

The Impact of Solar Flares and Coronal Mass Ejections on Earth's Climate

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Abstract

This paper examines the impact of X flares, sunspots, and other solar phenomena on the Earth's surface, which contribute to climate anomalies. The analysis focuses on global events and variations. The Earth's magnetic field protects from solar radiation, which impacts the Northern and Southern Hemispheres differently. Specifically, two years with lower average temperatures, 2008 and 2011, were selected for detailed study. Subsequently, the year 2024, the warmest on record since 1850, was analyzed in the context of these records.

Keywords

X Flares, Sunspots, Earth's Temperature, Weather Anomalies

1. Introduction

Solar cycles affect Earth in several ways, affecting climate, space weather, and communication systems. The Sun's energy output fluctuates during these cycles, influencing atmospheric temperatures and weather patterns. Space weather events such as solar flares and coronal mass ejections can disrupt radio communications, affect power grids, and pose risks to astronauts. Increased solar radiation during solar maximum heats Earth's atmosphere. Sun's energy output during solar cycles fluctuates slightly; these changes affect Earth's climate, influencing atmospheric temperatures and weather patterns. Space weather is created by solar flares and coronal mass ejections, disrupting radio communications, affecting power grids, and posing risks to astronauts. During solar maximum, solar radiation increases, leading to greater heating of the Earth's atmosphere. CMEs occur near sunspots, usually at the dividing line between areas of oppositely directed magnetic fields. Hot matter called plasma interacts with the magnetic field, sending a plasma burst up and away from the Sun as a flare. Solar flares emit X-rays and magnetic fields,

which bombard the Earth as geomagnetic storms. If sunspots are active, more solar flares will increase geomagnetic storm activity for Earth. Therefore, during sunspot maximums, the Earth will experience an increase in the Northern and Southern Lights, as well as a potential disruption in radio transmissions and power grids. The storms can even change polarity in satellites, which can damage sophisticated electronics. Therefore, scientists will often position satellites in a different orientation to protect them from increased solar radiation when a strong solar flare or coronal mass ejection has occurred. Sunspots increase and decrease through an average cycle of 11 years.

Dating back to 1749, we have experienced 23 complete solar cycles, during which the number of sunspots has fluctuated from a minimum to a maximum and back to the following minimum, following approximately 11-year cycles. We are now well into the 25th cycle, as shown in **Figure 1**. One interesting aspect of solar cycles is that the Sun experienced a period of near-zero sunspot activity from approximately 1645 to 1715. This period of sunspot minimum is called the Maunder Minimum. The “Little Ice Age” occurred over parts of Earth during the Maunder Minimum. So, how much does solar output affect Earth’s climate? There is debate within the scientific community about how much solar activity can or does affect Earth’s climate. Research shows that Earth’s climate is sensitive to very weak changes in the Sun’s energy output over time and 100s of years. Times of the most significant sunspot activity are associated with a very slight increase in the energy output from the Sun.

For example, research shows that the Maunder Minimum occurred during a period of low sunspot activity and coincided with a multi-decade episode of large volcanic eruptions. Significant volcanic eruptions are known to hinder incoming solar radiation. Our observations will focus mainly on the last solar cycles, Cycle 22, 23, 24, **Figure 2**, which showed an increase of global temperatures, disagreeing with some author [1] who said that the periods with less sunspots as Maunder Minimum would agree with the decrease of worldwide temperatures as observed between 1645-1715, in the period the number of sunspots, became almost zero. Many scientists took the Maunder Minima to explain the low temperatures in Europe and North America. However, some southern European and Canadian/Greenland regions experienced milder temperatures [1].

Finally, there is evidence that some of the major ice ages Earth has experienced were caused by Earth being deviated from its average 23.5-degree tilt on its axis. Indeed, Earth has tilted anywhere from nearly 22 degrees to 24.5 degrees on its axis. However, there will always be a question of the degree of effect due to terrestrial and oceanic interactions on Earth.

This research aims to investigate how solar activity may influence the Earth’s average global temperature. However, other considerations, such as the Northern and Southern Hemispheres, may react differently to the solar impact in the magnetosphere through the electromagnetic circuit that encompasses the entire Earth. The chosen period has more observations, which enable a proper analysis of Solar activity and its implications for the observed seasonality and climate anomalies

during that period.

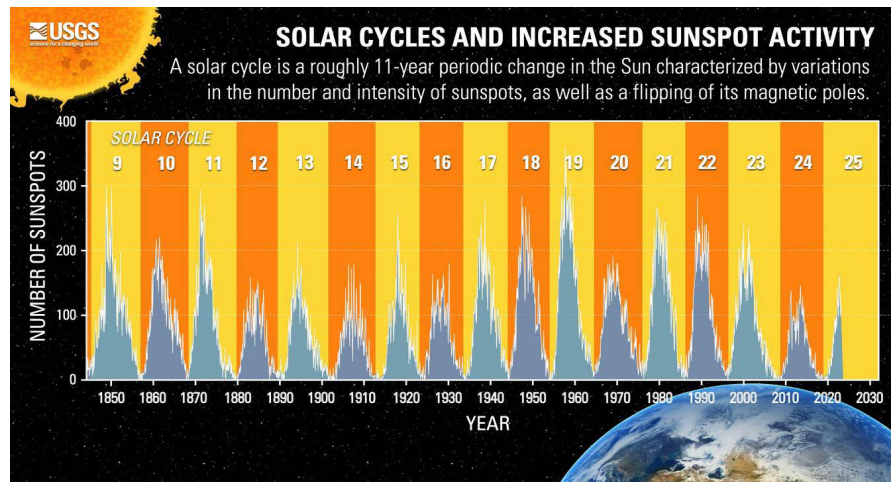


Figure 1. The solar cycle variation from 1850 to 2025.

Sunspot became significantly reduced, and the total amount of energy emitted by the Sun was lower during this period. It also coincided with increased volcanic activity, particularly in the Northern Hemisphere. Volcanic aerosols, composed of particles and gases, create a layer in the upper atmosphere that reflects a part of the Sun's rays into space. This reduces the amount of solar energy reaching the Earth's surface, decreasing temperatures.

2. Solar Flares and CMEs' Interactions with Earth's Atmosphere

Solar storms typically begin when twisted magnetic fields on the Sun get contorted and stretched so much that they snap and reconnect (in a process called magnetic reconnection), releasing enormous amounts of energy.

These powerful eruptions can generate any or all of the following:

- a bright flash of light called a solar flare.
- a radiation storm, or flurry of solar particles propelled into space at high speeds.
- An enormous cloud of solar material, called a coronal mass ejection, billows away from the Sun. X-class flares can go even higher and have no upper limit. The most powerful flare ever measured occurred in 2003, recorded as an X28 before our sensors were overwhelmed. The energy from a flare travels at the speed of light, which means it reaches Earth about 8 minutes after a flare happens. When we see a flare, most of its effects are here. Fortunately, harmful radiation from a flare does not physically affect us on the ground, as Earth's atmosphere and magnetic field shield us. However, intense flares can disrupt radio communications that pass through the upper atmosphere and affect satellites or spacecraft beyond the protection of our planet.

