Iranian Journal of Astronomy and Astrophysics
Vol. 11, No. 1, Winter 2024, 1–16
©Available online at http://ijaa.du.ac.ir
DOI: 10.22128/ijaa.2024.768.1176
Online ISSN: 2383–403X

Iranian Journal of Astronomy and Astrophysics

Research Paper

Space Climate and Solar Energetic Particles

Ehsan Tavabi[1] · Sima Zeighami*[2] · Yones Kharaghani[3]

[1] Physics Department, Payame Noor University (PNU), 19395–3697-Tehran, I. R. of Iran; email: e_tavabi@pnu.ac.ir

[2] Department of Physics, Tabriz Branch, Islamic Azad University, Tabriz, Iran; *email: zeighami@iaut.ac.ir

[3] Physics Department, Payame Noor University (PNU), 19395–3697-Tehran, I. R. of Iran; email: uneskha@yahoo.com

Received: 25 December 2023; **Accepted:** 13 March 2024; **Published:** 3 April 2024

Abstract.

In this paper, we investigate the effect of solar corona magnetic activities during 11-year periods and energetic particles on global warming. According to atmospheric changes during the past years, the relationship between these two issues should be investigated. How the activities of the solar corona affect the average temperature of the Earth and also the increase in its temperature, have been the attention of researchers in recent years. For this purpose, we use the source of data recorded from the momentary position of the Sun in reliable sites, as well as information recorded from the flow of cosmic particles on the surface of the Earth by the GOES (Geostationary Operational Environmental Satellite) detector, which belongs to the NASA space agency. Solar activity affects the Earth's geomagnetic field and creates a geoelectric field on the Earth's surface. This phenomenon can affect technological systems, such as power grids, oil and gas pipelines, and railway systems, leading to damage to power grids, equipment, line breaks, and even blackouts. Results of this study show that there is a significant relationship between the magnetic activities of the Sun in 11-year cycles and the temperature of the Earth, which can be considered an essential parameter in predicting many crises and climate changes on the Earth's surface. Our results also indicated that changes in the number of sunspots and cosmic particles are inversely to each other.

Keywords: Solar Activity, Energetic Particles, Space Climate

1 Introduction

Until today, the Earth is the only known planet in the world whose climate is suitable for the formation of life, so every factor that affects this precious blessing, i.e. life, should be considered important. One of the factors that has affected and endangered this precious blessing today is the heating or temperature increase [1,4,21]. In recent years, the issue of temperature increase has become especially important with the development of industries and factories and the consumption of fossil fuels and the creation of greenhouse gases by

* *Corresponding author*

humans. Although the development of industrial life and the increase in energy consumption have contributed significantly to global warming, other factors and parameters have also been effective in this warming. In general, the factors that have played an effective role in increasing the average temperature are the Sun radiant energy , greenhouse gases [3], volcanic activities [2], and El Nino phenomenon or climate cycle change [20]. Solar activity affects the Earth's geomagnetic field and creates a geoelectric field on the Earth's surface, which can affect technological systems, such as power grids, oil and gas pipelines, and railway systems, leading to damage to power grids, equipment, line breaks, and even blackouts [28]. Even small changes in solar activity can greatly affect the climate of the Earth. However, compared to many stars in the galaxy, the Sun is considered a stable star. Solar magnetic field extent from the photosphere, chromosphere, TR, and corona into the interplanetary space. Various incidents and events happen on the surface of the Sun [11,14,15]. Therefore, various structures can be seen on the solar surface. Energetic particles originate from the solar flares and coronal mass ejections [33–35]. Spicules are thin long structures stretching from the chromosphere into the solar corona as plasma gaseous [5,7–9,9,12,22–24]. When solar chromosphere is observed in the quiet Sun, magnetic bright points (MBPs) or magnetic network at rosettes of super granules are seen [10,17,18,26]. Explosive events (EEs) are structures indicating high turbulence or jets with upward-moving material with velocities exceeding the sound velocity in the corona. EEs were characterized using on-disk far-ultraviolet observations conducted in emission lines originating from the hot transition region [13,16,19,25]. Some stars experience extreme changes in size, amount of light, and even explosions, but only experiences a 0.1 change in its light amount in relatively constant 11-year patterns known as the solar cycle. The energy of sunlight that reaches the top of the atmosphere of the Earth is about 2,500 times more than the total resources of this planet. Accordingly, even 0.1 of the amount of sunlight surpasses all sources of energy in the Earth's atmosphere, such as radioactivity, which is naturally emitted from the core of this planet. In this paper, we investigate the effect of solar activity and energetic particles on space climate and global warming, and relation between the number of sunspots and cosmic particles.

2 Observations and data reduction

To investigate as much as possible how these small changes in solar energy affect the Earth's weather conditions, the "National Research Council" (NRC) has gathered dozens of experts and scientists in various fields (plasma physics, solar activities, atmospheric chemistry, fluid dynamics and physics of energetic particles). Most of the effects of fluctuations of solar activities on the Earth are complex in nature. For example, high-energy solar particles and cosmic rays can lead to the reduction of ozone levels in the stratosphere. This issue also changes the behavior of the lower atmosphere and may even lead solar storms to the surface. The breaking of ozone molecules that are located at the bottom of the stratosphere by ultraviolet light can cause local warming. Also, when the ozone disappears, the stratosphere becomes cooler and increases the temperature difference between the equatorial and polar regions. The temperature difference in the stratosphere and upper troposphere leads to instability in the atmospheric flow from west to east. Instabilities create opposite currents and irregular movements. These opposite currents strengthen the "jet streams" and finally, they change the currents of the upper troposphere and the atmospheric layer close to the Earth's surface. Therefore, the Sun may play an important role in this type of process. In addition, solar variability has a definite effect on weather, especially in the Pacific Ocean. Figure 1 presents the direct relationship between the sunspot's number and the solar irra-

diance temporal variation. Simultaneous increasing the number of sunspots, the radiation energy on the Earth's surface increases. In the southern latitudes of the Atlantic, Pacific and Indian oceans, the change in solar activity can account for approximately 50 percent of the total sea surface temperature change in the southern latitudes of the Atlantic, Pacific and Indian oceans with a delay of 28-37 years [27].

