As authors of the manuscript angeo-2019-153, we thank the anonymous referee for the constructive suggestions and comments. In enhancing the quality of the paper, all the remarks we received on this research will be taken into consideration and we present our response to each of them individually below. For the convenience of the referee we have repeated in the response the relevant comments and then given texts we intend to add in the revised manuscript in blue.

Response to Anonymous Referee #2 comments

General Comment: The authors compare density irregularities observed in-situ by the Swarm satellites with ground-based observations of plumes made by the Jicamarca unattended long term investigations of the ionosphere and atmosphere (JULIA) radar and ionosondes. Using data between 2014 and 2018, the authors investigate whether Swarm can be used as indicator of plasma plumes/Spread F observed on the ground. Showing a few case studies and by comparing the statistical trends between the in-situ and ground-based instruments, the authors conclude that Swarm can be used to detect the presence of well-developed plumes. The manuscript is carefully organized, the figures and presentation are clear, and the text is generally well written. While comparisons between in-situ and ground-based is worthwhile, and the datasets well suited, the novelty and importance of the findings are not significant enough, in my opinion. However, I think this work has potential values after significant additional work and resubmission. Suggestions and comments are given below.

Major Comments:

1. The author mention that their main focus is to determine whether Swarm can be used to detect plumes and Spread F. Even though previous studies used lower sampling resolution/single cases, I have difficulties understanding why the previous work(s) is(are) not sufficient to determine whether Swarm can detect plumes or not? There is even a standard Swarm data product called the Ionospheric Bubble Index (IBI) to detect equatorial irregularities (which does not seem to be referred to).

Response: The differences between this work and the previous works may not have been demonstrated and highlighted clearly in our manuscript. In the revised version, we are going to improve our article organization and put more description to highlight this. Below are the points we want to address in this study:

- Most previous studies (e.g, Kelley et al., 2009; Siefring et al., 2009; Hysell et al., 2009; Roddy et al., 2010; Nishioka et al., 2011) have mostly compared zonally oriented in situ plasma density measurements from Communication Navigation Outage Forecasting System (C/NOFS) satellite with JULIA observations. The Swarm satellites revisit neatly the same area in orbits oriented in the merdional direction. Therefore, our study compares sub-kilometer in situ ionospheric irregularities recorded by Swarm in the meridional direction with observations from Jicamarca. We found that the results based on the JULIA radar and ionosonde agreed with the plasma density obtained from measurements of the Swarm faceplate for single satellite passes over or near the JRO.
- Previous comparison of Swarm in situ measurements with ground-based radar observations (Zakharenkova et al., 2016, e.g,) mostly used LP measurements at 2 Hz frequency. The faceplate carried by Swarm as part of the Electric Field Instrument (EFI) has enabled the discovery of small-scale (down to 500 km length scale along the spacecraft track) ionospheric irregularities. In this study, we used Swarm faceplate measurements at a frequency of 16 Hz. Coherent scatter radars e.g, the JULIA radar can monitor irregularities at high spatial resolution (3 m scale length for the case of JULIA) and therefore these were compared with Swarm faceplate observations of ionospheric irregularities of small scales. The high-resolution faceplate data enabled smaller scale structures to be identified in electron density. Also, previous comparison of Swarm in situ measurements with ground-based radar observations (Zakharenkova et al., 2016, e.g,) were mostly single case presentations. Our study provides an extended statistical analysis covering years from 2014 to 2018.
- As far as we know, a quantitative statistical relationship between plasma bubbles observed in situ in the meridional direction, 250 MHz amplitude scintillation, and JULIA observations were reported by Burke et al. (2003) using data recorded by the polar-orbiting Defense Meteorological Satellite Program (DMSP). However, DMSP orbited at an altitude of about 840 km and this was a limitation in that most ionospheric irregularities didnot ascend to DMSP altitude. In our study, we used the polar orbiting Swarm satellites which has provided a renewed opportunity to compare in situ and JULIA observation at altitudes of 460 km (Swarm A and C) and 510 km (Swarm B). Compared to DMSP, Swarm allows comparison of measurements from identical instruments at different altitudes and in different longitudinal sectors.

