Open Journal of Earthquake Research, 2025, 14(3), 145-163
https://www.scirp.org/journal/ojer
ISSN Online: 2169-9631
ISSN Print: 2169-9623

Solar and Seasonal Influences on Volcanoes and Earthquakes: The Rule of X Flares

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How to cite this paper: Hagen, M. and Azevedo, A. (2025) Solar and Seasonal Influences on Volcanoes and Earthquakes: The Rule of X Flares. *Open Journal of Earthquake Research*, **14**, 145-163.
https://doi.org/10.4236/ojer.2025.143009

Received: May 20, 2025
Accepted: June 23, 2025
Published: June 26, 2025

Abstract

This study examines whether global earthquake activity increases during solar maximum and seasonal changes and how it impacts the Earth's surface. Previous research indicates that certain regions are susceptible to seasonal events influenced by variations in solar wind speed, which can compress or decompress the magnetosphere. The length of the magnetosphere ranges from 10 Re to 6 Re, affecting pressure on the Earth's surface. Consequently, increased solar wind speed raises this pressure. Seasonal changes affect the Earth differently depending on how the Hemisphere is focalized. Summer in the Northern Hemisphere corresponds to Winter in the Southern Hemisphere. These external disturbances are significant in hazardous events on the Earth's surface, such as earthquakes and volcanic activity. Areas like the Pacific Ring of Fire and the South Pacific experience high seismic activity, varying with local tectonics and depth differences. This study analyzes these tectonic differences, depths, and their correlation with solar activity and seasonality.

Keywords

Solar Maximum, X Flares, Seasons, Earthquakes, Volcanos

1. Introduction

A prior study [1] examined the seasonality variation and periodicities for deep and ultra-deep earthquakes worldwide (DQ and UDQ). The main reason is that the number of shallow earthquakes may have several non-natural causes, including human interference. Hence, a statistical result will be compromised to provide an honest answer unless we establish variables to keep it connected with natural events. One example is seasonality worldwide, which is a trick for earthquakes.

*Retired.

Northern and Southern hemispheres deal with opposite seasons simultaneously, as Summer in the North means Winter in the South, as we will describe later. The authors in the paper [2] pointed out the Sun as a potential precursor to earthquakes. The problem arises when we compare solar data with earthquake events worldwide. A few facts are missing, such as the interaction between the increase or decrease of the solar wind, the earth's tectonics variation by area, such as subduction or the kind of fault, and the magnitude of the earthquake event.

Many results in investigations may be misleading or inconclusive. Earthquakes and volcanic eruptions happen according to several factors, such as location and tectonic activity in the area studied. It is a try to find out if the seasons and solar activity are able to enhance or decrease the hazard natural events.

The earthquake catalogs used were the American catalog, USGS, and the European-Mediterranean Seismological Centre (EMSC). For volcanoes, the reports came from the Smithsonian Institute, and for solar events, are from NASA and NOAA. Catalogs have shown the possibility of taking data for a lengthy period and offer reliable information nowadays.

Other variables must be considered since the Earth's surface is inhomogeneous, and its structure varies in the Northern hemisphere, where we have more land, from the Southern hemisphere, with more oceans.

On Earth's surface, there are three main types of faults: standard, reverse, and strike-slip. These faults are classified by the direction of movement and the separation angle from the surface. Faults are an essential factor for developing our analysis in this paper, as seen in [1]-[3]. The deepest earthquakes considered in the paper happen in the subduction zones. However, South America does not follow this rule.

Before going ahead, the depths of earthquake occurrences are categorized into groups: shallow, intermediate, and deep. The shallow tremors are within the earth's crust and typically have a depth of 0 - 70 km. Those events could be triggered by anthropogenic events or superficial ones such as meteorites, oil and gas exploration, and other superficial disturbances. The intermediate tremors happen at the upper mantle, ranging from 70 - 300 km depth. Deep earthquakes reach into the mantle with depths between 300 - 700 km. Very deep occurrences occur under subduction zones. Extremely deep earthquakes happen below 700 km and are seldom detected. Subdividing the depths will not cause misleading information; therefore, it is better to ignore all the shallowest earthquakes since it is not possible to know what triggers shallower earthquakes.

The levels considered here are 70 - 100 km, 100 - 200 km, 300 - 400 km, 400 - 500 km, and ≥500 km. Some areas produce earthquakes in almost all depths, although saw later that regions where one of those depths did not produce any tremor, or it was so rare that the data was ignored.

Our records in USGS, for deepest earthquakes are all in the location known as upper mantle. This paper deals with locations below 70 km and the level below the Moho discontinuity observed in the diagram.

There are a few studies about stratigraphy and physiography in the Southern

Pacific, most at the Nazca subduction zone, that do not explain the lack of deep-depth earthquakes in the area; instead, the deep-depth seismic activity is all in the area discussed in other papers [4] [5].

The depths involved complexity, and, in this report, we consider the Earth's crust divided into several layers, as explained later. In South America was proposed an occurrence of a possible anomaly in the lithosphere within the approximate coordinates 22.954 N, 60.253S, −58.98E, −140.273 W. Those coordinates delimit a region that shows intraplate events in the South American tectonic plate. Data suggested that the fabric formation at this depth does not follow the upper mantle theory. Our results indicated that the activity observed is different for each level considered.

We compared this area with other regions, including the Northern Pacific, which comprises China, Japan, the Philippines, and Russia, and the Southern Pacific, which includes Indonesia, Australia, Samoa, and New Zealand. It all fits the theory that earthquakes at those depths are located at the subduction zones. However, South America does not support this explanation since the observed ultra-deep depth events were happening far from the subduction zone and entirely within the continent, most for depths ≥ 500 km, where the earthquakes were intraplate. Therefore, the coordinates around the area differ from worldwide approaches and are being studied separately. Once the depths for earthquake occurrence worldwide, we are going to examine how external factors would influence the surge of such events [6]-[8].

A detailed statistical study for ultra-deep earthquakes, as defined here, will provide evidence of any enhancement of such events during seasons, which are determined by the Earth's movement around the Sun.

In January, the Earth is at the perihelion, the minimum distance from the Sun. A similar study on the moon has already been published [3]. For seasonal changes, consider the tilt of the Earth's axis at 23.5 degrees, which causes the Sun's light to hit different regions of the Earth.

