Highlights on Spanish Astrophysics IX, Proceedings of the XII Scientific Meeting of the Spanish Astronomical Society held on July 18 – 22, 2016, in Bilbao, Spain. S. Arribas, A. Alonso-Herrero, F. Figueras, C. Hernández-Monteagudo, A. Sánchez-Lavega, S. Pérez-Hoyos (eds.)

The stealth geomagnetic storm on 2015 January 7: forecasting, solar sources and interplanetary medium interactions

Consuelo Cid[1], Judith Palacios[1], Elena Saiz[1], and Antonio Guerrero[1]

[1] Departamento de Física y Matemáticas. Universidad de Alcalá

Abstract

On 2015 January 7 a moderate geomagnetic storm occurred, according to the Dst index. Analyzing data recorded at L1 point, a magnetic cloud appears clearly as the trigger of the storm, but the associated CME was missed by most space weather agencies worldwide. Even more, the intensity of the storm was clearly modified due to the erosion of the magnetic cloud because of its interaction with a fast stream from a coronal hole.

1 Introduction

Coronal mass ejections (CMEs) are eruptions of plasma from the solar atmosphere into the interplanetary space. When the ejection observed by the coronagraph reaches a spacecraft with in-situ instrumentation, located at the interplanetary space, the transient is labeled as interplanetary CME (ICME). Several signatures have been considered to identify the ICME passage [9]. Among them, there are three features that, if are satisfied simultaneously, an ICME is passing the spacecraft can be univocally identified: low proton temperature, high magnetic field strength and smooth rotation of interplanetary magnetic field (IMF) vector over a large angle on a trajectory. In that case the ICME is labelled as magnetic cloud [2].

CMEs are commonly associated with the most hazardous space weather effects. The reason for this association is that ICMEs are the interplanetary structures with larger southern IMF and speed. The combination of these two parameters favours the reconnection between solar wind and terrestrial magnetosphere and therefore, the injection of energy to the terrestrial environment [3], [8]. But most CMEs do not reach the terrestrial environment. Consequently, the first task in the forecasting process is to estimate whether the CME would reach the Earth.

CMEs that are Earth-directed are expected to show up as partial or full halo around the occulter of the coronagraph as they propagate away from the Sun. For this reason, halo

CMEs always draw attention of space weather forecasters, who start to analyze the whole Sun-to-Earth scenario as soon as one CME of this kind is detected. Unfortunately, nowadays worldwide space weather agencies rely on automatic analyses of coronagraph images which usually miss faint ejections especially when they are non-halo type. Nevertheless, a faint or narrow CME may result in a geomagnetic storm. This is the case of the CME on 2015 January 3, which would have passed unperceived if a magnetic cloud would have not passed the L1 point some days later.

2 Storm forecasting and solar sources

On 2015 January 7, the interplanetary magnetic field (IMF) at L1 point was enhanced, above 20 nT, because of the arrival of a magnetic cloud which triggered a geomagnetic storm (Fig. 1). On January 8 at 0030 UT, the NOAA Space Weather Prediction Center delivered a document entitled 'Forecast Discussion'. Some text on that document is the following:

'Solar wind parameters, measured at the ACE spacecraft, began the period consistent with coronal hole high speed stream (CH HSS) influence. Wind speeds averaged near 450 km/s. B_t averaged near 8 nT, until around 07/0530 UTC, when an unanticipated disturbance passed ACE and Earth. B_t impulsively increased to 14 nT at transient passage, eventually reaching a peak of 23 nT. B_z was primarily positive prior to the event, then decreased to as much as -21 nT and remained steadily negative until about 07/1200 UTC. B_z was positive for the majority of the rest of the period. After further analysis, it is unclear if this activity is related to the 03 Jan CME or a possible Co-rotating Interaction Region (CIR) ahead of the anticipated positive polarity CH HSS. There was no immediate reflection in solar wind speed, density or temperature which would typically suggest a CME. Phi angle was in a predominately negative (towards) sector until the time of the disturbance, when a rotation to a positive (away) orientation was observed. Solar wind speeds slowly began to increase from 410 km/s to near 510 km/s beginning around 07/1400 UTC, in conjunction with a slow rise in temperature. Further analysis will be completed in an attempt to determine the source of this activity as data comes in.'

