

Interactive comment on “Spatial and seasonal effects on the delayed ionospheric response to solar EUV changes” by Erik Schmölder et al.

Anonymous Referee #2

Received and published: 19 August 2019

The article **Spatial and seasonal effects on the delayed ionospheric response to solar EUV changes** presents a study that examines the relationship between solar EUV irradiance and F-region ionospheric density. This study builds off of previous work, confirming previous results using higher resolution calculations. It also examines seasonal and latitude variations for a small region of the globe. Both the validation efforts and the study into local European variations are of interest to the scientific community. The presentation and language are not high enough quality for publication and the authors do not consistently give proper credit to related work. The length of the paper is adequate. I believe this study could contribute positively to the scientific community if substantial changes are made.

C1

1 Title and abstract

The title is clear and appropriate. Although it contains an acronym, the acronym is commonly known throughout the community and does not have common alternate definitions. Grammatical corrections include:

1. (Line 1) “...EUV radiation to analyse the delayed ionospheric response to test and improve previous studies on the ionospheric delay. Several...”
2. (Line 4) “...the analysis at an hourly resolution...”
3. (Line 13) “...Results confirm that geomagnetic activity and the 11-year solar cycle also affect the ionospheric response to solar EUV changes”

Alternatively, lines 6–14 could be re-written to more accurately summarise the conclusions.

2 Major Issues and Questions

1. The motivation provided through GNSS in the introduction (around Line 25) is not appropriate. If the authors wish to continue with this motivation, the following issues need to be addressed:
 - (a) Not all terms are defined (e.g., a different definition of “high temporal resolution” is used on line 27 when compared to the rest of the paper)
 - (b) Citations to GNSS work are absent. The motivation would be strengthened by citations of articles that have proved high accuracy GNSS products require accurate ionospheric models, as well as citations to articles that highlight missing physics in ionospheric models when handling the ionospheric

C2

delay. Given studies such as Ren et al. (2018), which show that ionospheric models do capture the ionospheric delay to solar EUV irradiance, I would recommend that the authors find a different motivation for their study.

- (c) Finally, this motivation also requires citations that demonstrate that other higher order GNSS correction issues (such as the bending terms) are not as important as the parts of the refractive index terms that would be affected by the (to have been) demonstrated issues with ionospheric models that are affected by the ionospheric delay.
- 2. The authors highlight the differences between the regions covered by the two ionospheric parameters used in this study. While it is true that GNSS TEC includes information about the entire ionosphere-plasmasphere system through which it travels, it is also true that the F_2 region is responsible for most of variations in TEC (e.g., Petrie et al. 2011). Text and data interpretations would benefit from clarifying the relative contributions from the different ionospheric regions and plasmasphere to the TEC, as well as the expected agreement between the column integrated plasma density and the critical frequency of the F_2 layer based on past studies.
- 3. In the introduction, the authors do not sufficiently discuss the contributions of previous ionospheric delay studies. Specifically, there is no discussion as to the physical reason behind the ionospheric delay, although this has previously been investigated (e.g., Ren et al. 2018).
- 4. A motivation behind using the European and Australian regions is needed. For example, why not use North and South America (see coverage for 1 January 2011 in the attached Figure)? This figure is included not to say that there is not a good reason to use European and Australian data, but to show that “good data coverage for Europe” is not a good reason in and of itself.

C3

- 5. The authors state that they use two important ionospheric parameters that are appropriate to investigate the processes responsible for the ionospheric delay (data section), but they state in the conclusions that the processes for the delayed ionospheric response still need to be described. If the first statement is true, then an investigation of the underlying physical processes should be included in this paper. If such a study is beyond the scope of this paper, then the statements made about the ionospheric parameters used to study the characteristics of the ionospheric delay should be altered.
- 6. The authors state that the TEC is more important than the foF_2 but do not back up this valuation, especially since they say in the introduction that the ionospheric delay for the two parameters is very similar. The reason given, “TEC is...less sensitive to disturbances, such as plasma redistribution, than other parameters” is not substantiated. Additionally, since TEC is regularly used to study plasma redistribution (e.g., Foster 2008; doi:10.1029/181GM12), the degree of sensitivity difference between TEC and foF_2 needs to be shown to be significant (either by the authors or through appropriate referencing) for this valuation to be believable.
- 7. (Line 64) The resampling method needs to be described in more detail. Was an interpolation used? If so, between which points? Was the nearest value taken?
- 8. (Line 67) What is the temporal resolution of the ionosonde data and were they hand scaled or autoscaled?
- 9. What is the effect of the difference in geographic longitude and magnetic location (including location relative to the auroral oval, declination, and inclination) on the locations in Europe and Australia?
- 10. (Line 76) How are data resampled in this instance? From the context, it appears that the authors are downsampling data from a minute-scale resolution to a one

C4

hour resolution, but this is unclear (especially since the same wording was used for a different process on line 64).

