Coronal Mass Ejections: The Relation of Speeds to Shocks During Solar Cycles

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About

Coronal Mass Ejections (CMEs) play a major role in the space environment surrounding Earth and in the solar system. Some CMEs are able to drive shock waves, which are highly energetic. Their ability to drive shock waves potentially varies as the Sun passes through periods of maximum and minimum activity. Understanding the nature of shock-driving CMEs can provide insight into solar activity during these periods. Shocks are created when the velocity of the CME, in the solar wind frame, exceeds the local magnetosonic speed. Utilizing data from four NASA satellites over the years 1997 to present, we seek to determine whether CMEs drive shocks more frequently at lower velocities during the unusually quiet period of the current solar cycle. Initial indications show no statistically significant increase in the frequency of CME-driven shocks in the low velocity regime during periods of reduced solar wind speeds.

CME Shocks: Qualifying Parameters

CME-driving shocks occur when the difference between CME velocity and upstream solar wind velocity is greater than the local magnetosonic speed (V_{MS}), as given by **Equation 1**:

$$V_{CME} - V_{UP} > V_{MS}$$

A CME can be identified in spacecraft data as a period of decreased temperature and proton density and an increase in magnetic field. A shock is a sharp increase in all quantities (magnetic field, velocity, density, temperature) simultaneously. These variables plotted over time are clear indicators a CME shock has occurred.

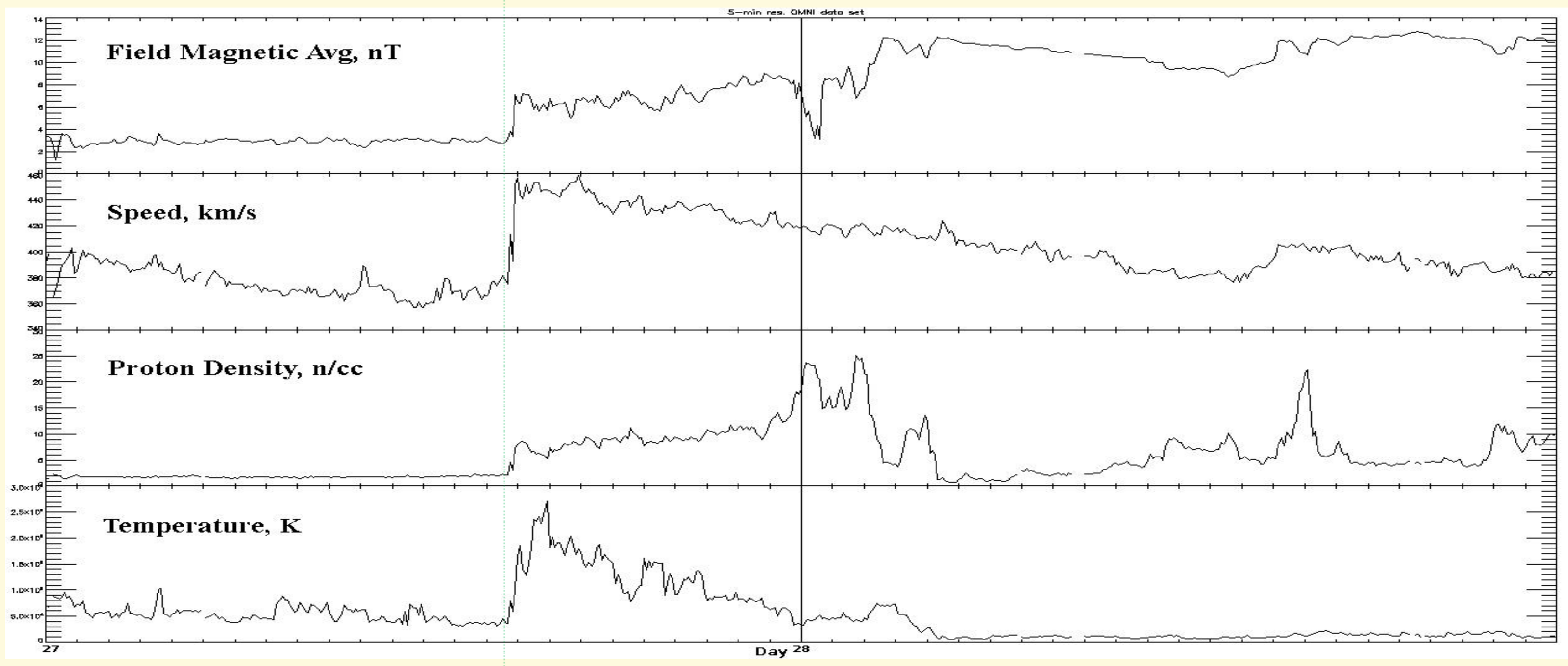
Spacecraft, Solar Activity & Data Range

The Sun oscillates between periods of maximum and minimum activity, following an 11 year cycle. Data for this analysis is taken from the years 1996-2015. These dates encapsulate two solar cycles, one strong and one weak. The strong solar cycle, solar cycle 23, took place during 1996-2007. Solar cycle 24 is currently a weak solar cycle and passed its solar maximum around 2012.[1] Solar minimums, maximums and strengths are determined by sunspot quantity. Strong cycles, including solar maximums, typically consist of more frequent CMEs and solar flares.

