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Assessment of cloud cover distribution with sunspot and cosmic rays of the Iraq region

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This research aims to provide insight into the impact of solar activity on climate change by examining the relationship between the sunspot number index and cosmic rays with low cloud cover and temperature over Iraq, located at latitude 33°N and longitude 43°E. Sunspot data for this study are obtained from the World Data Center for the international sunspot number, cosmic ray data from the Neutron Monitor Database, and atmospheric parameter data from the Climate Data Store for the period 1996–2021, representing solar cycles 23, 24, and 25. Time series and regression analyses are employed. The results showed a strong inverse relationship between sunspot cycles and cosmic rays, while the relationship between low cloud cover and both sunspots and cosmic rays is weak. As both cosmic rays and temperatures increased, cosmic rays did not play an effective role in cooling the climate by acting as cloud condensation nuclei.

Keywords: Cosmic rays; Cloud cover; Sunspots; Solar cycle; Climate change.

1. INTRODUCTION

Nanoparticles in the atmosphere originate from various sources. In urban areas, nanoparticles are typically formed from combustion processes during energy production and transport by petrol and diesel vehicles, as well as other industrial processes. In rural areas, the nucleation and growth of new particles (i.e., new particle formation) represent an important source of atmospheric nanoparticles [1]. Nanoparticles may also escape into the atmosphere during the manufacture and use of engineered nanoparticles Clouds consist of particles, aerosols, supercooled water droplets, and ice crystals suspended in the air. They form when air is cooled to saturation and reaches the dew point temperature [2]. Clouds are classified into three types: low clouds with heights up to 2 km, middle clouds at 2–6 km, and high clouds above 6 km [3, 4]. Clouds are a critical factor in climate studies because they cover more than 50% of the Earth's surface, act as a source of precipitation, and contribute to either warming or cooling depending on their height, thickness, and composition. High clouds generally contribute to warming, while low clouds contribute to cooling [5–7]. The Sun, being the primary source of energy for Earth, is believed to influence the climate system, making the study of solar variability essential to understanding climate change [8–10]. To evaluate how solar activity affects climate, some researchers have investigated the correlation between the solar cycle and cloud cover, considering it a clear indicator of the relationship [11,12]. One of the primary indicators of solar activity is the sunspot cycle, which repeats approximately every 11 years. Sunspots are cooler, darker regions on the solar surface associated with strong magnetic fields [13,14]. Their number increases at the beginning of a solar cycle, reaches a maximum, then gradually decreases to a minimum before a new cycle begins [15–17]. Earth is continuously exposed to cosmic rays originating from supernova explosions. However, during periods of high solar activity, the increased solar wind reduces the influx of cosmic rays reaching Earth [18,19]. Therefore, cosmic ray intensity varies by about 15% over the solar cycle [20–22]. Cosmic rays, consisting mostly of high-energy protons (about 87%), interact with the atmosphere upon entry [23–25]. According to Henrik Svensmark's theory, cosmic rays enhance cloud formation by ionizing particles in the troposphere. Early studies in mid-latitude ocean regions observed a correlation between cosmic rays and cloud cover; however, with improved satellite monitoring between 1992–1994, the correlation weakened, and the earlier results are not confirmed [26–28]. Cosmic rays have been associated particularly with low cloud cover, which contributes to climate cooling by reflecting solar radiation [29–31]. Thus, a decrease in cosmic rays during solar maximum could lead to reduced low cloud cover and enhanced warming [32–34]. Studies conducted for the periods 1993–2009 and 1950–2012 in Nigeria using time series and Spearman correlation analyses reported a strong inverse relationship between sunspot cycles and galactic cosmic rays. Trends in cosmic rays and low cloud cover agreed between 1850 and 1995, but diverged afterward [35–37]. In this study, an attempt is made to determine the type of correlation between solar activity, cosmic rays, and low cloud cover—which significantly influences precipitation—for the period 1996–2021, representing a time frame not previously investigated in detail.

2. METHODOLOGY

To conduct this study, data from solar cycles 23, 24, and 25 are used. Sunspot numbers are obtained from the World Data Centre (SILSO) for the production, preservation, and dissemination of the international sunspot number. Cosmic ray data are taken from the Ionosphere Institute's Neutron Monitor in Almaty, Kazakhstan (AATB), the closest station covering the study period, located at latitude 43.14°N and longitude 76.60°E, and available through the Neutron Monitor Database [38,39]. For atmospheric parameters, low cloud cover and temperature data over Iraq are extracted from the ERA5 model provided by the Copernicus Climate Change Service through the Climate Data Store [40,41]. The dataset spans 26 years (1996–2021) for all variables [42,43].

