Geomagnetic storm
The space environment during the ”Vortex” and ”BROR” rocket launches

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1 Introduction

Geomagnetic storms is disturbance in Earth's magnetosphere, as the charged particles from the solar winds interfere. The solar wind with a vast amount energy and charged particles, produces big changes in the currents, plasma's and Earth's magnetosphere [1]. Solar winds that's is the most favorable for geomagnetic storms, are high speed solar winds which have a long periods and that the solar wind magnetic field is southward directed at the day side of the magnetosphere.

Larger geomagnetic storm, are closely related to coronal mass ejection's (CME), which release vast amount's of plasma from the sun and reach Earth after some days but it's observed reach Earth after just 20 hours [1][2]. Another important contribution for geomagnetic storms, is when we have a co-rotating interaction regions (CIRs) created. CIRs is created when a high speed solar wind stream collides with slower solar winds ahead of them, the geomagnetic storm created from this is less intense than what CME gives raise to [1].

Through out a geomagnetic storm, we can find that it undergo different phases. In the *initial phase*, we have a sudden impulse where the horizontal component of Earth's magnetic field increases at some period caused by the ram pressure from the solar wind. This is followed up by the *main phase*, where we have the horizontal magnetic field is decreasing. It all round's up by the *recovery phase*, where it's returning to normal conditions [3][2].

The objective and the motivation of this work, is to contribute to a more understanding of the geomagnetic storms and it's impact. Specially since, we know that the geomagnetic storms can have a significant impacts on our modern technological infrastructures. They can disrupt power grids and interfere with satellites. Which raise concerns about communications, financially losses and safety concerns. As already seen, from the great geomagnetic storm of August 28 to September 3 1859 also called the Carrington event which is said to be the greatest space weather event in the last two hundred years. This was the first time, we have seen and observed a event of this type and the impacts a geomagnetic storm can have [4]. In the earlier years, we had a event when SpaceX lost 38 Starlink satellites on 3 February 2022 as a effect of a geomagnetic storm as result in enhanced neutral density. As the geomagnetic storm leads to a thermosphere expansion, hence enhancement in neutral density and enforce drag on the satellites. The Starlink satellites reentered the Earth atmosphere after some days [5]. By studying the phenomena of geomagnetic storms and solar winds, in the future can help us protect our orbiting satellites and notifications systems regarding geomagnetic storms and solar winds.

2 Satellites and Quantities

Data for the solar wind conditions originates from the satellite called WIND [6], that's was a spin stabilized space craft and was launched on November 1, 1994. WIND had numerous missions, but the main tasks was to give further understanding of the static and the dynamic properties of the solar wind and the second task was to investigate how the solar wind influence the Earth's magnetosphere. In 2020 the WIND was moved in to a halo orbit about Lagrange point L1, where our data originates from [7][6]. Quantities used from the data is the magnetic field in different directions (BX_GSE, BY_GSM, BZ_GSM), the solar wind density (proton_density), the solar wind velocity (flow_speed) and the SYM/H index (SYM_H)

The data retrieved for the ionospheric response, comes from the three Swarm satellites which was launched on November 22, 2013. All the Swarm satellites have a near-polar orbit, but with different altitudes. Main goals for the Swarm satellites, is to study the magnetic field of Earth [8]. Quantities used from the Swarm satellites, is the electron density (Ne), the field aligned currents (FAC) and the northward and eastward current sheets (J_NE).

3 Observations

We first gone take a look at the plot for the solar wind conditions 1, in the period between 2023/03/20 and 2023/03/26. The plots to the left, shows the x-, y- and z-axis of the magnetic field of earth, with nanotesla (nT) on the y-axis and time span on the x-axis. To the right we have plot of the proton density with a y-axis showing the number of particles per cubic centimeter (n/cm^3), next is the flow speed with a y-axis describing the kilometer per second (km/s) and at last is the plot of the SYM-H index with nT at the y-axis. On all of the plots, we see that as days get closer to 2023/03/24 the graphs shows some sort of anomaly. Which can be result of when the solar wind caused a geomagnetic storm. This is highlighted with red on the plots which illustrates a 6 hour period, and for comparison we have highlighted how it's is usually.