– Concerning the IBI index, it is a standard Level 2 product of the Swarm mission (Park et al., 2013). IBI provides information on climatology of ionospheric Irregularities itself as well as on the disturbance level of the magnetic field data by taking both electron density and magnetic field measurements into account. Following the referees suggestion, we accessed the IBI index for all the Swarm satellites from `https://swarm-diss.eo.esa.int/#swarm%2FLevel2daily%2FLatest_baselines%2FIBI` and generated the distribution of ionospheric irregularities derived from the IBI as a function of quasi-dipole latitude and Local time. The results for Swarm C are presented here in Fig. 1. It is important to note that the IBI is just

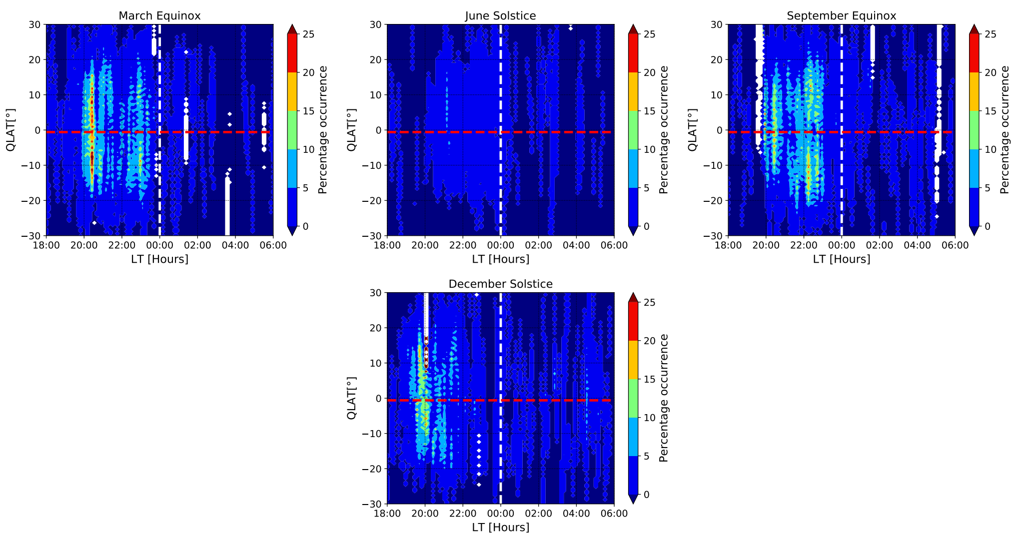

Figure 1. Distribution of ionospheric irregularities derived from the IBI as a function of quasi-dipole latitude and Local time for Swarm C.

either 1, 0, -1 for bubble detected, not detected or undetermined, respectively. Therefore, to generate the results in the figure, the datasets were first grouped into different seasons corresponding to March Equinox (Feb-Mar-Apr), June Solstice (May-Jun-Jul), September Equinox (Aug-Sep-Oct), and December Solstice (Nov-Dec-Jan). For each season, the data was then binned into $1^\circ \times 0.1$ hr quasi-dipole latitude-local time bin. For each quasi-dipole latitude-local time bin, the percentage occurrence was obtained by dividing the number of observations with $\mathrm{IBI} = 1$ by the total number of observations. The distribution of ionospheric irregularities derived from the IBI shows similar seasonal dependence to the ones shown in Figure 11(see manuscript), with highest percentage occurrence in the equinoxes and December solstice.

– It is interesting to know how ionospheric irregularities are classified by the plasma bubbles detection algorithm. Therefore, we are going to consider adding the IBI index analysis in the revised version of the manuscript.

2. I agree that statistical studies can provide additional information. However, it is not clear to me what the authors actually get from their statistics, except for similar trends as the ones published in the literature (both from ground-based and Swarm "irregularity" studies). I am fairly certain that with their interesting dataset, the authors can reach more substantial conclusions, especially with the spatial/altitudinal separation and sampling rate of Swarm.

   Response: After presenting single case examples in Fig. 4, 5, and 6, we wanted to investigate the characterisitics of the small-scale structures in more details with the help of a statistical study. Concerning the observations and conclusions from the statistical analysis, these may not have been demonstrated and highlighted clearly in our manuscript.

– Specifically for Fig. 7, the effect of spatial and altitudinal separation among the Swarm satellites can be observed and the following observations and conclusions will be added in the revised manuscript in this regard:

