Shock-to-Storm: How Long?

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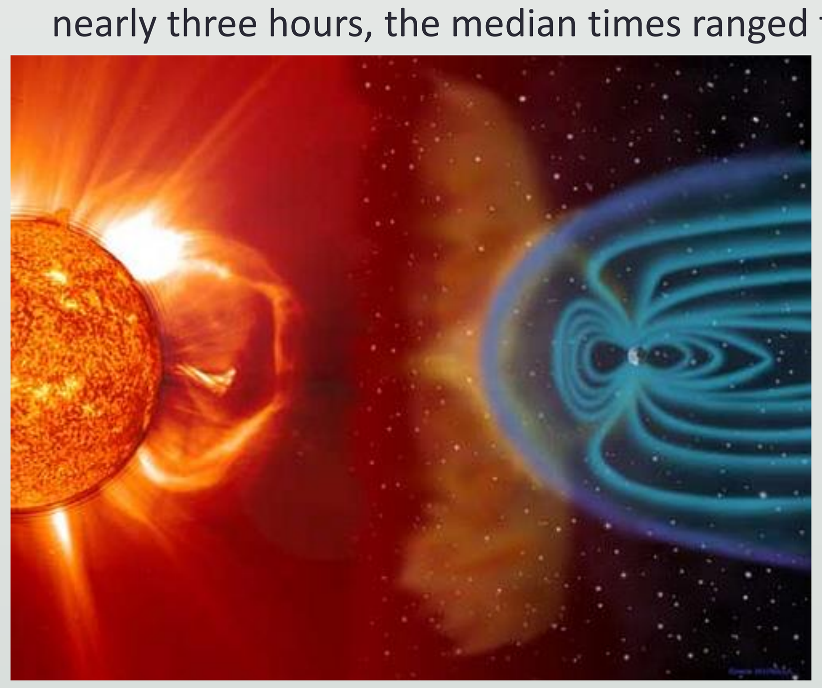
BACKGROUND AND MOTIVATION

Geomagnetic storms driven by interplanetary coronal mass ejections (ICMEs) threaten electric power distribution systems worldwide. Accurate predictions of ICME arrival and subsequent storm initiation allow utility providers to minimize disruptions to the grid. While operational numerical models have reduced the error associated with ICME arrival predictions, little guidance exists for forecasting geomagnetic storms in terms of three-hourly planetary K-index (K_P) values specified in the Space Weather Prediction Center's (SWPCs) Three Day Forecast product. The aim of this work is to establish empirical guidelines for space weather forecasters based on an examination of previous shock-storm episodes. We compare local and planetary geomagnetic K-index-based storm alerts issued by SWPC to lists of shocks observed by the (ACE) spacecraft. We examine 180 cases and calculate elapsed times from shock arrival to specific K_p thresholds, associated with minor to extreme geomagnetic storms. While the resulting minimum times range from 15 minutes to nearly three hours, the median times ranged from 2 to 6 hours.



INTRODUCTION TO THE K-INDEX

Geomagnetic disturbances can be characterized by the K-index. The local K-index is derived from three hourly measurements of the horizontal magnetic field component with the greatest departure from a "quiet day" background. Measurements from several stations can be combined to produce a planetary K-index, K_P. The K-index ranges from 0 to 9. Geomagnetic storm conditions range from minor (K_P=5) to extreme (K_P=9).

