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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 previous studies.
Specific comments:

1. Table 1 and 2 displays the geographic coordinates of GPS stations and of magnetic observatories however, since you are investigating the effects of a geomagnetic storm on the ionosphere, the position in the magnetic reference frame is much more relevant.
Answer: In the revised version of the manuscript Table 1 and 2 also contain geographic



and geomagnetic locations of the GPS stations and observatories.

2. Figure 1 would be much more useful if all plots were all stacked up, instead of being separate. Moreover, Figure 1 seems to have been downloaded by the OMNI web-page, it is preferable for the authors to draw their own figures.
Answer: All the plots in Figure 1 are revised according to the referee's suggestions.

3. It is not clear how vTEC has been evaluated. Please specify it.
Answer: The vertical Total Electron Content (vTEC) is extracted from the International GNSS Service (IGS) Global Ionosphere Map(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. For any time, the vTEC data can be obtained from IONEX files at the time resolution of 2-h.

4. The description of the event investigated, given in the Case Study section, is very inaccurate and incorrect. Values of the peaks of SymH and AE are wrong, as well as their occurrence time. The time of the arrival at the Earth's surface of the effect of the CME is wrong, being the correct time 23:00 UT (see http://www.obsebre.es/php/geomagnetisme/vrapides/ssc_2017_d.txt). G-classes of geomagnetic storms are here mentioned but never explained or referenced. The sentence with the value of geomagnetic index kp = 8 at 23:50UT. makes no sense, being Kp an index estimated on intervals of 3 hours. Also the sentence 'The solar wind speed increased from 500 to 785km/s'. makes no sense, the time interval when this happened being not specified. The timing of AE maxima does not coincide with that of Sym-H minima.

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 23 : 00 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 23:43, 23:00 and 20:02 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 23: 00 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 about 146 nT thus producing the first minima of the SYM-H index at 1: 08 UT. From 1: 08 UT until 11: 00 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 11:55 UT and remains southward until 13 : 56 UT, the SYM-H also reaches to its second minimum value of about 115 nT. This is the end of the main phase of the storm which lasted for around 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 1: 08 UT and 13: 56 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 14:00 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 2UT and after 12 UT it gradually decreases. The IEF is the Ey component of the electric field which is calculated as E = -Vsw $\times$ 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.

5. Data (as well as figures, see above) from the OMNI website are used, but the acknowledgment OMNI is completely missing.
Answer: We have acknowledged the OMNI data base: OMNI data base https://omniweb.gsfc.nasa.gov/form/dx1.html.

6. Figures 3 and 4 are missing the labels on the horizontal axes.
Answer: In Figures 3 and 4 the horizontal axes are labeled.

7. Concerning the description of Figure 3: 1) the increase of TEC on the day of the storm is visible only in BJFS, not in YAR2; 2) in Africa the enhancement during the storm is clearly visible also in Wind (why do you say that is less significant?).
Answer: In the revised manuscript following description has been added: On the day of the storm, the northern and southern mid-latitude stations (BJFS and YAR2) in the Asian sector show an increase in the vTEC. However, in the equatorial station (BAKO) relatively less increase in the vTEC is observed. In the African region, the largest increase in the vTEC is observed for the equatorial and southern mid-latitude stations (NKLG and WIND) during the storm. However, a small increase in the vTEC can be seen in the northern mid-latitude station (NOTI) in this sector.

8. Concerning Figure 4. It is not explained how maps covering the latitudinal range from -60° to 60°have been obtained.

Answer: The four plots in Figure 4 represent the vTEC over Asia, Africa, America and Pacific regions which are extracted from the IGS-GIM data (available on ftp://cddis.gsfc.nasa.gov/gps/products/ionex/). These IONEX files contain the vTEC data for the entire globe. Therefore, for a fixed longitude a contour plot covering the latitudinal range of -90° to 90° is made by using MATLAB script. These longitudes are given as: 110° E for Asia, -10°E for Africa, -70°E for America and 150°E for pacific.

