On the solar disk sources of very intense geomagnetic storms

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Abstract

In this work we present solar events responsible for producing very intense geomagnetic storms (Dst < -200 nT) occurring during both the ascending phase and maximum of solar cycle 23. Attempts are made to study the possible association between active regions and coronal holes observed on the solar disk and interplanetary geoeffective features, in particular coronal mass ejections (CMEs). We discuss the characteristic features of the coronal holes and flares or filament eruption as observed by SXT telescope on board Yohkoh and other ground-based observatories. The study of this association is important since it has geoeffective consequences and thus it could serve as a tool to predict geomagnetic activity.

Introduction

Coronal mass ejections (CMEs) from the Sun drive solar wind disturbances in terms of magnetic field, speed, and density, which in turn cause magnetic disturbances at the Earth. Geomagnetic storms have been found to be particularly sensitive to the presence of an intense southward interplanetary magnetic field that allows efficient energy transfer from the solar wind into the Earth's magnetosphere through magnetic reconnection (Dungey 1961; Fairfield & Cahill 1966; Gonzalez & Tsurutani 1987). Although this general idea of the solar cause of geomagnetic storms has been established for decades, the exact solar sources and their characteristics have not been well identified and studied until the advent of Solar and Heliospheric Observatory (SOHO) spacecraft observations in 1996. A number of studies related to eruptive phenomena such as filament eruptions and flares have been made during several years in order to understand the solar terrestrial relationship that led to intense geomagnetic activity (Joselyn and McIntosh, 1981; Watanabe and Schwenn, 1989). Low latitude coronal holes (CH) boundaries have been also suggested as important factors in coronal eruptive events. Webb et al. (1978) found that large scale Skylab X-ray transients preferentially occurred near CH boundaries, in general, and growing low latitude CH in particular. Gonzalez et al. (1996) also found that the inferred source of CMEs giving rise to intense geomagnetic storms were regions of adjacent growing low latitude CHs, active regions (ARs) and source surface current sheets (CS), denoted with the acronym CHARCS. Similarly, Bravo et al. (1998) argued that CMEs were most geoeffective when they were associated with flaring AR near low latitude CHs. In a separate study of interplanetary magnetic clouds, Bravo et al. (1999) found that the solar source of regions of clouds nearly always lay close to low latitude CHs. Bhatnagar (1996) found that X-ray blowouts always erupted from or near the boundaries of CHs. With white light data at the solar minimum, Lewis and Simmet (2000) found the most active CME region to lie close to the equatorial extension of the northern polar CH. All these authors have suggested that the magnetic reconnection between the open fields of the CHs and the adjacent closed fields along the CH boundaries can cause or facilitate some CMEs.

In this work, using Yohkoh and ground-based observations we intend to look into this issue by investigating detailed temporal relationship between CMEs, flares or filament and coronal holes.

Observations and discussion

In this work we investigate the solar sources of six very intense geomagnetic storms characterized by a value of Dst index <-200 nT listed in Table 1. These storms occurred during the ascending phase and maximum of solar cycle number 23, since May, 1998 until April, 2001. The solar origins of these events were identified from National Oceanic and Atmospheric Administration (NOAA) solar activity reports and by analyzing daily Extreme Ultraviolet Imaging Telescope (EIT) images of solar disk. The dates on which this solar activity related to the geomagnetic storm was observed as well as the heliographic coordinates of these events are also listed on Table 1.

Table 1: Characteristics of solar sources associated with intense geomagnetic storms.

Nr.	Storm Date	Dst	Source Date	Source Type *	Source Location
1	May 4, 1998	-216	May 2, 1998	FLA	S15 W15
2	October 22,1999	-237	October 18, 1999	FLA	S20 E10
3	April 7, 2000	-321	April 4, 2000	FLA / DSF	N16 W66
4	July 15, 2000	-300	July 14, 2000	FLA	N17 E01
5	August 12, 2000	-237	August 9, 2000	FLA	N22 E12
6	March 31, 2001	-377	March 29, 2001	FLA	N13 W06

* DSF = disappearing filament, FLA = flare

The evolution of coronal holes was studied by analyzing solar images from Solar X-ray Telescope (SXT) on board Yohkoh and daily coronal hole maps provided by Kitt Peak National Observatory. Coronal hole boundary estimates are obtained from National Solar Observatory / Kitt Peak Vacuum Telescope (NSO / KPVT) 1083 nm (He I line) and magnetic field data. They also provide information about position and area of coronal holes for different Carrington rotations. In what follows, we present a brief summary of the solar activity for each event.