A coronal mass ejection (CME) is an enormous cloud of electrically charged gas, known as plasma, which erupts from the Sun. A single coronal mass ejection

can simultaneously blast billions of tons of material into the solar system. CMEs occur in the Sun's outer atmosphere, called the corona, and often look like giant bubbles bursting from the Sun. When they interact with Earth's magnetic environment, CMEs can induce electrical currents that flow through power grids, potentially damaging components such as transformers, relays, and circuit breakers, which can lead to power outages.

Solar flares and CMEs emit different things, look and travel differently, and have other effects near planets. Both events occur when the Sun's interior motion contorts its magnetic fields. Like a twisted rubber band's sudden release, the magnetic fields realign, driving vast amounts of energy into space. This phenomenon can create a sudden flash of light, a solar flare. Flares can persist for minutes to hours and contain immense energy. Traveling at the speed of light takes eight minutes for the light from a solar flare to reach Earth. Some energy released in the flare also accelerates high-energy particles that can reach Earth in tens of minutes. The magnetic contortions can also create a different explosion that hurls solar matter into space. These are the coronal mass ejections, also known as CMEs [2]. Scientists classify solar flares according to their X-ray brightness, in the wavelength range 1 to 8 Angstroms. Flare classes have names: A, B, C, M, and X, with A being the tiniest and X being the largest. The strength of an event within a class is noted by a numerical suffix ranging from 1 up to, but excluding, 10, which is also the factor for that event within the class. Hence, an X2 flare is twice the strength of an X1 flare, and an X3 flare is three times as powerful as an X1. M-class flares are a tenth the size of X-class flares with the same numeric suffix. An X2 is four times more powerful than an M5 flare. X-class flares with a peak flux that exceeds 10^{-3} W/m^2 may be noted with a numerical suffix equal to or greater than 10. This system was initially devised in 1970 and included only C, M, and X. These letters were chosen to avoid confusion with other optical classification systems. The A and B classes were added in the 1990s as instruments became more sensitive to weaker flares. Around the same time, the backronym moderate for M-class flares and extreme for X-class flares began to be used. Solar flares cause a rapid increase in solar radiance, particularly in the X-ray and extreme ultraviolet (EUV) regions. These flares are sudden, localized bursts of electromagnetic radiation, often near sunspots. While the energy released during a flare is substantial, the total solar irradiance (TSI) change is relatively small but measurable. During a solar flare, the Sun emits electromagnetic radiation, including X-rays, EUV, visible light, and radio waves. This surge can last for minutes to hours.

3. Solar Irradiance Effects on Earth

Irradiance (insolation) measures the amount of sunlight power that falls upon one square meter of exposed surface, usually measured at the top of Earth's atmosphere. This energy fluctuates with the seasons and varies with your latitude on Earth, being lower in winter and higher in Summer, and lower at the poles and higher at the equator. However, the Sun's energy output also changes during the

sunspot cycle. **Figure 2** shows the solar irradiance and sunspot number since January 1979 according to NOAA's National Geophysical Data Center (NGDC) [3]. The thin lines show the daily irradiance (red) and sunspot number (blue), while the thick lines show the annual running average for these two parameters. The total variation in solar irradiance is about 1.3 watts per square meter during one sunspot cycle. This is a slight change compared to the hundreds of watts we experience due to seasonal and latitude differences, but it may impact our climate. The solar irradiance data obtained by the ACRIM satellite measures the total number of watts of sunlight that strike Earth's upper atmosphere before being absorbed by the atmosphere and ground.

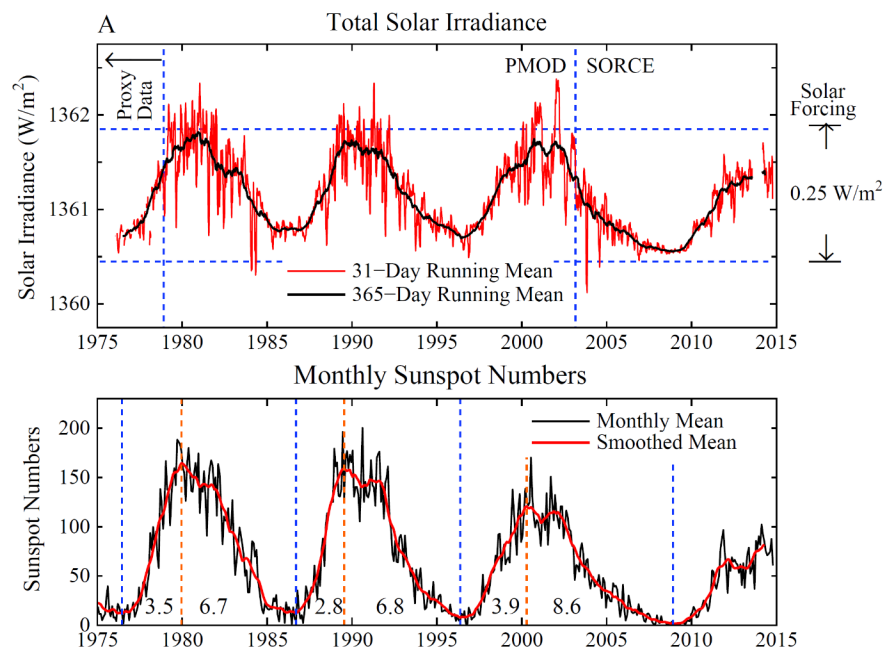


Figure 2. Sunspot variations and solar irradiance period 1978-2004 (NASA).

The more sunlight a surface absorbs, the warmer it gets, and the more energy it radiates as heat. The re-radiated heat is then absorbed by greenhouse gases and clouds, warming the atmosphere through the greenhouse effect. The Earth's surface is more effective at absorbing solar radiation than air, most of which is dark in color. Earth's different surfaces and atmospheric parts absorb solar radiation at different rates. Due to its shape, Earth will not receive the same amount of solar radiation. Near the equator, the Sun's rays strike the Earth most directly, while at the poles, the rays strike at a steep angle. The Earth is unevenly heated because of its spherical shape.

Near the equator or at lower latitudes, one receives more direct sunlight, resulting in higher irradiance. The Sun's rays are more concentrated at lower latitudes because they strike the Earth's surface at a different angle. Near the poles or higher latitudes, less direct sunlight results in lower irradiance. The Sun's rays are spread over a larger area at higher latitudes. They must pass through a greater amount of

atmosphere, leading to increased scattering and absorption of solar radiation. Earth's tilt on its axis causes different hemispheres to receive direct sunlight at various times of the year. During Summer, the hemisphere tilted toward the Sun gets higher irradiance and longer daylight hours. In contrast, during winter, the hemisphere tilted away from the Sun experiences shorter daylight hours and lower irradiance [4].

Reflection occurs when incoming solar radiation bounces back from an object or surface that strikes the atmosphere, land, or water, and is not transformed into heat. The proportion of incoming solar radiation the Earth reflects is known as its albedo. Overall, Earth reflects about 29% of the incoming solar radiation; therefore, the Earth's average albedo is 0.29.

The Earth's orbit around the Sun is slightly elliptical, meaning it is closer to the Sun during certain times of the year (perihelion) and farther away (aphelion). While this orbital variation does not cause significant fluctuations in overall solar irradiance, it does contribute to minor variations in solar radiation received throughout the year.