9. Concerning Figure 4. It would be very helpful in the interpretation of this figure to have the SymH plot aligned and with the same size of those above.
Answer: The SYM-H plot is re-sized and aligned with the other plots in Figure 4.



10. Concerning the description of Figure 4: 1) in the Asian sector a pattern similar (in shape and values) to that observed on the 8 th of September is observed also on the day after the storm; 2) in the African sector a pattern similar to that observed on the 8th of September is observed also on the two days preceding the storm. How do you explain these features?
Answer: The space weather conditions during 4-14 September are highly disturbed due to multiple CMEs and HSSWS.
All the four longitudinal sectors show an enhancement in the vTEC on 6 September. This behavior can be associated with the impact of the CME1 which arrived at 23:43 UT on 6 September. During the initial phase of the storm on 7 September, it can be seen that the vTEC enhancements mainly occurred in the crest regions of the EIA with a clear latitudinal separation. On the day of the storm that is 8 September, a strong enhancement in the vTEC can be observed clearly in the crest regions of the EIA and in the equatorial regions over the four longitudinal sectors. Also the latitudinal extent of the enhanced vTEC also increases up to the mid latitudes. In the Asian sector, the regular behavior of the vTEC that is having well defined crests can be observed except on the day of the storm. On September 9 that is during the recovery phase, the vTEC return back to its normal pattern with well defined crests. In the African/Pacific sector, the vTEC exhibits an irregular behavior; i.e., sometimes one and sometimes two crests of the vTEC appear. In the American sector, we mostly observed one crest of the vTEC and a very strong ionization on the day of the storm which return to its normal level after the storm on 9 September. Besides, the enhancement in the vTEC on September 5 and 11 can be due to the HSSWS effect. Moreover, the solar radio flux F10.7 varies greatly during this period which can also affect the vTEC.
11. Concerning the “interpretation” of Figure 5, this is just a mere description of what is the well-known and expected behavior of the geomagnetic field during a geomagnetic storm.
Answer: The three plots in Figure 5 represent the magnetic field variations at the three

equatorial magnetic observatories corresponding to the three longitudinal sectors of Asia (GUA), Africa (MBO) and America (KOU). Each plot shows the variation in the horizontal (H) component of the magnetic field (in black), the quiet daily variation (Sq) (in blue) and the disturbances (Diono) (in red). The following features of the H component can be noticed in all the three sectors:

– Firstly, an increase in the H component occurred during the initial phase of the storms. This enhancement is due to the Chapman-Ferraro current resulting from the contraction of the magnetosphere Chapman and Ferraro(1931).

– Secondly, a strong decrease in the H component can be observed during the main phase of the storms. It can be attributed to the equatorial ring current. The enhanced ring current in the magnetosphere induced the magnetic field opposite to the Earth's northward dipole field which strongly reduces the H component.

– Following the strongest decrease in the H component, the recovery phase started which lasted for several hours. During the recovery phase, the ring current decays and the H component of the magnetic field returns back to the normal levels.

– Two pronounced dips in the H component at 1:08 UT and 13:56 UT on September 8 are observed in the three stations. It can be seen that the first minima is strongly negative for MBO as compared to GUA and KOU. However, the second dip is strongly negative for MBO as compared to GUA and KOU. This behavior is due to the local time variation of the ring current during the storm. Overall, the largest disturbance of the H component of the magnetic field with amplitude $-180$ nT is observed at MBO as compared to $-150$ nT at KOU and $-140$ nT at GUA. The disturbance due to ionosphere electric current Diono which is the sum of the PPEF and the disturbance dynamo electric field (DDEF), is represented by the red curve in Figure 5. It follows anti-Sq signature during the storm period. It can be noted that during the first southward excursion of the magnetic field, the Diono, decreases at the GUA which is the noon sector. However, an increasing trend in the Diono is observed for the MBO and KOU which are the night sector. During the second southward excursion of the magnetic field, Diono decreases significantly for the MBO and KOU which are now on



the day side.

