Responses to interactive comments on**, "Modeling Total Electron Content derived from radio occultation measurements by COSMIC satellites over the African Region"**

By Mungufeni et al.

March 03, 2020

We thank the reviewers for taking time to evaluate our manuscript. All the comments are addressed as shown below.

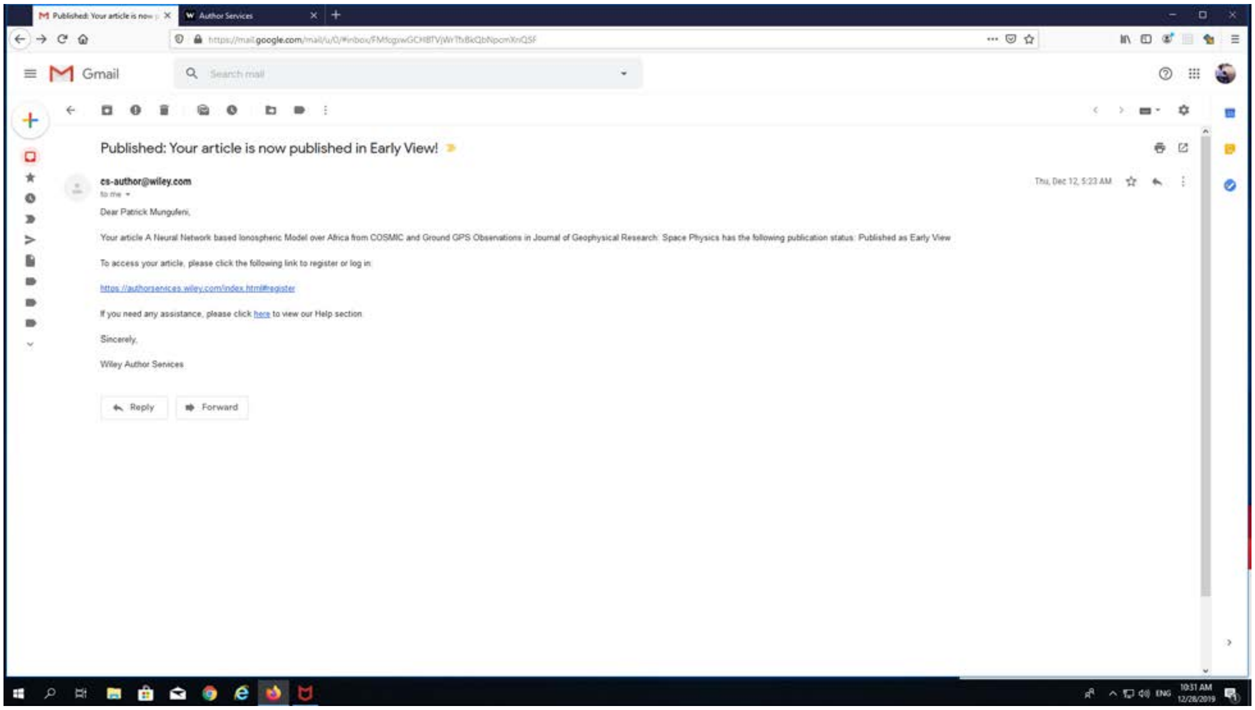
Reviewer 1:

Comment:

An author of this paper (Patrick Mungufeni) along with a long list of other authors have recently published the following paper: Okoh, et al. (2019). A neural network based ionospheric model over Africa from COSMIC and Ground GPS observations. Journal of Geophysical Research: Space Physics, 124. https://doi.org/10.1029/2019JA027065. In that particular paper the authors perform an adjustment using Neural Networks according to which they correct the reasonable discrepancy between TEC from ground based receivers (up to 22000 Km) and occultation measurements up to 700 Km. They seem to apply no such procedure in this paper. This is a major problem of this paper. They also need to make special reference to that paper.

Response:

Indeed, Patrick Mungufeni contributed to the paper in the comment which was published on Thur, Dec 12, 5:23 PM. The current manuscript under discussion was submitted on Saturday, Nov 23, 2:09 PM (Korean time). Therefore, we could not reference Okoh et al, (2019) since it was published later after the current submission. Below are the screen shots of emails to prove the dates. Anyway, we shall reference Okoh et al. (2019).



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cs-author@wiley.com
to me
Thu, Dec 12, 5:23 AM

Dear Patrick Mungufeni,

Your article A Neural Network based Ionospheric Model over Africa from COSMIC and Ground GPS Observations in Journal of Geophysical Research: Space Physics has the following publication status: Published as Early View

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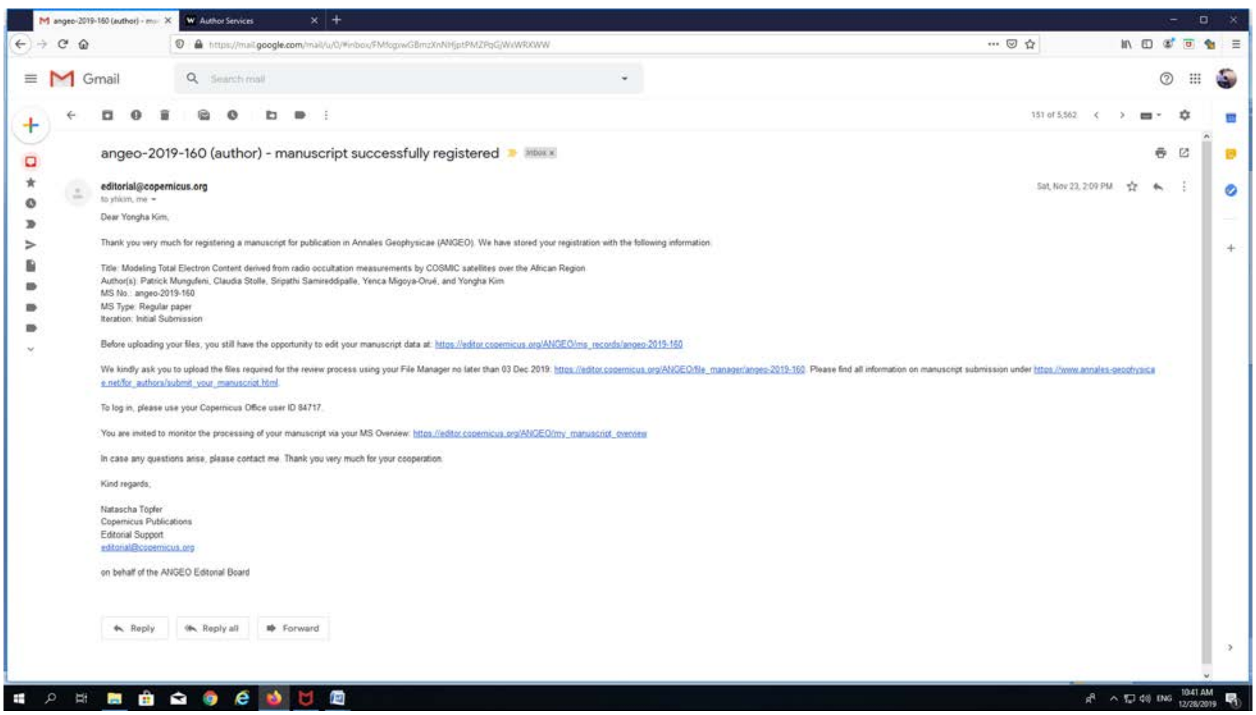

angeo-2019-160 (author) - manuscript successfully registered

editorial@copernicus.org
to yhkim, me
Sat, Nov 23, 2:09 PM

Dear Yongha Kim,

Thank you very much for registering a manuscript for publication in Annales Geophysicae (ANGEO). We have stored your registration with the following information:

