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Research Paper

A Comprehensive Analysis of Intense Solar Activity from NOAA Region 13664 (AR3664) and Its Impact on Multiple Systems in May 2024

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ABSTRACT
On May 8, 2024, a highly active solar region, designated as NOAA region number 13664 (AR3664), unleashed a series of significant solar events, including an X1.0-class flare and multiple M-class flares. These activities triggered the launch of several coronal mass ejections (CMEs) directed towards Earth. The following day, on May 9, AR3664 generated two powerful flares: an X2.25-class flare and an X1.12-class flare, both accompanied by full-halo CMEs. The intense solar activity persisted, culminating in an X3.98-class flare on May 10. On May 11, at 01:23 UTC, the region produced another potent X-class flare, with a magnitude ranging from 5.4 to 5.7, along with an asymmetrical full-halo CME. This article analyses the scientific perspective on the aurora event, its impact on satellites, ground-based observatories, and other systems. It also discusses specific events related to this phenomenon. Data collected from three magnetometer stations are analysed to determine the actual strength of the solar storm on Earth's atmosphere from May 1 to May 16. Despite the disruptions, the May 11 auroral event provided a wealth of data invaluable for future research. The aurora event on May 11 highlighted the interconnectedness and vulnerability of modern technological systems to space weather. While it caused disruptions and required significant mitigation efforts, it also underscored the importance of continued research and preparedness to safeguard our increasingly space-dependent infrastructure.

Key words*: Aurora, solar wind, NOAA, May 2024, Satellite Disruptions and Damages*

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I. INTRODUCTION

In the May 11 and 12 the scientific community closely monitored an exceptional auroral event triggered by heightened solar activity. This surge in geomagnetic activity provided a rare opportunity to study the dynamics of the Earth's magnetosphere and the impacts of space weather on both natural phenomena and human-made systems such as satellites and observatories.

Scientific Perspective on the Aurora Event

The aurora borealis is a visible manifestation of complex interactions between the solar wind and the Earth's magnetosphere. On May 11 and 12 a series of strong solar flares and coronal mass ejections (CMEs) from the sun had reached the Earth. These events are characterized by the release of vast quantities of charged particles and electromagnetic energy into space. When these particles interact with the Earth's magnetic field, they are guided toward the polar regions, where they collide with atmospheric gases, resulting in the stunning auroral displays.

During this particular event, the interplanetary magnetic field (IMF) was oriented southward. This orientation enhances the coupling between the solar wind and the Earth's magnetosphere, allowing more solar particles to penetrate the Earth's magnetic shield. This process significantly increases the intensity and spread of the auroras. [1] – [6]The particles, primarily electrons, and protons, excite oxygen and nitrogen molecules in the upper atmosphere, causing them to emit light. The resulting emissions produce the characteristic colours of the aurora: green from oxygen at lower altitudes, red from oxygen at higher altitudes, and blue and purple from nitrogen.[7]

Impact on Satellites
The influx of charged particles during intense auroral activity can have significant effects on satellites orbiting the Earth.[8],[9] On May 11, the increased geomagnetic activity posed several challenges:

1. Radiation Damage: The energetic particles can penetrate satellite shielding and cause damage to electronic components. This can lead to malfunctions or even complete failure of satellite systems. Satellites in low Earth orbit (LEO) and geostationary orbit (GEO) are particularly vulnerable during such events.
2. Surface Charging: The accumulation of charged particles on the surface of satellites can create differential charging. This can result in discharges or sparks that can damage sensitive electronics and disrupt satellite operations.
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4. Orbit and Attitude Control: The enhanced drag on satellites in LEO due to increased atmospheric density can alter their orbits. This necessitates adjustments to maintain the intended orbital paths, which consumes additional fuel and resources.

