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Sun Disturbances on Earth's Volcanism

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ABSTRACT

This paper searches for a connection between volcanoes and solar variability. Solar events have been investigated as possible interference with hazardous natural events on Earth. The first results pointed out that during the solar minimum, the frequency and strength of volcanoes increased. However, solar variability is not the only factor disturbing volcanic eruptions; there is also seasonality. There is a double interference from the Sun on the volcanoes, one from the solar cycles, and the second is the seasons.

1. INTRODUCTION

Our former papers showed that Earth is influenced by the Sun's variability, which can affect the manifestation of earthquakes [1-5].

Solar activities include the ejection of energetic particles besides the electromagnetic radiation from its helicoidal field. Sun's field hits the Earth, creating a shield against high-energy particles and the solar wind.

Solar cycles are a variation of 11 years of activity on the Sun's surface, perturbing Earth's climate variability. The question is how it would disturb the natural hazard events such as earthquakes, and volcanoes, for example. The former research tried to be accurate, considering the length of each solar Cycle, around 11 years and examining the earthquake occurrences during at least 1 - 5 cycles. The earthquake occurrences studied in our papers are events in various depths, most 50 - 10 km with several exceptions, magnitudes above 5, in worldwide locations with an emphasis on faults, trenches, and sometimes intraplate earthquakes. Earthquake events are mainly in the subduction zones and can happen at several depths from 5 - >500 km. Volcanoes are created internally and below the crust: the eruption occurrences at the Earth's surface on the ocean concerning submarine volcanoes. Therefore, the influence of such events on the climates must be immediately verified and its possible atmospheric influence investigated.

It must be associated with the solar pressure on the magnetosphere. The solar pressures vary according to the wind speed, which is also unpredictable and depends on sun events such as flares. The solar pressure on the magnetic Earth's field affects the entire environment since the magnetosphere shrinks,

sometimes becoming half of its size. The sudden compression and decompression of the area cause earthquakes in some parts of the terrestrial surface.

During solar minima, the pressure from the solar wind over the magnetosphere is relaxed. As a result, the Earth's magnetosphere is extended, the area expands, and earthquakes happen less frequently in different geological features on the Earth's surface. Although the Sun's influence on the magnetosphere must be a ubiquitous phenomenon, each area on Earth answers differently since the surface is heterogeneous with different ground geological formations, which makes the area receive energy respond in varied ways.

The Earth's surface has three kinds of plate boundaries convergent, divergent, and transform; therefore, the external factor will excite the areas, but the response is diverse.

The distribution of earthquakes throughout the world is far from random. Stronger earthquakes happen at the edges of tectonic plates. These zones are called plate boundaries. Some seismologic events occur in areas named intraplate regions. Earthquakes also happen along fault lines, cracks in Earth's crust where the tectonic plates meet. In places where plates are subducting, spreading, slipping, or colliding. It is known that 80% of earthquakes occur where plates are pushed together, called convergent boundaries. However, earthquakes happen along plate boundaries, subduction zones, transform faults, and spreading centers. The authors have studied the seasonality of earthquakes. Some isolated research has been done regarding small areas such as Japan. Heki [6] pointed out that small earthquakes do not show seasonality.

The enhancement of seasonal variation for more significant earthquakes might be due to the longer duration required for the premonitory nucleation phase of more significant earthquakes; smaller events often fail to show a clear correlation with tides. Zhan & Shear found that larger deep-focus earthquakes (magnitude > 7, depth > 500 km) had strong seasonality in their occurrence times since the beginning of global earthquake catalogs. The seasonality is most substantial in the northwest Pacific subduction zones and weakest in the Tonga region. They reported that from 1900-2015, the events M > 7 deep focus occurred 2 to 3 times more often in the middle half of each year, *i.e.*, in the Northern Hemisphere in the summertime.

Our investigation of worldwide earthquakes seasonality pointed out to be connected to the Northern Hemisphere, where events are enhanced during Spring and Summer. Southern Hemisphere showed an increase of events during Fall/winter that would mirror the occurrences in the Northern. Those results were found for Ultra Deep Earthquakes since they happen independently from other sources. The shallower tremors usually make it hard to distinguish the origin that causes an earthquake epicenter [2]. There was an issue with South America located at the South Atlantic Anomaly, as investigated in another paper [3]. The anomaly in the region disturbed earthquake occurrences with 200 km depth. The seasonality found for deep earthquakes was during Summer/Fall. Solar minima appeared to be when more variations of earthquakes happened in South America.