The CME on 2015 January 3 was not the most eye-catching solar activity in that period. Figure 2 shows the solar disk as observed by AIA/SDO in 193 Å on January 5. A huge coronal hole appears at Southern pole, explaining the solar source of the high speed stream observed by ACE. Another extended coronal hole appears at low latitude in the Northern hemisphere. Flaring activity was medium, with an M1.3 flare from AR12253, at S07W17 that day. On January 5, the Spanish Space Weather Service (http://www.senmes.es) warned about a halo CME, not related to the M1.3 flare. The daily report on that date, which relies on image observation by experienced researchers, anticipated the possibility of arrival of this CME to the Earth:

'At least a full halo CME appears clearly in LASCO. However, its velocity onto the plane of the sky is very low (SeNMEs estimates less than 300 km s^{-1}). As a result, although it might be travelling following the Sun-to-Earth direction, relevant disturbances in the terrestrial environment are not expected.'

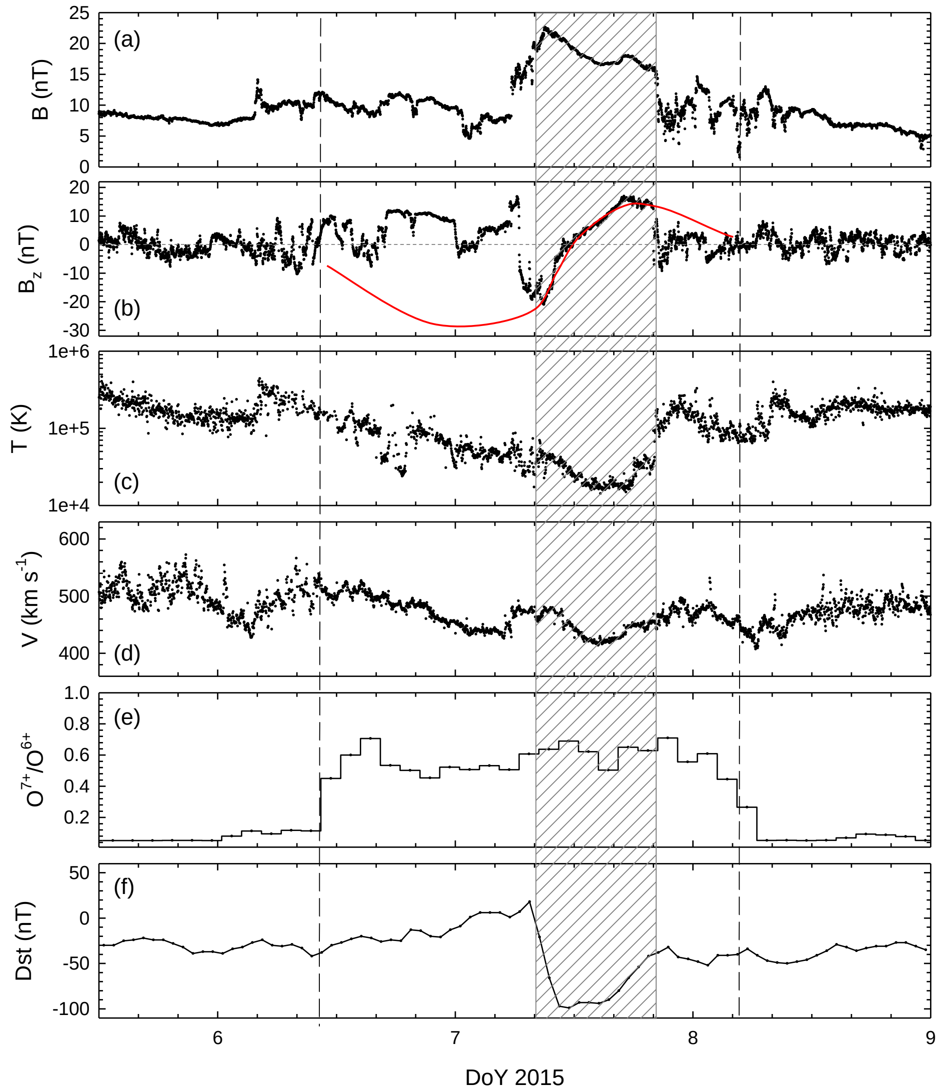

Figure 1: Solar wind parameters and geomagnetic activity during the interval 2015 January 5.5-9. From top to bottom: (a) the interplanetary magnetic field strength and (b) the GSM z-component of the IMF from Wind/MFI; (c) the proton temperature and (d) the solar wind speed from Wind/SWE; (e) the O^{7+}/O^{6+} ratio at a 2-hour cadence from ACE/SWICS, and (f) the Dst geomagnetic index. Dashed area corresponds to the magnetic cloud interval. Vertical dashed lines indicate the boundaries of the ICME material considering compositional anomalies.

