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Interactive comment on "Response of low to mid latitude ionosphere to the Geomagnetic storm of September 2017" *by* Nadia Imtiaz et al.

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General Comments:

In the revised version we have tried to explain our results on the basis of studies published by Fuller-Rowell,ÂăÂăBlanc and Richmond, Fejer andÂăBalan.

Specific comments: 1. Specify which exactly GIMs have been used in the study. IGS gives access to GIMs created by different providers (CODE, IGS, ESA, JPL etc.)? Answer: The vertical Total Electron Content (vTEC) is obtained from the IGS-GIM data which is available in the standard IONEX format on the NASA's website; i.e., Crustal Dynamics Data information system (ftp://cddis.gsfc.nasa.gov/gps/products/ionex/). These IONEX files contain the vTEC data for the entire globe and for any time, the

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Discussion paper

vTEC data can be obtained from IONEX files at the time resolution of 2-h. The tomographic kriging (UQRG-GIMs) computed by the Technical University of Catalonia (UPC) at 15 minutes time resolution have been used to study the Global and Regional electron content.

2. Specify what was the calibration technique used to obtain TEC data for individual GPS stations?
Answer: We didn't use any calibration technique in this study. However, we have extracted the vTEC data of a particular GPS station from the IGS-GIMs by using a MATLAB script. We have validated our methodology by reproducing the results of the previous studies particularly the analysis of the ST. Patrick day storm of MARCH 2015 published by Nava et al. 2016 and Kashcheyev et al. 2018.

3. Provide the criteria on how the quite days were selected and what were these quite days when computing the difference for REC and GEC and for vTEC from individual GPS stations.
Answer: We considered the three quiet days before the storm having Ap index below 22 nT. These quiet days are 2, 3, and 4 September.

4. Fluctuations in Asia REC show a regular pattern with a local maxima at the beginning of the day (e.g. 5, 7, 8, 9 and 11 September). It should be discussed/explained. A proper selection of the quite days might affect the results in this respect.
Answer: It can be seen that during the period 4-14 September 2017, the REC varies significantly over the four longitudinal sectors. The observed behavior of the Δ REC can be attributed to the energy inputs from the solar wind to the magnetosphere Nava et al. (2016). The AE index which is an indicator of the energy transfer from the solar wind to the magnetosphere is shown in Figure 2. It can be noticed that the AE index shows several episodes of the energy inputs (having the maximum value of the AE

index greater than 1000 nT) which occur on 4, 7, 8 and 13 September. In response to these energy inputs, the amplitude and the occurrence time of maxima/minima of the REC also vary.

5. To understand better the fluctuations of REC and their influence on GEC, please extend Figure 2 plot with the REC computed for the fourth sector.
Answer: The fourth region that is the Pacific sector has been included in the revised version. Please see Figure 2.

6. The behavior of vTEC at BAKO station should be discussed/explained. 8 out of 9 days show a significant deviation from a quiet day behavior. Again, the proper selection of quite days might affect this result.
Answer: The vTEC for all the stations have been revised with the proper selection of the quiet days.

7. For the sake of comparison purposes, please shrink the bottom panel of Figure 4 so that is has the same width as vTEC plots (without colorbar).
Answer: The size of the bottom panel has been adjusted in Figure 4 of the revised manuscript.

8. Provide information on the technique how magnetic field disturbances (D) was computed. At the same time, how daily quite variation (Sq) was computed.
In order to calculate the magnetic field variations we adopted the approach of Nava2016, Kashcheyev2018. The brief description of this approach is given here. During the geomagnetic storm, the horizontal component 'H' of the Earth's magnetic field can be expressed as:

$$H = H_o + D_M + D_{iono} + S_R^H,$$

where H_o represents the magnetic field component due to Earth's external core dynamics, D_M is the disturbance which comes from the magnetospheric currents mainly due to Chapman Ferraro current, ring current and tail current **?**. It can be calculated as:

$$D_M = SYM - H.cos\phi,$$

here ϕ is the geomagnetic latitude.
The S_R^H is the quiet daily regular variation of H and is computed by using the four quietest days having $Kp < 2$ such as:

$$S_R^H = \frac{1}{n}\sum_{i=1}^{n}(H_i + D_i^H) - H_o,$$

where n is the number of quiet days. The D_i^H depicts the disturbances coming from the ionosphere D_{iono} and the magnetosphere D_M. The magnetic disturbance due to ionospheric electric currents can be written as:

$$D_{iono} = \Delta H - S_q - SYM - H.cos\phi,$$

here $S_q =< S_R^H >$ is the hourly amplitude of daily variations of the geomagnetic field.

