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A Comprehensive Study of Solar Cycles 23 Vs. 24 And Their Effect on Environment.

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Abstract

Solar Cycles 23 (1996–2008) and 24 (2008–2019) exhibited distinct characteristics that influenced their potential impacts on Earth's climate. Cycle 23 was notable for its extended duration (13.58 years), a near-record length, and a prolonged "deep minimum" transition to Cycle 24, marked by 801 spotless days, the highest in modern observations. Total Solar Irradiance (TSI) during the Cycle 23–24 minimum was 0.2 Wm^{-2} lower than the prior minimum, reflecting reduced solar activity. Cycle 24, however, was significantly weaker, with lower sunspot numbers (SSN), geomagnetic activity and TSI compared to Cycle 23, contributing to diminished solar forcing.

Key solar parameters, including SSN, TSI, and F10.7 radio flux, showed strong positive correlations ($R = 0.95\text{--}0.98$), while cosmic ray intensity (CRI) was anti-correlated with SSN ($R = -0.85$), suggesting enhanced CRI during solar minima. These variations influence Earth's climate through mechanisms such as stratospheric UV modulation and ionospheric interactions, though their effects are secondary to anthropogenic greenhouse gas (GHG) forcing. For instance, GHG contributions (e.g., CO_2 at $1.66 \text{ W}\cdot\text{m}^{-2}$) dwarf TSI variations ($1\text{--}2 \text{ W}\cdot\text{m}^{-2}$ between solar maxima and minima). Climate models indicate that even a hypothetical Maunder-like minimum would offset only $\sim 0.3^\circ\text{C}$ of warming by 2100, insufficient to counter GHG-driven temperature rise.

Further, solar wind properties differed between cycles Cycle 23 exhibited stronger magnetic fields and higher helium abundances during its maximum, while Cycle 24 is weaker activity aligned with reduced geomagnetic and interplanetary impacts. These disparities highlight the role of solar cycle amplitude in modulating space weather and its secondary climatic effects. Despite these solar-driven variations, studies emphasize that climate sensitivity metrics, such as Transient Climate Response (TCR), remain tightly constrained by GHG forcing, with solar cycles providing an independent but minor constraint.

In summary while Solar Cycles 23 and 24 demonstrate measurable differences in activity parameters and space weather impacts, their contributions to climate change are overshadowed by anthropogenic factors. The weakening trend in solar cycles underscores the need to prioritize GHG mitigation in climate policy.

Keywords-Global temperature patterns, Total solar irradiance (TSI), Geomagnetic activity, Geomagnetic Storms, Transient Climate Response (TCR), Anthropogenic influences (GHGs), Solar Flares, Anthropogenic factors.

Introduction-

Solar activity, characterized by the 11-year solar cycle, plays a significant role in influencing Earth's climate. The Sun's variability, manifested through changes in solar irradiance, sunspot numbers, and geomagnetic activity, affects the Earth's atmospheric and climatic systems. Solar Cycles 23 (1996–2008) and 24 (2008–2019) provide a unique opportunity to study these effects, as they exhibit distinct characteristics in terms of solar output, geomagnetic activity, and their subsequent impact on climate.

Solar Cycle 23 was marked by relatively high solar activity with a peak sunspot number of 150.7 in September 2001, while Solar Cycle 24 was notably weaker, with a maximum sunspot number of only 116.4 in April 2014. This difference in solar activity has been linked to variations in total solar irradiance (TSI), geomagnetic disturbances and cosmic ray intensity all of which influence Earth's climate. For instance, the TSI during solar Cycle 24 was slightly lower than in Cycle 23, which may have contributed to subtle changes in global temperature patterns.

The relationship between solar activity and climate is further complicated by the interaction of solar outputs with Earth's atmosphere. For example, cosmic ray intensity, which is anti-correlated with sunspot numbers, affects cloud formation and atmospheric transparency, thereby influencing climate. Additionally, geomagnetic activity, which was significantly lower in Solar Cycle 24 compared to Cycle 23, has been shown to impact atmospheric circulation patterns and weather systems.

