Relationship of the Pre-Reversal Enhancement (PRE) and the Bottomside Ionospheric Structure to Equatorial Plasma Bubble (EPB) Formation

Salvador Espinoza[1], Phillip C. Anderson[1], Cesar Valladares[1]

[1]The University of Texas at Dallas

Author contact: sal@utdallas.edu (Salvador Espinoza)

ABSTRACT

Equatorial plasma bubbles (EPBs) are ionospheric irregularities that cause radiowave scintillation, which poses problems in satellite communications and navigation. We report the examination of the ionospheric conditions that precede their formation. Two phenomena related to EPB formation are the pre-reversal enhancement (PRE), an enhancement of the vertical E × B drift due to the eastward electric field at the evening terminator at the magnetic equator, and the structure of the bottomside ionosphere. Three databases were generated from satellite measurements of the equatorial ionosphere. The first is a database of identified EPB occurrences and the associated ionospheric characteristics from the *in situ* ion velocity meter (IVM) instruments aboard the Communication/Navigation Outage Forecasting System (C/NOFS) and the Ionospheric Connections Explorer (ICON) satellites. The second database consists of the characteristics of the vertical drifts at 18-19 magnetic local time, to identify instances of PRE using in situ data from the C/NOFS and ICON IVM instruments. The third database contains information on the altitude profiles of ionospheric density, in particular the structure of the bottomside ionosphere, observed by the Far-Ultraviolet (FUV) imager aboard ICON. We examine the relationship of EPB occurrence with the strength of the PRE and the structure of the bottom-side F layer.

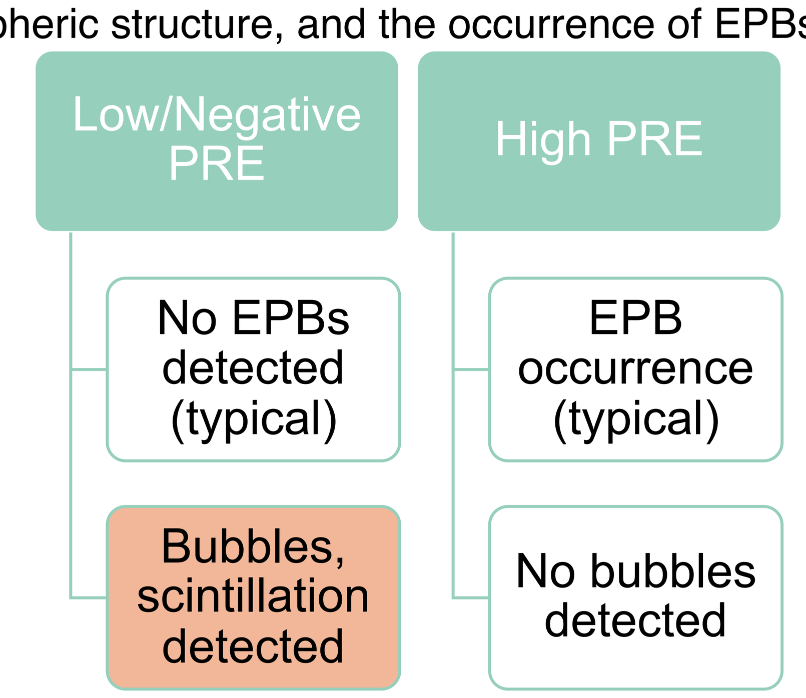
BACKGROUND

Just before sunset, an eastward electric field is commonly seen near the equator; this leads to vertical drift. It is possible for this drift to raise the F layer by 100km or more before the electric field reverses direction after sunset. It is thought that this PRE is a main factor in the generation of EPBs. The PRE drift needed to aid in the generation of EPBs isn't clear. Some suggest that drifts over 20 m/s are sufficient and that this value can change throughout the year and solar cycle.

EPBs are depletions in the ionosphere in post-sunset regions.

- EPBs are a source of scintillation in the ionosphere. The S_4 scintillation index is critical in understanding how impactful they are to communications.
- The Rayleigh-Taylor instability (RTI) is an accepted mechanism for the growth of EPBs.
- The RTI alone cannot explain the occurrence of all EPBs. Without a known mechanism that introduces a perturbation in the bottomside F layer we cannot explain the day-to-day occurrence of EPBs.