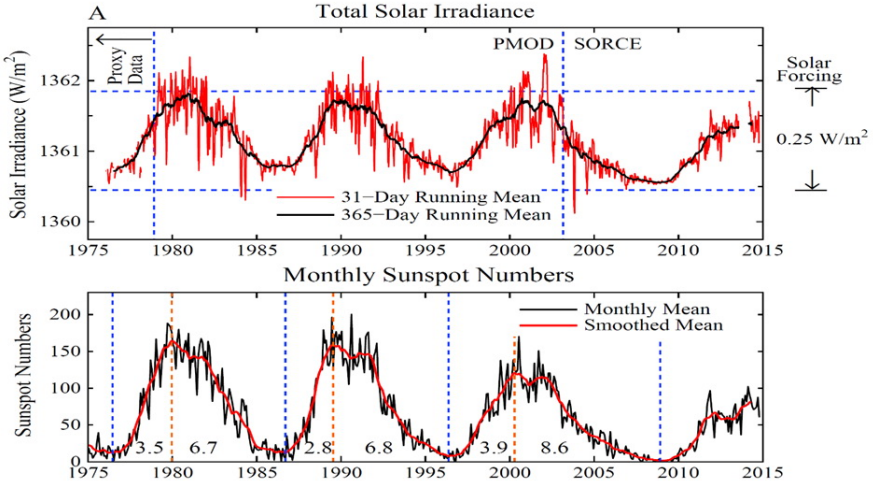

Figure 1: Top: Solar irradiance. Bottom: Number of sunspots since 1975 based on the National Geophysical Data Center of NOAA; Indicates NGDC.

Magnetic activity has 11-year cycles (Figure 2), which means that every 11 years the magnetic activity reaches its peak and decreases again. When the Sun is in maximum activity, due to the interactions and explosions that take place in the different layers, more particles are separated from the Sun. These particles affect the space, and naturally, the Earth are affected by the flux of them. Many of these particles are deflected under the influence of the Earth's inherent magnetic field and cannot enter the Earth's atmosphere, but due to their high energy, many of them can pass through the Earth's atmosphere and reach the Earth's surface. In contrast to these particles, also there are other particles that are emitted from the space outside the solar system, which are at a higher level of energy than the particles emitted from the Sun. It generates from the center of the Milky Way galaxy and outside it. These cosmic rays are protons and atomic nuclei that travel around the universe at speeds close to the speed of light. When these particles flow into the upper atmosphere of the Earth, they create a cascade of secondary particles. Their distribution is similar to a shower, which can spread over 40 km^2 or more on the Earth's surface and affect the environment that neutron detectors also make measurements. Our atmosphere provides protection from cosmic rays, but they can affect the weather. How their effect is in their collisions with the seeds released from the Sun and can affect the Earth's climate. When the Sun is at its most active time, these collisions are many and the particles of the Sun destroy these cosmic particles. Due to the fact that these particles are responsible for the fertility of clouds, they will reduce the fertility of clouds [36], and this will cause the reduction of clouds and increase in temperature.

Large solar flares are linked to changes in Earth's cloud cover solar flares protect the Earth's atmosphere from cosmic rays. According to new findings the eruption of solar flares

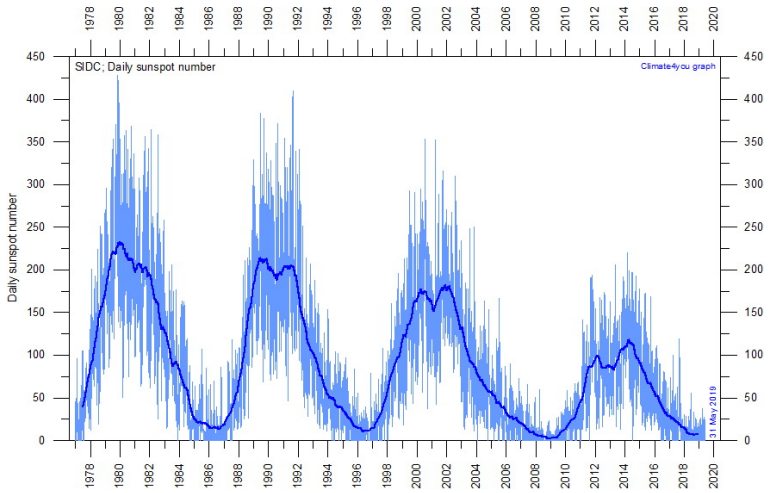

Figure 2: A graph of daily sunspot number observations since January 1, 1977, according to the Solar Impact Data Analysis Center (SIDC). The thin blue line represents the daily number of sunspots, while the dark blue line represents the annual average number of sunspots. The effect of low solar activity in recent years can clearly be seen in the low amounts of solar radiant energy. Data source: WDC-SILSO site of the Royal Observatory of Belgium, Brussels. Last day displayed: May 31, 2019. Chart last updated: June 1, 2019.