  - For instances when Swarm registered events, while JULIA and ionosonde recorded no signatures, we checked on the longitudinal separation between the satellite passes and the ground-site. The longitudinal separations obtained between the Swarm passes and the ground site were often $\approx 5°$ and the magnitude of the in situ perturbations were relatively low. Ionospheric irregularities tend to be magnetic field aligned (Ossakow, 1979; Kil and Heelis, 1998; Nishioka et al., 2008; Kelley, 2009) and therefore, Swarm may encounter irregularities in situ of relatively low magnitudes, while JULIA and ionosonde do not identify any events, for wider longitudinal offset of a pass from the ground site.
  - In addition, for irregularities observed by Swarm only, Swarm B had the lowest percentage occurrence close to about 5% compared to Swarm A/C. The observed difference may be because of the progressive temporal and altitudinal separation between Swarm B and A/C (Zakharenkova et al., 2016). Swarm B orbits at a higher altitude compared to A/C and it crosses the same region later than A/C.
  - Generally, in Fig. 7, a difference in percentage occurrence in all categories is observed between Swarm A and C although they orbit at the same altitude above sea-level. The large scale longitudinal bubble structure is sometimes observed with the two Swarm satellites (Xiong et al., 2016), but for small scale irregularities, the $1.5°$ longitudinal separation between the satellites is too large for a significant correlation between them.

The points stated above will be included in the revised manuscript.

3. (section 3.3) The description of the method to calculate the statistics (selection of events, number of events, how occurrence rates are calculated, exact months, description of quantities shown in figures etc.) is insufficient.

Response: The description of the method to calculate the statistics may not have been described in detail. In the revised manuscript, we are going to incorporate detailed description of the methods we adopted. Below is the methods we used in the statistical analysis:

- For Section 3.3.1
  - The Swarm satellites regress in longitude by about 15° between orbital ascending nodes. Therefore, in comparison with JULIA and ionosonde data, the Swarm passes were allowed to be within ±5° magnetic longitude of the JRO to make sure that a sufficient amount of Swarm passes could be used for the statistical examination. Summary plots such as those presented in Fig. 4 were generated for all days during the years from 2014 to 2018 for which all data sets existed. In total, 560 night-time orbits were used for which JULIA, Swarm, and ionosonde data were available concurrently. The outputs of the summary plots could be categorized into four cases considering the presence (or not) of irregularities. In general, these four cases are, "Irregularities observed both on the ground and in situ", 'No irregularities observed both on the ground and in situ", "Irregularities observed only in situ", and "Irregularities observed only on the ground". For each RTI plot, the SNR corresponding to the peak height was determined and an event was identified as a significant irregularity when the peak height was greater than or equal to 400 km. For peak height less than 400 km, these were classified as weak or no irregularities. For the in situ Swarm observations, we assigned a threshold of $1 \times 10^{10}\ \mathrm{m}^{-3}$ for std(ΔN_e) to be considered a significant irregularity event, while for std(ΔN_e) less than the threshold were considered as weak or no irregularities. For the ionosonde measurements, QF values greater than or equal to 20 km were considered as significant irregularity events.
  - For each category, the percentage occurrence was computed as the ratio of the total number events in that category to the number of observations.
- For Section 3.3.2:
  - To obtain the results presented in Fig. 8, ground-based JULIA SNR data for the years from 2014 to 2018 were used. To eliminate the impact of geomagnetically disturbed conditions on the statistical outcomes, the data were filtered and only those recorded during quiet geomagnetic conditions ($\mathrm{Kp} \leq 3$) were taken into account. (see Pg. 12 L. 7-8) The JULIA data accumulated for the years from 2014 to 2018 were sufficient for examining the seasonal variation. Therefore, the seasonal dependence of local time distribution of JULIA observations of ionospheric irregularities was also examined by grouping all the data into different seasons corresponding to March Equinox (Feb-Mar-Apr), June Solstice (May-Jun-Jul), September Equinox (Aug-

Sep-Oct), and December Solstice (Nov-Dec-Jan). For each local time-height bin, the percentage occurrence was obtained by dividing the number of observations with $\mathrm{SNR} > 10\ \mathrm{dB}$ by the total number of observations (Smith et al., 2016). (see Pg. 12 L. 9-10)

- Figure 10 shows the QF indices derived from ionosonde observations as a function of local time and months. To obtain the results presented in Fig. 10, ground-based ionosonde data for the years from 2014 to 2018 were also used. The data were also filtered and only those recorded during quiet geomagnetic conditions were considered. To generate the results presented in Figure 10, for each month (y-axis), the QF indices were averaged over 0.1 hr Local time bins.
- Figure 11 shows the QLat-LT distributions of std(ΔN_e) for the Swarm satellites for the years from 2014 to 2018. Recall that the Swarm passes were allowed to be within $\pm 5°$ magnetic longitude and $\pm 40°$ QLat. The results presented in Fig. 11 were also generated considering only the geomagnetically quiet conditions ($\mathrm{Kp} \leq\ 3$). The N_e data collected for the five years were also grouped into different seasons similar to those presented in Fig. 9. The std(ΔN_e) was then calculated in bins of $1° \times 0.1\ \mathrm{hr}$ resolution in QLat and Local time. The occurrence rate of ionospheric irregularities does not always correspond to the highest amplitude of irregularity structures (Wan et al., 2018). Therefore, we presented the calculated std(ΔN_e) per bin as a function of QLat and Local time as seen in Fig. 11.