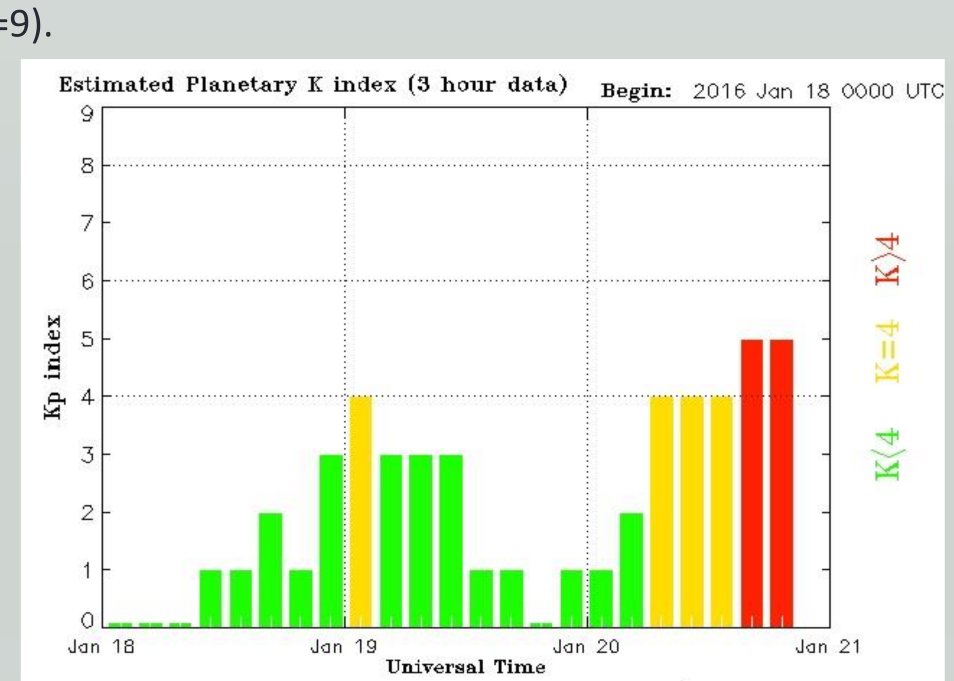


Figure 1: Estimated 3 hour planetary K-index from SWPC

ASSUMPTIONS/CONSIDERATIONS

From 2002-March 2011, SWPC issued geomagnetic storm alerts based on the Boulder K-index (K_B). After March 2011, alerts were issued based on SWPCs estimated planetary K-index (K_P). No differentiation between the two was made for this study and will be referred to as K or K_P.

Shocks also occur at the interface between high speed solar wind streams and slower, ambient solar wind. No attempt was made to determine the origin of the shocks, since high speed solar wind streams can also produce geomagnetic disturbances, albeit typically weaker than those produced by ICMEs.

METHODS AND RESULTS

Shocks recorded at the L1 Lagrange point by the ACE spacecraft were contained in two data sets: a list manually compiled by Cash et.al. covering the period from March 2002-December 2006, and a list produced by an automated shock detection algorithm describe by Vorotnikov et.al. and covering the period from March 2002-December 2014. These were compared to a list of K-based alerts issued by SWPC. We calculated the elapsed time from shock arrival to the various thresholds (K=5 to K=9) using an algorithm written in Octave. The elapsed time was limited to 24 hours or less to exclude unrelated events. Results are shown below. While the resulting minimum times range from 15 minutes to nearly three hours, the median times ranged from 2 to 6 hours.

Elapsed Time from Shock to Kp Level (hours) using Vorotnikov et.al.						
Kb and Kp: 03/2002-12/2014						
K-Index	Mean	Median	Minimum	Maximum	Standard Deviation	Number of Cases
5	3	2	0	9	2	53
6	4	3	0	14	3	42
7	6	4	0	23	6	20
8	6	5	1	13	4	9
9	5	6	2	6	2	3
Kb: 03/2002-12/2011						
K-Index	Mean	Median	Minimum	Maximum	Standard Deviation	Number of Cases
5	3	3	0	9	2	49
6	4	3	0	13	3	38
7	6	4	0	23	6	18
8	6	6	1	13	4	8
9	5	6	2	6	2	3
Kp: 12/2011-12/2014						
K-Index	Mean	Median	Minimum	Maximum	Standard Deviation	Number of Cases
5	2	2	0	6	2	4
6	5	3	2	14	5	4
7	6	6	4	7	1	2
8	N/A	N/A	N/A	N/A	N/A	0
9	N/A	N/A	N/A	N/A	N/A	0

Table 1: Comparison of time from shock alert for Boulder, CO K-index (K_b) and planetary K-index (K_P).