is the cause of the reduction of about two percent of the Earth's clouds and as a result of the removal of about one billion tons of liquid water from the atmosphere [37]. Cosmic rays resulting from the explosion of massive stars affect the Earth's climate. According to research, the ions released from supernovae or supernova stars that enter the Earth's atmosphere cause the formation of clouds. As the amount of clouds increases, the weather becomes colder and this cooling has an important long-term effect on the climate. These emitted particles are also affected by the Earth's magnetic field and deviate from their path and cannot pass through the Earth's atmosphere and enter the middle layers of the atmosphere, but in contrast to many of them they pass through the Earth's magnetic belt and enter the Earth's middle atmosphere. Due to the high energy level of the cosmic particles, they can affect the climate of the planet after passing through the Earth's atmosphere. Considering the effect of these particles is on the Earth's atmosphere in the first place, they can be an important factor in the fertility of clouds and the shape of clouds. But the particles separated in maximum solar activity, collide with these particles that enter the Earth's atmosphere from the center and outside of the galaxy, and as a result of collision with each other, many energetic cosmic particles they destroy. Figure 3 shows changes in cosmic rays received on the Earth's surface [43]. This factor reduces the impact of these cosmic particles on the fertility and formation of rain clouds, but when the Sun is in its minimum period or magnetic cycle, the number of these collisions decreases and the energetic particles that come from the center and outside of the galaxy coming towards the Earth, they can penetrate into the middle layers of the Earth's atmosphere and cause an increase in the fertility of clouds, which is an important factor in reducing the average temperature of the globe. The energy is compared to the particles that are emitted from the center of the galaxy and outside the galaxy, considering that is currently in the twenty-fourth cycle of its activity and at its lowest level of activity, it can be concluded that these collisions are at their lowest level. Penetration of cosmic particles into the middle layers of the atmosphere

is at its maximum, and the formation and fertility of clouds is in favorable conditions, and it can be an important factor in increasing the fertility of clouds and rainfall, and as a result, reducing the gradient of global warming.

For investigating relationship between the solar activities and cosmic particles, we use

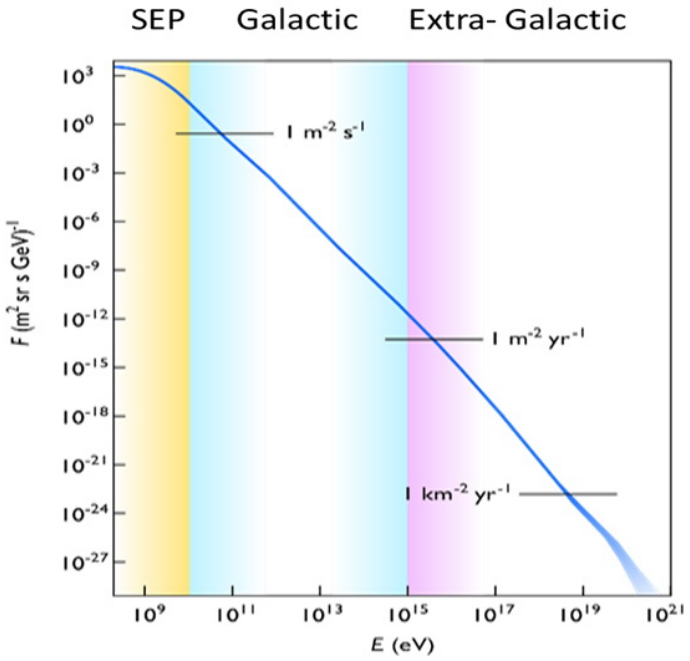

Figure 3: Changes in cosmic rays received on the Earth's surface [43].

the information of activities recorded in real time by reliable scientific centers and probes such as GOES belonging to the NASA space organization, which are circulating outside the atmosphere and in certain orbits. This information includes the following items: the number of sunspots, the proton flux that enters the interstellar space at any moment, the flux of electrons that collide with the Earth at any moment, and also the amount of energy of the particles. In addition, there are scientific centers that record the number and amount of energy of cosmic particles at any moment, which have higher energy than the particles released from the surface of the Sun . This information is actually a reference so that we can communicate with them. Find out between the magnetic activities of and the particles released from solar surface as well as the cosmic particles and how they affect the heating and climate of the Earth. In order to obtain the relationship between the magnetic activities and cosmic particles, it is necessary to obtain the annual changes in the number of sunspots and the annual changes of solar particles and cosmic particles. For this purpose, we can see from Table 1 the annual changes in solar activities, which is the same as the change in the number of sunspots. Also, in Table 1, we can see the annual changes of cosmic particles. By drawing the graph of the changes of these two parameters, we can see the relationship between them. Figure 4 indicates diagram of annual changes in the number of sunspots and the particles received on the Earth from 1964 to 2019. It is seen that the period of these changes is 11 years [42]. Also it can be seen that the changes in the solar magnetic activities and cosmic particles are inversely proportional to each other . In other words, in the maximum solar activity, the flow of cosmic particles on the Earth is in the lowest level.

Table 1: Annual changes in the cosmic particles rate and average number of sunspots.

Year	Corrected rate of change of cosmic rays/min	Annual average of sunspot number
1964	6459	15
1965	6517	22
1966	6295	66.5
1967	6033	132.9
1968	5877	150
1969	5772	149.4
1970	5809	148
1971	6191	94.4
1972	6293	97.6
1973	6293	97.6
1974	6344	54.1
1975	6407	2205
1976	6446	18.4
1977	6421	39.3
1978	6239	131
1979	5945	220.1
1980	5794	218.9
1981	5638	198.9
1982	5583	162.4
1983	5771	91
1984	5868	60.5
1985	6152	20.6
1986	6384	14.8
1987	6431	33.9
1988	6053	123
1989	5480	211.1
1990	5416	191.8
1991	5432	203.3
1992	5922	133
1993	6203	76.1
1994	6280	44.9
1995	6387	25.1
1996	6502	11.6
1997	6545	28.9
1998	6399	88.3
1999	6209	136.3
2000	5784	173.9
2001	5879	170.4
2002	5806	163.6
2003	5759	99.3
2004	6093	65.3
2005	6157	45.8
2006	6479	24.7
2007	6633	12.6
2008	6662	4.2
2009	6804	4.8
2010	6623	14.9
2011	6416	80.8
2012	6269	84.5
2013	6209	94
2014	6153	113.3
2015	6147	69.8
2016	6474	39.8
2017	6598	21.7
2018	6687	7
2019	6705	15

Considering in these conditions, the penetration of cosmic particles into the middle layers of the atmosphere will also be at its lowest. It is expected that with decreasing cloud fertility, we will see an increase in the Earth average temperature.

