Relationship between storm time disturbance and mass density on short time scales

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Abstract

This paper looks at how various magnetosphere conditions behave around the onset of geomagnetic storms.

1 Introduction

Storms consisting of high energy particles in the magnetosphere have the capacity to damage satellites and ground-based electrical systems. Learning how they behave and what sort of preconditioning goes into making stronger storms helps to forecast storms and mitigate damage caused. This paper intends to investigate conditions immediately before geomagnetic storm onset to determine trends and useful correlations, specifically looking at the effects on equatorial mass density (ρ_{eq}).

Takahashi et al. [2010] state that spikes in the Disturbance Storm Time (D_{ST}) index coincide with with significant changes in ρ_{eq} at an L-shell of $6.8R_E$. For five storms over a 20 day period two had ρ_{eq} spikes after the D_{ST} drop, two had ρ_{eq} spikes before the drop, and one showed little change in ρ_{eq}. They then show an epoch analysis where ρ_{eq} is seen to spike the day of a D_{ST} drop, using a daily average of 30 minute ρ_{eq} and one hour D_{ST} measurements.

The prior paper, Takahashi et al. [2006], show how trends in storm dependence on mass/density only appear in longer timescales. Looking at Kp vs mass (amu) in the range of 6 to 7 R_E, a trend shows up in the 1.5 day averages that doesn't appear in the 3 hour averages.

Lavraud et al. [2006] show that storms preceded by a northward interplanetary magnetic field (IMF) tend to have higher plasma density than those preceded by a southward IMF, and suggest an increased geoeffectiveness from a northward IMF and dense plasma sheet.

Tsurutani and Gonzalez [1997] show how the density of a corotating interaction region (CIR) shows strong preconditioning for a drop in D_{ST} and spike in magnetic field intensity. Assuming a reasonable amount of coupling between that region's density and the plasmaspheric density, this result could be relatable to others focusing on the plasmasphere.

Denton et al. [2006] show how D_{ST} affects the distribution of plasma density along different magnetic latitudes, and specifically along the same field lines as looked at in later papers (6-8R_E). Though this shows that the trends for density may differ between field lines, it's mentioned mostly as a point for future research as the data used in this paper is already adjusted for one field line, as described by Takahashi et al. [2010].

2 Our work

Our work takes the datasets from Denton [2007] and Kondrashov et al. [2014], uses a mean interpolation to take the mass density parameter from a highly non-uniform 15 minute grid of the former to the contiguous one hour grid of the latter, and looks for storms based on the definition of storm periods provided by Takahashi et al. [2010], namely when $D_{ST} < -50nT$. The former has a time coverage of 1980-1991, but covered by different satellites in different years (sometimes with overlap), and the latter data set covers 1972-2013. By then looking at an hourly average of variables from 24 hours before storm onset to 48 hours after, short timescale trends can be discerned.

In this paper we try to test the relationship of short timescale effects on mass density from D_{ST}, $F_{10.7}$, and B_Z, in comparison to the long time scales presented in Takahashi et al. [2010, 2006], as well as looking at other preconditioning factors by analysis of hourly data within a day surrounding storm onsets. We will briefly compare our results to other published results to verify our methods and handling of data. We also hope that by looking at all possible storms under less stringent qualifications, instead of hand selected storms with specific selection criteria, our results will be more generalizable and less prone to bias.

2.1 DST Storm

Two storm indicators are looked at in this study. The first is looking for a drop in DST below the threshhold of $-50nT$ specified in Takahashi et al. [2010], dubbed the "onset", and then considering the timeframe a storm until D_{ST} passes back above the $-50nT$ threshold. This method finds 669 such periods between May 1983 and August 1991 with an average duration of 9 hours and a median duration of 3 hours. A subset of longer duration storms will be looked at later. Figure 1 shows the average values of B_Z, V_{SW}, D_{ST}, $F_{10.7}$, and Mass Density for a period of 24 hours before and 48 hours after a storm onset, as well as a plot of mass density with the found storm times highlighted.

This figure shows a definite spike in the Z component of the magnetic field, as well as the defined drop in DST, but no obvious change in mass density at an hourly timescale. This points to an issue with only looking at long-timescale trends between density and D_{ST}, and allows for the possibility that other factors are influencing the long term correlation since there's no obvious connection on a short timescale. One possibility is that, as suggested in Takahashi et al. [2010], $F_{10.7}$ plays a significant role in driving long term density values which biases the long term correlation of density and D_{ST}.

2.2 Mass Density Storm

Figure 2 shows this same algorithm, but looking for a rise in mass density over a value of $40g/cm^3$. This results in 130 storms with a mean duration of 32 hours and a median duration of 17 hours, marked in red on the left figure.

This shows that when using all data for mass density derived storms, almost no significant changes can be seen around storm onset.

