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Comparison of Response to Severe Geomagnetic Storm of IRI-2012 and IONOLAB TEC Values

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Outline

- Introduction
- Material and method
- Results and discussions
- Conclusions

1- Introduction

- Geomagnetic storms are probably the most important phenomenon among those related to solar wind and high energy particles. They produce large and global disturbances in the ionosphere, they affect also the neutral atmosphere, including the middle atmosphere and troposphere.

- The effects of geomagnetic storms at different altitudes and latitudes differ in development in time and in intensity. They reflect different features of geomagnetic storms, therefore their mechanisms are different.

- Geomagnetic storms can be categorized, in terms of geomagnetic activity index (Dst), into three categories:
- (1) major (intense or severe) storms, minimum Dst (Dstmin) of −100 nT or less;
- (2) moderate storms, Dstmin falls between −50 and −100 nT; and
- (3) weak storms, −30 nT < Dstmin < −50 nT

- Geomagnetic storms are major space weather events. A geomagnetic storm can affect space vehicle operation, interrupt radio communication, and disrupt power grids.

- On 17 March 2015 the first severe storm of solar cycle 24 occurred.
- The storm was notable for two reasons: the first that it was at that point the strongest storms of the solar cycle, the second that space weather agencies around the world failed to predict it.

- 17 March 2015 (The St. Patrick’s Day) geomagnetic storm was associated with a Coronal Mass Ejections (CMEs) event that occurred in the Sun.

- The ionospheric total electron content (TEC) is a widely used parameter to determine the ionospheric state, especially during geomagnetic storm periods. During the geomagnetic storm, the solar wind energy stored in the magnetosphere is gradually transferred into the ionosphere and the thermosphere. It is stated that this process will cause large increase or decrease in ionospheric TEC value.

- The ionospheric TEC value can be calculated by means of GPS stations, which are ground based and widely spread to the earth's surface, and satellites. The TEC value is also estimated with the aid of the empirical models (such as the International Reference Ionosphere-IRI (with lower versions such as IRI-2007, IRI-2012-2016, IRI-PLAS), NeQuick, etc.).

- The main purpose of this study is to compare the response to the severe geomagnetic storms of the TEC values obtained with GPS-based IONOLAB estimation method and the empirical IRI model. Also, the effects of this geomagnetic storm in the ionosphere at Ankara in Turkey have been investigated.

2- Material and Method

- In this study, TEC values were obtained from IRI model and IONOLAB estimation method at Ankara station (39.7 N; 32.76 E) in Turkey.
- Geomagnetic (Kp, Ap and Dst) and solar (Bz, Vp and Np) indices are chosen to describe the severe geomagnetic storm. These indices values are taken from the NSSDC database (http://omniweb.gsfc.nasa.gov/form/dx1.html).
- Comparisons of the TEC values obtained by two different ways are made before, during and after the storm by means of correlation analysis.

- In the literature, a disturbed day is defined as a day of Kp>= 4, Ap>= 26 nT and Dst <= - 30 nT. In this study, the sensitivity of the IRI model and IONOLAB estimation method to the changes of the ionospheric TEC values three days before and three days after the severe geomagnetic storms on March 17, 2015 (Dst = - 223 nT, Kp = 8 and Ap = 179 nT) at Ankara station are compared and the reasons for the TEC changes are discussed.

3- Results and discussions

- **Variation of solar and geomagnetic indices during the storm**
- Variations of the interplanetary and geomagnetic parameters during 14–20 March 2015 are presented in Figure 1. From Figure 1-c, it is seen that Bz has two peaks in both north and south direction on the day of the storm. On March 17, the Bz value at 05:00 UT reaches first peak value of 19 nT with a sudden increase in the north direction. This is the signal that the interplanetary energies reach the earth's magnetosphere.