Event 1: May 2nd, 1998

GOES satellite registered an increase in X-ray flux between 13:31 and 13:51 UT, resulting in an intense class X1.1 flare. This flare occurred on active region NOAA AR8210, where another flare, observed in optical wavelength of importance 3B was observed at heliographic coordinates S15 and W15. A CME was detected by LASCO C2 at 14:06 UT. The daily maps in He I and SXT images reveal a coronal hole appearing this day. The geomagnetic storm was on May 4th, 1998 and the peak on Dst index was of –216 nT.

Event 2: October 18th, 1999

A C1.0 flare was reported to occur between 00:01 and 00:07 UT approximately at S20 E10. A likely associated CME was observed by LASCO C2 for the first time at 00:06 UT. By analyzing corresponding coronal holes maps and SXT images was possible to detect one located near this active region. Changes neither in morphology nor in original localization were observed. In Figure 1 it is shown the coronal hole and the active region position for this event. Four days later, on October 22th, 1999 a geomagnetic storm arrived to Earth producing a Dst peak of –237 nT.

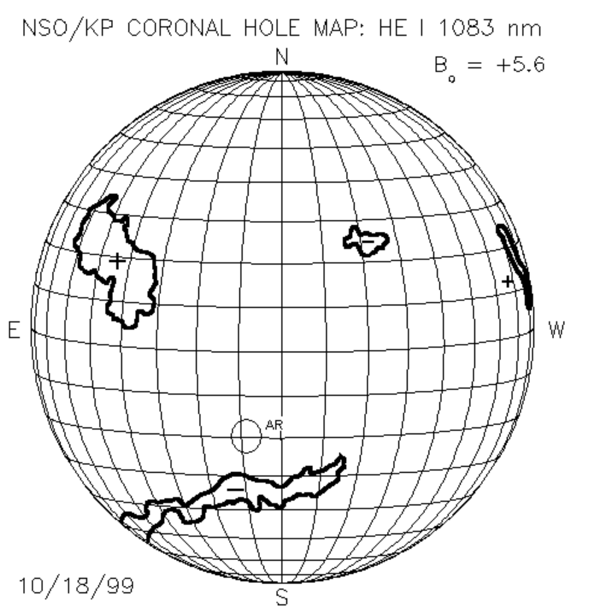

Figure 1: Coronal hole boundaries for October 18th, 1999 event. The active region near the coronal hole is indicated with a circle.

Event 3: April 4th, 2000

On this day, three events developed probably related to active region NOAA AR8933. They could be the solar source of the CME observed for the first time at 16:32 UT with the LASCO C2 coronagraphs onboard SOHO. The first one is a filament disappearing at heliographic coordinates N25 W55 between 14:41 and 15:35 UT. Later, it was reported an optical flare of importance 2F at N16 W66 between 15:11 and 17:24 UT, and a C9.7 flare starting almost simultaneously. Coronal holes are observed in Yohkoh images as well as in He I line images, near this active region as can be seen in Figure 2. A very intense geomagnetic storm occurred on April 7th, 2000 characterized by a Dst minimum value of –321 nT.

