Reviewer 1

Comments to "Latitudinal variations of ionospheric-thermospheric responses to Geomagnetic Storms from Multi-Instruments" by Rasim Shahzad et al.

Ionospheric responses to magnetic storms have been widely investigated due to the remarkable influences of storms on the space environment. In this paper the authors used multiple measurements that cover low to higher latitudes to investigate ionospheric and thermospheric responses to the magnetic storms of June 2015 and August 2018, including TEC measurements of ground-based receivers and the SWARM satellites, TIMED/GUVI [O/N2] ratio, Magnetometer observations, and various indices and solar wind parameters. My major concern is that the ionosphere has complex background variations and day-to-day variations, in Figures 4-8 how did the authors exactly (there are many quantitative descriptions for the responses to the storms) determine the responses to the different phases of storms from the complex TEC variability caused by multiple factors. Maybe you have done such, whereas there is no a detailed explanation in the text. A reference for the background variation of TEC may be helpful.

In the "Discussion" section, many explanations are suggested for the physical processes that cause the storm time responses, I think there are somewhat short of convinced observation evidences and detailed analyses. Figures 9-13 may be moved to the "Discussion" section to analyze the mechanisms in more detail.

Dear Reviewer thanks for your suggestion and useful comments. We have tried to improve the discussion as per your comments.

Moreover,

Lines 305-309: Please explain why the reductions (enhancements) of the [O/N2] ratio result in the increment (depletion) of vTEC.

Ans: Done

in O/N2 values resulting in rise of vTEC in that specific region (Figure 3, 4 & 9). The combined effect of an increment of oxygen (O) along with a decrease in molecular nitrogen (N2) can lead to enhancement in O/N2 and vice versa. As thermospheric oxygen or molecular N2 supplies from

high latitudes varies during storms, ionosphere plasma density can get higher or less dense depending on recombination probability (Paul et al. 2018, 2020). There are several reports in

Line 317-324: You mentioned TEC enhancement and larger TEC variation. How did you confirm them to be related to the storms, not ionospheric background variations?

Ans: We also analyzed the data of 10 to 20 days before and after the commencement of geomagnetic storms. But, to show clear storm time variation we only utilized 2 days before and 1 day after the geomagnetic storm. As in Fig 4 to 6 of GNSS Receiver's vTEC one can clearly see the vTEC fluctuation in various region in reference to different geomagnetic storms indicated in figure as well. Further GUVI, Magnetometer, Geomagnetic indices along with PPEF data depicted strong correlation with vTEC variation showing these variations are due to geomagnetic storms.

The PPEF and disturbed dynamo electric field are emphasized. You may further check the changes in the latitudinal structure of the low-latitude ionosphere such as EIA to analyze the effect of the zonal electric field, not only talk about the low-latitude density enhancement.

Ans: Dear reviewer, the GIM maps show clearly the EIA variations at different latitudes. The GNSS VTEC from stations at different latitudes also mean to clear the extent of variations in EIA at different latitudes. Thanks for your brief comments.

Minor comments:

Line 66-80: It is not a logical introduction.

Ans: Thank you very much. We have revised the text.

"In the equatorial and low latitudes, the electrodynamics in the ionospheric E and F regions influences the plasma distribution (Heelis, 2004). Field Aligned Current System (FACS) controls the transfer of energy and momentum from the magnetosphere to the ionosphere (Binod et al. 2017). The neutral wind dynamo induces electric fields in the low latitude regions during dayside (night side) having eastward (westward) direction (Fuller-Rowell, 2011). The zonal electric field corresponding to horizontal component of magnetic field generates plasma upwelling due to E×B effect. As a result, negatively and positively charged particles form on top and bottom of the ionospheric E region, respectively. At an altitude of 90-130 km, the migration of electrons produces an electric current known as the equatorial electrojet (EEJ). "

Tables 1 and 2: Why the geomagnetic locations of the stations change between 2015 and 2018? Is that due to the secular change of the Earth's magnetic field?

