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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-RC1:

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 comments that helped to improve the quality of this work. The comments are addressed as shown below.

Reviewer 1

General comments

1. **The study attempts to show how the difference between the TEC of two close GNSS stations can be used as a precursor of ionospheric irregularities in the post-sunset period over both stations. The study being the first of its kind in the African sector is worthy of interest couple with the fact that it is well written and it gives insight about a possible relation between electric field and irregularities in the post sunset period. However, the authors first need to give a good justification why they want to use TEC gradient between two stations as a proxy of irregularities.**

   Response:
   It is well known that ROTI is a proxy for the occurrence of ionospheric irregularities and scintillations. The relationship between the spatial gradient of TEC and ROTI was established to observe how the gradient of TEC affect radio signals, hence give information that the horizontal electron density gradient as an important parameter to predict ionospheric scintillation. After establishing this relationship showing that both parameters give information about ionospheric irregularities, TEC gradient method may be an alternative as it is a simple computation of establishing the difference. The motivation why we used TEC gradient between two stations as a proxy of

irregularities are explained (Page 2: Lines 22-35 and Page 3: Lines 1-23).

2. **Giving the fact that ROTI which can be easily estimated is already an indicator of irregularities why use the gradient between two stations to do the same work?**

   Response:
   Our main interest in establishing the spatial gradient of TEC as indicator of irregularity is due to the following reason:

   It is well known that pre-reversal enhancement (PRE) is a postsunset phenomenon. PRE can uplift the ionosphere and create a conducive condition for irregularity formation. This implies the magnitude of the zonal electric field is an important parameter for real-time prediction. It is also k own that PRE is due to the spatial gradient of electron density near solar-terminator. We know TEC is the integral of electron density. So the TEC gradient would help us to estimate the strength of the zonal electric field (Page 3, Lines 7 - 15).

3. **What if the constraints "over the same latitude, but separated by a longitudinal of about 5 degree" is removed? What happens to the relation?**

   Response:
   We thank the reviewer for the important point raised. We have a plan to investigate the optimum separation between two GNSS receivers that can provide the best correlation between TEC gradient and irregularity. This will be done in a separate work.

Specific comments

1. **How does the relationship between TEC gradient and ROTI is established? The study never really specified or took into consideration the quietness and/or disturbed nature of the days used.**

   Response:
   To show the relationship between the TEC gradient and ROTI, the 10 quiet international days in the year 2014 were used. In this study period, there are about 364 days fully available in both stations simultaneously. The quiet international days are obtained from http://wdc.kugi.kyoto-u.ac.jp/qddays/index.html. In total, about 120 quiet days were used in investigating the relationship between TEC gradient and ROTI. The absolute value of the spatial gradient of TEC was used to observe the correlation between the gradient of TEC and ROTI (Page 14, Figure 6). Moreover, in the revised version of the manuscript, we also considered the effect of a geomagnetic storm in developing the relationship between TEC gradient and the occurrence of ionospheric irregularities (Page 12, Figure 4).

2. **In establishing a relation between equatorial electric field and spatial gradient, the authors used only four days in year 2014. Is this sufficient enough to show any kind of relationship between both quantities?**

   Response:
   In the previous version of the manuscript, we used four quiet days as a typical example to observe a relation between equatorial electric field and spatial gradient of TEC which is not sufficient enough. In the revised version of the manuscript, however, we modified Figure 2 by adding more data/months to establish the relationship between the equatorial electric field and spatial gradient. In the updated graphs, we took the monthly-quiet mean of the equatorial electric field and TEC gradient of the year

2014 (Page 10, Figure 2).

3. **In Justifying the magnetic data gap (the H component of the Earth's magnetic field) in 2014, the authors performed a correlation between the equatorial electrojet ΔH and equatorial electric field (EEF) for quiet days in 2012. No information is given on these days and how they were selected and how many they are?**

   Response:
   Five quietest international days of each month of the year 2014 were utilized to perform the correlation between the equatorial electrojet ΔH and the equatorial electric field (EEF). These days are obtained from http://isgi.unistra.fr/data_download.php. Out of 60 days, only 38 days of data were available simultaneously in both magnetometer measuring stations (Page 8, Figure 1b).

4. **The authors assumed the correlation between ΔH and EEF as obtained in 2012 (0.7) will be the same in 2014.**

   Response:
   We did the correlation between ΔH and EEF to justify the performance of the model over the equatorial region of Africa using available magnetometer data (the year 2012). As can be seen from their relation, the day time EEF model and day time ΔH correlated positively. Since the performance of the model was good, we used the real-time electric field model for the year 2014 in the absence of ΔH data to observed the possible relation between electric field and irregularities/TEC gradient in the post-sunset period. Actually, the two selected years have a different solar condition. However, the average value of F10.7cm for the quiet days in the two years does not show significant variation (Page 8, Figure 1b).