Ground-based and space-based observatories also feel the effects of heightened geomagnetic activity:

1. Ground-Based Observatories: The bright auroras can interfere with optical telescopes, as the intense light can overwhelm observations of faint celestial objects. This limits the ability of astronomers to conduct research on deep-space phenomena during periods of high auroral activity.
2. Radio Observatories: The increased ionization of the Earth's ionosphere can cause significant radio wave absorption and reflection. This interferes with radio telescopes' ability to receive signals from space, complicating studies of radio-emitting celestial bodies and cosmic phenomena.
3. Space-Based Observatories: Instruments on space telescopes, such as the Hubble Space Telescope, are designed to operate above the Earth's atmosphere. However, increased radiation from geomagnetic storms can still affect their sensors and electronics, necessitating protective measures such as temporarily shutting down sensitive instruments to prevent damage.

Data Collection and Research
Despite the challenges, the May 11 auroral event provided valuable data for scientists studying space weather. Instruments on satellites and ground-based observatories collected extensive data on the interaction between the solar wind and the Earth's magnetosphere. These observations help improve models of geomagnetic storms and their impacts, contributing to better prediction and mitigation strategies for future events.[10] – [14]
Researchers used data from the event to gain insights into the processes governing auroral formation and the behavior of the Earth's magnetic field. By analyzing the spatial and temporal variations in auroral displays, scientists can refine their understanding of how solar activity influences the Earth's space environment.
In conclusion, the auroral event on May 11 was not only a spectacular visual phenomenon but also a significant occurrence for scientific research and technological systems. The data collected during this period will enhance our understanding of space weather and its effects, helping to protect and optimize satellite operations and observatory functions in the future.

II. RESULT AND DISCUSSION

Data collected from various scientific organizations worldwide have been meticulously analysed to assess the impact of the solar storm. The findings reveal significant disruptions and phenomena attributed to the intense solar activity from NOAA region 13664 (AR3664).

On Earth, the solar storm caused substantial geomagnetic disturbances, leading to auroras being visible at much lower latitudes than usual. These geomagnetic storms interfered with satellite operations, causing temporary communication blackouts and navigation system errors. Power grids in several regions experienced fluctuations, prompting utility companies to implement protective measures to prevent outages.

In the aviation sector, increased levels of radiation necessitated adjustments to flight routes, especially for polar flights, to ensure passenger and crew safety. Astronauts on the International Space Station had to take precautions to mitigate exposure to elevated radiation levels.

The solar storm also had a notable impact on radio communications, particularly in high-frequency bands. The X-class flares caused R3 (strong) radio blackouts, affecting aviation, maritime, and emergency communication systems. The S1 to S2 solar radiation storm levels led to temporary signal degradation and increased noise in communication channels.

Overall, the data indicate that the solar storm from AR3664 had far-reaching effects on various technological systems and necessitated coordinated responses from multiple sectors to mitigate its impact.

The aurora event on May 11, driven by a potent geomagnetic storm, caused notable disruptions and damages to various technological systems, particularly satellites and observatories. This event highlighted the vulnerabilities of modern infrastructure to space weather phenomena and underscored the importance of resilience and preparedness in our increasingly satellite-reliant world.

Satellite Disruptions and Damages

1. Communication Satellites: Several communication satellites experienced signal degradation and intermittent outages. The influx of charged particles interfered with the transmission and reception of signals, leading to disrupted services for satellite-based communication systems. This affected broadcasting, internet services, and mobile communications, particularly in regions closer to the poles.
2. GPS Systems: - GPS satellites faced significant challenges during the auroral event. Increased ionospheric activity caused by the geomagnetic storm led to signal delays and positional inaccuracies. Navigation systems in aviation and maritime sectors reported deviations, which necessitated reliance on backup navigation methods to ensure safety.
3. Satellite Electronics: The energetic particles from the solar wind caused temporary malfunctions in the electronics of several satellites. Some satellites went into safe mode, automatically shutting down non-essential systems to protect themselves from potential damage. This led to brief interruptions in data collection and transmission.
4. Orbital Adjustments: Satellites in low Earth orbit (LEO) experienced increased atmospheric drag due to the heightened geomagnetic activity. This caused slight orbital decays, requiring operators to perform corrective manoeuvres. The need for such adjustments consumed additional fuel, impacting the long-term operational lifespan of the satellites.