Ans: Yes, it is due to the secular variation of Earth's magnetic field. In July 2020 scientists report that analysis of simulations and a recent observational field model show that maximum rates of directional change of Earth's magnetic field reached ~10° per year. Further, Studies of lava flows on Steens Mountain, Oregon, indicate that the magnetic field could have shifted at a rate of up to 6° per day at some time in Earth's history.

Line 100: What does "duration of the solar activity" mean?

Ans: It means time duration of geomagnetic storm from commencement of storm to final phase of geomagnetic storm i.e., recovery phase.

Line 155: What does “dTEC” stand for? Please explain in the text.

Ans: It is the deviation from quiet-time variability (dTEC)

caused due to geomagnetic storms. The resulting deviation from quiet-time variability is noted here as dTEC. The Calabia and Jin model is available at https://zenodo.org/record/3563463.

Figures 7 and 8: It is better to mark the different phases of the storms in the figures. Please explain how you calculated dTEC. What is the reference value?

Ans: Dear reviewer, we apologize for missing descriptions: “In order to investigate the abrupt TEC anomalies during geomagnetic storms, the new empirical vTEC model of Calabia and Jin (2020, 2019) is used as quiet-time background. In this model, vTEC observables from 2003 to 2018 were reduced to a lower-dimensional through the principal component analysis, and the resulting time-expansion coefficients were parameterized in terms of solar and magnetospheric forcing, annual, and LST cycles. The quiet magnetospheric forcing is set during the geomagnetic index condition at Am=6. In this scheme, the diurnal, annual, and solar cycle variations are eliminated, and the residuals mainly show the short-term variations due to magnetospheric forcing; i.e., those variations mainly caused due to geomagnetic storms. The resulting deviation from quiet-time variability is noted here as dTEC. “

Fig 7 and 8 is updated according to storm phases.

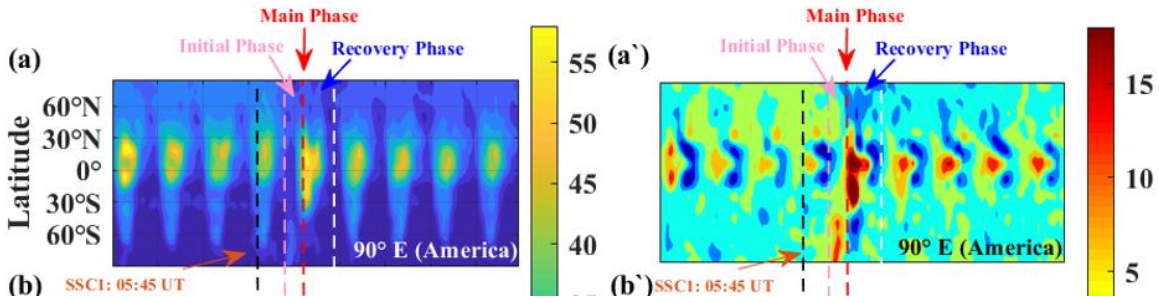
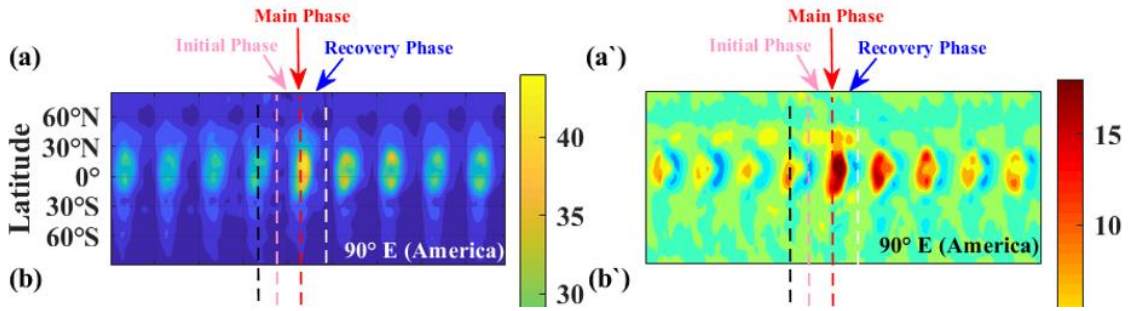


Fig 8



Line 239-240: The lowest Dst value was -203nT around 07:00 h UT on 26 August.

