Response to Referee #1

Firstly I would like to sincerely thank once again the referee for his/her valuable comments in an effort to improve my article.

In the new revised version I have already addressed all the concerns of referee #1:

The reply of the author that the same effect has been found in another paper is not an answer. 1) The storms studied are different 2) In the paper of Edemskiy et al.2018 they analysed TEC but also foF2 data. 3) The background that they used is not calculated considering 8 days

1) Dear referee, as there are not too many papers explicitly describing LTEs, only Edemskiy et al. Annales Geophysicae, 2018 and Sotomayor-Beltran International Journal of Geophysics, 2018 which study response to a G3 and G2 storm, respectively, another storm of the same category (G4) was looked for. Unfortunately the St. Patrick's day G4 storm did not show any LTEs. 2) Indeed they analyzed GIMs and foF2 data, but they did not analyzed further the GIMs, for example by applying the technique I am using in my paper. Hence, I am sure my work presents potential useful results for the community. 3) As just mentioned Edemskiy et al. Annales Geophysicae, 2018 did not use any background as they did not produce ΔTEC maps. They only used GIMs along with geomagentic indices and other parameters, like f0F2 data, to indicate the existence of their detected LTE; not even a originative mechanism is suggested. In my study I provide a further analysis of the GIMs which is the generation of the ΔTEC maps. On the other hand I have run my software for 10 and 12 days window and the results after a thorough inspection are the same as in Figure 2. It is worth mentioning, I hope, that Zhu et al. 2011 Geodesy and Geodynamics 2, 61-65 and other related studies about ionospheric anomalies have used a time window of 10 days in TEC maps obtaining reliable results.

At first the author should change the background, secondly he has to analyze ionosonde data. This spot with increased TEC covers Australia and it is possible to check this increase using Australian ionosonde stations. 02UT was a daytime in the Australian sector and the NmF2 increase due TAD moving equatorward is a standard situation in the beginning of a strong geomagnetic disturbance. This should be seen Checking ionosonde data.

Dear referee, as I indicated above, a window of 10 or 12 days does not produce any observable difference. In regards to ionosonde data, I have found out that some really interesting ones would be the ones from Canberra, Hobart and Macquarie Is. Unfortunately in the website of the Space Weather Services from the Australian Government Bureau of Meteorology only public data is available until 2014 and also unfortunately I do not have access to other private data. However here in Peru, I am already in talks with a founding member of the Low-Latitude Ionosphere Sensor Network (Valladares and Chau 2012 Radio Science, 47) which do not only own GPS stations but also Ionosondes and it is very likely that for a follow up study I may use their data. Back to the LTE from September 8, 2017 I have found a work by Lei et al. 2018 where they actually used among a diversity of instruments, ionosondes, to analyze the response to the geomagnetic storm of September 8, 2017 in the Asia-Australian region. After analyzing the ionosondes' data (NmF2 and hmF2) they could see and enhancement in the TEC, as you are also suggesting, and they also attribute this effect not only to TADs but possibly also to PPEFs; hence a combined effect. This last bit has been added to the paper in sections 3.5 and 4, and in the abstract as well.

Response to Referee #2

Firstly I would like to sincerely thank once again the referee for his/her valuable comments in an effort to improve my article.

In the new revised version I have already addressed all the concerns of referee #2:

1) First of all, the presented paper is not the first publihed results of TEC analysis for 8.09.2017. See the paper of J. Lei et al. (DOI: 10.1029/2017JA025166) and the report of D. Horozovic (DOI: 10.13140/RG.2.2.33749.73442).

Dear referee, indeed, this paper is not he first results; hence in the Abstract "first results" was changed to "results". Also the reference of Lei et al 2018 has been added to the text in section 3.1, 3.5 and 4.

2) The title shows that the article investigate TEC during 8.09.2017 but 2 out of 5 figures and almost a half of the Results section text are dedicated to St. Patrick's storm. Either reflect it in the title or reduce St. Patrick's part adding more information about storm from the title

Dear referee, in order not to change the title, the St. Patrick part was reduced (to one subsection) in section 3 and more information about the September 8, 2017 was added (4 subsections) in the same section. Very relevant information about the generation mechanisms was added as well in subsection 3.5

3) How did you check the effectiveness of the presented method in the LTE detection? It should be shown that it gives the claimed dtection of 95%. According to the text using the method you detected LTE which is turned out to be the southern crest of EIA. Here is CODE GIM map for 18UT of March 17, 2015 with the clear LTE near Weddell sea. Why did not you mentioned its presence? Is it due to absence of significant ΔTEC variations?

Dear referee, by using 2σ, it is considered that te confidence level of the detections are at 95%, which has been already indicated and checked by for example Zhou et al 2009 J. Atmos. Sol. Terr. Phys. 71, 959-966; Zhu et al. 2010 Geodesy Geodyn. 1, 23-28; Yao et al 2012 Chi. Sci Bull 57, 500-510. On the other hand, TEC enhancement in the Weddell sea is not mentioned because even though there is a variability, this variability is not outside the 2σ tolerance under consideration; hence, this especific anomaly does not show up in the produced ΔVTEC maps.

4) I would also recommend to show a series of ΔTEC maps to present the LTE dynamics more clearly

Dear referee, an additional figure (Fig. 3 in the revised version) was added showing the dynamics more clearly

5) Writing conclusions about "increment in intensity for this LTE" what level do you use as background? One can think that you mean that LTE exists all the time and became visible increasing its intensity

Dear referee, as indicate in section 2 I am using as a background basically the mean and to detect anomalies the tolerance of 2σ. The part of the sentence you are indicating "increment in intensity for this LTE" was reformulated to "increment of TEC to produce this LTE" in the conlcusion section.

6) Two out of three paragraphs of conclusion are dedicated to St. Patric's storm LTE and the one detected by other authors at August 15, 2015, with presentation of their suggestion of negative Bz influence on LTE generation. It would be better to describe in more details your statement of LTE generation connection with fountain effect and gives some specific detals of the investigated LTE manifestation

Dear referee, the two metioned paragraphs were reduced to one where also the storm of August 15, 2015 is mentioned. Also a better explanation of how the LTE from the September 8, 2017 was produced is indicated in section 3.5 following the work from Lei et al. 2018.

7) Figures 1 and 4 present data for a whole month whereas author uses only several days to analyze. Moreover such long series makes impossible to see details of indices variations and to check the timestamps presented in the text. Remove the data you are not using and add hours to timescale. Since you compare Dst and Bz dynamics in the text, it would be better to place Kp panel at the bottom of the figure.

