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Interactive comment on "Spatial gradient of total electron content (TEC) between two nearby stations as indicator of occurrence of ionospheric irregularity" *by* Teshome Dugassa et al.

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Response to reviewers' comments on the manuscript angeo-2018-131-RC2: Spatial gradient of total electron content (TEC) between two nearby stations as indicator of occurrence of ionospheric irregularity

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The authors thank the reviewer for his/her comments that helped to improve the quality of this research. The comments are addressed as shown below.

Reviewer 2

Printer-friendly version

Discussion paper

1. Figures 2 and 3 needs a bit more clarification. I understand that the blue curves in Figure 3 shows the spatial gradient and the blue curve in Figure 2 shows enhancement in spatial gradient. What does the authors mean by enhancement/depletion in spatial gradient? Please mention how the enhancement/depletion in spatial gradient is calculated in Figure 2. I am just confused if the blue line in Figure 2 represent spatial gradient in TEC or enhancement in spatial gradient in TEC. The two sentences in lines 3-4 on page 8 are confusing. Considering Figures 2 and 3 are the most important figures of this manuscript they must be explained properly.

Response:

In both of the graphs (Figures 2 and 3), the blue curves show the diurnal variation in the gradient of TEC. In Figure 2, the authors try to relate the electric field derived from equatorial electric field model and the spatial gradient in TEC. Whereas, Figure 3 was presented to show the trends of the time variation of ROTI and the gradient in TEC. In both figures, the maximum enhancement/reduction in the gradient of TEC was observed.

On the computation of the spatial gradient of TEC between the two nearby located stations (ASAB and DEBK), the gradient of TEC may be either positive/negative value. Both the negative and positive values obtained from the differences of TEC between the two stations show the gradient of TEC. It is obvious that the positive/negative gradient in TEC is obtained when the minuend is larger/smaller than the subtrahend. A positive gradient in TEC denotes a higher in TEC/ electron density over ASAB relative to DEBK and a negative gradient in TEC indicates a lower in TEC/electron density over ASAB than DEBK, i.e, a higher in TEC/electron density over DEBK than ASAB.

In the manuscript, we have used the term maximum enhancement /reduction in the gradient of TEC (in terms of magnitude) when the nighttime value of gradient of TEC was larger than the daytime value. Since fluctuation in ionospheric plasma density was

prevalent during the nighttime hours, we have used the state of the night time gradient of TEC compared to daytime to describe the relationship between the gradient in TEC and the occurrence ionospheric irregularities.

The authors modified the term enhancement/depletion in the spatial gradient of TEC to maximum enhancement/reduction in the gradient of TEC. In the current study, there was no quantitative method that we have used to calculate the maximum enhancement/reduction in the gradient of TEC. We rather described the state of the gradient of TEC (which shows maximum positive/negative in TEC/electron density during nighttime relative to the daytime) by observing the values of gradient of TEC. The gradient in TEC was calculated by taking the difference of TEC between two stations (ASAB and DEBK) and divided by their longitudinal differences. If the gradient of TEC during nighttime is positive/ negative values, the state of gradient of TEC show enhancement/reduction in gradient of TEC. (Page 4, 9).

2. Page 8 Line 9-10: The authors state: "The spatial gradient of TEC observed during the day time was relatively small compared to the evening time values for most of the days." If you take a look at Figure 3c, the daytime peak and the post sunset peak of the spatial gradient are almost of same values.

Response:

The statement was modified as, "most of the day time value of spatial gradient in TEC was relatively small in magnitude compared to the night values."

3. Also the authors need to explain what do the increase or decrease in the spatial gradient in TEC mean physically. For example, in case of ROTI, it is very straight forward. If you look at Figure 3, the day time ROTI stays around zero. Postsunset, the ROTI values increase showing fluctuations in TEC (hence density). In case of ROTI, a standard value of 0.5 is considered to identify ionospheric irregularities.

However, in case of spatial gradient of TEC, you can see daytime fluctuations as well. So what you see postsunset, may not entirely be due to fluctuations in TEC or irregularities. It may have a significant contribution due to zonal plasma drift. How do you eliminate that possibility?

Response:

The increase/decrease in the spatial gradient in TEC shows the difference in the value of TEC/plasma density observed over the stations. The increase/decrease in the gradient in TEC indicates the higher/smaller in TEC/plasma density over ASAB relative to DEBK. The maximum enhancement/reduction in the gradient of TEC mostly observed in the nighttime period. Even though the two stations were located near each other, they do exhibit difference in TEC/plasma density. The difference might be attributed to zonal thermospheric wind and ExB drift. (Page 10-11)

At a basic level, there are two independent ways of estimating the TEC gradient values using ground based GPS receiver data (Lee et al., 2006). The first method uses a pair of closely-spaced receiver stations. The second method uses a single GPS receiver station to infer the spatial TEC gradient values based on the observed temporal rate of change in TEC. The two methods actually have their own merit and demerits. In our study, we have used the first method (i.e., station-pair method). This station-pair method gives us an instantaneous estimate of the TEC gradient along a fixed direction determined by the line segment connecting the two stations. It is true that the zonal drift might have an effect on TEC gradient. As the two stations used to get TEC gradient are close to each other, the same irregularity have a chance to be observed at these stations almost at the same time and hence difference of TEC at these stations can eliminate the contribution of zonally drifting irregularity on TEC gradient variation. However, in case of the single station-method we must note that the background ionospheric plasma drift/circulation speed can potentially inflate as well as deflate the estimated TEC gradient values obtained (Datta-Barua et al., 2010).