Title: Modeling Total Electron Content derived from radio occultation measurements by COSMIC satellites over the African Region
Author(s): Patrick Mungufeni, Claudia Stolle, Sripathi Samireddipalle, Yenca Migoya-Orué, and Yongha Kim
MS No.: angeo-2019-160
MS Type: Regular paper
Iteration: Initial Submission

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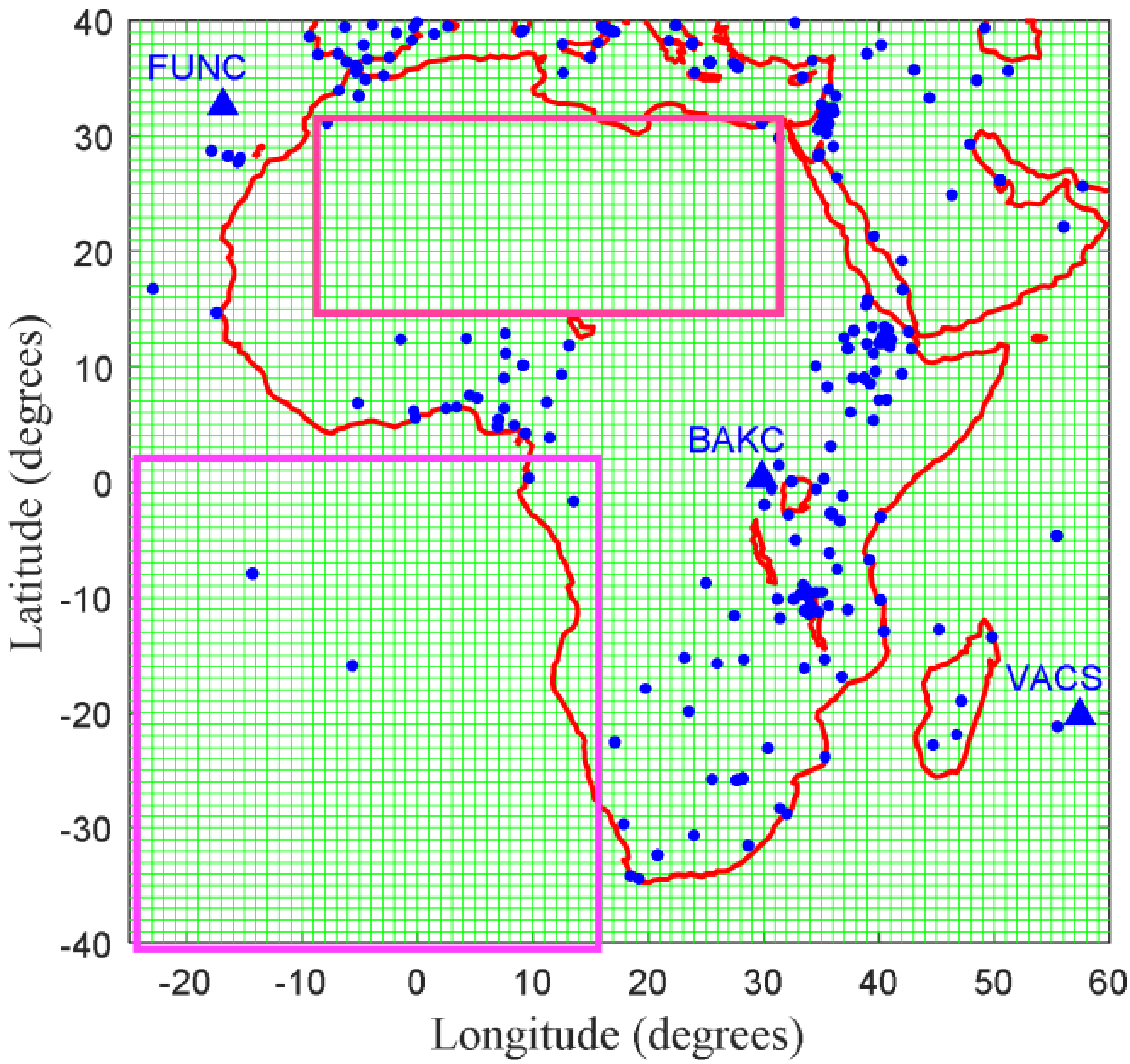
In case any questions arise, please contact me. Thank you very much for your cooperation.

Kind regards,

Natascha Töpfer
Copernicus Publications
Editorial Support
editorial@copernicus.org

on behalf of the ANGEO Editorial Board

Although the reviewer is recommending creation of data base consisting of both ground and space based TEC measurements, such data base may be subjected to criticism. For example, the observation in Okoh et al. (2019) where the ratio between ground based and COSMIC TEC varies spatially implies that neural network may not learn the relationship between the two data sets over locations which only have COSMIC TEC data. We have highlighted with magenta boxes in Figure below such regions which mostly have COSMIC TEC. The Figure was taken from Okoh et al. (2019). Over the boxes, the adjustments made to COSMIC TEC may not be trusted because of large distances over which interpolations are done.



When a study opts to have both adjusted COSMIC TEC data and ground based GPS TEC data, some locations will be represented by adjusted COSMIC TEC (remember not trusted) while others will be represented by ground based GPS TEC. Obviously, there is still disparity. For purposes of consistency, it might be fair to use entirely adjusted

COSMIC TEC since it can also be available where there is ground based GPS TEC. Since we do not trust the current known procedures for adjusting space based observations (Okoh et al. (2019) and Mungufeni et al. (2019), *Estimation of equivalent ground-based total electron content using CHAMP-based GPS observations*, Adv in Space Res 64, 199 - 210) the current manuscript used only COSMIC TEC without any adjustment.

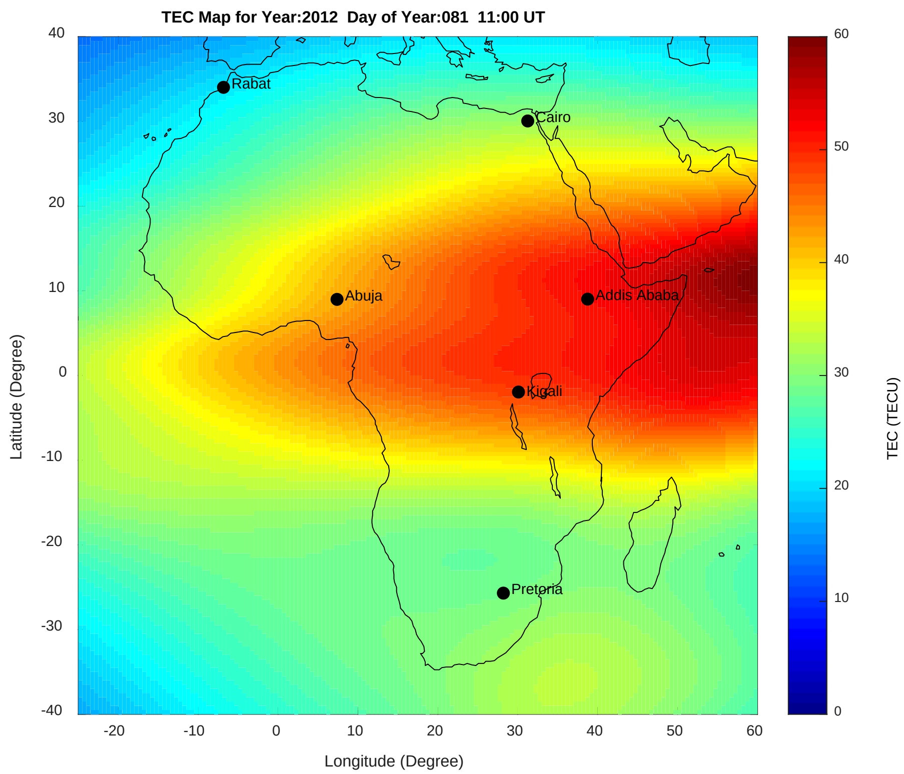
Comment:

Maybe they should compare the output of the NN model out of that paper with the output of the spline model for this paper despite that the COSMIC dataset is used as a basis for both models. In this way they will prove their approach for this paper (omitting any correction for the plasmaspheric contribution which is expected to be high at middle African latitudes

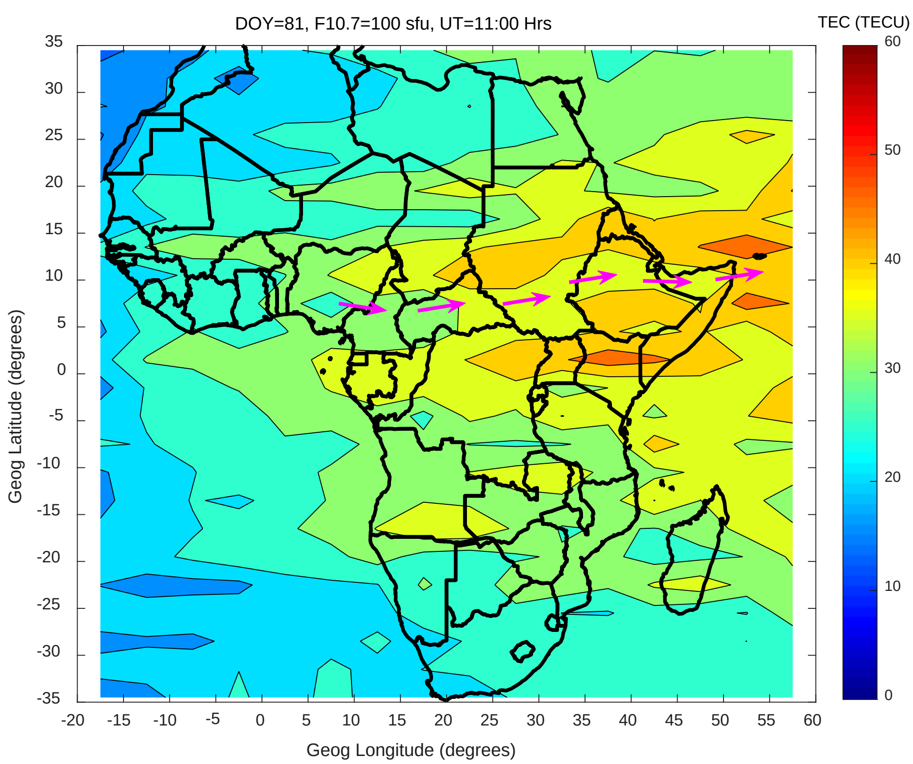
Response:

The suggestion in the comment will be implemented. As indicated in Okoh et al. 2019, TEC plots based on NN model can be obtained from MATLAB Central website

(https://www.mathworks.com/matlabcentral/fileexchange/69257-african-gnss-tec-afritec-model?s_tid=prof_contriblnk). We present in Figure below an example of TEC generated by NN model on March 21, 2012 at 11 UT.



The corresponding TEC map generated based on our model (spline method) is presented below.



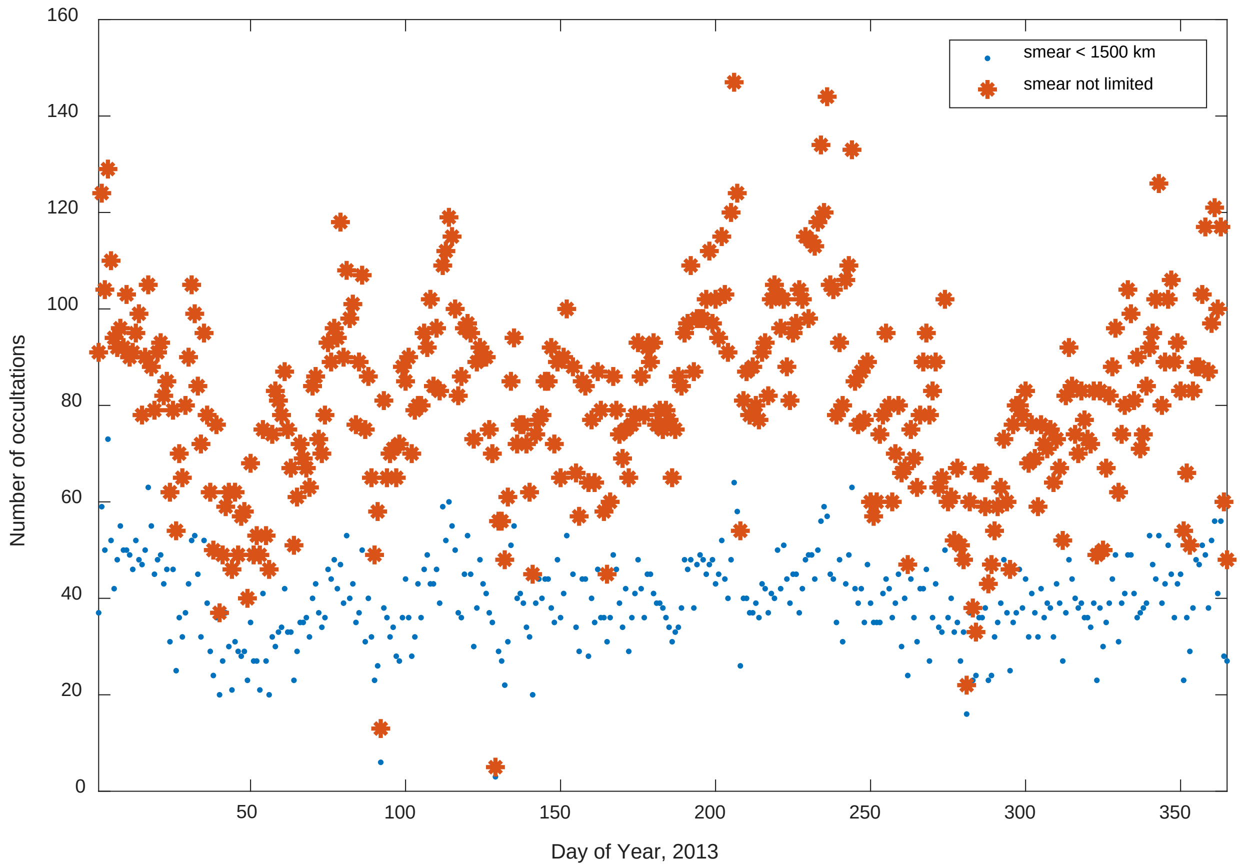
In the two TEC maps above, it can be seen that unlike our TEC map which shows the EIA trough (see magenta arrows), the NN TEC map failed to capture the EIA trough. This short fall in NN model TEC map might be due to poor data to represent day of year during model development. This point has been illustrated properly in the response to the next comment. It would be interesting to compare error levels produced when some measured TEC is compared with (i) NN TEC map and (ii) our spline model. We may not perform such analysis since model in (i) is based on electron density that is integrated from ground up to GPS satellites, while model in (ii) is based on electron density integrated up to ~800 km.

Comment:

The authors do not provide any scheme by which they would reject any unrealistic COSMIC profiles. There have been numerous validation studies with Digisondes that verify this problem especially in the bottomside.