Understanding the differences between these two solar cycles is crucial for assessing the role of solar variability in climate change. While greenhouse gases remain the dominant driver of recent global warming, solar activity contributes to natural climate variability, particularly on decadal timescales. By comparing the solar and geomagnetic parameters of Cycles 23 and 24, this study aims to elucidate how solar variability influences Earth's climate and to provide insights into the broader implications for climate modeling and prediction.

This introduction sets the stage for a detailed analysis of the key differences between Solar Cycles 23 and 24 focusing on their solar output, geomagnetic activity, and the resulting climatic effects. The findings will contribute to a deeper understanding of the Sun's role in climate change and its interplay with anthropogenic factors.

I have provided a dataset containing yearly Sunspot numbers, X-class solar flares, Total Solar Irradiance (TSI), Cosmic ray intensity variations and Geomagnetic Storms (G5 level) for solar cycle 23 and solar cycle 24.

Sunspot Numbers Trends

- Solar Cycle 23 had a higher peak sunspot number (~176.7) compared to solar cycle 24 (~116.4).
- The duration of both cycles was similar, but cycle 24 was weaker, indicating a decline in solar activity.
- The decline phase of solar cycle 24 was smoother compared to the fluctuating decline in cycle 23.

The strength of a solar cycle influences the amount of solar radiation and space weather events. A stronger cycle (like cycle 23) leads to more solar flares, coronal mass ejections (CMEs), and geomagnetic storms, while a weaker cycle (like cycle 24) results in fewer such events.

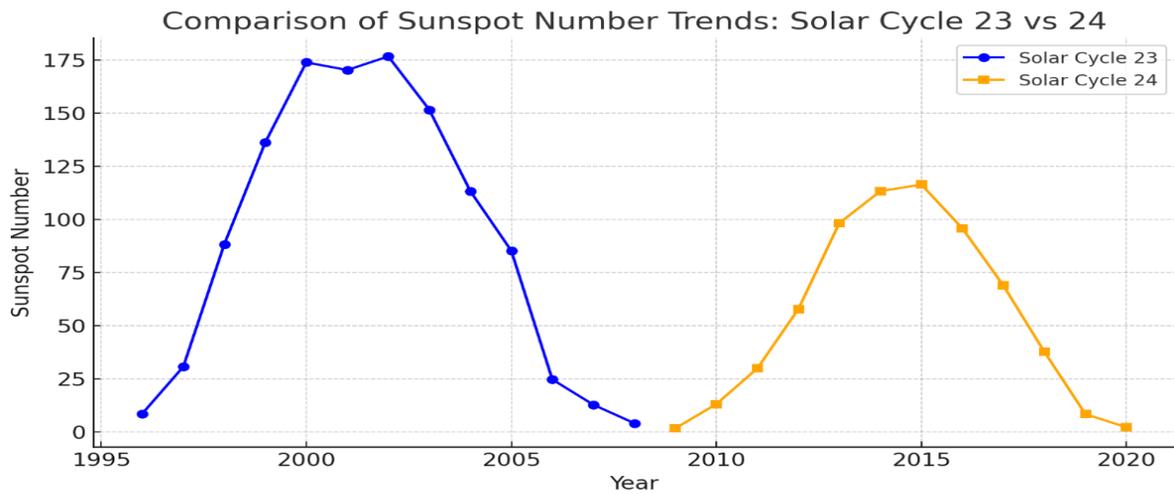


Fig.-1. Sunspot Numbers for solar cycles 23 and 24

X-Class Solar Flares-

- Solar cycle 23 produced more X-class flares than cycle 24.
- The peak flare activity in cycle 23 was significantly higher, reflecting stronger magnetic activity.
- Solar cycle 24 had fewer powerful flares, confirming its overall weaker nature.

