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Interactive comment on "Application of Fengyun 3-C GNSS occulation sounder for assessing global ionospheric response to magnetic storm event" *by* Weihua Bai et al.

Weihua Bai et al.

bjbwh@163.com

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Dear Chris Watson and Editor

Thank you for your comments concerning our manuscript entitled "Application of Fengyun 3-C GNSS occulation sounder for assessing global ionospheric response to magnetic storm event" (Manuscript Number: doi:10.5194/amt-2016-291-RC1). The comments and revises are very important for our paper's improving. We discussed and studied those valuable comments earnestly and made the updated manuscript and response carefully, we hope meet with approval. The new manuscript in the supplement is based on the helpful comments from the two referees during the state of the open discussing.

The responds to the nice comments from Chris are as flowing:

General comments: 1ãĂĄ . . .. . . The ionospheric response to the March 2015 storm has been extensively studied using (e.g. Astafyeva et al. 2015, Nava et al., 2016, etc.. a quick Google search reveals many). Discussion and references to these previous studies should be added, as well as consistencies or inconsistencies between GNOS RO observations and pervious results. Also add discussion on Habarulema et al., 2016, “Long-term analysis between radio occultation and ionosonde peak electron density and height during geomagnetic storms”, which is directly related to the analysis attempted in your study. . . .. . .

Response:

Thanks for the very good suggestions. We have added some discussion including the previous studies that you suggested. Please see Para. 5 in Section 1, Para. 1-4 in Section 4, and also renewed the Reference list.

Specific Comments:

1. P2 L30-37 Please specify receiver and antenna models.

Response:

According to the comment, we have revised the introduction to the payload GNOS in the first paragraph of the section 2, Page 3, line 8-10.

2. Figure 2: Individual hardware components shown in the figure should be labelled.

Response:

We have labeled the individual components in Fig. 2 in the uploaded manuscript. Thanks.

3. P3 L33: Equation 1 does not eliminate differential code biases due to receiver and satellite hardware, as implied in the text. Please discuss the techniques applied to

account for these biases.

Response:

Right. The code biases due to receiver and satellite hardware are difficult to eliminate totally. For the receiver, in order to eliminate the hardware delay of the two frequencies for one occultation satellite, we finished the calibration using the simulator on the ground before the launching, which can make the hardware delay caused by receiver lower than 1 ns. For the delay of the GPS satellite, we can get the correcting parameter form the GPS service centre (e.g. IGS). In equation 1, the L1 and L2 imply the ambiguities of the carrier phases and the hardware biases, so the TEC is the related TEC. It's not the absolute TEC. Moreover, begin with the equation(1), the derivative of the TEC can directly obtain electron density (see in Eq.(14) of Schreiner, et al., 199; Eq. (7.16) in Jin S., et al., 2014), so we do not need to consider the effect of the constant and bias in one occultation event processing.

4. Equation 2: Direct inversion of the TEC is usually sufficient for obtaining F region ionospheric densities. Is there a reason for using the bending angle inversion?

Response:

According to our old inversion method, we derived the bending angle and impact height from TEC, bending angle , used able inversion to get refractivity, then according to , we could get the electron density , eventually. But, we had updated the better inversion method (see in Eq.(14) of Schreiner, et al., 199; Eq. (7.16) in Jin S., et al., 2014) to obtain electron density profiles directly. Therefore, here is a mistake. We have replaced the Eq.(2) to , where is Electron density, r0 is the straight-line impact distance, see in section 2, Page 4 , line 3-5 in new manuscript.

5. Equation 2: Please provide the method used for obtaining bending angle from the excess phase. Also specify how bending angles above satellite altitude are accounted for (since you are integrating to infinity).

Response:

The same as the comment 4, we have corrected the Eq.2, and don't need to derive the bending angle. It's a very good question for the upper limit of integral. Because the altitude of the FY3C is around 833km, it's a better height to integral; the effect of the integral from the LEO satellite altitude to infinity is small enough, and neglected.

6. Please indicate whether ionograms were scaled manually or "auto-scaled". Ionospheric parameters derived from manually scaled ionograms are generally more reliable.

Response:

we downloaded the ionosonder products of the SWPC worldwide stations from it's website(ftp://ftp.swpc.noaa.gov/pub/lists/iono_month/), and got the final ionospheric parameters. All these products had the quality identify, we chose the good quality data. For the ionosonder products from the China Meridian Project stations, we had all the raw data, so we scaled ionograms manually.