The inclination of the axis and the position around the Sun means that other seasons are observed at various points in the year in the Northern and Southern Hemispheres. Summer and maximum sunlight in the Southern Hemisphere fall in January, while peak sunlight and the summer season in the Northern Hemisphere are in July. Spring and Fall happen when the Sun's energy appears to be directed toward the Earth's Equator. March 20 or 21 defines the vernal equinox, which marks Spring in the Northern Hemisphere and Fall in the Southern Hemisphere. On September 22 or 23, the Earth reaches the autumnal equinox, indicating the arrival of Fall in the Northern Hemisphere and Spring in the Southern Hemisphere. The following section starts by examining the occurrence of deep and ultra-deep quakes worldwide. The magnitude of events is M ≥ 4.5 if there are shallower events. If the quakes are deeper, we must decrease the magnitude to M2.5, meaning the deeper depth is the earthquake and the magnitude detected by the instruments.

It is essential to say that the recorded volcanoes are mostly on land around the Ring of Fire; thousands of submarine volcanoes have not been monitored so far. For the Sun connections, we use NASA and sometimes the NOAA catalogs. There are other variables to consider since the Earth is not a homogeneous surface, and its structure varies in the Northern Hemisphere, where we have more land and oceans than in the Southern Hemisphere. In this 3D system, the Earth is a non-homogeneous structure, as evidence shows beneath the crust, with variable earthquakes and volcanic events [9]-[11].

The lithosphere is highly irregular, and the structure of the crust varies in the North, with more land and ocean in the South. There are also differences among the plates or faults: convergent, divergent, and transform. It discussed the influence of the platform's shapes during an earthquake and how important the subduction zones are for deep-depth tremors.

2. Worldwide Analysis of Earthquakes by Depth

The first pictures show the evolution worldwide during the two solar cycles. There are some crucial facts in **Figure 1**. Minor enhancements were observed during the solar maxima years, such as 2000 and 2014, but the increase in the events that occurred most in the minima range occurred from 2003 to 2008; then, the quakes started to increase again. In this period, the earthquakes between 70 - 100 km were deeply affected, and after 2010, they restarted to rise, with a maximum occurrence in the solar maxima 2014 [12].

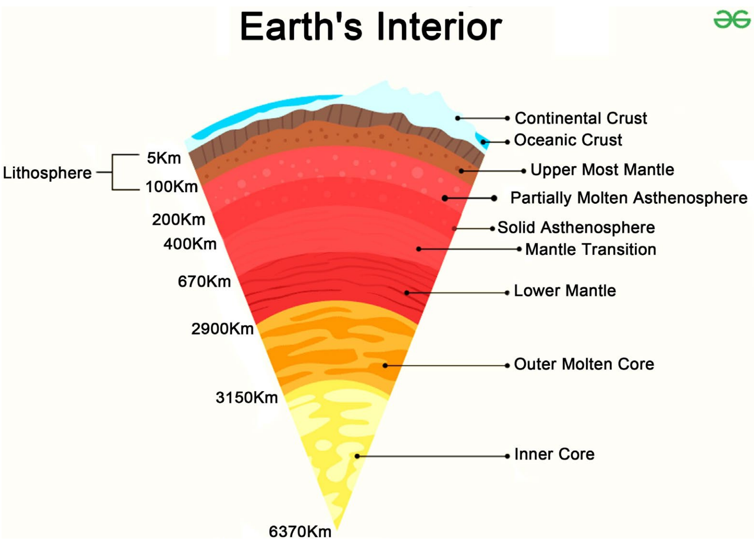

Figure 1. Earth's internal layers and their discontinuities. Our paper examines each of these layers as shown. (https://www.drishtiias.com/mains-practice-question/question-911/pnt)

Then, the next step was to observe in which areas the enhancement occurred and analyze the particularities of each area where the enhancement occurred.

The following plot, **Figure 3**, shows how events vary at the Northern Pacific plate during the same period in depth.

The depths in the plot are 100 - 200 km, 200 - 300 km, 300 - 400 km, ≥500 km. The first three ranges vary according to solar variation, such as the solar minimum, such as 2010 and 2016.

The three shallow layers exhibit varying activity differences within the upper mantle. The 100 - 200 km layer displays a smoother behavior compared to the 300 - 400 km layer, which shows increased activity between 2003 and 2009. Conversely, the 200 - 300 km layer experienced a decrease in activity during the same period, with a notable decline from 2001 to 2009. Each 100 km interval reveals distinct performance characteristics, indicating ongoing processes within these regions of the upper mantle that are not yet fully understood. It is incorrect to categorize a specific region as the "upper mantle" without additional considerations and assumptions for each location. While ultra-depths such as 400 - 500 km or greater than 500 km are still considered part of the upper mantle, the performance of the first layer differs significantly from the second, with augmented activity observed only in 2008 at the deepest depths.

However, it is not synchronized with depths, indicating that the deeper depths show increases, perhaps connected with the Earth's core instead of outside. The following characteristics of 2010 are observed: the maximum number of events that occurred at depths greater than 500 km, the frequency of quakes on the west side of the North Pacific, and below this depth.

There was no evolution increasing to those depths or any connection with solar cycles, and tremors appeared unlikely following the rule of Solar cycles, see **Figure 2**.

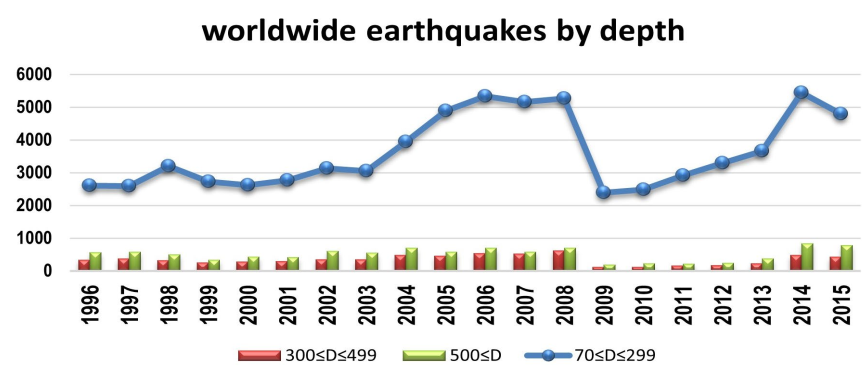

Figure 2. The variation of earthquakes 1996-2015, two solar cycles, all the depths showing an enhancement in the solar cycle maxima as 2000, 2014.

Now, the South Pacific plate is divided into two parts: the Southern Pacific and South America. This is due to the extreme location differences seen in the subsequent plots. **Figure 3** shows Australia, Indonesia, Samoa, and New Zealand; the maximum was in 2008, at depths of 300 - 400 km.