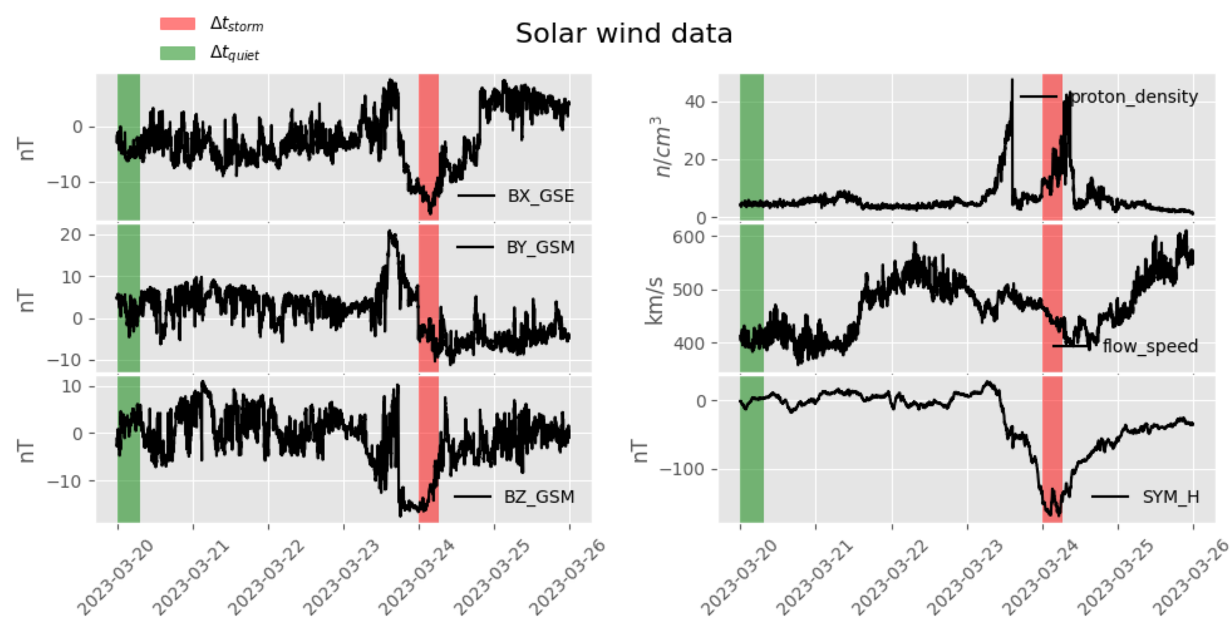

Figure 1: Data used from OMNI data base, which shows the solar wind conditions from 2023/03/20 to 2023/03/26. Where ΔT_{storm} and ΔT_{quiet} is highlighted.

In figure 2, we have the data retrieved from the Swarm Alpha satellite. The plots, shows the ionospheric response in the period between 2023/03/20 and 2023/03/26. The plot in upper

left, shows the field aligned currents with micro-amperes per square meter ($\mu A/m^2$) on the y-axis, down left we the electron density where y-axis is labeled with cm^{-3}, to the right we have the north- and eastward current sheets with A/km on the y-axis.
As we closing in on the day 2023/03/24, we see futures standing out on the graphs which can correspond to a geomagnetic storm. Our storm and quiet periods is highlighted with the colors red and green.