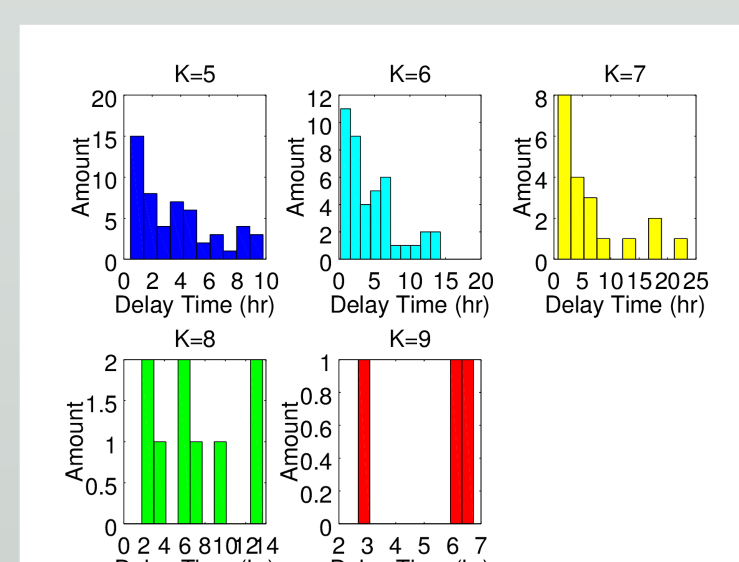


Figure 2: shock distribution from Vorotnikov et al. after 2002

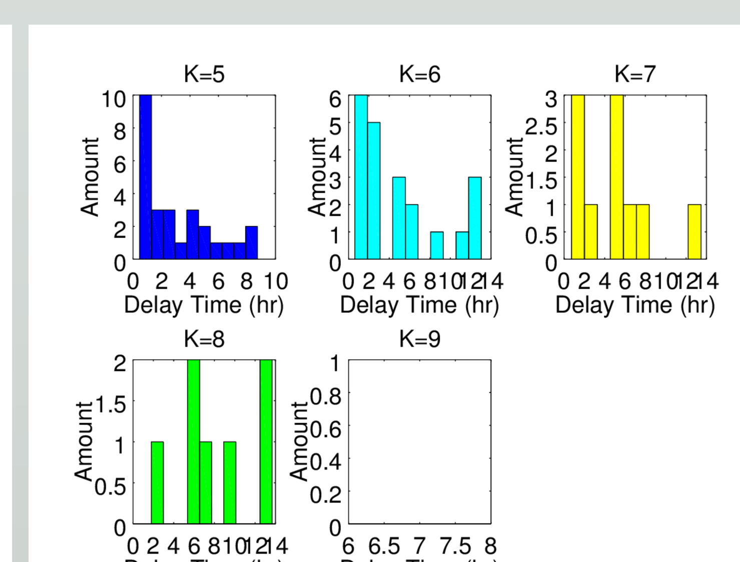
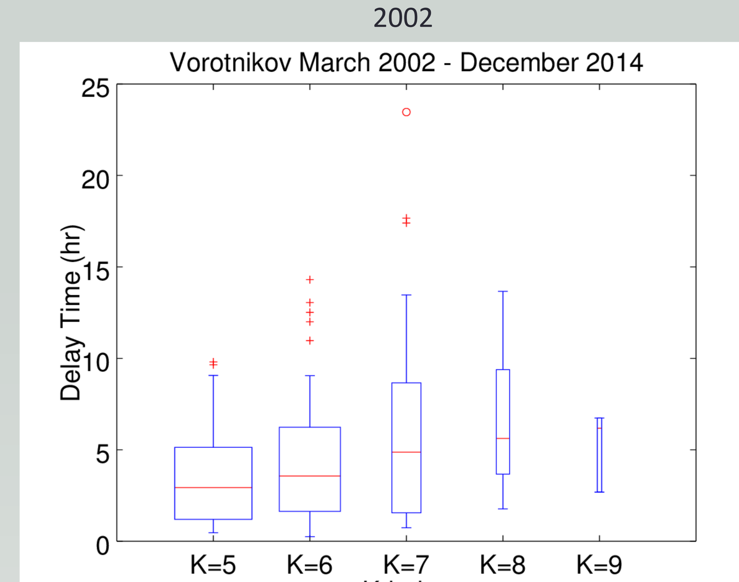
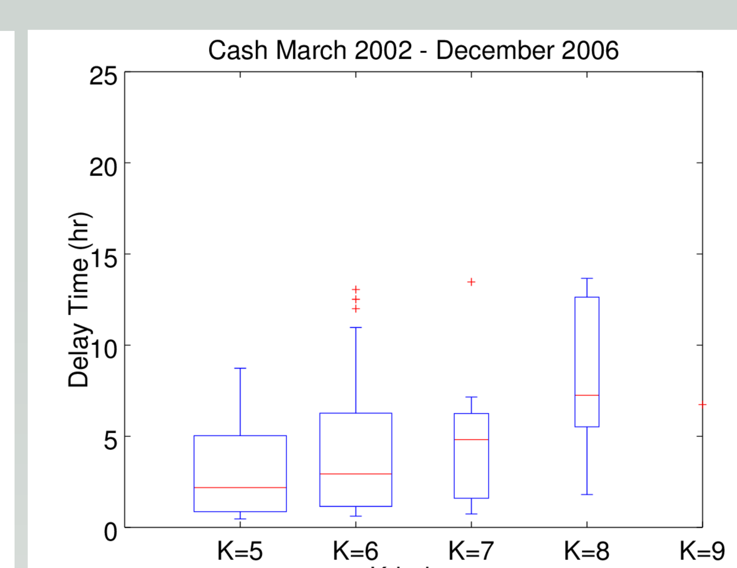


Figure 3: shock distribution from Cash et al. after 2002





Median time from shock to K_P level derived from Vorotnikov et.al. (Figure 4) and Cash et.al. (Figure 5) shock tables. Wider boxes represent more cases while the red bar represents the median.