Observatory Interruptions

1. Ground-Based Observatories: Optical observatories faced significant challenges due to the bright and pervasive auroral lights. The intense glow overwhelmed sensors, making it difficult to observe faint celestial objects. Scheduled observations of deep-space targets had to be postponed or canceled, impacting research timelines.
2. Radio Observatories: Radio telescopes experienced severe interference from increased ionospheric activity. The auroral event caused fluctuations in radio signal strength and quality, complicating the reception of data from space. Researchers reported noise and signal distortion, which affected ongoing studies of cosmic phenomena such as pulsars and distant galaxies.

Specific Incidents

1. NOAA's GOES-16 Satellite: The National Oceanic and Atmospheric Administration (NOAA) reported that their GOES-16 satellite, which monitors weather and space weather conditions, encountered anomalies in its imaging instruments. The increased radiation levels from the geomagnetic storm temporarily degraded the quality of space weather monitoring data.
2. SpaceX's Starlink Satellites: Several of SpaceX’s Starlink satellites experienced heightened drag and required repositioning to maintain their designated orbits. While no satellites were lost, the increased drag and subsequent manoeuvres added stress to the fleet and consumed additional fuel reserves.
3. European Space Agency's (ESA) Swarm Satellites: ESA’s Swarm mission, which studies the Earth's magnetic field, recorded significant data on the geomagnetic storm. However, the increased particle flux caused temporary data gaps as the onboard instruments automatically adjusted to prevent damage.

Data Collected from Magnetometer Stations

Data collected from three major magnetometer stations—Boulder, Halley Bay, and Sanae—were analysed to compare the strength of the solar storm during the period from May 1 to 16. Figures 1, 2, and 3 illustrate these comparisons. The graphs clearly indicate that intense solar activities significantly impacted Earth's atmosphere on May 11 and 12.

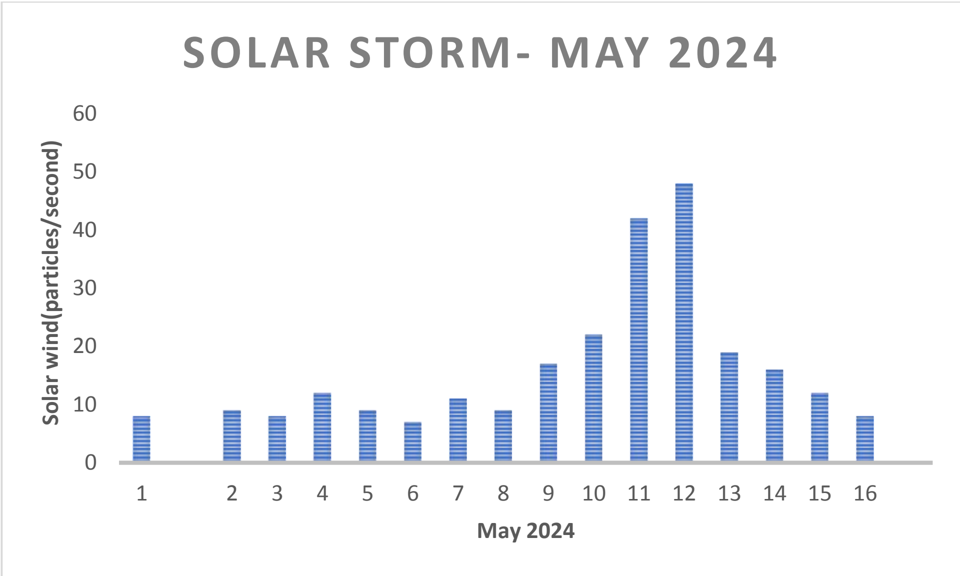

Figure (1). The solar wind variations May 1 – 16, Boulder 40.02°N magnetometer station.