7. State the maximum tangent point – ionosonde separation distance used in NmF2 validations.

Response:

The criteria of the matching pairs of GNOS and ionosoder data have given in section 2 of the old manuscript:"The criteria used for matching GNOS and ionosonde data were a time interval within ± 1 hour, and geographic latitude and longitude within $\pm 2^{\circ}$ ". So, we used the geographic coordinates, the furthest distance between the maximum tangent point and ionosonde is around 200 km.

8. Since occultation hmf2 is being used for analysis in this study, it should be validated as well. It shouldn't be too difficult to compare occultation and ionosonde hmf2, similar to the Nmf2 validation.

Response:

Correct. In fact, we have validated the occultation hmF2 and shown well with about 5km bias and 25km STD between two measurements. However, considering the length of our manuscript and the main purpose of our paper aiming at analyzing the variation of the daily and zonal average of the NmF2 during the geomagnetic storm, we would like to omit the corresponding figures for validating GNOS hmF2.

9. The Discussion in Section 3.2 seems to imply that the variations in NmF2 are a geographical effect (e.g. Line 28: “large increases in the South Atlantic region”), however these are observations over a 10 hour period, and thus temporal effects would be large, particularly during a geomagnetic storm. I’m not convinced that a few occultation events over a 10 hour period are sufficient to characterize the ionospheric behavior in a particular geographical region. From Figures 7a-b, the most I would conclude is that equatorial/low latitude NmF2 increases during daytime, and decreases at night. I have the same concerns for the geographical trends are also discussed on Page 7, Lines 17-23.

Response:

Sorry, here it seems easy to lead to some misunderstanding. We noted the LT distribution of FY3C orbits flying over magnetic inclination -80o $\sim$ 80 o in day and night time is mainly around 10:00 LT and 22:00 LT as shown in figure 4 and 5. So the GNOS observations during pre-storm and storm over South Atlantic region have the similar LT in 2-3 consecutive orbits, but their events are really lack with about ten times. In other words, the GNOS observations over the same region have the similar LT distributions, therefore over the same place their differences obtained by GNOS observations between pre-storm and storm could mainly be attributed to the storm effects, although the GNOS observations are only a few times. As for the variations of NmF2 at low latitudes, in previous studies Astefyeva et al. [2015] have pointed out the most dramatic positive ionospheric storm occurred at low latitude Eastern Pacific and American regions in the morning and post-sunset sectors. But seen from Figures 7a-b, we are difficult to evaluate the ionospheric storm effect due to the sparse GNOS observations over many regions in low latitude. As for the Eastern Pacific region between the longitudes from -180 o to -120 o over low latitude in the morning as shown in Figure 7a, there seems to be more daytime GNOS observations on 14 March 2015 during pre-storm and on 18 March 2015 during recovery phase of the storm. By comparing their intensities of NmF2, we found the increase of NmF2 over this specific region, which, as one positive ionospheric storm effect, has been reported by Astefyeva et al. [2015]. Similarly, by comparing the nighttime GNOS observations over Eastern Asian in low latitude on 14 and 18 March 2015 as shown in Figure 7b, we reconfirmed the negative ionospheric storm effect which was also displayed in previous studies [e.g., Astefyeva et al., 2015; Nava et al., 2016]. About this aspect, we have added some discussion. Please see them in Section 4, Para 2-3, pp7-8.

10. Figure 8 averages NmF2/hmF2 from mid-latitude, trough, and auroral regions. Since the ionospheric structure can vary significantly over these regions, please comment on the potential effects of this averaging, and whether the trends shown in Figure 8 would change if only mid-latitudes or auroral regions were considered.