However, the depth of earthquakes in the South Pacific is highest around the Fiji region, with more tremors with depth ≥ 500 km than those with depth 300 - 400 km. The southern Pacific did not show any specific pattern. Were there any sudden increases in the events during the entire period, South America showed the only differences in the earthquakes on the continental shelf. The conditions of earthquakes in the Southern Pacific are different than those in the North due to the vast continental land in the North and massive oceans in the South. (Figure 4)

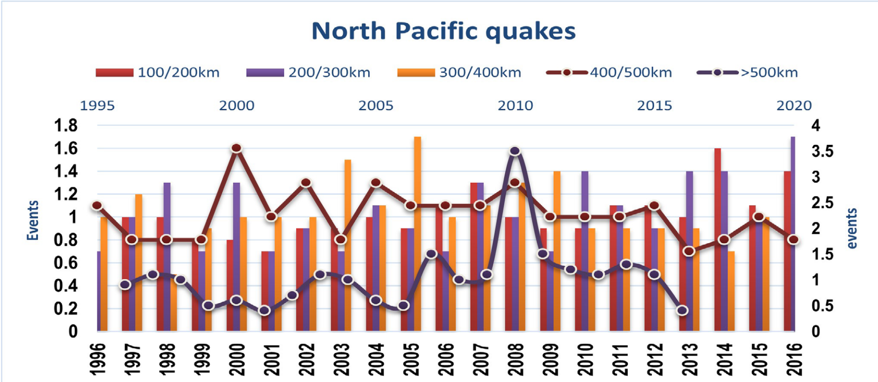

Figure 3. The variation in the North Pacific plate from 1996 to 2016 for several depths, more complicated than the worldwide variation, displayed.

Despite those differences between the North and South Pacific, examining a special plate, such as the South American plate, is still necessary. Ultra-deep earthquakes in South America showed a pronounced increase in activity in 2015. That means the tremors occurred inland, but there are few quakes between 300 - 500 km, which are happening most on the border of South America. (Figure 5)

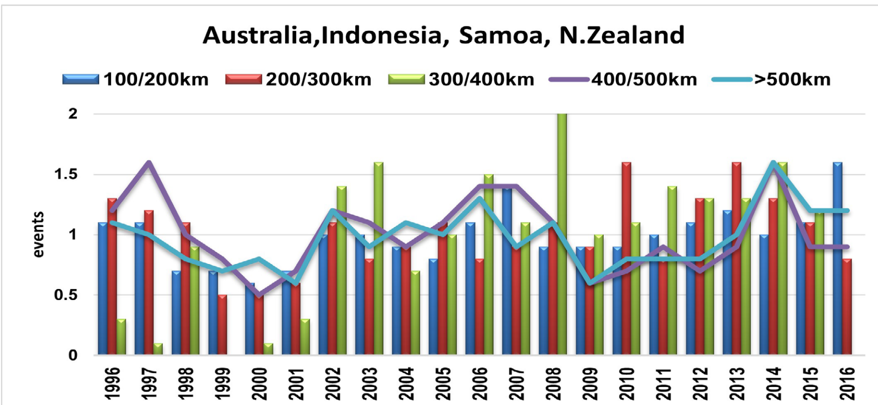

Figure 4. The depth variation in the locations as, Australia, Indonesia, Samoa and N. Zealand at Southern Pacific. Observe the total activity for the layers, 400 - 500, ≥500 km followed the same pattern.

An analysis of the South American platform, concerning the depth of the lack of data, between 300 - 500 km, shows that the occurrences where such a small number made a statistical view impossible (Figure 5). When we work in deep depths, it is a challenge to know if those occurrences are disturbed by external factors. However, by dividing the layers as displayed in Figure 1, it is easy to perceive the differences in the seismic activity variations. The following paragraph aims to find out if seasonality and tremors have some connection between the events.

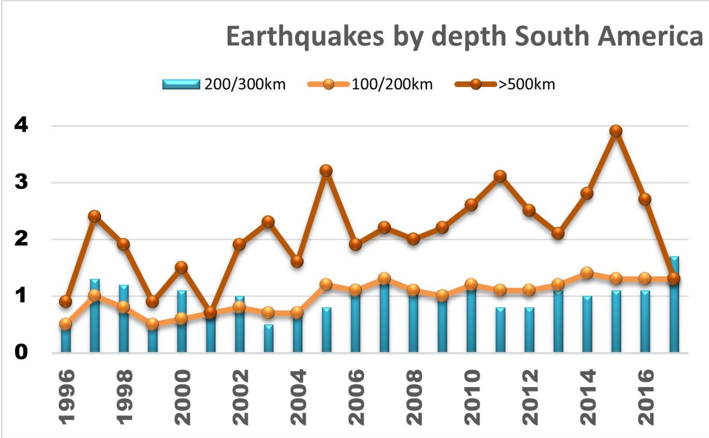

Figure 5. The South American earthquakes by depth, observe that the 300 - 400 km depth was insufficient to be considered.

Analyzing three regions revealed differences in earthquake behavior within the upper mantle layers. Despite significant similarities among the levels, deeper depths exhibited different earthquake activity compared to the upper layers. Additionally, it was observed that low solar activity corresponded with a higher number of tremors than coinciding with high solar activity.

The solar minimum showed for all the layers examined some variations in the seismic activity. The earthquakes worldwide evolution revealed that the upper mantle is heterogeneous, with varying patterns to different depths over time. The next step is to explore the seasonality and whether the earthquakes responded to seasons.

3. Seasonality of Earthquakes Worldwide

Let us observe the analysis of earthquakes in the North Pacific, which presented anomalies in 2004 and 2005 in the Summer and Fall. Figure 6 first shows this variation in the North Pacific region.

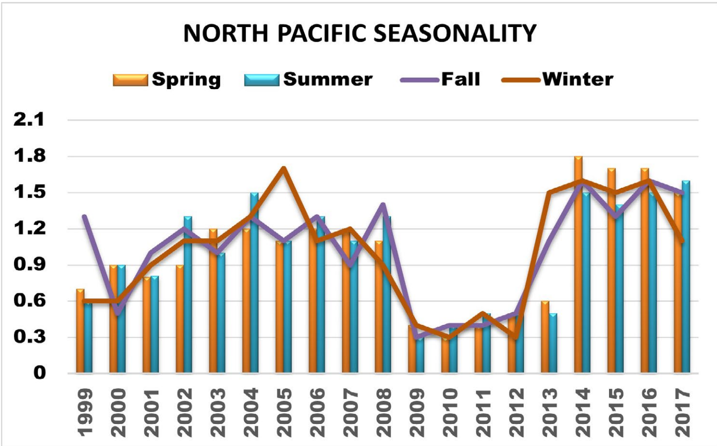

Figure 6. The variation of quake occurrences during two solar maxima. Observe that the decrease in events is correlated with the year. Observe the decreasing trend from Winter 2009 to Spring 2012.

