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**Examining the influence of solar activity on Earth through auroral expression and the validity of aurorae as an indicator of space weather**

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***Abstract***

Earth is constantly buffeted by the powerful, ever-changing stream of charged particles flowing from the Sun known as solar wind. Solar wind is a major contributing factor to space weather and is responsible for the interplanetary magnetic field (IMF) that permeates throughout the solar system. It is important to understand and predict space weather, as solar events can have a devastating impact on Earth’s telecommunication systems and even power grids (in extreme cases). Aurorae, including *aurora borealis* (northern lights), are also caused by solar wind as it interacts with Earth’s magnetic field. Solar activity, such as sunspots or coronal mass ejections, can significantly strengthen solar wind intensity. This intense solar wind can be fairly destructive as mentioned previously, but it can also lead to beautiful and intense auroral displays.

Auroral expression is unique because it demonstrates the ways in which solar wind is directly interacting with Earth’s upper atmosphere and the state of space weather very close to Earth. I intend to utilize this property of aurorae by analyzing the connection between solar events and auroral expression. This study is aimed at providing a direct relationship between solar activity and the effects felt by Earth and its immediate surroundings.

***Introduction***

The relationship between the Sun and Earth enables and dictates many aspects of life on this planet. Our experience on Earth is closely entwined with solar activity and events, increasingly so in the modern world. Much of modern technology, especially telecommunication systems, depend heavily on satellites that orbit about Earth.[[1]](#footnote-1),[[2]](#footnote-2),[[3]](#footnote-3) Coronal mass ejections (CMEs) occur when the Sun expels a large number of charged particles and are one example of solar activity that can damage Earth’s advanced communication systems.[[4]](#footnote-4) These eruptions drag along magnetic field components, which can cause powerful geomagnetic storms affecting Earth.[[5]](#footnote-5),[[6]](#footnote-6) The locale of the storm denotes the area in space where Earth’s magnetic field is dominant, also referred to as the magnetosphere. When they occur, the effects of geomagnetic storms are widespread within the magnetosphere and they can hinder, critically damage, or even destroy satellites.[[7]](#footnote-7)

While the Sun and solar events can be quite destructive, they are also a source of beauty. Dating back to approximately 30,000 BC, the first depictions of the northern lights demonstrate humanity’s early fascination with space and aurorae.[[8]](#footnote-8) The northern and southern lights, *aurora borealis* and *aurora australis* respectively, both result from solar wind wrapping around Earth.[[9]](#footnote-9) Solar wind is the stream of charged particles (plasma) flowing from the Sun’s outer surface. These particles are diverted and concentrated around the poles by Earth’s magnetic field. The quickly flowing plasma joins with ionized gas molecules in Earth’s upper atmosphere to produce the spectacle of the northern (and southern) lights[[10]](#footnote-10). Coronal mass ejections cause some of the most brilliant and intense displays of aurorae. My research is aimed at charting the appearance, extent, and intensity of the northern lights with respect to solar wind, in order to determine how aurorae expression is influenced by solar activity.

***Background***

Solar wind stretches out from the Sun for about 18 billion kilometers, carrying magnetic field components that comprise the interplanetary magnetic field (IMF).[[11]](#footnote-11) This span of the Sun’s magnetic field is referred to as the heliosphere. Resulting from a number of complex variables and interactions, the nature of solar wind is not fully understood.[[12]](#footnote-12) Differing speeds, magnetic field strengths, magnetic field orientation, and temperature are all fluctuating aspects of solar wind.[[13]](#footnote-13) These constantly changing attributes, especially magnetic field direction, have a profound effect on space weather, with a southward directed field causing the most activity in the magnetosphere.[[14]](#footnote-14) Sunspots are a contributing factor to solar wind and are of particular interest, as we don’t fully understand how they participate in various solar processes.[[15]](#footnote-15)

It has been shown that ‘fast’ solar wind flows outward from sunspots of the corona; however, little is known about the origin of ‘slow’ solar wind. Understanding ‘slow,’ or ambient, solar wind would provide insight to internal processes of the Sun and improve predictions and models of space weather.[[16]](#footnote-16) The acceleration of solar wind and solar energetic particles therefore merits further investigation. A central goal of my research is to connect solar activity (largely sunspots and CMEs) to the aurorae, using solar wind data as an intermediary. A correlation between sunspots and aurorae could better inform future sunspot specific studies.[[17]](#footnote-17),[[18]](#footnote-18) NASA’s recently launched Parker Solar Probe is currently en route to the Sun on a mission to gather data relating to solar processes dealing with the acceleration of solar wind and sunspots.