Response:

Right. The regions of GNOS observations in geomagnetic inclination 40 -80 degree would mainly locate at the mid-latitudes, and some parts would locate at main ionospheric trough, even at auroral regions, because the March 17 storm can vary significantly the ionospheric structure. As we know the trough mainly occurs in nighttime and locates just at the outside of the auroral oval; its minimum is usually situated in 60-65° magnetic latitudes in quiet time [e.g., Karpachev et al, 2016]. Along with the trough moving into the lower magnetic latitudes during the storm, the numbers of GNOS observations over the trough would increase but the corresponding NmF2 values would decrease. Thus, the zonal averaging value in NmF2 would result in decrease. However, the reverse effect on the zonal averaging value in NmF2 would be occurrence when the auroral regions with significantly enhanced ionization in the nighttime expand largely on the equatorward during the storm [e.g., Watson et al., 2011]. Hence, these two effects on the NmF2 may counteract each other. Nevertherless, it is difficult for us to identify how many GNOS observations lie in the trough or auroral regions during the storm and then check out the exact effects on the zonal averaging in NmF2 over trough or auroral regions. Roughly, the trends shown in Figure 8 would change more or less due to the effects of these regions, but not large since most of the GNOS observations in Fig.8 located at mid-latitudes. Please see them in Section 4. Para. 3, line 15-29, pp8.

11. On a related note, please comment on the occurrence magnetospheric substorm activity, which can result in significantly enhanced ionization in the nighttime auroral region. I would strongly suggest analyzing mid-latitude and auroral regions separately, instead of a broad region covering 40 to 80 degrees inclination.

Response:

It's a good suggestion for analyzing mid-latitude and auroral regions separately. We would have studied the mid-latitude and auroral regions, individually. Unfortunately, the numbers of iononsphere occultation events were few, in Fig.8, the lowest number of the GPS occultation event was just 12 per night. In order to remain the significance of statistic, we had to analyze them in the bigger region. In the next, we plan to analyze the characteristics of this storm in smaller regions using both FY3C and COSMIC data.

12. The standard deviation for each averaged HmF2 and NmF2 value should be shown in Figures 8 and 12, perhaps as error bars.

Response:

Good. They were added in both Fig.8 and 12 in new manuscript.

13. P6 L8: NmF2 is maximum on March 16 according to Figure 8, as opposed to March 17 as stated in the text.

Response:

Here nighttime hmF2 is maximum on March 17 (green line), and nighttime NmF2 is maximum on March 16 (blue line) in Figure 8. See it in Section 3.3, line 16, pp6.

14. P6 L32: Is there an explanation for the few stations that observed a sustained daytime NmF2 enhancement on March 18?

Response:

The exact reasons for the daytime NmF2 enhancement on March 18 are not clear. The major factors are including the neutral composition changes, theremospheric winds, disturbance dynamo electric field, or some combination of those [e.g., Crowley et al, 2006; Balan, 2011; Richmond and Lu, 2000]. The further work combined with more data analysis and modeling calculations will be needed to study the mechanism of the observed results. The corresponding discussions are given in Section 4, Para. 4, lines 37 -6, pp8-9.

15. Integrating NmF2 over all local times in the top panel of Figure 12 seems meaningless.

Response:

OK. We have removed the top panel of figure 12 and re-plot the figure 12 with error bars.

16. P7 L5-6: GNOS observations at 40-80 magnetic inclination extend into the auroral region, well poleward of the northernmost ionosonde station (Moscow) in Figure 9, and thus the averaged ionosonde NmF2 wouldn't include significant auroral region effects. This may help explain discrepancies in Figure 12. For completeness, consider including ionosonde measurements from stations north of Moscow, of which there are several.

Response:

Yes. The observed regions are larger about 8 degree inclination by GNOS instrument than by ionosondes. If the more ionosonde data from stations north of Moscow are available, it will be better for us to make the comparison between two different data. Unfortunately, we have achieved none. Currently, we have recalculated the averaging NmF2 observed by GNOS within 40-72° inclination in the Supplement Figure (S. Fig.) 1. Here, the chosen 72° inclination aims at including all 17 ionosonde stations. Comparing the extents of GNOS NmF2 close to ionosonde observations between S. Fig. 1 and Figure 12, we can see that the approaching is better in S. Fig. 1 than in Figure 12, especially in the daytime. In the S. Fig. 1, the discrepancies between GNOS and ionosonde also exist. There should be other factors resulting in the obvious discrepancies. The major factor is due to the GNOS observations outspreading over the world, whereas the ionosondes locate at the several longitudes on the continents.

Supplement Figure 1: Comparison of averaging NmF2 values from the 17 ionosonde stations and GNOS in the 40-72° inclination in the NH.

17. P7 L6-7: "..indicating significant differences still exist between the two measurement techniques." Please specify the differences this statement is referring to.