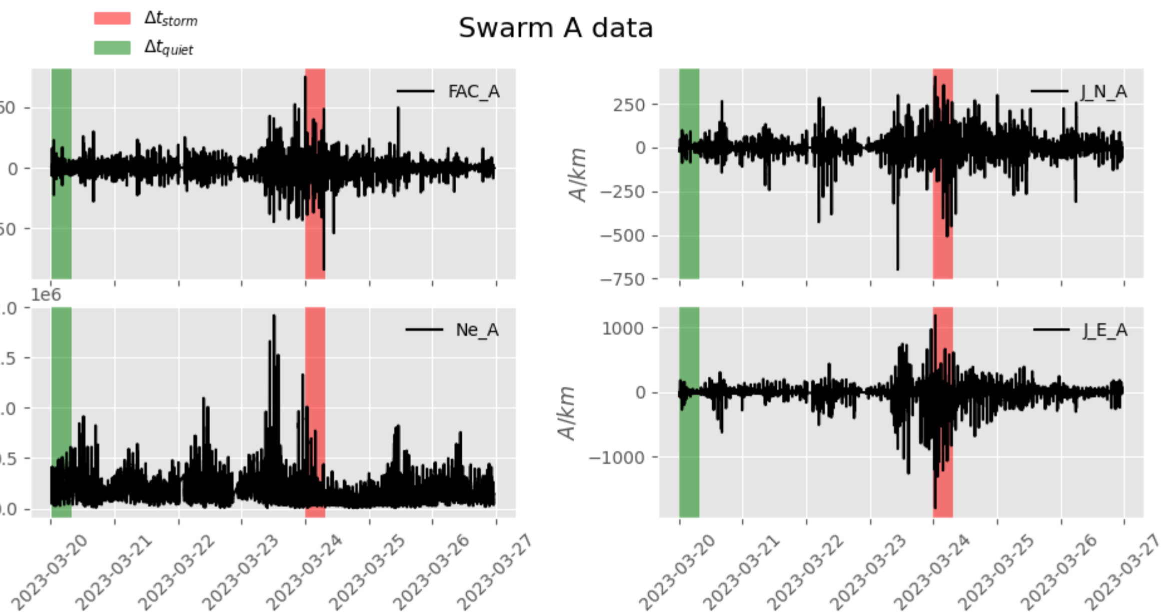

Figure 2: Data used from ViRES services, plot's shows the ionospheric response from the Swarm Alpha satellite. From 2023/03/20 to 2023/03/26. Where ΔT_{storm} and ΔT_{quiet} is highlighted.

Figure 3, shows the ionospheric response from the Swarm Beta satellite in the period 2023/03/20 to 2023/03/26. The plots have the same description as mention for figure 2 for the ionospheric response from the Swarm Alpha.

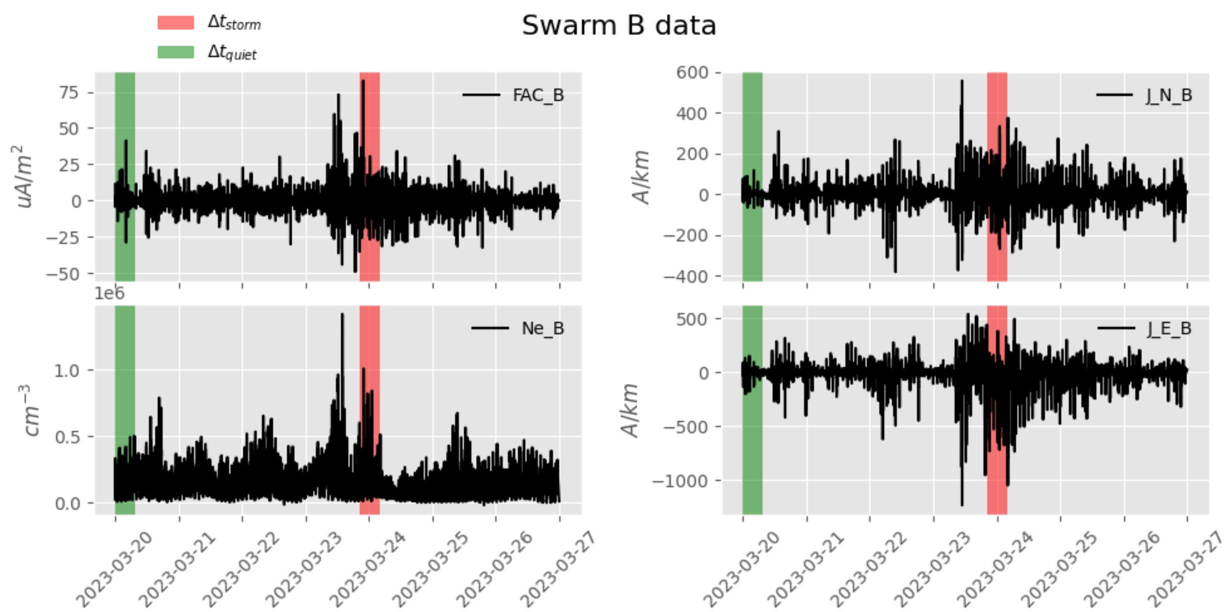

Figure 3: Data used from ViRES services, plot's shows the ionospheric response from the Swarm Beta satellite. From 2023/03/20 to 2023/03/26. Where ΔT_{storm} and ΔT_{quiet} is highlighted.

The last figure 4, we have the ionospheric response from the Swarm Alpha satellite. Where we have focused on the geomagnetic storm period in color orange, and compering it with how it is usually which we have marked with the color blue. From the plot it's comes more clear that we have a geomagnetic storm, by compering it with the quiet period which is way more linear and don't have a lot of oscillations. This data is collected from a 6 hour period, and it's shown with the latitude on the x-axis.