The North Pacific region shows earthquakes rising in 2005 and suffering a severe decrease between in all seasons for 2009 and 2012 Spring. In 2013, Fall and Winter showed an increase, remaining high for the rest of the period examined. It happened for the next two seasons after 2014, the second solar maximum in the period analyzed.

Therefore, it is the first indication that earthquakes follow paths not only depending on seasons but also from the location examined.

As we see in Figure 7, the locations in the Southern Pacific are shown. In this part of the study, all the decay of events between 2009 and 2012 was observed. Winter and Spring sparked a small increase in some years. However, the seasons play smoother variations for earthquakes in this area.

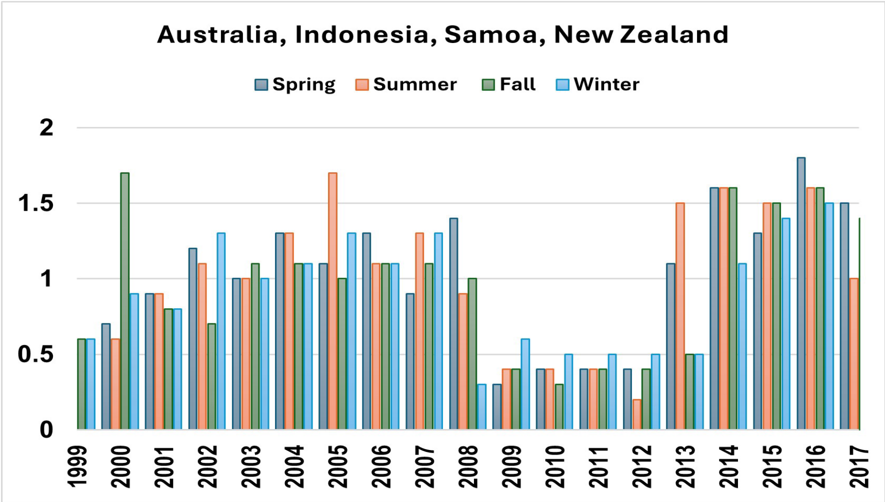

Figure 7. The variations of tremors with the seasons in some locations in Southern Pacific. Observe the decreasing period from winter 2008 to winter 2012.

In Figure 7, earthquakes increase more in the Summer or Fall. It is also clear in the picture that there is a gap between 2008 and 2013 when the tremors decreased and began to increase again in the Spring of 2013; however, it falls to a minimum in the Fall and Winter. At the solar maximum of 2014, the quakes increased except during the Winter. However, the path the quakes have increased most in Spring or Summer is still in the picture. Observations of earthquakes in this region indicated a decay in the number of quakes between 2009 and 2013. The variations for earthquakes during seasons show those occurrences for all seasons, including the enhancement in some seasons. However, in the solar maximum, more events appeared, mostly in spring, summer, and fall [13] [14].

Figure 8 shows the Philippines and the variations of earthquakes in the region. It is observed that the events did not change much, and the only year presenting a difference and sudden increase in the events was in 2010 during the Summer. Another interesting observation was in the Winter of 2012, with no occurrence of earthquakes in the region studied. The number of earthquakes decreased after 2010 compared with the previous years. The Philippines shown that earthquakes most happen in Spring and Summer, and in 2010, there was an anomaly in events during the Summer.

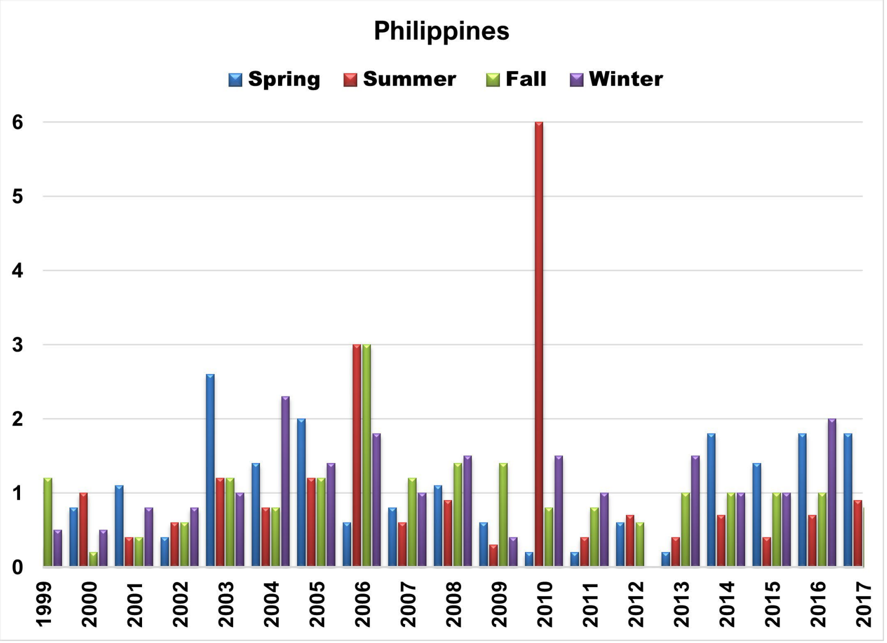

Figure 8. The variation in the Philippines and a considerable enhancement in 2010 during the Summer. Other years do not have remarkable variations for any season.

The next region is South America, which is an abnormal region. There are seasons without quakes occurring during the solar minima. South America has presented unusual behavior through the seasons, which makes us unsure how much it is due to external factors. Figure 9 shows an interesting seasonal characteristic in the region: there were not enough events during some of the seasons.

The seasons with absent quakes were Spring 2000, 2001, and 2017. The increase in events occurred in 2015, as well as in the spring.

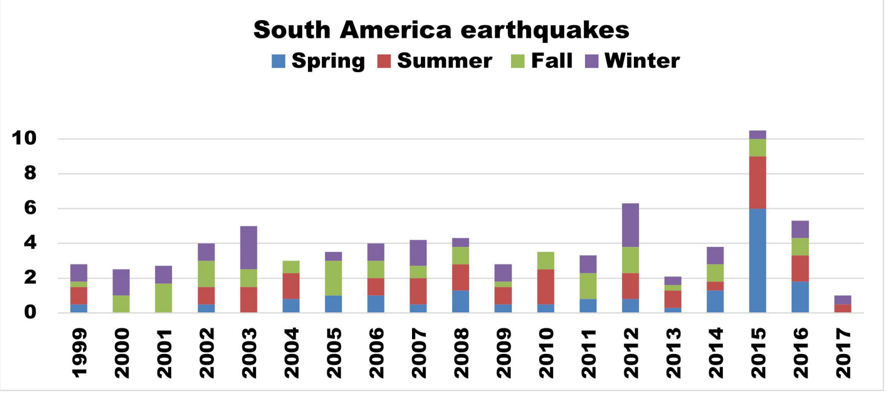

Figure 9. Shows the seasonal earthquakes in South America.