Dear referee, as per suggested, the range of days shown in both figures were reduced. Additional ticks were added to the x- axes of the Dst and Bz plots. The panel of the Kp index was moved to the bottom of both figures

8) Figure 1 label: Bz is a north-south component of IMF and only negative values correspond to southward direction

Dear referee, indeed you are correct. The captions of Figure 1 and also Figure 4 were corrected to properly indicate the vertical component of the IMF.

9) Figures 2 and 5. TEC maps are discussed before ΔTEC ones To make the reaading less confussing it would be better to place TEC to the left ad ΔTEC to the right. To make ΔTEC maps more contrast it would be better to use some other color map with wite in a middle.

Dear referee, the order of the GIMs and ΔTEC maps were changed as well as the color map in the ΔTEC maps.

10) Figure 3 Please use the same style labels. Replace square brackets with round ones and add TEC before TECU. Why do you use fractional values for latitude? It will be easier to read integer numbers.

Dear referee, the square brackets and y axis title were changed. Some of the x-tick labels are fractional values due to the increment chosen between the x-ticks. To avoid confusion with the numbers they were rotated.

11) pg 3 ln12: "5-" instead of "-5"

Corrected

12) pg3 lns 28-30 This is a well-know fact, but here it is formulated as some new or at least unusual result.

Indeed, it is a well-known fact, thus the sentence was reformulated.

13) pg 4 The top paragraph takes 4/3 of the page and is difficult to read. Split it.

The Result section was split in subsections, and now is more easy to read.

14)pg4 lns 10-11 I did not understand why do you duplicate here the information presented above

Corrected

15) pg 4 ln 23, pg 5 ln 20, pg 6 ln13 Accodring to Space Weather storm of Augus 15, 2015 was rated as G3. Where did you get G2?

Indeed it is rated G3. The correction was done in the lines and pages indicated.

16) pg 5 ln8: "several" not "some"

Corrected

17) pg 5 ln 10: repalce 4 with 5 in Fig.4

Corrected

18)pg 5 lns 11-12 What do you mean by "increment or decrement of "VTEC"? If it is not about a temporal variations it would be better to describe them as deviations from medium value.

Yes, it is a deviation from the mean value which I am refering to, but in this case for March 17 and 19 at 02:00UT (Fig 5) there are not ionospheric anomalies visible due to the tolerance of 2σ used. Hence, the sentence was reformulated in the text to: "there are no anomalous variations of TEC observed"

19) pg6 ln 10: "What is was discovered was .." is not a good formulation, Rewrite this part.

Corrected

20) That looks like you are citing the paper of Hathaway and Upton only to explain what do you mean by solar cycle 24-25 minimum. I should note, that mentioned authors wrie more correctly: "from early 2016 to the end of 2019 - near the expected time of Cycle 24/25 minimum". I recommend to replace "solar cycle 24-25 minimum" by "since 2016".

Dear referee, this was changed in the Abstract, the last sentence of the Results and Discussion, and Conclusions sections.

Emergence of a localized total electron content enhancement during the severe geomagnetic storm of September 8, 2017

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Abstract.

In this work, the ~~first~~ results of the analysis on total electron content (TEC) data before, during and after the geomagnetic storm of September 8, 2017 are reported. One of the responses to geomagnetic storms due to the southern vertical interplanetary magnetic field (B_z) is the enhancement of the electron density in the ionosphere. Vertical TEC (VTEC) from the Center for Orbit determination in Europe (CODE) along with a statistical method were used to identify positive and/or negative ionospheric storms in response to the geomagnetic storm of September 8, 2017. When analysing the response to the storm of September 8, 2017 it was indeed possible to observe an enhancement of the equatorial ionization anomaly (EIA); however what it was unexpected, was the identification of a local TEC enhancement (LTE) to the south of the EIA (~40° S, right over New Zealand and extending towards the south-eastern coast of Australia and also eastward towards the Pacific). This was a very transitory LTE that lasted approximately ~~2~~ four hours, starting at ~02:00 UT on September 8 where its maximum VTEC increase was of 241,2%. Using the same statistical method~~we looked for~~ , comparable LTEs in a similar category geomagnetic storm, the 2015 St. Patrick's day storm~~; however forthis storm,~~ , were looked for. However, for the aforementioned storm no LTEs were identified. As also indicated in a past recent study for a LTE detected during the August 15, 2015 geomagnetic storm, an association between the LTE and the excursion of B_z ~~observed~~ seen during the September 8, 2017 storm ~~is observed . Nevertheless~~was observed as well. Furthermore, it is ~~more~~ very likely that a direct impact of the super-fountain effect along with ~~another ionospheric physical mechanism~~ travelling ionospheric disturbances may be playing an important role in the production of this LTE. Finally, it is indicated that ~~this~~ the September 8, 2017 LTE is the second one to be detected ~~during the current solar cycle minimum (24-25).~~ since the year 2016.

1 Introduction

Anomalies in the ionosphere can be product of different natural phenomena (Afraimovich et al., 2013). For instance earthquakes can produce positive or negative ionospheric anomalies ~~(e.g., Zakharenkova et al., 2008; Yao et al., 2012; Guo et al., 2015; Li et al., 2015)~~(although such variations are expected to be localized within the earthquake's preparation region (Dobrovolsky et al., 1979). On the other hand, major changes in the ionosphere are caused by geomagnetic storms (e.g., Buonsanto, 1999; Danilov, 2013). The response of the Earth's ionosphere to the geomagnetic storms are known as ionospheric storms. These ionospheric storms can disrupt technologies relying on transmission of radio frequencies (e.g., Buonsanto, 1999; Borries et al., 2015), and thus they can have an impact in the modern society in general.

In order to understand better ionospheric variability in time and space produced by geomagentic storms, Global Navigation Satellite System (GNSS) receivers, due to its global coverage, are used as one of the tools for ionospheric studies. According to several studies (e.g., Huang et al., 2005; Mannucci et al., 2005; Astafyeva, 2009), one common response to a geomagnetic storm due to the excursion of the southward interplanetary magnetic field is the significant increment in the equatorial and mid-latitude total electron content (TEC), which manifests as an enhancement of the equatorial ionization anomaly (EIA; Appleton, 1946; McDonald et al., 2011). Such increase of TEC in the EIA is possible to visualize in global ionospheric maps (GIMs). Besides changes in the EIA, it was recently observed by Edemskiy et al. (2018) and Sotomayor-Beltran (2018) that localized TEC enhancements (LTEs) can also emerge as a response to geomagnetic storms.

