Simultaneous Ground-based and In Situ Swarm Observations of Equatorial F-region Irregularities over Jicamarca

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 #1 comments

Comment: Present work describes comparison of ionospheric irregularitiy data between the satellite SWARM electron densities and groundbased JULIA radar data and ionosonde data,using the data obtained over Peru from 2014 to 2018. In terms of identification of ionospheric irregularities, they found good similarities between the three different data set. Their final conclusion was that SWARM data can be used as a tool to indicate presence of plasma plumes and Spread F occurrence. The data sets used in the manuscript are interesting and comparison of them in terms of plasma bubble finding, or validation study for identification of the plasma irregularities, are useful. However, if one asks what is a new finding in this work I could not find anything. The authors could have a new aspect if they further discuss in the data analysis, I guess. Therefore my conclusion is that the present work will not be acceptable as a scientific paper without any further scientific new finding.

Response: We are glad that the referee finds the data sets used in our paper interesting and comparison of them in terms of plasma bubble finding, or validation study for identification of the plasma irregularities useful.

The main focus, findings and innovations 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 our findings. Below are the points we want to address in this study:

- The main focus of this study is to determine whether Swarm in situ observations can be used as indicators of the presence of plasma plumes and spread-F on the ground by comparing simultaneous observations of plasma plumes by the Jicamarca unattended long term investigations of the ionosphere and atmosphere (JULIA) radar, ionogram spread F generated from ionosonde observations installed at the Jicamarca Radio Observatory (JRO), and irregularities observed in situ by Swarm. The combined multi-instrument measurements provide a more integrated and comprehensive way to study the morphological structure, development, and seeding mechanism of ionospheric irregularities.
- 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 comared with Sarm 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.

– As far as we know, Wang et al. (2014) were the first to make concurrent observations of strong range spread-F and ionospheric irregularities measured in situ using ROCSAT-1 satellite and they found that strong spread-F were caused by the ionospheric irregularities. However, ROCSAT-1 orbited at about 600 km altitude with 35° orbital inclination. Therefore, we also compared the JULIA and Swarm observations of ionospheric irregularities with spread-F signatures recorded by an ionosonde colocated with the JULIA radar.

We are going to highlight these points as listed above in the revised manuscript.

Minor Comments:

Comment1: Page 4, line 29, “Ngwira et al. (2013a)”: change to“(Ngwira et al., 2013a)

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

Comment2: Page 5, line 8, “Smith et al„„”: change to “(Smith et al., 2015;Zhan et al. 2018)

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

Comment3: Page 5, line 29, “from the left panel of Fig. 1”: change to “fromthe right panel of Fig. 1”

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

Comment4: Page 7, Figure 3: Please explain why the authors plotted themaximum ranges as a function of time (days). It seems to have no relation between themaximum range and Time(days).

Response: The maximum ranges were plotted to check the altitude coverage of the various types of plumes observed by the JULIA radar compared to the Swarm altitudes. The maximum ranges were obtained for each “day of the month” 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”.

Comment5: Page 12, Figure 7: The authors did not discuss in the case of “Irregularities observed by SWARM only”. According to the height coverage of Julia radar (90 to 800 km), any irregularities detected by SWARM should be detectedby Julia radar. It could be difference of threshold of detection amplitude (?), further discussion would be helpful for readers.

Response: Ideally, any irregularity detected by Swarm would be detected by JULIA depending on the proximity of the Swarm pass to the JULIA longitude and the magnitude of the irregularitiy. Given the longitudinal range (±5°) that was used for good statistical coverage (see Pg 10 Line 3), there were chances that Swarm would record ionospheric irregularities without JULIA identifying any plume structures. This is because ionospheric irregularities tend to be magnetic field aligned (Ossakow, 1979; Kil and Heelis, 1998; Nishioka et al., 2008; Kelley, 2009).