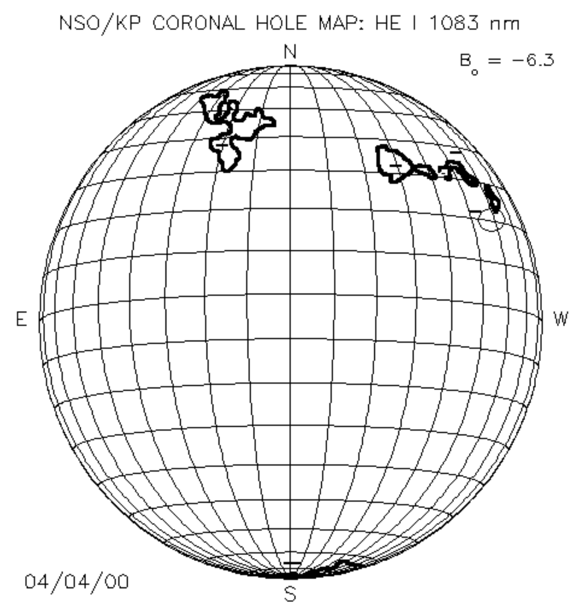

Figure 2: Coronal hole and active region (circle) positions on the solar disk for April 4th, 2000 event.

Event 4 : July 14th, 2000

During this day it was recorded a very intense flare occurring in active region NOAA AR9077 near central meridian starting at 10:03 and 10:43 UT and corresponding to a X5.7 X-ray event. Between 10:12 and 11:46 UT, an optical flare was observed at N22 W07 in the same region. The CME probably associated to this event was first detected by LASCO C2 at 10:54 UT. To study the evolution of coronal holes for this event, SXT images were analyzed. In the day before the event, a coronal hole extended as a coronal channel from the eastern limb and towards the active region where the flare occurred. In the following day it is possible to observe an area increase of this channel. Figure 3 shows a solar image from SXT taken before the flare event. The coronal hole boundary is drawn in white. On July 15th, 2000 a geomagnetic storm was registered with a Dst peak of –300 nT.

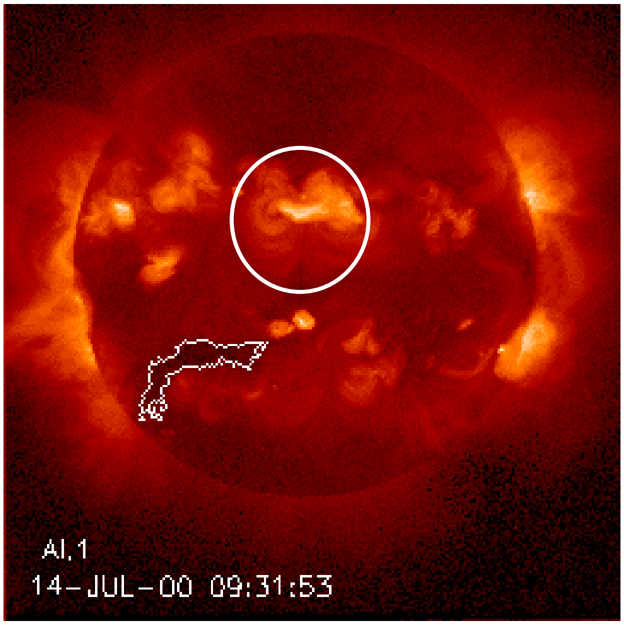

Figure 3: Solar image obtained with SXT instrument onboard Yohkoh satellite on July 14th, 2000. The coronal hole boundary is shown in white color and the active region is indicated with a circle.

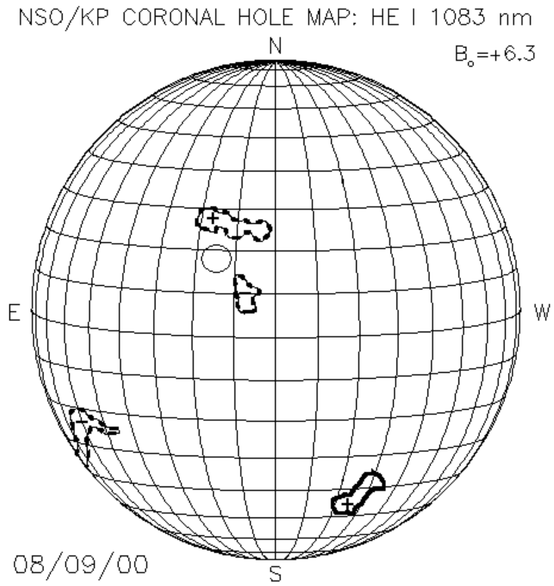

Figure 4: Coronal holes and active region (circle) associated to the geomagnetic storm registered on August 12th, 2000.

