Point-to-point Response:

General remark:
We thank the two referees for their comments and suggestions which have led to an improved, revised manuscript. We reformulated the introduction. We added an image about the dependence of ΔTEC on local time and added a short discussion about spread F during the post-sunset rise of the equatorial ionosphere. In the revised manuscript we also emphasize that the behaviour of F region irregularities during a geomagnetic storm is the main topic of the study.

Referee 1:

In the reviewer opinion, the introduction is not addressed with a logical structure. The authors should improve globally the introduction in order to show the reader: 1) an initial contextualization, 2) the related works (state of the art), 3) the objective and 4) the contribution of the new findings (positioning of the manuscript in the state of art). After reading the introduction, it is important for the reader to have a clear context of what is the contribution of the paper in comparison to past works. This is maybe,
from my point of view, the less accurate section of the manuscript. Furthermore, many sentences in the introduction have no connections between each other and a global rephrase of the sentences should improve the manuscript.

We agree that the introduction was a bit disordered. Now we begin with the main objective (F region irregularities). Then we review studies in the literature about F region irregularities. Then we focus on global maps of F region irregularities and studies related to our study. Finally we give an overview on our article.

The section that describes the used methodology should be improved. After carefully reading the proposed method for obtaining ΔNe and ΔTEC, the reviewer still found dif- ficult to understand how they were obtained. Including formulations explaining what is ΔNe and ΔTEC would benefit the manuscript. Indeed, before a proper understanding of what these parameters mean, the reviewer cannot make a fairly evaluation of the analysis.
Considering two occultations with tangent points between specific altitudes (e.g. 400 and 500 km), is ΔTEC the difference between the TEC of one occultation minus the TEC of the other occultation? Please, explain it better. Explain also what is the time resolution between the differences. Also, explain why are you referring this as "TEC profiles".

ΔTEC is obtained in the same manner as ΔNe where we described ΔNe in detail in Figure 1. Now we added a sentence where we inform that ΔTEC is obtained in the same manner as ΔNe. ΔTEC is not obtained as difference between two occultations. It is the difference between the TEC profile and its smoothed (filtered) TEC profile (as in Figure 1).

It is also important to better describe how the high pass filtering in the s-domain was obtained. Additionally, the authors need to be clear with the meaning of the bottom tangent point. The bottom point is located at 400 km in Figure 1? And, in this case of Figure 1, the tangent point is the point located at 500 km?

We added a sentence that the height of the bottom tangent point is usually between 50 and 150 km.

In the results, it would be important to include distributions not only referred to the longitude but also to the local time. The RO observations do not cover worldwide for every local time. Therefore, sometimes the irregularities seen in a specific location of the maps is not seen in another part because of the different local times. In the way that it is now, each pixel of the global distributions is referred for a distinct instant. The manuscript lacks a proper analysis on this. Even better would be if the authors could plot the maps in terms of magnetic latitude vs local time. Then the authors would be capable of showing a fair global distribution of irregularities.

Yes, we agree, the dependence of ΔTEC on local time is important. The revised manuscript provides a figure for the local time dependence in September 2013 (new figure 4). We find an increase of F rgion irregularities in the post-sunset equatorial ionosphere. At high latitudes the irregularities seem to be independent on local time.

One last principal question that remains about the manuscript is: Does it is possible to detect irregularities with such a low spatial resolution of the global representations? The authors said it is possible to detect small-scale fluctuations with spatial scales < 50km with RO. However, the global representation of such information is obtained with a spatial resolution of 5°x5° or 10°x10°. As far as I understood, such maps just give a general information of the number of irregularities in each pixel, but does not describe the irregularities itself. Instead of median, a more informative representation would be the number of times that the gradients of TEC are above some limit (e.g. ΔTEC>0.01 or another value to be defined in the manuscript with a proper reason). Even better would be the percentage of ΔTEC above the defined limit. Then you would have a global representation of irregularities. This because, as far as I understood, the blue up to ~green values are not irregularities, so that, you are not showing maps of irregularities. The way it is now, the irregularities are depending on the spatial resolution of the maps (compare the colorbar of Fig. 4 and 6), which has not a true meaning.

We analysed the TEC profiles having a high vertical resolution of about 1 km. From the fluctuation profiles, we derived the average global distribution of F region irregularities based on several days or a month of observations. In the past we also tried to analyse TEC gradients and the results were similar. However we think that the analysis as described by Figure 1 is most easy to understand and thus we selected this method.

A few other points:
a) In the abstract, COSMIC should read COSMIC/FORMOSAT-3.

Yes, we changed it.

b) Section 2 - Include that UCAR has first processed the data level 1 and level 2.

Yes, we changed it.

c) pg. 3 - change the word cigar to cylinder.

Yes, we changed it.

d) pg. 4 - NASA should read National Aeronautics and Space Administration (NASA)

Yes, we changed it.

e) pg. 4 - Citation of Zakharenkova and Astafyeva (2015) is lost in the middle of the text.

We started a new sentence with the finding of this study.

f) pg. 4 - "In the following, we average the TEC disturbances over all local times". Did you used the mean (average) or the median?

It is the mean. We added a new sentence.

g) It appears to me that the colorbar of the global Figures (such as Fig. 4) is truncated.

No, the color bar is not truncated.

Thank you for your review!

Referee 2:

Based on my reading of the manuscript, it was not so clear if the desired emphasis of the paper is:
- a demonstration of the usefulness of the dataset and the analysis technique (?), or
- a highlight of the geophysical phenomena consequential to the storm event (?), or
- a broad overview of the expected geospatial distribution of ionospheric irregularities under various condition (?)