The authors concluded that worldwide earthquakes presented some sensibility to seasons depending mainly on the Hemisphere they happened. Moreover, the following studies indicate that the Earth's magnetic field interactions with the Sun's magnetic field and the solar speed variations according to extreme Sun events are equally crucial for increased seismicity. The location of SAA is 450 to 500 km from the Earth's surface. However, there is an asymmetry; the inner Van Allen belt is closest to the surface over the South Atlantic Ocean, where it dips down to 200 km in altitude, and farthest from Earth's surface over the North Pacific Ocean. Although the shape of SAA changes over time, the southern limit remains roughly constant while a long-term expansion has been to the northwest, the north, the northeast, and the east.

From some of our earthquake results, it was discovered that events related to the different crust features involved the Earth's magnetic field anomalies. We aim to investigate the possible connections worldwide between volcanos, solar variability, solar cycles, and seasons. The Sun's measures compared to the planet increase its influence on Earth's magnetic field.

Earth volcanoes are most found where tectonic plates are diverging or converging. Most are found underwater; the Mid-Atlantic Ridge has volcanoes caused by divergent tectonic plates. The Pacific Ring of Fire has volcanoes caused by convergent tectonic plates. Subduction zones studied in our former paper [4]

are where chains of volcanos called volcanic arcs exist, such as the cascade Volcanoes, the Japanese Archipelago, or the Sunda Arc of Indonesia. As the authors studied formerly concerning earthquakes, those areas are well affected by solar variabilities and seasons. This paper aims to find the connections between volcanos, solar cycles, and seasons. The earthquakes showed a fair connection with both variables. Both events have similarities and connections; now, we must find the connections between volcanoes with external factors created by the Sun or the Earth's positioning according to the Sun (seasons).

The experience acquired with earthquakes is applied to develop a similar study on volcano activities. Herdiwijaya [7] investigated the relationship between solar and global volcanic activities and found that during the declining solar cycles, the average frequency of eruptions is significantly more critical in the falling phase and warming period. They concluded that the Sun's interplanetary space, ionosphere, the Earth's atmosphere, and volcanic phenomena are part of an integrated physical process in the Sun-Moon-Earth system. Nevertheless, our first paper clearly connected Sun-Earth and earthquake incidences worldwide.

Earth volcanoes are most found where tectonic plates are diverging or converging. Most are found underwater, Mid-Atlantic Ridge has volcanoes caused by divergent tectonic plates. The Pacific Ring of Fire has volcanoes caused by convergent tectonic plates. Subduction zones studied in our former paper [4] are where chains of volcanoes called volcanic arcs exist. Typical examples are the Pacific Ring of Fire, such as the cascade Volcanoes or Japanese Archipelago, and the Sunda Arc of Indonesia. As the authors studied, those areas are well affected by solar variabilities and seasons. Volcanic eruptions' connections to solar activity have been studied by [7-9]. The authors studied the possible connection between solar activity and volcanoes, considering the solar influence on Earth. Some of them said that there are different responses from the Northern compared with the Southern Hemisphere. Vasilieva & Zharkova found that volcanic eruption from the past for 270 years ago with the variations of solar activity and summary curve of principal components of the solar background magnetic field. They obtained a dominant 22-year period of volcanic activity and a weaker peak of 10.7 years [10]. Volcanoes and seasonal variations are studied in several papers, one by Mason *et al.* [11].

They analyzed volcanic activity during the last three hundred years, revealing that volcanic eruptions exhibit seasonality to a statistically significant degree. In some regions, seasonal fluctuations amount to as much as 50% of the average eruption rate. They suggested that the deformation of the Earth's surface that accompanies the annual movements of water mass from the oceans to continents imposes a fluctuating boundary condition on volcanoes such as volcanic eruptions tend to be concentrated throughout the year. Stevenson *et al.* [12] studied the El Nino/Southern Oscillation (ENSO) response to tropical volcanic eruptions, which has critical worldwide implications. The eruption-year atmospheric circulation response is strongly seasonally dependent, affecting European winter warming, the intertropical convergence zone, and the Southeast Asian monsoon. Sun *et al.* investigate [13] the impact of northern high latitude volcanic (NVH) eruptions on ENSO based on ensemble simulations with the community earth system model. The seasonality of atmospheric circulation influences the NVH aerosol dispersion causing a more substantial (weaker) Northern Hemisphere cooling after the January and April (July and October) eruptions. It also specified the eruption season, the atmosphere's background state, and eruption time. This paper aims to find the connections between volcanoes and Sun cycles and seasons. In this research, we will investigate volcanic eruptions and how they increase or decrease in an extended period of solar cycles. We also investigate worldwide if seasonality affects the eruptions by region. A volcano is a rupture in the Earth's crust. Most are found where tectonic plates diverge or converge, and most are found underwater. Submarine volcanoes and volcanic events happen mainly in the area, converging or diverging.