4. If you look at Figures 3b and 3d, the peaks of the red and blue curve matches, but their values say a different story. The value of ROTI-index in Figure 3b is higher than that in Figure 3d. But the values of the spatial gradient show an opposite trend. The value of spatial gradient in Figure 3b is lower than that in Figure 3d. So in terms of ROTI, the ionospheric scintillation is stringer in Figure 3b than 3d. But in terms of spatial gradient, it looks opposite. How to explain it.

Response:

The values of ROTI in each panel of Figure 3 (a-d), shown as representative cases, was greater than 0.5 TECU/min, a threshold value showing the presence of irregularities. However, they show difference in the strength of irregularities. These difference could be attributed to the difference in the strength of PRE, and other factors. Similarly, the value of the spatial gradient in TEC was different. For example, the value of the spatial gradient in TEC in Figure 3d is higher than that in Figure 3b, while ROTI value in Figure 3b is higher than that in Figure 3d. This might indicate the difference in the cause of the maximum enhancement/reduction in the gradient in TEC and ROTI, for example zonal neutral wind and ExB drift. (Page 10-11).

5. Figure 3(c): It has almost similar +ve and -ve phases around 16-22 hours. What do the negative phase of the spatial gradient mean physically?

Response:

When we apply Equation 1, we might obtain positive and/or negative values in the gradient of TEC, mostly around 16-22 hrs. Both the positive and negative phase indicates the gradient in TEC. These values are the relative TEC/plasma density between the two stations. The negative value in gradient of TEC indicates the higher TEC/plasma density over DEBK relative to ASAB, i.e., a reduction in TEC/plasma density over ASAB, showing a decrease in plasma density over ASAB compared to DEBK.

6. The authors here have just shown 4 cases where ionospheric irregularities

were present. They also need to show cases when there were no ionospheric irregularities.

Response:

Cases where absent in the occurrence of ionospheric irregularities were presented in the modified manuscript in Figure 4 (a-d). (Page 13)

7. Figure 4 (a-c): The authors need to modify the color codes of the three figures to make it clear. Right now, the minimum limit of ROTI in Figure 4(a-b) is set at 0.5 which is considered as the onset of ionospheric irregularities. Set it to zero so that a clear picture can be seen.

Response:

The color codes of Figure 4 (a-c) given in the manuscript were modified, and we can find in the revised manuscript in Figure 5 (a-c). (Page 15)

8. The manuscript do not show any evidence yet, to prove the spatial gradient can be used as an indicator of ionospheric irregularities. It is in a stage where it actually investigates the relationship between spatial gradient of TEC and ionospheric irregularities. So I will suggest the authors suitably change the title of the manuscript. Technical:

Response:

To show the relation between the spatial gradient in TEC and the occurrence of ionospheric irregularities over the equatorial region, the authors present the correlation between them as shown in Figure 7. In this study, the relation between the spatial gradient of TEC and ROTI was presented with correlation coefficients (C = 0.58 for DEBK, C = 0.53 for ASAB). We got hits that could lead us to relate the spatial gradient of TEC and the occurrence of ionospheric irregularities. To obtain the gradient of TEC we used a pair of closely-spaced receiver stations such that the two receivers share the same GPS satellite (less than 2°) to calculate the difference in TEC values between the two

neighboring ionospheric piercing points (IPP) at any given time. In our case, however, the two stations are separated by 5o. The moderate correlation obtained might be attributed to the wider longitudinal separation $(5°)$ between the two stations. The other factor for the moderate correlation between the gradient of TEC and occurrence of ionospheric irregularities might be the way ROTI was computed (since ROTI contains both the spatial and temporal variation in TEC). If we can reduce the contribution of the temporal part of ROTI, we may get a better relationship. (Page 15, Lines 7- 16; Page 16 Lines 1:16)

The title of the manuscript is modified as:

Investigation of the relationship between the spatial gradient of total electron content (TEC) and the occurrence of ionospheric irregularities.

9. Page 8: line 3: Figure 2a and d should be Figure 2 (a-d). **Response:**

We modified the way we referred the figures, as suggested.

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2018-131/angeo-2018-131-AC2-supplement.pdf

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