Targeted comments:

Page 1, lines 15-17: The classification of geomagnetic storms that is most widely accepted in the magnetospheric/geomagnetic community is that compiled by Gonzalez et al. (1994), so I suggest to refer to it in place of that by Loewe and Prolls (1997). Moreover, the citation of Tsurutani et al. (1992) at this point is not appropriate. I therefore suggest to cite Tsurutani et al. (1992) in place of Gonzalez et al. (1994) and vice versa. Of course, when citing the classification of Gonzalez et al. (1994) please check the thresholds of the Dst intervals and change the names of the different intensities of the geomagnetic storms.

Answer: In the revised manuscript following modification is done:

On the basis of the Dst index and the Bz component of the IMF, the geomagnetic storms can be categorized as follows: weak or minor storms (Dst $\leq -30$ nT, Bz $\leq -3$ nT during 1 hour), moderate storms (Dst $\leq -50$ nT, Bz $\leq -5$ nT during 2 hours), intense storms (Dst $\leq -100$ nT, Bz $\leq -10$ nT for 3 hours) and severe storms (Dst $\leq -200$ nT) (Gonzalez et al. (1994); Tsurutani et al. (1992); Loewe and Prolss (1997)). Some scientists have used the SYM-H geomagnetic index as a replacement of the Dst index due to advantage of its 1 min time resolution compared to the 1 h time resolution of the Dst index (Wanliss and Showalter (2006)). The 3 h value of the Kp index has also been used for the classification of the geomagnetic storms as: weak or minor storms ($5- \leq$ Kp $\leq 5$), moderate storms(Kp $\geq 6$), intense storms ($7- \leq$ Kp $\leq 7$) and severe storms (Kp $\geq 8-$) (Gosling et al. (1991)).

Page 1, line 19: Change "Therefore, the effects of geomagnetic storms are non uniform in different regions of the magnetosphere." Into "Therefore, geomagnetic storms produce effects that are different in the different regions of the magnetosphere".

Answer: The change is incorporated in the revised manuscript.

Page 1, line 21: Change “...observed which is almost two times higher than that of the quiet day value.” Into “...observed, these have an amplitude that is almost twice that of a quiet day.” Here the authors refer to “the quiet day”. Are they referring to a specific quiet day or in general to “a quiet day”?
Answer: The change is incorporated in the revised manuscript.

Page 2, line 1: PPEF is generally used as the acronym of Prompt Penetration Electric Field and not Prompt Penetration Effects. Please correct the sentence.
Answer: The change is incorporated in the revised manuscript.

Page 2, line 2: Change “It is also found that the prompt penetration effect is almost uniform along the longitudinal direction.” Into “It is also found that the effect of the prompt penetration electric field is almost uniform along the longitudinal direction.”
Answer: The change is incorporated in the revised manuscript.

Page 1, line 19: “The ionosphere features vary along the latitudes and longitudes due to different current systems flowing in the magnetosphere.“ This sentence is too general and not completely correct. Better to say “During geomagnetic storms, the ionosphere features vary along the latitudes and longitudes also due to different current systems flowing in the magnetosphere.”
Answer: The change is incorporated in the revised manuscript.

Page 2, line 29: Please specify something about the “energy transfer”, e.g. it occurs between . . .
Answer: Following modification is done:
Many authors have analyzed the St. Patrick day storm (the largest geomagnetic storm



of the Solar cycle 24) by using the GPS-TEC data analysis techniques to understand the positive and negative ionospheric-storm effects due to energy transfer between the solar wind and the magnetosphere.

Page 2, line 32: I do not understand the logical sense of using “However” at this point.
Answer: ‘However’ has been removed.

Page 3, line 1: For the first time in the manuscript you mention here a “Northern equator anomaly”. Which anomaly are you talking of? Please add something more.
Answer: Following modification is done in the revised manuscript:
A rapid enhancement in the ionospheric electron density distorts the structure of the northern equatorial ionization anomaly region. It is also observed that during the main phase a significant decrease in the vTEC occurs at the high latitude as compared to the lower latitude region. Moreover, the height of the peak electron density in the F2 layer also increases during the geomagnetic storm.

