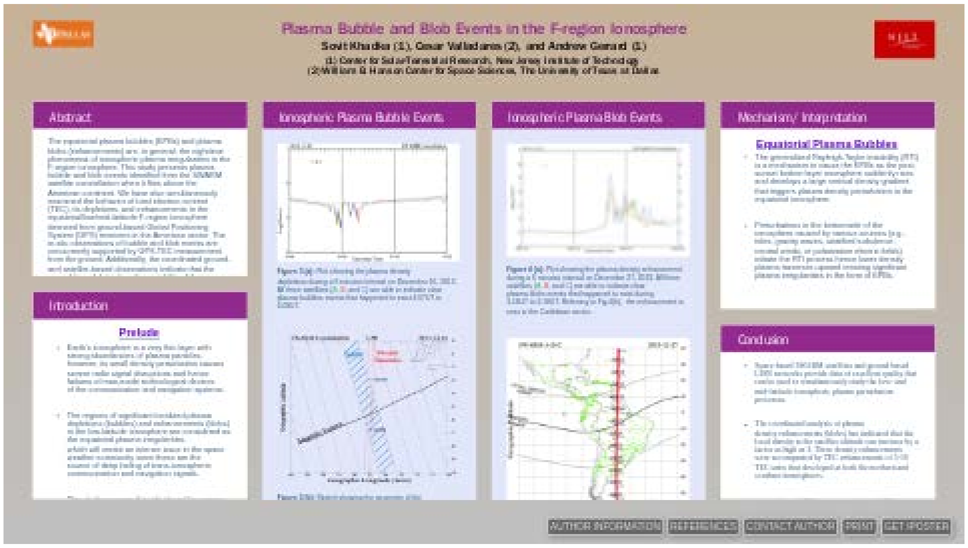
Plasma Bubble and Blob Events in the F-region Ionosphere



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ABSTRACT

The equatorial plasma bubbles (EPBs) and plasma blobs (enhancements) are, in general, the nighttime phenomena of ionospheric plasma irregularities in the F-region ionosphere. This study presents plasma bubble and blob events identified from the SWARM satellite constellation when it flies above the American continent. We have also simultaneously examined the behavior of total electron content (TEC), its depletions, and enhancements in the equatorial/low/mid-latitude F-region ionosphere detected from ground-based Global Positioning System (GPS) receivers in the American sector. The in-situ observations of bubble and blob events are concurrently supported by GPS-TEC measurement from the ground. Additionally, the coordinated ground- and satellite-based observations indicate that the ground-based data show the variability of the background ionosphere prior, during, and later than the development time of the EPBs as seen by the SWARM. For this limited analysis, the plasma blob events are mostly seen at/nearby mid-latitude regions. Finally, we discuss the possible mechanism of the generation, evolution, and relationship between EPBs and plasma blobs in the F-region ionosphere.

INTRODUCTION

Prelude

- Earth's ionosphere is a very thin layer with strong abundancies of plasma particles, however, its small density perturbation causes severe radio signal disruptions and hence failures of man-made technological devices of the communication and navigation systems.

- The regions of significant localized plasma depletions (bubbles) and enhancements (blobs) in the low-latitude ionosphere are considered as the equatorial plasma irregularities which will create an intense issue in the space weather community since these are the source of deep fading of trans-ionospheric communication and navigation signals.

- This study presents the role played by various ionospheric parameters of the equatorial F-region ionosphere in the various characteristics of plasma irregularities seen in the EPBs and blobs by two independent techniques—ground-based Global Positioning System (GPS) and in situ Langmuir probe (LP) measurements.

Bubbles & Blobs

- The equatorial plasma bubbles (EPBs) refer to the region of post-sunset ionospheric structures where the ionospheric plasma densities are reduced significantly compared to the surrounding plasma. The plasma density enhanced regions relative to the background ionosphere are called plasma blobs.