DISCUSSION

The results suggest that, in general, as the K index increases, so does the time to reach that threshold. Additionally, the histograms in Figures 2 and 3 suggest shorter times are more likely to be observed. Table 1 shows the elapsed time statistics did not differ significantly when evaluating K_B and K_P based alerts separately or lumping them together. The Figures 4 and 5 show that out of the 120+ and 60+ cases respectively, there were few outliers on the high end of the elapsed times. The magnitude and timing of the geomagnetic storm is linked to the southward component of the magnetic field (B_z). If the magnetic field is primarily northward in the early part of CME passage, but then turns southward later, the storm can be postponed. For example, a shock was detected on April 13, 2006 at 11:12, yet the alert wasn't issued until nearly 24 hours later. Figure 6 shows B_z (red line) remained mostly neutral or northward for approximately 12 hours before turning southward. This delayed the storm significantly. Finally, the applicability of the analysis is tempered by the paucity of severe and extreme storm cases.

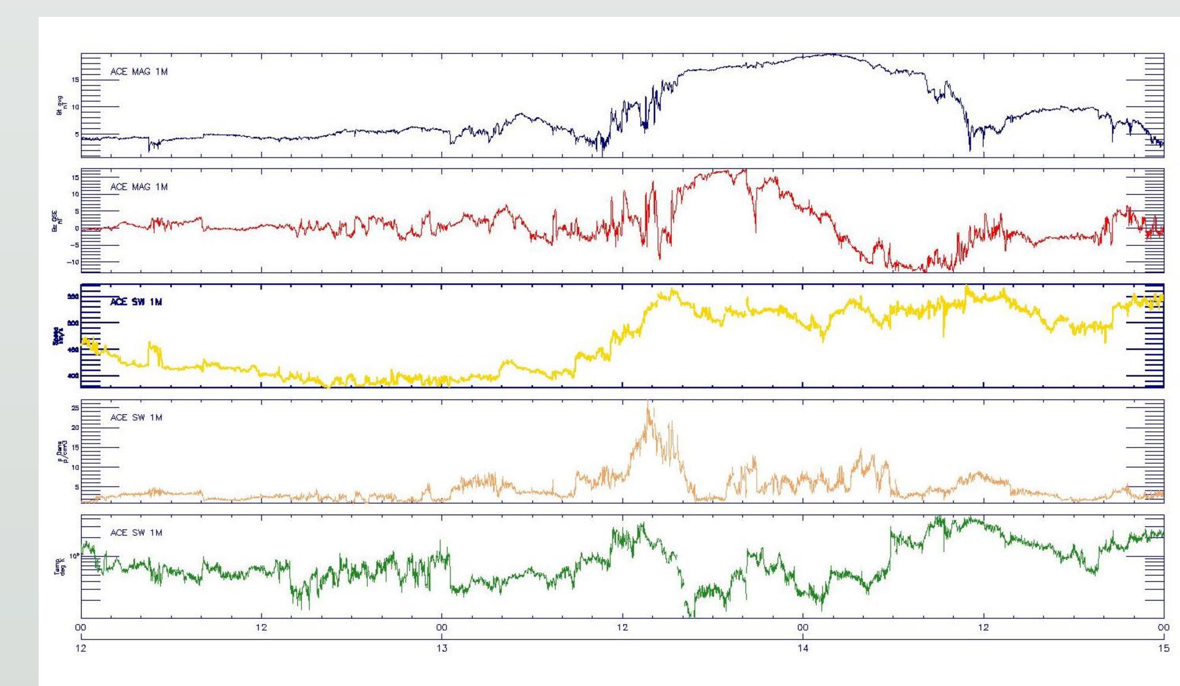


Figure 6: ACE spacecraft solar wind data for April 12-15, 2006.

CONCLUSION AND FUTURE RESEARCH

The geomagnetic response to ICMEs and high speed solar wind streams results from an amalgam of solar wind characteristics, including speed, density, and most importantly, the embedded magnetic field. Because there is no reliable operational method to determine the magnetic profile of ICMEs before they arrive at ACE, creating a one to three day, three-hourly K_P forecast can be daunting. This work provides a preliminary climatology of shock-to-storm elapsed times which will allow the forecasters to make reasonable K_P predictions based on the expected shock arrival time. Future research can be directed towards creating separate statistics for ICME-based shocks and those associated with high speed solar wind streams to see if significant differences emerge.

ACKNOWLEDGEMENTS

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