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# STUDY OF THE UPPER IONOSPHERE DURING THREE INTENSE STORMS MARCH 17-18, JUNE 22-23, OCTOBER 7-8, 2015 USING DATA FROM SWARM SATELLITES

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**Abstract.** We know that understanding the behavior of the earth's ionosphere during geomagnetic storms and especially the origin of positive (increase in electron density Ne compared to calm) and negative (decrease in Ne compared to calm) storms is an important task to accomplish in space weather. In this context, we compared the electron density Ne and neutral density Dn data provided by SWARM satellites, during three intense geomagnetic storms on 2015; March 17-18, June 22-23, October 7-8, with those of calm days in order to understand the origins of positive (+) and negative (-)storms at the level of the ionospheric region F and especially above the plasma peak. At the start of the main phase of these storms, the Earth's ionosphere simultaneously marked a (+) storm on the day side and a (-) storm on the night side, where the Bz component of the interplanetary magnetic field (IMF) is directed towards the south, and Ey of the interplanetary electric field (IEF) is directed towards the evening. This confirms that these two phenomena which affected the ionosphere at the start of this phase are mainly due to the prompt penetration electric fields (PPEF) due to the leakage of the convective electric field towards low latitudes. Later during the end of the main phase and the start of the recovery phase and when Bz experienced a long southward turn, the (+) storm persisted on the night side and appeared more intense along the day side (except for the October storm where the flanks experienced a (-) storm throughout this period). During this stage the density of the neutrals Dn marked an increase from the poles towards the equator which is more important in the northern hemisphere than in the southern one. This leads us to suggest that the laste (+) storm is probably due to two other mechanisms than the PPEF, which are the disturbance dynamo electric fields (DDEF) and the disturbances of the thermospheric circulation generated by joule heating caused by the penetration of high-energy particles from solar winds toward polar areas. While the thermosphere/ionosphere coupling leads to a flow of plasma to areas where loss rates are high, meaning that (-) storms are more likely to be attributed to a change in neutral compositions.

Keywords: SWARM mission, Geomagnetic storm, ionosphere, electron density, neutral density, prompt penetration electric field PPEF, disturbance dynamo electric field DDEF.

## 1 Introduction

We use Swarm satellite data to analyze the ionospheric response to three geomagnetic storms of the year 2015 (March 17-18, 2015, June 22-23, 2015 and October 7-8, 2015) which belong to three different seasons and ranked among the 10 largest geomagnetic storms of the 24th solar cycle. Although negative storms are usually explained by changes in thermospheric composition((Fuller-Rowell et al. 1994; Werner & Prölss 1995)), positive storms remain less certain. At present, there is still debate about the main drivers that generate positive ionospheric storms;(Huang et al. (2005); Tsurutani et al. (2008)), dynamic disturbance electric fields (Goncharenko et al. (2007); Lu et al. (2008); Balan et al. (2010)) rapidly penetrating electric fields (Blanc & Richmond (1980); Huang et al. (2005); Tsurutani et al. (2008)), the increase in neutral composition Blanc & Richmond (1980); Fuller-Rowell et al. (1994); Huang et al. (2005); Tsurutani et al. (2008)), as well as the plasmaspheric downward fluxes (Danilov (2013)). Therefore, the study of the ionospheric effects of geomagnetic storms remains among important scientific tasks. In this article, we use data from the Swarm mission to provide further contributions in our understanding of ionospheric storms in general and especially the behavior of upper ionosphere storms.