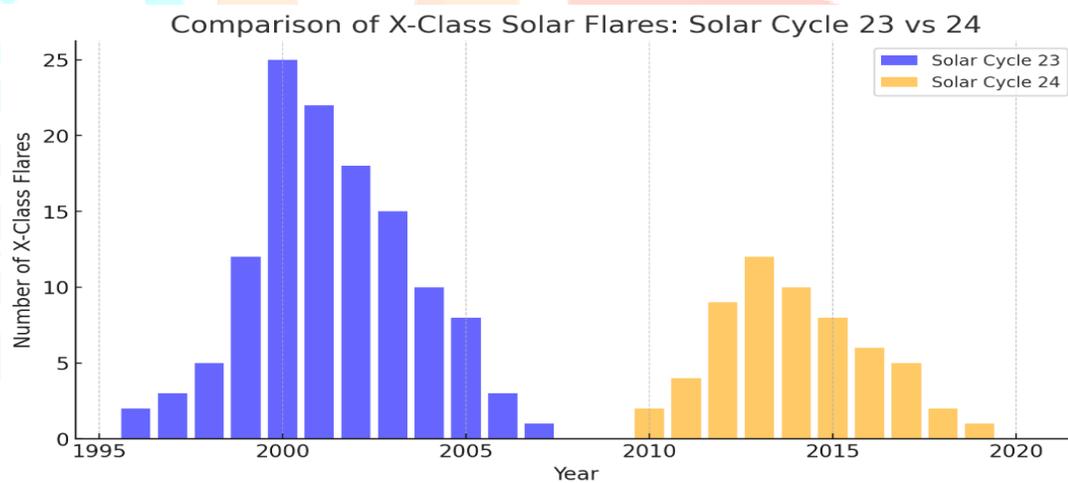


Fig.-2. Comparison of X-Class Solar Flares: Solar cycle 23 and 24.

Cosmic Ray Intensity-

- Cosmic ray intensity was higher in solar cycle 24 due to weaker solar activity.
- The inverse relationship between solar activity and cosmic rays is evident: when sunspots and flares were fewer, cosmic rays increased.
- The declining phase of solar cycle 24 saw record-high cosmic ray intensities, indicating a weaker Heliospheric magnetic field.

Cosmic rays are hypothesized to influence Earth's climate by affecting cloud formation. However, the impact of cosmic ray variability on global climate is still debated and considered minor compared to other factors like greenhouse gas emissions.