Submarine volcanoes and volcanic events are standard features on specific zones of the ocean floor. The unlimited water supply surrounding submarine volcanoes can cause them to behave differently from volcanoes on land. The main problem with the submarine volcano is finding possible connections between them and the stratosphere/troposphere disturbances, which creates anomalies in the climate. Submarine eruptions may produce seamounts that break the surface to form volcanic islands and island chains.

It is little known how submarine volcanoes would interact with the atmosphere. This study will inves-

tigate some aspects of volcanic activity since 1960. The solar cycles involved are Solar Cycle 20 - 25. The volcanic activity worldwide decreased between 1800-1950. In some regions, such as Canada and Kenya, volcanic activity is extinct. Overall, the volcanic events are much lesser activity. In the picture it is the worldwide volcanoes nowadays.

This paper will discuss some aspects of volcanoes and how to connect them with solar activity, seasonality, and climate change. Figure 1 shows the location of the significant active volcanoes worldwide. It is crucial to notice that they are all at the borders of continents or islands.

Figure 2 shows how the volcanoes are formed around the Pacific and oceanic spreading ridge. The picture shows some facts about the volcanoes' formation and occurrence on the different kinds of plates.

However, most volcanoes are located within the continent's borders. The aim of this paper is to investigate how Solar Cycles and seasons will affect the eruptions.

2. NORTH HEMISPHERE VOLCANOES ERUPTION VARIATIONS ALONG SOLAR CYCLES AND SEASONS

The first aspect of volcano eruptions to be studied is how they vary in different Hemispheres. The first results pointed out that events in the Northern are double the number of occurrences in the Southern. Most active volcanoes are around the Northern Ring of Fire in the Pacific. Nevertheless, a critical issue is unknown: submarine volcanoes whose events are unreported, only a limited number of known eruptions. Southern Hemisphere is a lesser land mass than the Northern. The investigation covers at least five complete five solar cycles, between solar cycle 20-solar cycle 25 or the period 1960-2022. Let us start the analysis for the Northern Hemisphere; along the period searched, the number of events during the three seasons, Spring, Summer, and Winter, reached the maximum number of events in the Northern.