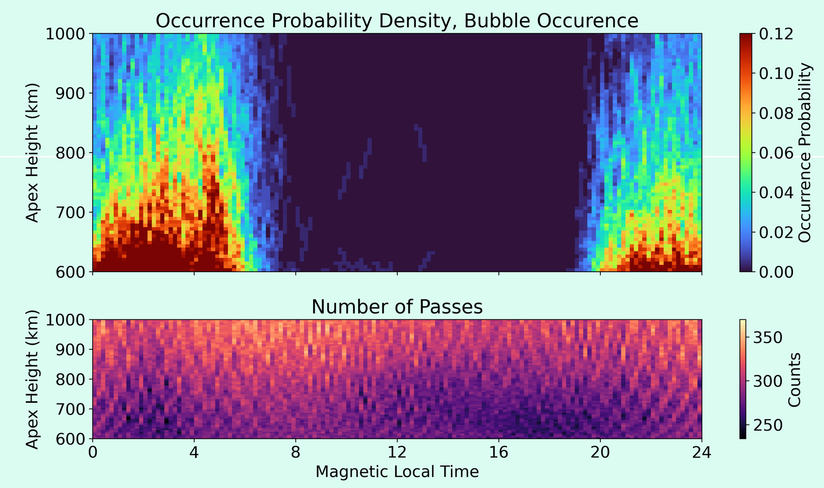
We are using the GOLD and ICON databases to investigate the relationship between PRE magnitude, bottomside ionospheric structure, and the occurrence of EPBs.



DATABASE CREATION

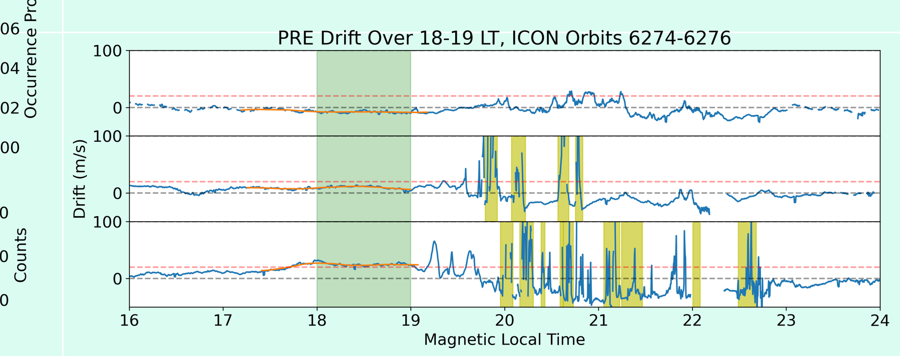
Bubble Occurrences

- We use a rolling ball algorithm to identify > 17,000 EPB events over ICON's mission
  - Depletions of at least 33% in ion density over background
  - Database created of ionospheric characteristics
- Statistics for bubble occurrence throughout ICON's mission is shown below



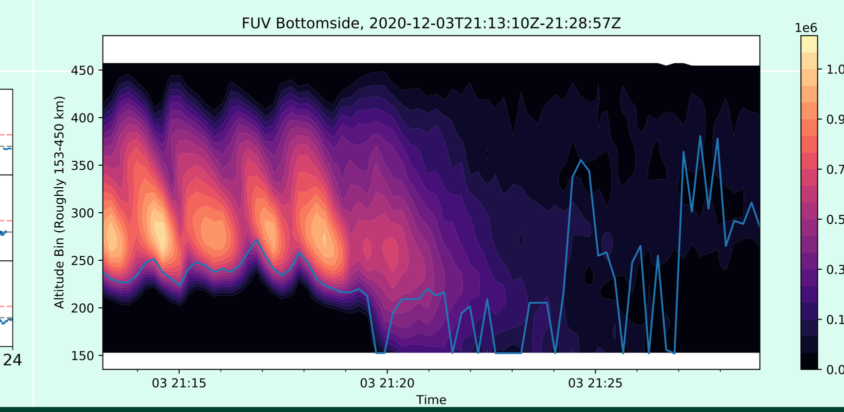
PRE Drift

- We use *in situ* IVM vertical drift data.
- Observations limited to when ICON is within ±10° MLAT, 18<MLT<19 hrs
- A 2-minute running average is then performed on the vertical drifts.
- Maximum drift in MLT window identified as PRE magnitude
- Below: three consecutive orbits. The blue line is the vertical drift, the orange line is the running average. EPBs are observed within the yellow windows (in density data not shown)