Response:

Empirical modeling requires adequate data for the mathematical functions to capture the physics inherent in the data. However, to minimize measurement errors, studies that have used COSMIC data commonly reject measurements with horizontal smear > 1500 km. We have presented in Figure below the number of COSMIC TEC measurements per day during the year 2013 over the longitude and latitude ranges of -15 – 60^o and -35 – 35^o, respectively.

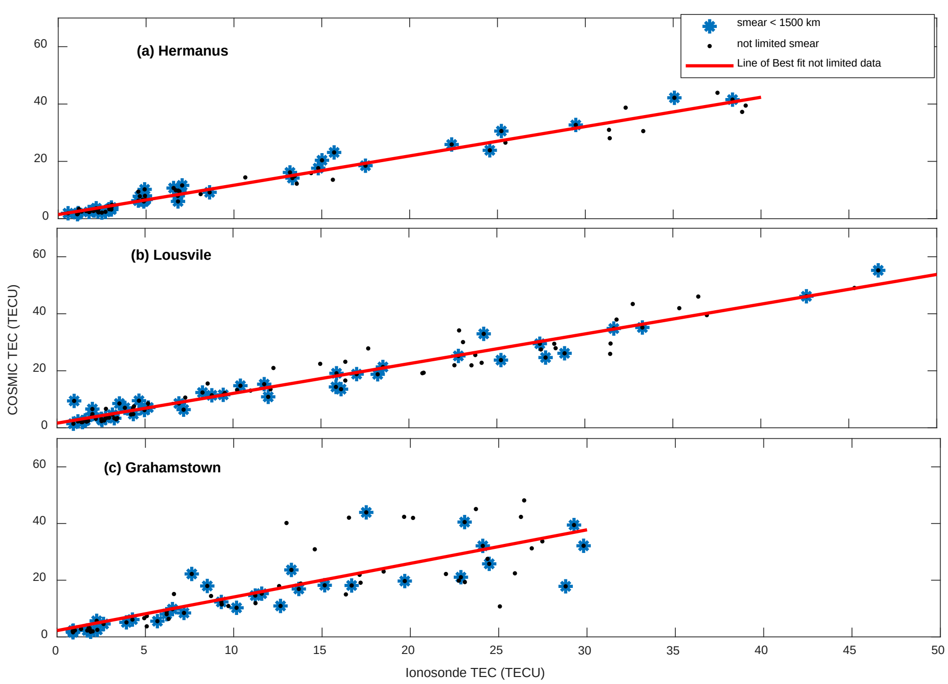


The blue dots indicate COSMIC TEC measurements when the horizontal smear is < 1500 km, while the red stars indicate COSMIC TEC measurements without limitation of horizontal smear. It can be noticed that when the horizontal smear is limited, ~40 observations may be made per day. Obviously, the 40 measurements may not cover very well all the 24 hours in a day and all the grid cells. This shows clearly that the seasonal or day number of year variation does not have good input data for the entire African region. This is clearly manifested in NN TEC model presented previously. In order to have fairly adequate data, we did not apply restriction to the horizontal smear. Therefore, in a day, there were about 80 observations as shown with red stars in Figure above.

We established that the COSMIC TEC data values with smear > 1500 km do not introduce alarming errors. This was done by analyzing COSMIC TEC data which were coincident with TEC observed by ionosonde stations at Hermanus, Grahamstown, and Louisvale. The observations of the year 2013 were considered. Table below presents the root mean squared error between (i) ionosonde and COSMIC TEC without limiting the horizontal smear, and (ii) ionosonde and COSMIC TEC with horizontal smear limited to 1500 km.

Station	Smear < 1500 km		No limitation	
	Number of observations	RMSE (TECU)	Number of observations	RMSE (TECU)
Hermanus	38	1.838	65	2.256
Grahamstown	34	6.479	73	7.923
Louisvale	42	2.765	91	3.252

The table shows that the RMSE for the two cases over a particular ionosonde station are not grossly different. Based on these results, trading off accuracy may not be costly compared to trading off adequate need of data. Therefore, we decided not to impose any restriction on the horizontal smear. Although the RMSE appear to be smaller when the smear < 1500 km, some of the data points that were subjected to this restriction are also far from the linear least squares fitting line. See blue stars in Figure below.



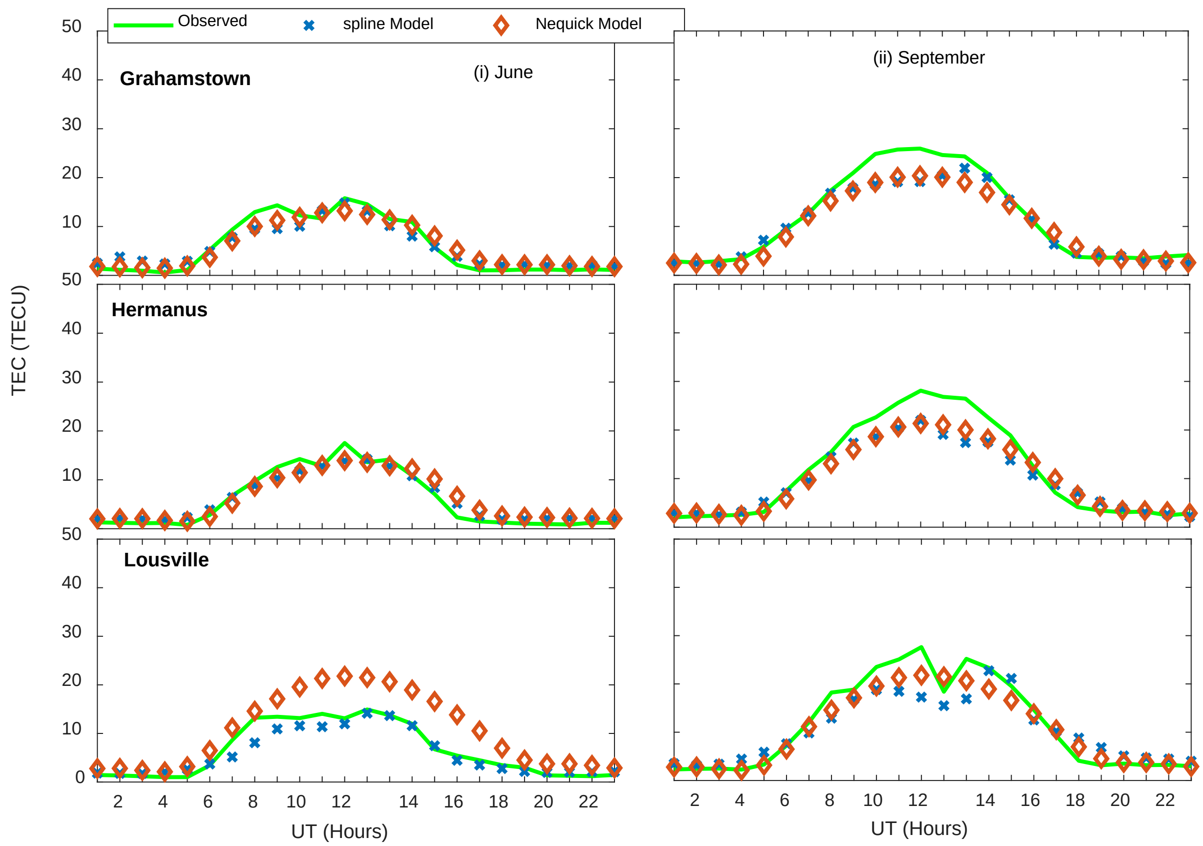
Most likely, the ~80 COSMIC TEC data points in a day may not still cover very well all the 24 hours in a day and all the grid cells. This problem might be solved by adopting appropriate data binning criteria. Therefore, instead of binning data according to year, we binned data according to only three different solar flux levels. This technique proved to be good and it was published in Mungufeni et al, (2019), *Characterization of Total Electron Content over African region using Radio Occultationobservations of COSMIC satellites*, Adv in Space Res 65, 19 – 29.