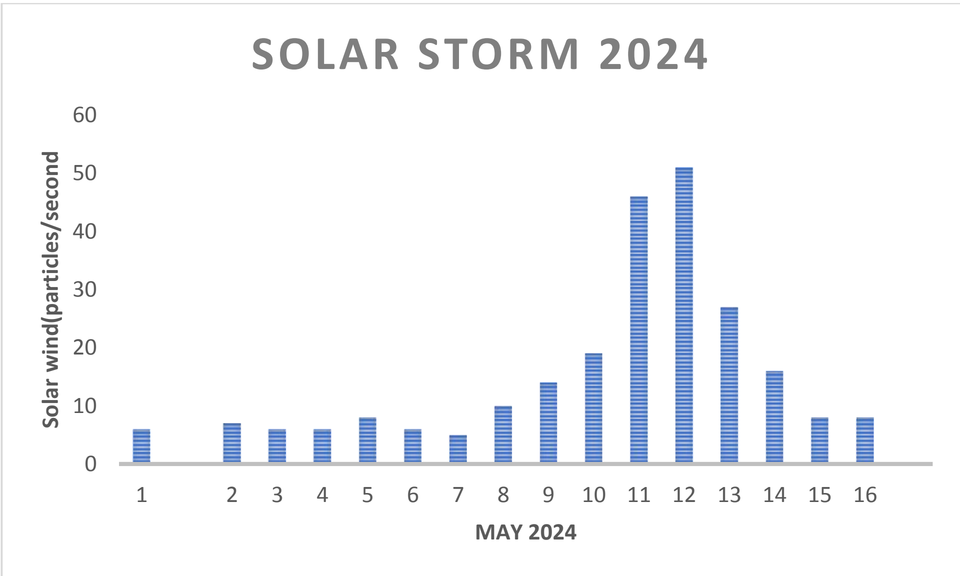

Figure (2). The solar wind variations May 1 – 16, Halley Bay 28.8°N magnetometer station

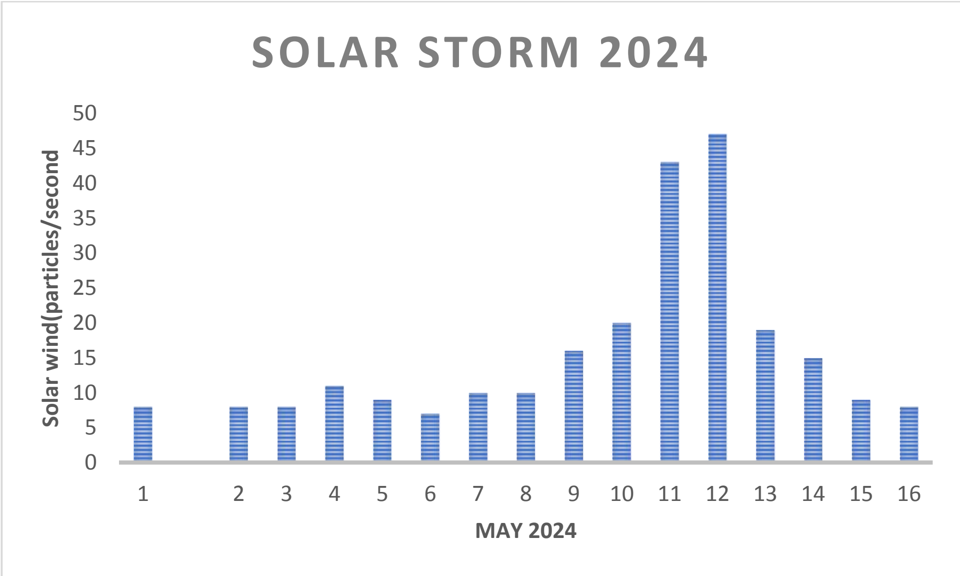

Figure (3). The solar wind variations May 1 – 16, Sanae 44.1°N magnetometer station

III. CONCLUSION

Despite the disruptions, the May 11 auroral event provided a wealth of data that will be invaluable for future research. Understanding the specific impacts on satellites and observatories will aid in the development of more robust systems and improved space weather forecasting models.

In summary, the aurora event on May 11 highlighted the interconnectedness and vulnerability of modern technological systems to space weather. While it caused disruptions and required significant mitigation efforts, it also underscored the importance of continued research and preparedness to safeguard our increasingly space-dependent infrastructure.

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