Page 4, lines 5-10: Please add a reference for Sym-H index and for AE index.
Answer: In the revised manuscript the references for the SYM-H and the AE indices have been added.

Page 4 line 15 Change “definite” into “definitive”.
Answer: “definite” has been replaced by “definitive”.

Page 5, lines 17-19: What differences are you talking of? Please specify. Correct, accordingly, also the caption of Figure 2.
Answer: The following modification is done in the revised manuscript:
Figure 2 shows the $\Delta$ REC (top), the $\Delta$ GEC (middle) and the SYM-H index (bottom)

during the period September 4-14, 2017. The $\Delta$ REC is calculated by taking the difference between the REC of each sector and the average daily values of the three quiet days before the storm having the Ap index below 22 nT. Similarly, the $\Delta$ GEC is the difference between the GEC and the average daily value of the three quiet days as considered in $\Delta$ REC.
Page 5, line 19: What do you mean by "the five quiet days"? Maybe "the five quietest days"? In any case you have to specify, for these days, the level of geomagnetic activity by using some geomagnetic activity index (e.g., Dst, Kp...). Answer: The quiet time variations are computed by using the five quiet days before the storm having the Ap index below 22 nT.

Page 5, lines 24-29: Change "panel" into "plots" everywhere in these lines. Panels are usually a composition of plots.
Answer: Panels has been replaced by plots in the revised manuscript.

Page 5, line 28: Invert the order of "daily" and "quiet".
Answer: Correct order "quiet daily" has been used in the revised manuscript.

Page 6, line 19: Change "magnetometer variations" into "magnetic field variations".
Answer: In the revised manuscript "magnetometer variations" is replaced by "magnetic field variations".

Page 7, line 1: Invert the order of "daily" and "quiet".
Answer: Correct order "quiet daily" has been used in the revised manuscript.

Page 7, line 1: Specify how the "disturbances" have been calculated.
Answer: In order to calculate the magnetic field variations we adopted the approach of



Nava et al. (2016); Kashcheyev et al. (2018). The brief description of this approach is now added in the revised manuscript as:
The storm time magnetic field variations are analyzed by using the data from the three low latitude observatories in three sectors: Asia (KOU), Africa (MBO) and America (GUA). The quasi-definitive data of these observatories which are available at http://intermagnet.org have been used for the analysis. Table 2 shows geographic and geomagnetic locations of these observatories. In order to calculate the magnetic field variations we adopted the approach of Nava et 2016, Kashcheyev 2018. 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 $\phi$ 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

Page 11: Caption of Figure 3, indicate what the dashed line is for.
Answer: The three dashed lines correspond to the impact of the CMEs on 6, 7 and 12 September 2017.

Typo/language comments:
Answer: In the revised manuscript the Typo and language mistakes have been removed according to the referee's suggestions.
Most Typo/language comments have been made directly on an annotated pdf. Below, additional comments.
"Data" is commonly used as with a plural meaning, please change verbs accordingly throughout the manuscript.
Answer: In the revised manuscript the verb has been changed according to the referee's suggestions.
Add a space between the value and its unit (for instance, change 10nT into 10 nT) throughout the manuscript.
Answer: In the revised manuscript a space has been introduced between the value and the unit.
Change "Index" into "index" if not at the beginning of a sentence, throughout the manuscript.
Answer: In the revised manuscript 'index" has been changed according to the referee's suggestions.
When referring to mid latitudes you use both "mid" and "middle", choose one of the two terms and use it always.
Answer: In the revised manuscript the "mid" has been used to refer mid latitudes.
Concerning the use of acronyms. Two ways can be followed: 1) not to define them, 2) to define them but then to use them. For instance HSSWS is defined twice and never used.
Answer: In the revised manuscript the acronym HSSWS has been removed since we



haven't used it.
References in the bibliography are formatted with different styles, please refer to the specific reference style of the journal.
Answer: In the revised manuscript the bibliography has been updated according to the Journal style.

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-19/angeo-2019-19-AC4-supplement.pdf

Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-19, 2019.