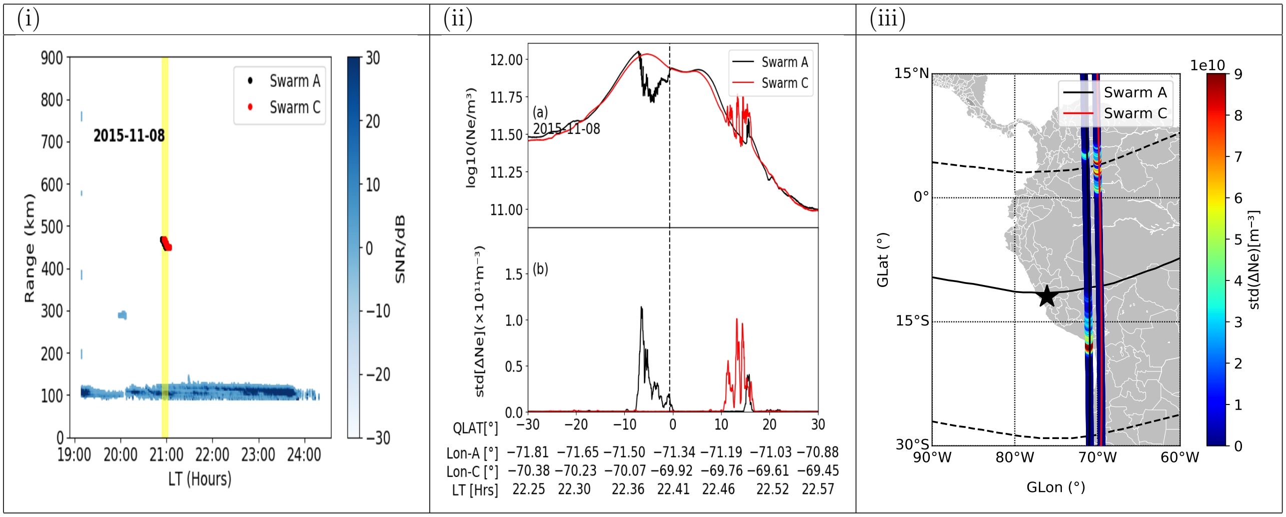

Figure 1. Example of collocated observation by Swarm and JULIA on 2015-11-08.

An example is presented here in Figure 1. On the day 2015-11-08, Swarm encountered ionospheric irregularities, while JULIA recorded no plume structures. Clearly, the Swarm passes were offset from the JULIA longitude to the east. The following discussion will be added in the revised manuscript, to explain “Irregularities observed by SWARM only”

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.

Comment6: Page 16, line 1, “The Bragg condition”: Please explain what is “Bragg condition” for readers who are not familiar to the phrase.

Response: Bragg-Scattering explains the effect of periodic or quasi-periodic variations of the refractive index on the propagation of electromagnetic waves when the scales of the variations are of the order of the wavelength. The radio waves fulfilling the Bragg condition scatter at periodic variations of the refractive index such that a coherent superposition of reflections occurs and a reflected waves propagates in the direction of the radar receiver. The Bragg condition describes when the constructive interference occurs in a certain ratio between the transmitted wavelength and the distance of the reflective sub-surfaces:

$\mathrm{d} = \frac{\lambda_t}{2.\cos\theta}$

d=distance between maxima and minima of the refractive index

λ_t=transmitted wavelength

θ=incident angle

The following sentences will be included in the manuscript as further explanation of the “Bragg condition”:

The Bragg condition for backscatter means that a radar can only observe structures in the refractive index with scale sizes close to the half radar wavelength (Kelley, 2009; Hocking et al., 2016).

Comment7: Page17, Conclusions, lines 13-14: "A few exceptions were also observed when„,": Furtherscientific discussion would be valuable for readers

Response: This has been addressed in response to **Comment5**.

In addition, the following sentences will also be included in the conclusion as further discussion for the observation made in lines 13-14:

For the case when JULIA and ionosonde recorded irregularity signatures, while Swarm observed no structures, the plume structures may not have ascended to Swarm altitudes by the time the satellites passed over Jicamarca or the satellites were simply in a different location. Swarm was able to detect ionospheric irregularities in situ, while no signature was recorded on the ground because the irregularities occurred at magnetic longitudes which were largely offset from the longitude of the ground-site.

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