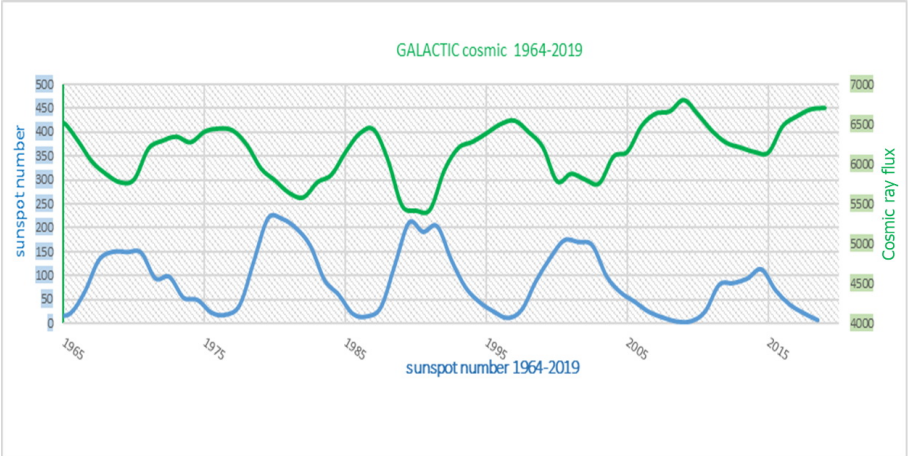

Figure 4: Changes in the number of sunspots and cosmic particle flow relative to each other.

3 Changes in X-ray flux, Proton flux and Cosmic ray flux in solar flare

On 10 September 2017, due to the fact that the Sun was currently spending its minimum activity and no X-class flares have been observed in it in recent years, therefore, one of the flares that occurred in 2017 was used to connect cosmic particles and solar particles. In the following , we can see the changes in X-ray flux, Proton flux, and Cosmic ray flux in the solar flare of September 10, 2017. As the diagram in Figure 5 shows, when the solar flare of X class occurred, the X-ray flux starts to increase. With increasing X-ray flux, proton particles or Proton fluxes also start to increase (Figure 6). With a little time delay, the flow of the Cosmic ray fluxes starts to decrease. In other words, solar particles and emitted cosmic particles are in the opposite phase. Figure 7 shows proton flux from 9 to 12 September. Figure 8 indicates cosmic ray flux on 10-12 September.

4 Effect of magnetic activity on the Earth temperature

As can be seen from the Figure 4, the increase or decrease in the magnetic activity of the corona, which is the same as the change in the number of spots on the surface, causes a decrease or increase in the flux of cosmic rays entering the middle layers of the Earth's atmosphere. As it was said, these cosmic rays are an effective factor in the fertility of clouds and the increase of precipitation on the Earth, so it can be concluded that with the increase in the flux of cosmic rays in the middle layers of the atmosphere, we see an increase in clouds and, as a result, a decrease in temperature on the planet. It will be noted that one of the important parameters that can be used in determining the temperature in different stages to measure temperature changes is the measurement of the temperature at the surface of the seas during different years, as the following diagram shows the temperature from 1960 to

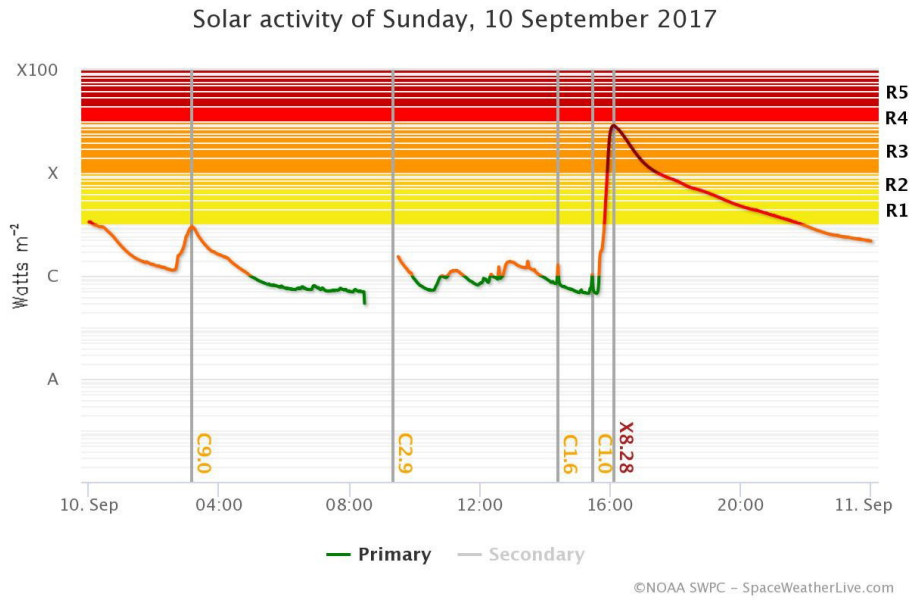

Figure 5: Solar activity on September 2017 [38].