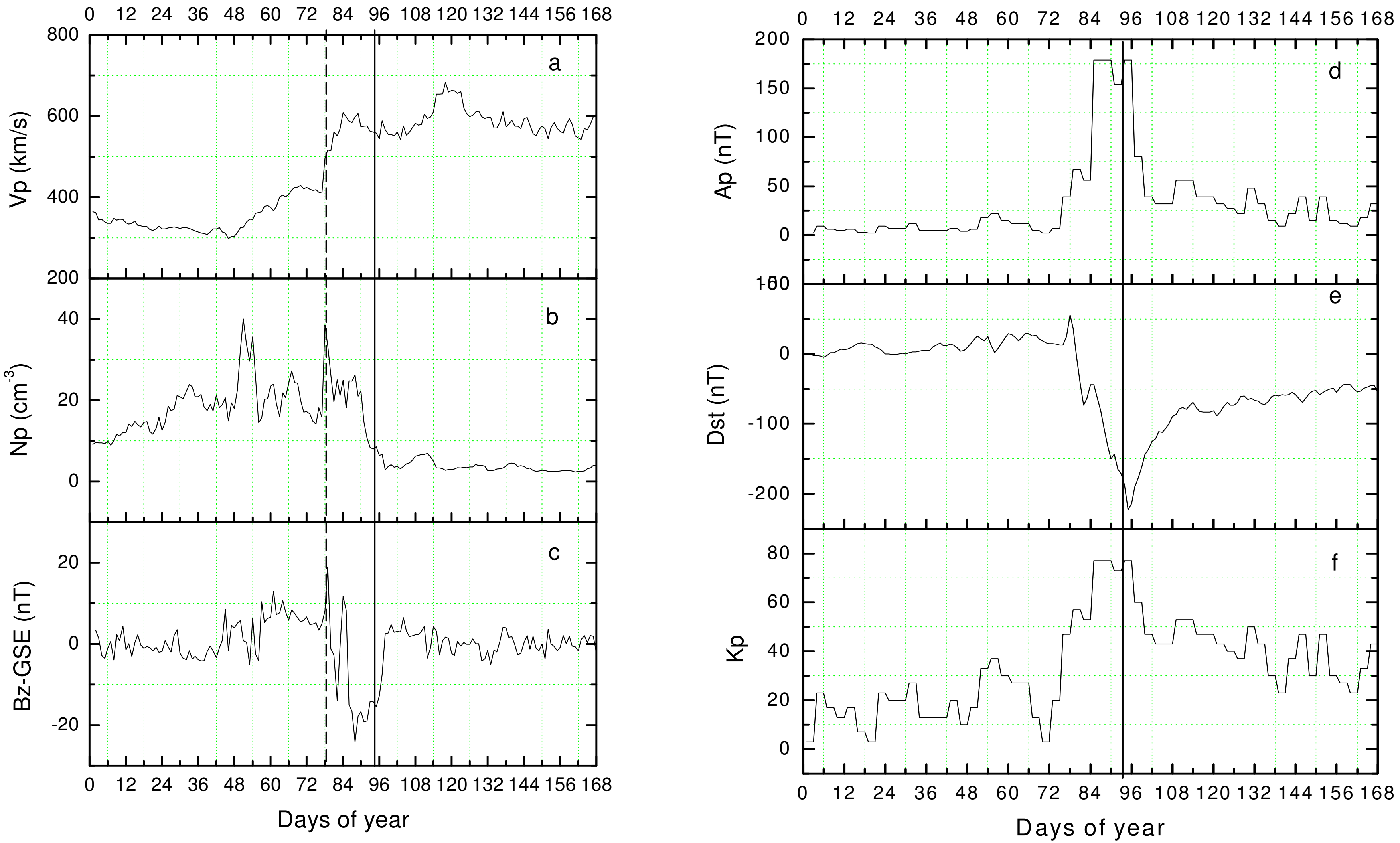

Figure 1. Time-dependent change of interplanetary and geomagnetic parameters on 14-20 March 2015.

- At the same time, the Vp value increases from about 400 km/s to 500 km/s, the Np value rise from 15.9 cm^{-3} to 38.5 cm^{-3} , the Kp index reached 5, Ap reached 39 nT and Dst peaks in the positive direction with a value of 56 nT.
- An increase in the positive direction of the Dst index points to a sudden storm-commencement (SSC), as described in some studies (D’ujanga et al., 2013, de Jesus et al., 2016, De Jesus et al., 2012).
- Afterward, the development of the storm can be divided into three typical stages: the initial phase (~05:00–08:00 UT), the main phase (~08:00–23:00 UT), and the recovery phase (after 23:00 UT).