Listing of technical corrections

Abstract

1. **Line 9: Change correlation to relation. I did not see any correlation study between both variables in this work.**

   Response: Corrected (Page 1, Line 9).

2. **Line 11: Maximum positive/depletions. Why not use maximum enhancement and reduction. The spatial gradient will either be positive or negative. A negative gradient means reduction in electron density. Let's avoid using the word depletion since it can be mistaken for TEC depletion.**

   Response: Corrected (Words and phrases stated maximum positive/depletions was corrected to maximum enhancement and reduction). (Page 1, Line 10).

3. **Line 15-16: The spatial gradient of TEC between the two nearby stations could be used as an indicator of the occurrence of ionospheric irregularities. Is it over both stations or it is a general statement?**

   Response: Over both stations (We did correlation for both stations) (Page 1, Line 15 - 18).

   Introduction

   Page 2

4. **Line 8: Attests**

   Response: Corrected (Page 2, Line 7).

5. **Line 14. Remove mechanism**

   Response: Corrected (Page 2, Line 11).

6. **Line 18. ESF write in full. First time used.**

   Response: Corrected (Page 3, Line 2).

7. **Line 30. GPS write in full. The GPS scintillation index, S4 is not an instrument. The GPS is.**

   Response: Corrected (Page 1 , Line 5).

8. **Line 31. Global Navigation Satellite System (GNSS). Use either GNSS or GPS.**

   Response: Corrected (Page 2, Line 19).

   Page 3

9. **From lines 1-2, a mention of some work done over Africa has been made. However nothing was said about the scope of such studies, their limitations/gaps and how they relate to this study. Kindly address.**

   Response: Modified (Page 3 Lines 1- 10)

10. **Line 26. "and see". Change to as well as study.**

    Response: Corrected (Page 3 , Line 10).

11. **Line 27 "A closely found" change to closely located**

    Response: Corrected (Page 3, Line 14).

12. **Line 28. I am not comfortable with the word 'longitudinal'. Change to spatial for uniformity with title.**

    Response: Corrected (Page 3, Line 16).

13. **Line 27-28. What is the justification for the study of the relation between longitudinal (in this case spatial) gradient of TEC derived from two GPS receivers and occurrence of ionospheric irregularities still using GPS?**

    Response: Modified (Page 3 Lines 1-23)

14. **Line 29. Same as in line 28.**

    Response: Corrected.

    Page 4

    Data and methods

15. **Line 2-3: Kindly read that statements and adjust for easy flow.**

    Response: Corrected (Page 3, Lines 25-33; Page 4 , Lines 1-9).

16. **Line 5: Why 2014 only? Is there any particular justification for th choice of this year?**

    Response: It is because this year had sufficient simultaneous data for both stations for statistical values to be reliable.

17. **Line 6: Remove "of"**

    Response: corrected.

18. **Lines 7-8: Change the first average to “mean“.**

    Response: Corrected.

19. **Line 10: change were to ”was“**.

    Response: Corrected.

20. **Line 10: ”then analyzed to show the possible indicator of“. This statement is not correct. Adjust**

    Response: Adjusted.

21. **Line 11: ”The spatial gradient of TEC between the two nearby stations are located nearly along the same“. Adjust statement. May be you should delete ”are“.**

    Response: Corrected.

22. **Line 14: Any reference for equation 1?**

    Response: corrected (Page 4, Line 8).

23. **Line 16-17: I am not satisfied with your definition of $\triangle H$ the way it is and the way you associate it to the EEJ in these particular lines. In addition you need to add how the H was processed and corrected for baseline value and non cyclic variations**.

    Response: modified (Page 5, Lines 10-25; Page 6, Lines 1-14).

24. **Line 22: ...is a transfer function model which to models the daily variations**. . .**Check the sentence**.

    Response: corrected.

    Page 5

25. **Line 1: ”which are mapped from interplanetary electric field (IEF) data“. Change to ... which are mapped in the interplanetary electric field (IEF).**

    Response: corrected.

26. **Line 5: I think you need to clearly explain the various options that the model provides and then proceed to tell us exactly which of the three options you used and why.**

    Response: corrected.

27. **Line 16: add ”s“ to station.**

    Response: Corrected.

28. **Line 23: Put a comma after reliable.**

    Response: Corrected.

29. **Line 24: Change “from the model” to ‘it’**

    Response: corrected.