Targeted comments:
P.1 L.7 "It is observed that the storm time response of the TEC over the pre-noon

sector (Asia) is earlier than Africa and America." This sentence has to be modified, as it might be confusing when it comes to the time reference the authors refer to. It can be changes to e.g. "It is observed that the storm time response of the TEC over the pre-noon sector (Asia) is smaller than over Africa and America."
Answer: The storm time response of the TEC over the Asia/Pacific is earlier than over Africa/America. The observed positive ionospheric storm phase over the local dayside sectors is strongly linked with the occurrence time of the two SYM-H minima.

P.1 L.14 "In the modern space era, the strength of the geomagnetic storm is characterized by the minimum Dst". It is not clear how space era is related to Dst index, as it is based on ground based measurements. Please change/rephrase the sentence.
Answer: The sentence has been rephrased in the revised manuscript.

P.4 L.7 Explain index "I" of vTEC (Iil) in the formula. Provide information on how vTEC value is computed for a cell, having 4 vTEC values (4 vertices of the rectangle).
Answer: The GEC is obtained from the UPC-GIM data by the summation of the vTEC values in a cell Ii,j multiplied by a cell's area Si,j over all GIM cells and it is given by Afraimovich et al. (2006),

$$GEC = \sum_{i,j} I_{i,j}.S_{i,j}.$$

Here i and j represent the latitude and longitude of a certain GIM cell. The latitudinal and longitudinal extent of the elementary GIM cell is about 2.5âŮę and 5âŮę, respectively.

P.5 L.5-10 Please make sure you use the correct SYM-H data. According to OmniWeb, the minimum SYM-H was -146nT at 01:08 UT (not -148nT at 2 UT) and the second

minimum was -115nT at 13:56 UT (not -122nT at 15 UT). Correct also the statement that two AE maxima of 2000nT and 2500nT coincide with the two peaks in SYM-H. It is not correct. As at the times of SYM-H minima, (01:08 UT and 13:56 UT), AE (according to OmniWeb) equal to 784nT and 1259nT correspondingly. At the same time, the two maxima around that time in AE were 2447nT at 23:43 UT (September 7th) and 2677nT at 14:06 UT (September 8th). Therefore, only the second peak might be considered as "coinciding", while the first one is definitely not.

Answer: The case study is revised as: In early September 2017 mainly three CMEs with earthward trajectories were emitted on 4, 6 and 10 September. A CME originating from the massive X9.3 solar flare of 6 September, reached the Earth at 2300 UT on 7 September. The arrival of this CME caused a significant compression to the day side magnetosphere which provoked a severe geomagnetic storm having maximum value of the geomagnetic index Kp = 8. However, the arrival of the other two CMEs on 6 and 12 September lead to a minor geomagnetic storms of G1 category. Figure 1 illustrates the global morphology of these solar events. In Figure 1, the storm time variations of the various plasma parameters are depicted in the following order (from top to bottom): the solar wind speed (Vsw), the Bz component of the IMF, the Interplanetary Electric Field (IEF), the AE index, the SYM-H index and the Solar radio flux F10.7. The three vertical lines represent the CMEs that lead to the Sudden Storm Commencement (SSC) at 2343, 2300 and 2002 UT on 6, 7 and 12 September 2017, as reported by: http://www.obsebre.es/php/geomagnetisme/vrapides/. However, the present study focus on the effects of the G4 category storm which occurs on 8 September 2017. On the arrival of the interplanetary shock on 7 September at about 2300 UT, the initial phase of the storm begins with a rapid variations in plasma parameters. During the main phase, the Bz component of the IMF is more southward reaching to the maximum lowest value of about -32 nT and then it rapidly increases to the value of approximately +16 nT. It again performs a negative excursion and reaches the value of approximately -16 nT. It can be seen that the SYM-H index also follows the behavior of the Bz component. During the main phase of the storm, the SYM-H also decreases