In this paper vertical TEC (VTEC) maps, also known as global ionospheric maps (GIMs), due to its reliability on ionospheric information (Hernández-Pajares et al., 2009), were used to analyse the response to the geomagnetic storm of September 8, 2017. Section 2 introduces the ionospheric data and the technique for the corresponding analysis. In Sect. 3 the results and the discussion are presented. Section 4 presents the final remarks or conclusions.

2 Data and methods

VTEC maps were downloaded via ftp[1] from the Center for Orbit Determination in Europe (CODE) between August 21, 2017 and September 20, 2017. VTEC maps, which have a resolution of 2.5° x 5° (latitude and longitude, respectively), come in daily IONnosphere Map EXchange files (Schaer et al., 1998) and they are produced every hour. Due to the format of the IONEX files, which consists of headers and the actual VTEC data, a code entirely written in Python was implemented for this work. Using the NumPy[2] library, which handles relatively easily N-dimensional arrays, the VTEC data was stored in a 3D cube for further analysis. The x, y and z axes in the 3D cube are longitude, latitude and number of maps, respectively.

In order to indentify ionospheric anomalies a running window of 8 days to every cell in the 3D VTEC cube ~~is~~ was applied (e.g., Liu et al., 2004; Zhu et al., 2010; Zou and Zhao, 2010; Li et al., 2015; Sotomayor-Beltran, 2018). Assuming that for each cell or line-of-sight, the VTEC follows a Gaussian distribution, the mean (μ) VTEC and its associated standard deviation (σ) are calculated in order to define the upper and lower bounds:

$$UB = \mu + 2\sigma, \quad (1)$$

$$LB = \mu - 2\sigma. \quad (2)$$

[1] ftp://ftp.aiub.unibe.ch/CODE/
[2] http://www.numpy.org/

If a VTEC value for a certain day at a particular time falls above the UB, then a positive ionospheric anomaly is detected with a confidence level of 95%. The difference between the VTEC and UB or LB is defined as differential VTEC (ΔVTEC). On the other hand, if the VTEC falls bellow the LB, then a negative anomaly is detected. In this way, a cube of ΔVTEC ~~is~~ was created, with a total of 744 maps. If $UB >$ VTEC $> LB$, then ΔVTEC = 0

Some important geomagnetic parameters ~~are~~ were also needed to be taken into account for the analysis. The Dst index (Sugiura, 1964) provides information about the strength of the ring current around the Earth. According to Loewe and Prölss (1997) a magnetic storm can be considered as weak when -50 nT $<$ Dst $\leq$ -30 nT. A moderate and strong storm occurrs when -100 nT $<$ Dst $\leq$ -50 nT and -200 nT $<$ Dst $\leq$ -100 nT, respectively. Finally, a severe storm happens when Dst $\leq$ -200 nT. For this study Dst data for the month of September 2017 was downloaded from World Data Center for Geomagnetism in Kyoto[3]. Another very important index which measures the fluctuations caused in the Earth's magnetic field by a geomagnetic storm is the Kp index. According to Gosling et al. (1991) when Kp $\geq$ 8- and Kp $\geq$ 6- for at least three 3-h intervals, the storm can be considered a major one. A large storm occurs when 7- $\leq$ Kp $\leq$ 7 and Kp $\geq$ 6 for at least three 3-h intervals. For other cases when Kp $\geq$ 6- for at least three 3-h intervals the storm can be considered of medium strength. Finally, a small storm happens when ~~-5~~ 5- $\leq$ Kp $\leq$ 5. Kp data for September 2017 was retrieved from the German Research Centre for Geosciences (GFZ[4]). The vertical interplanetary magnetic field (B_z; Tsurutani et al., 1988) also is a good indicator of a geomagnetic storm. When there is a strong southward B_z for more than 3 hours a geomagnetic storm is in development (Gonzalez et al., 1994; Liu and Li, 2002). Hourly averages for B_z ~~where~~ also for the month of September 2017 were dowloaded from the OMNI datasabe[5]. In Fig. 1 the Dst and Kp indices and also ~~the southward interplanetary~~ B_z (in geocentric solar magnetospheric coordinate system) can be observed for a range of days (September 3 – September 16) within the month of September 2017.

3 Results and ~~discussion~~Discussion

Figure 1 shows that Kp = 8 during the last 3 hours (UT) of September 7 and the first three hours of September 8. According to the National Oceanic and Atmospheric Administration (NOAA) space weather service[6], this geomagnetic storm can be classified as a G4 severe storm (Kp = 8). Additionally, for September 8, 2017 between 00:00 and 04:00 UT the Dst index had values lower than -100 nT (Fig. 1).

The origin of this geomagnetic storm lies in the coronal mass ejection (CME) that occurred on September 6, 2017 at $\sim$12:40 UT. This CME was observed with the Camera 2 of the Large Angle and Spectrometric Coronograph on board of the Solar and Heliospheric Observatory (SOHO[7]). Figure 1 also shows that on September 8 at $\sim$00:00 UT the vertical interplanetary magnetic field decreased significantly to a minimum of -24 nT. One hour before (September 7 at 23:00 UT), B_z already decreased considerably to -20.6 nT, time of the storm sudden commencement (Fig. 1). In addition, it can be noticed that almost

[3] http://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html
[4] https://www.gfz-potsdam.de/en/kp-index/
[5] https://omniweb.gsfc.nasa.gov/form/dx1.html
[6] https://www.swpc.noaa.gov/noaa-scales-explanation
[7] https://sohowww.nascom.nasa.gov/

simultaneously with the drastic change of B_z, the Dst index reached its peak at 01:00 UT on September 8, 2017. ~~This~~ As it is already well-known, this relationship between B_z and the Dst index hints to a physical response of the ring current in the magnetosphere to the interplanetary field B_z (Patel and Desai, 1973; Gonzalez and Echer, 2005).