I would suggest that the authors emphasize one particular aspect as a focal point, and the discussion of other aspects may revolve around it. I hope this re-organization of abstract/conclusion sections would not be too much to ask.

We agree. Now we emphasize at various places of the study (e.g., end of introduction) that the focus of our study is the global behaviour of F region irregularities during a geomagnetic storm. This is the new point of the study which was not covered by Watson and Pedatella (2018). We also reformulated the whole introduction section so that the intention of our study becomes clearer.

Furthermore, I would also like to suggest that extra labels are added to some of the figures in order to improve clarity.
Figure 3a: add a label "Arithmetic Mean" on the top of the colormap plot
Figure 3b: add a label "Median Function" on the top of the colormap plot
Figure 4a: add a label "Solar Minimum" on the top of the colormap plot
Figure 4b: add a label "Solar Maximum" on the top of the colormap plot
Figure 6a: add a label "Quiet Geomagnetic Condition, h=400-500 km" on the top of the colormap plot
Figure 6b: add a label "Geomagnetic Storm Condition, h=400-500 km" on the top of the colormap plot
Figure 7a: add a label "Quiet Geomagnetic Condition, h=200-300 km" on the top of the colormap plot
Figure 7b: add a label "Geomagnetic Storm Condition, h=200-300 km" on the top of the colormap plot

Good idea! We added the suggested labels in the new figures.

Global sounding of F region irregularities by COSMIC during a geomagnetic storm

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Abstract. We analyze reprocessed electron density profiles and TEC profiles of the ionosphere in September 2008 (around solar minimum) and September 2013 (around solar maximum) obtained by the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC/FORMOSAT-3). The TEC profiles describe the total electron content along the ray path from the GPS satellite to the low Earth orbit as function of the tangent point of the ray. Some of the profiles in the magnetic polar regions show small-scale fluctuations with spatial scales < 50km. Possibly the trajectory of the tangent point intersects spatial electron density irregularities in the magnetic polar region. For derivation of the morphology of the electron density and TEC fluctuations, a 50 km high pass filter is applied in the s-domain where s is the distance between a reference point (bottom tangent point) and the tangent point. For each profile, the mean of the fluctuations is calculated for tangent point altitudes between 400 and 500 km. First at all, the global maps of ΔN_e and ΔTEC are quite similar. However, ΔTEC might be more reliable since it is based on less retrieval assumptions. We find a significant difference if the arithmetic mean or the median is applied to the global map of September 2013. In agreement with literature, ΔTEC is enhanced during the post-sunset rise of the equatorial ionosphere in September 2013 which is associated with spread F and equatorial plasma bubbles. The global map of ΔTEC at solar maximum (September 2013) has stronger fluctuations than those at solar minimum (September 2008). ~~Finally,~~ We obtain new results when we compare the global maps of the quiet phase and the storm phase of the geomagnetic storm of 15 July 2012. It is evident that the TEC fluctuations are increased and extended over the Southern magnetic polar region at the day of the geomagnetic storm. The North-South asymmetry of the storm response is more pronounced in the upper ionosphere (ray tangent points h=400-500km) than in the lower ionosphere (ray tangent points h=200-300km).

1 Introduction

~~The study aims at the retrieval of global maps of the amplitude of small-scale ionospheric irregularities with scales from 2-50 km in the ionospheric $F2$ region between 400 and 500 km altitude using the~~ GPS radio occultation ~~technique. This technique was already utilized to derive global maps of sporadic E layers around 90-120 km altitude (Arras et al., 2010; Wu et al., 2005; Hocke et al.,~~

~~GPS radio occultation~~ can be regarded as a bistatic limb sounding of the atmosphere where the transmitter is on a GPS satellite and the receiver is on a Low Earth Orbit (LEO) satellite. The technique was described in detail by Rocken et al. (1997) and Hajj et al. (2002). GPS radio occultation was already utilized to derive global maps of sporadic E layers around 90-120 km altitude (Arras et al., 2010; Wu et al., 2005; Hocke et al., 2001). One of the main advantages of the GPS radio occultation technique is the high vertical resolution of about 1 km. ~~The~~

Our study aims at the retrieval of global maps of the amplitude of small-scale ionospheric irregularities with scales from 2-50 km in the ionospheric F_2 region between 400 and 500 km altitude using the GPS radio occultation technique~~was described in detail by Rocken et al. (1997) and Hajj et al. (2002).~~ . F region irregularities are inducing phase and amplitude scintillations in radio signals. Aarons (1982) showed a scheme of a global scintillation map where the scintillations are strong at high geomagnetic latitudes in the polar caps or after sunset around the geomagnetic equator (20°S to 20°N). Fejer and Kelley (1980) classified the F region irregularities into three groups: equatorial spread F, high-latitude irregularities and mid-latitude irregularities. Satellite measurements of the electric field and plasma density fluctuations indicate that the high-latitude ionosphere is highly structured and bounded by an extremely sharp transition between the disturbed polar region and the quiet ionosphere outside (Fejer and Kelley, 1980). The authors identify three main sources in production of high-latitude irregularities. There are production by particle precipitation, generation by electrostatic turbulence, and plasma instabilities. In addition, quasi-dc electric fields play an essential role in transporting irregular plasma at high-latitudes (Fejer and Kelley, 1980).