This cannot be seen from Figure 3. The lowest Dst did not reach -200 nT.

Ans: It is corrected.

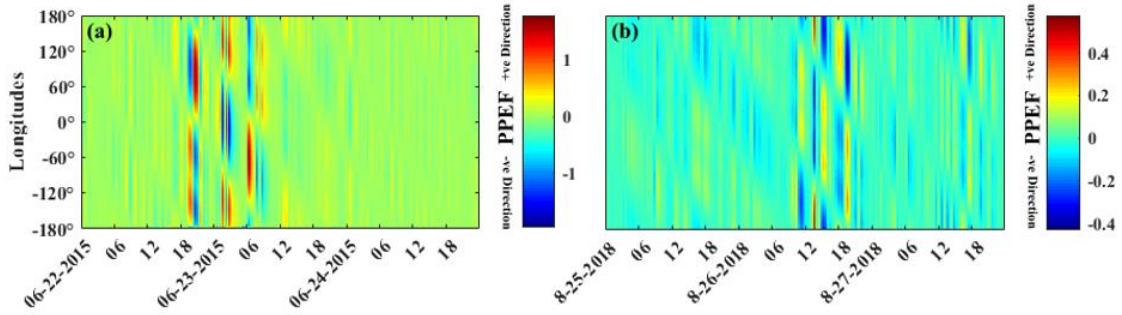
ɔurs of the SSC, at 09:00 h UT, a rapid drop in Dst
August. The lowest Dst value was -174nT around

Figures 10 and 11: It is better to add local time information into the figures. The distribution of the plasma density depends on local time.

Ans: Dear reviewer: 'We analyzed the storm time variations in ionosphere during different phases around the globe in UT using GNSS receivers. Therefore, for SWARM time is also in UT to confirm the observed vTEC variations. In future we will work on local time as well.'

Figure 12: Please indicate the positive direction of the PPEF.

Ans: Done.



In the "summary":

line 464: How did you identify ionospheric irregularities (bubbles, blobs?) from SWARM TEC measurements?

Ans: Dear reviewers: 'In present study we quantify the impact of geomagnetic storms during multiple storm phase in ionosphere GPS vTEC variations. And, SWARM is only used to verify thee variations on global scale.'

Line 469: EEJ is not a direct driver of TEC variations, the driver is ionospheric electric field.

Ans: It is corrected as EEJ>>EIA (Typing Mistake). As low and mid latitude go through storm time variations generated by fountain effect leading to strong EIA.

most part of world during main phase of both the storms. These ionospheric variations at low-and mid-latitude regions during main phases of the both the storms are mainly driven by thermospheric O/N2 ratio, PPEF and enhanced EIA.

There are many English/grammar mistakes, some suggestions (not cover all mistakes) are as follows:

Line 22: analyze -> analyzed Done

Line 41: trigger -> triggers Done

Line 67: please delete "due to PPEF", repeat with the front Done

Line 68: induced -> induce Done

Line 75: in eastward -> are in eastward Done

Line 76-77: The zonal electric field corresponding to horizontal component of magnetic field Done

Line 101: we need satellites Done

Line 124: a measure of -> positively correlated with Done

Line 125: please delete "increases in N2 decreases electron density", the determining factor is the [O/N2] ratio. Done

Line 171: This data aims -> these data aim Done

Line 172: is -> are Done

Line 251: VTEC -> vTEC, please keep consistent throughout the text. Done

Line 252: 42~50 TECU … Done

Line 254: 18~20 TECU … Done

Line 349: this due to -> this is due to Done