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# Relative geoeffectiveness of high-speed solar wind streams from different solar sources

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**Abstract**

We study relative geoeffectiveness of the high-speed streams (HSS) coming from different sources on the Sun, identified from 16 years (1996–2011) of continuous plasma and field data. These HSS could be associated to a single coronal hole, multiple coronal holes, single coronal mass ejection, multiple coronal mass ejections, or both the coronal holes and the coronal mass ejections. We analyze the solar wind plasma and field data during the passage of the HSS, and study the relative importance of different parameters in influencing the geomagnetic activity. We apply the method of superposed epoch analysis on the geomagnetic as well as solar plasma and field data. Based on our analysis, we found that the average (Dst)min is lowest ($\sim$20 nT) due to streams from single coronal hole and multiple coronal holes, and it is comparatively higher ($\sim$25 nT) due to compound streams. However, as compared to single coronal hole, the (Dst)min is nearly twice ($\sim$40 nT) and thrice ($\sim$65 nT) due to single coronal mass ejection and multiple coronal mass ejections, respectively. We found differences in not only the magnitudes but also the time profiles and recovery characteristics of geomagnetic disturbances due to the HSS from different solar sources. We performed correlation analysis between (Dst)min and the amplitudes of various plasma/field parameters, separately, due to the HSS associated with different solar sources. We found that, during the passage of all five group of streams, the (−Bz) and/or Ey is best correlated with the Dst amplitude. However, comparatively, the relationship between the amplitudes of (−Bz) and (−Dst) is weakest (cc = 0.71) during the passage of multiple coronal holes associated stream, and the relation is strongest (cc = 0.89) during the passage of single CMEs. As regards the relationship between (Ey) and (−Dst) amplitudes, it is weakest (cc = −0.71) during multiple coronal associated streams and strongest (cc = −0.91) during streams due to multiple coronal mass ejections.


*Keywords:* Solar wind; High speed stream; Coronal mass ejection; Coronal hole; Geomagnetic activity; Space weather

## 1. Introduction

Solar wind streams with speed >400 km/s are often observed not only in the near-Earth space, but also in the deep interplanetary space from space-based observations. These high speed streams (HSS) and their associated structures have been the subject of great interest as they, for example, influence the geomagnetic activity (e.g., Mavromichalaki et al., 1988; Tsurutani et al., 1990; Gosling et al., 1991; Turutani and Gonzalez, 1997; Sabbah, 2000; Kudela and Brenkus, 2004; Alves et al., 2011; Zhang et al., 2007; Badruddin and Singh, 2009; Gupta and Badruddin, 2009; Richardson and Cane, 2011; Mustajab and Badruddin, 2011, 2013; Yermolaev et al., 2012, 2014; Xystouris et al., 2014; Subramanian and Shanmugaraju, 2016; Badruddin and Falak, 2016; Kilpua et al., 2017 and references therein) and affect the space

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weather (e.g. see, Borovsky and Denton, 2006, Kudela et al., 2000; Badruddin, 2006; Kane, 2007; Bothmer and Zhukov, 2007; Badruddin and Kumar, 2015).

Most of these studies were concentrated on the effectiveness of HSS in influencing the geomagnetic activity, with limited attention on their solar sources. However, as observed in the near–Earth space, these HSS may arise as a result of streams from a single coronal hole, multiple coronal holes, single coronal mass ejection (CME), multiple CMEs or streams both due to coronal holes and CMEs (e.g. see, Gupta and Badruddin, 2010; Kumar and Badruddin, 2014). In addition to differences in their speed, their magnetic properties (field strength, topology, etc.) may not be same in the HSS associated with different solar sources.

In this work, we study how and to what extent, the HSS from different sources influence the geomagnetic activity and hence affect the intensity of the resulting geomagnetic storms. We also search for the solar wind parameters that play important role in influencing the amplitude, duration and the time profile of geomagnetic disturbances during their passage. For a historical perspective of geomagnetic storms, see Lakhina and Tsurutani (2016) and references therein.

