFs and EQs, despite the low likelihood to accurately predict future EQs based on reported SF events.

Methods and data

The EQ data was acquired from the Earthquake Catalog of the United States Geological Survey (https://earthquake.usgs.gov/earthquakes/search/). The dataset used in this research was collected for the Balkan peninsula during the 24th SC, covering a 11-year time period with EQs of at least magnitude M≥4.0. Further data processing was conducted in QGIS to eliminate any EQs that are not exclusively located within the Balkan Peninsula.

The algorithm developed for this study was thoroughly presented in Arnaut et al. (2021). Utilized algorithm relies on the use of 5 parameters in total. The parameters used in this study include the time period (measured in days), the number of SFs of a specific class (X- class), the number of EQs, the look-back parameter that defines the duration of days before the EQ that are considered, and the number of iterations conducted by the algorithm.

The algorithm's workflow involves selecting a random sample from a specific time period for two separate groups of data. The first group, referred to as Group A, selects random numbers from a range of 1 to the value of the time period. This group is alternatively referred to as the SF group, as it employs a random distribution of SFs within a given time period. The second group, referred to as Group B, is designated as the EQ group, and values for this group are selected at random from a range of 1 to the value of the time period. This group emulates the random distribution of EQs throughout the specified time period. The initial iteration of the workflow examines each value in group B to determine if there are any values in group A prior to the given value of group B in the length of the look-back parameter. In this way, SFs and EQs are randomly distributed throughout the duration of the analyzed period. Each EQ was assessed to determine if there was a SF in the N days (lookback value) before it. The process was iterated 10,000 times, and the final outcomes were examined. Prior to executing the simulation, we conducted a count of the number of EQs that had an X-class SF(s) for the period of 14, 7, 4, and 1 day(s) before the EQ itself. If the simulated count was greater than the actual count, the results cannot be interpreted as indicating that SFs trigger EQs in general, as they do not differ from a random chance draw. In order that any correlation between these two phenomena can be considered valid, a higher occurrence rate compared to one obtained in the case of random chance alone is expected.

Results and discussion

The simulation was initially conducted for a look-back value of 14 days, which was an extremely generous duration, as there is currently no evidence to support a two-week effect following an SF. Based on random chance, the simulation predicted that 139 EQs should have an SF in the two weeks prior to the EQ. This value ranged from 102 to 176 out of the 633 EQs in total (16-27%). The actual count of the number of EQs that were affected by SF in the two weeks prior to the current data was 62 (Table 1). This number is insufficient to be considered an actual correlation for all of the instances that were displayed.

The simulation was replicated for a 7-day period prior to the occurrence of the EQ as well. The actual count of EQs that experienced an X-class SF in the week preceding the EQ was 30. However, the analysis indicates that the average count is 74, with a minimum of 46 and a maximum of 101, solely due to random chance. Just like in the previous example, this cannot be considered a correlation, since for establishing the correlation, it would be expected that the number of positive cases is much higher compared to the case of a random distribution.

The simulation was also conducted for a retrospective period of 4 and 1 day(s), yielding results for the 4-day period relatively similar to those previously discussed. However, results obtained for the 1-day period are quite intersecting. In period one day prior to an EQ itself, there were a total of 8 earthquakes with an X-class SF occurring the day before the EQ. The simulated values ranged from a minimum of 1 to a maximum of 23, with an average value of 11. The simulation was replicated with an increased number of 250,000 iterations, yielding comparable overall results, albeit with a higher maximum value of 27.

Table 1. Obtained results of the simulation

Simulation 1	**Mean**	**Min**	**Max**
Look-back parameter [days]	14	/	
True number of EQs with a SF before it	62	/	
Simulated expected occurrences EQs with SF affected days before	139	102	176
Simulation 2			
Look-back parameter [days]	7	/	
True number of EQs with a SF before it	30	/	
Simulated expected occurrences EQs with SF affected days before	74	46	101
Simulation 3			
Look-back parameter [days]	4	/	
True number of EQs with a SF before it	21	/	
Simulated expected occurrences EQs with SF affected days before	43	24	72
Simulation 4			
Look-back parameter [days]	1	/	
True number of EQs with a SF before it	8	/	
Simulated expected occurrences EQs with SF affected days before	11	1	23

SF- Solar flare; EQ- Earthquake; Number of iterations 10,000; Total number of days in the 24th Solar cycle 4379; Number of X-class SFs in the 24th Solar cycle 77; Total number of EQs in the 24th Solar cycle 633

An in-depth analysis was conducted for cases of these 8 EQs that experienced an X-class SF during the day prior. Among these 8 cases, two were noteworthy as they were involved in multiple X-class SFs in the days leading up to the EQ. The first EQ analyzed in detail was one that took place on September 25, 2011, and was “associated” with several SFs. Specifically, an X-class SF with a magnitude of X2.14 occurred on September 22, two X-class SFs with magnitudes of X2.74 and X1.02 occurred on September 24, and one X-class SF with a magnitude of X1.07 occurred on the day of the EQ. The second EQ analyzed in detail occurred on May 15th, 2013, and was “associated” with multiple X-class SFs. Specifically, there were two X-class SFs on May 13th, 2013 (X4.11 and X2.51), one on May 14th, 2013 (X4.64), and one on the day of the EQ itself (X1.85). The initial EQ occurred within the borders of Albania (city of Durres), while the subsequent one took place in Montenegro (11 km from Herceg Novi).

Based on the obtained results, SFs cannot serve as a trigger for EQs, mainly due to the complex nature of EQs, which involve numerous parameters that cannot be measured or modeled in an adequate manner. The sample size of 8 earthquakes is insufficient to draw any statistically reliable conclusions about the correlation between analyzed SFs and EQs, specifically the triggering effect of SFs on EQs. However, it remains an intriguing avenue of research that can hold significance if approached appropriately and with statistical rigor. It should be kept in mind that much previous research attempted to establish correlations between various phenomena and EQs but ultimately failed to do so, leaving the identification of a potential trigger for EQs as a still-open and very interesting topic of research.

Conclusions

This communication presents a statistical analysis of reported SFs and registered EQ events conducted to investigate whether SFs have a triggering effect on EQs in the Balkan Peninsula zone during the 24th SC. The analysis determined that although there are certain instances that warrant additional research, it is not possible to definitively establish a causal relationship between SFs and EQs or to utilize SFs as reliable predictors of EQs. In general, the evidence suggests that SFs are unlikely to be a factor in causing EQs.

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