30. **Line 32: Was ROTI introduced to quantify the ROT measurements or ionospheric irregularities? Clarify please.**

    Response: modified.

    Page 6

31. **Line 6: Adjust to (Ma and Maruyama, 2006).**

    Response: adjusted.

32. **Line 23: I thought the scope of the study was 2014. Why use data from 2012? Have you accounted for the yearly variation and solar activity influence in juxtaposing your 2012 and 2014 data? Please could you clarify this?**

    Response:
    Since magnetometer data during the year 2012 was available simultaneously both at dip equator (Addis Ababa) and off-equator (Adigrat) we used these data to observe the performance of equatorial electric field model over equatorial region of Africa. The model correlates moderately over equatorial region of Africa, and hence we used the model over the region, during the year 2014 (Page 5, 6).

    Results and Discussions

33. **Line 22: For some of selected. Remove of**

    Response: corrected

34. **Lines 22-23. How did you select those quiet days? How many where there? What is the temporal resolution of both $\triangle H$ and EEF. Is the correlation obtained from "some selected quiet days" be an adequate representation of all other quiet days in year 2012? Check Figure caption in Figure 1 and harmonize. Let's know whether you use some days or quiet days of month of year 2012**.

    Response:
    The quiet days used in this study are the international five quiet days of each month of year 2014 obtained from Kyoto website. Only 38 quiet days available. The temporal resolution of $\triangle H$ is 1 min and EEF is 5 min. We corrected the resolution of $\triangle H$ to 5 min resolution. We modified the

    correlation between the EEF and $\triangle H$ using the quiet days of year 2012. The graph is replotted. Caption of Figure 1 is modified (Page 8, Figure 1).

    Page 7

35. **Lines 2-5. You gave us a beautiful description of how $\triangle H$ can be derived between the two magnetometers just for you to come and tell us that the data were not available for year 2014. I think it should have been the other way round.**

    Response: Modified (Page 5, Lines 7-25; Page 6, Lines 1-11)

36. **Line 3. Correct Adegrat to Adigrat.**

    Response: corrected.

37. **Line 4-5. To solve this data gap we used the daytime information of equatorial electric field derived from the real-time prompt penetration electric field model as an option. Did you use the real time model of Ionospheric electric fields of the real-time prompt penetration electric field model?**

    Response: We have used the real time model of Ionospheric electric fields of the real-time prompt penetration electric field model.

38. **In Page 6 lines 21-23 the authors claimed the relation is for some selected quiet days of months of year 2012 but in Page 7, lines 5-7 they state that the same relation is for year 2012. This may be extremely misleading.**

    Response: The relation is modified by considering the international quietest days of months of year 2012.

39. **We need a clear explanation on how you wish to use correlation result for 2012 to support some of your results in 2014. You must be aware of the solar activity influence on vertical drift. It will not be totally accurate to say that the correlation in 2012 will be the same as those in 2014. May be you did that as an indication of something. You need to clarify.**

    Response:
    The correlation between the equatorial electric field model and ΔH in the year 2012 was made to observe the performance of the model over the equatorial region of Africa, East Africa. We choice the year 2012 just because of availability of magnetometer data at both stations (Addis Ababa and Adigrat). The performance of the model over this sector was moderate (C = 0.6).

    Page 8

40. **Line 5: Be consistent. Is it Figure or Fig? (check in all texts and harmonize).**

    Response: We used Figure/Fig ways in referring figures according to the style of the journal.

41. **Line 7. Replace "but lags' with " but after "'...**

    Response: corrected.

42. **Line 8: The depletions in the gradient. I am not comfortable with the word depletion. Kindly use the reduction in the gradient.**

    Response: modified.

43. **Line 9: ...maximum positive of the spatial gradient of ... Replace with " the peak of spatial gradient" or "the maximum spatial gradient".**

    Response: corrected.

44. **Line 11: Change depletion with reduction.**

    Response: corrected.

45. **Lines 16-19: Why over Asab only?**

    Response: Graph of Debark also added (Page 11 and 12, Figure 3 and 4).

    Page 9

46. **30 March 2014, 10 April 2014, 20 September 2014, 10 October 2014. Where these days selected randomly?**

    Response:
    Over equatorial/low-latitude regions of Africa, since a high rate of occurrence of irregularities observed in the equinoctial seasons, and we selected the equinoctial seasons of the year 2014. And, these days are quiet days of the selected months.

47. **The caption in Figure 3 should be self explanatory and should tell us the stations (Asab and Debark) that were used for the ROTI.**

    Response: The caption in Figure 3 modified (Page 11, Figure 3).

    Page 10

48. **Line 1: Do you have any reference for this?**

    Response: Yes (Page 9, Line 31).