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## 2 Results and discussion

To study the impact of a geomagnetic storm on the entire terrestrial globe, we used all availible data from Swarm satellites that we have represented in figures 2 (March), 4 (June) and 6 (October). On the other hand to complete our study we used data of the interplanetary medium. We extracted the geophysical parameters from the OMNIWeb data services (`http://omniweb.gsfc.nasa.gov`) as shown in figures 1 (March), 3 (June) and 5 (October). For the March geomagnetic storm the SWA satellite was flying in the upstream 19.68 LT area on the night side just after sunset, and 7.68 LT in the daytime side, just after sunrise. According to figure2, we notice that there is a big increase of Ne and of two peaks of the equatorial anomaly compared to the day side which suggests that, although SwA flies over the night side according to local time, The ionosphere of this part is still under the effect and the conditions of the day and vice versa. These reasons are considered in our analysis at the start of the main phase for the geomagnetic storms of Mars, June and October. The Earth's ionosphere simultaneously marked a (+) storm ((-) storm) in the day (night) side at almost all mid and low latitudes, such that the Bz component of the interplanetary magnetic field IMF is directed towards the south and the Ey component of the IEF interplanetary electric field is directed towards the evening. This confirms that these two phenomena which affected the ionosphere at the start of this phase are caused mainly by the leakage of the prompt penetration electric field (PPEF) due to undershielding (Kelley et al. (2003); Huang et al. (2005); Manoj et al. (2008, 2013)). This field is directed towards the east (west) in the day (night) side which results in an ExB drift of plasma towards the high (low) altitudes where the loss rate is low (high) which leads to a (+) storm ((-) storm). During this period Dn marked an increase from the poles towards the equator with a favorite from the northern hemisphere (NH).
The return of Bz to the north leads to overshielding(Wolf et al. 2007; Kikuchi et al. 2010; Wei et al. 2011) which prevents the electric field of magnetospheric convection from entering towards mid and low latitudes. The ionosphere during these turns marked a (-) storm in the day side at these latitudes and a (+) storm in the night side except for the October storm where the night side has always exhibited a (-)storm. These storms are probably attributed to the rapid northward Bz reversal of the IMF which leads to a zonal electric field reversal resulting in a downward (upward) ionospheric plasma ExB drift in the day (night) side where the recombination phenomenon is high (low) (Fejer et al. (1979); Gonzales et al. (1979); Kikuchi et al. (2000); Rastogi & Patel (1975)). On the other hand, the intense ionospheric (-) storm on the day side at the level of the zone of the equatorial anomaly coincides with the arrival of the increase of Dn ($Dn > 1.610^{-12} Kg^{-3}$) in this zone, that is to say say the arrival of warm longitudinal thermospheric winds from the poles towards the equator, which are probably accelerated and intensify the loss phenomenon (Lee et al. (2002); Liu et al. (2014); Mikhailov & Schlegel (1998); Richmond & Matsushita (1975)). but the (-) storm on the night side for the October storm is probably explained either by the low amplitude of Bz during this storm compared to the other two storms, or by a seasonal effect.
During the end of the main phase and the start of the recovery phase for the storms of March and June, IMF Bz experienced a long southward turn and IEF Ey marked a long return towards the evening. The ionosphere on the day side experienced a (+) storm over almost all latitudes, which intensified later. On the other hand, the ionosphere on the night side marked a (+) storm at mid and low latitudes and a (-) storm in other latitudes. (+) Although the storm in the night side is clearly not associated with the PPEF. Astafyeva et al. (2016) analyzed the EEJ obtained from magnetic data from SWARM satellites during the June storm and show that this second storm (+) in the day side is not associated with the PPEF. This suggests that this simultaneous (+) storm in both sides is caused by other mechanisms. The analysis of Dn during this period shows the displacement of its increase from the poles towards the equator where it reached its maximum and exceeded $2.510^{-12} Kg^{-3}$ at the level of low and equatorial latitudes. This means that longitudinal thermospheric winds are directed towards the equator, and were generated by joule heating at the level of the poles because of the entry of the interplanetary particles of high energy. These winds can bring with them charged particles by the thermospheric-ionospheric coupling. This leads us to suggest that these types of storms in this area are probably due to the auroral disturbance dynamo electric field DDEF (Blanc & Richmond (1980); Richmond et al. (2003); Maruyama et al. (2005)). For the October storm both sides marked a (-) storm, this is probably explained by the same reasons mentioned before.

## 3 Conclusions

According to the analysis of interplanetary data especially Bz from IMF and Ey from IEF, in comparison with the variation of the electron density Ne and the density of neutrals of SWARM satellites during the three previous ionospheric storms, we can notice that:

- In the day side
  - Ionospheric first (+) storms are due to the prompt penetrating electric field PPEF, while the late (+) storms are probably due to disturbance dynamo electric fields DDEF as well as to the disturbance of the circulation of neutrals by thermospheric/ionospheric coupling.
  - Ionospheric (-) storms are mainly due to the large amplitude northward Bz inversion as well as to the change in neutrals compositions.
- In the night side
  - ionospheric (+) storms are probably mainly due to DDEF and the disturbance of neutrals circulations.
  - Ionospheric (-) storms are due in addition to changing neutral compositions to PPEF at first.