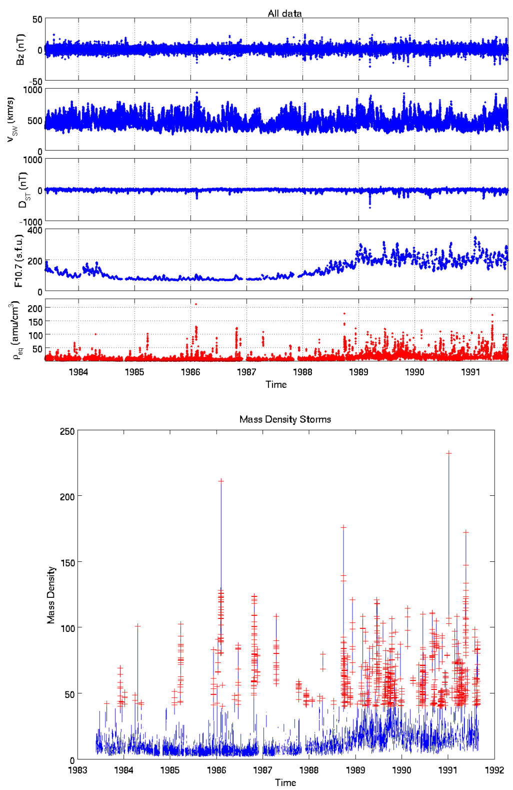

Figure 1: All used data (left) and selected storm times highlighted (right)

3 More specific storms

It's hypothesized that progressively picking more specific storm criteria will allow for the possibility of more significant results, at the expense of more bias in the selection process and potentially less overall usefulness of the results. That said, the predictability of extreme storms is of definite interest, so an attempt has been made to find some reproducible method of prediction. Looking at storms that last longer than 12 hours and storms with an onset threshhold greater than $70g/cm^3$ results in the left and right sides of Figure 3 respectively.

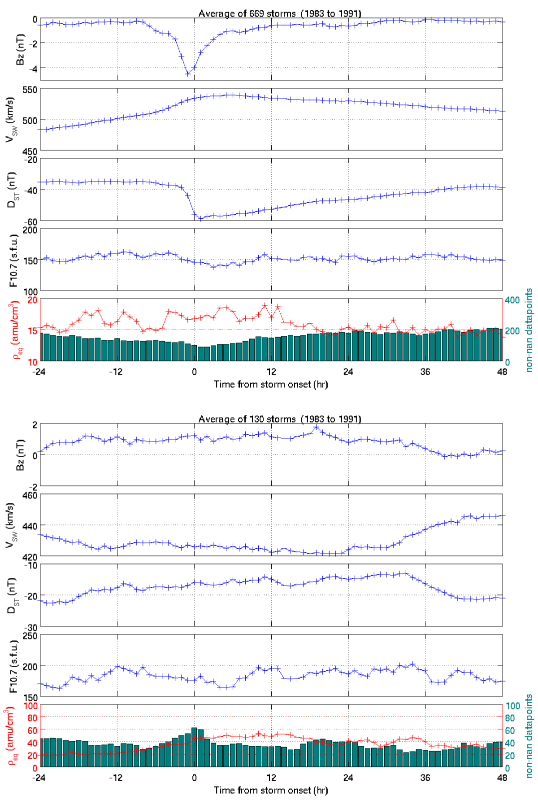

Figure 2: $D_{ST} < -40nT$ onset, Mass Density $> 40amu/cm^3$

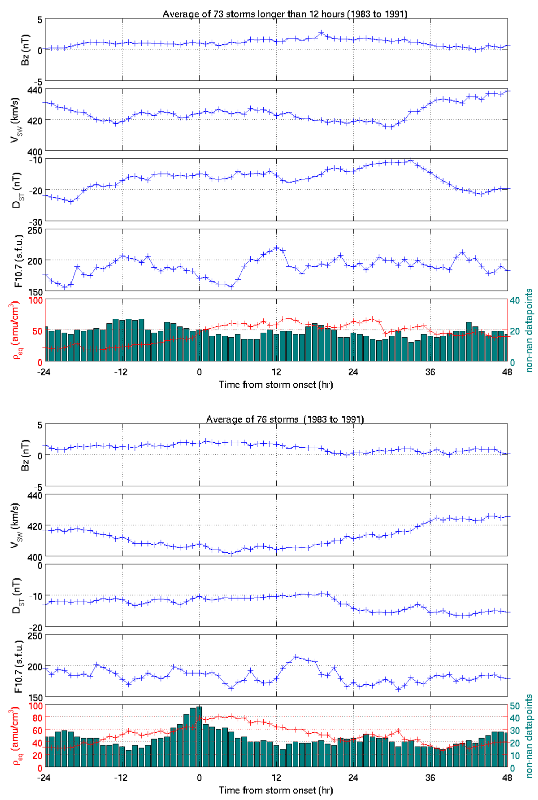

Figure 3: Duration > 12 hours, Mass Density $> 70amu/cm^3$

Neither of these seem to indicate anything too significant, so looking at D_{ST} storms instead to look for something that causes a significant change in Mass Density results in Figure 4. This shows that by either looking only at D_{ST} storms that last longer than an hour (left) or at storms where the onset condition is $D_{ST} < -80nT$, a spike in mass density is seen, but also a definite lack of data availability to the point where that spike may be coming from less than five of the total 143 storms.