Observe the year of solar maximum 2000, and the absence of earthquakes in

Spring and Summer.

In 2015, there was a spike in the spring and summer, particularly noticed in 2014, when the maximum solar cycle was 24.

External factors such as X flares generate geomagnetic storms that may affect earthquakes and volcanoes on Earth's surface.

South America is one of the most complicated continental structures. The Nazca plate subducts under the platform and pushes against or towards the land; therefore, with several external forces such as Earth's rotation, the axis translations, the variation of Solar wind speed, and variable pressure on the magnetosphere. Dividing each location into North Pacific, South Pacific, Philippines, and South America, it is observed that regions near the Equator show less pronounced seasonal variations. Polar regions experience extreme seasonal differences, with extended periods of darkness in some months. The Northern Hemisphere has seasons that are opposite to those of the South.

Tropical areas near the Equator have wet and dry seasons instead of four distinct seasons. This study considered meteorological seasons based on temperature cycles, such as Spring, Summer, Fall, and Winter. Most locations experiment with four seasons; however, the timing and intensity of those seasons vary significantly based on location and regional climate conditions. At this point in the research with different scenarios and regions examined, the connection between solar cycles and quakes is not pronounced, although there is a minor increase during springs.

Still important to investigate Solar activity in its extreme events as X flares towards the Earth's magnetic field.

The 29-31 October 2003 space weather superstorm, also called the Halloween storm, attracted wide attention in scientific and industrial communities and among the public. It is probably one of the best publicly reported storms and the best-recorded storm event ever because of the increasing scientific instrumentation, especially in space.

Let us go back to the earthquake analysis during this year and the following year. This flare occurred in October; it was the end of 2003, so it is expected to affect the following year, despite being at a solar minimum. It confirmed that it happened next year (2004) during the Winter in the Northern Hemisphere and the Summer in the Southern Hemisphere. The most recent data for earthquakes and solar flares during the period 2023-2025 indicated disturbances in the climate temperature. However, in the next paper, we will try to explain the real possibility of those connections to the weather system. Next, the paragraph examines if there is a seasonality in volcanic eruptions.

4. Seasonality of Volcanic Eruptions

Figure 10 shows the data on the North Volcanoes from the 1960-2020 seasonality. Observations must be divided into two kinds of plots, verifying the maxima and minima for each season. Spring and Winter are directly proportional, while Summer and Fall are inversely correlated. The enhancement of eruptions occurred mostly during the year of the minimum solar cycle; however, it may relate to other events, such as the X solar flares.

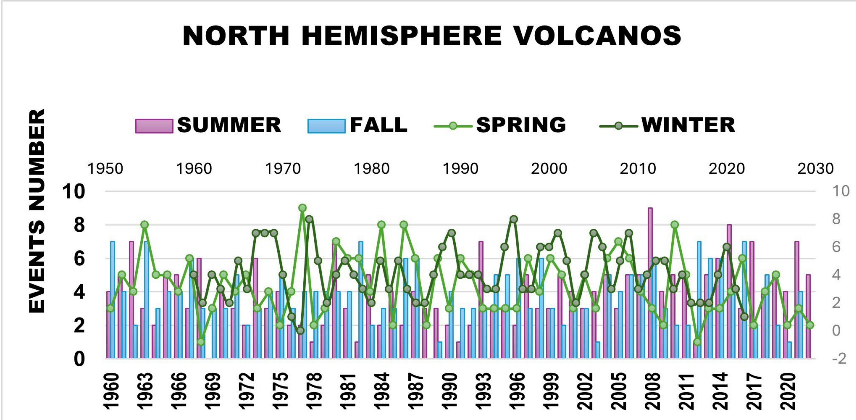

Figure 10. Eruptions Northern Hemisphere 1960-2020.

The next plot, **Figure 11**, shows the Southern Hemisphere eruptions between 1961 and 2020. It is clearly connected to Fall as a season of an enhancement of eruptions, corresponding to the Spring in the North. In 2003, there was an apparent increase in volcanic activity. As we discussed, in the Northern Hemisphere, there is a solar minimum, but Earth was hit by a massive solar storm this year. Observe that volcanic eruptions and a surge of earthquakes happen most in Spring and Summer in the Northern Hemisphere in subduction zones, near faults and fractures, and at triple junctions. Solar activity is vital to visualize the enhancement in volcanoes and earthquakes. It is clearly connected to Fall as a season of an enhancement of eruptions, corresponding to the Spring in the North.

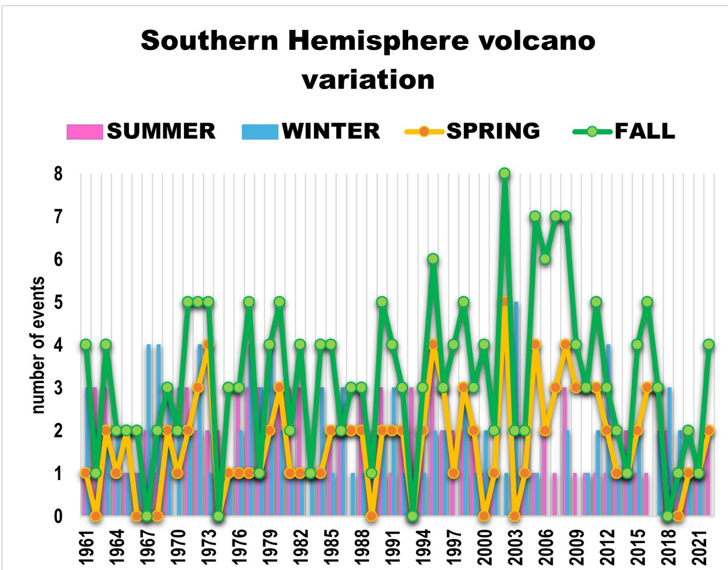

Figure 11. Shows the volcanoes' eruptions variations in the Southern Hemisphere.