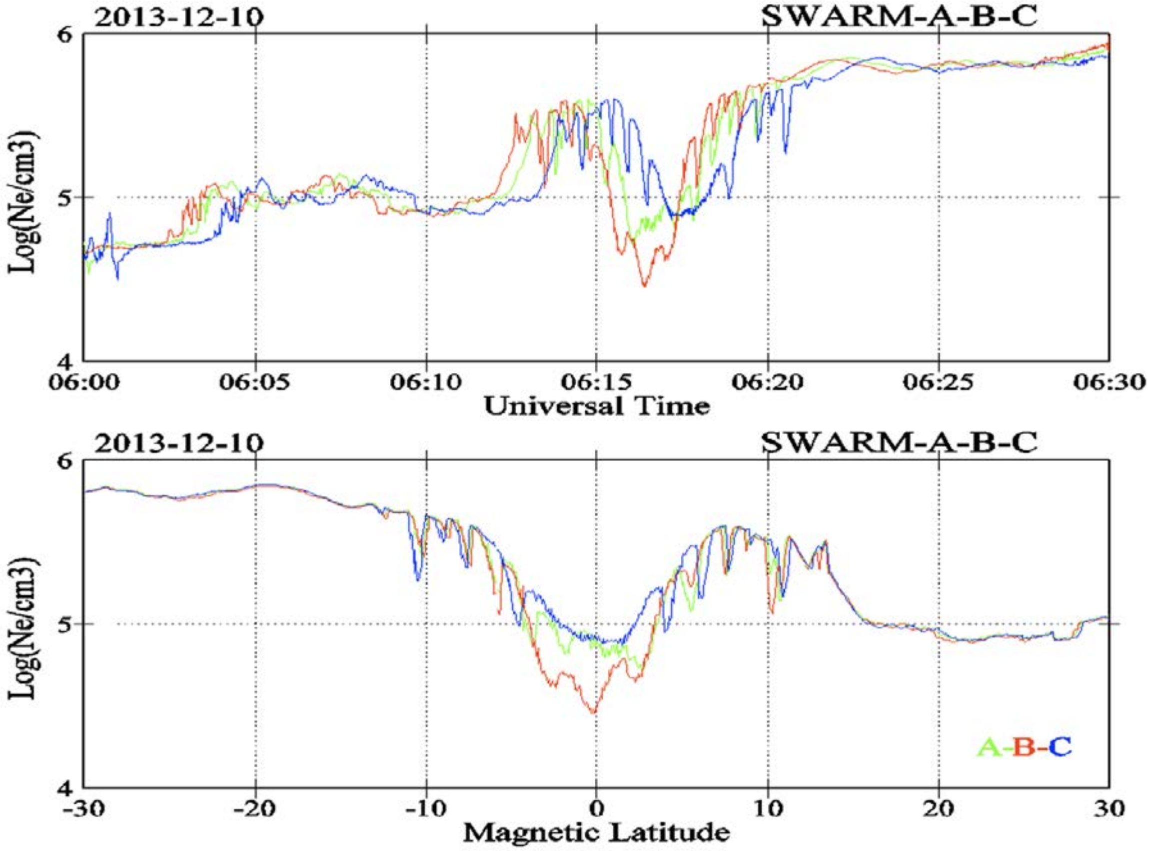

Figure 1 (a): Upper plot showing depletion pattern of the plasma density as a signature of EPBs against time from three SWARM satellites. It is clearly seen that there is a sharp decrease in plasma density during nighttime. The lower plot is for the variation of the same against magnetic latitude indicating bubbles in the low latitude.

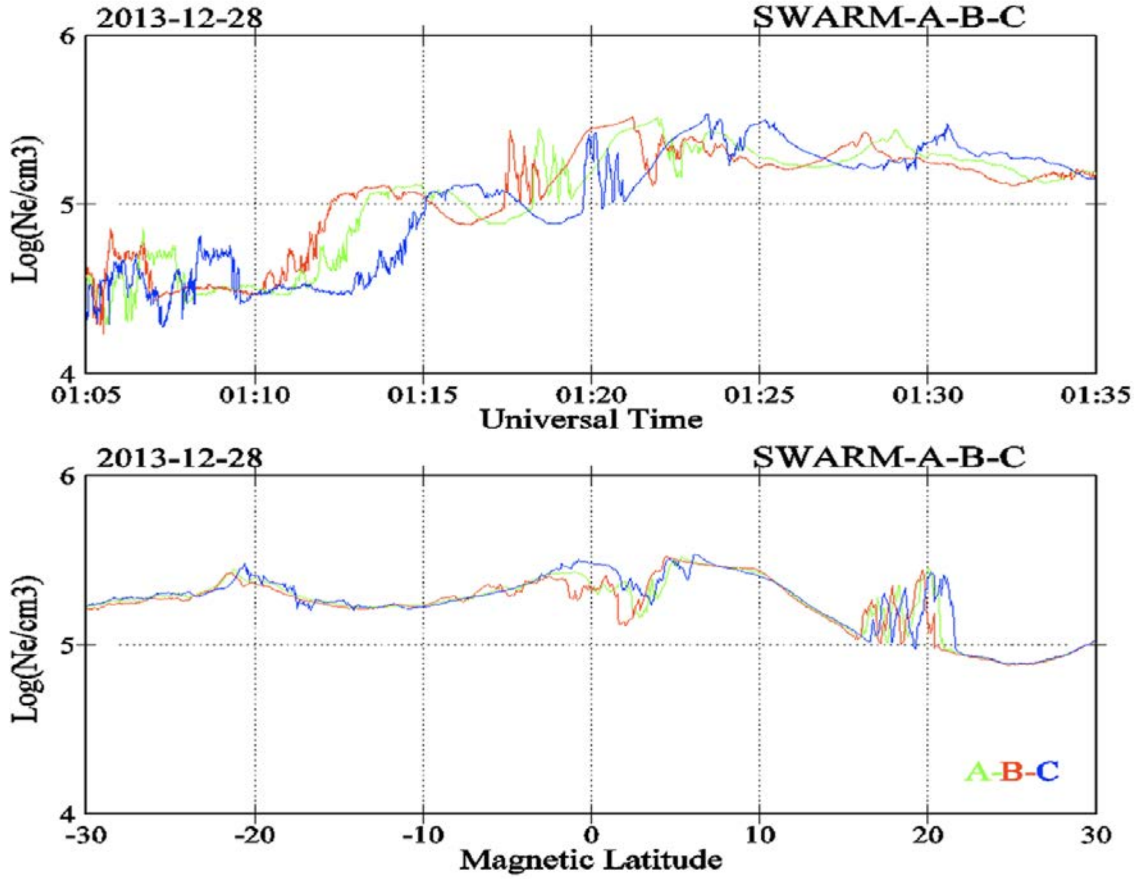

Figure 1 (b): Upper plot showing enhancement pattern of the plasma density as a signature of blobs against time. It is seen that there is a sharp increase in plasma density during nighttime. The lower plot is for the variation of same against magnetic latitude indicating blobs near 20°.

Instruments & Dataset

- We used almost simultaneous in-situ measured data from the early phase of the SWARM whence the distance between the trajectories of all three satellites of the constellation was tens of km and the temporal separation was of order one minute. Concurrently, two different ionospheric processes have been studied using ground-based GPS total electron content (TEC) data from the LISN network in the low-latitude ionosphere.

- SWARM is a minisatellite constellation of three satellites, two will fly at a lower altitude, measuring the East-West gradient of the magnetic field, and one satellite will fly at a higher altitude at a different local time sector. The SWARM constellation consists of three identical satellites named Alpha, Bravo, and Charlie; launched on 22 November 2013.

- Low-Latitude Ionospheric Sensor Network (LISN) is a permanent array of geophysical instruments in South America to answer key questions about the electrodynamics of the equatorial to the mid-latitude ionosphere and to develop forecasting capabilities.

