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Coronal Hole-Active Region-Current Sheet (CHARCS) association with intense interplanetary and geomagnetic activity

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Abstract. Intense geomagnetic storms ($Dst \leq -100$ nT) have been associated with interplanetary structures involving large-intensity ($B_s \geq 10$ nT) and long-duration ($T \geq 3$ hours) values of the southward component of the IMF. We show that near solar maximum, the solar origin of such structures seems to be associated with active regions* (involving flares and/ or filament eruptions) occurring close to the streamer belt and to growing low-latitude coronal holes. It is also shown that low-latitude coronal holes had a dual-peak solar cycle distribution during solar cycle 21, similar to that previously reported for the above mentioned interplanetary and geomagnetic phenomena.

Introduction

Although there has been considerable amount of work published about the general role of solar coronal mass ejections (CME) in the development of interplanetary and geomagnetic activity [e.g. *Burlaga et al.*, 1987; *Gosling et al.*, 1991], very little information exists about the specific nature of the CMEs involved in such a solar-interplanetary-geomagnetic coupling.

It is the purpose of this letter to examine some new solar aspects of this coupling for the 10 intense geomagnetic storm events that occurred in the interval of August 1978–December 1979, as studied initially by *Gonzalez and Tsurutani* [1987].

Solar features of the 1978–1979 events

During the interval of August 16, 1978, and December 28, 1979, ten intense magnetic storms ($Dst \leq -100$ nT) were associated by *Gonzalez and Tsurutani* [1987] and *Tsurutani et al.*, [1988] with interplanetary structures having southward magnetic fields of large amplitude ($B_s \geq 10$ nT) and long duration ($T \geq 3$ hours). Subsequently, with the interest of learning where at the sun and to what type of solar phenomena these interplanetary structures could be associated with, *Tang et al.* [1989] reported a list of possible *solar sources* involving flare or prominence eruption candidates, which could have occurred within about 2 to 4 days prior to the geomagnetic storm onset. Seven out of the ten events were associated with flares and three with filament eruptions.

Clearly we realize that the flares and/or prominence eruptions are not causing CMEs, but that some phenomena at the sun are causing both and we can use the solar events as a marker for when and roughly where the CME was released.

In addition to the information provided by *Tang et al.* [1989] we have studied the location and dynamics of low-latitude coronal holes and of the heliospheric current sheet at its solar base. The location of coronal holes were studied following the works by *Hewish and Bravo* [1986] and by *Gonzalez and Tsurutani* [1994], updated with revised data published by the NOAA-Boulder Solar Geophysical center using H_α synoptic charts as well as *HeI* observations. The location of the neutral lines/current sheet was obtained from H_α synoptic charts, supplemented by the Stanford photospheric and source-surface magnetic maps [*Hoeksema and Scherrer*, 1986].

Figure 1 shows, in Carrington rotation plots, the relationship between coronal holes, active regions* (including flares and/or prominence eruptions) and the current sheet (CHARCS for short) for the ten events during the 1978–1979 interval of study. The active region* is marked by an X if it involves a flare or by a dotted line if it has a prominence eruption associated with it. Among the low-latitude coronal holes present in each rotation those nearby the active regions* are indicated by hatching, the current sheet section nearby them is indicated by a dashed curve. In each Carrington rotation the small vertical arrow at the top indicates Central Meridian at the time of the flare or filament eruption onset.

Due to a lack of a better (and short) name we use the generic name *active regions** to represent the regions involving the flares and filament eruptions found in this study, although two of the prominence eruptions (events 1 and 8 in Figure 1) probably were of the quiescent type.