11. (Line 90) A better explanation of why the correlation coefficient is still useful even though the values specify that the data sets being compared are uncorrelated is needed.
12. What data quality constraints were applied to the input and processed data? Why were periods when the data quality is stated to be poor included?
13. The authors state that the ionospheric delays show a good correlation with the geomagnetic activity, but this is not demonstrated. If the authors believe that they have demonstrated this correlation, they should improve the clarity of the figure presentation and the text surrounding it.
14. (Line 184) The authors are quick to attribute differences between the TEC and foF_2 ionospheric delays to differences between the F_2 peak and the ionosphere-plasmasphere system, but there are other possibilities (including the background model used in the TEC calculation) that should be acknowledged or eliminated.
15. There appears to be an offset between solstice and equinox occurrence and the seasonal variations shown in (Figure 10). Why is this? Has it been seen before?
16. Figures 7 and 8 show a lot of scatter at the individual stations. The analysis presented in section 5 makes claims about latitude variations based on these figures that do not appear to be significant, due to this scatter. This analysis would be improved by including another figure with delay differences between the sites or, possibly, by adding confidence bars (perhaps standard deviations) to the hourly delays in Figures 7 and 8.
17. (Line 191) The authors state that the latitudinal dependence in the European sector is not visible in the winter. However, Figure 7b shows a latitudinal variation

C5

that is perhaps clearer than that in the summer, just different.

18. How is the resampling for Figure 12 performed? Is a running period or binned week used? Clarify this analysis process so that others may reliably replicate these results.
19. (Line 211) What about the winter variations? Does the longitudinal ionospheric delay variation have a seasonal variation at all? It seems likely that this lack of variation is related to the small range of magnetic declination over Europe, which leads to longitudinally similar ionospheric transport processes regardless of season. Whatever the authors believe the reason to be, it should be discussed.
20. The last sentence of the conclusions omits the work done by Ren et al. (2018). The article would be improved by a discussion of the results in the context of the physical mechanism presented in that article and also by providing a clearer motivation behind using the ionospheric delay to validate or improve physics-based models.

3 Figures and tables

1. (Table 1 caption): "...provide an approximate ionospheric delay to solar activity at a daily resolution."
2. (Figure 1): This figure would benefit by over-plotting magnetic field information (such as the IGRF declination or at the hmF_2) and the geomagnetic equator.
3. (Table 2): Which magnetic coordinate system is used for the geomagnetic coordinates?
4. (Figure 2): Rows should be labeled with "Weekly", "Daily", and "Hourly"

C6

5. (Figure 2 caption): "...data, as well as the resulting correlation coefficients (red), for..."
6. (Figure 10): Mark the locations of the equinoxes and solstices.
7. (Figure 11): Mark the locations of the European stations, to improve comparisons between Figure 11 and Figure 7.

4 Grammar and organisation

1. Throughout the paper both 3rd person and impersonal tenses are used. This should be changed so that the tense throughout the article is consistent
2. Throughout the paper approximations are used for numbers that do not need them (e.g., the locations on Line 95 specify the approximate location of Rome and this is already appropriately expressed by limiting the number of significant figures)
3. (Lines 27,) "which" should either be preceded by a comma or replaced with "that"
4. (Line 17) "dominating" should be "dominant"
5. (Line 20) "...ionospheric variations that may depend on time or location."
6. (Line 21) "...in the solar spectrum'...'. This change is necessary because the authors, in this sentence, are referring to the entire ionosphere, which means that X-rays and higher energy irradiance that impact the D and E regions are also important.
7. (Line 22) "...and composition at specific..."

C7

8. (Line 23) "...electron density distribution. An understanding of the ionospheric chemical and physical processes is important, since..."
9. (Line 28) remove duplicated text "is needed"
10. (Line 32) "...have revealed that ionospheric parameters have a delayed response to solar variability. A selection of these studies..."
11. (Line 33) "...was calculated using different EUV proxies or measurements of the EUV flux at daily resolutions."
12. (Line 35) "...the delay at a higher temporal resolution of one hour. Furthermore, we examine the hemispheric dependence of the ionospheric delay with a detailed study of the European region."
13. (Line 37) "is made based on" should be "uses"
14. (Line 37) "The" needed before "Time series"
15. (Line 43) "...the ionosphere without complicating contributions from the plasmasphere and lower ionospheric layers. As expected, the results..."
16. (Lines 45-47) This text belongs in the data or analysis section, not the introduction.
17. (Data) This section would benefit by subsections for either the different data sources or between the presentation of the data sources and the data analysis techniques
18. (Line 49) "...spectrum have been continuously measured since 2000 C.E., with EUV observational data publicly available from..."
19. (Line 55) "...have a temporal resolution of 20 seconds. EVE data also cover several years (2011 to 2014)..."