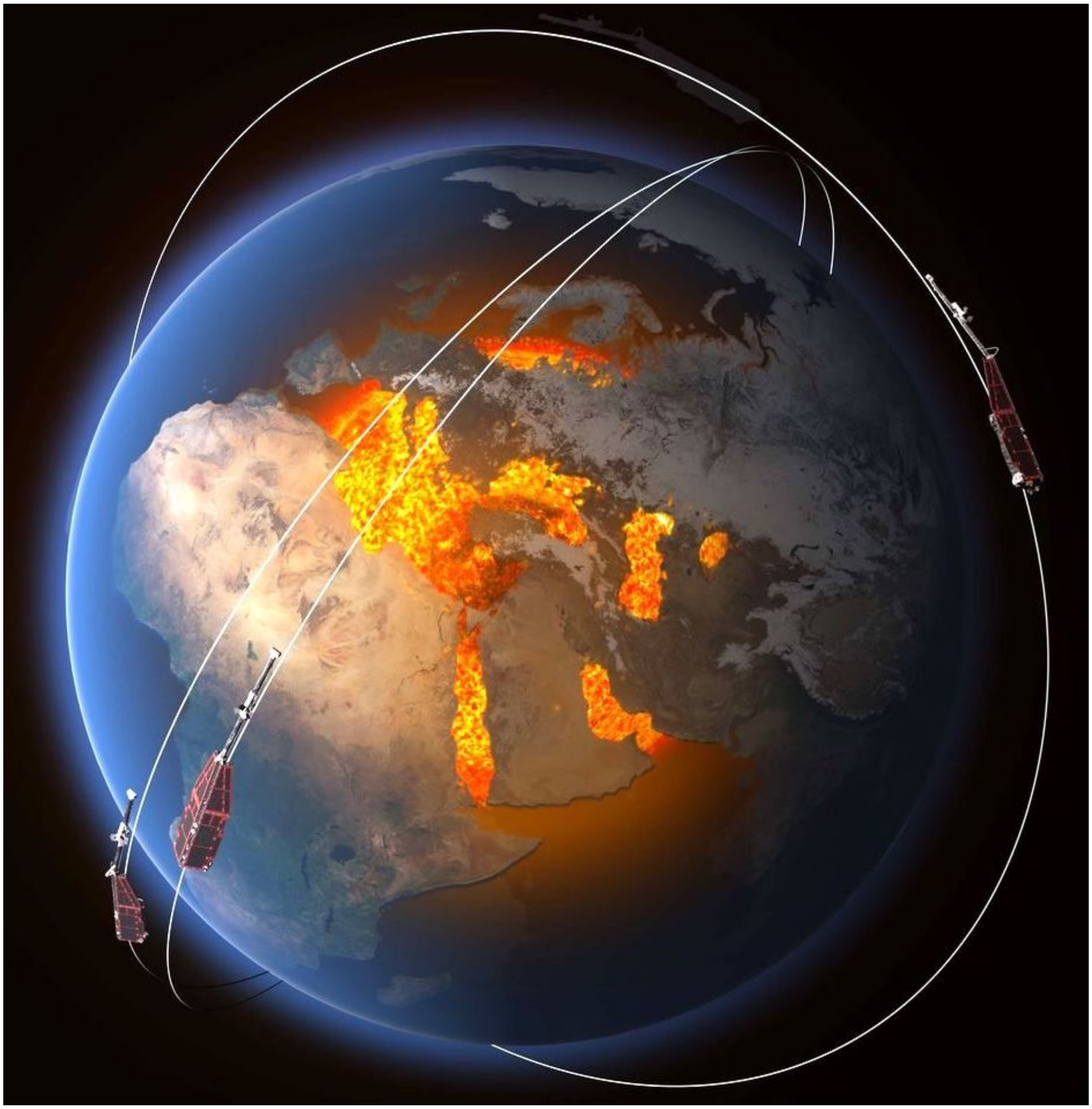

Figure 2 (a): Showing the orbit configuration of the constellation of SWARM satellites (image credit: ESA). Satellite pairs at 450km initial altitude, flying side-by-side with 1.5° longitude separation whereas the third satellite is at 550km initial altitude.