Recently, global distributions of topside ionospheric irregularities (above the LEO orbit) were retrieved by using in situ data of LEO satellites (Zakharenkova and Astafyeva, 2015). Hocke et al. (2002) attempted to extract the fluctuations of total electron content along the GPS-LEO link at tangent point altitudes between 400 and 600 km. However, the global coverage of the occultation events of the early GPS/MET experiment was poor, and the measurement phase was during solar minimum in 1995 when less ionospheric irregularities are expected. Another approach is the use of the ground station network of GPS and GLONASS receivers. Cherniak and Zakharenkova (2017) monitored high-latitude ionospheric irregularities during the geomagnetic storm of June 2015 and derived polar maps of the distribution of the plasma irregularities based on the observations of the ground station network. Carter et al. (2013) analysed the scintillations of the GPS signals received by COSMIC-FORMOSAT-3. They found a spatio-temporal distribution of the GPS scintillations which is similar to those of equatorial spread F and equatorial plasma bubbles. However, high-latitude F region irregularities were not found by Carter et al. (2013). Watson and Pedatella (2018) derived characteristics of medium-scale F-region plasma irregularities as observed by the COSMIC radio occultation receivers. They analysed 2 to 50 km vertical fluctuations of the observed TEC profiles. The most intense equatorial irregularities are observed around 20:00-24:00 MLT, and correspond to a decrease in the average irregularity scale-size.

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~~three main sources in production of high-latitude irregularities . There are production by particle precipitation, generation by electrostatic turbulence, and plasma instabilities. In addition, quasi-dc electric fields play an essential role in transporting irregular plasma at high-latitudes (Fejer and Kelley, 1980).~~ Our study is related to the study of Watson and Pedatella (2018) but we will add an analysis of the change of TEC irregularities before and during a geomagnetic storm. Our study takes advantage of the dense spatio-temporal sampling of ionospheric occultations provided by six LEO satellites. Section 2 describes the GPS radio occultation mission COSMIC and the data analysis for the extraction of ionospheric fluctuations. The results are shown and discussed in section 3. The new result and the focus of the study is the behaviour of the ionospheric irregularities during the geomagnetic storm of 15 July 2012..

2 Instrument, data and analysis

The joint Taiwan - U.S. Constellation Observing System for Meteorology, Ionosphere, and Climate/Formosa Satellite Mission 3 (COSMIC/FORMOSAT-3, hereafter COSMIC), a constellation of six microsatellites, was launched on 15 April 2006 into a 512-km orbit. After launch the satellites were gradually deployed to their final orbits at 800 km, a process that took about 17 months (Anthes et al., 2008).

The study is based on reprocessed profiles of electron density (N_e) and total electron content (TEC) from the COSMIC mission. The TEC profiles describe the total electron content along the ray path from the GPS to the LEO satellite as function of the ray path. The small bending of the ray is neglected in the ionosphere. The analysed data are level1 data (podTec) and level2 data (ionPrf) which were processed by the University Corporation for Atmospheric Research (UCAR) in Boulder (USA). The data are provided in the directory cosmic2013 of the COSMIC Data Analysis and Archive Center (CDAAC). The applied retrieval technique of the N_e profiles is the Abel inversion which assumes local spherical symmetry. The number of electron density profiles is about 1000 per day with a good global coverage. The altitude sampling rate is about 1 km, and the tangent point moves in average 180 km through the ionosphere at altitudes from 400 to 500 km during about 5 minutes. Thus, the profiles are usually not measured above a fixed geographical location. This means that plasma fluctuations in the horizontal, vertical and temporal dimension may contribute to the small-scale fluctuations of an electron density profile or an TEC profile. We assume that the plasma is frozen so that we do not care about temporal fluctuations. Further, we do not try to distinguish between horizontal and vertical fluctuations. Instead, we consider the fluctuation in the s-domain where s is the distance between the bottom tangent point and the tangent point. The height of the bottom tangent point is usually between 50 and 150 km. In addition, we interpolate the profile to an equally spaced s-grid with a spacing of 1 km. Generally, the tangent point approximately moves along a straight line trajectory in the F region. Hence, the small-scale fluctuations are plasma fluctuations which are projected to the trajectory line of the tangent point of the occultation event. The sounding volume at the tangent point is like a ~~cigar~~ cylinder with a length of about 200km in direction of the GPS-LEO ray, and about 2 km across the ray and about 1 km in altitude. Thus, small-scale fluctuations in ray direction can be smoothed out, occasionally.

We extract the fluctuations in electron density and TEC by means of high pass filtering in the s-domain. In case of TEC, we have to compute the location of the ray tangent point (height, latitude and longitude) by using the coordinates of the GPS and the LEO satellite in the podTec file. The profiles $N_e(s)$ or TEC(s) are filtered with a digital non-recursive, finite impulse response (FIR) high pass filter performing zero-phase filtering by processing the profiles in forward and reverse directions. A cutoff scale length of 50 km was selected that means that oscillations in electron density with wavelengths less than 50 km are passing the filter. The number of filter coefficients corresponds to three times of a 50 km-interval, and a Hamming window has been selected for the filter. Thus, the high pass filter has a fast response time to vertical changes in the electron density profile. More details about the digital filtering are given by Studer et al. (2012).

The left-hand-side panel of Figure 1 shows an example of a disturbed electron density profile (blue line) in the southern polar region during the geomagnetic storm of 9 March 2012. In addition, the red line shows the low-pass-filtered profile with scales > 50km. The right-hand-side shows the high-pass-filtered electron density fluctuations $N_{e,1}$ with scales < 50km. A similar analysis is performed for the TEC profiles. For each fluctuation profile (Fig. 1b), we compute the mean of the absolute fluctuations within the altitude range 400-500 km which is called ΔN_e or ΔTEC and which is a measure of the mean amplitude of high frequency fluctuations.

