Response to Reviewer 1 comments

The authors of this manuscript thank the reviewer for the suggestions and comments. Our response to the comments and suggestions are presented below.

General Comments

- The results shown confirm earlier published findings, and some other analyses do not seam fully consistent (see specific comments). The submitted manuscript provides an excellent report to indicate that identified fluctuations in electron density time series obtained by the TII faceplate technique onboard the Swarm satellites with 16Hz sampling rate are most probably related to equatorial post-sunset plasma irregularities. But it is unlikely that the report enhances present scientific knowledge and evidence.

  My major concern is, however, that this analysis does not show any findings based on the 16Hz samplings that could not have been achieved with the 2Hz samplings onboard Swarm. The authors are encouraged to exploit the high value of the 16Hz sampling.

- **Response:**
  - Thank you for your valuable feedback. Our research is the first to use the measurements of Swarm 16-Hz faceplate electron density to characterize ionospheric irregularities. This study also directly compares the relative and absolute perturbation of electron density from a meridional point of view using data from Swarm 16 Hz over low latitude.
  - This study aimed at checking the capability of the Swarm 16-Hz faceplate electron density measurements for ionospheric irregularity observations. In this study we do not disregard the capability of the 2 Hz electron density measurements made by the Langmuir Probes on board Swarm. However, as stated in P.2,L.28, high-resolution data enables smaller scale structures to be identified in electron density (Nishioka et al., 2011,https://doi.org/10.1029/2011ja016446).
  - We agree with the reviewer about exploiting further the 16 Hz Swarm electron density measurements. In fact, Alfonsi et al., 2007, http://dx.doi.org/10.1016/j.asr.2017.05.021 recommended Swarm high resolution electron density measurements as input to the WAM model. However, as stated in P.2, L.7-9, the dependence of ionospheric irregularities on the geophysical parameters, remains a problem in modeling their variation for predictive purposes (Yizengaw and Groves, 2018,https://doi.org/10.1029/2018sw001980). The results presented in this study, characterize ionospheric irregularities basing on various geophysical parameters as a first step towards developing a model from Swarm 16-Hz in situ measurements of electron density. Currently, the team involved in this paper are carrying out further research involving modeling of amplitude scintillation from Swarm 16 Hz measurements using the WAM model. Thank you for your suggestion.

Selected specific comments:

1. The concept of deriving electron density from the TII faceplate technique is an extended product in the concept of the Swarm mission. A bit a more detailed description of the retrieval and the data shall be added, next to refering to "Buchert, S.: Extended EFI LP data FP release notes, ESA Technical Note, 2016." (I did not find the document in the web, and do not know if/where it is accessible.)

- **Response:**
  - The ESA Technical report and a link to the 16 Hz electron density data are accessible to everyone via ftp at: `ftp://swarm-diss.eo.esa.int/Advanced/Plasma_Data/16_Hz_Faceplate_plasma_density`.
  - More detailed information about obtaining electron density from the TII can also be obtained from Knudsen et al, 2017, doi:10.1002/2016ja022571.

2. P2, L1-14: The authors have access to the full Swarm mission data to perform orbital analyses, such as the spacing of Swarm A/C or the local time processing. Alternatively, they may refer to classical papers, such as provided in doi:10.5047/eps.2013.07.001 if needed. You might reconsider, if Kil et al. or Xiong et al. are suitable references in this broad context.