and reaches to the negative value of âĽČ −146 nT thus producing the first minima of the SYM-H index at 108 UT. From 108 UT until 1100 UT the Bz in northward; i.e., it increases to the positive value. Following the Bz, the SYM-H index also increases from −146 nT to the value of −38 nT. During this partial recovery phase, the Bz becomes southward again by performing a negative excursion of −17.6 nT at 1155 UT and remains southward until 1356 UT, the SYM-H also reaches to its second minimum value of âĽČ −115 nT. This is the end of the main phase of the storm which lasted for âĹij 15 h. The main phase can be characterized by the occurrence of the two pronounced minima of the SYM-H with values −146 nT and −115 nT at 108 UT and 1356 UT respectively on 8 September 2017. The recovery phase started after 13:56 UT on 8 September. During the recovery phase, the SYM-H increases slowly and returned to its normal value at 1400 UT on 11 September. The recovery phase lasted for about 3 days. On September 8, the Vsw also exhibits an abrupt change by attaining a maximum value of about 840 km/s around 2 UT and after 12 UT it gradually decreases. The IEF is the Ey component of the electric field which is calculated as E = -Vsw × B. It depends on the Bz component of the IMF and the x component of the Vsw. It means that the positive northward IMF leads to the westward IEF on the day side and eastward field on the night side. It can be seen that the IEF fluctuation occurs between −15 and +20 mV/m during this storm. The next two plots represent the AE and Kp indices. After the arrival of CME1, there is an increase in the auroral activity such that the AE index reaches to the peak value of about 1430 nT on 7 September at 09:07 UT. However, the occurrence of the two strong peaks exceeding 2000 nT in the AE index indicates that the most intense auroral activity occurred after the arrival of CME2. The Kp index shows two episodes of the maximum value of approximately Kp = +8 for 3 h between 0-3 UT and 12-15 UT on 8 September. The bottom plot illustrates variation in the solar radio flux F10.7. It can be seen that the solar flux fluctuates significantly during the period 4-14 September 2017.

P.6 L.10 It would be beneficial to present the vTEC subplot from the fourth sector too.

Answer: The VTEC plot for the Pacific sector has been included in Figure 4 of the revised manuscript.

P.7 L.3 Please explain why disturbed part of H component of the magnetic field has index 'l', is it supposed to be 'i'?
Answer: There was a typo and the correct index is "i".

P.7 L.3 Indicate the time of the beginning of the initial phase of the storm.
Answer: The initial phase of the storm begins at 2300 UT when CME2 hits the Earth's magnetosphere.

P.7 L.5 Please specify the time of the beginning and the end of the main phase of the storm.
Answer: The main phase begins at 2300 UT on September 8, 2017 and it ends up with the occurrence of the second SYM-H minima at 1356 UT on the same day. After that recovery phase started which lasted for about 3 days when SYM-H returns to the quiet conditions.

P.7 L.15 It should be indicated that at the same time as an enhancement in O/N2 ratio is observed at low to equatorial latitudes, it decreases significantly at mid to high latitudes.
Answer: The change has been incorporated in the revised version.

P.8 L.2 (also on P.6 L.17) "Most of the TEC is confined to the equatorial and low latitude regions." Please clarify what exactly part of the TEC is discussed in this sentence. It is a regular ionospheric feature to have most of the TEC in low and equatorial latitude regions. Answer: During the storm period, an enhancement in the vTEC along with the

latitudinal extension of the EIA is observed. These two features have been explained in the revised version.

P.8 L.7 It is difficult to understand why the authors acknowledge some of the data centers, but not the others in the acknowledgment section. Please do acknowledge all data centers or only those that are not already mentioned in the 'Data Sets' section.
Answer: We have acknowledged all the data centers.

Typo/language comments: The corrections regarding Typo/language have been corrected according to the suggestions mentioned below.

Change "SYM – H" to "SYM-H" throughout the manuscript.
Answer: 'SYM – H' has been replaced by 'SYM-H' throughout the manuscript.

Please specify the titles of the papers in the 'References' section. It might be challenging for the reviewer to find the corresponding paper based on the information given.
Answer: Titles of the papers has been included in the revised manuscript.

P.1 L.20 Change "to investigate" to "to investigation of"
Answer: "to investigate" is replaced by "to investigation of" in the revised manuscript.