~~In the right~~

3.1 GIM maps

In the left column of Fig. 2, GIMs for September 7, 8 and 9, 2017 at 02:00 UT are presented. It is clearly seen in the GIM of September 8 at 02:00 UT (just three hours after the storm sudden commencement) that the VTEC was enhanced in the EIA region with respect to the day before (September 7) and the day after (September 9) at the same hour. ~~This~~ A recent study by Lei et al. (2018), using diverse instruments (e.g., satellites and ionosondes), has also observed this TEC enhancement in the Asian-Australian region for this geomagnetic storm. The increment of VTEC in the EIA was already observed in previous studies about ionospheric responses to geomagnetic storms (e.g., Zhao et al., 2005; Pedatella et al., 2009; Astafyeva et al., 2015; Chakraborty et al., 2015). ~~Moreover,~~

3.2 Differential VTEC maps

What it was quite compelling was the detection of a ionospheric localized anomaly (∼40° S), or as named by Edemskiy et al. (2018) a localized TEC enhancement (LTE), to the south of the southern conjugate geomagnetic region of the EIA~~was~~. This LTE can be identified in the GIM map of September 8, 2017 at ∼02:00 UT ~~. This LTE was very transitory, in the ∆VTEC maps it appeared at ∼02:00 UT on September 8 and at ∼04:00 UT it was already gone~~(Fig. 2). In the ~~left~~ right column of Fig. 2, ∆VTEC maps for September 7, 8 and 9, 2017 at 02:00 UT are also presented. It can be seen from these ∆VTEC maps that a day before and after that the LTE appeared, no anomalies were visible. However as already indicated, the day that the ionospheric storm occurred (September 8), the dramatic enhancement of the VTEC to the south of the EIA, manifested as a LTE, ~~is observed.~~ was observed.

In Fig. 3 the dynamics of the LTE can be clearly seen. It can be noticed that this LTE was very transitory, in the ∆VTEC maps it appeared at ∼02:00 UT on September 8 and at ∼06:00 UT it was already gone. This unforseen positive ionospheric storm covers most of New Zealand and extends westward towards the south-eastern part of Australia and eastward towards the Pacific. The maximum peak of this LTE happened as well on September 8 at 02:00 UT with ∆VTEC = 6.47 TECU (where 1 TECU = 10^{16} electrons/m^2).

3.3 Shape of the EIA

To better visualize this LTE to the south of the EIA, the shape of the VTEC along the meridional line of 170°E is shown in Fig. ~~3~~ 4 between September 7 and 9, 2017 at 02:00 UT. From the ∆VTEC maps (Fig. 2), it can be confirmed that the EIA follows its normal variability one day after (September 9 at 02:00 UT) and before (September 7 at 02:00 UT) that the storm occurred (no anomalous VTEC enhancements are visible). However, on September 8 at 02:00 UT the EIA ~~is~~ was significantly enhanced and hence this ~~translates~~ translated in a much sharper definition of the double-crest with a trough shape observed in Fig. ~~3~~4. This shape is expected because when the LTE is above New Zealand, it is still day time, the local time is 14:00 (02:00 UT). In addition to the two crests from the EIA, a third one in the southern hemisphere is visible (Fig. ~~3~~4). This third crest is simply the LTE observed in the ΔVTEC and GIM maps for September 8 at 02:00 UT (Fig. 2 and 3). The peak increment for this day and this time in the southern crest of the EIA is of 172% and in the LTE of 241,2%. Edemskiy et al. (2018) have also reported for the August 15, 2015 ~~G2~~ G3 geomagnetic storm that the two LTEs they observed were located to the south of the EIA (between Africa and Antarctica), whereas Sotomayor-Beltran (2018) has also identified to the south of the EIA a LTE over the Indian ocean during the G2 moderate storm of April 20, 2018.

3.4 The St. Patrick's day 2015 geomagnetic storm

In order to look for ~~such~~ comparable LTEs in a similar geomagnetic storm category, the author turned to the G4 geomagnetic storm that ~~happened~~ occurred during the St. Patrick's day of 2015 ~~,~~ which has been thoroughly studied (Astafyeva et al., 2015; Cherniak et al., 2015; Nava et al., 2016; Yao et al., 2016; Jin et al., 2017; Zhang et al., 2018). ~~This storm was also product of a CME and it was reported that the storm sudden commencement was at ∼04:45 UT on March 17, 2015 (Yao et al., 2016).~~ In Fig. ~~4~~5, the variability of the geomagnetic indices, Dst and Kp~~during the month of March 2015 can be observed. The Kp index reached a value of 8 at 12:00 UT on March 17, 2015, whereas the Dst index started to decrease drastically starting at ∼08:00 UT until 22:00 UT of that same day; at this time it reached its minimum of -222 nT. On the other hand it can also be seen in Fig. 4, that B_z decreases significantly to -16 nT at 08:00 UT. The~~ , and the vertical interplanetary magnetic field ~~remained afterwards with values lower than -10 nT between ∼~~for a period of days (March 13 ~~:00 and 23:00 UT on March 17, 2015. The statistical method applied to the G4 storm of September 8, 2017 in this paper was also applied to GIMs during the St. Patrick's storm. IONEX files from CODE were downloaded and processed with the Python software written for this work for the range of days between February~~ – March 27~~,~~) in the month of March 2015 ~~and April 3, 2015. Part of the resultant~~ can be observed. GIMs and ΔVTEC maps are shown in Fig. ~~5. Going through~~ 6. In the ΔVTEC maps ~~created for the aforementioned range of days,~~ it was possible to observe a positive ionospheric storm starting on March 17, 2015 at ∼18:00 UT right over the southern Atlantic, right north off the Antarctic coast. This positive storm started to move westward and it reached its maximum strength on March 18, 2015 at ∼02:00 UT with a peak of ΔVTEC = 12.88 TECU (Fig. ~~5~~6). In this case however, the enhancement of VTEC observed in the southern hemisphere is not a LTE, it is only the sourthern crest of the EIA which underwent an increment of VTEC and shifted ~~some~~ several degrees southward. On the other hand in the ΔVTEC maps of March 17, 2015 starting at ∼22:00 UT, negative ionospheric storms were also observed and they lasted until the end of the day of March 18, 2015. These both results agree well with the ones from previous studies, using different methods, for the St. Patrick's day 2015 storm (Astafyeva et al., 2015; Yao et al., 2016). It can also be finally noticed in Fig. ~~4~~ 6, in the ΔVTEC maps, that at 02:00 UT the day before and the day after the maximum peak of the positive ionospheric storm ~~, the increment or decrement of VTEC are minimal~~there are no anomalous variations of the observed TEC.