Diurnal variation, solar irradiance increases from sunrise to noon and decreases from noon to sunset. The peak irradiance occurs at noon when the Sun is highest in the sky, and its rays are most direct. Clouds absorb and reflect a portion of the Sun's energy, reducing the amount of solar irradiance that reaches the Earth's surface. Cloudy conditions can significantly reduce the amount of solar radiation reaching the surface. Air pollution can also absorb and scatter solar radiation, reducing the amount of solar irradiance. The solar cycle, which involves increased and decreased sunspot activity, can also influence the amount of solar irradiance reaching the Earth.

In summary, solar irradiance varies with position locations across the globe and throughout the year due to factors such as latitude, time of year, time of day, atmospheric conditions, and solar activity.

4. Solar Flares and Climate Anomalies

This part analyzes the frequency of X-flares and climate anomalies between 1996 and 2025 (Figure 3). Although data for the year (2025) is incomplete, several events have been recorded up to June. The plot reveals gaps in events during specific periods, such as 2007-2011 and 2015-2020.

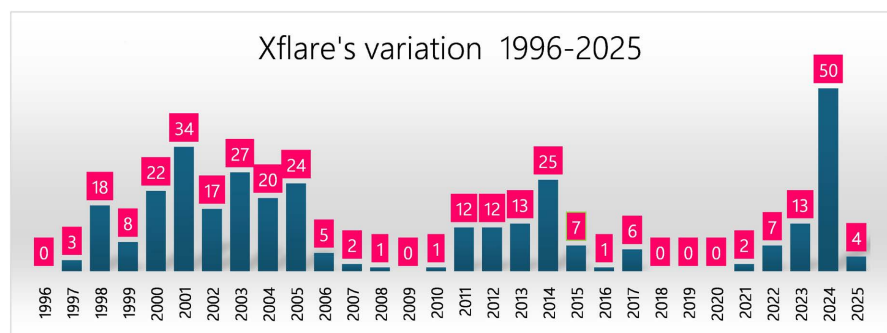


Figure 3. The number of X flare events during 1996-2025 (Beginning).

The following plot illustrates the evolution of X-flares over a shorter period, from 1996 to 2010, with monthly intervals, enabling us to compare the events and X-flares within a shorter period. Observe X-flares that occurred between 1996 and 2010 in plot 5. This plot shows that the beginning of our records indicates zero X-flare occurrences in some recorded months (**Figure 4**).

Let us analyze the year 2001, when a second maximum in X flares occurred. The combined temperature of land and ocean across the globe was 0.55°C (0.99°F) above the 1880-2000 long-term mean. This was the second-warmest April in the 1880-present record, second only to April 1998, when the combined land and ocean temperature anomaly was 0.74°C (1.33°F). Ocean surface temperatures also ranked as the second warmest on record (0.39°C [0.70°F] above average), which was 0.13°C (0.23°F) cooler than during the 1998 El Niño episode. Temperatures averaged over land surfaces were 0.92°C (1.66°F) above average, or the third warmest April on record, but 0.31°C (0.56°F) cooler than the record April land temperature set during the El Niño event of 1998. A gradual dissipation of La Niña conditions continued during April as temperature anomalies returned to more neutral values. Tropical temperature anomalies in the oceans were 0.34°C (0.61°F) above the long-term mean. Temperature anomalies in the extratropical regions were even higher, most notably in the southern hemisphere, where the combined land and ocean temperature was 0.62°C (1.12°F) above average. This was the second-warmest April on record south of 20°S latitude. Global Ocean Temp Anomalies in April 2001.

Across land areas, anomalies were slightly positive in the tropics, with temperatures 0.64°C (1.15°F) above average. Extratropical land areas of the Northern Hemisphere experienced their 4th warmest April, or 1.19°C (2.14°F) above average.

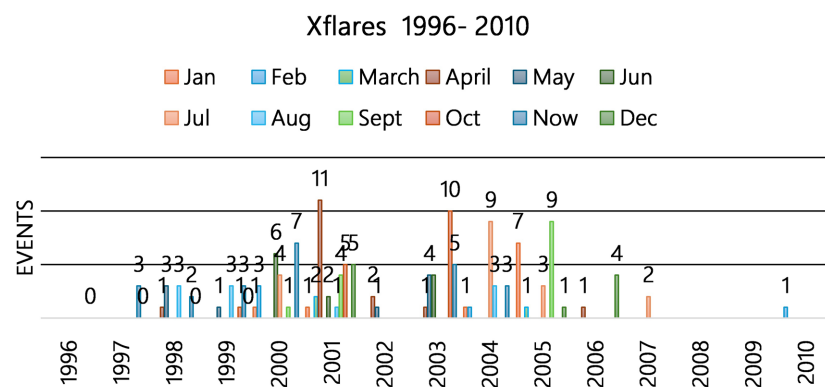


Figure 4. The X-flare variation monthly, 1996-2010. It is possible to determine when the flares were emitted most frequently.

Based on preliminary data for October 2003, the global average combined land and sea surface temperature was the warmest on record. Observe the number of flares in October in **Figure 5**. Temperatures were significantly above average across the Middle East, the western U.S., and Alaska, with below-average temper-

atures in Europe, the northeastern U.S., and most of Australia. Precipitation during October 2003 was above average in the U.S. Pacific Northwest and Europe, with drier-than-average conditions over the United Kingdom and most of the U.S.

Slightly warmer than normal Sea Surface Temperature (SST) remained across the equatorial Pacific basin, showing the possibility of a developing weak El Niño event.

Globally average ocean surface temperatures were 0.54°C (0.97°F) above the 1880-2002 mean, also the warmest on record for October 2003. October 2003, temperatures across the Northern Hemisphere were the warmest on record, 0.79°C (1.42°F) above the long-term mean

Temperatures throughout the Southern Hemisphere were the fourth warmest, 0.50°C (0.90°F) above average. The discrepancy between the Northern and Southern Hemispheres and global temperatures did not correspond to being similar between the hemispheres [6].

Based on preliminary data for July 2004, the global average combined land and sea surface temperature was the sixth warmest on record. July temperatures were above average throughout Alaska, the western half of North America, and Scandinavia, with below-average temperatures in the Great Plains of the U.S. and adjoining parts of Canada, as well as the United Kingdom.

Precipitation during July was above average across the Great Plains of the U.S., most of Europe, and much of South America, with drier-than-average conditions in Alaska, India, and Japan. Near-neutral SSTs across the central equatorial Pacific basin prompted forecasts of a developing El Niño. Based on preliminary data, the global average combined land and sea surface temperature for September 2005 was the warmest on record.

September temperatures were above average over Alaska, Asia, eastern Europe, and most of the U.S. Colder-than-average conditions occurred in France, western Australia, and the U.S. Pacific Northwest. Precipitation during September was above average over India, Alaska, and parts of Canada, with drier-than-average conditions over eastern Europe, Mexico, and the U.S. East Coast. Neutral ENSO conditions continued during September.