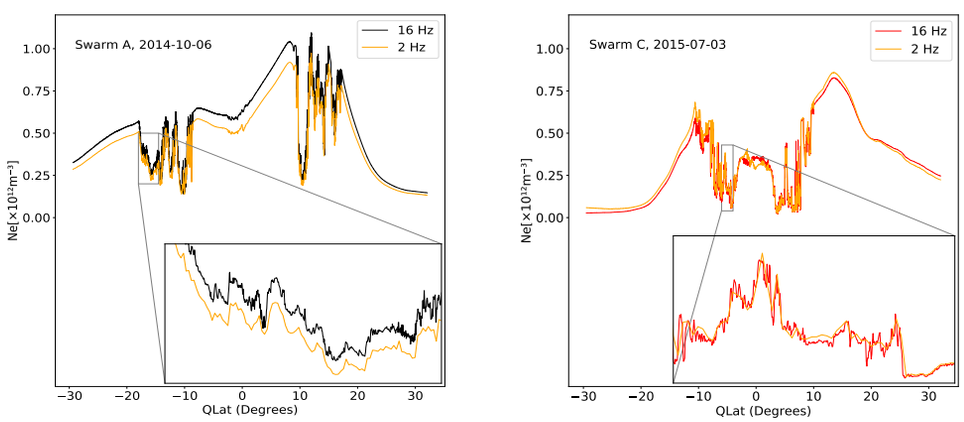
- **Response:**
  - We agree with the reviewer that it would be interesting to perform an orbital analysis for the available Swarm 16 Hz data set. In fact, an earlier study presented by Xiong et al. (2016),https://doi.org/10.1186/s40623-016-0502-5, utilized the strategic orientation of Swarm A and C (i.e, spacing between the two satellites) to check the scale sizes of irregularity structures using Swarm 2 Hz electron density measurements. The current study was designed to focus mainly on characterizing ionospheric irregularities using the Swarm 16 Hz electron density measurements and we'd like to keep the focus intact. Thank you for the suggestion.

3. P2, L25ff: The proposed detection method identifies amplitudes of deviations from a 2s-average and attribute a level of higher than $0.25 \times 10^{10}\mathrm{m}^{-3}$ of its RMS as being an irregularity. By this method, identifying an RMS over a time window of 2 seconds (15km), information from the 16Hz seconds are smoothed out.

- **Response:** The window to calculate dNe should be short, but has to be long enough to avoid spurious detection of irregularities. We also tried 1 s, 16 points, instead of 2s, 32 points, and the outcome was similar and reasonable. It seemed a good compromise to go for RMS at 2 s (15 km) to quantify ionospheric irregularities.

4. Figure1/P5, L3: 'multi-peak' variations appropriate to the 16Hz samples in comparison to the 2Hz samples cannot be identified in either the zoomed figures in Figure 1. Many peaks are equally visible in the 2Hz data.

- **Response:** We present here inset plots which are zoomed in further. It can now be clearly seen that multiple



electron density peaks are observed on the 16 Hz data than in the 2 Hz data. The 2Hz data appears to be smooth and cannot show detailed small scale structures.

5. Page 10,L9: "Large values of both ΔN_e and $\Delta N_e/N_e$ often occur in locations of large depletions in Ne." It is not clear, where else they could be expected?

- **Response:** In the low latitudes, the values of both parameters are expected to be high in locations of plasma density depletions between the EIA crests close to the geomagnetic equator, but also at the bottom of large scale bubbles/depletions. However, ΔN_e is high at the crests and at the edge of large scale bubbles/depletions. So high values of both ΔN_e and $\Delta N_e/N_e$, do not occur at the same place, but at different places. We have shown this for the crests/equator in Figures 6 and 7.

6. Page 5, L15-23: The effect of relative variation compared to absolute variation was extensively discussed, e.g., for polar patches in DOI: 10.1002/2017JA024811 .

- **Response:**We thank the author for citing out relevant literature. In the present manuscript we extended the comparison of relative and absolute variation in the low latitude region using the polar orbiting Swarm satellites, where the distribution of ionospheric irregularities seems to be quite different from that at the polar region.

7. P7, L3: The authors describe that the irregularities occur between 18-06 LT, however, no other LT is shown in Figure 3.

- **Response:**Indeed as noticed by the reviewer, other local times are not included in Figure 3. The local time sector was fixed between 1800-0600 LT since over the low latitude region, ionospheric irregularities are a night time phenomena and this has been stated in the manuscript on Page 5, L. 25-27. The reviewer is referred to the the literature cited in Page 5, L. 25-26. Most of the earlier studies cited in Page 5, L. 25-26 also limited their analysis over the low latitude region to the local time sector 1800-0600 LT.

8. Figures 6,7,12 base on color scales that lie below the detection threshold by at least to 50%

- **Response:** To generate climatology maps presented in Figures 6,7,12,14, all Swarm passes were considered irrespective of whether there were irregularities or not. This was done because of the limited data.