3.5 Creation of September 8, 2017 LTE

For the case of the St. Patrick storm of 2015, ~~when~~ for the observed positive ~~storm~~ one in the southern hemisphere and negative storm in the northern hemisphere~~are co-existing (what is also known as hemispheric asymmetry), it could be assumed that the mechanism at work producing this asymmetry was the storm-time thermospheric circulation (Fuller-Rowell et al., 1994; Fang et al., 2012). However according to this theory, the positive ionsopheric storms are expected in the winter hemisphere and the negative ionospheric storms in the summer hemisphere; hence, ~~,~~ , Astafyeva et al. (2015) and Yao et al. (2016) ~~ruled out this theory as a possibility for the origin of the detected ionospheric storms. They, nevertheless, indicated three more suitable candidates~~ indicated three suitable candidates as the origin mechanisms: the strength of the geomagnetic field, the B_y component of the interplanetary magnetic field and composition changes in the thermosphere. On the other hand, for the moderate ~~G2~~ G3 storm of August 15, 2015 ~~(Edemskiy et al., 2018)~~ there was not a clear mechanism put forward by Edemskiy et al. (2018) to account for the observed LTEs. Only a dependance of the emergence of these LTEs to the interplanetary B_z was hinted at, but still as indicated by the authors of that study it was not their definite conclusion.

For the LTE observed during the September 8, 2017 severe storm in this work, an excursion of the interplanetary B_z ~~,~~ along with a consequent decrease of the Dst index ~~,~~ was also observed (Fig. 1). Thus, it can be suggested that there is as well an association between the interplanetary B_z and the emergence of the LTE. In this vein, Lei et al. (2018) have gone further and indicated that for the September 8, 2017 geomagnetic storm not only B_z could produce prompt penetration electric fields (PPEFs) which enhance the EIA (super-fountain effect) but also could produce traveling atmospheric disturbances (TADs). These TADs, which originate in the polar regions, can transport equatorward winds that drive plasma upwards in the middle and lower latitudes and as a consequence the ionosphere moves to higher altitudes (Chen et al., 2016). It is very likely then, as suggested by Lei et al. (2018), that the combined effect of TADs and the PPEFs are responsible for the creation of the LTE observed in Fig. 2 and 3. As per to the overall enhancement of the EIA (Fig. 2 and 3) and shifting of the crests in the direction of the poles observed in Fig. ~~3, it is~~ 4, as previously mentioned and suggested by many studies (e.g., Tsurutani et al., 2004; Mannucci et al., 2005; Astafyeva, 2009; Astafyeva et al., 2014; Chakraborty et al., 2015) ~~that~~ the mechanism at work ~~for this change of shape of the EIA~~ is the ionospheric super-fountain effect. ~~How this effect is connected or contributes to the appeareance of the LTE observed on September 8, 2017 at ~02:00 UT is still not clear, but that the super-fountain effect is playing an important role in its origin can not be ruled out. A partial contribution of this effect to the production of the LTE observed during the April 20, 2018 storm was suggested by Sotomayor-Beltran (2018). Furthermore,~~ Finally, it is also worth mentioning that this would be the second time a LTE is detected ~~during the solar cycle 24-25 minimum (Hathaway and Upton, 2016)~~since 2016, as the first one was the one observed during the April 20, 2018 geomagnetic storm (Sotomayor-Beltran, 2018).

4 Conclusions

Ionospheric response to the G4 severe geomagnetic storm of September 8, 2017 was analysed by using VTEC maps from CODE along with a statistical method to identify ionospheric anomalies. By producing differential VTEC maps it was possible to identify not only an enhancement of the EIA but also a localized TEC enhancement. The maximum intensity of this LTE was on September 8, 2017 at 02:00 UT and it was localized right over New Zealand and extending towards the south-eastern coast of Australia and eastward towards the Pacific. The LTE was quite transitory, it lasted only about two hours , for about four hours and on September 8 at 0406:00 UT it faded away. This LTE is the second one to be observed during the solar cycle 24-25 minimum. since 2016. By analyzing the latitudinal profiles, it could be determined that the increment in intensity for of TEC to produce this LTE was of 241.2%.

Due to its category, the G4 storm from March 17, 2015 was also investigated in order to look for LTEs; howevercomparable LTEs. However, there was no LTE detections . What is was discovered was and instead a hemispheric asymmetry of ionospheric storms in the northern and southern hemisphere . The origin of this asymmetry was explained in past studies by the strength of the geomagnetic field, the B_y component of the interplanetary magnetic field and composition changes in the thermosphere.

was observed. One geomagnetic storm which presented the same traits (LTEs) as in the one of September 8, 2017 was the G2 G3 August 15, 2015 moderate storm. During this storm also LTEs were identified south of the geomagnetic conjugate region of the EIA. These LTEs, was indicated, seem to be associated with the negative excursion of B_z. Because for

For the September 8, 2017 storm in the present study also such negative excursion was observedof the vertical component of the interplanetary magnetig field was observed; hence, it can be suggested then that the vertical interplanetary magnetic field component this has an effect on the origin of the LTE. However, due to the fact that the EIA undergoes a dramatic enhancement, the contribution of the Furthermore, it is very likely that TADs along with the super-fountain effect, the two of them due to B_z, are having a significant effect in the generation of the LTE would have to be taken into account as well. observed LTE. To shed more light into how these LTEs are created, further observations of these events along with physical modeling of the effects of the B_z on the super-fountain effect, TADs and possibly other contributing ionospheric mechansims would be needed.

Competing interests. The author declares that he does not have conflict of interest.