- In the main phase, the solar wind speed (~600 km/s) and proton density (~ 38.5 cm^{-3}) increased significantly relative to the quiet days, with a Kp index between 5 and 8, which indicated that the storm reached a moderate to active level. Dst index falls – 223 nT at 23:00 UT on 17 March 2015. Ap value reached 179 nT.
- After this time, all parameters start to return to their ground state values.

TEC changes during the storm

- The change in IONOLAB-TEC values during the storm is shown in upper panel of Figure 2. The days prior to the beginning of the geomagnetic storm (March 14-16), IONOLAB-TEC values do not show very sudden changes. However, an average deviation of 5 TECU from the previous day occurs. At the beginning of the geomagnetic storm (at 05:00 UT), IONOLAB-TEC values begin to increase linearly.
- IONOLAB-TEC values during the storm's main phase and reach a maximum value of 64 TECU at noon. The increases in the TEC values at the initial and the main phase of severe geomagnetic storm have also expressed in previous studies (Adebiyi et al., 2014, Adeniyi, 1986, Basu et al. , 2001, Joshua et al., 2011, Lastovicka, 2002, Lopez-Montes et al., 2015). At the advancing hours of the main phase, the TEC values decrease to minimum values at 23:00 UT.

Figure 2. Time-dependent change of TEC values during the storm .

- After 23:00 UT, the TEC values continue to decrease and receive a minimum value of 7 TECU at 03:00 UT on March 18. Then, TEC values start to increase, and reach to its values before the storm at 12:00 UT on the March 18. A marked decrease in TEC values occurs especially in the days after the storm (on 19 and 20 Mrach). It can be stated that the decrease in TEC values on the days following the storm is due to the movement of the middle latitude trough toward the equator (Basu et al., 2001). Also, it has been stated in the literature that sudden decreases in TEC values after storm days represent a storm negative phase due to a change in composition in the ionospheric environment (Basu et al., 2001, Buonsanto, 1999).

- The change in IONOLAB-TEC values from 14 to 20 March 2015 indicates that the positive storm effects during geomagnetic storm occur in the initial and main phase of the storm and negative storm effects occur in the recovery phase of the storm.

- The lower panel of the Figure 2 shows the change in IRI-TEC during the period March 14-20, 2015. As can be seen from this figure, no disturbance in the TEC values obtained with IRI model in all phases (initial, main and recovery) of the March 17 severe geomagnetic storm has occurred. The IRI-TEC values show a similar distribution in the time period studied here. The TEC maximum values for all days have averaged 38 TECU.

- Correlation analysis is used to compare the changes in TEC values obtained in two different ways. As a result of the correlation analysis between IONOLAB-TEC values and IRI-TEC values, the relationship coefficients were calculated as R = 0.98 for the pre-storm (14 March 00:00 UT-17 March 04:00 UT) R = 0.85 during the storm (17 March 05:00 UT-18 March 20:00 UT) and R = 0.95 after the storm (18 March 21:00 UT-20 March 23:00 UT). It is seen that the correlation coefficient during the storm is decreased compared to other cases (pre-storm and after storm). This reduction shows the sensitivity of the IONOLAB-TEC values and the insensitivity of the IRI-TEC values to the disturbances occurred in the ionosphere during the storm.

Conclusions

- IONOLAB TEC values change due to severe geomagnetic storm, while IRI-TEC values do not change.
- The changes in the IONOLAB-TEC values before, during and after the severe geomagnetic storm indicate that the positive storm effects in the ionosphere are in the initial and main phases of the storm while negative storm effects are in the recovery phases of the storm.

- While IRI model predicts lower the TEC values during initial and main phase of the storm compare to the IONOLAB estimation method, it predicts higher during recovery phase of storm. This result is consistent with previous study (Adewale, 2013).
- It can be said that the IONOLAB-TEC values are more sensitive than the IRI-TEC values to the changes occurred during the storm in the ionosphere, since the correlation coefficient before and after the storm is greater than during the storm.

- As a result, IRI model needs to be made more precise to detect ionospheric disturbances that occur during the geomagnetic storm.
- Also, it is necessary to conduct further investigations at different latitudes in order to determine both the effects of positive and negative ionospheric storms during severe geomagnetic storms and the responses to the severe geomagnetic storms of IRI model and IONOLAB estimation method.

- THANK YOU FOR YOUR ATTENTION