49. **Line 1: From the figure, ... Which Figure? Specify.**

    Response: corrected.

50. **Lines 2-3: A convincing and quantitative way to demonstrate inferences in lines 3-4 is by performing correlation between spatial gradient and irregularities.**

    Response: Modified and plotted (Page 14, Figure 6).

51. **Lines 7-8: An ionosphere gradient of 518 mm/km was discovered, generated by a plasma bubble. Read the statement and rephrase.**

    Response: Adjusted.

52. **Line 14: (see., Fig. 5). Change to as seen in Figure 5.**

    Response: corrected.

53. **Line 17: Change "a" by "the"**

    Response: corrected.

54. **Line 18: Change "indicates" to "shows"**

    Response: corrected.

55. **Line 19: ...in section (2)... which section 2? Change to as stated earlier.**

    Response: corrected.

56. **Line 23: Put 's' to period**

    Response: corrected.

57. **Line 23-24: Equation (1) was applied to all days of the year 2014? Including disturbed days? This is where it is important to separate disturbed days from quiet ones. We know that gradients can be significant during geomagnetic storms.**

    Response: The correlation between the TEC gradient and ROTI was done only for the quiet days (Page 11, Figure 3; Page 14, Figure 6).

58. **Line 28 - 32: Most of the observed features have not been discussed and plausible answers not given to explain them.**

    Response: Modified (Page 13, Lines 7-13, Page 14, Lines 1-13)

59. **Line 32: Change depletions to reductions.**

    Response: corrected.

60. **Figure 4: a) Diurnal variation of the spatial gradient of TEC over ASAB and DEBK , b)Daily maximum value of the spatial gradient of TEC variation, c) Diurnal variation of ROTIave over ASAB station and d) Daily maximum value variation of ROTIaave over ASAB station in the year 2014. Check this Figure caption and adjust according to your Figures (e) and (f) are missing.**

    Response:: Figures captions are adjusted (Page 13, Figure 5).

    Page 11

61. **Lines 1-2. If you can show it don't say it.**

    Response:: Modified (Page 13, Figure 5).

62. **Lines 10-11. "The trend they show has similarity with" The trend is already a similarity. Adjust the statement.**

Response: Adjusted.

63. **The caption of Figure 4 is misleading. Please check and let it conform with what you have in the texts.**

    Response: The caption of the figure is adjusted (Page 13, Figure 5).

64. **Why not add a correlation plot between spatial gradient and ROTI over each station? This is a better way of obtaining quantitative information between both quantities.**

    Response: Correlation plot between spatial gradient and ROTI over each stations are plotted (Page 14, Figure 6).

Page 12

65. **Line 3: What about Debark? Why is it not presented? Besides, is this Figure for quiet and disturbed periods? How did you segregate the effect of transient disturbances?**

    Response:
    Percentage of occurrence of ionospheric irregularities for Debark is plotted (Page 16, Figure 7). The figures are both for quiet and disturbed periods. We didn't segregate the effect of transient disturbances, since it is not the objective of the study. This may be worked in the future.

66. **Line 26: Basu et al., the year is missing.**

    Response: corrected.

Page 13

67. **Line 6: Change "has not been seen" to something suitable.**

    Response: corrected (Page 16, Line 15).

Page 14

Conclusions

68. **Lines 2-3: This is inconclusive and cannot feature in this section given the fact the relation between EEF and TEC gradient was investigated for just for 4 days (Figure 2).**

    Response: Modified. Quiet-monthly mean of EEF and TEC gradient were used to observe the relation between them (Page 10, Figure 2).

Acknowledgments

69. **Line 6: Remove and.**

    Response: corrected.

70. **Lines 7-8: We acknowledge http://www.geomag.org/models/PPEFM/RealtimeEF.html for providing the data the Prompt penetration equatorial electric field model. Give proper acknowledgement please.**

    Response: acknowledged correctly (Page 17, Lines 7-8).

71. **Line 8: Provide adequate acknowledgement for using the AMBER data (Visit AMBER website for adequate acknowledgement).**

    Response: acknowledged adequately (Page 17, Lines 8-9).

References

Page 15

72. **Line 31-32: Incomplete reference.**

    Response: corrected.

Page 16

73. **Line 16-20: Arrange references chronologically.**

    Response:: We are using bibtex and the references are printed automatically. May be it is the style of the journal.

74. **Line 36: Adjust the initials.**

    Response: Adjusted.

Page 17

75. **Line 1-5: Arrange references chronologically. Also consider the reference in P.16 line 36-37 in the chronological arrangement.**

    Response: We are using bibtex and the references are printed automatically. May be it is the style of the journal.