The ΔN_e or ΔTEC-values of the selected profiles are binned into $5^\circ \times 5^\circ$ latitude-longitude grid cells and are averaged by the median function in order to get the global distribution of electron density irregularities.

3 Results

First at all, we like to compare the global maps for ΔN_e and ΔTEC. Figure 2a) shows the result of ΔN_e, and Figure 2b) shows the result for ΔTEC both for September 2013 where the COSMIC satellites collected about 30'000 occultation events. Both images have quite similar patterns with enhanced fluctuations in the magnetic polar regions. The coordinates of the geomagnetic and magnetic pole were provided by the World Data Center for Geomagnetism in Kyoto. Generally, the ΔTEC values are a bit enhanced compared to the ΔN_e values. We suppose that the ΔTEC values are more reliable than the ΔN_e values since the ΔN_e values require the Abel inversion and the assumption of local spherical symmetry of the ionosphere. Thus, we provide in the following only the results for the ΔTEC values.

Another question is the influence of the averaging method on the retrieved global map. Figure 3a) shows the ΔTEC map of September 2013 for the case that the arithmetic average is applied to the binned values in the grid cells. On the other hand, Figure 3b) shows the result if the median function is applied to the ΔTEC values. Generally, the arithmetic mean leads to higher values. Especially at the equator, there are some strong fluctuations which may result from the sporadic appearance of equatorial plasma bubbles in the F_2-region. However, in case of monthly global maps we prefer the median-function since it reduces the effect of outliers in the data. In case of daily maps, we only have about 1000 occultation events for the globe, and here it seems to be better to apply the arithmetic mean. It is not good to apply the median function if only a few values are present.

Figure 4 shows the dependence of ΔTEC on local time and magnetic latitude during September 2013 obtained by the median function for tangent points between 400 and 500 km altitude. At low latitudes, there is an enhancement of the strength of irregularities after sunset and before midnight. The increase of the strength of the F_2 region irregularities is possibly due to spread F. The post-sunset rise of the equatorial F layer is regularly seen in ionospheric measurements, and this phenomenon is associated with the occurrence of spread F (Tsunoda, 1981; Tsunoda et al., 2018). One form of spread F are the equatorial plasma bubbles which are upwelling during the post-sunset phase of the equatorial ionosphere (Tsunoda, 1981). At high magnetic latitudes, ΔTEC is enhanced at each local time in Fig. 4.

It is also interesting to investigate the solar cycle effect in the ΔTEC global maps. Figure 5a) shows ΔTEC at solar minimum in September 2008 while Figure 5b) depicts ΔTEC at solar maximum in September 2013. Particularly, the fluctuations are stronger in the magnetic polar regions during solar maximum. A small increase is observed for the equatorial TEC fluctuations during solar maximum. The observations of a sharp transition between high-latitude irregularities and those outside of the polar region is in agreement with Fejer and Kelley (1980).

A large geomagnetic storm was on 15 July 2012. The geomagnetic index Ap had a value of 78, and a maximum Kp value of 7 was reached. We selected this event since the geomagnetic storm was not preceded by another storm. The storm started after 18:00 UT on 14 July 2012. Figure 6 shows the BX, BY and BZ components of the interplanetary magnetic field (near to the Earth) as provided by NASA's the Omniweb data center of the National Aeronautics and Space Administration (NASA). Further the temporal evolution of the Kp index is shown in the bottom panel. For the data analysis, two days-intervals are indicated by the vertical lines for the quiet phase and the storm phase in Fig. 6 . During the storm phase, positive anomalies occur in BX and BY while a negative BZ anomaly is present. That means BZ is southward and the interplanetary magnetic field can reconnect with the magnetospheric field lines which results in a high geomagnetic activity during the storm. According to theory and former observations, the positive deviations of BX and BY during the storm phase shall generate an asymmetric storm response in the Northern and Southern hemisphereZakharenkova and Astafyeva (2015). It is expected . Zakharenkova and Astafyeva (2015) found that geomagnetic activity is larger in the Southern winter hemisphere than in the Northern summer hemisphere. The 15 July 2012 geomagnetic storm was analysed in detail by Wang et al. (2013).

In the following, we average the TEC disturbances over all local times during the quiet phase (12.07.2012 12:00:00 UT to 14.07.2012 12:00:00 UT) and compare this result to the storm phase (14.07.2012 12:00:00 UT to 16.07.2012 12:00:00 UT). Here, we use the arithmetic average since the number of occultation events is not sufficient for the median function. We compare the global maps of ΔTEC (with tangent points at h=400-500km) during the quiet phase (Figure 7a) , and during the geomagnetic storm phase (Figure 7b). The ΔTEC-values of the selected profiles are binned into $10° \times 10°$ latitude-longitude grid cells. The spatial resolution in Figure 7 is selected to be lower than in Figure 5 since the number of occultation events is 1405 for the quiet phase and 1993 for the storm phase. Comparing Figures 7a) and b), it is evident that ΔTEC is increased during the storm phase. Particularly, the Southern magnetic polar region shows a strong increase of the ΔTEC values. There are also patterns of enhanced ΔTEC values at low latitudes during the storm phase.