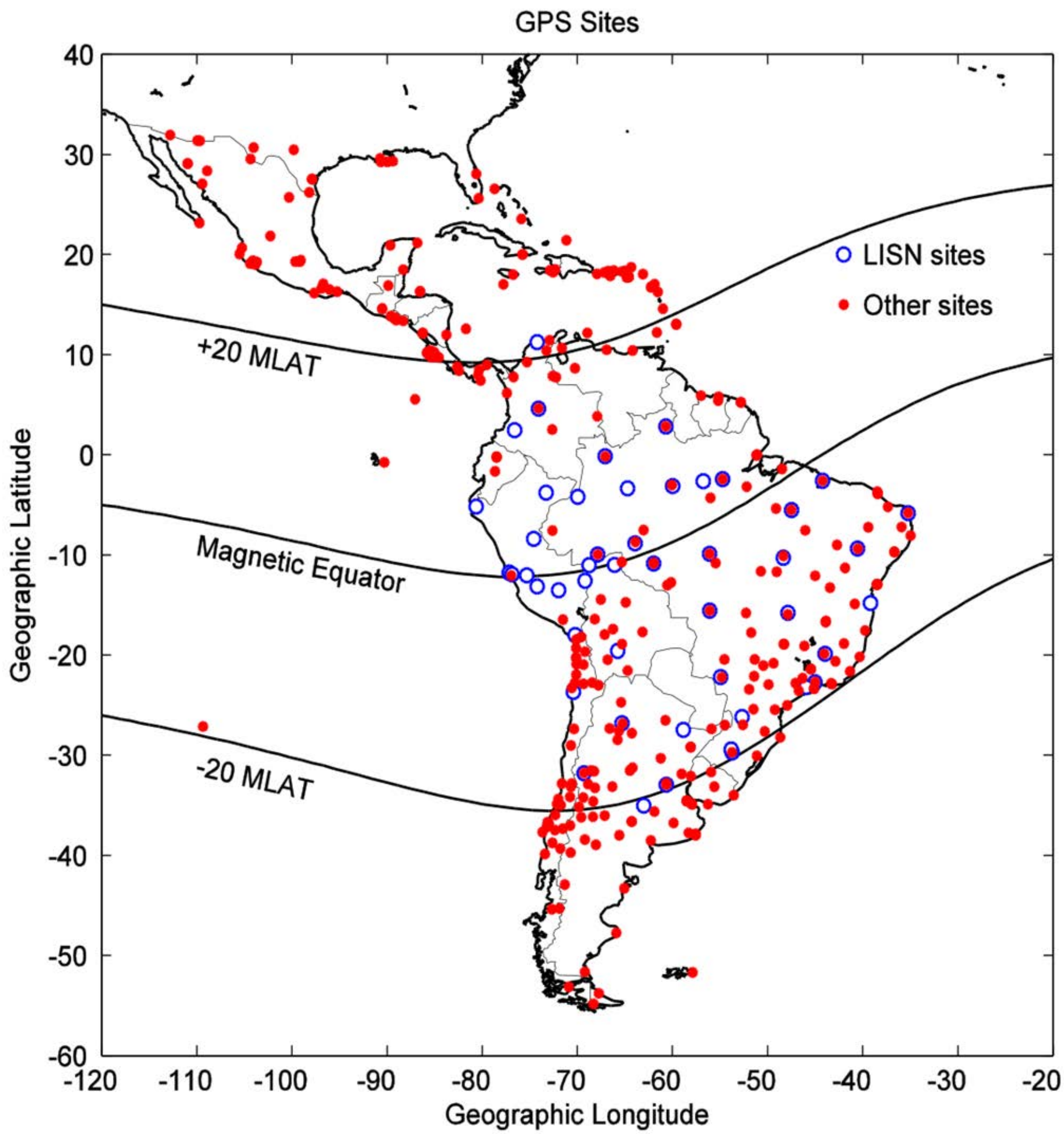

Figure 2 (b): Showing the location of GPS receivers under the Low-Latitude Ionospheric Sensor Network (LISN) and others in South and Central America.

IONOSPHERIC PLASMA BUBBLE EVENTS

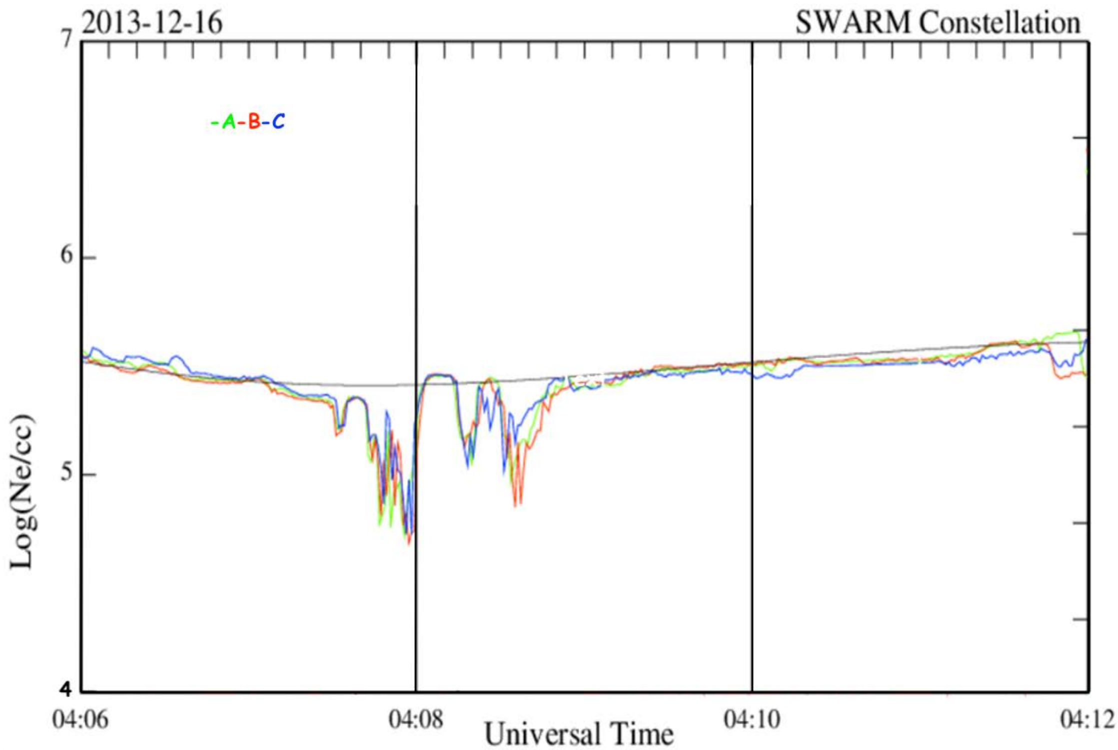

Figure 3 (a): Plot showing the plasma density depletions during a 6 minutes interval on December 16, 2013. All three satellites (A, B, and C) are able to indicate clear plasma bubbles events that happened to exist 4:07UT to 4:09UT.