5. Solar Flares and Hazardous Natural Events Worldwide

Solar flares impact Earth's magnetosphere by causing geomagnetic storms, which lead to various effects like auroras, radio signal disruptions, and potential damage to satellites and power grids. These effects are primarily due to the interaction of the energetic particles and radiation released during solar flares into the magnetosphere and ionosphere. During events X, flares and coronal mass ejections release larger-than-normal amounts of solar energy from the Sun, and the speed of Solar wind increases from the normal amount of 400 km/h to 1000 km/h. The magnetopause is the boundary established by the pressure balance between the Solar Wind flow and the magnetosheath. Generally, this pressure balance is between the solar wind, the dynamic pressure, and the magnetic pressure of Earth's dipole field. The causes and effects of pressure variation on the Earth's surface are not understood. However, it affects hazardous events such as earthquakes and volcanoes [14]. It is shown how an external factor affects earthquake surges [15]. Solar activity is important in the visualization of the enhancement in volcanic and earthquake surges by external factors [16].

The top solar flares in 2023 presented 13 X-flares, which started in January and were distributed throughout the year. The most powerful X flare in 2023 was on 31/12 as X5.01, compared with 2024 as 10/03, an X9 flare. Comparing both years, 2024 recorded the most X solar flares since 1997. More than 50 occurrences of X flares were recorded. Our statistical analysis is going to compare the surge of X flares with the volcanic eruption by season and determine if the surge of X flares disturbed or enhanced the occurrences of eruptions, especially in the last few years.

Remember that volcanic events are poorly recorded, and most submarine eruptions are unknown when and where they happened. There is a high probability that seasons or flares somehow influence the magma chambers; however, there is not enough data to prove it.

The history shows that Earth hazard activities increased during the years with strong coronal mass ejections (CMES) that occurred in 2005 (X17), 2001 (X14.4), and 2003 (X10), with auroras visible at mid-latitudes.

In 2014, the solar maximum was smooth, and the influence on volcanoes and earthquakes was weak. Solar cycle 25 displayed a recent development this year as January 25, X1:8 flares, with a following flare X1.1 on March 28. Now, the resulting scenario according to intensity: X2, (23/2), X1.85 (04/01) X1.1 (28/03), X1.1 (03/01). March showed X flares with high potency in a brief period. It is important to the space environment to understand what damage or perturbations these flares will mean to the entire system.

The period encompasses several X-flare events together, and they disturb and raise earthquakes and somehow perturb the volcanoes erupting most on the Ring of Fire. However, it is impossible to make any assumptions about submarine volcanoes, which are supposed to be more than 10 km deep worldwide. Those two hazards are phenomena happening below the crust, which means the external factors described here are a burden to connect with any of them. Technically, the number of variables influencing events is too high, and it is impossible to isolate the event and link it with any solar activity.

Figure 12 shows a possible connection between the X solar flares and eruptions. However, our plot indicates that the number of flares increased during the years 2000, 2001, 2014, and 2024, which coincides with the Solar maximum, except 2024, which is not considered a solar maximum.

We observed that the number of volcanic eruptions increased in 2004-2008, 2012, 2013, 2015, 2016, 2021, 2024.

Most of those years corresponded to the solar minimum, although the total of known eruptions increased. Figure 13 shows a different event, such as the earthquakes above M7, and a possible variation associated with the solar flares.

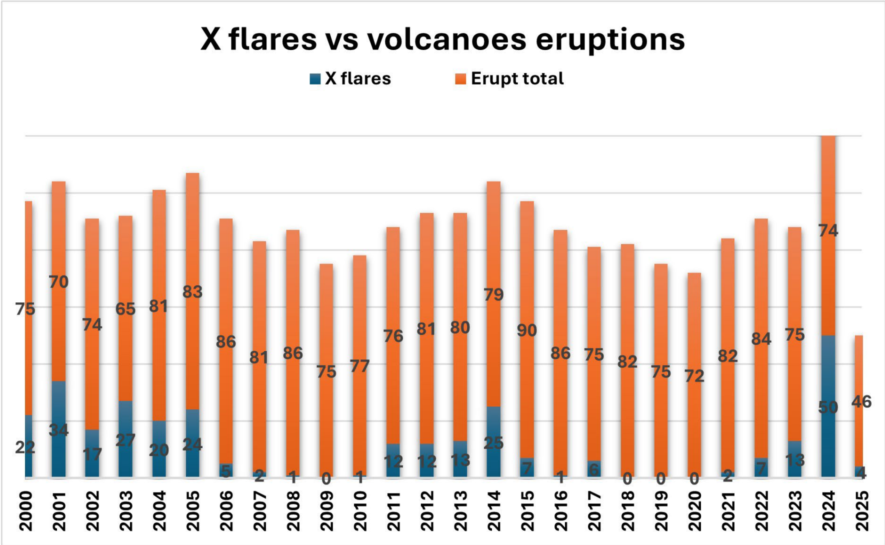

Figure 12. Total of volcanic eruptions (orange), and X flares (blue) the correspondence or influence of flares is null.

Between 2007 and 2010, a higher number of M7 earthquakes were observed while the number of X flares was low. Similarly, from 2018 to 2021, X flares either did not exist or decreased. It was concluded that M7 earthquakes tend to occur more frequently with less solar activity. Initially, X flares were studied because it is easier to collect records with M7 than other kinds of earthquake magnitudes. There appears to be a correlation between occurrences of M7 or above magnitudes and lower solar pressure. This suggests a mechanism where the magnetosphere is compressed by high-speed solar winds and decompressed afterward. Years with many X flares during solar minimum, such as 2004, correspond to fewer tremors. The highest number of X flares in history was recorded in the previous year, and the number of strong earthquakes was average or below.

Between 2018-2021, and between 2008-2010, there were no occurrences of X flares, and earthquake numbers remained at an average level. The results indicated correlation or inverse dependency between X flares and earthquakes. The investigation pointed out that the number of worldwide earthquakes with depths 0 - 100 km, M7 or bigger in the period 1996-2025 were 314 events, the subsequent depth 100 - 500 km presented 69 occurrences all around the Ring of Fire, and finally, to deepest events above 500 km happened 36 tremors in the same region. Those occurrences indicated that the Pacific region is extremely sensitive to earthquakes with higher magnitude, and they surge at any depth. The analysis points out that X flares are unable to interfere with high-magnitude earthquakes or volcanic activity.