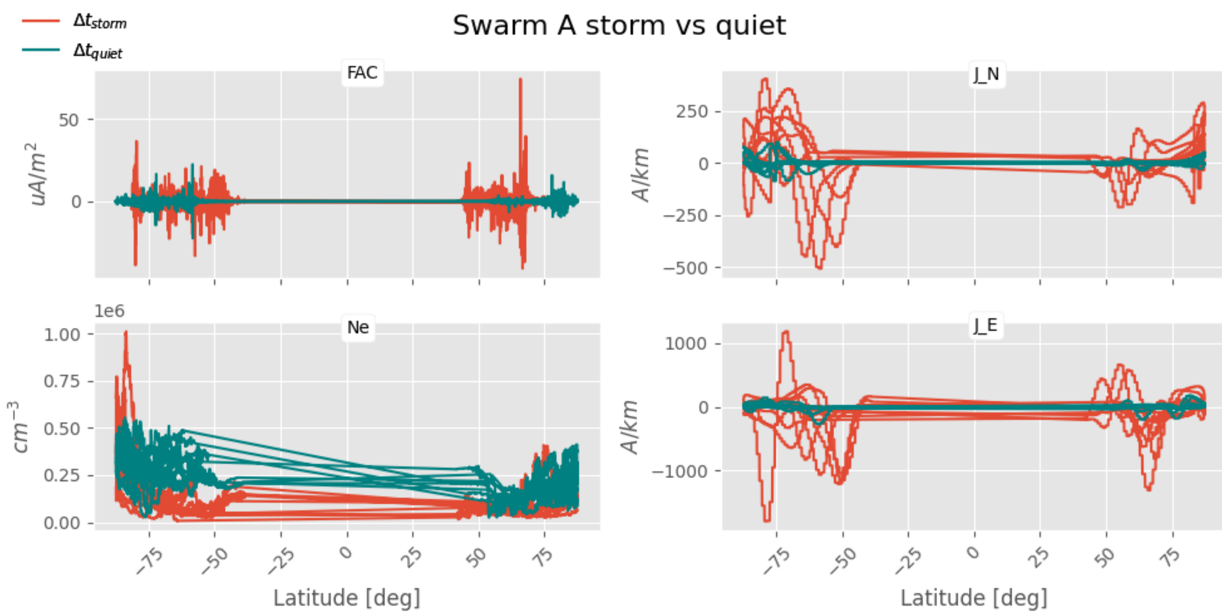

Figure 4: Data used from ViRES services, plot's shows the ionospheric response from the Swarm Alpha satellite. With comparison between the geomagnetic storm and when not.

4 Brief discussion

To choose the time of the geomagnetic storm (Δt_{storm}), we firstly look at the graphs where we had the most anomaly which tends to be around the date 2023/03/24. To be more certain for where the storm take place, we focused on the SYM-H graph. Since SYM-H is a geomagnetic activity index used to quantify the strength and intensity of geomagnetic storms caused by solar activity, particularly the interaction Earth's magnetosphere and solar wind. The SYM-H index represents the deviation of the horizontal component of Earth's magnetic field. Negative values of SYM-H indicates the strength of the storm's magnetic disturbance [9], from the plot in figure 1 we have huge negative values of SYM-H index indicating that, we a have more severe geomagnetic storm than at the "quiet times". By highlighting the Δt_{storm} and Δt_{quiet} in the plots, it comes clear that this is where our geomagnetic storm takes place as we have a lot of deviation in this area.

In zoomed inn portion of the storm, in figure 4 from the Swarm Alpha satellite. We can see that through out the storm period the graphs have more deviation, than at the quiet period. Similarities from plot, is that the disturbance happens at around latitude $-75°$ and $75°$. Which comes from scaling, but can be a indication at which place on Earth was facing the sun. Plot for the field aligned current (FAC), we have higher and lower peaks than what we have for the quite period. During a geomagnetic storm the FAC is often associated by getting an increase in the strength and intensity, which is a result form the influx of charged particles from the solar wind and the interaction with Earth's magnetic field. FACs during a geomagnetic storm also tends to be highly variable, as seen from the plot 4. Due to the increase flow of charged particles along the field lines, this also contribute to generation of auroras.

During a geomagnetic storm, there's often a increase in electron density (Ne) in certain areas of the ionosphere, it's often associated with the arrival of charged particles from the solar wind and ionizes particles which leads to higher electron density [10]. This comes clear by looking at the plot for electron density (Ne), in figure 4 and compering it with the quiet period.
Where we see the most deviation from the storm period and the quiet periods is in the current sheet (north and east), as shown in figure 4. As the currents sheet get inflicted with high energy solar winds, this some time's leads to what we call magnetic reconnection. Magnetic reconnection occurs when the high energy solar wind interacts with Earth's magnetosphere, this leads to the magnetic field lines becomes tangled or opposite direction. In the process of having the magnetic field lines stable, it releases energy. As the magnetic reconnection results in transfer of energy from the solar wind to Earth's magnetosphere, this energy transfer leads to heating of charged particles, acceleration of particles and can generate electrical currents [11][12]. By compering the magnitude of the current sheets during the storm period and the quiet periods, we see that the currents have way higher energy (in amperes [A]) than at the quiet period.