Event 5: August 9th, 2000

From He I solar observations it is possible to distinguish the presence of two small coronal holes localized near active region NOAA AR9114, which shows flaring activity. Between 15:19 and 17:00 UT, a C2.3 flare was detected and later an optical flare occurred between 15:33 and 17:10 UT in the same region at N11 W11. At 16:30 UT a CME was observed by LASCO C2. Observing the daily coronal hole maps it was possible to identify two coronal holes that are not present the day before the event. They appear to evolve forming two separate new holes as can be seen in Figure 4. Unfortunately, it is not possible to follow the evolution of the coronal holes in SXT images, due to the high intensity of the active region in the neighboring. The consequent geomagnetic storm was registered on August 12th, 2000 with a minimum Dst value of –237 nT.

Event 6: March 29th, 2001

An intense X1.7 flare was observed in active region NOAA AR9393 (N13 W06) starting at 09:57 UT and finishing at 10:32 UT. This activity is suggested as the possible cause that gave rise to the CME that was detected by LASCO C2 at 10:26 TU. As can be seen in Figure 5, these phenomena occurred in the neighboring of coronal holes as they are observed in He I line. The daily maps provided by Kitt Peak Observatory showed an evolution in coronal hole configuration, probably associated to this event occurring on solar disk. In Yohkoh images, it was possible to detect a coronal hole area growth in the day after the event. The corresponding geomagnetic storm was the most intense observed during the selected period of time and recorded a Dst peak of –377 nT.

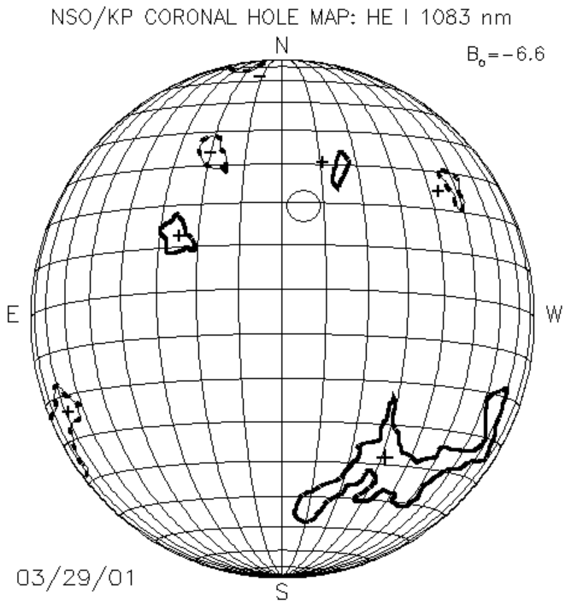

Figure 5: Solar disk map showing coronal hole boundaries and active region position (circle) for March 29th, 2001 event.

Conclusions

In this section we summarize the results described above:
1. 5 of 6 events are associated with flaring activity observed in H-alpha and all the events present activity in X-ray. Only one filament disappearing filament was reported as solar source of geomagnetic storms. This result is different from similar studies made by Srivastava et al. (1997), Webb (1992) in which geoeffective events are more likely associated to filament eruptions than solar flares.

2. In all the events described here it was possible to find a coronal hole near the active region, mainly lying near central meridian and low latitudes. According to Srivastava et al. (1997), this scenario is suggestive of providing an effective connection with the Earth for the propagation of the ejected material of the CME through the interplanetary magnetic field lines.

3. In a few observed cases a transient change in the coronal hole geometry has been observed after the CME. In particular, it was possible to observed a coronal hole growth occurring after the solar flare for three events: July 14th, 2000; August 9th, 2000 and March 29th, 2001. This behavior was also observed by Gonzalez et al. (1996) while Watanabe et al. (1992) reported a coronal hole growth after filament eruptions.

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