Comment:

I strongly suggest to compare the output of their model with ionospheric TEC (up to 700 km) from all over four stations Digisonde stations over South Africa https://spaceweather.sansa.org.za/products-andservices/current-conditions/ionograms. This will provide a much more realistic comparison test to their model

Response:

The suggestion in the comment will be implemented. We illustrate in Figure below with continuous green lines the diurnal patterns of TEC measured by ionosonde stations at Grahamstown, Hermanus, and Lousville. The corresponding TEC generated by our model and Nequick are superimposed with crosses and diamonds, respectively. We need to mention that during computation of TEC using Nequick, the height was limited to the approximate altitude of the COSMIC satellites (800 km). The panels in columns (i) and (ii) show TEC on DOY 160 (June) and 260 (September), respectively. Both days are of the year 2013. Preliminarily, there appears to be good correspondence between the observed and the modeled TEC. We intend to generate such data plotted in the figures for the entire year 2013 and then perform statistical analysis of the differences between the observed and the model TEC data.



Reviewer 2

Comment:

The manuscript presents an empirical model describing ionosphere total electron content over African region. Authors use experimental TEC data obtained using dual frequency GNSS RO receivers onboard of COSMIC satellites to construct the model. They validate the model using same type of data that was used to construct the model but for a different period.

Response:

In addition to using the same type of data for validating our model, we shall also use TEC measured by ionosonde stations over South Africa. This has been demonstrated in the response to the previous comment.

Comment:

General impression is that the present work has no contribution to the current understanding of the low latitude ionospheric physics/modelling. The work brings a little science and the newly created model could hardly be used in any real-life application. Authors are making too many assumptions and mistakes, sometimes trying to deliberately present performance results better than they are. Moreover, the performance of the model has not been compared to any other well-known model, leaving a room for doubts. Therefore, I recommend the manuscript (in its present form) is **rejected**. At the same time, the work might be improved and worth publication after substantial modifications. Please find below a list of critical issues along with possible improvements/corrections for a potential future re-submission.

Response:

Later comments reveal that the reviewer has kindly elaborated with examples of the above comments. Therefore, appropriate responses have been given later following the elaborated comments. Since all comments have been addressed appropriately, we do not expect a decision to reject our manuscript.

Comment:

P.1 L.27: Replace “good” with “applied”. Otherwise, provide a proof of the model “goodness”

Response:

The suggestion will be implemented.

Comment:

P.2. L.35-38: Not all GNSS systems support ionospheric corrections. E.g. GLONASS does not broadcast any ionospheric model parameters. Correct the sentence accordingly.

Response:

The correction will be done as suggested.

Comment:
P.2 L.40: Provide a reference to the original description of Klobuchar model: *"Klobuchar JA (1987) Ionospheric time-delay algorithm for single frequency GPS users. IEEE Trans Aerosp Electron Syst 23(3):325–331. https://doi.org/10.1109/TAES.1987.310829"*

Response:

The reference will be added as suggested.

Comment:
P.2 L.41-42: NeQuick G model is based on the NeQuick model, but not NeQuick 2. Correct the statement and the reference accordingly, e.g. *"EC (2016) European GNSS (Galileo) Open Service—Ionospheric correction algorithm for Galileo single frequency users, Issue 1.2, Sept. 2016, European Commission"*

Response:

The correction will be done and the suggested reference will also be added.

Comment:
P.2. L.42: Change "The NeQuick is" to "The NeQuick and its subsequent modifications (NeQuick G and NeQuick 2) are"

Response:

The suggestion will be implemented.

Comment:
P.2 L.53: IRI model does not provide information about "electron and ion velocities". It

only provides information about equatorial vertical ion drift. Correct the sentence accordingly.

Response:

The sentence will be corrected as, “For the international standard specification of ionospheric parameters (such as electron density, electron and ion temperatures, and ion drift velocity) ….”

Comment:
P.2 L.55-56: Change “The model is primarily” to “IRI is an empirical model primarily”

Response:

The suggestion will be implemented.

Comment:
P.3 L.74: Change “GIM” to “global ionosphere model”, as GIM is already defined to be Global Ionosphere Map.

Response:

The suggestion will be implemented.

Comment:
P.3 L.76: Change “GIM model” to “global ionosphere model”

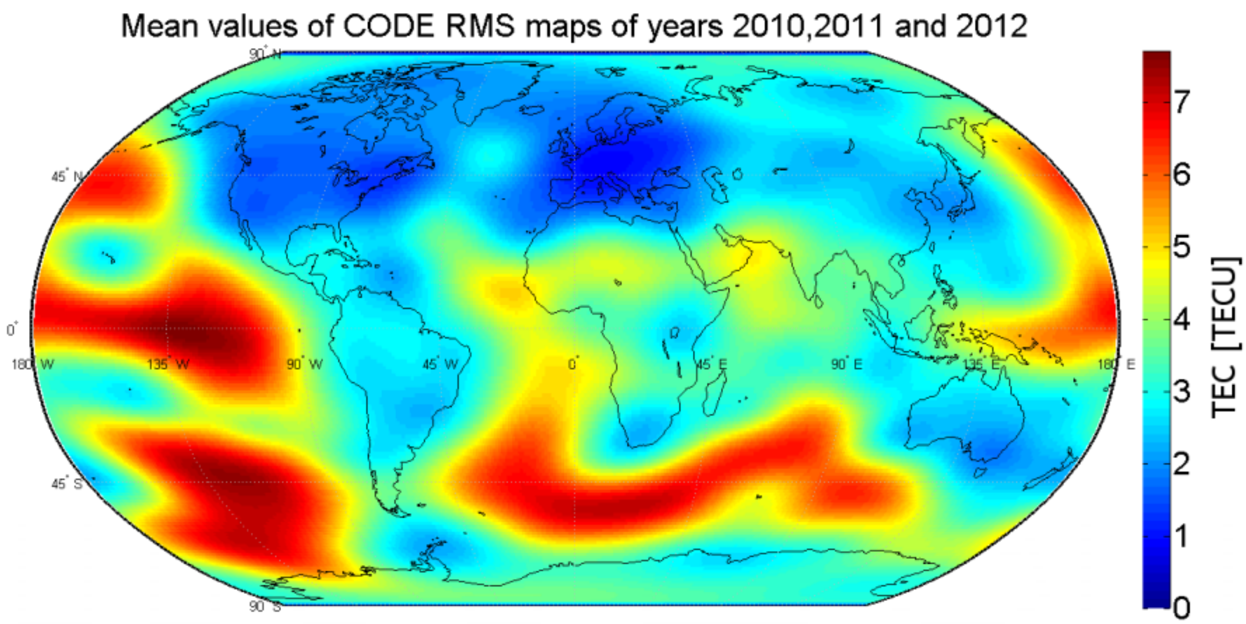
Response:

The suggestion will be implemented.

Comment:
P.3 L.80-82: The high values of RMS in low latitude region provided by CODE is, primarily, due to the inability of the selected model function (spherical harmonics) to describe ionospheric structure in low latitude. Modify the sentence accordingly.