P.2. L.4 Change "is seasonal dependent" to ""is season dependent""
Answer: "is seasonal dependent" is replaced by ""is season dependent" in the revised manuscript.

P.2 L.7 Introduce abbreviation for the term "International Ground Station"
Answer: The abbreviation for "International Ground Station" has been introduced in

the revised manuscript.

P.2 L.9 Change “inter planetary” to “interplanetary”
Answer:“inter planetary” has been changed to “interplanetary” in the revised manuscript.

P.2. L.10 Change “The author” to “The authors”
Answer: “The author” has been replaced by “The authors” in the revised manuscript.

P.2 L.16 Change “clear evidence of a” to “clear evidences of”
Answer: “clear evidence of a” has been changed to “clear evidences of” in the revised manuscript.

P.2 L.20 Change ”Momani” to “Momani (2012)”.
Answer:”Momani” has been changed to “Momani (2012)” in the revised manuscript.

P.2 L.27 Remove “Momani (2012)”
Answer: Momani (2012) has been removed.

P.2 L.30 Introduce abbreviation for the terms “Global and Regional electron content”
Answer: The abbreviations GEC and REC have been introduced for the Global and Regional electron content.

P.2 L.33 Change “and magneto-meter data” to “of the magnetometer data”
Answer: In the revised manuscript “and magneto-meter data” has been to “of the magnetometer data”.

P.2 L.34 Change “disturbance Dynamo” to “disturbance dynamo”
Answer: In the revised manuscript “disturbance Dynamo” has been changed to “disturbance dynamo”.

P.2 L.34 Change “Crustal movement network of China” to “Crustal MovementÂăObservationÂăNetwork of China”
Answer: In the revised manuscript “Crustal movement network of China” has been changed to “Crustal MovementÂăObservationÂăNetwork of China”

P.2 L.35 Change “distort” to “distorts” or “distorted”
Answer: In the revised manuscript “distort” has been replaced by “distorts”.

P.3 L.3 Change “«” to “<”, correct subscript “st” to have “Dst”
Answer: In the revised manuscript “«” has been replaced by “<” and subscript “st” has been removed to have “Dst”.

P.3 L.5 Define abbreviation “CME” for “coronal mass ejections”
Answer: The abbreviation “CME” for “coronal mass ejection” has been introduce.

P.3 L.14 Change “multi instruments” to “multi-instrument”
Answer: In the revised manuscript “multi instruments” has been changed to “multi-instrument”.

P.3 L.16 Change “pulsation” to “pulsations”
Answer: In the revised manuscript “pulsation” has been replaced by “pulsations”.

P.3 L.18 Start sentence “This paper. . .” from a new line
Answer: In the revised manuscript “This paper. . .” is from a new line.

P.3 L.18 Change “This paper” to “Present work”
Answer:“This paper” has been changed to “Present work”.

P.3 L.23 Change “Section 2 deals with the” to “Section 2 presents a”
Answer: In the revised manuscript “Section 2 deals with the” has been changed to “Section 2 presents a”.

P.3 L.23 Change “data sets and the GPS” to “data sets, GPS”
Answer: In the revised manuscript “data sets and the GPS” has been changed to “data sets, GPS”.

P.3 L.24 Change “describe” to “describes”
Answer: In the revised manuscript “describe” has been changed to “describes”.

P.3 L.29 Remove “the coronal mass ejection” or “CME”, as it was already defined earlier.
Answer: We have removed “the coronal mass ejection” and used CME in the rest of the revised manuscript.

P.3 L.30 Remove “the high speed solar wind stream” or “HSSWS”, as it was already defined earlier.
Answer: In the revised manuscript “the high speed solar wind stream” has been

removed.

P.4 L.2 Remove “the interplanetary magnetic field” or “IMF”, as it was already defined earlier.
Answer: In the revised manuscript “the interplanetary magnetic field” has been removed.

P.4 L.5 Change “energy transferred from storm” to “energy transfer from the solar wind”
Answer: In the revised manuscript “energy transferred from storm” has been changed to “energy transfer from the solar wind”.

P.4 L.7 Change “450Km” to “450 km”
Answer: In the revised manuscript “450Km” has been changed to “450 km”.