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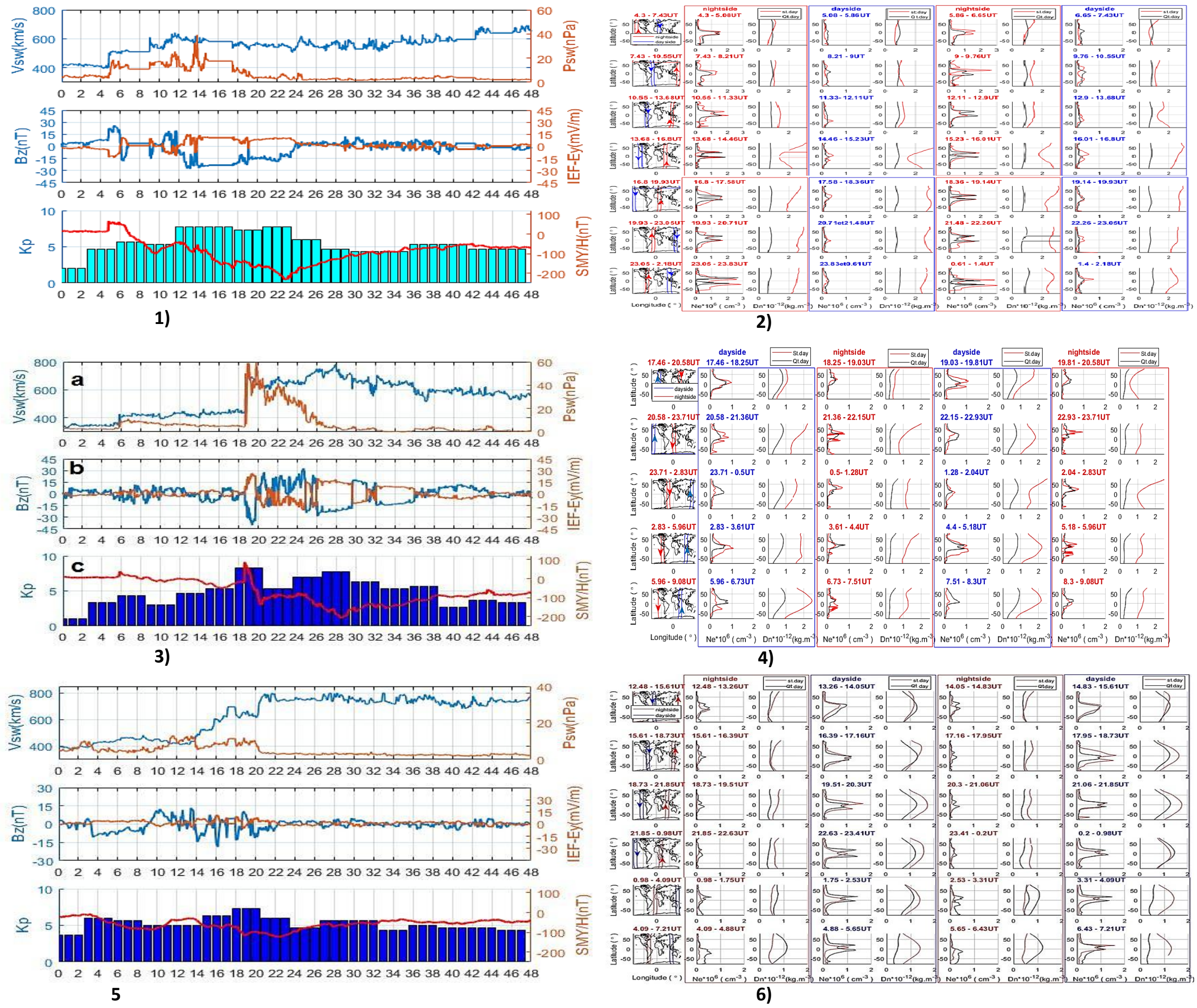


**Fig. 1.** *1,3et5:the Variation of interplanetary and geophysical parameters during the three geomagnetic storms of March, June and October 2015. a - solar wind speed (Vsw, blue) and solar wind pressure (Psw, red); b - component Ey of the interplanetary electric field (IEF Ey, red) and component Bz of the interplanetary magnetic field (IMF Bz, blue) in GSM coordinates; c - the kp index (green bars) and the SYM-H geomagnetic activity index (red). 2,4 and 6 represent Results of Swarm A (SWA) of 3 successive storms in the night orbit (red curves ) and on the orbit of the day (blue curves) .the data of the electron density Ne (in cm$^{-3}$) and the density of neutrals Dn (in kg.m$^{-3}$) of the night are represented in two successive columns in a red frame, while the same parameters of the day are framed by a blue frame. The values of these two storm day parameters (red curves) are compared to the calm day values (black curves). The time in UT of the start and end of the satellite trajectories is indicated in red for the night side and in blue for the day side.*