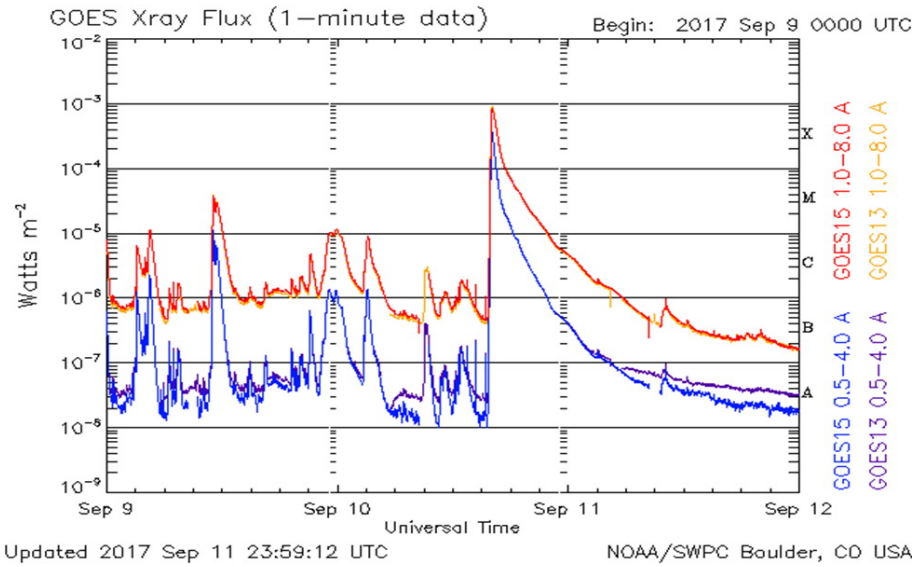

Figure 6: X-ray flux [39].

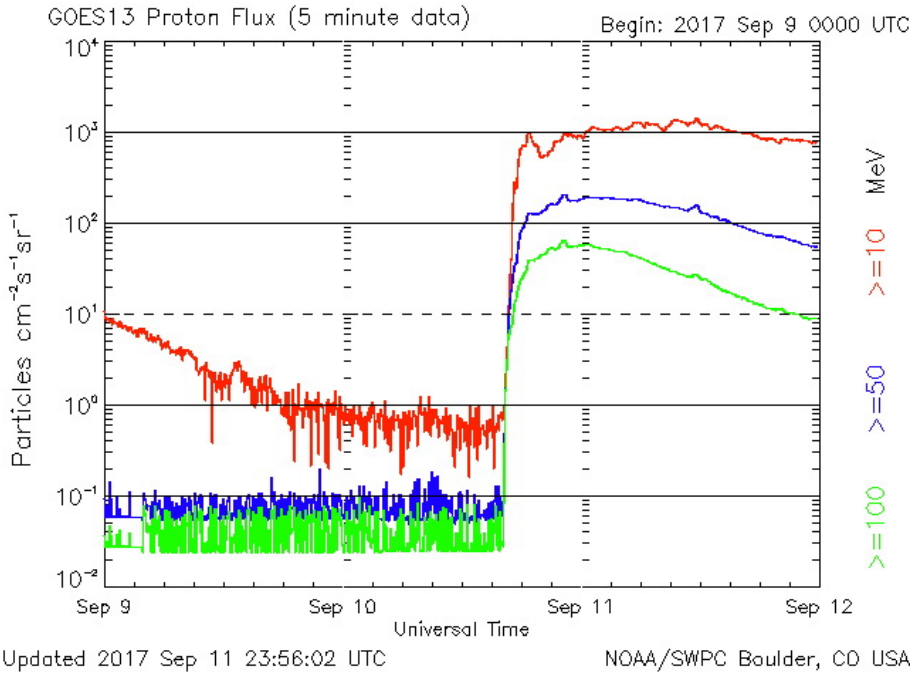

Figure 7: Proton flux from 9 to 12 September [39].

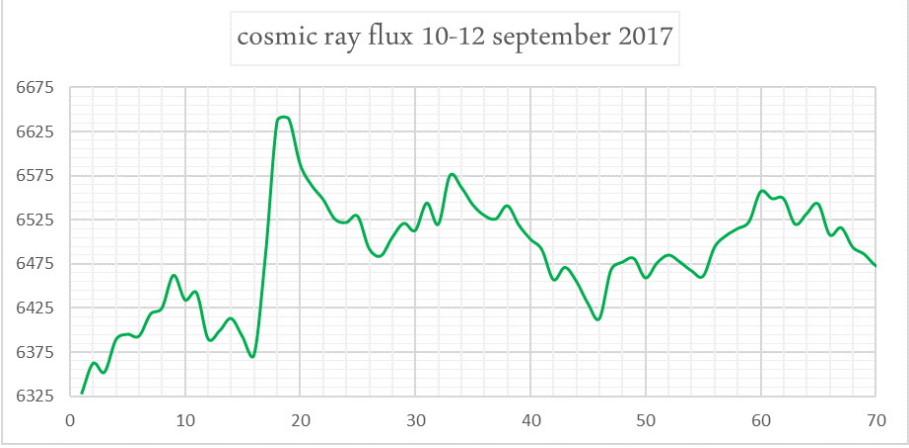

Figure 8: Cosmic ray flux on 10-12 September [40].

2019. Until 2019 (see Figure 9), there has been an upward trend and the global temperature has become warmer by about 0.8 degrees Celsius. The change in global temperature during a period of sunspots is about 0.2 degrees Celsius, in the Figure 9 we can see the trend of temperature increase during the 11-year period. Decreasing temperature in the years of 1973 and 1998 originated from the oceanic effects of El Niño. Also, based on this research, magnetic activity affects the way cosmic rays hit the Earth. When is calm like it is now, more cosmic rays enter the atmosphere and the Earth gets cooler. But when it is activated, its magnetic field prevents many cosmic rays from reaching the Earth, and as a result, less clouds are produced and the temperature of the Earth increases.