– In the revised manuscript, we are going to highlight statistical procedures as listed above.

Minor Comments:

P.3 l.30: Doesn't the faceplate actually record Ni, from which Ne is calculated?

Response: Ion density, N_i is derived from the faceplate current assuming that the current is carried by ions hitting the faceplate due to the orbital motion of the spacecraft. However, due to quasi-neutrality N_i must be equal to the electron density N_e (Buchert, 2016).

This will be added in the manuscript for clarification.

P.4 l.18: "vs" should be "versus"

Response: This will be changed as suggested by the referee.

P.4 l.29: "Ngwira et al. (2013)" should have (. . .)

Response: The citation identified by the referee will be changed as suggested.

P.4 l.30: Is the standard deviation also calculated on a 2sec running window? Are the scales selected important for you results?

Response: The standard deviation of the residuals was calculated at a running window of 2-s and this was used to represent the magnitude of the electron density perturbation.

This information will be added in the revised manuscript.

Concerning the scales selected, it is important for our results since we concentrated on small-scale ionospheric irregularities. The window to calculate dN_e and the standard deviation (for the case of small-scale ionospheric irregularities) should be short, but has to be long enough to avoid spurious detection of ionospheric irregularities. We also tried 1 s, 16 points, instead of 2s, 32 points, and the outcome was similar and reasonable.

In addition, the Coherent scatter radars e.g, the JULIA radar can monitor irregularities at high spatial resolution (3 m scale length for the case of JULIA) and therefore these were compared with Swarm faceplate observations of ionospheric irregularities of small scales which were quantified by using a running window of 2-s.

P.5 l.7: "Smith et. Al (2015); Zhan et al. (2018)" should have (. . .)

Response: The citations identified by the referee will be changed as suggested.

P.5 l.12: Definition of ISR.

Response: ISR stands for Incoherent Scatter Radar. This will be added in the revised manuscript.

P.5 l.14: How exactly do the authors define "nighttime"?

Response: In our manuscript, nighttime is defined as the time period between 1800 LT and 0600 LT. The sentence in P.5 L. 14 will be rephrased in the revised manuscript to make this clear as follows:

Therefore, to compare the Swarm observations with the JULIA measurements, only swarm satellite passes for the time period between 1800 LT and 0600 LT were considered.

P.5 l.19: Space between "explorer" and (Galkin. . .)

Response: This will be adjusted as suggested by the referee.

P.5 l.28: Definition of "QLat".

Response: QLat stands for quasi-dipole latitude (Laundal and Richmond, 2016). This will be added in the revised manuscript.

P.5 l28: "Much higher altitude". This is very subjective.

Response: The identified words will be removed from the revised manuscript and the sentence will be rephrased to:

Also, Swarm B which orbited at about 510 km altitude above sea level recorded ionospheric irregularity structures on 2015-04-05 as seen from the right panel of Fig. 1.

P.7 Figure 3. This figure and the explanation are not clear: do the authors bin the data by day of the month, and take the maximum for each day over 4 years?.

Response: The maximum ranges were obtained for each "day of the month" over the four years when the JULIA data was available. As identified by the referee, there indeed seems not be a direct relation between "Maximum range" and "Time (days)". Instead each maximum range corresponds to "a day of the month". Therefore, the xlabel of Figure 3 will be changed to "Day of the month".

P.8 l.14: Definition of "EIA".

Response: EIA stands for Equatorial Ionization Anomally. This will be added in the revised manuscript.

P.8 l 30: "20.05 LT to 21:00 LT" I don't read the same time interval from the Figure.

Response: To make it clearer, the x-axis tick labels for LT will be changed to LT(hh:mm) in the revised manuscript as shown here in Fig. 2: To be exact, the time interval will be changed to 20:27 LT to 21:05 LT, in the revised manuscript.

P.15-16 Figure 10 and Figure 11: Could the authors describe in more detail how those figures are obtained?

Response: The referee is referred to the response to major comment 3.

P.16 l.2: Didn't the authors use the 16 Hz? (Why is 2 Hz relevant here?)

