Effect of interplanetary shock strengths and orientations on storm sudden commencement rise times

C. Wang, C. X. Li, Z. H. Huang, and J. D. Richardson

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[1] We make a statistical survey of interplanetary (IP) shocks and storm sudden commencements (SSCs) observed between 1995 and 2004. We find that 75% of SSCs are associated with shocks, consistent with previous work. We use this survey to investigate the effect of the interplanetary shock strength and orientation on the SSC rise time. We find that the higher the speed of an IP shock, the less time it takes to sweep by the magnetosphere, and thus the shorter the rise time of the corresponding SSC. The orientation of an IP shock also affects the SSC rise time. Generally speaking, a highly oblique shock causes asymmetric compression of the magnetosphere with respect to the noon-midnight meridian, takes more time to sweep by magnetosphere, and thus results in a longer rise time of the SSC. Citation: Wang, C., C. X. Li, Z. H. Huang, and J. D. Richardson (2006), Effect of interplanetary shock strengths and orientations on storm sudden commencement rise times, Geophys. Res. Lett., 33, L14104, doi:10.1029/2006GL025966.

1. Introduction

[2] A storm sudden commencement (SSC) is an increase in the low-latitude, ground-based magnetic field intensity which typically lasts for tens of minutes and then is followed by a magnetic storm or by an increase in geomagnetic activity lasting at least one hour. SSCs precedingGeomagnetic storms may be caused by the global compression of the magnetosphere as a result of interplanetary disturbances such as shocks and dynamic pressure pulses [Wilken et al., 1982; Tsurutani et al., 1995; Takeuchi et al., 2002a]. Chao and Lepping [1974] show that a majority of SSCs are caused by shock waves and only a small number are caused by tangential discontinuities. Smith et al. [1986] looked at approximately 50 shocks and SSCs observed between 1978 and 1980 and found that when an SSC was seen, a shock was associated with it with an 80–90% probability. More details about shocks and SSCs can be found in their paper.

[3] To interpret the SSC rise time, Takeuchi et al. [2002b] introduced the concept of a “geoeffective magnetopause” to replace the “magnetic cavity” of Nishida [1966] and conjectured that the geoeffective magnetopause would be confined within about ~30 R_E, since the effect of a compression of the distant tail magnetopause would not be detected on Earth’s surface. The time for an IP shock to sweep by the geoeffective magnetopause predominantly determines the SSC rise time. They attributed the extremely long, ~30 min, rise time of the SSC on December 15, 1995 to the high inclination of the causative interplanetary shock. They concluded that the orientation of an IP shock plays an important role in determining the SSC field observed on the ground, and that knowing the orientation is important for space weather prediction. Recently, Wang et al. [2005] conducted a global MHD simulation of the interaction between the magnetosphere and IP shocks with different orientations. The model results show that a highly oblique shock requires more time (in the order of minutes) to compress the forward part of the magnetosphere. Thus, the IP shock orientation plays an important role in determining the SSC rise time.

[4] In this paper, we examine the IP shocks and SSCs observed from 1995 to 2004 to investigate the effect of the interplanetary shock strength and orientation on the SSC rise time.

2. Data Sets

[5] The instruments onboard the WIND satellite provide solar wind data starting in 1994. However, WIND sometimes crosses the bow shock when it is near periapsis. To make sure we use only uncontaminated solar wind data for this study, we use data from times when the satellite is located more than 30 Re upstream of Earth. Since its launch in 1995, the ACE satellite has remained in orbit about the Earth-Sun L1 point and also provides upstream solar wind data. The solar wind SWE data from WIND with 90 second time-resolution were obtained from ftp://space.mit.edu/pub/plasma/wind and data from ACE with 64 s. time resolution was obtained from http://www.srl.caltech.edu. SSC events were obtained from the National Geophysical Data Center (NGDC) (ftp://ftp.ngdc.noaa.gov/STP/SOLAR/DATA). The SYM-H index [Iyemori, 1990] is essentially the same as the hourly Dst index [Sugiura, 1964] except that the SYM-H index provides 1-min time resolution. Accurate determination of SSC rise times requires higher time resolution than 1 min. However, it is impossible to have one instrument with higher time resolution to measure every SSC event at the same location. In order to allow comparison of as many SSC events as possible, as a tradeoff, we use the SYM-H index (http://swdcwww.kugi.kyoto-u.ac.jp) to determine the rise time and amplitude of SSCs.

3. Statistical Results

[6] We first used an auto-search computer program to find potential shock and shock-like solar wind structures in
the WIND and ACE data sets, and then visually inspected each event. We identified 299 fast forward IP shocks in the solar wind data between 1995.01 and 2004.12. For each shock case, Magnetic Coplanarity (MC), Velocity Coplanarity (VC), three Mixed methods (MX1, MX2, MX3) [Schwartz, 1998], and the Rankine-Hugoniot method were used to determine the shock normal, shock speed, and Mach number [Berdichevsky et al., 2000]. Since the SYM-H index is representative of the average SSC signature, we use it to determine the SSC rise time, which is calculated from the SSC onset time to the time of the largest amplitude. During this period, 278 SSCs were observed, of which 225 are associated with IP shocks, so the probability that a specific SSC is associated with a shock is 225/278 = 0.75, consistent with earlier work [e.g., Smith et al., 1986]. Figure 1 shows the distributions of the shock speeds and the shock orientations (the angle between the shock normal and the GSE X-axis which points toward the Sun). Most of the IP shocks have speeds in the range 350–650 km/s with the average speed near 500 km/s. Most of the shock orientations are the range 135–180°; an angle of 180° indicates the shock front is perpendicular to the solar wind flow and thus hits the magnetosphere head-on.

[8] As mentioned above, the SSC rise time is mainly determined by the time it takes for an IP shock to sweep by the geoeffective magnetopause, therefore the shock strength (represented by the shock speed in this study) and the shock direction are expected to have the most impact on the SSC rise time. To separate the effect of these two factors, we first examine the effect of the shock speed on the SSC rise time. We divide IP shocks into three categories according to their shock speeds: (1)350–450 km/s, (2)450–550 km/s, and (3)550–650 km/s. As before, we assume the IP shocks in each category have similar speeds. Figure 2 shows the relationship between the SSC rise time and the shock orientation for each of the three speed bins, respectively. The best linear fits to the observations are shown by the solid lines. The correlation coefficient (r) is also indicated in the figure. The data show that the bigger the angle between the IP shock normal and the Sun-Earth line, the shorter time the SSC rise time.

4. Discussion and Summary

[9] More than 30 years of study has shown that Storm Sudden Commencements (SSCs) are caused by the global

![Figure 1. Number of IP shocks observed during 1995.01–2004.12 as a function of (a) the shock speed and (b) the shock orientation, the angle between the shock normal and the GSE X-axis.](image1)

![Figure 2. The SSC rise time as a function of the shock speed for IP shocks having orientations of (a) 135–145°, (b) 150–165°, and (c) 165–180°.](image2)
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Acknowledgments.

We acknowledge the use of data from Wind, The SSC rise time as a function of shock orientation for IP shocks with similar orientations, when IP shock normal and the Sun-Earth line, the shorter the rise time.

References