Data in solar cycle 23 was collected by the NASA satellites Wind & ACE These two satellites are similar in objective and capability, and data from these were used in conjunction during data analysis.

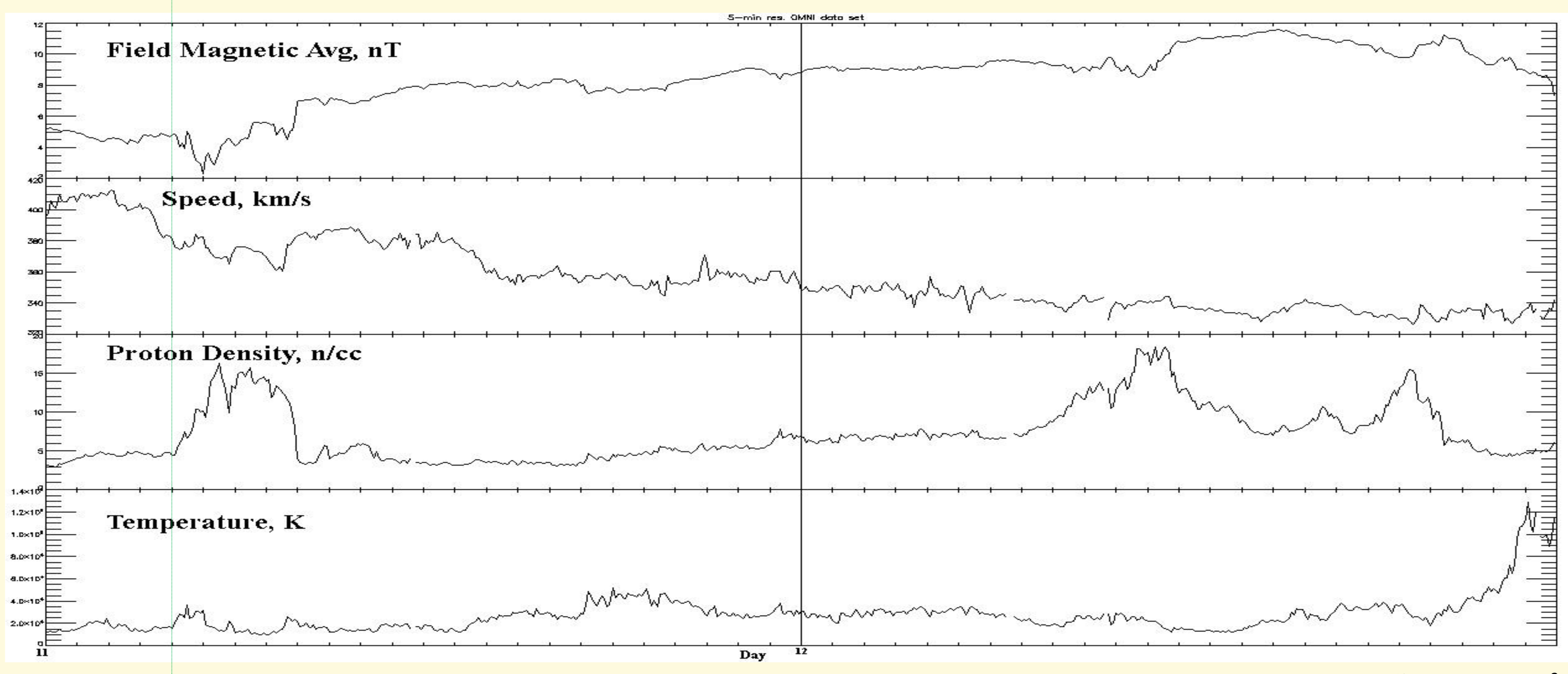
Solar cycle 24 data was acquired from the Wind, ACE and STEREO A & B satellites. We use all four satellites partly because the cycle is incomplete but also because it is weak, and we want to compare similar quantities of CMEs.