The study area is Iraq, located at latitude 33°N and longitude 43°E, with a total area of 437,072 km² [44–46]. The geographical location of Iraq is shown in the corresponding figure. The SigmaPlot program is used to analyze monthly and annual behaviors of the variables. Additionally, simple linear regression analysis is performed to determine the relationships between variables [47,48].

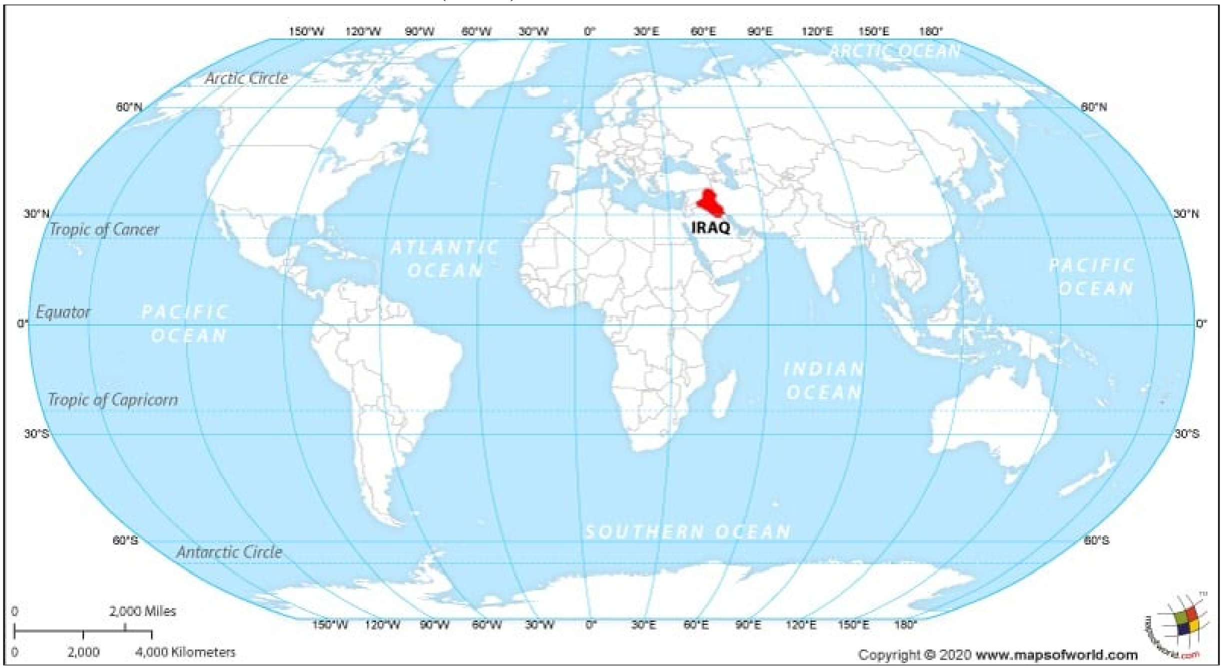

Figure 1 Location of Iraq in world.

3. RESULTS AND DISCUSSION

To study the relationship between sunspots and cosmic rays for the period from 1996 to 2021, time series are drawn to illustrate the progression of this relationship. Figure 2 shows an opposite trend in the monthly averages, where cosmic rays increased during periods of low solar activity for solar cycles 23, 24, and 25. This can be explained by the fact that, during periods of high solar activity, the solar wind pushes cosmic rays away from the Earth's atmosphere, while during periods of low activity; the weakened solar wind allows more cosmic rays to penetrate the atmosphere. Figure 3, which represents the regression analysis between the monthly averages of sunspot numbers and cosmic rays for the period 1996–2021, shows a good inverse relationship, with a regression value of 0.7.