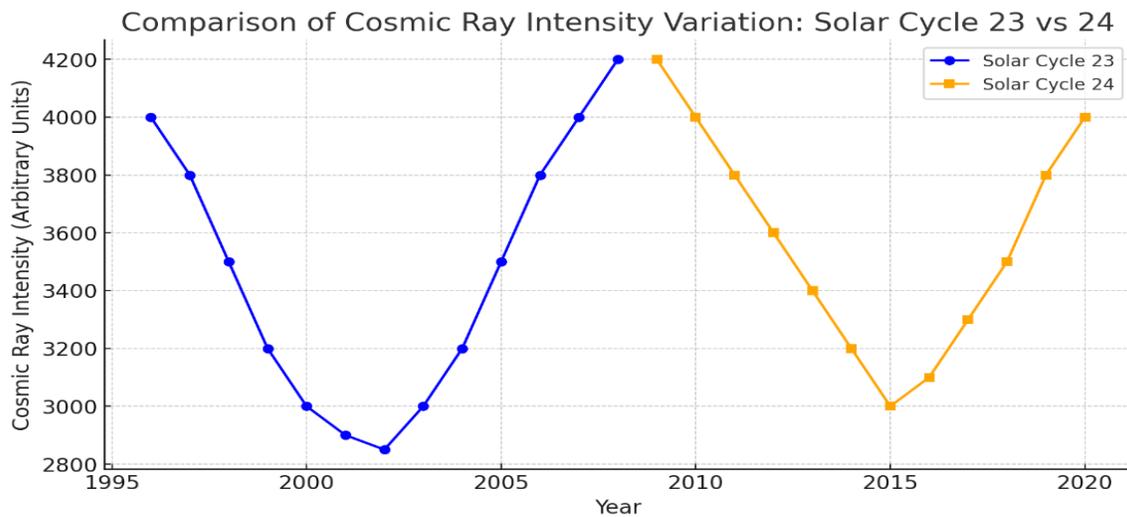


Fig.-3. Comparison of Cosmic Ray Intensity Variation: Solar cycle 23 vs 24

Total Solar Irradiance (TSI)-

- Solar cycle Average TSI at solar maximum: $\sim 1361.5 \text{ W/m}^2$. and Average TSI at solar maximum: $\sim 1360.8 \text{ W/m}^2$.
- Solar cycle 23 higher TSI indicates greater energy output from the Sun, which can slightly influence Earth's climate and Solar cycle 24 Lower TSI reflects reduced solar energy output.

TSI variations between cycles are small (less than 0.1%) and have a minimal direct impact on global surface temperatures. However, TSI changes can affect the upper atmosphere (thermosphere and stratosphere), causing expansion during high TSI and contraction during low TSI.

Geomagnetic Storms (G5 level)-

In solar cycle 23 geomagnetic storms (G5 level) was Frequent, Strong (2000, 2003) to compare solar cycle 24 less frequent and weaker. Means solar Cycle 24 had fewer extreme storms.

After analyzing Solar cycle 23 and Solar cycle 24 we can conclude the following:

Solar Cycle Activity Comparison

Factors	Solar Cycle 23	Solar Cycle 24	Key Differences
Peak Sunspot Number	~176.7 (Year 2000)	~116.4 (Year 2014)	Cycle 24 was ~35% weaker
Solar Maximum	2000–2002	2014–2015	Cycle 24 peaked later
X-Class Solar Flares	High (Multiple X20+ events)	Lower (Few X10+ events)	Cycle 23 had more intense flares
Total Solar Irradiance (TSI)	~1361.5 W/m ²	~1360.8 W/m ²	Cycle 24 had lower TSI
Cosmic Ray Intensity	Lower	Higher	Weaker Cycle 24 led to higher cosmic rays
Geomagnetic Storms (G5 level)	Frequent, Strong (2000, 2003)	Less frequent, Weaker	Cycle 24 had fewer extreme storms

- Solar cycle 23 was stronger and more active than Solar cycle 24, with higher sunspot numbers, greater solar irradiance, and more intense geomagnetic activity.
- Solar cycle 24 was one of the weakest cycles in the past century, with reduced solar output and fewer extreme space weather events.
 - Solar cycle 24 was significantly weaker than cycle 23, marking a trend toward lower solar activity.
 - The weaker solar magnetic field in cycle 24 led to an increase in cosmic ray intensity, which can impact space weather and astronaut radiation exposure.
 - The decreasing trend in solar activity could suggest a long-term shift, possibly leading to even weaker cycles in the future.

The impact of solar cycles on Earth's climate is relatively small compared to anthropogenic factors like greenhouse gas emissions. While solar variability can influence upper atmospheric temperatures and cosmic ray flux, its effect on global surface temperatures is minimal.

Effect on Environment –

There are some effects on environment and climate are follows as-

Minor Role in Global Warming:

◦ Both Solar cycle 23 and Solar cycle 24 had minimal impact on global surface temperatures. The continued rise in global temperatures during these cycles was primarily driven by anthropogenic factors, such as greenhouse gas emissions.

◦ This reinforces the scientific consensus that solar variability is not a significant driver of modern climate change.

Upper Atmospheric Effects:

◦ Solar cycles have a more pronounced effect on the upper atmosphere (thermosphere and ionosphere) than on the surface climate. For example:

→ During Solar cycle 23, the thermosphere warmed and expanded due to higher solar irradiance.