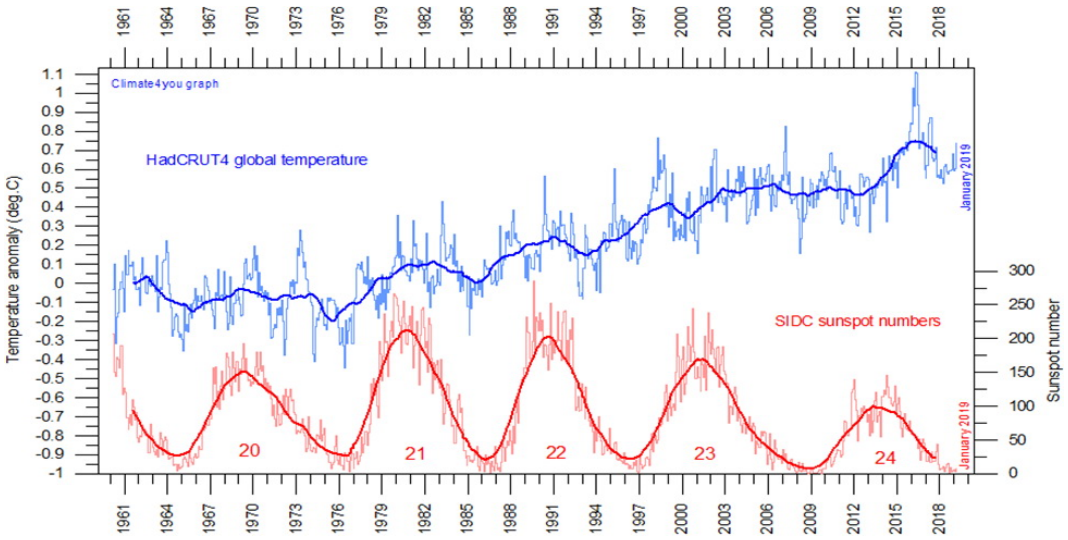

Figure 9: Changes in global sea surface temperature (HadSST3) and number of sunspots (Solar Effects Data Analysis Center (SIDC) since 1960) show the thin lines represent monthly values, while the thick lines represent changes over a 37-month period. It shows that the changes in global temperature during a sunspot period are about 0.2°C, which shows that the overall warming trend is increasing during the period.

Also, the studies conducted on the average air temperature and its relationship with the number of sunspots by the Solar Data and Effects Analysis Center (SIDC) from 1960 to 2019 show that the average temperature increase. According to Figure 9, the change in global sea surface temperature is 0.15-0.2 degrees Celsius during a sunspot period, which is shown on the overall growth trend during the period. The nearly asymmetric temperature "drop" between 1973 and 1998 reflects the oceanic effects of El Niño. Another parameter that is used to measure temperature changes is the amount of humidity in the air. Figure 10 shows that with increasing air temperature, the average humidity in the air have a downward trend.

5 The effect of carbon dioxide on the increase in Earth's temperature

Carbon dioxide is one of the greenhouse gases that slows down the process of escaping heat from the atmosphere to space. Trees and other plants absorb carbon dioxide gas from the

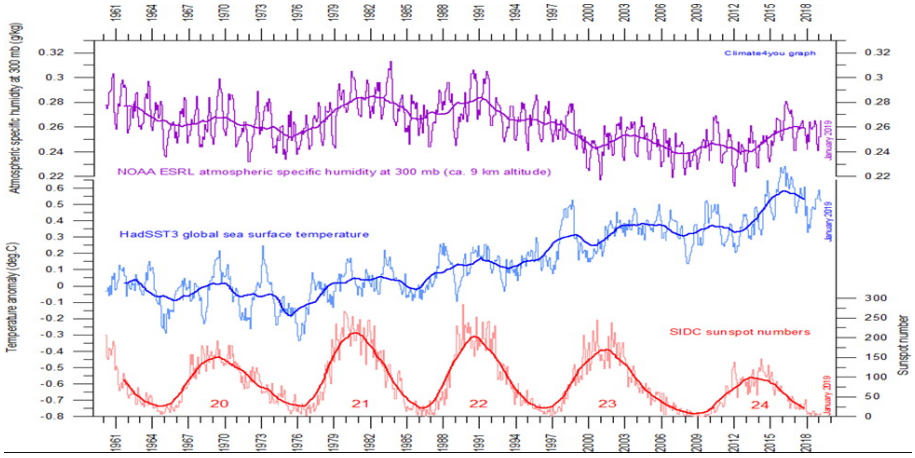

Figure 10: Changes since 1960 of global sea level (HadSST3), number of sunspots (Solar Effects Data Analysis Center (SIDC)) and specific humidity (g/kg) at 300 m above sea level (Research Laboratory Earth System 1990-1961 (NOAA): The thin lines in the chart represent the monthly values, while the thick lines are the 37-month average changes, which is roughly the same as the last 3-year average.

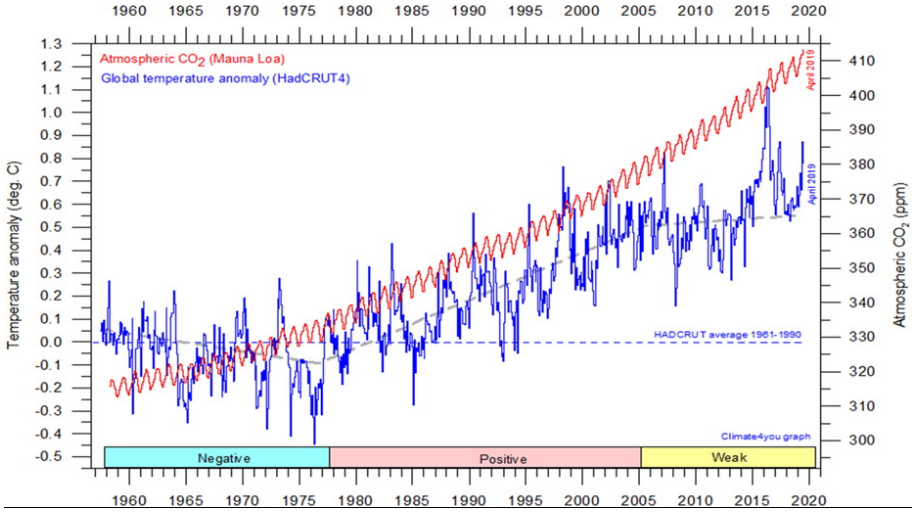

Figure 11: Chart showing HadCRUT4 monthly global air temperature (blue) and monthly CO_2 content (red CO_2) based on observations at Mauna Loa, Hawaii. The Mauna Loa data series begins in March 1958, with 1958 as the starting year for the chart. It has been chosen to reconstruct current CO_2 concentrations in the atmosphere (before 1958) not included in this chart, because past CO_2 values using other methods (ice cores, stomata or old measurements using different methods) are derived and therefore with atmospheric measurements. The gray line shows the approximate overall development, generally linear, and the boxes at the bottom of the graph show that the relationship between atmospheric CO_2 and global air temperature is negative or Positive.