The dashed curves in Figure 1 representing the current sheet were identified as follows. By using H_α synoptic charts and the Standford photospheric mag-

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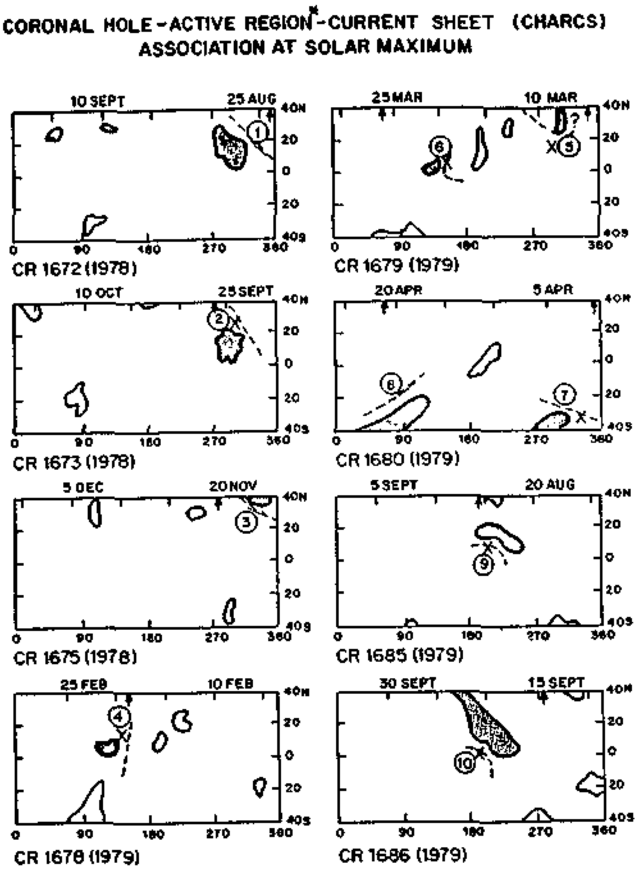


Figure 1. Carrington rotation maps of CHARCS for the ten events of the 1978–1979 interval. See the text for details.

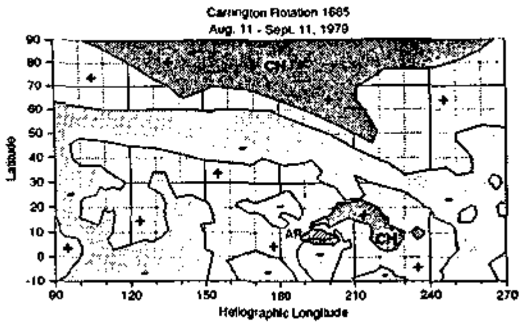
netic field observations we selected the closest neutral lines near the active region* and the coronal hole for each of the ten events. Then we found that the source-surface current sheet demarcation of the Stanford maps overlapped very closely to one of the selected neutral lines, at least in their average longitude and latitude positions, even though their relative orientations were different in several of the events (not important though for the purpose of this work). This neutral line/current sheet correspondence held for practically all events (with exception of events 8 and 9 for which such a correspondence was not evident). However, in Figure 1 what is plotted as dashed curves are the photospheric neutral lines. Note that during this (maximum) phase of the solar cycle the current sheet is highly inclined at low latitudes, as one can see in the sections plotted for these events.

The most important aspect of Figure 1 is the coexistence of three closely spaced phenomena: low latitude coronal holes, active regions* and the current sheet, as a combined *solar source* for the ensuing solar, interplanetary and geomagnetic active events. We have not examined this relationship for other time intervals yet. However, the fact that this CHARCS association exists for practically each of the ten events of the 1978–1979 interval is, in our opinion, quite interesting and may lead to greater understanding of the release mechanism(s). Among the CHARCS candidates only the one for event 5 is in question due to the poor coronal hole information existent in this case.

It is important to note in Figure 1 that the CHARCS events occurred mostly at low latitudes and near central meridian. We leave for the discussion section the possible geo-effective importance of these characteristics of the CHARCS.