CME With Shock



June 27-28, 2013 [2]

CME Without Shock



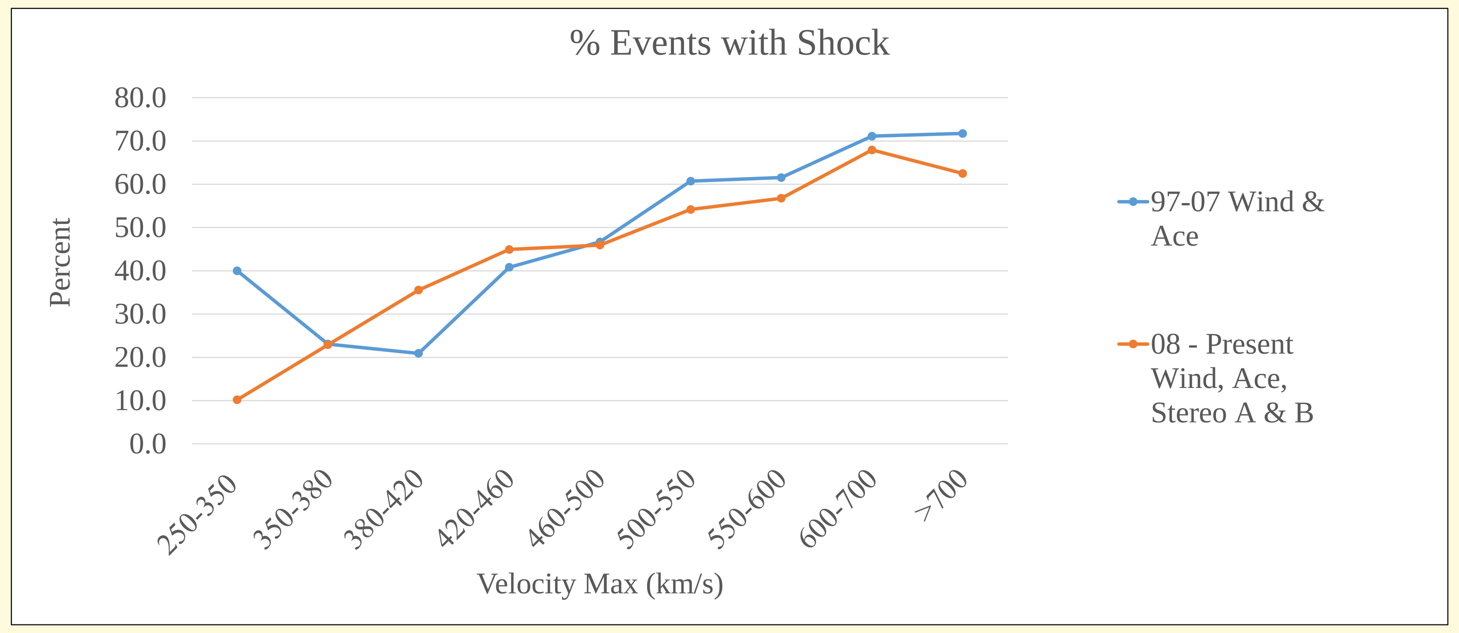
April 11-12, 2014 [2]

Data Analysis

96-07: Wind & ACE	
Events with Shock	163
Total CMEs	313
% Events with Shock	52.1
Velocity Max (km/s)	% Events w/ Shock
250-360	40.0
361-390	23.1
391-430	20.9
431-470	40.8
471-510	46.7
511-560	60.7
561-610	61.5
611-700	71.1
>700	71.7

08-Present: Wind, ACE, STEREO A & B	
Events with Shock	178
Total CMEs	322
% Events with Shock	55.3
Velocity Max (km/s)	% Events w/ Shock
250-360	10.2
361-390	22.9
391-430	35.6
431-470	44.9
471-510	45.9
511-560	54.2
561-610	56.8
611-700	67.9
>700	62.5

Results



Analysis shows more CMEs driving shocks in the low velocity regime during periods of **increased** solar wind speeds, contrary to the initial hypothesis. The rate of shocks increases with higher velocity CMEs, as expected.

Discussion

Initial assumptions supposed CMEs would drive shocks more frequently in low velocity regimes during periods of slow solar wind speeds. However, analysis reveals the opposite. **Equation 1** applied to data from solar cycle 23 (1996-07) requires the difference (V_{CME} - V_{UP}) be greater than 60 km/s. Current solar cycle 24 requires a difference greater than 40 km/s. Because the magnetosonic speed and the solar wind speed are lower in solar cycle 23 than in cycle 24, the difference given in **Equation 1** should be surpassed more frequently due to a lower threshold. Solar cycle 24 is, in general, less active than previous solar maximums, perhaps causing this discrepancy. Another possible source of discrepancy is CME expansion during different cycles. Particles in the front of the CME may have a greater tendency or ability to expand the CME at a rate which surpasses the threshold required to drive a shock.

Further Work

More study is needed to understand whether these findings are isolated to solar cycles 23 and 24, or a broader trend. A larger quantity of data, or perhaps re-assessing the data and imposing greater restrictions on shock qualifications, may yield more informative results.

Acknowledgements & References

- This project uses data from the Heliospheric Shock Database, generated and maintained at the University of Helsinki. (http://ipshocks.fi/database)
- This project uses data from the Richardson and Cane Database for Near-Earth Interplanetary Coronal Mass Ejections generated and maintained at the California Institute of Technology. (http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm)
- CC2CEPS Scholarship Funded by the NSF

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