air during photosynthesis. By destroying plants, the amount of carbon dioxide in the air increases. The decomposition of plants also leads to the increase of this gas. The main human activity that leads to global warming is the burning of fossil fuels (coal, oil and natural gas) and the destruction of forests. Most of the fossil fuel is used in cars, factories and power plants. Burning these fuels produces a gas called carbon dioxide with the abbreviation CO_2. Global warming is the name of the phenomenon that has led to an increase in the average temperature of the surface of the Earth and oceans(see Figure 11). Over the past 100 years, the Earth has abnormally warmed by about 0.74 degrees Celsius, which worries scientists. Some scientists believe that the last decades of the 20th century were the hottest years of the last 400 years. Reports indicate that 10 of the world's hottest years were recorded from 1990 to 2007 alone, which is unprecedented in the past 150 years. It seems that industrial activities are very effective in creating this problem and contribute to global warming.

6 Consequences of temperature rise

Global warming is one of the most worrying issues in the world today. This issue is so important that in recent years, many agreements such as the "Kyoto" agreement have been signed between many countries of the world for this purpose. Some of the deadly effects of global warming are as follows

- Increased drought
  Just as the increase in the heat of the Earth causes the ice to melt and increase the volume of water in some areas of the Earth, at the same time, in some parts of the Earth, this issue will lead to [29]. In the African continent, we see the largest volume of droughts for this reason. The water resources in this continent are very few and there will probably be many wars in the future to control these resources.

- Economic losses
  The effects of global warming are not only on nature. Another devastating effect of this phenomenon is on the economy. Due to this phenomenon, many regions in the world suffer from storms, floods or droughts and many other types of natural disasters, and the economy and trade in these regions are destroyed.

- Loss of polar ice [30]
  The loss of glaciers in the North and South Poles is one of the most worrying effects of global warming. The melting of this large amount of ice and snow will cause the water level in the oceans to rise and many coastal areas in the world will be submerged. Another bad effect is the loss of many polar animals, which will disrupt the life and nutrition chain in the North and South Poles. Another harmful effect of this problem is that the snow and ice in the poles reflect light and reduce the temperature of the Earth. With the disappearance of these ices, this property will be lost and the Earth will be warmer than before.

- Massive fires
  As the Earth continues to warm, hot and dry areas that are normally prone to fires will experience much more widespread fires. At the same time, the carbon dioxide contained in the fires will also cause more air pollution.

- Destructive storms [31]
  Due to the fact that the temperature of the oceans plays an effective role in the discussion of the occurrence of storms and tornadoes, it should be noted that this

temperature change in this recent period leads to an increase in the number and destructive power of storms. According to the calculations, the destructive power of storms has increased by 50 in the last 30 years. The warmer the surrounding air and the surface of the oceans, the more destructive the storms will be.

- cold wave [32]
  At first glance, it may seem illogical that the warming of the Earth will cause a cold wave, but it must be said that with the extensive changes that this phenomenon has caused on the Earth, it is possible that a large amount of sunlight is absorbed by the oceans, and cause a decrease in temperature and the creation of polar cold waves in the world. This cold wave can cause huge damages to a large amount of infrastructure facilities, energy transmission lines, as well as humans and other living beings.

- Deadly lightning
  Due to the increase in temperature and humidity, we should expect more dangerous thunderstorms. According to existing theories, at the end of this century we will face a 100 increase in deadly and powerful lightning. According to research, the increase in heat and especially humidity is effective in causing lightning and has a direct relationship with it.

7 Environmental problems of increasing Earth's temperature

Continued warming will melt large amounts of ice on Earth's surface over several centuries. As a result, the water level in the whole Earth rises. Many coastal areas may suffer from flooding, soil erosion, loss of dry land, and seawater intrusion into freshwater. Rising seas may drown cities, small islands, and other habitats. There are definitely drastic changes in the natural habitats of animals and plants. Many species will have many problems to survive in the new conditions. For example, many flowering plants will not bloom without going through a cold winter. Contrary to the claims of some climatologists who believe that human-made greenhouse gases are the main cause of global warming, many other climatologists believe that solar activities are the main cause of this issue. According to "Greg Koop", a solar physicist at the University of Colorado, the energy of light that reaches the top of the planet's atmosphere is about 2,500 times more than the total resources of this planet. Accordingly, even 0.1 of the amount of sunlight surpasses all sources of energy in the Earth's atmosphere, such as radioactivity, which is naturally emitted from the core of this planet. Energetic solar particles and cosmic rays can lead to depletion of ozone levels in the stratosphere. This also changes the behavior of the lower atmosphere. Changes in the magnetic activity of alter the influx of cosmic rays to Earth. When is magnetically lazy, there are more cosmic rays, more clouds, and cooler air. When is active, less cosmic rays reach the Earth, and with the lack of clouds, the world warms.

8 Conclusion

In this work, we estimate the effect of solar activity and energetic particles on global warming using a data source recorded from the instantaneous position of the Sun at reliable sites as well as data from the cosmic particle flux at the Earth's surface by the GOES detector. Due to solar activity, it affects the Earth's geomagnetic field and creates a geoelectric field on the Earth's surface. This phenomenon that can affect technology systems such as power grids,

oil and gas pipelines, and railway systems and lead to damage to power grids, equipment, line breaks, and even blackouts. The results of this research showed that the magnetic activities of the solar corona have a high correlation with the Earth's temperature, which can be used in predicting many crises and climate changes on the Earth's surface. Also, our results revealed that the changes in the number of sunspots and cosmic particles have an inverse relationship.