About the temporal evolution of the coronal holes we have noted that this type of coronal holes seem to change their area very fast prior to and in association with the flare or filament eruption event. Within the *HeI* daily data, scarcely available for the interval of our study, we have noted that the area of the hole tends to grow towards the active region*/current sheet from where the CME probably originated. For instance, Figure 2 shows the evolution of the coronal hole for event 9 of Figure 1, namely prior to the flare event manifestation of August 26, 1979. On Figure 2a we show

(a)



(b)

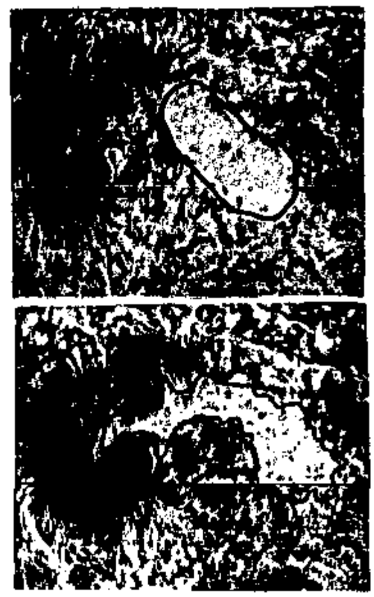


Figure 2a. Magnetic polarity chart for Carrington rotation 1685, involving event number 9. The white (gray) areas have positive (negative) magnetic polarities and the darker regions show coronal holes (from *He I* observations).

Figure 2b. *HeI* pictures of the evolving coronal hole for event number 9. See the text for details.

for Carrington rotation 1685 the positive and negative photospheric magnetic field polarities together with the active region* (AR) and the coronal holes (CH). On Figure 2b, we show the evolution of the (low latitude) coronal hole for about 3 to 2 days (bottom) and 1 day (below) before the flare event. On Figure 2b, the coronal hole is identified as a white area surrounded by a black curve whereas the active region* at the left of the coronal hole can be seen as a dark region, becoming more intense and closer to the growing coronal hole about a day before the flare event. It is interesting to see the large change (growth) of the coronal hole prior to the date of the flare event. Unfortunately there was no coronal hole data for the same day of the event. Previous studies about the growth of coronal holes near active regions [e.g *Harvey and Sheeley*, 1979; and most recently, *Watanabe et al.*, 1992, using Yohkoh SXT images] are in accord with our results, at least for some events probably of the CHARCS type.

Solar cycle variability of low-latitude coronal holes

Gonzalez et al. [1990] have studied the solar-cycle variability of intense geomagnetic storms ($Dst \leq -100$ nT) as well as of interplanetary B_z events of large intensity (≥ 10 nT) and long duration (≥ 3 hours), both for solar cycle 21. They showed that both distributions have a dual-peak, the less intense one occurring about a year before solar maximum (sunspot number), and the more pronounced one occurring 2 to 3 years after maximum.

Figure 3 shows the solar cycle distribution, for the same cycle 21, of the number of low latitude coronal holes (within ±30° of the equator and with a central meridian passage) according to *HeI* observations. It is interesting to note that this distribution is also of a dual peak type, with the peaks corresponding to those of the geomagnetic storms distribution, as reported by *Gonzalez et al.* [1990].

Discussion

As presented in Section 2, a clear CHARCS association exists for 9 of the 10 intense storms of the 1978–1979 interval. If we assume that this association is not coincidental we need to look into its possible physical meaning and implications. However we want to caution the readers about the labelings and characterizations related to CHARCS, as presented in this letter, that they should be regarded only as preliminary.

The association of the type of active regions* involved in CHARCS (with related flaring or prominence eruptions) with the current sheet has been widely discussed as being typical for the CME phenomena [e.g. *Hundhaussen*, 1993; *Low*, 1993]. Therefore, it is natural to expect, as seen in Figure 1, that the observed manifestation of the active regions* are practically lying on the neutral line/current sheet demarcation (dashed line).