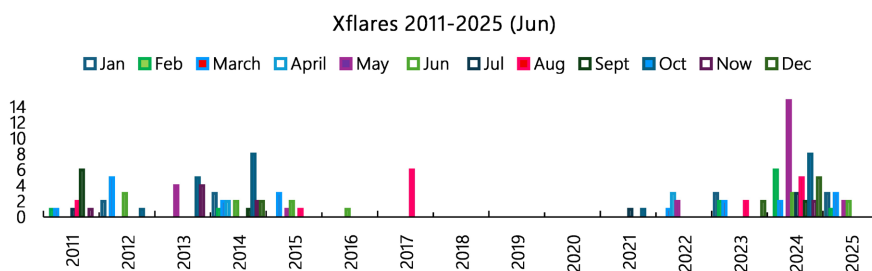


Figure 5. X flares period 2011-2025, see the gap after August 2017-September 2021.

During September 2005, above-average temperatures were observed over eastern Europe, Asia, Japan, most of North America, and parts of Brazil. Over France, Spain, western Australia, central South America, and along the U.S. West Coast,

cooler-than-average temperatures were observed. Much warmer-than-average sea surface temperatures occurred over the North Pacific and the North Atlantic. Cooler-than-average conditions were caught off the U.S. California coast and the South Atlantic. The following paragraph will analyze the Xflares occurrences for the final period.

Figure 6 shows that the frequency of X flares between 2015 and 2021 was at a minimum, then increased again in 2022, followed by a further increase to 2025. The year 2013 ties with 2003 as the fourth-warmest year globally since records began in 1880. The annual global combined land and ocean surface temperature was 0.62°C (1.12°F) above the 20th-century average of 13.9°C (57.0°F). This marks the 37th consecutive year (since 1976) that the yearly global temperature was above average. Separately, the 2013 global average land surface temperature was 0.99°C (1.78°F) above the 20th-century average of 8.5°C (47.3°F), the fourth-highest annual value on record. The 2013 global average ocean temperature was 0.48°C (0.86°F) above the 20th-century average of 16.1°C (60.9°F) and tied with 2006 as the eighth-highest annual temperature on record, the highest since 2010, the last time El Niño conditions were present in the central and eastern equatorial Pacific Ocean. ENSO-neutral conditions prevailed in this region throughout 2013. Precipitation measured at land-based stations around the globe was near average on balance for 2013, at just 0.31 mm above the long-term average. However, as is typical, precipitation varied greatly from region to region. This is the second consecutive year with near-average global precipitation at land-based stations. In 2023, the X flares became more constant and started an unusual trend of X flares and weather anomalies. One notable event on April 21, 2023, resulted in a severe geomagnetic storm (G4) on April 23, according to the National Oceanic and Atmospheric Administration (NOAA). Another CME on April 24, 2023, offered unique insights into how these events can create “Alfvén wings”, temporary connections between Earth’s magnetosphere and the Sun. Multiple CMEs with Earth-directed components also occurred on November 27, 2023, leading to potential G1 and G2 geomagnetic storms. Below, we read about the main Solar Storms in 2023. A faint CME on March 23, 2023, despite being missed by forecasters, caused a major geomagnetic storm.

The April 2023 Storms, triggered by a CME on April 21, 2023, resulted in a G4 geomagnetic storm on April 23. The storm was the third severe since Solar Cycle 25 began in 2019. November 2023 Storms, Multiple CMEs with Earth-directed components occurred on November 27, 2023. These were predicted to cause G1 and G2 geomagnetic storms on November 30 and December 1, respectively. An X5.0 flare on December 31, 2023, closed the year with high solar activity [7]. The year 2023 was the warmest since global records began in 1850, with a temperature 1.18°C (2.12°F) above the 20th-century average of 13.9°C (57.0°F). This value is 0.15°C (0.27°F) more than the earlier record set in 2016. The 10 warmest years in the 174-year record occurred during the last decade (2014-2023). Notably, the year 2005, which marked the first time a new global temperature record was set in

the 21st century, is now the 12th-warmest year on record. The year 2010, which had surpassed 2005 at the time, now ranks as the 11th-warmest year on record. When examining the data on “significant climate anomalies,” 2023 was ranked as having the highest temperatures in history since June and remained so for the rest of the year. Now, we will examine the 2024 X-flares and CMEs recorded during this period. In 2024, several powerful coronal mass ejections (CMEs) erupted from the Sun, with some having a significant impact on Earth. These events, often associated with solar flares, can trigger geomagnetic storms that impact technology, including satellites and power grids. One of the most notable periods occurred in early May, when a series of CMEs, some of which interacted with each other, resulted in a strong geomagnetic storm. Another series of CMEs in August also caused a severe geomagnetic storm, reaching G4 levels.

In 2024, global temperatures continued to increase, starting in January and reaching their highest levels since June 2023 by August. From September to December 2024, temperatures reached the second-warmest levels on record since 1850. In 2025, the number of X flares decreased in size, although several CMEs were documented, along with temperatures and climate anomalies. Still, it is a strong sign that both have been related to an unprecedented increase in temperature.

In 2025, the Sun has shown increased activity, including powerful solar flares and coronal mass ejections (CMEs). A strong solar flare, classified as X2.7, occurred on May 14, 2025, accompanied by two moderate flares. This activity has led to geomagnetic storm watches, including a G4 (Severe) geomagnetic storm watch for June 2, 2025, due to a CME expected to arrive on June 1.

Our next steps involve working with the available data measurements from several catalogs, including NOAA, USGS, and NASA. These observations, primarily obtained through satellite measurements, are compared with older, less precise data collected by other means.

5. Worldwide Temperature Rise 2020-2025: Plausible Causes

To understand the slow development of climate warming over the past year, 2020-2025, we will analyze the weather month by month, reporting for 2020.

Table 1 presents monthly temperature variations from 2020 to 2025, comparing them with records dating back to 1880. This period covers three solar maxima and minima, with the lowest temperatures seen during Northern Hemisphere winters and Southern Hemisphere summers. Notably, the coldest days occurred in January 2008, 2011, and 2012, as well as in December 2000, 2001, 2010, 2011, and 2012. The year 2011 recorded the lowest overall temperatures between 2000 and 2025. While these years experienced notable cold spells, they did not signify lasting global anomalies; temporary regional drops occasionally reduced the global average, but the overall trend remained one of rising temperatures worldwide.

During 2023-2024, the temperatures were high; however, the sequence was interrupted in January 2024, resulting in a shorter total number of months.

Table 1. Temperature rank monthly 2020-2025. June 2023-July 2024 monthly temperatures rank 1st worldwide.

month	2020	2021	2022	2023	2024	2025
January	2 nd	7 th	6 th	7 th	3 rd	1 st
February	2 nd	16 th	7 th	4 th	1 st	3 rd
March	2 nd	8 th	5 th	2 nd	1 st	3 rd
April	2 nd	9 th	5 th	4 th	1 st	2 nd
May	1 st	6 th	9 th	3 rd	1 st	2 nd
June	3 rd	5 th	6 th	1 st	1 st	3 rd
July	2 nd	1 st	6 th	1 st	1 st	
August	2 nd	6 th	6 th	1 st	15 th	
September	1 st	5 th	5 th	1 st	2 nd	
October	4 th	4 th	4 th	1 st	2 nd	
November	2 nd	9 th	9 th	1 st	2 nd	
December	8 th	8 th	8 th	1 st	2 nd	