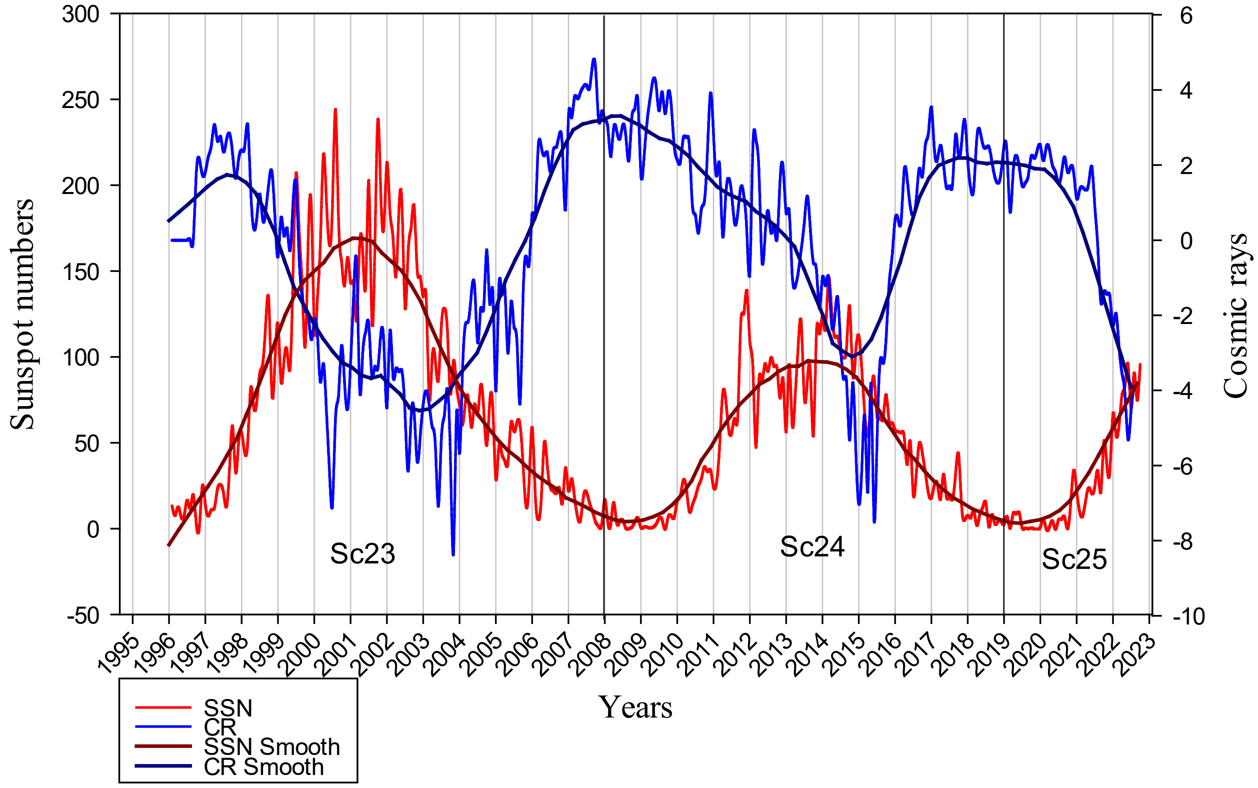

Figure 2 The relationship between monthly sunspot number and cosmic ray for solar cycles 23, 24, and 25 from 1996 to 2021.