Response:

We based on Fig below (obtained from Najman, P. and Kos, T.: Performance Analysis of Empirical Ionosphere Models by Comparison with CODE Vertical TEC Maps, Chapter 13, in: Mitigation of Ionospheric Threats to GNSS: an Appraisal of the Scientific and Technological Outputs of the TRANSMIT Project, InTech Open Science publications, pp. 162 - 178, doi:10.5772/58774, 2014) to make the statement, “This could be due to the poor distribution of IGS tracking stations over Africa and anomalies in the ionosphere related to the geographic and geomagnetic location”.



Indeed, figure above shows high RMS values over the oceans and land masses that have few/no ground based GPS receivers. This situation typically exists around and over the African continent.

Since figure above does not strictly show high values of RMS over all low latitude regions where EIA exists, we intend to remove EIA as a reason for the high RMS values over Africa.

Although the reviewer did not give reference, his/her suggestion of the inability of spherical harmonics to describe well low latitude ionospheric structure is consistent with existence of EIA over low latitudes.

Comment:

P.3 L.84: Change “the GIM model” to “global models”

Response:

The suggestion will be implemented

Comment:

P.4 L.115: Author use TEC integrated up to COSMIC satellite heights (800 km) to construct the model (*“integration being done up to the altitudes of the COSMIC satellites”*). However, the topside TEC values (according to numerous studies, e.g. by Bilitza 2009, Yizengaw 2008 etc.) can reach from 10% to 80% of the total electron content (from ground to GNSS satellite heights). This fact significantly reduces the scientific value and application of the developed model. Essentially, the model is useless for GNSS applications.

Response:

We think that lack of inclusion of plasmaspheric TEC in COSMIC RO TEC, does not render the data completely useless. This point can be illustrated by examining the available differences between coincident COSMIC RO TEC and ground based GPS TEC. Concerning the region under study, the upper quartile of the differences between coincident COSMIC RO TEC and ground based GPS TEC could reach ~11 TECU (Mungufeni et al, (2019), *Characterization of Total Electron Content over African region using Radio Occultation observations of COSMIC satellites*, Adv in Space Res 65, 19 – 29). Since the upper quartiles of the differences can reach up to ~11 TECU, the median/mean values might obviously be much lower than this value. This might be the reason for observing most of the well known ionospheric TEC features over the African region when the COSMIC RO TEC were appropriately binned in the above reference. The ionospheric features being referred to include; (i) occurrence of minimum and maximum TEC during 0:00–08:00 LT and 12:00–16:00 LT respectively, (ii) occurrence of secondary TEC enhancement (maximum) during 16:00–20:00 LT, (iii) lowest TEC values being observed in June solstice and highest TEC values observed in March equinox, (iv) TEC values increase as solar activity changes from low to high, (v) mid latitude TEC values are lower than those of low latitude regions, and (vi) occurrence of equatorial ionization anomaly.

Therefore, the current model was built with the aim of simulating these known ionospheric features. Such simulations are important for education purposes. Moreover we illustrated in a previous response that our model generates TEC values consistently with that observed by ionosondes. This implies that equivalent TEC measured by ionosondes over locations which do not have ionosondes can be predicted fairly well using our model.

Comment:
P.5 L.124-126: This statement "*Since the magnitudes of the TEC obtained from COSMIC occultation 124 measurements are close to ground based GNSS TEC*", is not consistent with the previous statement and studies by Mungufeni et al. 2019. Where they show that, depending on the location, the RMS error can vary from 2 to 8 TECU and error distribution plots show values from -24 to 20 TECU. Such large errors cannot be considered "*close to ground-based GNSS TEC*". Authors, at least, are expected to provide information about relative TEC errors (in %, rather than TECU) to claim that errors can be tolerated (if so).

Response:

This comment is similar to the previous one that was already responded to. Much as it appears good to report percentages of the error levels, it needs to be noted that only relying on percentages may be misleading. For example, 90 % which looks impressive can be obtained from 9 samples drawn from 10 observations. Statistically, the number of observations is too small to be relied on in order to draw a general conclusion. In addition to the number of different error levels reported in the stated references, we shall go back to analyze the data presented in the stated reference and also report the percentages of the different error levels.

Comment:
P.6 L.150: The title of the reference Emmert et al. 2010 is incorrect: *Emmert, J. T., Richmond, A. D., and Drob, D. P.: Statistical analysis of the correlation*

412 between the equatorial electrojet and the occurrence of the equatorial ionisation 413 anomaly over the East African sector, J. Geophys. Res., 15; A08322; 414 doi:10.1029/2010JA015326, 2010.

Response:

The correction will be made.

Comment:

P.6 L.157-167: The selected spatial resolution of 15º in longitude and 5-8º in latitude is too coarse to describe the ionosphere reasonably, especially for the low latitude region, where TEC is changing dramatically from the crest down/up to two peaks of EIA. E.g. GIM maps (the source of the data for most of the empirical models discussed by the authors in the introductions section) use at least 5º by 2.5º resolution (lon and lat). Moreover, 15º in longitude corresponds to 1 hour in LT. Gradients in TEC as a function of LT during sunrise and sunset hours may reach tens of TECU per hour (e.g. Mungufeni et al. 2019, Fig. 2). Therefore, such coarse spatial resolution in longitude will lead to big errors in the model description.

Response:

We have tried to develop the model using data binned in grids with longitude range of 5^{o} and latitude range of 3^{o}. Indeed, there is improvement in the output as shown in the figures presented in this document. With the exception of the last figure in this document, all the model outputs presented in this document were based on the new model.

Comment:

P.6 L.170: The whole solar cycle 24 has relatively low solar activity level compared to the two previous ones. Nevertheless, even if we look only at the 24th solar cycle, 2011 and 2016 could hardly be attributed as years of high solar activity level. Please, modify the statement accordingly (e.g. as it is done on P.7 L.182).

Response:

The sentence will be modified as, “Since there were many geomagnetically disturbed days during the years (2011 - 2016), ……”.

Comment:

P.7 L.189: Please clarify, how 36 solar flux bins were obtained. From the description, it is only 3 solar flux ranges and 12 months, that gives 36 (3x12). But when listing by a variable, only number 3 has to be specified, as it is done, for example with the rest of the variable (hour, lat and lon). Indeed, if we take 60,480 TEC values indicated in L.189, this number can be obtained by multiplying 5x14x3x12x24, but not 5x14x36x12x24.

Response:

In each of the 3 solar flux ranges, there are 12 nodes, corresponding to the months in a year (see table 2 and page 7, line 184). This results in to the 36 solar flux bins. The listing in equation 2 which appears as 3 will be changed to 36.

Comment:

P.8 L.205: According to the definition of cubic spline, it is a spline constructed of piecewise thirdorder polynomials, meaning none of the B splines used in the model were cubic (order 2 and 4). Change the “cubic B spline” into “B spline of different orders” throughout the text and abstract.

Response:

The suggestion will be implemented.

Comment:

P.9 L.218-220: Consider changing this sentence to something like “In order to assess the ability of the model to describe the data used to construct the model, modelled data were compared to the experimental one. The results of the self-consistency check are presented in Figure 1.”

Response:

This suggestion will be implemented in the manuscript

Comment:

P.9 L.228-229: It is surprising that the authors compare the results of the climatological model (i.e. model where input data were averaged over time, e.g. one month) with GIM map for a single day of that month. Such a comparison is not correct. On top of that, by looking at TEC maps obtained from COSMIC and later by B spline model (columns 2 and 1), one can hardly see any separation between the peaks of the EIA, that can, taking into account averaging in all the bins (e.g. lat and lon) performed by authors, hardly be comprehended.

Response:

The GIM-TEC panel will be removed.