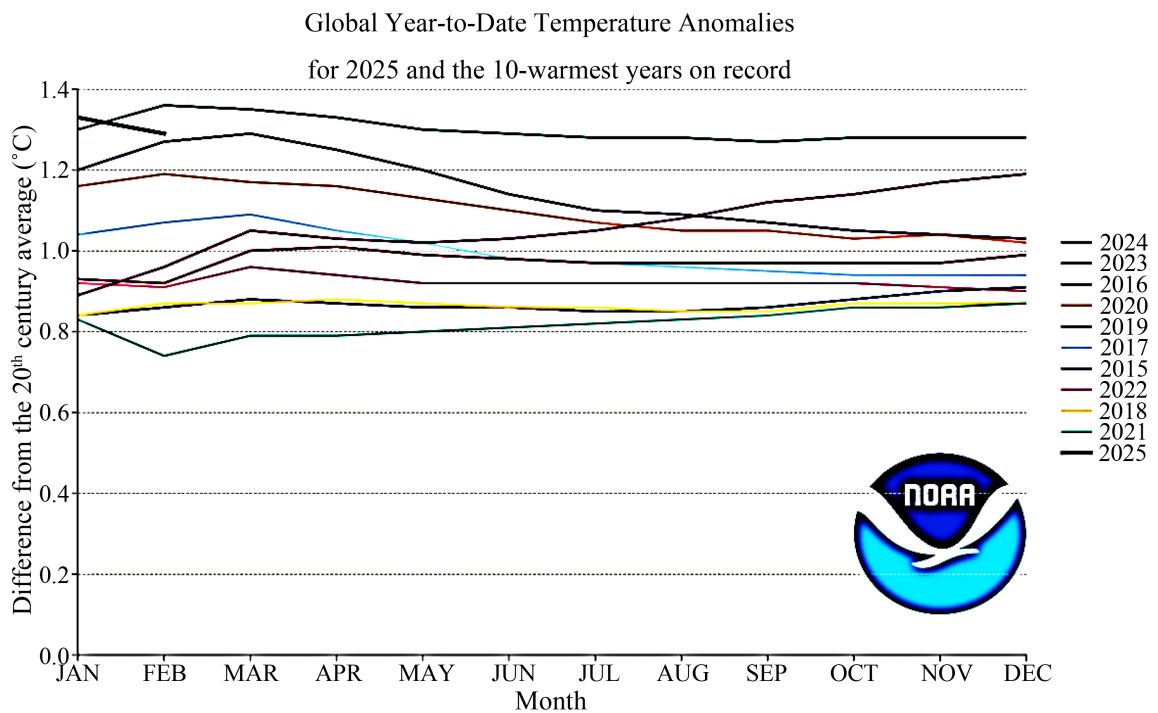


Figure 6. Global year-to-date temperature anomalies since 2000.

The ten warmest years in the 175-year record have all occurred during the last decade (2015-2025), as shown in **Figure 6**.

In 2005, a new global temperature record was set, though it now ranks as the 13th warmest year. From April 2023 to June 2024, there were 15 consecutive months of record-breaking temperatures, with January to April each surpassing earlier monthly records by at least 0.15°C above the 2016 records. Since 2007,

Arctic sea ice minimum has typically been under 5 million square kilometers, except for slight increases in 2009, 2013, and 2014. The Northern Hemisphere surface temperature reached a record high of 1.67°C above average, while the Southern Hemisphere experienced its warmest Summer at 0.90°C above average.

To analyze 2011, which was the coolest year between 2000 and 2024. It will include observations with the temperature recorded by month. Comparisons will be made with the known solar events. The solar events will be described as totality and by month. **Figure 7** shows the main climate anomalies in 2011 and observes a view about ENSO in a cold phase know as la Nina, most of the year.

Table 2. Significant climate events during 2011 anomalies.

<i>North Hemisphere</i>						
Month (Winter)	<i>ARCTIC</i>	<i>USA</i>	<i>INDIA</i>	<i>CHINA</i>	<i>EUROPE</i>	<i>SOUTH KOREA</i>
January	Sea Ice 8.7 less than average (1979-2010)	1 st coolest from XX century	coolest since 2003	2 nd low since 1961	Driest in 50 years	Heaviest snow since 1911
February	Lowest in the XX century	Strong snowstorms				
<i>South Hemisphere</i>						
March	2 nd lowest since XX century	Snowstorms/Canada				
Month (Summer)	<i>ANTARCTICA</i>	<i>BRAZIL</i>	<i>AUSTRALIA</i>			
January	Sea Ice 7.5% below average	Heavy rain	Rainfall - highest since 1899			
February		Bolivia heavy rain				
March						
Global tropical cyclone - well below average - 76 storms -38 hurricanes/typhoons/cyclones						

2011 was the 11th warmest year on record since 1880. It means it was the coolest year in the 21st century. La Niña was strong at the start of the year and persisted throughout the year, with a brief pause between May and August. La Niña is reported to have contributed to severe drought in the Horn of Africa and Australia; however, it was the 3rd wettest year in 112 years of record history. Some phenomena in **Table 2**, such as droughts from 2011 to 2012, were observed to last 8 months, corresponding to the East African drought.

Balances of below-average temperatures were observed across the eastern and central Pacific Ocean, west-central North America, and northern and central Australia, indicating lower-than-typical temperatures in these regions. Drought impacted 95% of Mexico and much of Europe, particularly from January to April. Temperature differences between hemispheres resulted in cooler conditions compared to previous years, particularly in the first quarter (see **Table 2**). Solar flare activity increased after July. Monthly global average temperatures should be displayed by hemisphere, as temperatures have remained near record highs since 1880 for most of the year.

2011 Significant Climate Anomalies and Events

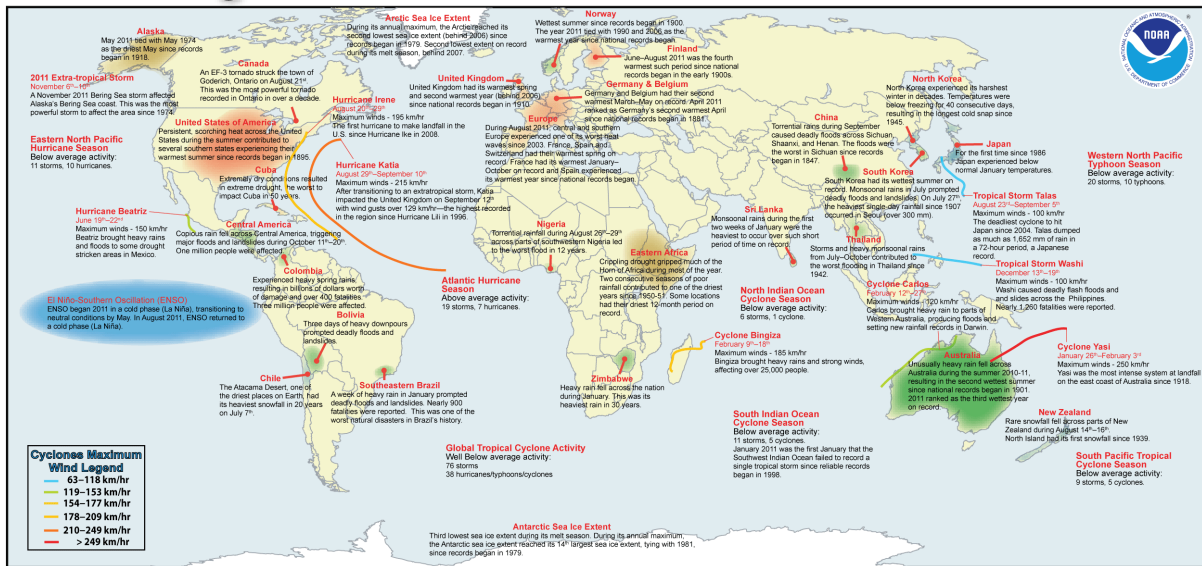


Figure 7. The climate anomalies worldwide in 2011. Observe ENSO in a cold phase for most of the year, and the climate anomalies are below average in the Southern Hemisphere.