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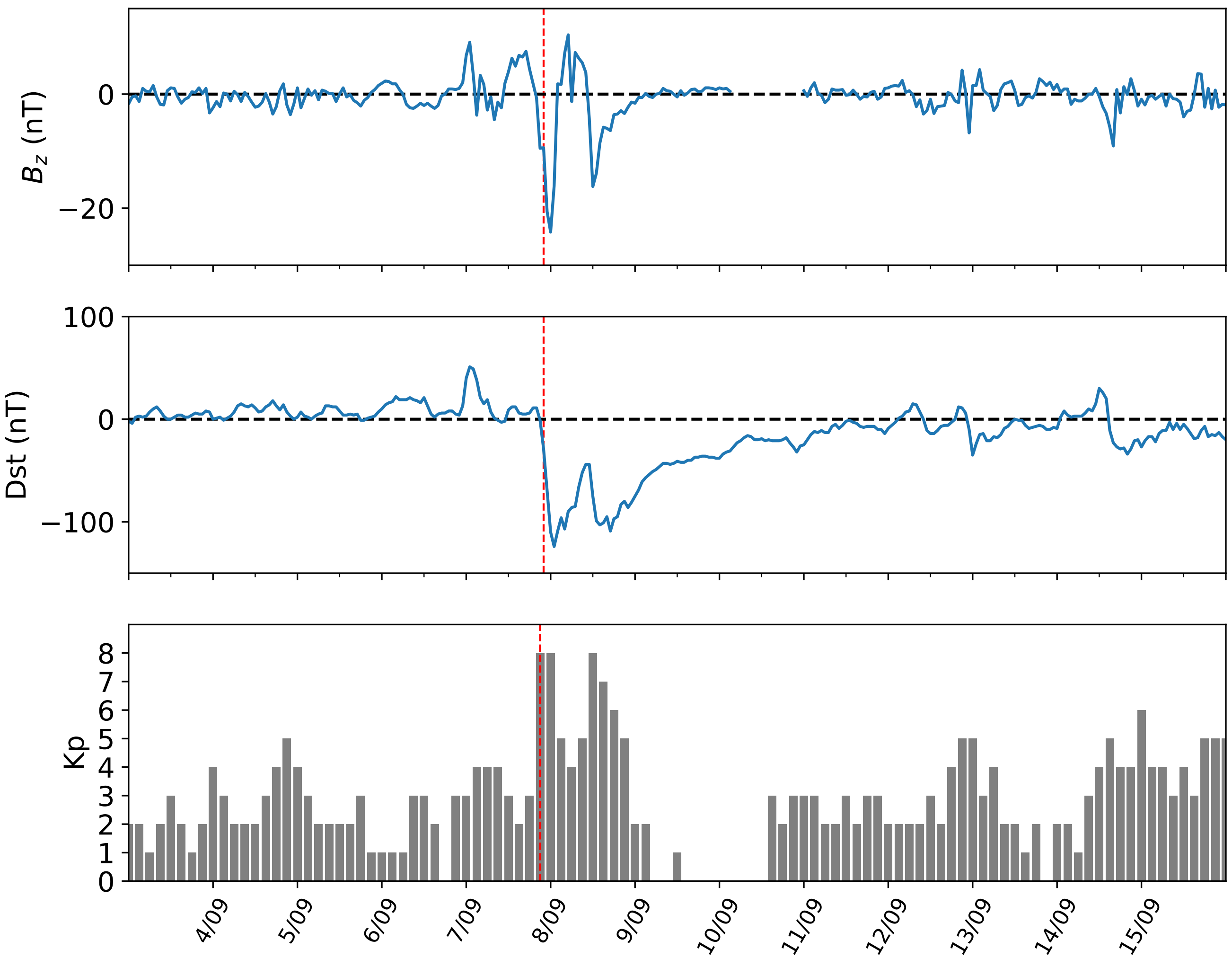

Figure 1. The ~~Dst and Kp indices and the southward~~ vertical component of interplanetary magnetic field (B_z) ~~for~~ and the ~~month of~~ Dst and Kp indices between September 3 and September 16, 2017. The vertical red dashed line in all the plots points to the storm sudden commencement.

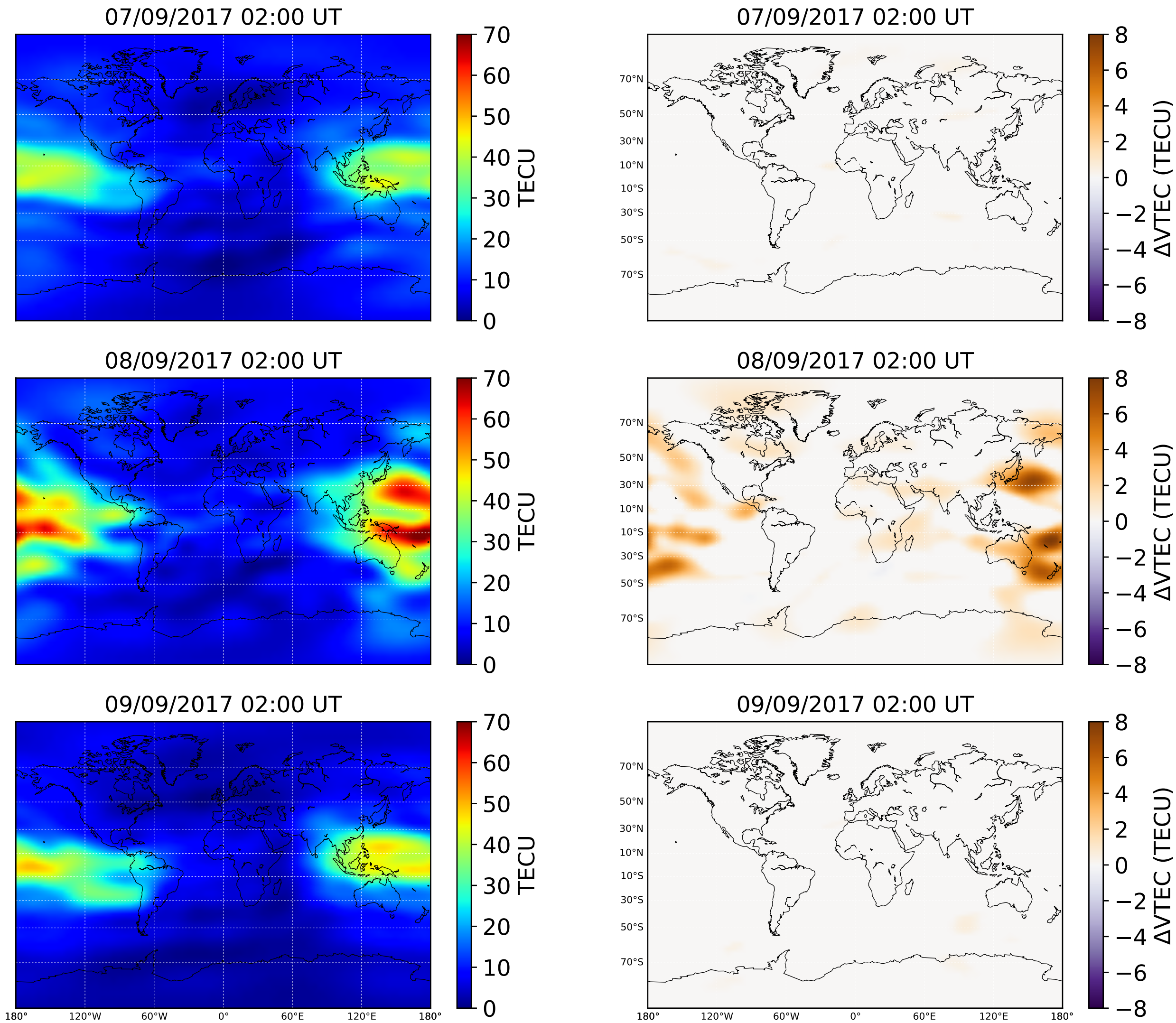

Figure 2. Left column: ~~Differential VTEC~~ Global ionospheric maps for September 7, 8 and 9, 2017 at 02:00 UT. Right column: ~~Global ionospheric~~ Differential VTEC maps for September 7, 8 and 9, 2017 at 02:00 UT.