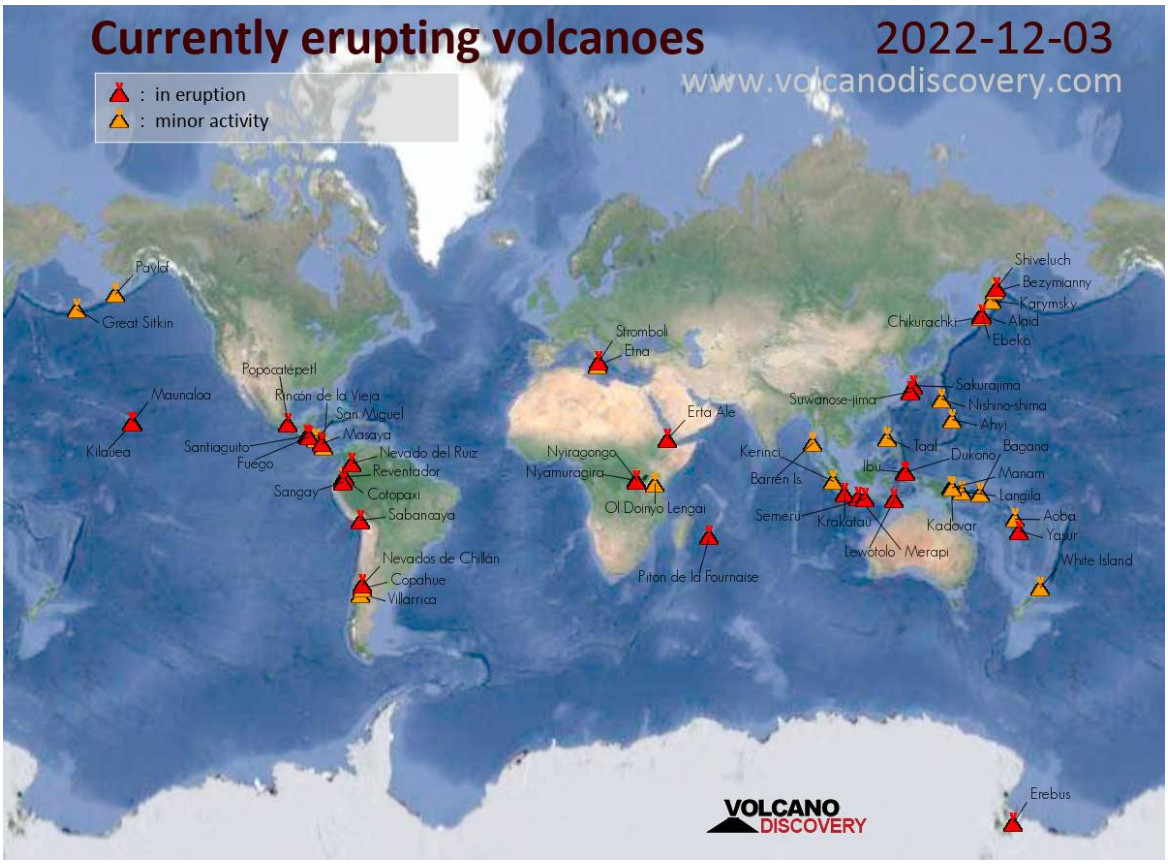

Figure 1. Those are the significant volcanoes active now worldwide.

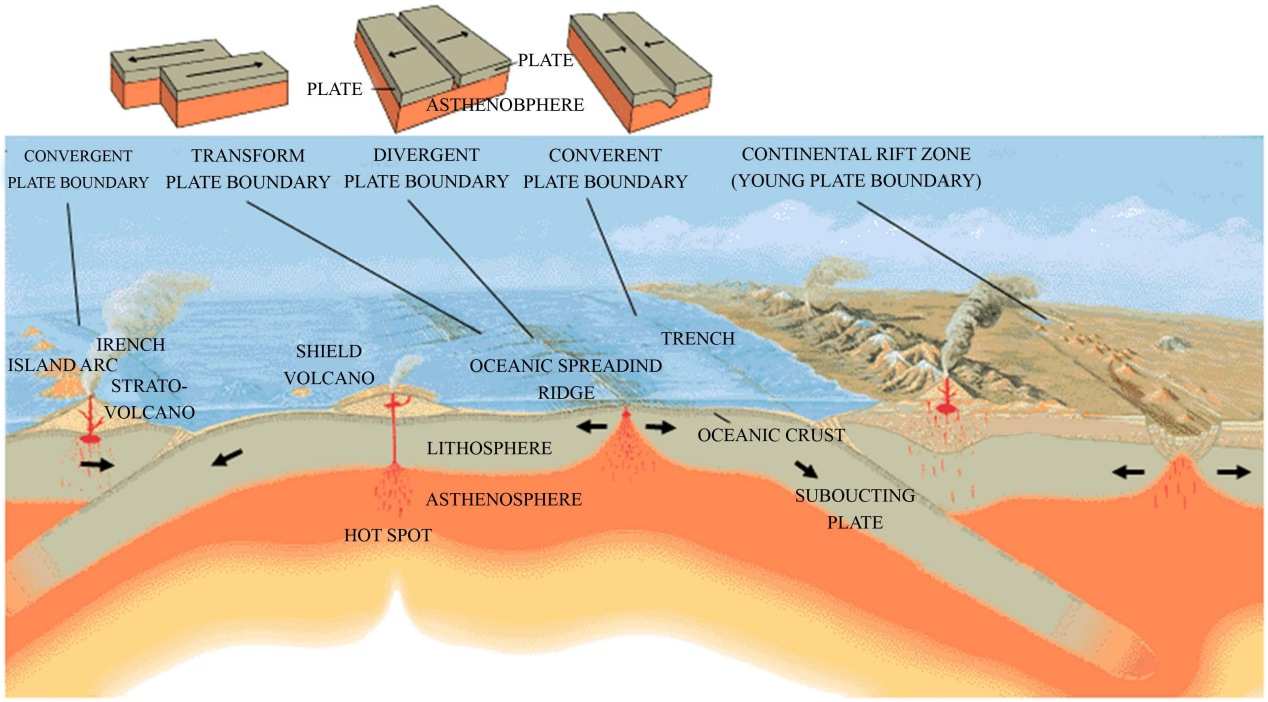

Figure 2. Several kinds of volcanoes are described in the picture, such as strato and shield. We also observe the connections between the asthenosphere and the earth's surface. The picture shows the three kinds of plates, convergent, divergent, and transform.

First, the investigation of the five Solar Cycles did not indicate enhancement of events during the years of maxima or minima in each Cycle. Therefore, there is not explicitly any direct interference on volcanoes due to the solar cycle variations. Nevertheless, it could be an intrinsic delay in the events' manifestations after maxima or minima, which we can't be sure of now. Therefore, this paper did not search for corroboration for such a hypothesis. Instead, it was focalized on the seasons, which is a more straightforward assumption.