Finally, we like to know how the geomagnetic storm acts on the lower ionosphere where we perform the same analysis but for TEC with ray tangent points from 200 to 300 km altitude. Figure 8 shows the result of ΔTEC for h=200-300 km, and it can be compared to Fig. 7 which showed the results for ray tangent points at h=400-500 km in the upper ionosphere. The number of analysed occultation events is 1176 during the quiet phase and 1603 during the storm phase. The number of occultation events is a bit smaller in Fig. 8 than in Fig. 7 since some occultations did not reach down to 100 km ray tangent point height which we took as a lower limit to ensure a good filtering process of the TEC values with tangent points at h=200-300 km. It is obvious that the quiet phase is not so quiet in the lower ionosphere where still TEC variations occur in the polar regions and at low latitudes. During the storm phase (Fig. 8b), the disturbed polar regions are extended and the intensity is stronger compared to the quiet phase. In addition the disturbances at low and middle (northern) latitudes are increased during the storm phase. It is obvious that the patterns of enhanced ΔTEC values at low and middle latitudes strongly vary with longitude. In case of the lower ionosphere (Fig. 8) the North-South asymmetry of the storm response is not so pronounced like in the upper ionosphere (Fig. 7).

4 Conclusions

The study is based on reprocessed profiles of electron density and total electron content from the COSMIC mission. We applied a special analysis method to extract the spatial fluctuations in electron density and total electron content where we calculate the mean value of the absolute values of the 50 km-high pass filtered fluctuations in the altitude region from 400 to 500 km. The analysis method filtered the irregularities along the path of the tangent point.

The global maps of ΔTEC are quite similar to those of ΔN_e. We find a significant difference if the arithmetic mean or the median is applied to the global map of September 2013. In agreement with numerous ionospheric observations from literature, ΔTEC is enhanced during the post-sunset rise of the equatorial ionosphere in September 2013. The post-sunset rise is associated with spread F and equatorial plasma bubbles (Tsunoda, 1981). At high magnetic latitudes, ΔTEC is enhanced during each hour of the day in September 2013.

The global map of ΔTEC at solar maximum (September 2013) has stronger fluctuations than those at solar minimum (September 2008). ~~Finally,~~ We find a new result when we compare the global maps of the quiet phase and the storm phase of the geomagnetic storm of 15 July 2012. It is evident that the TEC fluctuations (ray tangent points at h=400-500km) are increased and extended over the Southern magnetic polar region during the storm phase. This North-South asymmetry is possibly caused by the positive deviations of the BX and BY components of the interplanetary magnetic field. We find enhanced TEC fluctuations at low latitudes but confined to certain areas. In the lower ionosphere (ray tangent points h=200-300 km), the North-South asymmetry of the geomagnetic storm response is less pronounced than at upper altitudes. The spatio-temporal sampling of the ionosphere by the six LEO satellites of the COSMIC mission is actually not sufficient for a case study of a geomagnetic storm. However, our study gives a first impression on what can be achieved in some future if a larger number (e.g., >10) of LEO satellites with GPS receivers would be launched.

5 Code availability

Routines for data analysis and visualization are available upon request by Klemens Hocke.

6 Data availability

The level2 data are avaliable at the COSMIC Data Analysis and Archive Center (CDAAC).

Author contributions. Klemens Hocke carried out the data analysis. All authors contributed to the interpretation of the data set.

Competing interests. The authors declare that they have no competing interests.

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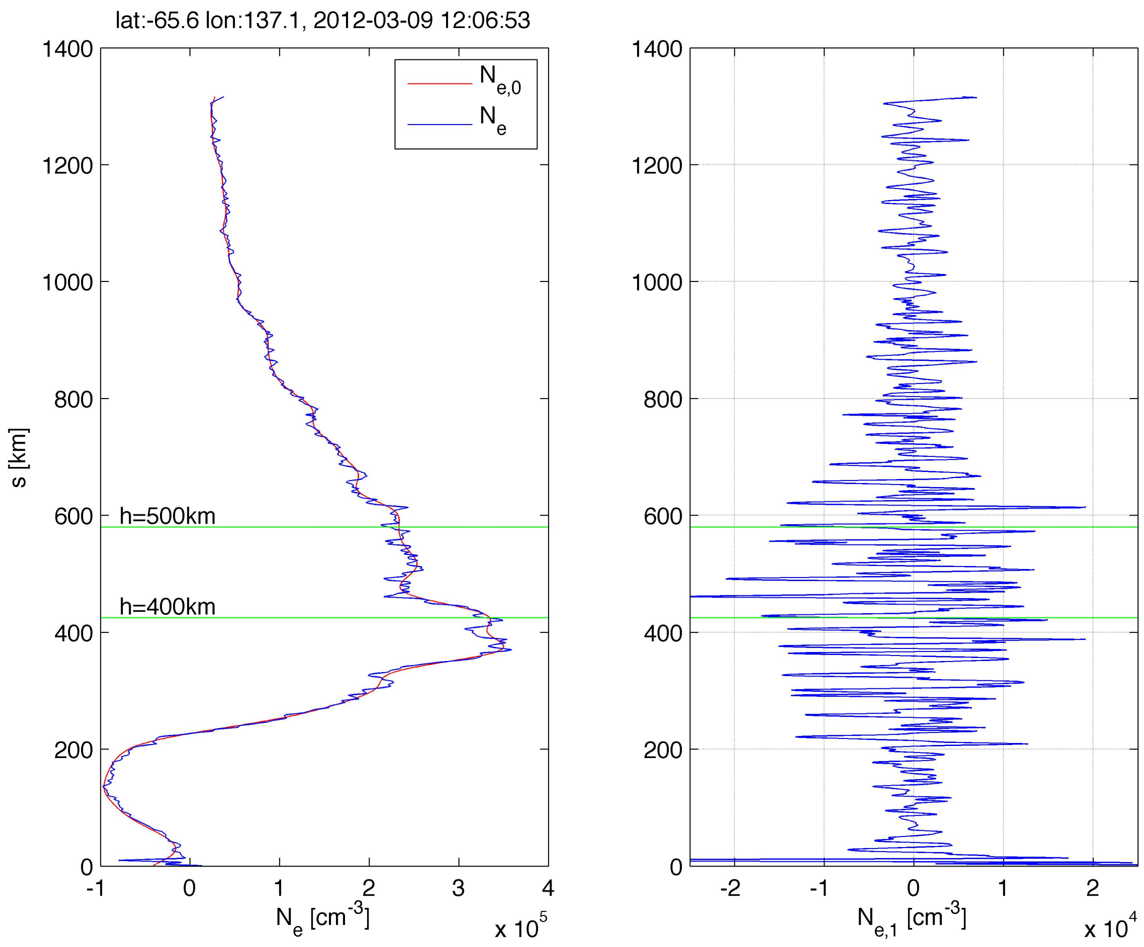