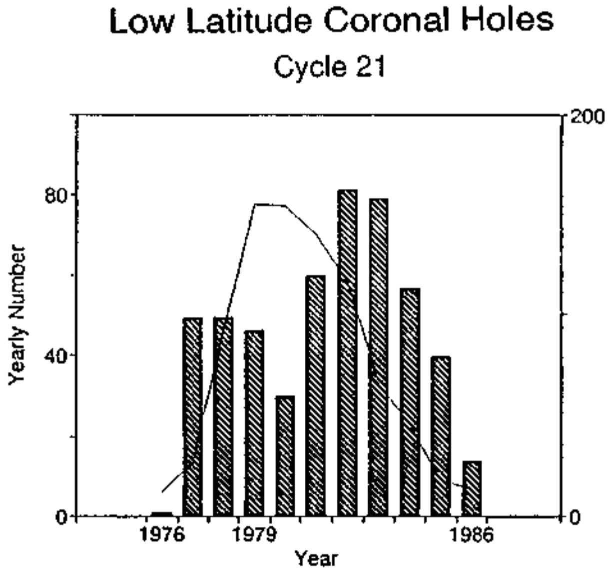


Figure 3. Yearly number of low latitude (within ±30°) coronal holes for solar cycle 21 together with the smoothed sunspot number curve.

Since it is known that CMEs are associated with enhanced intervals of interplanetary and geomagnetic activity [e.g. *Gosling*, 1991], what the information presented in Figure 1 could be showing us is that CMEs need to occur close to low-latitude coronal holes in order to lead, as a combined solar source (CHARCS), to more intense interplanetary and geomagnetic activity. In other words, CHARCS could be regarded as a highly geo-effective class of CMEs.

If this hypothesis becomes substantiated by a larger data base study, the CHARCS association can become an important observational tool to help us predict the occurrence of intense geomagnetic activity. At the moment there are some preliminary ideas about the possible role of coronal holes in the geo-effective character of the CHARCS association:

1. Since the coronal holes involved in the ten storm events of the 1978–1979 interval occurred mostly near central meridian and at fairly low-latitudes, the interplanetary open magnetic field lines rooted in such coronal holes can have an effective connection with the earth for the propagation of the ejected material.

2. The different open magnetic topology of coronal holes nearby that of a *closed* helmet streamer base could help to destabilize the current sheet and the nearby potential active regions* [*Low, private communication*, 1993; and *Low*, 1993].

3. *Gonzalez et al.* [1995] have discussed the geo-effective importance of large amplitude, interplanetary Alfvén waves in leading to enhanced geomagnetic activity and in some cases to intense geomagnetic storms, as the ones involved in the 1978–1979 interval of our present discussion. Since these Alfvenic fluctuations are known to be originated mainly at coronal holes [e.g. *Tsurutani et al.*, 1994], the Alfvenic solar wind rooted at the CHARCS coronal holes can in several instances

serve as a seed for the formation of intense southward fields [*Gonzalez et al.*, 1995].

However from the overall behavior of the CHARCS, as learned from Figures 1 and 2, one could also suggest that this type of low-latitude holes could have initially originated from a CME release (opening of closed field lines at a helmet streamer) and evolved through further CME releases, not necessarily being all geo-effective due to several possible limitations, such as low speeds and large distances from central meridian.

One can speculate that the opening of helmet-streamer closed field lines by a CME, enlarging the area of the nearby hole in a CHARCS configuration, could involve a large velocity jump from typical low helmet streamer speeds (around 350 Km/s or so) to much higher coronal hole speeds (around or larger than 700 Km/s), which could lead to a formation of a fast forward shock leading the ejected plasma. This appears to be in accord, at least partially, with the claiming by *Hewish and Bravo* [1986] and *Bravo* [1995] that coronal holes are the sources of interplanetary shocks during transient solar phenomena, such as those studied in this article.

Since the CHARCS relationship study of Section 2 involves only the interval of 1978–1979, the information given in Figure 3 can be regarded as a possible confirmation during a longer time interval about the importance of the role of low latitude coronal holes in the solar origin of transient interplanetary and geomagnetic enhanced activity.

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