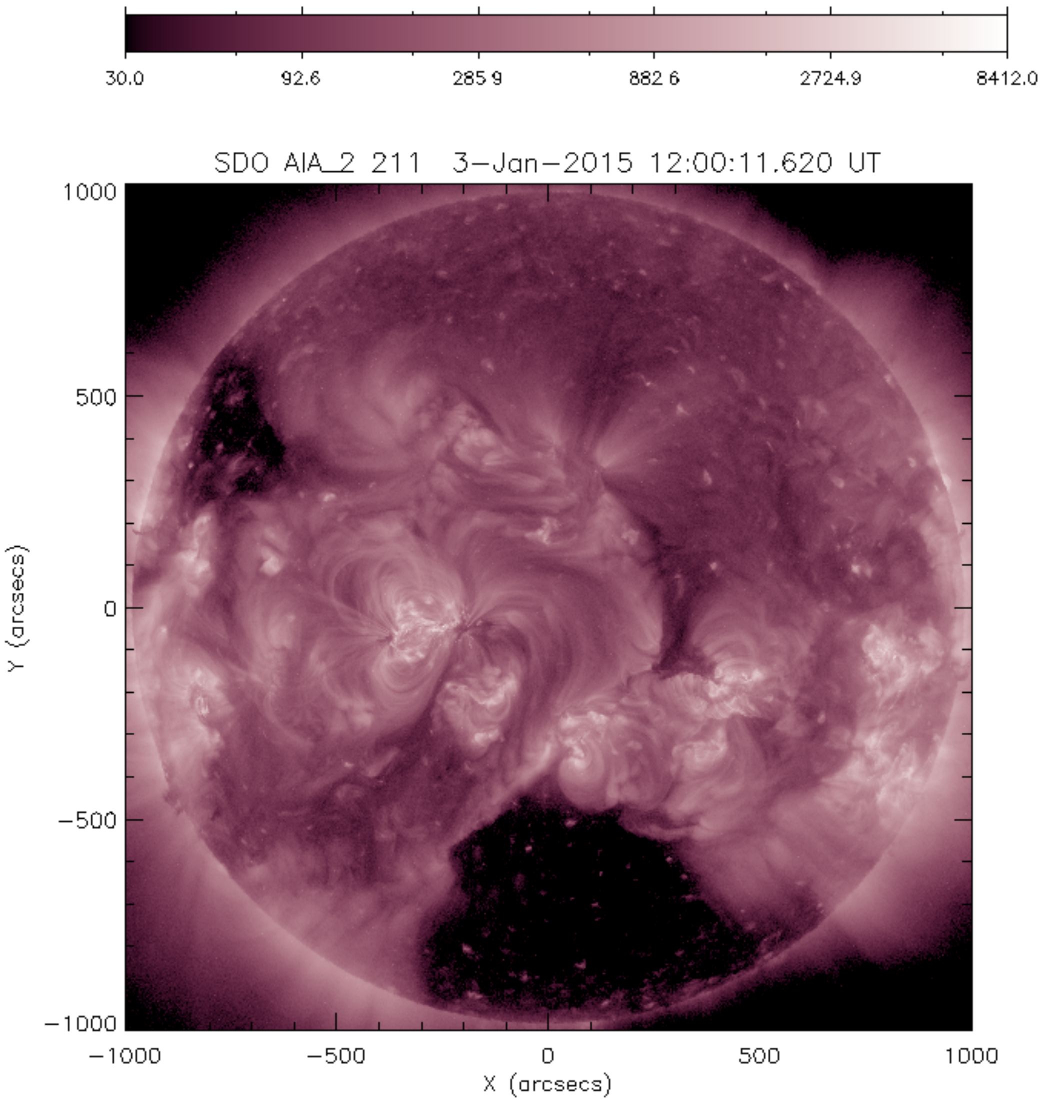

Figure 2: Image in SDO/AIA 304 Å on 2015 January 3 at 12:00 UT. An extended coronal hole is located at the Southern pole.