9. Figure 9 shows along track gradients of electron density, that are by nature directly related to ΔN_e for the detections. It is maybe not helpful to discuss their coincidence.

- **Response:** As the reviewer has mentioned, the along track gradients are indeed directly related to ΔN_e. An observation of interest was that there was a slight latitudinal difference between $\Delta N_e/N_e$ and ∇N_e and therefore, it was important to include ∇N_e and compare it to $\Delta N_e/N_e$ and ΔN_e. Also, from the best of our knowledge, seasonal dependence of latitudinal-longitudinal distribution of ∇N_e has not yet been presented for the case of the Swarm satellites.

10. Figure 12 divides below and above F10.7=140sfu. It is questionable if a significant amount of data is available for conclusions above F10.7=140sfu. See figures 10, 11 of the submission and https://services.swpc.noaa.gov/images/solar-cycle-10-cm-radio- flux.gif. Also, P 14 L 20ff: The authors mention similar comparisons by Huang et al., Su et al., Stolle et al. To the knowledge of the referee, these papers discussed the occurrence rate, not the amplitude of irregularities. Amplitudes are discussed by Wan et al., 2018. However, conclusion (iv) of the submitted paper mentions occurrence rates which is not compatible with Figure 12.

- **Response:**
  - For the case of Fig. 12, we agree with the reviewer that the data may not have been enough after categorizing with respect to $F10.7$ especially for $140 \leq F10.7 < 180$. This limitation was also stated in the manuscript in Page 14,L 19-20 and Page 16,L 1-2. However, irrespective of the limitation in data availability, ΔN_e shows dependence on moderate solar activity similar to what was presented in earlier studies i.e, high ΔN_e values are often observed when $140 \leq F10.7 < 180$.
  - As pointed out by the referee, it is true that Huang et al. (2001), Su et al. (2006), Stolle et al. (2006) did not present amplitudes of electron density perturbation, and amplitudes are discussed by Wan et al. 2018. However, Wan et al. 2018 did not present the dependence of amplitudes of ionospheric irregularities to different solar activity levels categorized in terms of $F10.7$, while the cited papers (Huang et al. (2001), Su et al. (2006), Stolle et al. (2006)) addressed the solar activity dependence of occurrence of ionospheric irregularities. A key difference between occurrence of ionospheric irregularities and their amplitudes stated by Wan et al. 2018 is that they show a totally different longitudinal pattern. The amplitudes presented in Fig. 12 seem to show similar dependence on different levels of $F10.7$ as the occurrence rates presented by Huang et al. (2001), Su et al. (2006), Stolle et al. (2006) with high ΔN_e values (or high occurrence rates) often observed when $140 \leqq F10.7 < 180$. Therefore, the dependence of amplitudes, ΔN_e and occurrence rate of ionospheric ionospheric show similar dependence on solar activity level.
  - Conclusion (iv) will be rephrased in terms of the amplitudes.

11. Palmroth et al., 2000 and Stolle et al., 2006 did first analyses on the relation between the occurrence rate of irregularities and the Kp index, that are not discussed in the submitted manuscript.

- **Response:** We thank the reviewer for citing relevant literature.

12. The authors might reconsider the added value of P11 L6ff to the concerned study.

- **Response:** Thank you for the suggestion. As stated in response to comment 2., orbital analysis such as spacing between Swarm A and C and altitude difference between Swarm A/C and B etc is interesting. In this paper we prefer to focus on traits of sub kilometer F region ionospheric irregularities, and so we will leave the orbital analysis aspect for further research.

  Selected technical comment: dNe, ΔN_e, and (nabla)Ne are used to express the same parameter.

- **Response:**
  - In the revised manuscript, we will replace ΔN_e with std(dN_e) to represent the absolute electron density perturbation and it is obtained by determining the standard deviation of the residual $dN_e = N_e - \overline{N_e}$.
  - ∇N_e in this manuscript represents the electron density gradient derived along the satellite tracks and it is given by: $\nabla N_e = \frac{(N_e)_f - (N_e)_i}{X_f - X_i}$, where X in this formula represents the latitude, f is the final position and i is the initial position.

  Final Remark : We thank the reviewer for the multiple comments.