Authors' Contributions

All authors have the same contribution.

Data Availability

We acknowledge that the presented goes/NASA data, including text, photographs, drawings, maps, video, illustrations, logos, slogans, research, are protected by intellectual property rights that belong to the NOAA Space Weather. Data presented by the NOAA, may only be used for private, educational or scientific purposes and published the scientific articles, (URL of the web page: Data Access | NOAA / NWS Space Weather Prediction Center).

Conflicts of Interest

The authors declare that there is no conflict of interest.

Ethical Considerations

The authors have diligently addressed ethical concerns, such as informed consent, plagiarism, data fabrication, misconduct, falsification, double publication, redundancy, submission, and other related matters.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or nonprofit sectors.

References

[1] Knudsen, M. F., Seidenkrantz, M. S., Jacobsen, B. H., & Kuijpers, A. 2011, Nature Commun.

[2] Kondratev, K., Moskalenko, N. I., Parzhin, S. N., & Skvortsova, S. 1985, Akademiia Nauk SSSR, Izvestiia, Fizika Atmosfery i Okeana, 21, 451.

[3] Qian, L., McInerney, J. M., Solomon, S., Liu, H., & Burns, A. 2021, J. Geophysical Research: Space Physics, 126, 3.

[4] Schlesinger, M. E., & Ramankutty, N. 1994, Nature, 367, 723.

[5] Tavabi, E., Koutchmy, S., & Ajabshirzadeh, A. 2011, New Astron., 16, 296.

[6] Tavabi E., Koutchmy S., & Ajabshirizadeh A. 2013, Sol. Phys., 283, 187.

[7] Tavabi, E., Koutchmy, S., & Ajabshirizadeh, A. 2011, Adv. Space Res., 47.

[8] Tavabi, E. 2012, J. Modern Physics, 3, 1786.

[9] Tavabi, E., Koutchmy, S., & Ajabshirizadeh, A. 2013, SoPh., 283, 187.

[10] Tavabi, E., & Koutchmy, S. 2014, Ap&SS, 352, 7T.

[11] Tavabi, E., Koutchmy, S., & Bazin, C. 2018, SoPh., 293, 42T.

[12] Tavabi, E., Ajabshirizadeh, A., Ahangarzadeh Maralani, A. R., & Zeighami, S. 2015, J. ApA, 41, 18.

[13] Tavabi, E., Koutchmy, S., & Golub, L. 2015, SoPh., 290, 2871.

[14] Tavabi, E., Koutchmy, S., & Golub, L. 2018, ApJ, 866, 35.

[15] Tavabi, E., & Koutchmy, S. 2019, ApJ, 883, 41.

[16] Tavabi, E., Zeighami, S., & Heydari, M. 2022, SoPh., 297, 76.

[17] Tavabi, E., & Sadeghi, R. 2022, JESP, 48, 749.

[18] Tavabi, E., Rajabi, M., & Zeighami, S. 2022, IJAA.

[19] Tavabi, E., & Zeighami, S. 2022, IJAA.

[20] Trenberth, K. E. , Fasullo, J. T. 2012, Space Sciences Series, Springer Netherlands, 41, 81.

[21] Veretenenko, S. V., & Ogurtsov, M. G. 2018, Geomagn. Aeron., 58, 973.

[22] Zeighami, S., Ahangarzadeh Maralani, A. R., Tavabi, E., & Ajabshirizadeh, A. 2016, SoPh., 291, 847.

[23] Zeighami, S., Tavabi, E., & Amirkhanlou, E. 2020, JApA, 41, 18Z.

[24] Zeighami, S., & Tavabi, E. 2021, JESP, 44, 671.

[25] Zeighami, S., & Tavabi, E. 2021, IJAA.

[26] Zeighami, S., Tavabi, E., & Ajabshirizadeh, A. 2023, JESP.

[27] Sherstyukov, B. G. 2022, Geomagnetism and Aeronomy, 62, 623.

[28] Pirjola R. 1985, IEEE Trans Power Appar Syst; PER-5(10), 2825.

[29] Park, J, & Chang, H. 2013, J. the Korea Space Science Society, 30, 241.

[30] Hood, Lon L., Bryant, I., & Van der Leeuw, J. 2022, Geophysical Research Letters, 49, 22.

[31] Chen, J., Tang, C., Chu, X., Wang, X., & et al. 2023, J. Geophysical Research, Space Physics, 128, 10,

[32] Hansen, S. C., & Cally, P. S. 2012, ApJ, 751, 1.

[33] Gopalswamy, N., Mäkelä, P., Akiyama, S., Yashiro, S., Xie, H., & et al. 2015, ApJ, 806, 8.

[34] Krucker, S., & Lin, R. P. 2000, ApJ, 542, L61.

[35] Mohammadi, Z., Alipour, N. Safari, H., & Zamani, F. 2020, J. Geophysical Research: Space Physics, 126, e2020JA028868.

[36] Kristjánsson, J. E., Kristiansen, J., & Kaas, E. 2004, Advances in Space Research, 34, 407.

[37] Svensmark, J., Enghoff, M. B., Shaviv, N. J., & Svensmark, H. 2016, J. Geophysical Research: Space Physics, 121, 8152.

[38] https://www.spaceweatherlive.com

[39] https://www.swpc.noaa.gov

[40] http://cr0.izmiran.ru/oulu/main.htm

[41] http://sidc.oma.be/cactus/

[42] http://www.sidc.be/silso/home

[43] http://cosmicrays.oulu.fi/

[44] https://www.climate4you.com

[45] https://www.nasa.gov

[46] http://www.iranastro.ir

[47] https://hupaa.com