But the halo CME reported by SeNMEs on January 5 was too slow to be related to a magnetic cloud on January 7 and SeNMEs associated this magnetic cloud with a previous CME: *'Solar wind reaching the Earth is disturbed due to the arrival of the CME observed last 3 January.'* (SeNMEs report issued on January 7 at 16:00 UT). Nevertheless, a real-time analysis was not enough to conclude on the solar source of the CME on January 3.

After a detailed analysis, we conclude that the solar source of the faint CME on 2015 January 3, and therefore of the magnetic cloud on January 7, was the ejection that created a large dimming close to the boundary of the southern pole coronal hole [4].

3 Interplanetary analysis of the event and geomagnetic consequences

Interplanetary data from Wind and ACE spacecraft and the Dst geomagnetic index for the period from 2015 January 5 12:00 UT to January 8 23:59 UT appear in Figure 1. The magnetic cloud corresponds to the shadowed region, where the magnetic field is enhanced and rotates smoothly from south to north. Solar wind temperature is also decreased in that interval. However, when considering the typical composition of ICMEs, compositional anomalies do not seem to fit with that interval but with a longer period. The interval for the ICME material can be also established by the sharp discontinuities in the oxygen charge state ratio O^{7+}/O^{6+} (vertical dashed lines), which has long been used as a good representative magnitude of the solar wind source region because of its relatively fast freeze-in process in the low corona [1]. A low O^{7+}/O^{6+} ratio is considered to be a very good signature of a stream from a coronal hole [10], while periods of unusually hot charge states, with high O^{7+}/O^{6+} ratio, are typically associated with CMEs [7], [5] . A deep analysis of interplanetary data, not limited to typical solar wind plasma and IMF, but also including compositional anomalies, guided us to propose in [4] that at least the front boundary of the ICME was eroded when travelling away from the Sun.

Magnetic flux erosion by reconnection occurring at the boundaries of magnetic clouds greatly influences its geoeffectiveness ([6]). This reconnection may be due to the unipolar magnetic field of the fast stream. Assuming no erosion, the magnetic cloud should extend until the vertical dashed lines, where the compositional anomalies fit with the expected values for ICME material. In that case, the non-eroded magnetic cloud would exhibit a large interval with southern magnetic field, which has dissappeared in the eroded cloud as a result of the reconnection between the ICME magnetic lines and the fluctuating IMF from the coronal hole. A red solid line in panel 2 of Figure 1 represents schematically the z-component of the IMF of the non-eroded magnetic cloud. Considering the large period of southward IMF of the non-eroded cloud, an intense geomagnetic storm with Dst reaching less than -200 nT would have happened. Instead, a moderate geomagnetic storm, with Dst reaching -99 nT took place.

Acknowledgments

This work was supported by MINECO project AYA2013-47735-P. We acknowledge the use of publicly available data products from Wind/MFI Wind/SWE, ACE/SWICS, SDO/AIA and the Dst index data from the WDC for Geomagnetism, Kyoto.

References

[1] Bürgi, A., & Geiss, J. 1986, SoPh, 103, 347

[2] Burlaga, L. F., Klein, L., Sheeley, N. R. J., et al. 1982, GeoRL, 9, 1317

[3] Burton, R. K., R. L. McPherron, & C. T. Russell 1975, JGR, 80, 4204

[4] Cid, C., Palacios, J., Saiz, E., & Guerrero, A. 2016, ApJ, 828, 11

[5] Henke, T., Woch, J., Schwenn, R., et al. 2001, JGR, 106, 10597

[6] Lavraud, B., A. Ruffenach, A. P. Rouillard, et al. 2014, JGR, 119, 26

[7] Lepri, S. T., Zurbuchen, T. H., Fisk, L. A., et al. 2001, JGR, 106, 231

[8] O'Brien, T. P., & R. L. McPherron 2000, JGR, 105, 7707

[9] Zurbuchen, T., & Richardson, I. G. 2006, SSRv, 123, 31

[10] Zurbuchen, T. H., Fisk, L. A., Gloeckler, G., & von Steiger, R. 2002, GeoRL, 29, 1352