After reducing the spatial resolution of the data, figure below (modified version of the figure being referred to in the comment) shows distinct two crests and a trough.

Comment:

P.9 L.231-232: By looking at the color plots, a reader can hardly assess the performance of the model. It is suggested, in addition to the plots, to present/discuss the results of the mismodelling in terms of a bias and RMS of the error.

Response:

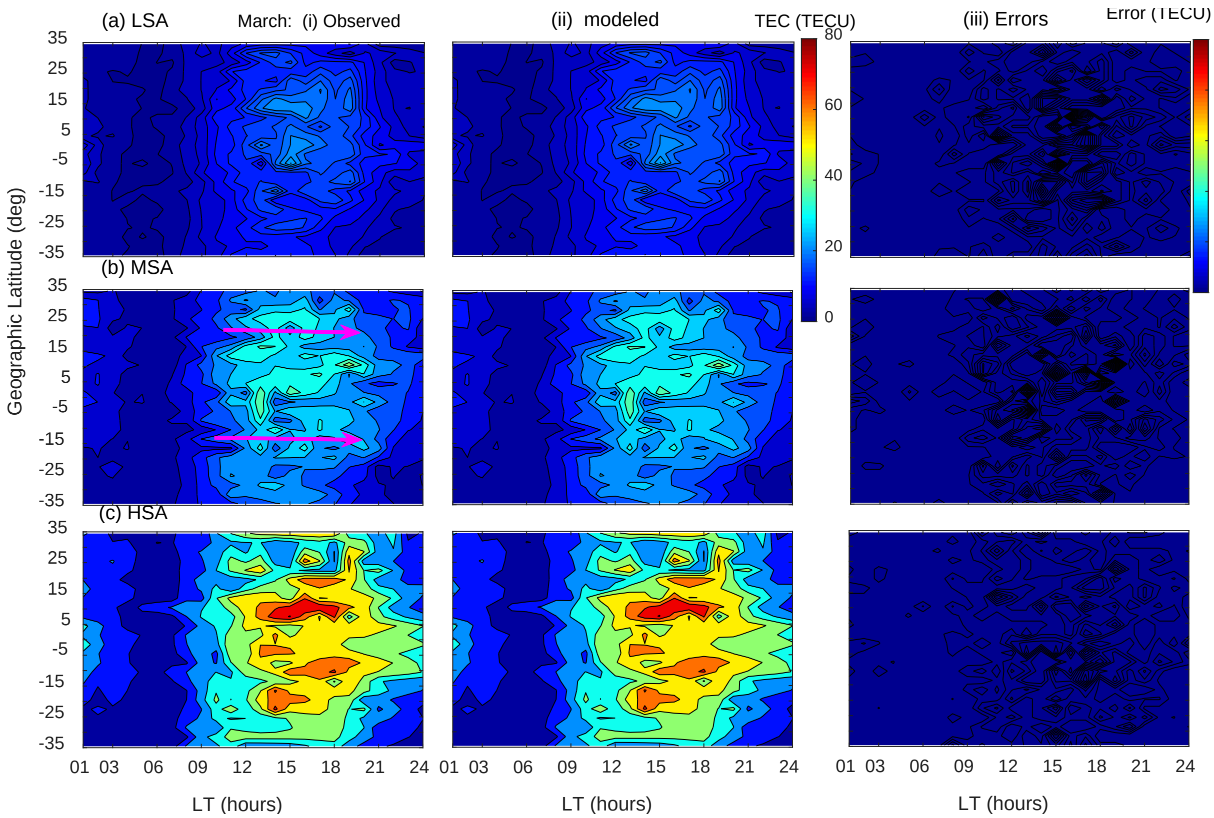
The suggestion in the comment will be implemented. See third column panels in Figure below. The error map shows error levels mostly < 0.5 TECU. We shall also perform statistical analysis of the error levels as recommended by the reviewer.

Comment:

P.10 L.250-252: From Fig 1 it cannot be clearly understood the secondary maximum if any, especially at -20 lat. Please, if you discuss a feature, try demonstrating it clearly to the reader. A separate figure, or at least, a dashed line at -20 and 4 in Fig 1 is needed to support the statement.

Response:

This suggestion will be implemented as demonstrated in Figure below. The two arrows in magenta color exist a long a particular latitude. The two different peaks in diurnal TEC along the arrows can be seen.



Comment:

P.11 L.269-270: In row (b), Fig 1, none of the panel show peaks of the EIA. There is no clear separation of the crest and peaks of EIA. Nor in panels b1/b2 neither in b3. Modify the sentence accordingly.

Response:

The above figure clearly shows the two different EIA peaks. Particularly, after 14:00 LT when EIA formation is at its maximum.

Comment:

P.277-279: The structure of the crest might differ based on various factors (including level of the geomagnetic disturbance). However, when taken as an average, a clear 2 peak structure is present in low latitudes, representing EIA.

Response:

The remark in the comment will be used to adjust the discussions on page 7, lines 275 - 281.

Comment:

P.12 L.298-299: The science question in this case is not how to model the observed data, but how to explain the data. What is the physical explanation for the absence of the EIA structure (two peaks and the crest) in TEC values calculated from the ground up to COSMIC satellite heights (~800km). And whether this phenomena is not a limitation of the technique applied to calculate TEC. Namely, TEC computed by integrating electron density profile, that by itself is a product of RO inversion, is subject to big errors, especially in places where big horizontal gradients exist (read, e.g. M.M Shaikh et al., Implementation of Ionospheric Asymmetry Index in TRANSMIT Prototype, DOI: 10.5772/58551). Without understanding the reasons of the observed behavior all the modeling efforts are meaningless.

Response:

In the paragraph under question, we mentioned asymmetry of EIA feature and occurrence of secondary peak in TEC over Africa. We further mention that these features can be seen in the data we used to develop our model. Therefore, our model emulates these features. We would like to mention that these two features have been well explained in the manuscript (see page 11, lines 256 – 27 and page 12, lines 284 - 286).

The reviewer’s phrase, “absence of the EIA structure (two peaks and the crest) in TEC values calculated from the ground up to COSMIC satellite heights (~800km)” does not exist in our manuscript. This makes it difficult for us to understand the point the reviewer would like to make. Anyway, we guess that the reviewer is talking about the absence of asymmetry of EIA feature in GIM-TEC. In case this is correct, the first reason might be poor distribution of ground based GPS receivers over the African region. The second reason as previously stated by the reviewer might be inability of the spherical harmonic function to map TEC over the low latitude regions. We already provided the first reason on page 11, line 253, we shall add the second reason to the manuscript.

Comment:

P.13 L.313: One cannot see the “perfect match” of the observed and modelled data just by looking at the plots. At least a third row in form of difference map (error map) has to be presented to visually assess the error level. Moreover, statistical results (e.g. RMS and bias of the error) must be presented in order to make such a bold conclusion.

Response:

We have provided in the third column panels of previous Figure the error levels between the observed and the measured data. The error maps mostly show values less than 0.5 TECU (see the color bar). This means as expected, the observed and the modeled data almost match perfectly. The Figure mentioned in the comment will be modified as suggested by the reviewer. Moreover, we shall also present the statistics of the error levels.

Comment:

P.13 L.312-324: Authors do not discuss at all the TEC behavior observed in September at lat ~ -20, where its diurnal variation has a maximum during local night hours (21-03 LT). This maximum seems to exceed any other TEC values on this plot (row c, column 1 and 2) and looks like an error in the data processing. Such behavior seems to have no physical explanation.

Response:

On page 13, line 313, we stated that, “among the many features of TEC exhibited ….” This means we were interested in the key features. Anyway, after carefully analyzing the data again the feature mentioned in the comment was no longer seen. We intend to provide details of the analysis in the revised manuscript.