Unforunately there are no storms in this time frame that are longer than 12 hours with D_{ST} minima lower than $-80nT$ that have existing mass density data around onset, so an analysis of this particular relationship can't be made.

4 F10.7 dependence

In an effort to analyze the dependence of mass density on $F_{10.7}$, a few tests were performed. Takahashi et al. [2010] mention a strong correlation between the two. The long term correlation could be a bias for D_{ST}'s effects, so a linear model was created, recreating mass density purely from $F_{10.7}$ in the form of $\rho_{eq}(t) = A * F_{10.7}(t)$. This re-created density shows around a 45% correlation with the actual density, suggesting a strong influence, while doing the same procedure with DST shows only a 20-25% correlation.

Taking this re-created data set and subtracting it from the original should remove the $F_{10.7}$ dependence from the data, and allow for a less biased analysis of the relationship between D_{ST} and mass density. Figure 5 shows the stack plot for the reduced $F_{10.7}$, where a more distinct peak after storm onset can be seen. It also shows what that removed trend looks like, of the form $\rho_{eq} - \rho_{eq,F_{10.7}}$.

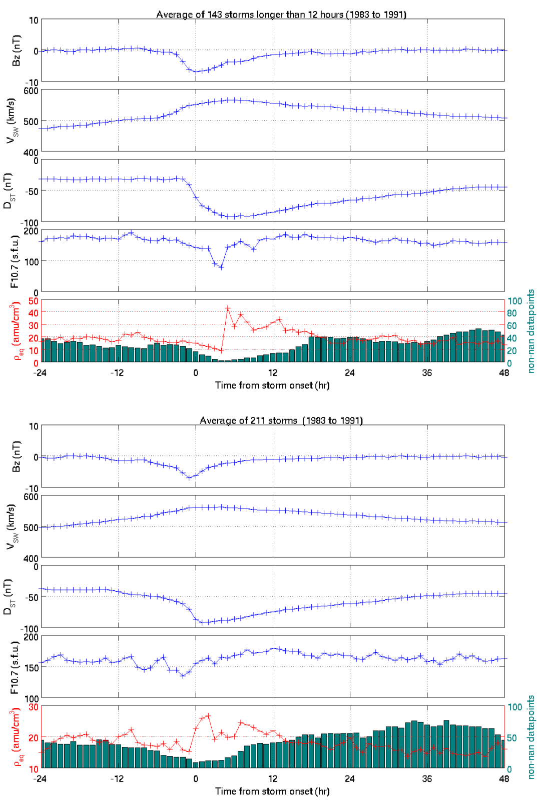

Figure 4: D_{ST} Storms > 12 hours, $D_{ST} < -80nT$

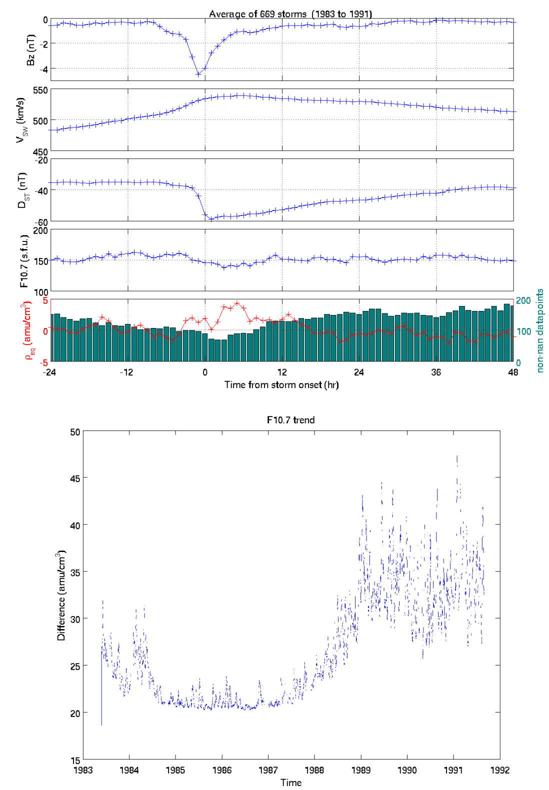

Figure 5: ρ_{eq} with $F_{10.7}$ removed, and Difference from original

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