P.4. L.13 Change “summation is restricted” to “summation being restricted”
Answer: In the revised manuscript “summation is restricted” has been replaced to “summation being restricted”.
P.4 L.17 Please explain term “quasi-definite data” or rephrase.
Answer: In the revised manuscript “quasi-definite data” has been rephrased as “quasi-definitive data”.

P.4 L.18 Change “inter-magnet.com” to “http://intermagnet.org”
Answer: In the revised manuscript “inter-magnet.com” has been changed to “http://intermagnet.org”.

P.4 L.18 Change “shows the geographic location” to “shows geographic locations”

Answer: In the revised manuscript “shows the geographic location” has been changed to “shows geographic locations”.

P.4 L.23 Remove “Coronal Mass Ejection”
Answer: In the revised manuscript “Coronal Mass Ejection” has been removed.

P.4 L.24 Change “solar flares” to “solar flare”
Answer: In the revised manuscript “solar flares” has been changed to “solar flare”.

P.4 L.24 Change “reached on the Earth” to “reached the Earth”
Answer: In the revised manuscript “reached on the Earth” has been changed to “reached the Earth”.

P.4 L.25 Change “CMEs” to “CME”
Answer: In the revised manuscript “CMEs” has been changed to “CME”.

P.5 L.3 Change “rapid variation” to “rapid variations”
Answer: In the revised manuscript “rapid variation” has been changed to “rapid variations”.

P.5 L.4 Remove “to the value” (from “reaching to the value”) or change to “reaching the value of”
Answer: “to” has been removed.

P.5 L.5 Remove “to” (from “reach to the value”)
Answer:“to” has been removed.

P.5 L.6 Remove “its” from “to the its”
Answer:“its” has been removed.

P.5 L.8 Remove “to” from “reaching to the value”
Answer:“to” has been removed.

P.5 L.5-10 Please harmonize “≤” signs in the text. Minimum value of -148nT is not “≤” to -150nT, also -122nT is not “≤” than 130nT. Should it be an “approximately” sign instead?
Answer: “≤” signs has been removed.

P.5 L.15-16 Remove “GEC”, “REC” and “vTEC” as they were defined above.
Answer: In the revised manuscript the abbreviations GEC, REC and vTEC have been used.

P.5 L.17 Remove “Regional Electron Content” and “Global Electron Content”, leave “REC” and “GEC”
Answer:“Regional Electron Content” and “Global Electron Content” have been removed.

P.5 L.19 Change “by using the five quiet days before the storm” to “by subtracting the quite time variation from the value itself. The quite time variation is computed using five quiet days before the storm. . .”. Explain what the criteria to select quite days were and what days they were.
Answer: The following modification has been done in the revised manuscript:

Both the Δ REC and ΔGEC are calculated by subtracting the quiet time variation from the value itself. The quiet time variation is computed using the three quiet day before the storm having the Ap index below 22 nT. The quiet days considered are 2, 3 and 4 September 2017.

P.5 L.24 Change “the individual station” to “individual stations”
Answer:“the individual station” has been changed to “individual stations”.

P.5 L.25 Change “the panels first to third represent” to “the first to third panels represent”
Answer: In the revised manuscript we have used “the plots from one to three”.

P.6 L.4 Change “vTEC increases” to “vTEC increase”
Answer: In the revised manuscript we have used “increase in the vTEC”.

P.6 L.14 Change “irregular pattern” to “irregular patterns” or to “an irregular pattern”
Answer: “irregular pattern” has been changed to “irregular patterns” or to “an irregular pattern”.

P.6 L.19 Change “magnetometer variations” to “magnetometer data variations”
Answer: In the revised manuscript we have used “magnetic field variations”.

P.6 L.20 Change “Asian” to “Asia”
Answer:”Asian” has been replaced by “Asia”.

P.9 L.5 ‘Blagoveshchenskya’ change to ‘Blagoveshchensky’

Answer:‘Blagoveshchenskya’ has been changed to ‘Blagoveshchensky’

P.13 “ionosphere disturbance current (blue)” change to “ionosphere disturbance current (red)”
Answer:“ionosphere disturbance current (blue)” has been changed to “ionosphere disturbance current (red)”.

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-19/angeo-2019-19-AC3-supplement.pdf

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