Table 3. Main climate events in 2011 and temperature anomalies.

2011 Climate anomalies and events	
Global average temperatures:	11 th warmest worldwide compared with 1880
Arctic Ice extent	reached its 2 nd lowest sea ice record (2006, the lowest) since records began in 1979.
Antarctica Sea Ice:	reached its 14 th sea extent
ENSO-Oscillates	between cold phase (La Nina) and neutral conditions in May, returning to cold in August.
North Pacific Hurricane season:	below-average activity, with 11 storms and 10 hurricanes.
Atlantic Hurricane Season-	Above-average activity: 19 storms, seven hurricanes.
Global tropical cyclone activity:	76 storms, 38 hurricanes/typhoons/cyclones
Western N. Pacific typhoon season:	below-average activity, 20 storms, 10 typhoons.
North Indian Ocean-Cyclone season	below six storms, one cyclone
South Indian Ocean	below average activity, 11 storms, 5 cyclones.
South Pacific Tropical season	below activity 9 storms, 5 cyclones

Table 4 and **Figure 8** show anomalies in the climate in 2008. The year is expected to be one of the coolest since 1910, with a temperature 0.5°C above average for the period 1880-2011. The global temperature was lower in the records examined. Arctic sea extent was the second lowest since 2006; the same was true for Antarctica. ENSO developed as follows: La Niña from July to November, neutral water from November to March 2009, and La Niña from March 2009 to the present. Global Tropical Cyclones above average activity, Western North Pacific average typhoon activity, North

Indian, South Indian, South Pacific Tropical, around average number of storms.

Table 4. Main climate events in 2008 and temperature anomalies.

2008 Climate anomalies and events	
Global average temperatures:	13 th warmest on record (1880-2025).
Arctic Ice extent is the second-lowest sea ice record since records began in 1979.	
Antarctica Sea Ice:	2 nd lowest sea ice since records began
ENSO-Oscillates between cold phase (La Nina) and neutral conditions, neutral conditions start in June.	
North Pacific Hurricane season:	average activity, with 17 storms and 7 hurricanes.
Atlantic Hurricane Season	below-average activity: 16 storms, 8 hurricanes.
Global tropical cyclone activity	90 storms, 42 hurricanes/typhoons/cyclones, 20 “major” hurricanes
Western N. Pacific typhoon season	average activity: 22 storms, 11 typhoons.
North Indian Ocean-Cyclone season	above average 7 storms, 1 cyclone
South Indian Ocean average activity,	12 storms, 8 cyclones.
South Pacific Tropical season	below activity 7 storms, 3 cyclones

Note: The lowest temperature years 2008 and 2011, relative to the entire record, had characteristics such as: Strong La Nina presence and droughts in Europe and Africa.

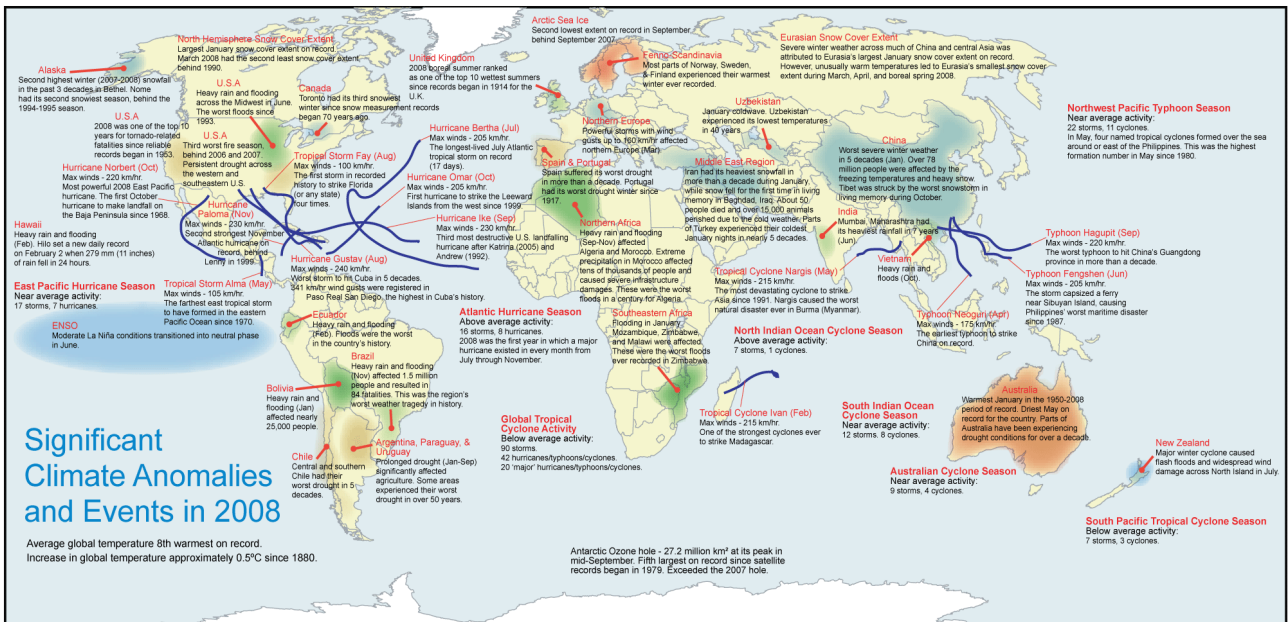


Figure 8. The principal climate anomalies in 2008.

The presence of La Niña indicates that drought conditions are more common during those years with lower temperatures, such as 2008 and 2011. In 2008, droughts occurred in Australia, while floods affected South Africa, Bolivia, and Spain. In 2011, floods occurred in Australia, and droughts affected the eastern USA, Europe, and Africa, with further floods in Australia. The presence of La Niña is a significant factor

influencing weather patterns and causing anomalies in various locations worldwide.

The map below shows global climate anomalies for 2008 and compares them to 2011, when temperatures dropped. As a result, many monthly temperatures exceed previous records in **Figure 9**.

6. The Warmest Year in Records 2024

The latest data is from 2024, when temperature anomalies reached their highest levels on record. Observations indicated that Asia has the lowest temperatures compared to other locations. The numbers listed in the table for each month compare the data to the earliest available data, dating back to 1850. As a result, many monthly temperatures are above previously recorded records.

Table 5. Observe the temperatures in separate locations and compare them, with earlier data in the northern hemisphere [5].