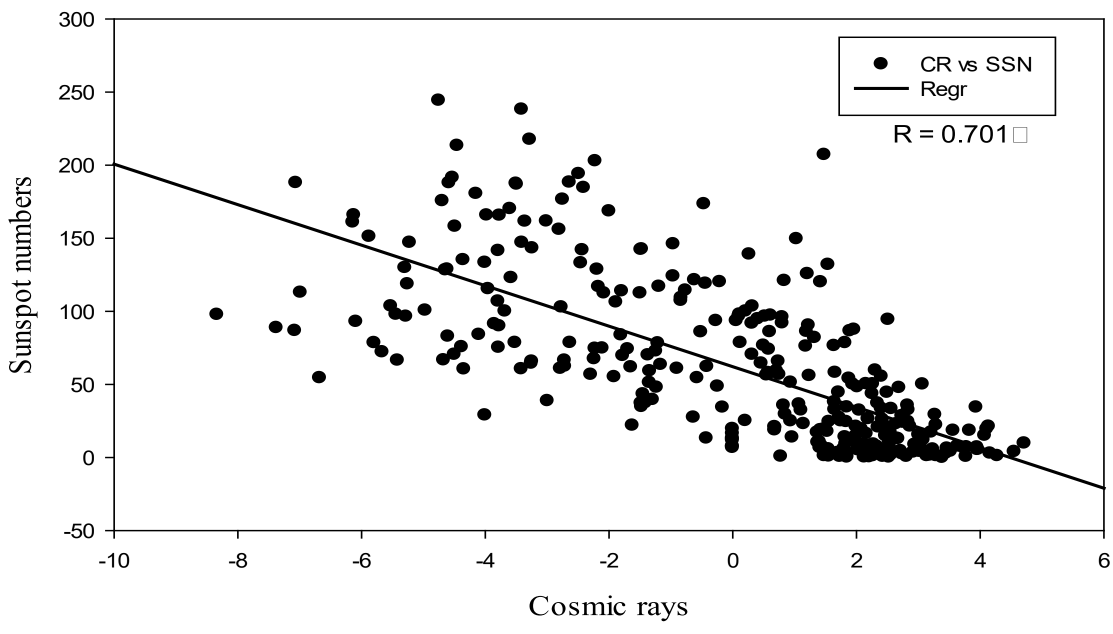

Figure 3 The regression between monthly sunspot number and cosmic ray for solar cycles 23, 24, and 25 from 1996 to 2021.

Figure 4 shows the relationship between the annual average of low cloud cover over Iraq and sunspot numbers from 1996 to 2021. An unstable relationship appeared between sunspots and low clouds, where an inverse relationship is observed during the periods 1996–1999 and 2017–2021, while periods of positive correlation are observed during the years of maximum activity, particularly from 2000 to 2012 and 2011 to 2016.

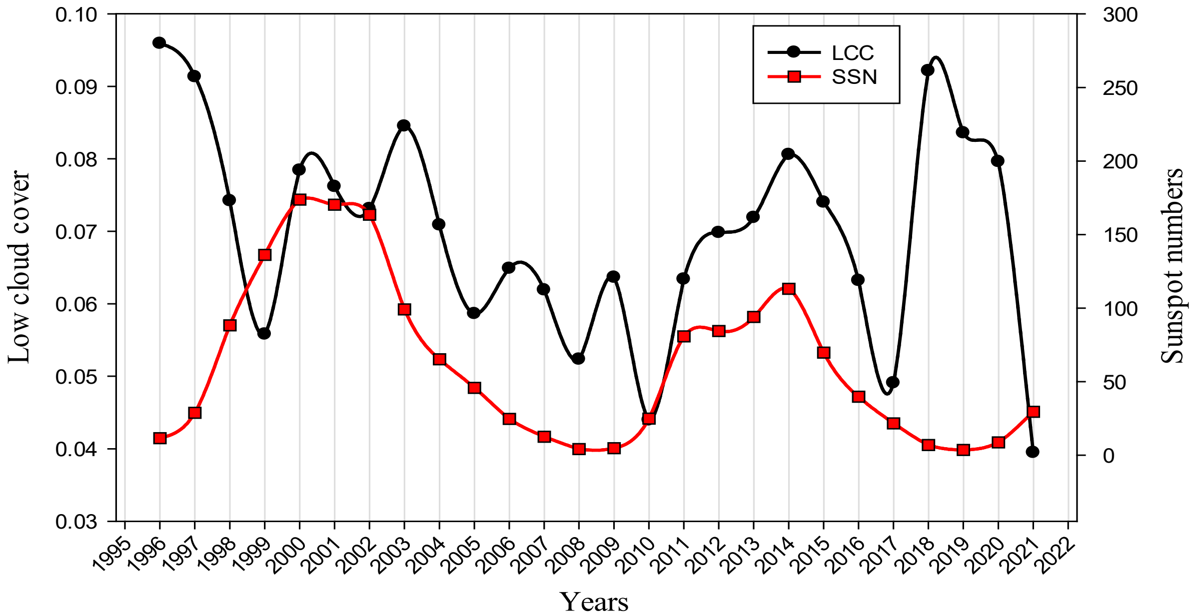

Figure 4 The relationship between the annual average of low cloud cover with sunspot numbers from 1996 to 2021 over Iraq.

Figure 5 illustrates the relationship between the annual average of cosmic rays and low cloud cover over Iraq for the period 1996–2021. The relationship shows an opposite trend, where low cloud cover increased during periods of low cosmic ray intensity for most of the study years.