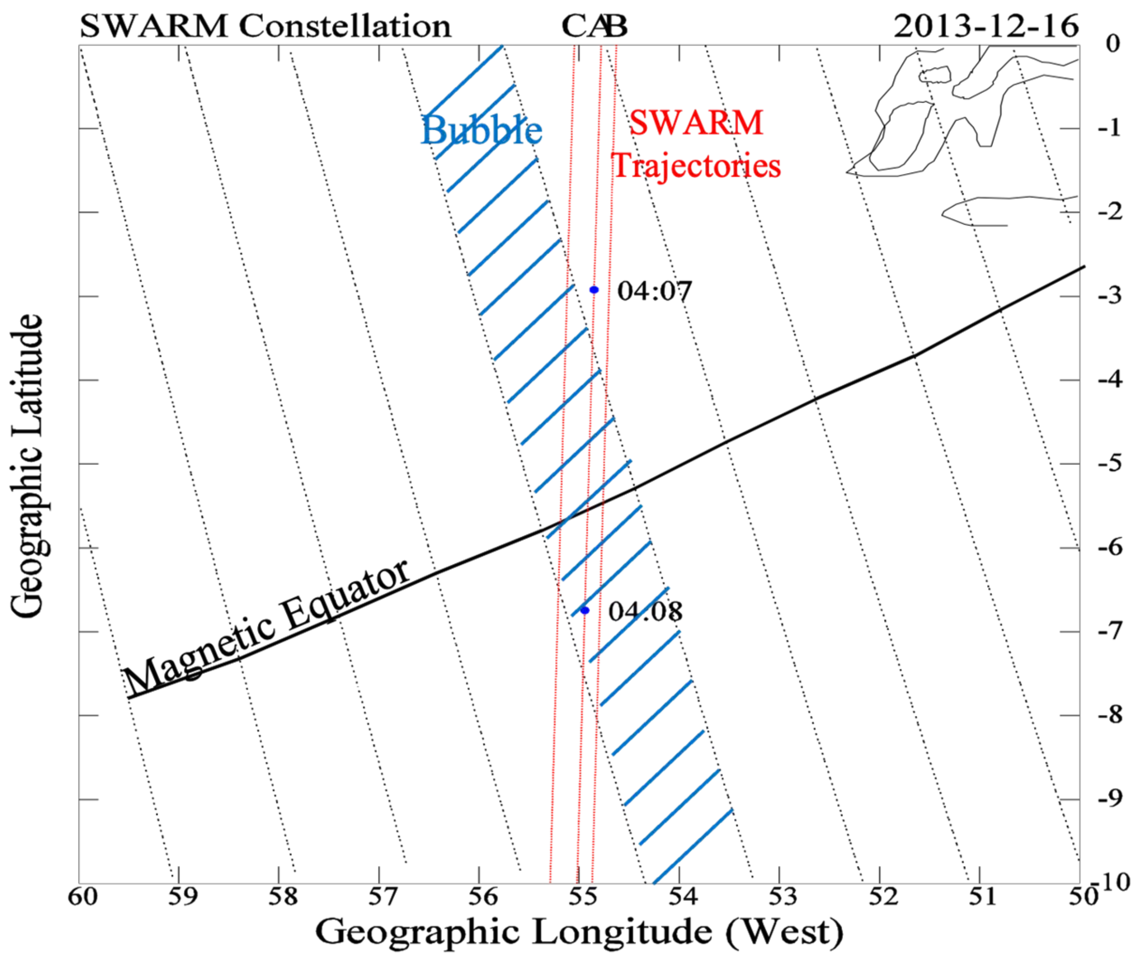

Figure 3 (b): Sketch showing the geometry of the SWARM constellation pass and the aligned plasma bubbles with the local magnetic field lines. It also shows the ground mapping of satellite paths as it sees plasma depletion along their trajectories.

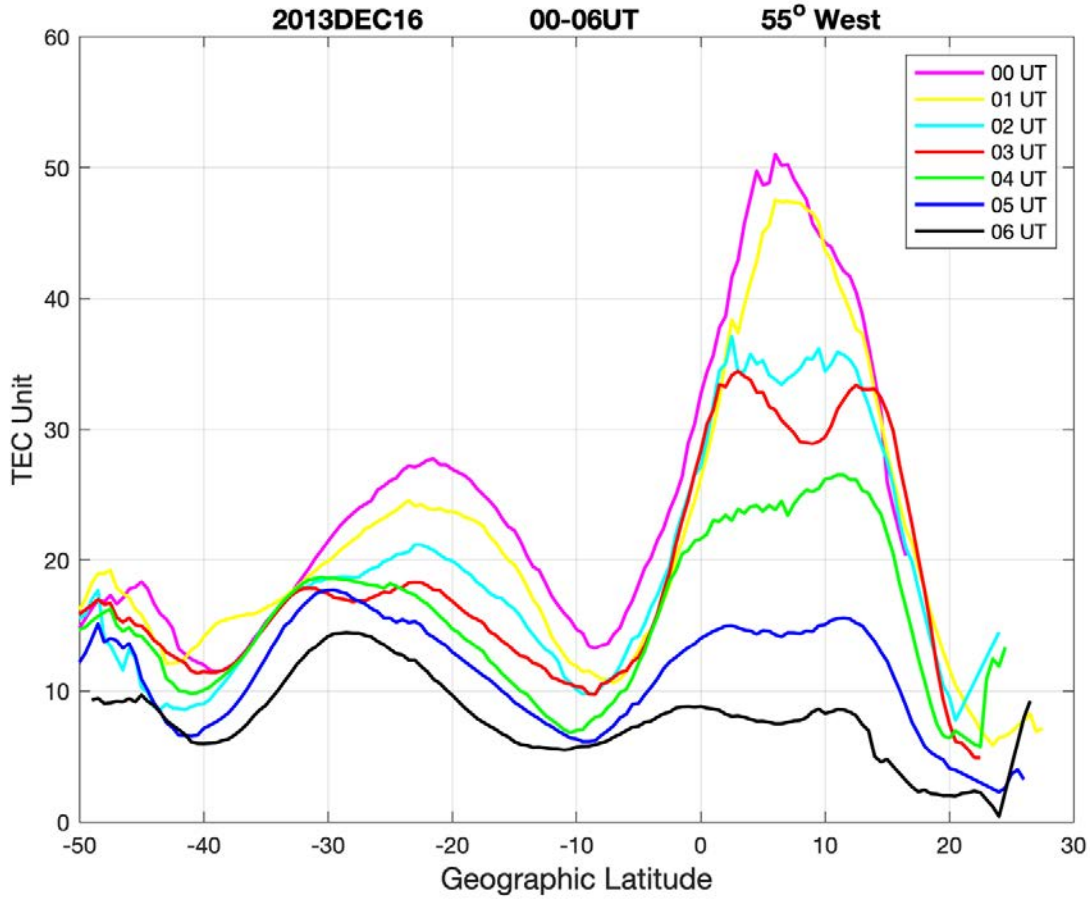

Figure 3 (c): Mass plots showing one-hour variations (total 7 hrs) of TEC against geographic latitude along with 55°W longitudes sector. It is seen that even though SWARM sees bubbles at 4:07UT to 4:09UT, the peak of the northern anomaly crests starts to deteriorate at 02UT because of bubbles. The in situ measurement of bubbles is simultaneously supported by GPS-TEC measurement from the ground.