North Hemisphere	USA	EUROPE	ASIA	AFRICA	CARIBE	ARTICO
January	20 th warmest	19 th warmest	9 th warmest	1 st warmest	2 nd warm	15 th warmest
February	1 st "	1 st "	26 th "	2 nd "	1 st "	3 rd "
March	4 th "	2 nd "	12 th "	1 st "	1 st "	14 th "
April	2 nd "	2 nd "	3 rd "	4 st "	2 nd "	6 th "
May	3 rd "	1 st "	4 th "	1 st "	1 st "	6 th "
June	4 th "	2 nd "	1 st "	1 st "	1 st "	7 th "
July	2 nd "	1 st "	1 st "	1 st "	1 st "	3 rd "
August	3 rd "	1 st "	3 rd "	2 nd "	1 st "	1 st "
September						
October						
November	2 nd "	2 nd "	2 nd "	2 nd "	2 nd "	2 nd "
December						

Table 6. Southern Hemisphere 2024 temperatures. The records for several locations are below temperatures from those in the North, except for South America.

South Hemisphere	South America	Australia	South Africa	Antarctica
January	1 st	3 rd	—	5 th
February	1 st	3 rd	drought	11 th
March	1 st	10 th	—	5 th
April	1 st	1 st	Wettest	10 th
May	1 st	6 th	1 st	5 th
June	1 st	7 th	1 st	2 nd
July	1 st	8 th	1 st	2 nd
August	1 st	1 st	1 st	Not known
September	2 nd	2 nd	2 nd	2 nd
October	2 nd	2 nd	10 th	11 th
November	2 nd	5 th	8 th	2 nd
December	16 st	3 rd	9 th	10 th

Selected Significant Climate Anomalies and Events: Annual 2024

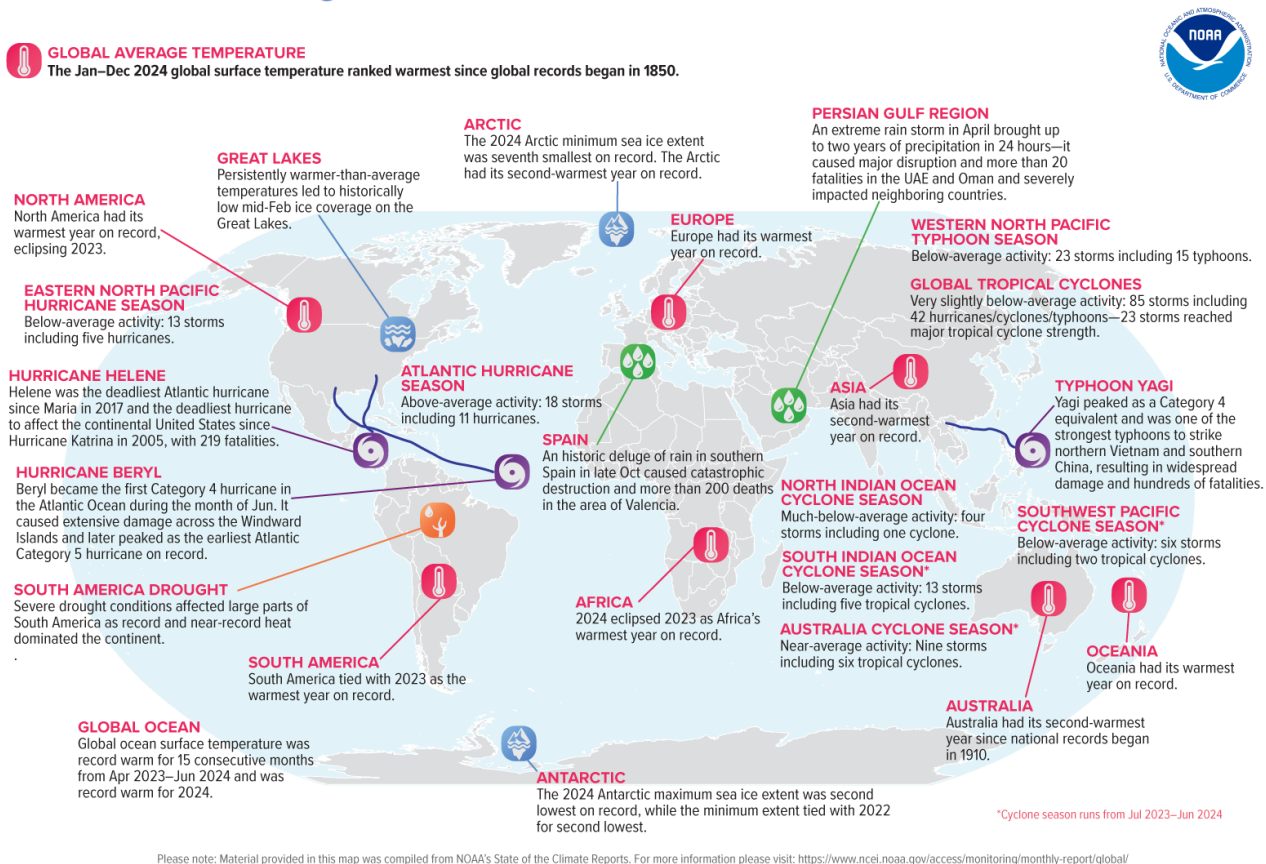


Figure 9. The climate anomalies worldwide in 2024. Observe that the characteristics of each event are different from those in 2011.

The key differences between the tables involve ENSO and varying activity in the Northern and Southern Hemispheres. Notably, hurricanes and typhoons in 2011 occurred at a slower pace compared to 2024.

Hurricanes and other climate-related disasters are expected to be more severe in 2024 than in 2011. It has a significant impact on the poles, as shown in the comparison between **Table 5** and **Table 6**. The sea surface temperatures for 2024 were record warm across much of the central and northern Atlantic Ocean, the northern half of the Indian Ocean, and parts of the western Pacific Ocean and the Southern Ocean. Sea surface temperatures were below average in parts of the western North Atlantic, the southwestern Atlantic, the southeastern Pacific, the southwestern Indian Ocean, parts of the Southern Ocean, including the Drake Passage, as well as the Bering Sea, the Gulf of Alaska, and the Sea of Okhotsk. In North America, the temperature was 2.22°C above the average, the warmest year on record. North America’s yearly temperature has increased at an average rate of 0.15°C per decade since 1910, while the average rate of increase over the past 50 years more than doubled the century-scale rate. South America’s annual temperature was 1.78°C above average, tying it with 2023. South America’s yearly tem-

perature has increased at an average rate of 0.15°C per decade since 1910, nearly double the rate of increase since 1975. The observed wildfires were produced by anomalous warmth combined with below-average precipitation. In 2024, Europe experienced its highest annual temperature, 2.45°C above average. This marked the 28th consecutive year with temperatures exceeding the 1910-2000 European average, and the nine highest years have all occurred since 2014. Since 1910, Europe's annual temperature has increased at an average rate of 0.16°C per decade. Africa's yearly temperature was 1.65°C above average in 2024, the highest on record, surpassing the previous record set in 2023. Much of Central Africa experienced record-high temperatures in March, and South Sudan saw widespread daily temperatures above 38°C . Asia experienced its second-highest annual temperature on record in 2024, at 2.17°C above average; this marked the 37th consecutive year with temperatures above the 1910-2000 average.

Table 7. Main climate events in 2024 and temperature anomalies.