5 Interpretation

By comparing our SYM-H index, presented in figure 1. With the following figure 5 from [13]. We see closely similarities between our data plot and the data plot they have provided, also regarding the similarities between the differences of the three geomagnetic phases.

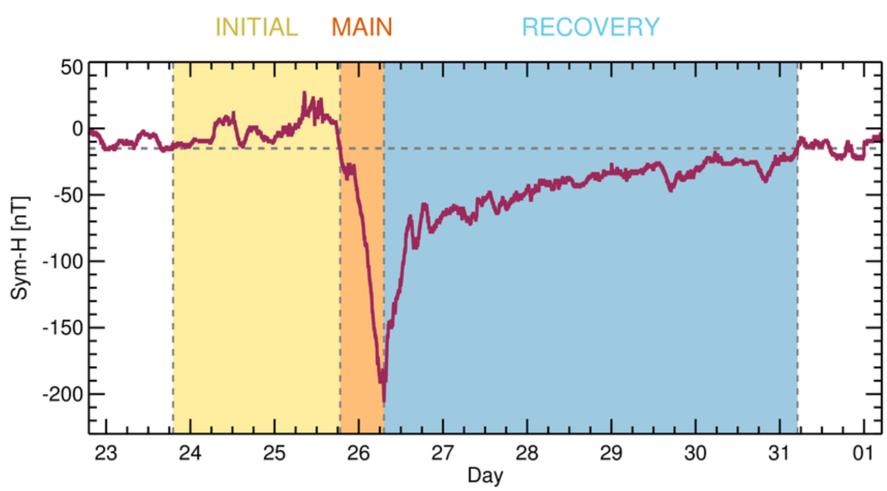

Figure 5: Description from [13]: The Sym-H trace during a geomagnetic storm, where the storm peak occurs at 07:11 UT on August 26, 2018. The colored regions show the phase identification using the Walach and Grocott (2019) algorithm, where the initial phase is in yellow, the main phase in orange, and the recovery phase in blue.

Forward we found some similarities, with the figure 6 from [14] as shown below. With comparison to the figure 4, we see great similarities that we have the field aligned current is highly varying and great peaks in both the positive and negative direction. These peaks also lay, in the same area of value as in our data plot for the FAC 4.

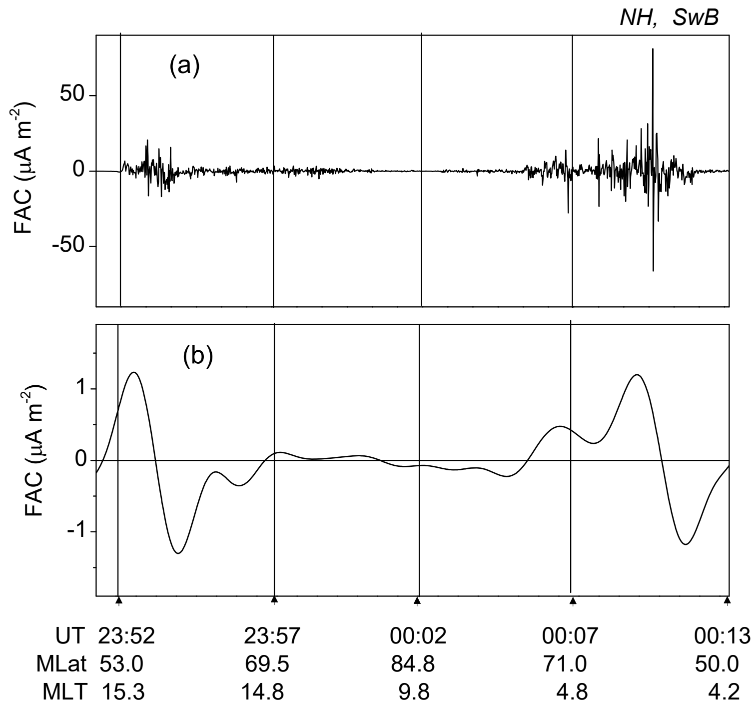

Figure 6: Description from [14]: (a) 1 s and (b) smoothed FACs measured by SwB in the northern polar region between 23:50 UT, 7 September, and 00:13 UT, 8 September. Downward (upward) current is positive (negative).

6 Conclusion

After the observation, discussion and the interpretation sections. It's evident that around the date 2023/03/24, we did have geomagnetic storm and more specific it had it's main phase in this period.

Acknowledgments

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