C8

20. (Line 106) Description of the IGS TEC maps belongs in the Data section.
21. (Line 108) remove comma between “show” and “that”
22. (Line 109) “...be calculated at an hourly resolution for fixed...”
23. (Line 123) The sentence, “Se do not see any...different variations” is confusing and should be rewritten.
24. (Line 124) “...keeping in mind that their magnitude may differ due to...”
25. (Line 128) “...in Table 1. For example, Jakowski et al. (1991) used the...”
26. (Line 129) “...satellite-based EUV-TEC measurements (Unglaub et al., 2011) and also calculated the delay with EUV fluxes. The validation with EVE EUV flux measurements was important because the solar rotation variations...”
27. (Line 135) The first two sentences of this paragraph belong in the introduction. The remaining sentences belongs in the data section.
28. (Line 138) Which calculation are the authors referring to?
29. (Line 144) “...negative values. In Figure 4, this was interpreted as a possible effect of geomagnetic activity.”
30. (Line 145) “...time period, the correlation coefficient drops due to data gaps and the applied interpolation method. (start new paragraph after this sentence)”
31. (Line 146) “...are smaller than those of the TEC. However, the trends of the two correlation coefficients are similar for the...”
32. (Line 148) “...Tromsø again show that the largest deviation from...”

C9

33. (Line 152) “The TEC and foF₂ correlation coefficients for the Australian stations are shown in Figure 6. In general, the Australian correlation...”
34. (Line 155) “...these results. Most notably, the decrease and...”
35. (Line 156) Which seasonal variations do the authors expect to be impactful? Referencing is appropriate but the text description should be slightly more detailed.
36. (Line 174) “...the delay at a daily resolution for longer time periods than the one used in this study.”
37. (Line 175) The sentence is unclear and needs to be reworded.
38. (Line 179) What do the authors mean by “global trend”?
39. (Line 179) The sentence is unclear and needs to be reworded.
40. (Line 183) “...a stronger seasonal variation...”
41. (Line 188) “...with latitude in northern summer. The station at...”
42. (Line 193) remove “where data from high latitudes are missing” because the Australian stations have a larger low-latitude extent than the European stations and this phrase does not reflect that.
43. (Line 194) recommend replacing “agree” with “are consistent”
44. (Line 197) “...good observational coverage...”
45. (Line 198) Remove repeated description of the IGS TEC map.
46. (Line 202) “...Figure 11, which maps the mean delay values for the mid-latitudes in summer (May-August) and winter (November-February). Figure 11 shows delays that are consistent with the results from the European ionosonde stations (Figure 7b).”

C10

47. (Line 205) "...hours over the entire region."
48. (Line 205) The sentence that begins at the end of this line is unclear and needs to be reworded.
49. (Line 207) "...the delay decreases with increasing latitude. From..."
50. (Line 208) "...70°N, or about -0.06 hours per degree in latitude."
51. (Line 211) "...is much smaller than the variation in latitude for the same season, with a change of..."
52. (Line 224) "...main analysis, we confirmed..."
53. (Line 234) Move the last two bullet points starting on this line to the previous paragraph where the authors were discussing the portions of previous studies that this study validated.
54. (Line 242) "Future analysis would benefit from high resolution ionospheric delay calculations for longer time periods that cover different..."
55. (Line 243) Sentence starting at the end of this line is unclear and needs to be reworded.
56. (Data availability and acknowledgements) Not all acronyms are defined.
57. (Line 297) "F 2" should be "F₂"
58. (Line 327) page numbers missing and filled using n/a–n/a

C11

5 Referencing

1. (Line 22) Reference needed for the impact of solar irradiance on the vertical ionospheric structure
2. (Line 44) Citation to a source that explains or demonstrated that TEC is dominated by the F₂ peak response is needed
3. (Line 63) Which model is included in the TEC calculation? Include a very short description and a citation to this model.
4. (Line 106) Citation for IGS TEC maps needed.
5. (Line 196) Citation needed.

Interactive comment on Ann. Geophys. Discuss., <https://doi.org/10.5194/angeo-2019-91>, 2019.

C12

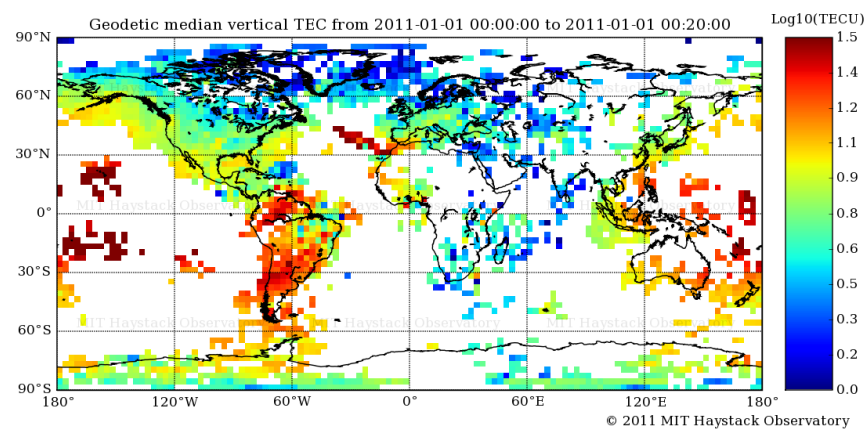


Fig. 1.