2024 Selected Climate anomalies and events worldwide
Global average temperatures have been the warmest since 1850
Arctic-Second warmest year on record
Antarctica-Second warmest year on record
Global Ocean record warm in 2024, Record warmest for 15 consecutive months from April 2023 to June 2024.
ENSO Oscillation continued El Niño from 2023, lasting 12 months, until May, then neutral waters so far.
Eastern North Pacific Hurricane 8 storms, 5 hurricanes,
Atlantic hurricane season 7 storms, 11 hurricanes
Western North Pacific 15 typhoons, 8 storms
Global tropical cyclones 82 storms, including 42 hurricanes, cyclones, typhoons.
Southwest Pacific below average, 4 storms, 2 cyclones
North Indian below activity 1 cyclone, 3 storms
South Indian 88 storms, 5 tropical cyclones

According to our **Figure 2**, 2011 was a year of minimum solar cycle; **Figure 5** shows that the number of X flares for this year was 12. It was not a year of maximum X flares, but rather an increase after the 2005 count of X flares, which was 24. It seems the impact of changes in the Sun is somehow affecting the Earth's surface that year. Let us also briefly consider the ENSO phenomenon in 2011. Since May 2010, La Niña has affected the North Pacific, lasting until May 2011, when the water became neutral between May and July, and then became cold again until 2012. After providing those explanations, we will examine the temperatures and their distribution worldwide. **Table 7**, indicating that the Arctic reached the 2nd lowest sea ice after 2006, while Antarctica reached the 14th lowest sea extent. Therefore, it sounds like the Southern Hemisphere was cooler than the

Northern Hemisphere. It also indicated that the South Indian Ocean and the South Pacific Tropical had below-average activity. New Zealand, Chile, Australia, South Brazil, and Zimbabwe experienced heavy rains during the Summer, and the same occurred in Central America. Therefore, the lowest temperatures within the twenty-year range were primarily events happening in the Southern Hemisphere. Another difference was the behavior of Pacific and Atlantic events; it seems that the Pacific overall had a performance for phenomena, such as Typhoons, cyclones, and storms, below average, while the Atlantic was above average, including the seven hurricanes. Now, we will analyze the events of 2024. The warmest in the records worldwide. Again, the Southern Hemisphere is cooler than the Northern Hemisphere. However, the Summer had similar temperatures and records in both hemispheres, including South America, South Africa, and in the North, Europe, Asia, Africa, and the Caribbean. South India experienced 88 storms, including five tropical cyclones, which is four times the number recorded in 2011. The Pacific, as presented below, has a higher number of typhoons. Atlantic showed 11 hurricanes. The global ocean has recorded unprecedented warmth for 15 straight months. Warming is more pronounced in the Northern Hemisphere, whereas the Southern Hemisphere has experienced less.

7. Discussion of Results

High solar irradiance implies rising temperatures, since the Earth's surface absorbs more solar energy. It means that more sunlight striking the surface leads to greater absorption of solar energy and higher temperatures. The world has been suffering from forest devastation, desertification, and many other events that are not quantifiable at present, leading to increased heat absorption and consequently rising temperatures. Studying solar flares to compare them with worldwide temperatures, it was examined over two years, 2008 and 2011, with the lowest temperature ranges. One important fact is that they presented the lowest number of X flares, and they also occurred during the solar minimum. To understand better, see the X flares distributed in the years 2008 and 2011. Both years belong to the Solar minimum. See [Figure 5](#) and [Figure 6](#). Also, note the year 2024, when the number of X flares surpassed the normal number, with most occurring in May and October, as shown in the figure. This year, temperatures rose from February, with an anomaly in August when the warming was the lowest. Comparing the solar events for the highest temperature years, 2016, 2019, 2020, and 2024, with the number of flares, the only year that X flares reached a maximum temperature was 2024. The other years have had no attachments to solar events. In the chosen years of 2008 and 2011, the Earth's surface events showed that ENSO was in a cold phase or neutral. Events such as cyclones, hurricanes, and typhoons were affected by the ENSO cold phase. Comparing [Table 3](#) and [Table 4](#), we clearly see those effects worldwide. The main problem in this analysis is the lack of knowledge about the other oceans, such as the Atlantic and Indian Oceans, and their current systems, which hinders the analysis of them according to climate variations. Most

climate events do not show a deeper connection with solar events, and it would be more of a small factor than a reality. Therefore, the rising Earth's temperatures are more closely connected with internal issues, and they all point to human interference on the crust. Our subsequent research aims to focus on the anthropogenic factors and actions that impact the oceans and the atmosphere. The anthropogenic impact includes air pollution, deforestation, wildfires, the desertification of areas, the accumulation of garbage thrown into rivers and aquifers, and the proliferation of dangerous bacteria in water resources and on shores. The accumulation of chemical and nuclear waste on land poses a significant threat to environmental quality and human health. The improper disposal and management of hazardous materials lead to soil, water, and air contamination, exacerbating the challenges faced by ecosystems and societies. The declining quality of agricultural land, characterized by nutrient depletion and diminished productivity, further undermines food security and the sustainability of agricultural practices. The combined impact of waste accumulation and poor agricultural land quality contributes to ongoing environmental degradation, presenting complex challenges for future generations.

8. Conclusions

The study investigates two distinct aspects of the Sun-Earth connection. The initial sections address solar cycles, the significance of solar phenomena such as Coronal Mass Ejections, solar flares, and solar radiation, and their impacts on Earth's climate. Although the influence of X-class flares on the magnetosphere and Earth's surface can be assessed, an analogous evaluation of Coronal Mass Ejections is still producing poor results due to a lack of satellite data on this subject.

Earth's magnetospheric disturbances cause disruptions to the crust and lithosphere; these solar events on Earth contribute to the climate anomalies observed today. Variations in land distribution between the Northern and Southern Hemispheres further influence climatic conditions. Analyzing data from 2008, 2011, and 2024 confirms that the Southern Hemisphere generally exhibits cooler temperatures than the Northern Hemisphere. Overall, Earth's temperature is subject to irreversible changes. The subsequent paper will examine the period from 2015 to 2016, during which Earth experienced elevated temperatures. Additionally, we will examine the influence of human activity on solar activity over the last two decades as a key factor in the degradation of human capabilities and survival.

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Conflicts of Interest

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

References

- [1] Friis-Christensen, E. and Lassen, K. (1991) Length of the Solar Cycle: An Indicator of Solar Activity Closely Associated with Climate. *Science*, **254**, 698-700. <https://doi.org/10.1126/science.254.5032.698>
- [2] Xflares Observations. https://en.wikipedia.org/wiki/Solar_flare#:~:text=The%20extreme%20ultraviolet%20and%20X,with%20short%2Dwave%20radio%20communication
- [3] Earth Observatory. <https://earthobservatory.nasa.gov/features/EnergyBalance/page2.php>
- [4] <https://sunclimate.gsfc.nasa.gov/article/solar-irradiance>
- [5] National Oceanic and Atmospheric Administration (2024) Layers of the Atmosphere. <https://www.noaa.gov/jetstream/atmosphere/layers-of-atmosphere>
- [6] NOAA National Centers for Environmental Information (2003) Monthly Global Climate Report for October 2003. <https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/200310>
<https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00672>
- [7] Scharping, N. (2024) Coronal Mass Ejection Gives Earth's Magnetosphere Rare "Wings". *Eos*, **105**. <https://doi.org/10.1029/2024eo240342>