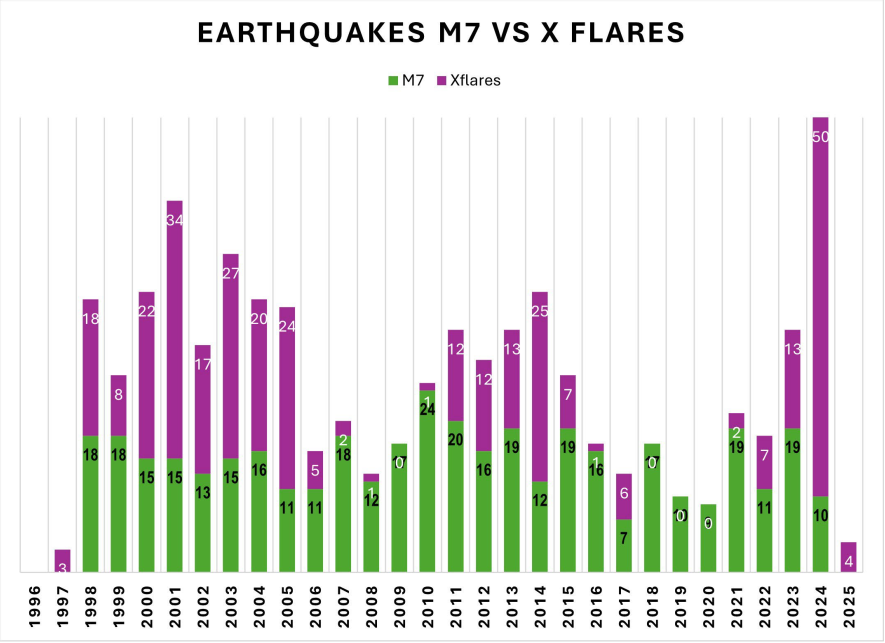

Figure 13. Earthquakes M7 and X flares occurrences.

The next step involves investigating the relationship between earthquake occurrences and their depth; this analysis must be conducted by region, as illustrated in **Figure 14** for the North Pacific. We divided the location into several depths: 100 - 200 km, 200 - 300 km, 300 - 400 km, and ≥500 km.

The X flares' numbers can't be compared with earthquakes since they have dissimilar energy sources, one of which is more electromagnetic, and the other is primarily mechanical. However, comparing the number of events gives us an idea about the frequency of each event.

The plot in **Figure 14** shows that the years with increased flares were 2000 and 2013. However, the number of earthquakes did not follow the same trend. For instance, in 2000, and 2002, remarkable events occurred at depths of 400 - 500 km; in 2010, most events happened at depths greater than 500 km; and in 2013, significant activities were recorded at depths of 200 - 300 km. What factors might contribute to the occurrence of earthquakes at varying depths? Notably, in 2016, the predominant depth was again 200 - 300 km.

The two diverse kinds of events do not show any connection, but even when X flares were minimal, all depths remained active. When the X-flares were huge, it was noticed that the events with more occurrences were the deepest and vice versa. There is an indication that X flares are acting as an induction for the earthquake surges in deep depths.

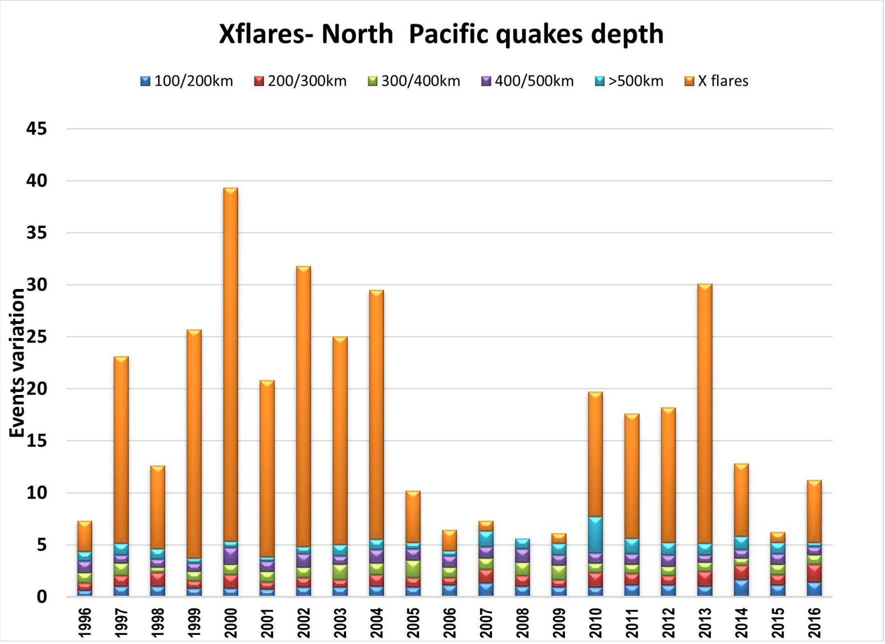

Figure 14. North Pacific quakes by depth vs X flares.

Figure 15 shows a correlation between earthquakes and flares in the South Pacific. The main difference between the two hemispheres, North and South, is mainly the continental land on the North, and the oceans on the South. This fundamental difference disturbs each hemisphere in diverse ways. Figure 15 displays the depth most affected during the time chosen, 300 - 400 km, an intermediary depth that occurred most at the solar minimum. The shallower depth shows disturbances most at the solar maxima.

Solar Flares seem to influence the deepest depths more than the shallow ones. However, when it happens during the solar minima, the surge of a sudden strong flare means more to the quakes than when it is a solar maximum. In both cases, when we studied the influence of the X flares and earthquakes, we noticed that deeper-depth earthquakes were affected by external factors more than shallower ones.

6. Discussion on Results

Our earthquake observations show an increase in deep-depth events (70 - 500 km) during the Solar minima (2003-2010) and again in 2014 with solar maxima. In the North Pacific, there was no increase at 100 - 200 km from 1996-2016; however, there was a sudden rise at 200 - 300 km in 2008, an increase at 300 - 400 km in 2005, enhanced events at 400 - 500 km in 2008, and an increase at >500 km in

2008. In southern regions like Australia, Indonesia, Samoa, and New Zealand, most increases occurred at 400 - 500 km in 1997 and 2013, and 300 - 400 km in 2006. The South America platform showed no tremors at 400 - 500 km, while the 100 - 300 km ranges had average events. Depths ≥ 500 km presented anomalies in 2005, 2010, and 2015.

