Reply to Second Reviewer's Comments:

Anonymous Referee #2

Received and published: 10 January 2021

The paper reports the time delay of ionospheric TEC responses to solar EUV irradiance using SDO-measured solar EUV flux, GNSS-based TEC observations, and simulated TEC from first-principle ionospheric model CTIPe. The study finds that the average time delay of about 17 and 16 hours for the observed and modeled TEC responses to EUV irradiance, a hemispheric asymmetry in the time delay, as well as the different CTIPe-simulated TECs using two different solar EUV irradiance models. The paper delivers an interesting and inspiring study with a clearly-presented motivation, methodology, and results. The study contributes to the scientific understanding of the ionospheric responses to solar irradiance and can guide the solar irradiance specification in ionospheric models.

Response: We are thankful for the reviewer's comments and suggestions which help us to improve the quality of the manuscript. We will address all the raised points in the revised version of the manuscript.

I only have some minor comments listed below:

1. Line 69, "ionospheric composition": ionospheric electron density (or ion density) is perhaps more precise here? There are plenty of neutral species in the ionosphere as well, whose densities drop with altitude.

Response: We agree with the reviewer's suggestion. We will improve this in the revised text.

2. Lines 74-75: It would be helpful to include a figure showing the GNSS ground receiver locations around 15 degree E, or at least some justification of how many ground receivers near the region were used to produce the TEC maps.

Response: Thank you. We will include this information in the revised version of the manuscript.

3. Lines 73-74, "moderate solar activity phase": is the interval during solar inclining or declining phase?

Response: The selected interval is during solar inclining phase of solar cycle 24. We will add this information in the revised text.

4. Line 177, "mid-day (11:00-13:00LT)": is it an average of the TEC values during 11-13LT?

Response: Yes, this is an average of the TEC values during 11-13 LT. We will clarify this in the revised version.

5. Lines 191-192, "The Figure 2(a) shows the two peaks of ionization during the spring 2011, but in autumn the maximum is shifted towards winter, clearly solar driven, and in 2013 there are local minima during equinox." What exactly are the "two peaks" during spring 2011, and what does "maximum is shifted towards winter" mean? These are not clear from Figure 2(a).

Response: We apologize for this confusion due to typos. Here two peaks of ionization refer to maximum TEC around the equator during the spring 2011. We will clarify and rephrase the paragraph in the revised version.

6. Lines 193-195: I suppose the "spring", "summer", "winter" refer to the seasons in the Southern Hemisphere? This should be stated in "The bias between the modeled and observed TEC is higher during the spring and summer season."
Response: Yes, "spring", "summer", "winter" refer to the seasons in the Southern Hemisphere. We will improve this in the revised text.

7. Line 212, are the TEC averages being taken within low, mid, and high latitude bands?
Response: Yes, the TEC averages being taken. We will clarify this in the revised version.

8. Lines 218-219, "the influence of other dynamical processes in the ionosphere (e.g., lower atmospheric forcing) is stronger. ": Is there any evidence supporting this statement? The weak 27d periodicity in F10.7 for 2011 and 2013 does not necessarily imply that the other dynamical processes have a stronger impact. Or the authors refer to the 27 d periodicity in TEC instead of F10.7 here?
Response: This sentence refers to the 27 d periodicity in TEC. We will rearrange the paragraph to avoid confusion.

Line 220, "The 27 d period is stronger in the winter season": Southern Hemisphere winter?
Response: We have analysed the period with respect to low-, mid-, and high latitudes. Hence we will improve this sentence.

9. Line 246, "daily data of 40N and 40S": Are there GNSS ground receivers nearby 40N and 40S, 15E? How accurate is the GIM TEC map at these two locations?

Response: There are no specific stations at this grid point, but around that grid point (European region) several ground stations are located (https://www.igs.org/stations/). Therefore, the impact of the applied interpolation in the TEC map calculation is expected to be smaller than in other regions. The accuracy of IGS TEC maps is given with 2-8 TECU (Chen et al., 2020). The mean RMS at 40°N is 6.92 TECU and the mean RMS at 40°S is 7.54 TECU for the whole period.

Reference: 1. Chen, P., Liu, H., Ma, Y. and Zheng, N.: Accuracy and consistency of different global ionospheric maps released by IGS ionosphere associate analysis centers, Advances in Space Research, 65(1), 163-174, https://doi.org/10.1016/j.asr.2019.09.042, 2020.
2. https://www.igs.org/products/

10. Line 250, "solar radiation": perhaps "solar EUV radiation" to be more precise? because F10.7 proxies the EUV irradiance only.
Response: We will improve this in the revised text.

11. Lines 257-260: attributing the unusual behavior for 2012 to the underlying model in the TEC maps is not convincing, since the underlying model of TEC maps should remain unchanged for different years.
Response: We agree with the reviewer's concern. We will remove this part from the manuscript.

12. Lines 289-290, "the ionospheric delay is increasing with increasing solar activity." Does this refer to the increasing delay from 2011 to 2013 and the solar activity enhances from 2011 and 2013?
Response: Yes, we will improve this in the revised text.

13. Lines 300-301, “This negative correlation indicates the effect of local dynamics.”: Can you provide more explanation on this?

Response: The negative correlation between the solar EUV and ionospheric TEC is still not well understood. As the concept is nearly nonphysical and needs further investigation, it suggests the ionosphere's unique and different behaviour from the normal conditions. The negative correlation suggests an unexpected increase in the TEC during low solar activity conditions. This might be possible due to additional heating sources or unknown factors such as the state of the ionosphere and its dominant physical processes. Another more important factor is lower atmospheric forcing, such as gravity or planetary wave. Gravity waves can induce wave and turbulent fluxes of heat and constituents and influence the upper atmosphere's thermal and compositional structures. These sources might lead to change in the ionosphere's local dynamics and contribute to the additional increase and decrease in the electron density irrespective of actual solar activity conditions.

14. Line 305, “The observed TEC always overestimated the model simulated TEC at all latitudes.”: Given the observed TEC is the “truth”, it sounds more natural to say that the model simulated TEC underestimate the observed TEC.

Response: Thank you for the suggestion. We will replace this sentence in the revised version.

15. Line 364, “The large bias observed in the physics-based model is mainly due to the solar EUV flux input and grid resolution.”: How grid resolution impact the agreement between simulated and observed TEC? A justification is necessary.

Response: The model has a 2^o resolution in latitude and 18^o resolution in longitude, and the observed TEC is available at $2.5^o/5^o$ lat/long resolution. The CTIPe model does not have sufficient good resolution to capture the small scale physics, such as sources of variability from the lower atmosphere, which are not included except in a statistical sense. The model does not directly include the impact of gravity waves and planetary waves originating from the lower atmosphere. Hence due to poor resolution, all the smaller scale physics is not included in the model and which might cause the bias between observed and model-simulated TEC.

Miyoshi et al. (2018) investigated the effects of the horizontal resolution on the electron density distribution using the Ground to topside model of Atmosphere and Ionosphere for Aeronomy (GAIA). They showed that the model simulation with high horizontal resolution of 1^o x 1^o produces fluctuations in electron density with periods of less than around 2 hours and length scales less than around 1000 km, which are in good agreement with observations and which are not seen in a low resolution (2.5^o x 2.5^o) simulation.

Reference: Miyoshi, Y., Jin, H., Fujiwara, H., and Shinagawa, H.: Numerical study of traveling ionospheric disturbances generated by an upward propagating gravity wave, Journal of Geophysical Research: Space Physics, 123, 2141–2155, https://doi.org/10.1002/2017JA025110, 2018.