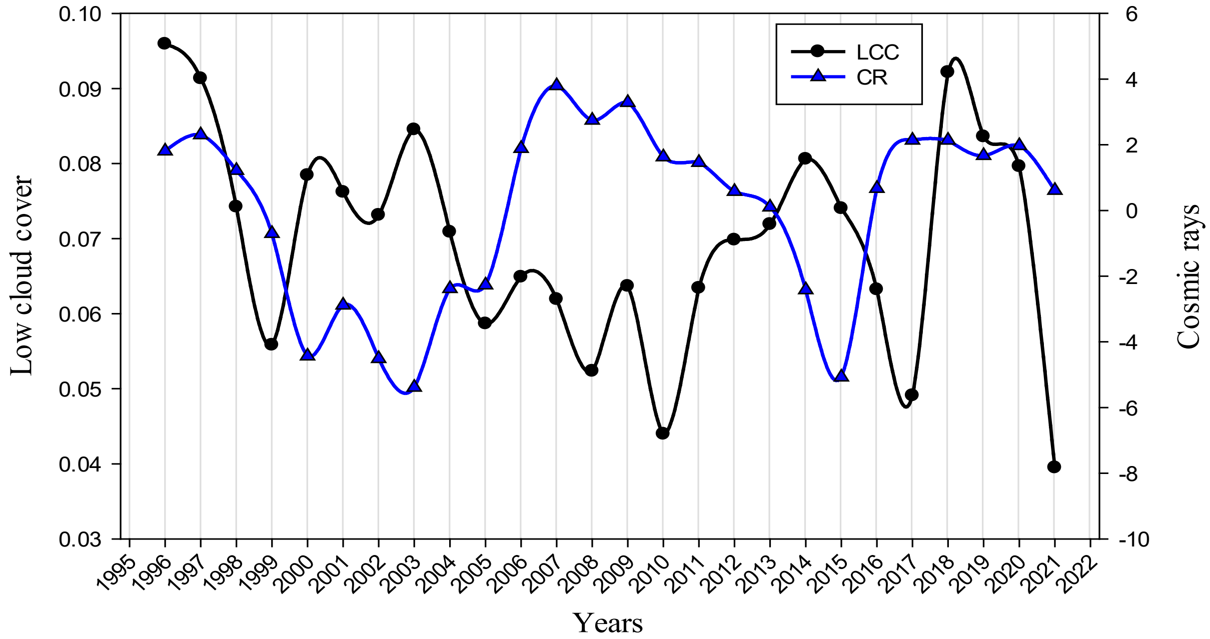

Figure 5 The relationship between the annual average of low cloud cover with cosmic rays from 1996 to 2021 over Iraq.

The regression is determined for low cloud cover with each of (a) sunspots and (b) cosmic rays, as shown in Figure 6. The figure indicates that low cloud cover has a weak positive relationship with sunspot numbers, with a regression coefficient of 0.13, and an inverse relationship with cosmic rays, with a regression coefficient of 0.2.