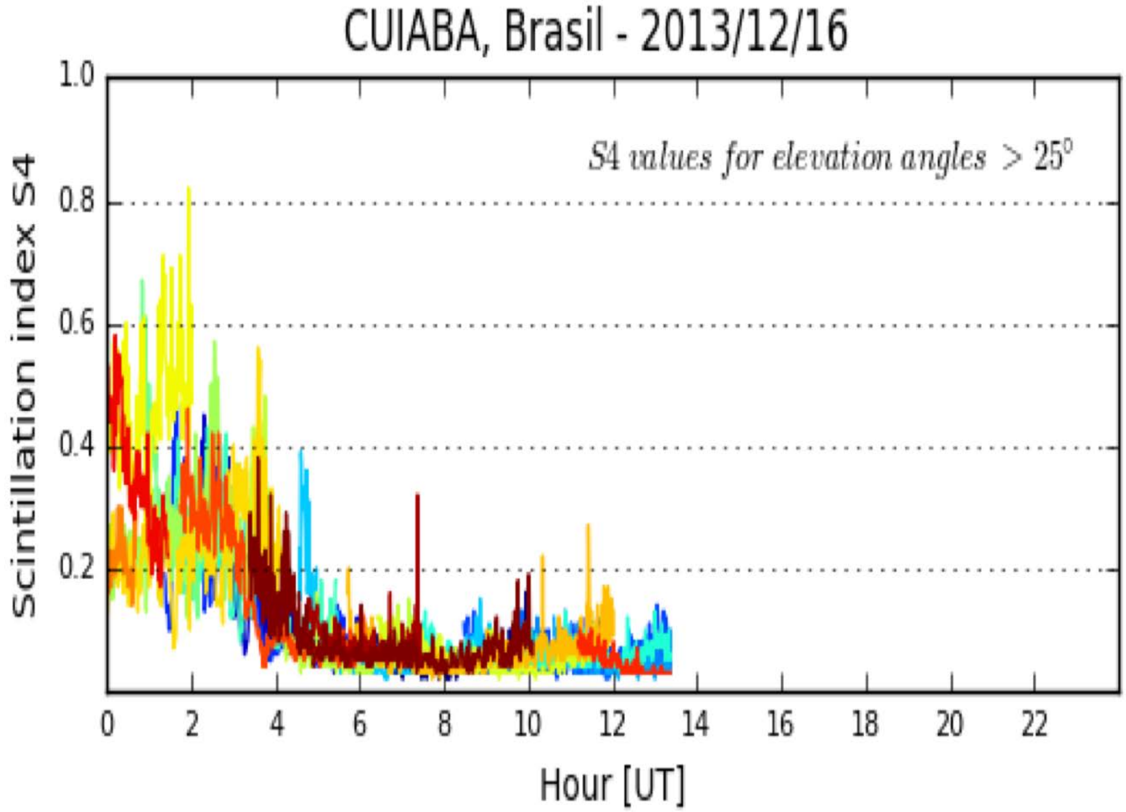

Figure 3(d): Plot showing scintillation index (S4) profile against Universal time reported by GPS receiver located at Cuiaba (15.560S, 56.070W). The surge of the S4 index from 00UT to 05UT is evidence of equatorial plasma irregularities caused by bubbles.

IONOSPHERIC PLASMA BLOB EVENTS

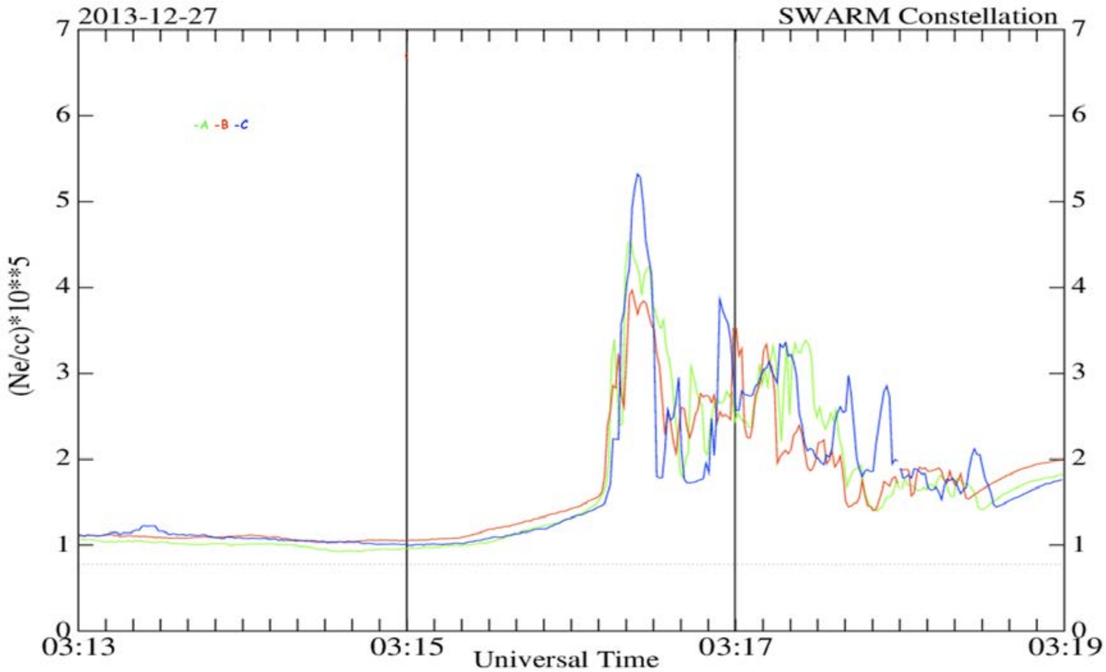

Figure 4 (a): Plot showing the plasma density enhancement during a 6 minutes interval on December 27, 2013. All three satellites (A, B, and C) are able to indicate clear plasma blobs events that happened to exist during 3:16UT to 3:18UT. Referring to Fig.4(b), the enhancement is near to the Caribbean sector.