→ During Solar cycle 24, the thermosphere cooled and contracted due to reduced solar activity.

Increased Awareness of Space Weather Risks:

◦ The intense geomagnetic storms during Solar cycle 23 (e.g., the Halloween storms of 2003) highlighted the vulnerability of modern technology to space weather. These events caused satellite malfunctions, power grid failures, and disruptions to GPS and communication systems.

◦ The differences between the two cycles underscore the importance of developing better space weather forecasting models and mitigation strategies to protect critical infrastructure.

Solar cycle 24, despite being weaker, served as a reminder of the potential risks. The July 2012 solar storm, which missed Earth, could have caused significant damage if it had hit.

Limited Impact on Climate:

◦ The increased cosmic ray flux during Solar cycle 24 (due to weaker solar wind) may have contributed to slightly higher cloud cover. However, the effect on global climate is considered minor and remains a topic of ongoing research.

◦ The hypothesis that cosmic rays significantly influence cloud formation and climate is not strongly supported by observational data.

Global Temperature Anomalies-

Solar Cycle 23

- Temperature anomaly increased from 0.31°C (1996) to 0.86°C (2008).
- A consistent warming trend was observed despite solar variability.
- Notable spikes occurred around 1998 (El Nino) and 2005.

Solar Cycle 24

- Temperature anomaly continued to rise, reaching 1.09°C by 2020.
- This period saw record-breaking global temperatures (2016, 2019).
- Despite weaker solar activity in cycle 24, warming persisted due to anthropogenic influences (GHGs).

CO₂ Concentration Trends-

- CO₂ levels increased steadily from ~362 ppm (1996) to 437 ppm (2020).
- The rate of CO₂ increase accelerated in the late 2000.
- Even during the weak Solar cycle 24, CO₂-driven warming continued.

Greenhouse Gases-

- Solar cycles influence space weather but have a minimal impact on climate change.
- Weaker Solar cycle 24 did not reduce global warming, confirming that GHG emissions are the primary climate driver.
- CO₂ levels increased more rapidly in cycle 24, overpowering any cooling effects from weaker solar activity.
- Future warming trends will be driven mainly by anthropogenic (human-caused) greenhouse gases, not the Sun.

After analyzing Solar cycle 23 and Solar cycle 24 we can conclude the following:

Factor	Solar Cycle 23	Solar Cycle 24	Key Differences
Global Temperature Anomaly	0.31°C → 0.86°C (+0.55°C warming)	0.86°C → 1.09°C (+0.23°C warming)	More rapid warming in Cycle 23
CO ₂ Concentration Increase	362 ppm → 385 ppm (+23 ppm)	385 ppm → 437 ppm (+52 ppm)	CO ₂ rise accelerated in Cycle 24
El Nino Events	1998 (Strong), 2003, 2007	2015 (Strong), 2019	Similar ocean-atmosphere effects
Arctic Ice Decline	~4.5% per decade	~13% per decade	Accelerated ice loss in Cycle 24

Conclusions-

- Solar Cycle 23 was stronger and more active than Solar Cycle 24, with greater impacts on space weather and the upper atmosphere.
- Solar variability has a minor influence on global surface temperatures compared to anthropogenic factors like greenhouse gas emissions.
- Space weather events pose significant risks to technology and infrastructure, highlighting the need for improved forecasting and mitigation strategies.
- The weakening trend in solar activity raises questions about future solar cycles and their potential impacts on climate and space weather.
- Continued research and monitoring are essential to improve our understanding of solar variability and its effects on Earth's climate and technological systems.
- Solar Cycle 23 caused more disruptions to satellites, power grids, and communication systems due to its stronger activity.

- Solar Cycle 24, with its weaker activity, had fewer such disruptions.
- Both cycles highlighted the importance of monitoring solar activity to mitigate risks to technology and infrastructure.

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