Comment:

P.14 Section 5: The authors fail to explain why they need yet another TEC model. Unless the performance of the newly created model is compared to existing models and it is demonstrated that its any better than the rest of the models present on the “ionosphere model market” (e.g. IRI, NeQuick, NTCM etc.), there is very little value in the study (both scientifically and application-wise).

Response:

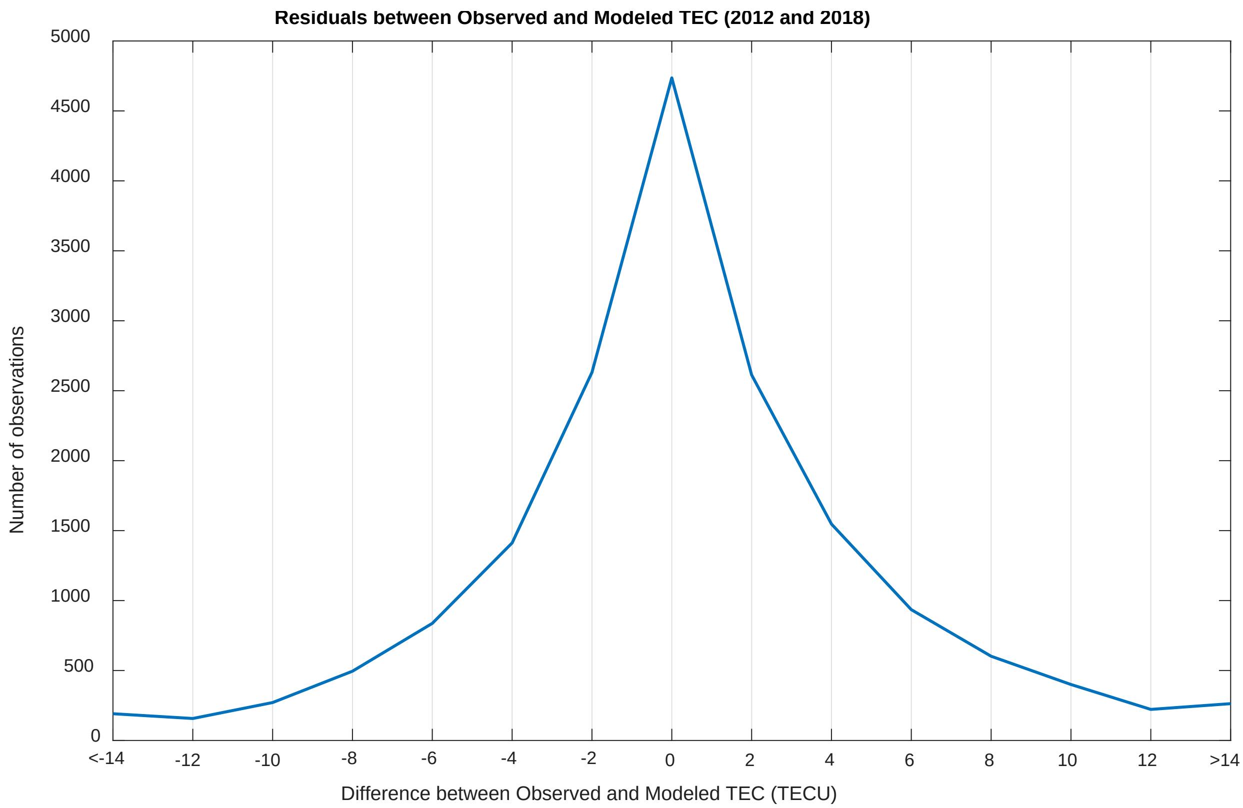
We shall compare our model with the existing models such as IRI, NeQuick, and AfriTEC (Okoh et al. 2019). Examples of the comparisons were already shown previously in this same document. The examples where we compared TEC output of our model with that measured by ionosondes seem to indicate that our model predicts well. Being able to predict well TEC measured by ionosondes is important in predicting such quantities over locations where there are no ionosondes. This might be the scientific significance of this study. Another scientific significance of this study is the demonstration of the potential of spline functions to model TEC over the African region.

Comment:

P.15 L.350-353: Figure 4 does not show the full picture of the error distribution. It is clearly cut at -14 and 14 TECU. Iif one looks at Figure 3, errors in TEC can easily reach +-20 TECU (just draw a vertical line at any value of Observed TEC, e.g. at 30 TECU). It looks like the authors deliberately try to improve the results of their model performance.

Response:

Actually, we should have not indicated ±16 on the horizontal axis. Moreover, we should have indicated on the horizontal axis < -14 (instead of merely -14) and > 14 (instead of merely 14). The total number of errors with values in the range of -14 – 14 TECU was 16858 (97.4 %), while the number of errors with values outside this range was 454 (2.6 %). By comparing these two percentages, it can be deduced that the number of errors with values outside the range of -14 – 14 TECU was insignificant. After implementing the above changes, Figure 4 would appear as below. A long side this figure, we shall also present the percentages of the different error levels. This is in accordance with the previous comment of the reviewer.



Minor/Typo comments:

P.1 L.17: Change “derived” to “obtained”

P.1 L.19: Change “Geomagnetically quiet time (Kp < 3 and Dst > -20 nT) data during the years” to “Data during geomagnetically quiet time (Kp < 3 and Dst > -20 nT) for the years”

P.1 L.22 Change “to obtain the model” to “to obtain model coefficients”

P.1 L.26 Change “COSMIC TEC” to “COSMIC RO TEC”

P.2 L.31: Change “using Global Navigation Satellite Systems” to “in Global Navigation Satellite Systems”

P.2 L.30 Change “during day” to “during the day”

P.2. L.49: Space is missing between “European Geostationary”

P.2 L.50: Change “GPS And Geo-Augmented Navigation” to “GPS-aided Geo Augmented Navigation”

P.3 L.63: Space is missing in “analysis centers”

P.3 L.64: Space is missing in “using the”

P.3 L.64: Change “Global Ionospheric TEC data Map (GIM)” to “Global Ionosphere Maps (GIMs)
containing vertical TEC data”

P.3 L.66: Change “Global Ionospheric TEC data Maps (GIMs)” to “GIMs”. It has been defined two linesabove.

P.3 L.70: Space is missing in “the average”

P.3 L.71: Space is missing in “by CODE”

P.3 L.76: Space is missing in “constructed a”

P.3 L.77: Space is missing in ”GPS radio”

P.3 L.82: Space is missing in “related to”

P.4 L.87: Change “localized ionospheric structure” to “localized ionospheric structures”

P.4 L.88: Change “on a global scale model” to “in global models”

P.5 L.140: Space is missing in “during geomagnetically”

P.6 L.147: Change “solar activity” to “solar activity level”

P.6 L.164: Remove “15” in “reduced 15 to 5”

P.7 L.181 Space is missing in “the F10.7”

P.9 L.223: Change “Global Ionosphere Map (GIM) TEC (GIM-TEC)” to “GIM TEC”, as it was defined earlier, remove “Center for Orbit Determination in Europe” – it was defined earlier

P.9 L.225-226: Remove “The daily GIM-TEC values are derived using the GNSS data collected from over 200 tracking stations of IGS and other institutions”, as this information was given earlier in the text

P.10 L.238: Space is missing in “in turn”

P.14 L.336: Change “;” to “:”

P.14 L.337: Space is missing in “root mean squared”

P.17 L.373: Change “:” to “.” In “0.93”

Response:

All minor comments will be addressed as suggested by the reviewer