Figure 1. Example of a disturbed electron density profile from COSMIC (blue line in the left panel). The red line are the 50 km low pass filtered data. The filtering is applied in the s-domain where s is the distance between the bottom tangent point and the tangent point. The right panel shows the electron density fluctuations filtered with the 50 km high pass filter. The study is focused on the altitude region h=400-500 km (with exception of Fig. 8) .

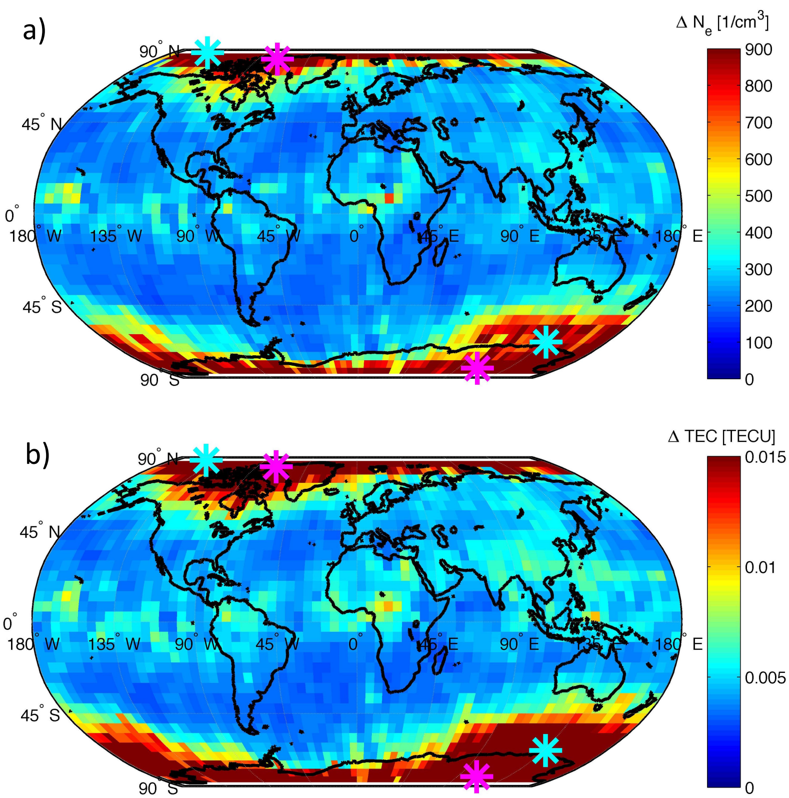

Figure 2. a) Global map of ΔN_e during September 2013 (analysis of ionPrf files of COSMIC). b) Global map of ΔTEC during September 2013 (analysis of podTec files of COSMIC). Both images are derived for fluctuations with scales < 50km in the height range 400-500km. The median function is applied to the binned cells ($5^\circ \times 5^\circ$ in latitude and longitude). The geomagnetic (magnetic) poles are indicated by the magenta (cyan) star symbols respectively.

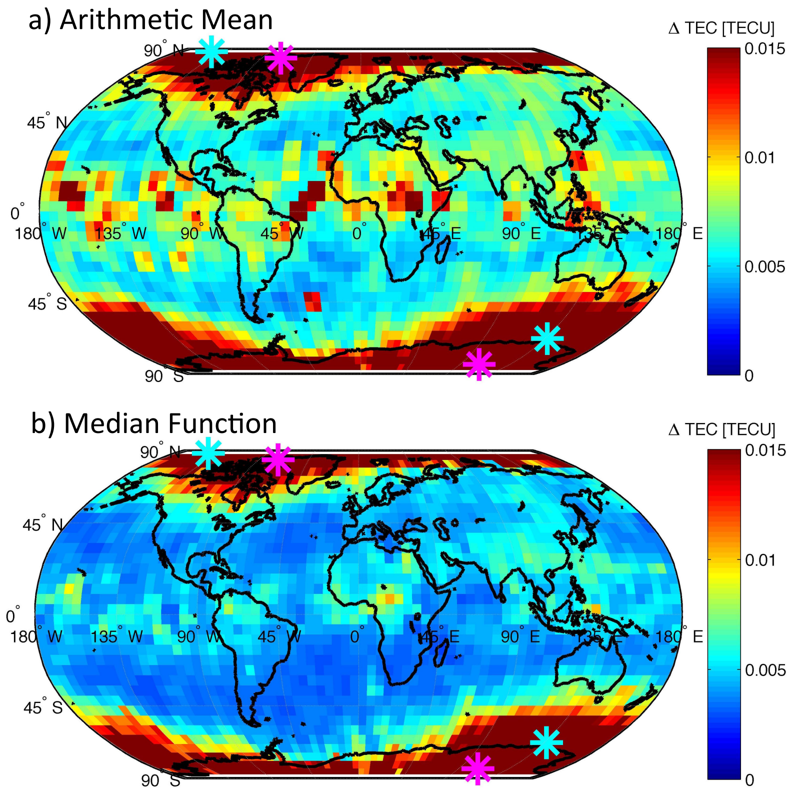

Figure 3. a) Global map of ~~f~~ ΔTEC during September 2013 obtained by the arithmetic mean of the values in the binned cells. b) Global map of ΔTEC during September 2013 obtained by the median of the values in the binned cells. The geomagnetic (magnetic) poles are indicated by the magenta (cyan) star symbols respectively.