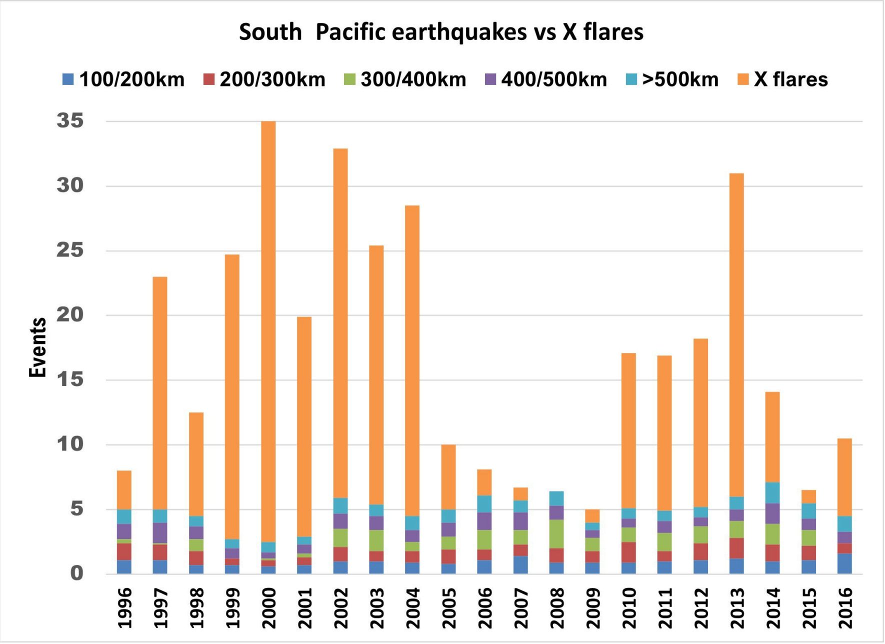

Figure 15. South Pacific depth earthquakes versus X flares.

Seasonality in the North Pacific increased notably in Winter during 2005, 2013 to 2016, and Fall after 2014. A similar pattern occurred in Australia, Indonesia, Samoa, and New Zealand from the summer of 2005 and spring of 2013 to 2016, with a peak in the Philippines during summer 2016.

Seasonality variations are similar between the Northern and Southern hemispheres, excluding South America.

Volcanic activity in the Northern Hemisphere exhibited seasonal peaks during spring 1977, summer 2009, and winters of 1979 and 1995, with no significant maximum observed in autumn.

While seasons did not significantly influence eruptions, enhanced activity was noted during the solar minimum periods. In the Southern Hemisphere, variations were random, with increased eruptions from 2000 to 2008, primarily occurring during spring or autumn. Volcanic movements are predominantly located on Earth's crust rather than in submarine volcanic activity, as witnessed in Tonga some years ago. Perhaps some single events alter the climate more than the average of them; for example, a Kilawea volcano disturbed the weather locally, and a Tonga volcano had a worldwide impact. Therefore, statistical analysis is not crucial in proving how the weather is disturbed by a specific eruption. The only factor important to our analysis is to be sure about the solar activity during the years.

Eventually, the impact of the magnetospheric events, or the distribution of ashes in the atmospheric layers, are important to the weather and climate changes, but at the moment, we do not have enough knowledge of how those atmospheric layers impact or interact with each other. It seems there are three layers of atmosphere important to the humans' life they are troposphere, stratosphere and mesosphere, however, the interconnections among those layers are unknown in detail.

Understanding these occurrences is crucial for several fields, including the influence on weather patterns and their connection with other solar parameters. A rigorous statistical analysis is impossible without knowing some factors about the inner Earth's structure and how earthquakes in deep depth occur for each location studied here. The volcanoes still do not have catalogs with more detailed information about the season the eruption started, and most of the data must be manually developed. Therefore, most external parameters, such as seasons or other external factors that could be important for the volcano analysis, are unknown.

7. Analysis and Further Investigation

Our analysis predominantly relies on deep-depth earthquakes, which currently have some of the most precise data recorded worldwide. However, shallow earthquakes in a global statistical analysis may be unreliable due to the potential for non-natural causes. Therefore, it is necessary to include other variables to ensure connectivity with external factors as described in the research. Comparing solar data with global seismicity poses a challenge due to the complex interactions between solar wind, magnetopause, magnetosphere, and tectonic variations, such as fault types, or event magnitudes. Many results may be inconclusive or misleading.

In South America, no coherent hypothesis or speculation fully explains intraplate seismicity, particularly at depths ≥ 500 km. There remains uncertainty about external factors influencing deep events across all occurrences at significant depths. An extended analysis between earthquakes, solar cycles, and seasons did not provide sufficient evidence to show any connection "beyond any doubt." Analyzing the connection between X flares and seismic events is challenging; essential considerations include verifying whether the flare directly impacted the magnetosphere. Current volcanic data catalogs lack records by month or season, making analysis difficult, especially for submarine eruptions. Partial results suggest that seasons or flares might influence magma chambers, but insufficient data exist to prove this. Total eruptions and X flares do not present a clear connection, as many volcanic surges occurred during solar minimums. A weak correlation was found between X flares and M7+ magnitude earthquakes. Comparing the number of events like X flares and M7+ magnitude earthquakes is complex due to the differing dissipative energy sources (electromagnetic vs mechanical). Known variables cannot clearly explain what occurs below the Earth's crust, and whether it is affected by external factors targeted here.

8. Conclusions

Further investigation to connect the environmental variables such as solar disturbances and sunspots, solar wind speed, interactions with magnetopause, disturbances from seasonal parameters, and Earth magnetic field interactions with sunspots and flares would help for a final answer to start to understand how those external variables are playing in climate changes. A better volcano catalog displaying the distinction between volcanic characteristics at the start of an eruption and its end, the display of the region affected. Submarine volcanic regions and update eruptions for each of them. Without such information, it has been impossible to construct a fair statistical analysis for volcanoes. The role of volcanoes in climate change has received limited attention, partly due to a lack of information about their impact on atmospheric layers and the gases and ashes they emit. The layers of the atmosphere are not yet well understood or studied, which is significant for environmental analysis, as evidenced by the recent eruption in Tonga and volcanic activity in Hawaii. These outstanding questions currently hinder a deeper understanding of climate change.

This paper examines the potential effects of solar cycles on earthquakes and volcanoes from 1996 to 2022, with additional analysis for 2024 due to a considerable number of X flares. Although indicators suggest the limited impact of solar activity on Earth's surface events, X flares appear to influence the frequency of geomagnetic storms, earthquakes, and volcanoes. The study indicates that solar activity can impact Earth's surface, particularly through interactions with the magnetosphere during X flares. This initial investigation into disturbances between solar system activity and the Earth's crust sets the stage for future studies on the possible associations between these interactions and recent weather anomalies.

Acknowledgements

The authors thank the anonymous referee for his valuable suggestions and improvements to this research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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