## 2. Data analysis

We have utilized data for the HSS detected during 1996 – 2011 (see, Gupta and Badruddin, 2010; Kumar and Badruddin, 2014). During this period, observations of solar wind plasma and field parameters are near complete and there are little data gaps, if any, in the data series. This whole period of study covers one complete solar cycle (23) and initial phase of current solar cycle 24.

For the data analysis, we have applied statistical procedures, including the superposed epoch analysis and the correlation analysis. Using these methods, we have analyzed the geomagnetic data, together with simultaneous solar wind plasma and field data during the passage of the HSS from different sources.

As a geomagnetic parameter, we have utilized the Dst index. Out of the available solar wind plasma/field parameters, we considered the solar wind velocity (V), the interplanetary magnetic field (B), sigma in interplanetary magnetic field ($\sigma$B), its north-south component (Bz), plasma temperature (T), proton density (N), dawn-dusk electric field (Ey), plasma beta (plasma $\beta$), interplanetary electric field (BV) and two more derivatives ($BV^2$ and $BzV^2$). Last two derivatives have the dimension of time variation of electric potential.

## 3. Results and discussion

### *3.1. High speed streams from different solar sources: Identification of the sources*

Coronal mass ejections (CMEs) associated with solar flares or with solar prominence eruptions are the predominant source of high-speed streams (HSS) during solar maximum. However, during solar minimum, main source of HSS is coronal holes. When these coronal hole-associated streams are long lasting, they lead to formation of corotating interaction regions (CIRs) in interplanetary space (Smith and Wolfe, 1976; Tsurutani et al., 1990).

Fast CMEs coming from the Sun into the interplanetary space contain high magnetic fields. A forward shock forms if the speed difference between the solar ejecta and the ambient upstream solar wind is greater than the magnetosonic speed. There is a sheath region just behind the forward shock followed by CME ejecta material (driver gas) itself. In the interplanetary space, the driver gas might be a so-called magnetic cloud (e.g. Burlaga et al., 1981). The magnetic cloud is a region of strong and slowly varying field, often has north-to-south (or vice versa) rotation in it. The plasma beta is exceptionally low in these structures. The sheath region, just behind the forward shock and ahead of magnetic cloud, is a compressed region of ambient plasma and field. This region is magnetically turbulent as against the magnetically ‘quiet’ field in the magnetic cloud. Moreover, in contrast to magnetic clouds, plasma beta is higher in the sheath region.

Coronal holes are low temperature regions above the Sun. Such regions are most prominent in polar regions during low solar activity. As regards the magnetic field, they are areas of open field lines. The Alfvén waves are continuously present in the high-speed streams. These high-speed streams emanating from coronal holes can create intense magnetic fields if the streams interact with streams of lower speed (Belcher and Davis, 1971; Turutani and Gonzalez, 1997). The fields of higher speed stream are radial because of higher speeds, while the magnetic fields of slower speed stream are more curved due to lower speeds. The stream-stream interface is the boundary between the slow stream and fast stream plasma and fields in CIRs.

Ahead of stream interface are compressed and accelerated slower speed plasma and fields. However, behind the stream interface are the compressed and decelerated high speed stream plasma and fields. When well developed, the CIRs are bound by fast forward and fast reverse shocks. The CIRs are characterized by intense magnetic fields (e.g. see, Turutani and Gonzalez, 1997 and references therein).

High-speed streams considered for this study were identified from the velocity-time profile of the solar wind velocity using OMNIWeb database. A solar wind stream was considered as a high speed stream (HSS) when the maximum velocity was more than 400 km/s (Vmax > 400 km/s) and there was considerable enhancement (dV > 100 km/s) in plasma speed from the pre-increase level, which persists for at least two days after the onset. The start time of a stream is taken as the time (hour) when solar wind plasma starts increasing towards maximum (Vmax) and the end time is taken as the time when the speed decreases to almost pre-enhancement level (Gupa and Badruddin, 2010; Kumar and Badruddin, 2014). After

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