Space weather is the product of many complex processes, interactions, and competing variables. As such, it is useful to study correlations and variable interactions in an isolated manner to pinpoint associations and dependencies.[[19]](#footnote-19),[[20]](#footnote-20) My research is targeted at mapping the appearance, extent, and intensity of the northern lights with respect to solar wind, geomagnetic storms, coronal mass ejections, and sunspots. By considering auroral data in addition to typical solar wind measurements, I hope to discern a more direct relationship between solar activity and space weather. The goal of my research is to analyze collected data for any trends that can be used to better predict and model the solar terrestrial system as well as assess the relationship between solar events and aurorae.

***Methods***

The initial stage of my proposed research would entail a comprehensive review and documentation of existing models for aurorae based on to space weather data. This survey in effect constitutes a literature review, albeit narrowly focused on the validity and efficacy of current space weather models. Such investigation may necessarily expand in scope to include nuanced space weather behaviors and specific solar events critical to the functioning of the prediction models. Each model will be evaluated and characterized by the most significant factors ascribed to the expression of the northern lights. This review of available models is estimated to take four weeks.

With the existing models documented and organized, I would then move to the data accumulation phase. Two sets of data will be collected: one from a period of solar minimum, the other from a period of high solar activity of solar maximum. Each data set will cover approximately one year. This fairly short time frame will be used to allow for better identification of specific solar events. Once dates have been chosen, data will be collected from resources made available by NASA, NOAA, and other space faring ventures or vehicles. Specifically, the accumulated data will include: solar wind speed, temperature, magnetic field direction; visible sunspots count, size, location; and aurorae DNB values supplemented by citizen reports.

A two-part statistical study will then be conducted on the data. In each data set, harvested data will be processed to create comparisons between solar wind intensity and auroral expression, partially accomplished through the production of graphs and figures. After this initial correlation between solar wind and aurorae is established, I will examine the extreme values in solar wind data and trace those fluctuations back to solar activity and events. Once the specific solar events have been identified and recorded, the aurorae data will be analyzed with two main goals: determining how closely aurorae is tied to solar events and how the aurorae’s response differs or compares to solar wind reactions. This analysis will strive to produce a regular or predictable trend in aurorae expression with varying degrees of solar activity and sunspot prevalence in the corona.

***Expected Results***

The intended outcome of this research project is a journal article describing my findings for the relationship between aurorae and solar activity. The paper will follow the data analysis path progression in detail, including figures and commentary to outline key aspects or notable discrepancies. An important feature of the paper will be the speculation or follow-up section, where the results of the study will be discussed with possible explanations and remaining opportunities for future work. I expect that auroral expression will deviate slightly from the values predicted by solar wind data.

In addition to the paper, I plan to create various graphics or posters that illustrate a simplified version of the findings in a clear and concise fashion. A central theme of these graphic illustrations will be the progression of solar wind from the Sun to the ionosphere, and how auroral expression is affected by variations in solar wind. The purpose of these graphic elements will be to increase awareness and interest in solar physics, motivating and enticing potential readers to look through the article. Possible journals for publication include the *Journal of Geophysical Research: Space Physics*, *Frontiers in Physics*, and *Advances in Space Research*.

***Conclusion***

Understanding the solar-terrestrial system is critical to the functioning of our modern society. Spacecraft launches, satellite deployment, and even internet availability all depend on our ability to accurately and reliability anticipate space weather. Without this preparation, we risk potentially catastrophic events, such as large CMEs and resulting powerful geomagnetic storms. To better understand how Earth is directly affected by solar events, I plan to study how auroral expression is influenced by solar events and activity. Considering the direct effect of solar changes on the aurorae will may yield a more direct comparison than using solar wind exclusively. My research will reveal the viability of aurorae as an indicator for solar activity by considering the cases of high solar activity (solar maximum) and low solar activity (solar minimum) and measuring the responses in auroral expression.

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***Timeline***

This project is estimated to last for a duration of about eight weeks. The first three weeks will be dedicated to a comprehensive review of existing aurorae models. By the end of this stage I will have compiled notes and categorized each model by accuracy and correspondence to solar activity. Once existing models have been recorded, I will begin building each data set and providing analysis and notes as detailed above. This process is expected to take three weeks. After reviewing the data and any correlations, I will spend the next two weeks writing and compiling the paper which will contain the findings of this project and any opportunities for further investigation.

***Budget***

Research stipend: $1,500

Literature costs: $200

Total Budget: $1,700

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