Response: Since we concentrated on the 16 Hz N_e, in the revised manuscript, the sentence will be rephrased to:

- The Swarm electron density measurements used in this study are limited by the sampling rate of 16 Hz and the orbital velocity of about 7.5 km/s to wavelengths of about 500 m, respectively, and longer.

P.17. l.1-3: The purpose of these sentences is unclear to me. It is well known that equatorial irregularities can cause scintillations.

Response: The sentence will be removed in the revised manuscript.

P.17 l.12: "directory" – "directly"?

Response: This will be changed in the revised manuscript as suggested by the reviewer.

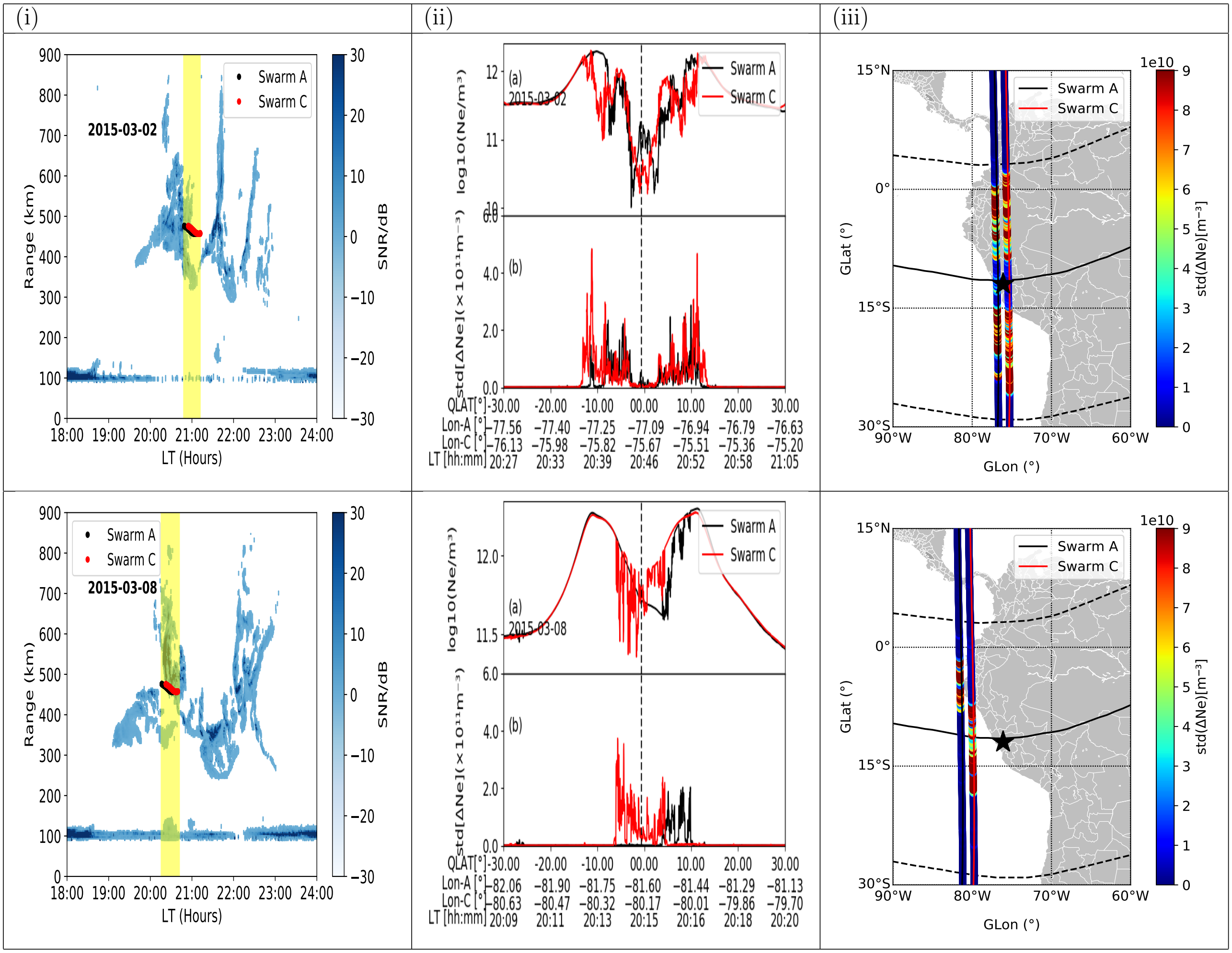

Figure 2. Examples of collocated observations by Swarm and JULIA radar on 2015-03-02 and 2015-03-08.

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