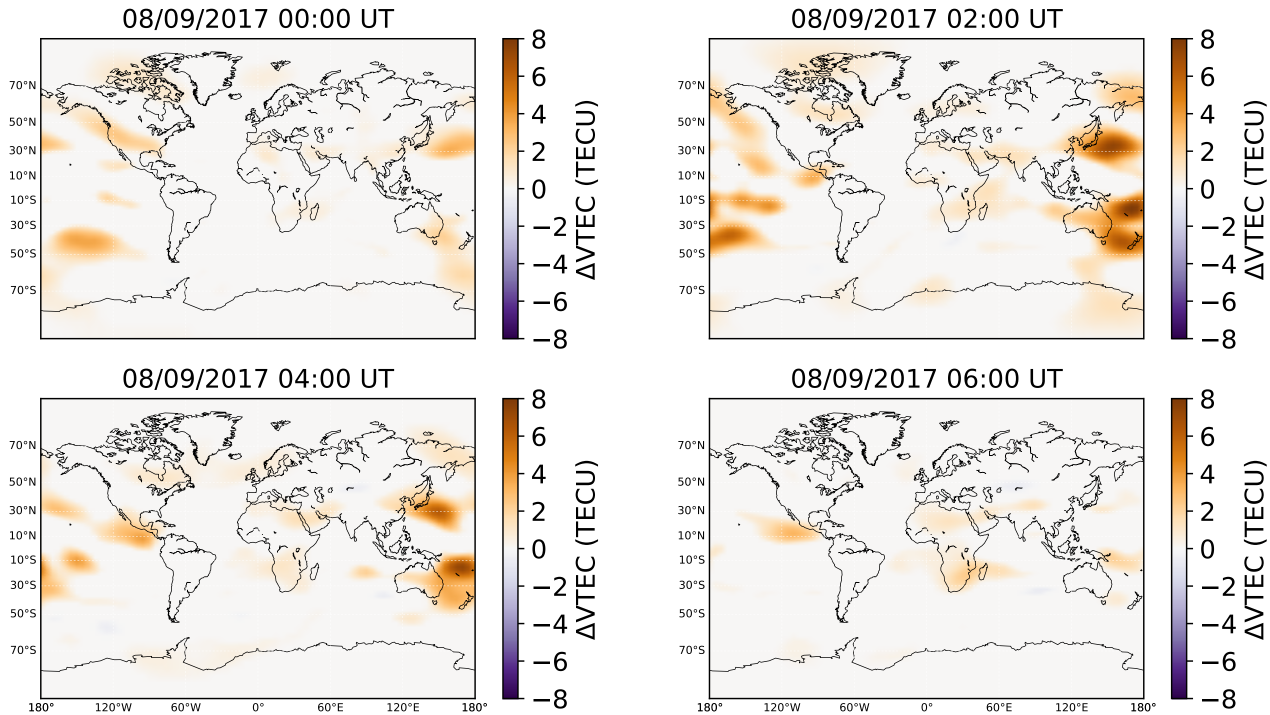

Figure 3. Differential VTEC maps for September 8, 2017 between 00:00 and 06:00 UT.

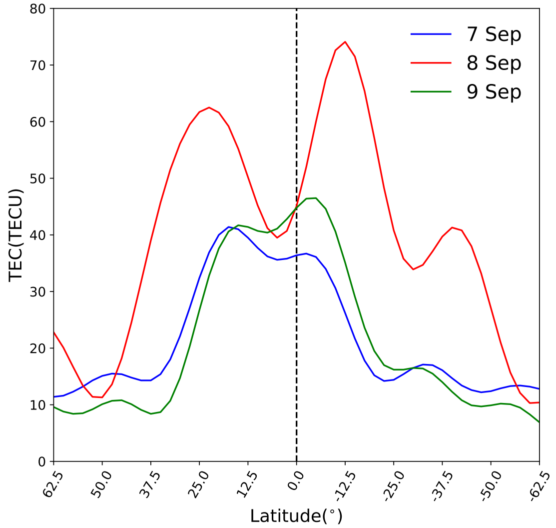

Figure 4. Structure of the VTEC for the 170°E meridian at 02:00 UT between September 7 and 9, 2017. A relevant range of latitudes is shown, 62.5°N–62.5°S. The vertical dashed black line indicates the Equator (latitude = 0°).