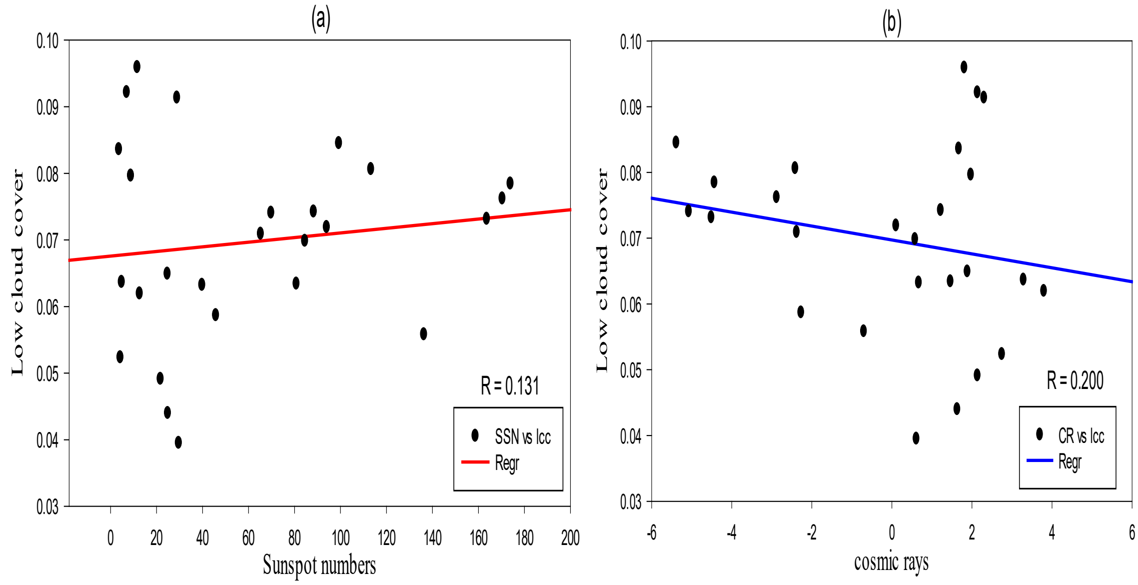

Figure 6 The regression correlation between Low cloud cover with (a) sunspot numbers and (b) cosmic rays from 1996 to 2021 over Iraq.

Figure 7 represents the relationship between the annual averages of cosmic rays and temperatures over Iraq from 1996 to 2021. The results show that both cosmic rays and temperatures tended to increase, but their trends did not exhibit similar behavior. The increase in cosmic rays occurred as a result of reduced solar cycle activity, while the rise in temperatures is associated with other atmospheric factors such as radiation and cloud cover, which are not affected by the increase in cosmic rays.

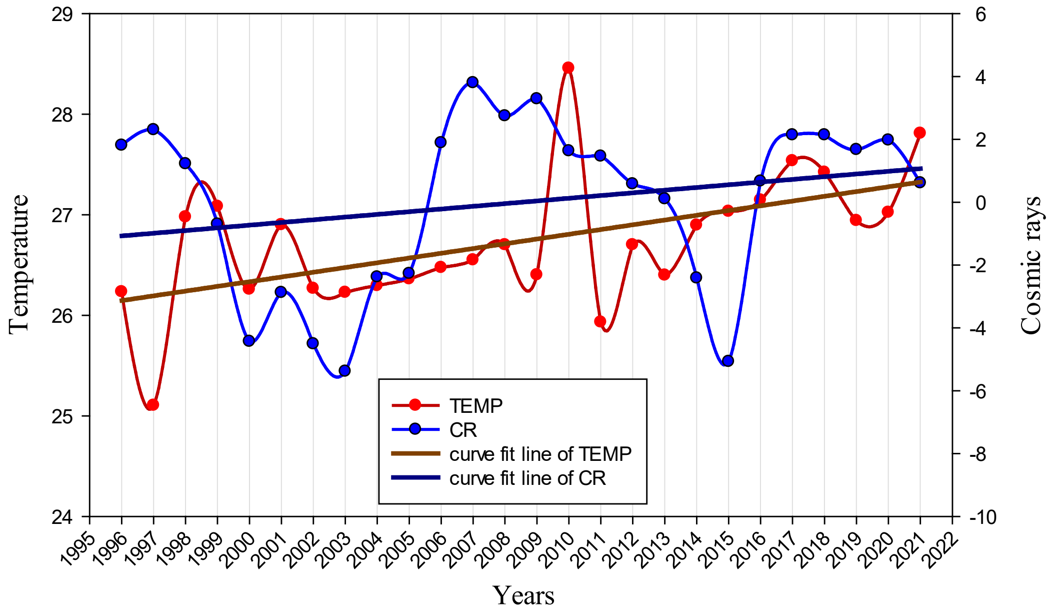

Figure 7 The relationship between annual average cosmic rays with temperature from 1996 to 2021 over Iraq.

4. CONCLUSIONS

The findings of this study indicate that the inverse relationship between sunspot numbers and cosmic rays persisted throughout solar cycles 23, 24, and 25 during the period 1996–2021. The results further showed that low cloud cover exhibited a positive relationship with solar activity and an inverse relationship with cosmic rays; however, both relationships were weak based on simple linear regression analysis. Additionally, the study revealed a decline in sunspot activity in recent cycles, accompanied by an increase in cosmic rays and temperatures. This suggests that cloud formation through proton ionization by cosmic ray particles was not sufficiently effective to produce a cooling effect on the climate.

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Conflict Of Interest

The researcher confirms that this work does not conflict with the interests of any other party.

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