The Spring in the Northern showed years with the highest number of eruption manifestations as 1977, and other smaller ones happening in 1963, 1984, 1986, 2005, 2010 (**Figure 3**).

The Summer presented increases in 2008, the highest number of occurrences followed by 2014, and more minor enhancements in 1962, 1980, 1992, and 2008, 2021 (**Figure 4**).

The Winter had only two years with increases in 1973 and 1995 (**Figure 5**).

The Fall, on average, did not present boosts in any part of the cycles. Therefore, the Spring showed to have the highest number of events. The explanation can rely on the Earth's axis tilted towards the Sun during Spring and Fall. During the Fall, the Northern has tilted away from the Sun. We concluded that the Earth's position concerning the Sun might affect the eruptions most in the Spring and the highest number of manifestations. Particularly in the Fall, the average number of occurrences is the lowest of all seasons. There are two limits the maximum which happens during the Spring, and the minimum numbers always happen during the Fall. The study showed inconclusive at this point regarding solar cycles. There is no immediate connection with seasons or cycles. Next paragraph, we are going to study the Southern Hemisphere and its events.

3. SOUTHERN HEMISPHERE VOLCANOES ERUPTION VARIATIONS ALONG SOLAR CYCLES AND SEASONS

Data obtained from Southern Hemisphere indicated that volcano eruption in the Southern is much

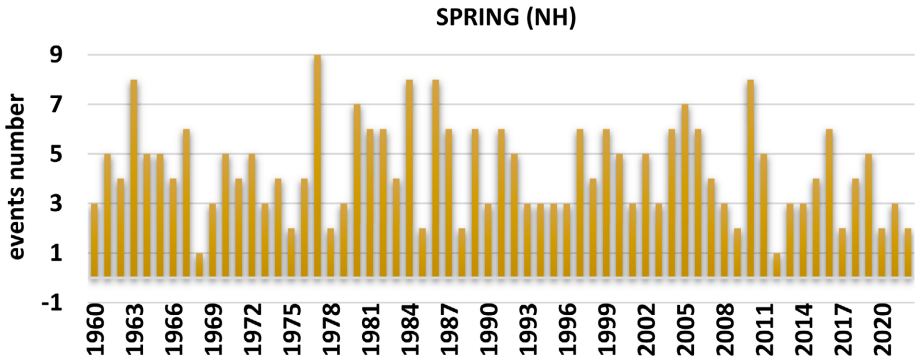

Figure 3. Volcano occurrences 1960-2020. Observe the maximum occurrence in 1977.

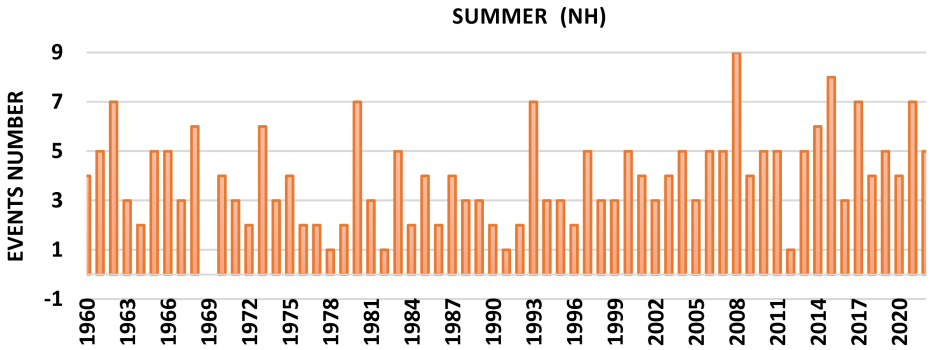

Figure 4. Volcanic eruptions during the Summer in the Northern Hemisphere. The maximum number of events occurred in 2008.