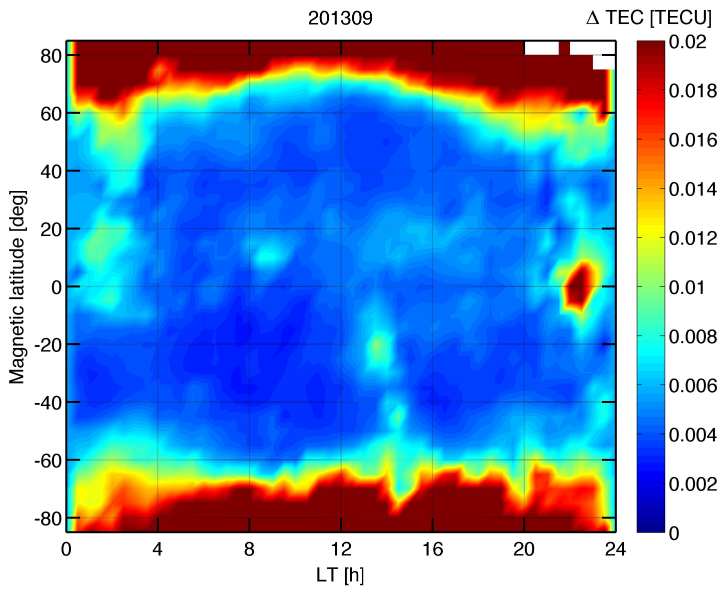

Figure 4. Dependence of ΔTEC on local time and magnetic latitude during September 2013 obtained by the median function for tangent points between 400 and 500 km altitude. At low latitudes, there is an enhancement of the strength of irregularities after sunset and before midnight, possibly due to equatorial plasma bubbles.

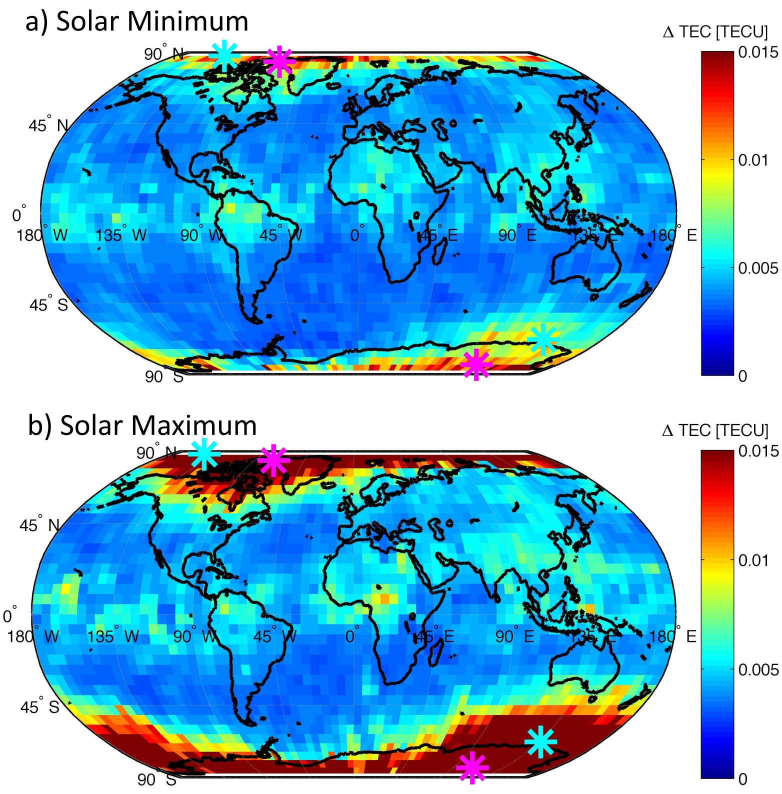

Figure 5. a) Global map of ΔTEC during September 2008 (solar minimum). b) Global map of ΔTEC during September 2013 (solar maximum). The geomagnetic (magnetic) poles are indicated by the magenta (cyan) star symbols respectively.

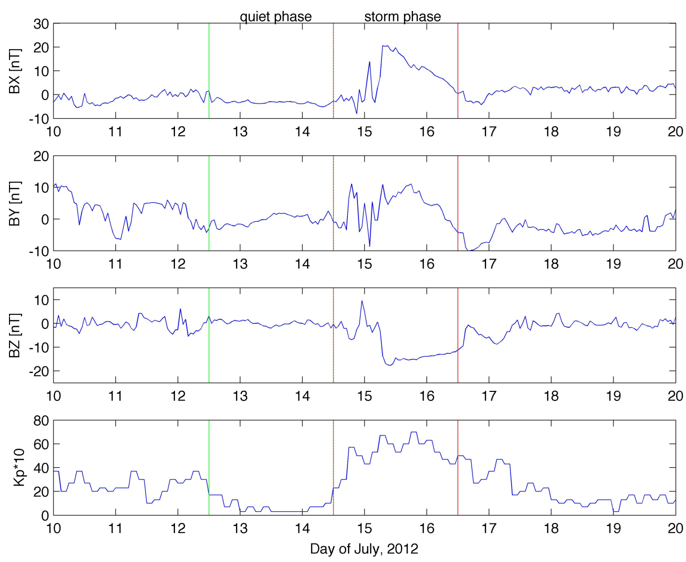

Figure 6. BX, BY and BZ of the interplanetary magnetic field (upper panels) and Kp index of the geomagnetic activity (bottom panel). Two days-intervals during the quiet phase before the geomagnetic storm of 15 July 2012 and during the storm phase are indicated by the vertical lines.