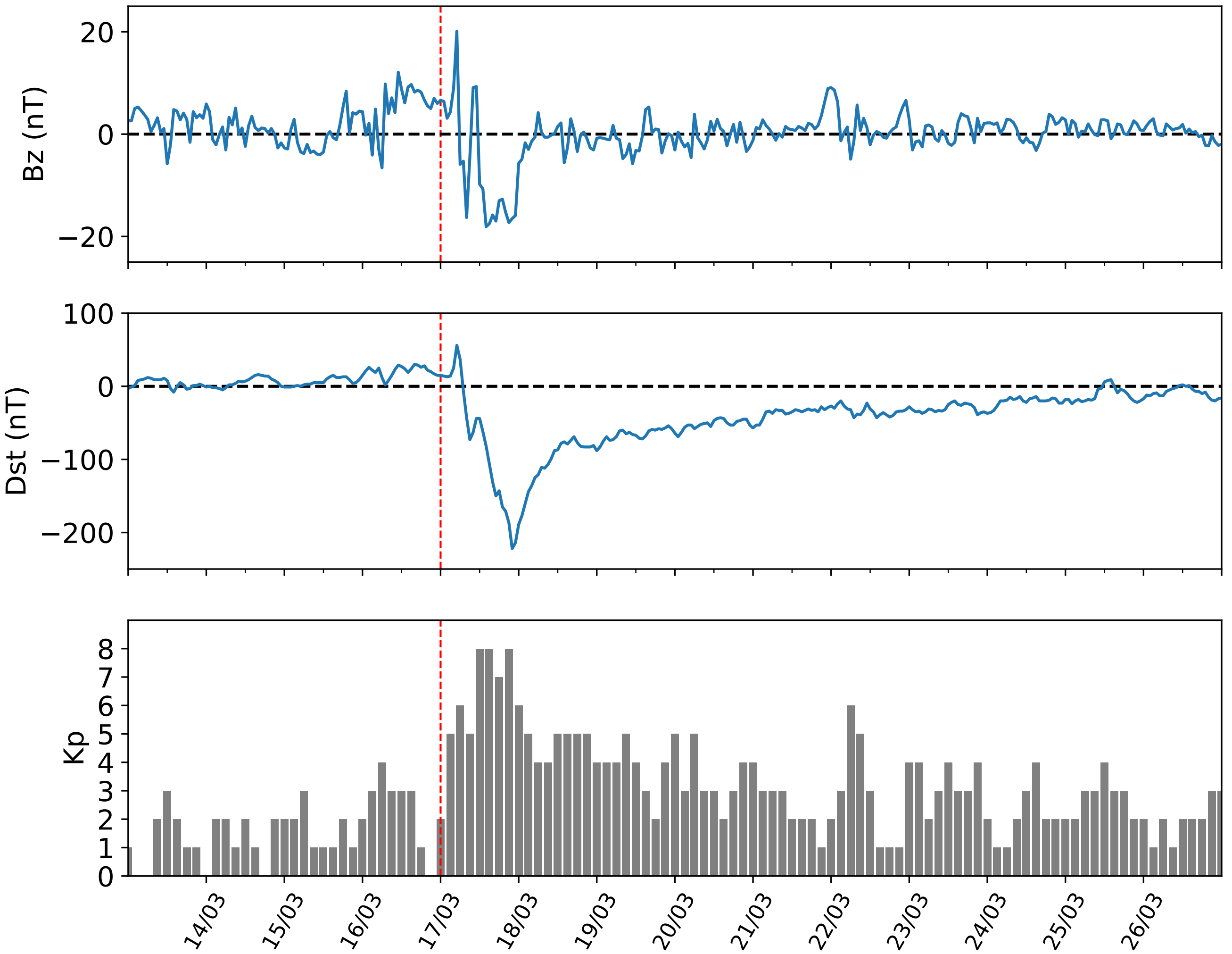

Figure 5. The ~~Dst and Kp geomagnetic indices and~~ vertical component of the ~~southward~~ interplanetary magnetic field (B_z) ~~for~~ and the ~~month of~~ Dst and Kp geomagnetic indices between March 13 and March 27, 2015. The vertical red dashed line in all the plots indicates the day that the 2015 St. Patrick's day storm occurred (March 17, 2015).

~~Left column: Differential VTEC maps for March 17, 18 and 19, 2015 at 02:00 UT. Right column: Global ionospheric maps for March 17,~~

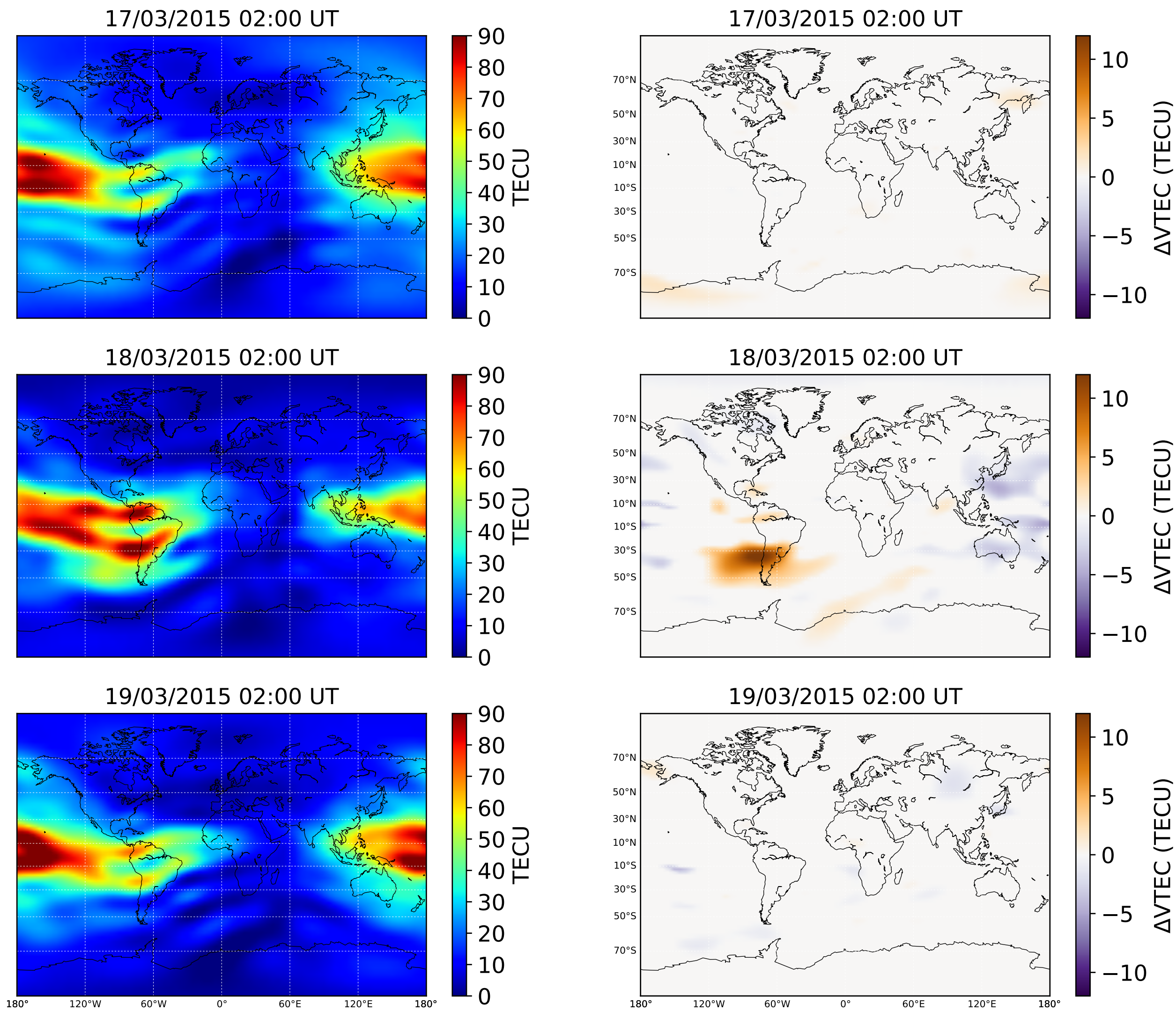

Figure 6. Left column: Global ionospheric maps for March 17, 18 and 19, 2015 at 02:00 UT. Right column: Differential VTEC maps for March 17, 18 and 19, 2015 at 02:00 UT.