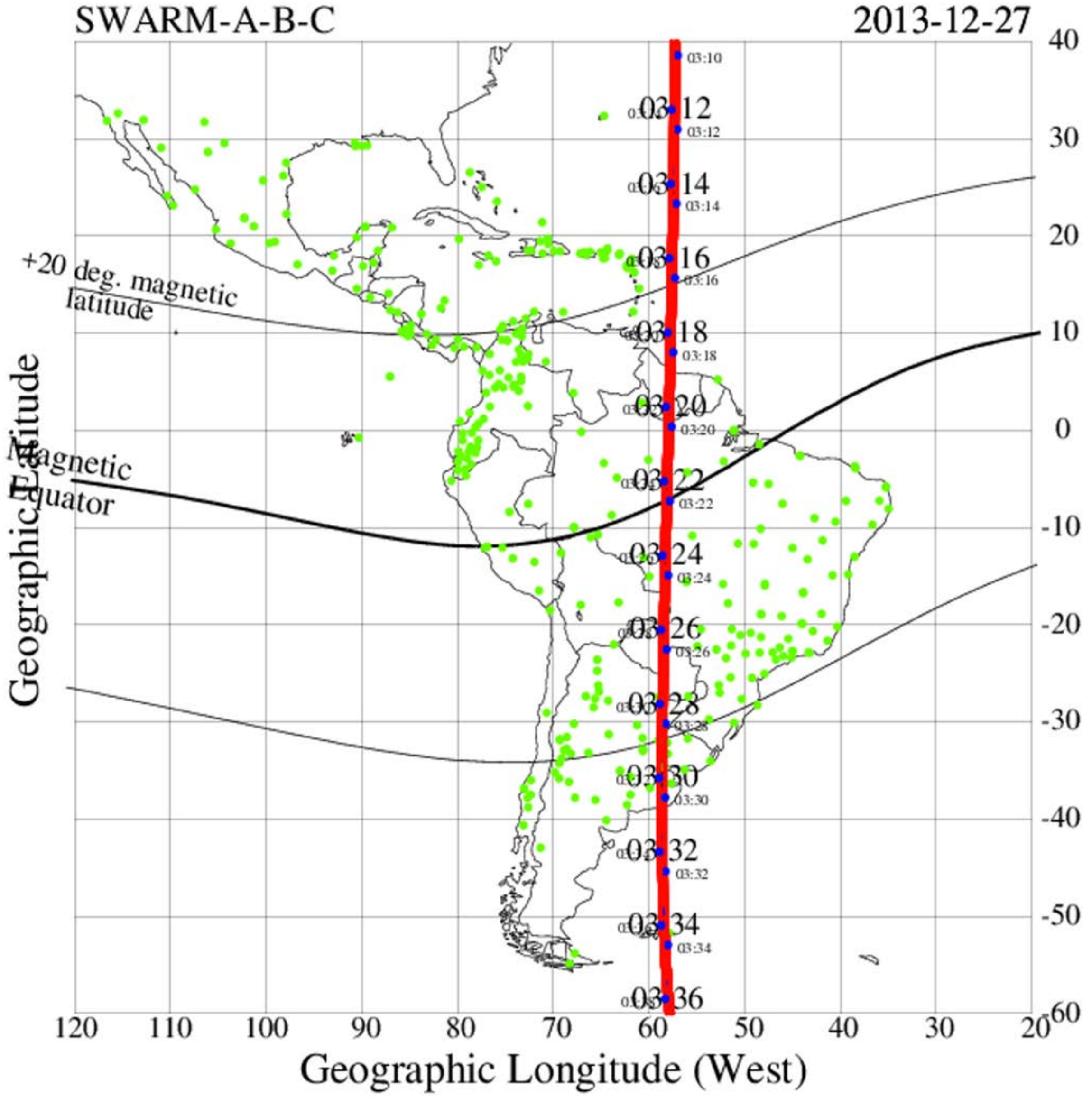

Figure 4 (b): South American continental map showing the geometry of the SWARM pass along the thick red line.

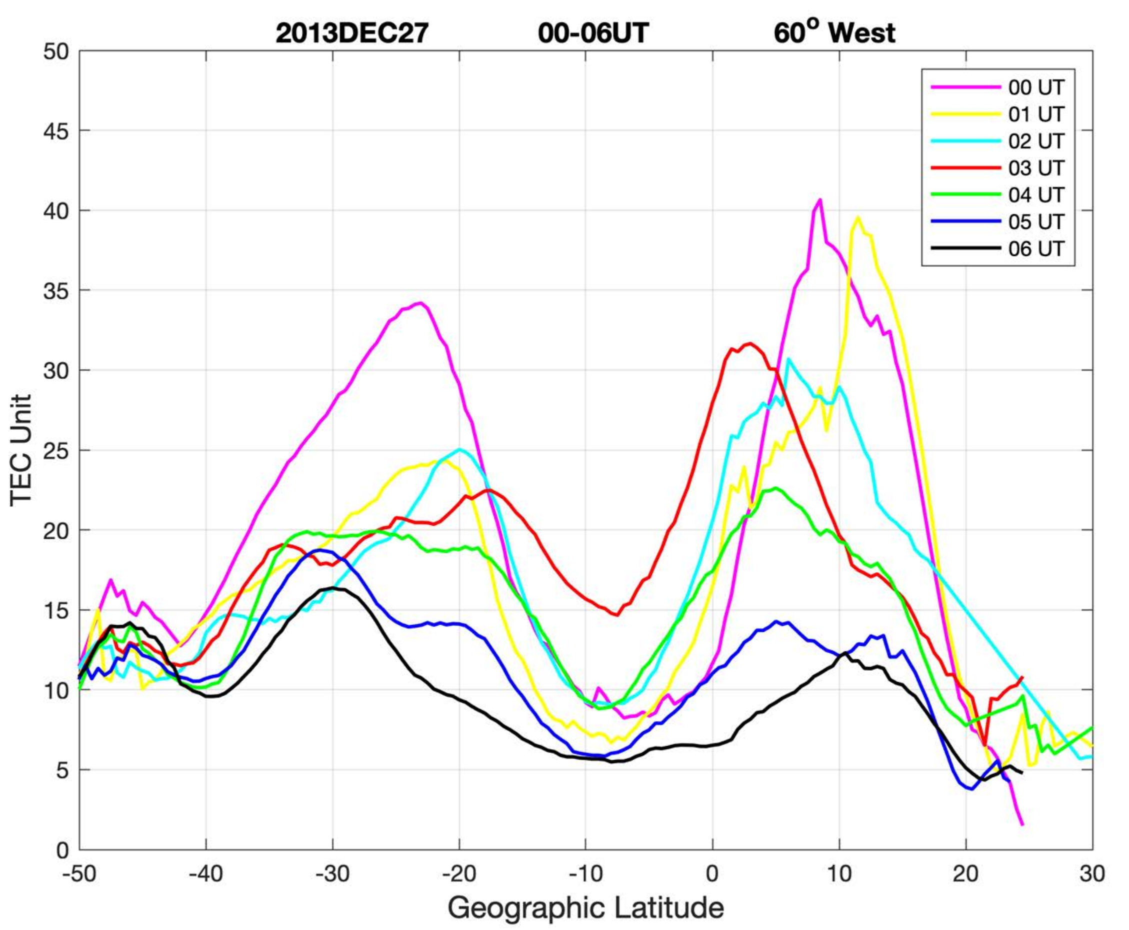

Figure 4 (c): Mass plots showing one-hour variations (total 7 hrs) of TEC against geographic latitude along with 60°W longitudes sector. It is seen that the northern anomaly crests prolong to descend from its peak creating a 'shoulder' because of plasma enhancement. The in situ measurement of blobs is simultaneously supported by GPS-TEC measurement from the ground.