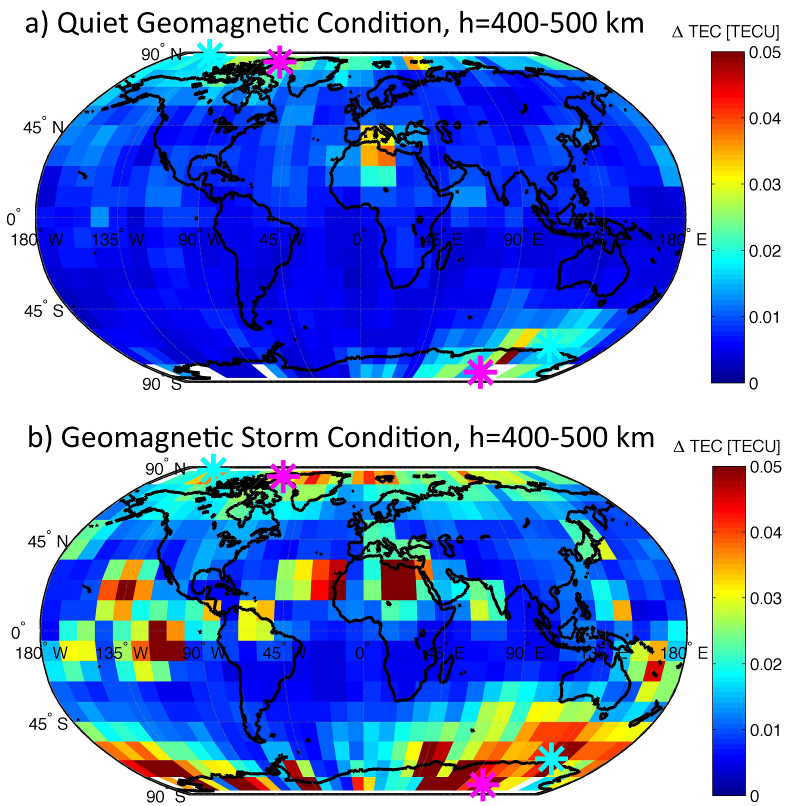

Figure 7. a) Global map of ΔTEC (tangent points at h=400-500 km) during the quiet phase, and b) during the storm phase of the geomagnetic storm of 15 July 2012. The arithmetic mean is applied to the values of the binned cells ($10^\circ \times 10^\circ$ in latitude and longitude). The geomagnetic (magnetic) poles are indicated by the magenta (cyan) star symbols respectively.

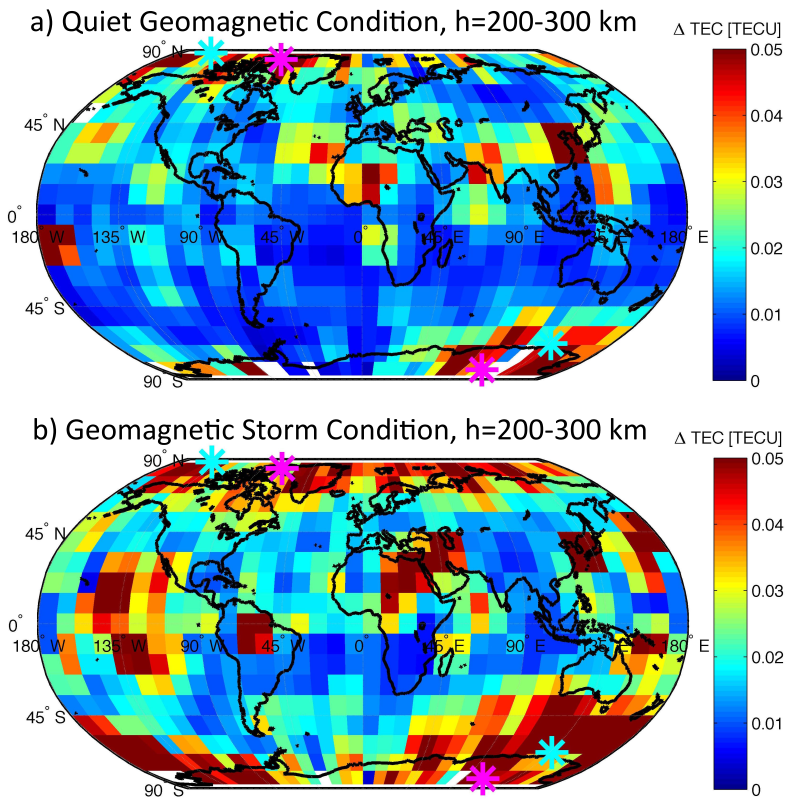

Figure 8. a) Global map of ΔTEC (tangent points at h=200-300 km) during the quiet phase, and b) during the storm phase of the geomagnetic storm of 15 July 2012. The arithmetic mean is applied to the values of the binned cells ($10^\circ \times 10^\circ$ in latitude and longitude). The geomagnetic (magnetic) poles are indicated by the magenta (cyan) star symbols respectively.