Response:

Good. These discrepancies may be due to the significant differences of the spatial observations between the two measurement techniques, i.e., GNOS can observe globally, whereas ionosondes mainly locate at several longitudes on the continents. We have made a revision in the manuscript accordingly. Please see it in Section 3.4, Para. 2, lines 14-16.

18. P7 L13: Spherical homogeneity of ionospheric density is also a very large assumption at high latitudes (trough, auroral, polar cap regions).

Response:

Yes. We have stated it in the section 4 , Page 7, line 23.

19. P8 L7: Instead of “GNOS data”, specify that GNOS NmF2 values are reliable, since this was the only parameter validated in the manuscript.

Response:

Ok, it a scrupulous expression, we accept it and corrected in new manuscript, Page 9, line 19.

Technical Corrections:

1. P1 L16: I suggest “space detection” be replaced with “space-based remote sensing” or something along those lines.

Response:

Ok, we replaced it in Page 1, line 16 in new manuscript.

2. P1 L26-28: Unless I’m misinterpreting the intended meaning, this sentence should read something like: “In the zone of 40-80° magnetic inclination, average NmF2 observed by GNOS and 17 ground-based ionosondes showed the same basic trends during the geomagnetic storm.

Response:

Yes, we rewritten this sentence, and make it more accessible, see in Page 1, line 27-29 in new manuscript.

3. P2 L4: “The GNSS radio occultation technique uses occultation receivers. . .”

Response:

OK. We revised it, see in Page 2 , line 4.

4. Figure 1 axis labels are difficult to read.

Response:

Sorry. We have revised it and replaced a new figure 1 in new manuscript.

We appreciate for your warm work earnestly, and hope that the response will meet with approval.

The references and the new update version paper are enclosed in supplement.

Thank you very much.

Yours sincerely,

Bai Weihua, Wang Guojun and other co-authors

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/amt-2016-291/amt-2016-291-AC2-supplement.zip

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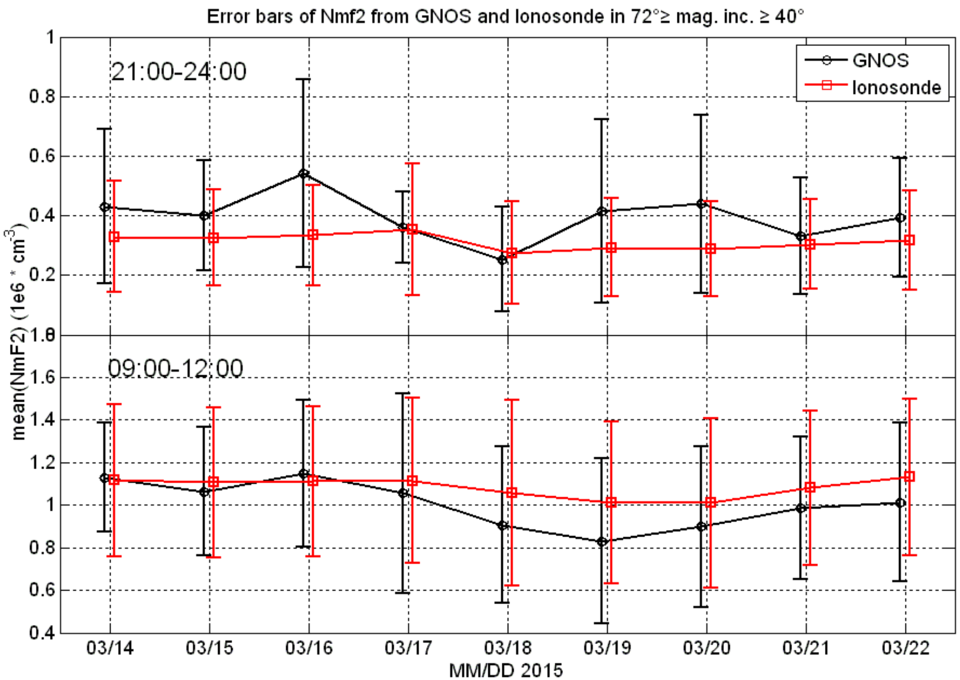

Fig. 1. Comparison of averaging NmF2 values from the 17 ionosonde stations and GNOS in the 40-72° inclination in the NH.

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Discussion paper