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A4 1 Auroras at the Equator

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Abstract

This paper discusses the required strength of a geomagnetic storm to induce a visible aurora at the equator, evaluating it via the difference between the magnetic reconnection rate on the dayside (using a value of $\sim$ 150 kV) and the nightside of the Earth. The nightside reconnection rate is quantified by the Sym-H index, a measure of the magnetic perturbation due to the ring current. We report that although feasible, such an event would be comparable to the Carrington Event ($H_{SYM} = -1750$ nT) [5], if not more devastating, requiring a Sym-H value of at least -1720 nT.

Introduction

Auroras are a natural light display that form in ovals around the magnetic poles of a planet. We will look at one possible condition required for the size of the auroral oval to extend to the equator.

Theory

A coronal mass ejection is a portion of plasma that is accelerated away from the solar surface, pulling out the magnetic field with it, becoming the interplanetary magnetic field (IMF). The adjacent IMF and geomagnetic field lines undergo magnetic reconnection. This process creates ‘open’ field lines, as opposed to closed field lines which are entirely contained in the Earth’s magnetosphere. The IMF portion of the ‘open’ field lines moves in the direction of the solar wind, which allows plasma to enter and transfer its energy and momentum to the Earth’s magnetosphere. As this energy builds up, the nightside magnetic field lines stretch until they sinks towards the tail centre, when they reconnect. This accelerates the plasma along the field towards the Earth, allowing the charged particles to interact with the ionosphere. This process creates aurora at the boundary between ’open’ and closed magnetic flux [1]. This cycle of dayside and nightside reconnection is known as the Dungey cycle.

The main factor that affects the size of the auroral oval is the difference in the reconnection rate on the dayside and nightside.

$$\frac{dF_{PC}}{dt} = \phi_D - \phi_N, [2] \qquad (1)$$

Here, the radius of the auroral oval correlates to F_{PC}, the amount of ’open’ flux in the magnetosphere. The dayside reconnection rate, ϕ_D, is at a maximum when the IMF is directed southward, opposite to the Earth’s magnetic field. The nightside reconnection rate, ϕ_N, is influenced by the westward ring current. The ring current is due to positively- and negatively-charged particles gyrating with different radii in opposite directions as a result of the radial gradient in the Earth’s magnetic field strength [3]. The ring current acts to reduce the magnetic field strength on the Earth's surface. This reduction is quantified by the Sym-H index, H_{SYM}. The ring current is enhanced by plasma in the inner magnetosphere due to nightside reconnection, further decreasing the magnetic field strength near the Earth's surface. It is at this point, when Sym-H is at a minimum, when the auroral oval radius reaches its maximum value [4].

Analysis

The auroral oval can be approximated as a circle offset from the geomagnetic pole allowing the radius, λ, to be determined in degrees of latitude, where $\lambda = 90°$ represents the equator.

$$\lambda = 18.2 - 0.038H_{SYM} + 0.042\phi_D, [2] \qquad (2)$$

This can be rearranged to find the ring current strength required for a typical dayside reconnection rate of ~ 150 kV [1].

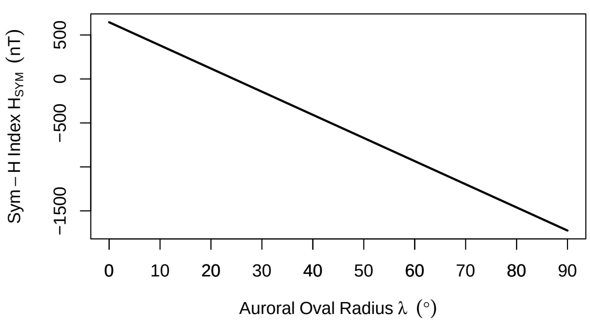

Figure 1: The Sym-H index as a function of the auroral oval radius.

Discussion

Figure 1 indicates that a greater perturbation to the magnetic field, meaning a larger ring current, is required for auroras to be observed at lower latitudes. A strong geomagnetic storm is indicated by $H_{SYM} = -300$ nT [4]. This corresponds to an auroral oval radius of $\lambda = 35.9°$, and a latitude of $54.1°$, which passes through North Yorkshire and the most southern area of Alaska. Overall, for $\phi_D \sim 150$ kV, $H_{SYM} = -1720$ nT would be required for auroras to be observed at the equator. The Carrington event is the most intense geomagnetic storm recorded in history, occurring in 1859. The highest estimated value of Sym-H during this event was -1750 nT [5]. This would indicate, according to equation 2, that the aurora during this event should have been seen worldwide. However, it has been recorded that the aurora was observed at latitudes as low as $\sim 18°$ [6], corresponding to $\lambda = 72°$. This means that the dayside reconnection rate must have been lower to account for the lack of auroras at the equator during the Carrington event.

Conclusion

The fact that $H_{SYM} = -1720$ nT has already been achieved during the Carrington event means that this is not an unrealistic possibility. Since we are approaching a solar maximum, there is a possibility for this to occur in the near future. However, the geomagnetic storm required to induce such an event could have potentially catastrophic consequences for technological infrastructure.

References

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