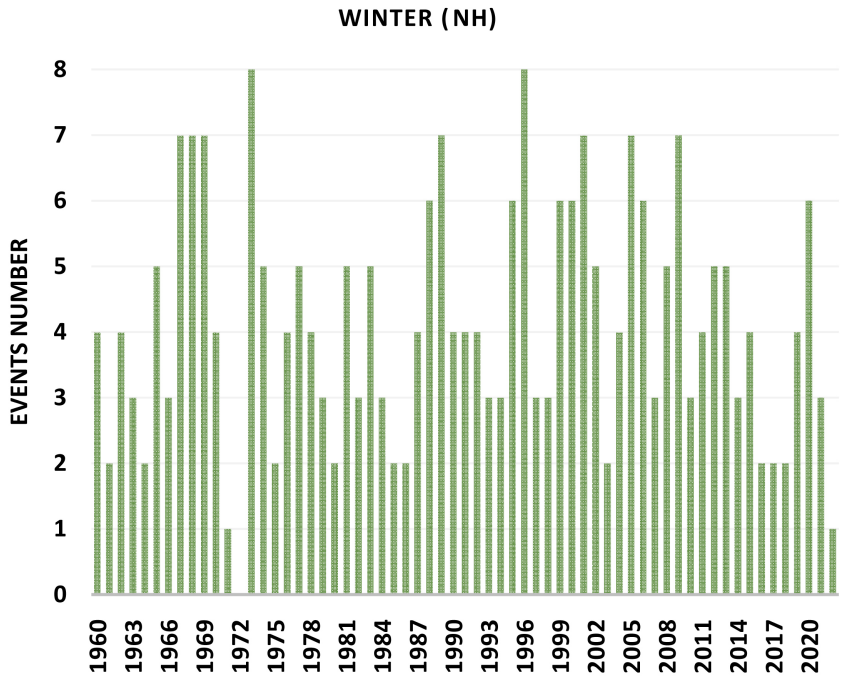

Figure 5. Volcanoes occurrences variations during the Winter. Observe that the two maximum was lower than during the Spring.

less than in the Northern. Figure 6 showed that only one year presented a maximum in 2003 during the Winter. Figure 7 indicates a maximum in 2002 during Spring. It does not look to relate to Solar cycles maximum or minimum. This investigation pointed out that the tendency occurrences are less in the Southern could be linked to bad data acquisition the submarine eruptions.

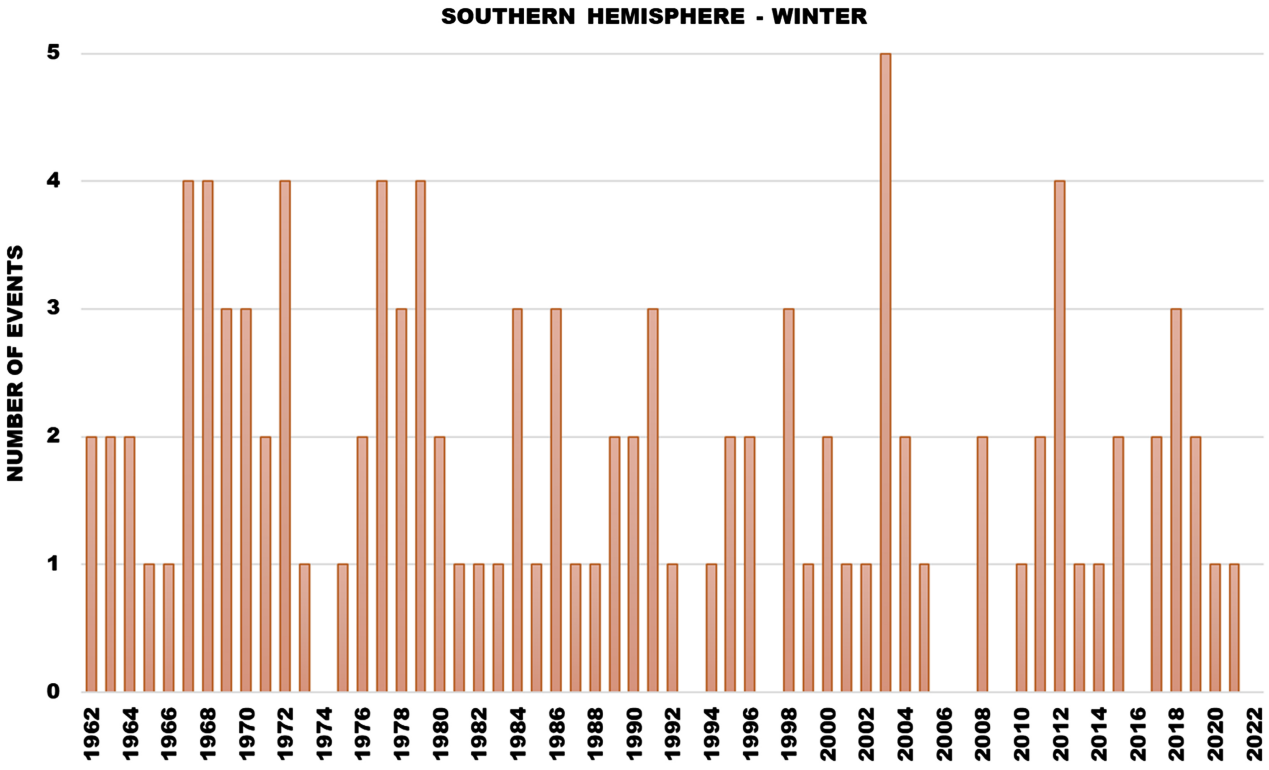

Figure 6. South Hemisphere volcanic eruptions, Winter. Observe that each solar cycle's years of minima or maxima are not enhanced.