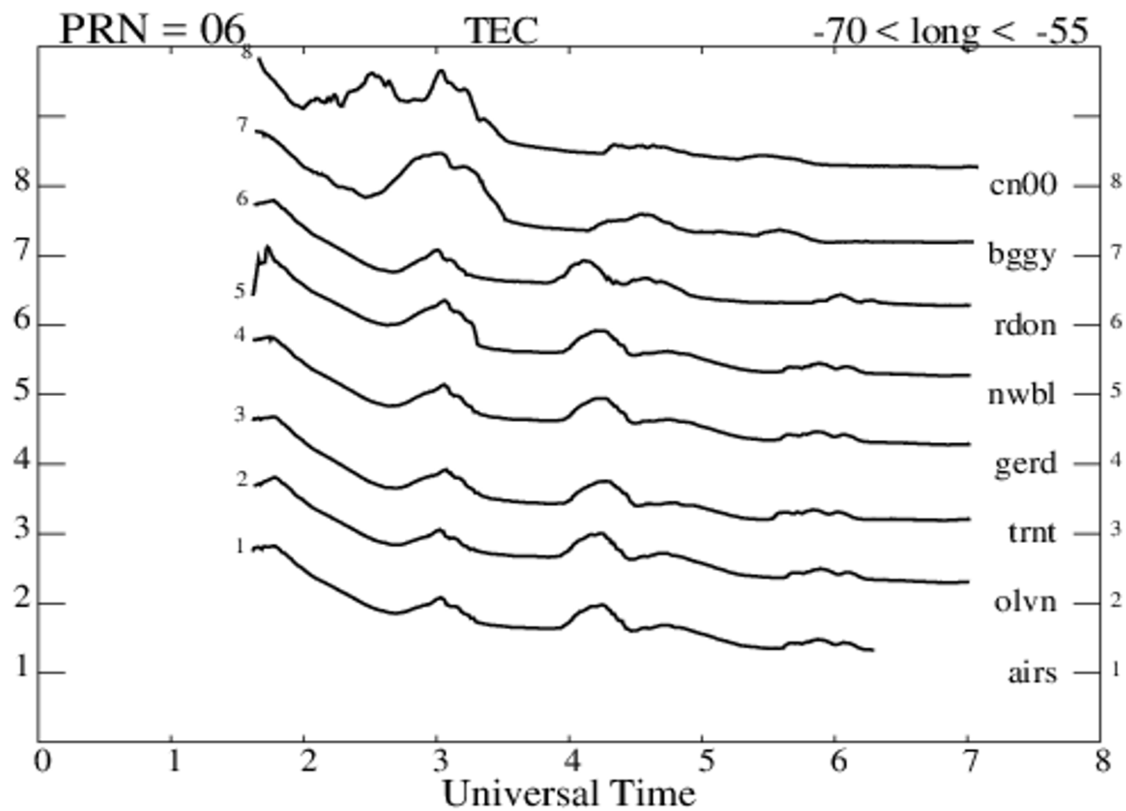

Figure 4 (d): Plot showing the TEC values collected by 8 GPS stations located in the Caribbean region. These receivers detected prominent TEC enhancements, larger than 5 TECu, at the same location where the SWARM sees.

MECHANISM/ INTERPRETATION

Equatorial Plasma Bubbles

- The generalized Rayleigh-Taylor instability (RTI) is a mechanism to cause the EPBs as the post-sunset bottom layer ionosphere suddenly rises and develops a large vertical density gradient that triggers plasma density perturbation in the equatorial ionosphere.

- Perturbations in the bottomside of the ionosphere caused by various sources (e.g., tides, gravity waves, stratified turbulence, neutral winds, or polarization electric fields) initiate the RTI process hence lower density plasma traverses upward creating significant plasma irregularities in the form of EPBs.

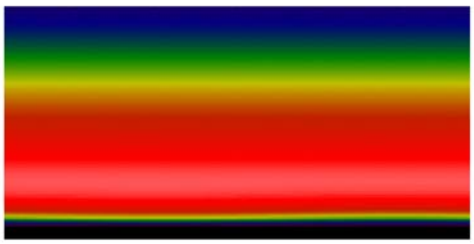

Figure 5 (a): Schematic illustration of the evolution of the plasma depletions (bubbles) from the RTI process (Adapted from Courtesy of J. Retterer).

Ionospheric Plasma Blobs

- Bubble Growing Phase: As plasma bubbles develop from the non-linear evolution of the Rayleigh-Taylor instability (RTI) near the geomagnetic equator, the plasma density enhancement appears above the bubble as a consequence of the uplift of the ionosphere

- Bubble Developed Phase: As bubbles are fully grown, the blobs remain only off the magnetic equator as a consequence of the diffusion of equatorial plasma along geomagnetic field lines. In most cases, bubbles are not the major source of blobs since bubbles are formed mainly in the equatorial region but blobs exist mainly off-equator at about mid-latitude.

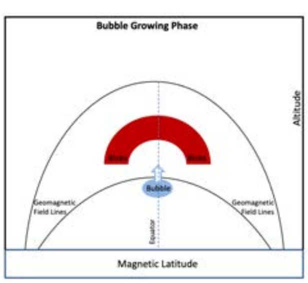

Figure 5 (b): Sequential graphics showing the evolution of the plasma enhancements (blobs) as RTI growth, bubble evolution, and fully developed plasma bubble processes push blobs away from the equator. The light blue and the red shadings denote plasma depletions and plasma blobs respectively.

CONCLUSION

- Space-based SWARM satellites and ground-based LISN networks provide data of excellent quality that can be used to simultaneously study the low- and mid-latitude ionospheric plasma perturbation processes.

- The coordinated analysis of plasma density enhancements (blobs) has indicated that the local density at the satellite altitude can increase by a factor as high as 3. These density enhancements were accompanied by TEC enhancements of 5-10 TEC units that developed at both the northern and southern hemispheres.

- Ground-based GPS receivers under the LISN network fully diagnose bubbles and blobs characteristics in terms of provided TEC and S4 index measurement.

- It can be said that SWARM only gives a snapshot of plasma bubble and blob events whereas ground GPS continuously monitors its impact for a longer period. For the examination of the generation to decay mechanism of EPBs/ blobs, GPS shall be a better instrument to bring into practice for coordinated analysis.

AUTHOR INFORMATION

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