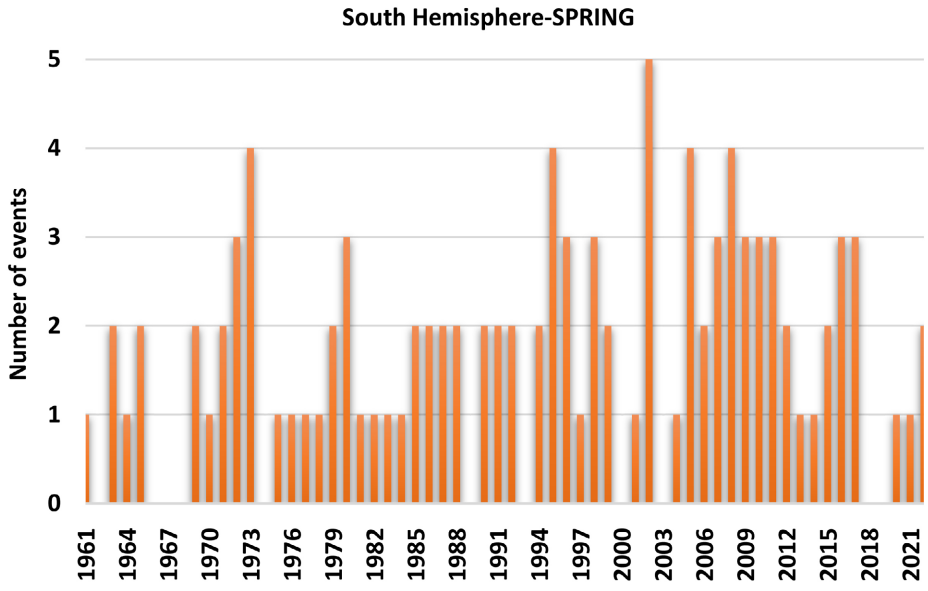

Figure 7. South Hemisphere volcano eruptions Spring.

The Southern events are half the ones in the Northern, most of which occur in the middle of Spring and end of Winter. The end of Winter means the Earth's axis is reaching the position it takes during the Spring. For both Hemispheres, the Earth's axis reaches an angle position concerning the Sun. The data for Spring or Fall is the most important in connection with volcanic eruption occurrences. Analyzing the data during five solar cycles, it was impossible to connect the sunspot evolution with volcanic activity. It depends on several factors for the enhancement of eruptions, such as interactions between sunspots and Earth's magnetic field, which is the only way that makes it possible to reach internal Earth features and perhaps increase the volcanic events.

Nevertheless, the Earth's geomagnetic features reactions could be delayed concerning the excitation from Sun's solar wind increases. It depends on how the lithosphere reacts to the Sun's actions.

Concerning seasons, it is easier to find a possible correlation between Earth and the enhancement of volcanoes. In this paper, we divided the Hemispheres between studying better each season in the respective Hemisphere since they are opposite on each Earth's side. Next paragraph, we are going to make a brief analysis of both hemispheres.

4. COMPARISONS BETWEEN NORTHERN AND SOUTHERN HEMISPHERE VOLCANO EVENTS

The examinations of the Northern Hemisphere indicate that eruptions enhance during Spring, Summer, and seldom the end of Winter. Instead, events are slightly delayed after solar maxima. With the results obtained Northern/Southern hemisphere, we made a comparison, and we did not find any immediate correlations to the Solar Cycles; however, if we make this search on the seasons, the pattern showed us that the eruption is most like to increase to the end of Winter and Spring in the Southern and end of Fall and Summer in the Northern. The different reactions Northern to Southern hemispheres are due to the distribution of land mass, which is more prominent in the Northern.

There is another possibility that the eruptions underwater occurring in the Southern could not be detectable and recorded. Our results are based on the eruptions showing a pattern indicating they are sensitive to the seasons.

Our last attempt in this investigation is to search for events worldwide concerning Solar Cycles. That would consider that the differences on Earth's surface or at the lithosphere, crust, are not enough under the disturbances created by the Solar Wind variations. Therefore, to study worldwide eruption behavior under the Solar cycle variations, we calculated the evolution of the events during the period 1960-2022.

Figure 8 shows worldwide eruption in two different aspects during Sun maxima or minima. The first is the eruptions started, and the second is the volcanoes active. After 2001 (a solar maximum), the number of active volcanoes augmented, with a peak in 2008 (a minimum). Overall, the number of eruptions has been increasing since 2008. The plot took all the volcanic eruptions during the solar maxima and minimum to determine if it has a special meaning in the volcanic patterns. Other minor increases occurred in 1976, 2008 and 2019.

In this study, we could reasonably present that volcanoes eruptions have been increasing over the years studied with remarkable increases due to the seasons and in minor importance along the solar minima.

5. DISCUSSION OF THE RESULTS

This investigation was to verify possible connections between solar cycles and other solar events on volcanoes. We divided the events between two hemispheres since the Earth's crust is quite different from Southern Hemisphere, which has more ocean mass.

Some evidence showed that maximum events in the Northern are higher than Southern. However, a direct connection with other solar variations did not occur. There is another topic in the volcanoes that is necessary to study. It is concerned with the climate. It is a possibility that more significant eruptions relate to the climate. Therefore, our next search will be to find out the connections between volcanoes and climate change.

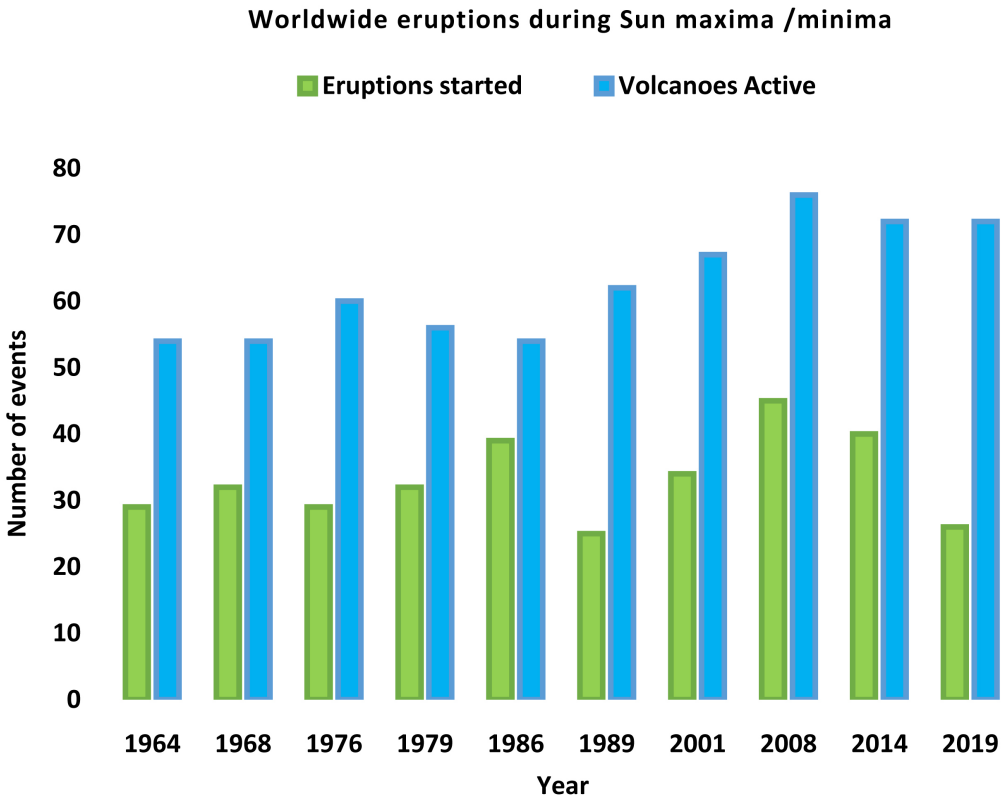

Figure 8. **Observe the maximum number of events that occurred after 2000, with maxima in 2008 (the blue is the volcanoes active and the green eruptions which started that year).**

6. CONCLUSIONS

We developed research with the connections between volcanoes versus Solar Cycles during five solar cycles, SC20, SC21, SC22, SC23, and SC24 or five solar cycles. We also divided the data between the two Hemispheres, Northern and Southern. We constructed our plots dividing by seasons showing events versus years by seasons. From the data recorded, our conclusions are the following:

1) There are small or no explicit connections between the Solar Cycle's maxima or minima and the enhancements of eruptions.

2) The enhancement of data at the Northern happened most during the Spring, Summer, and Winter.

3) The increase in data at the Southern occurred in two main seasons, Winter, and Spring.

The next paper will deal with the climate changes caused by volcanoes happening worldwide.

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CONFLICTS OF INTEREST

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

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