Bottomside Structure

- The FUV performs vertical scans of 135.6 nm emissions at night
- Look direction perpendicular to ICON orbit track
- Images are converted to ion density as shown below
  - Vertical structure in the bubbles can clearly be seen in the image.
  - The blue line outlines the bottomside structure



RESULTS

GOLD

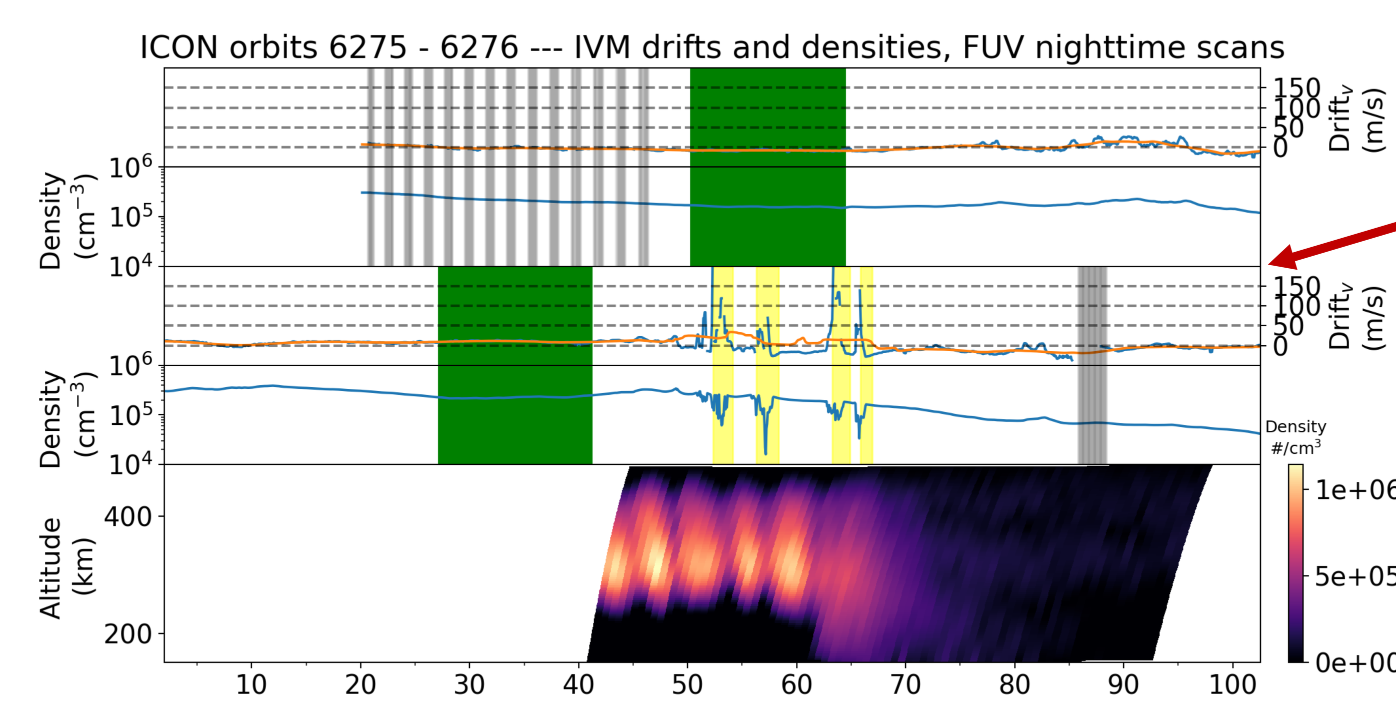
- Imager at geosynchronous orbit, 47.5° W GLON
- Provides nighttime images at 135.6 nm
  - ~20:00-24:00 UT
  - typically every 15 minutes

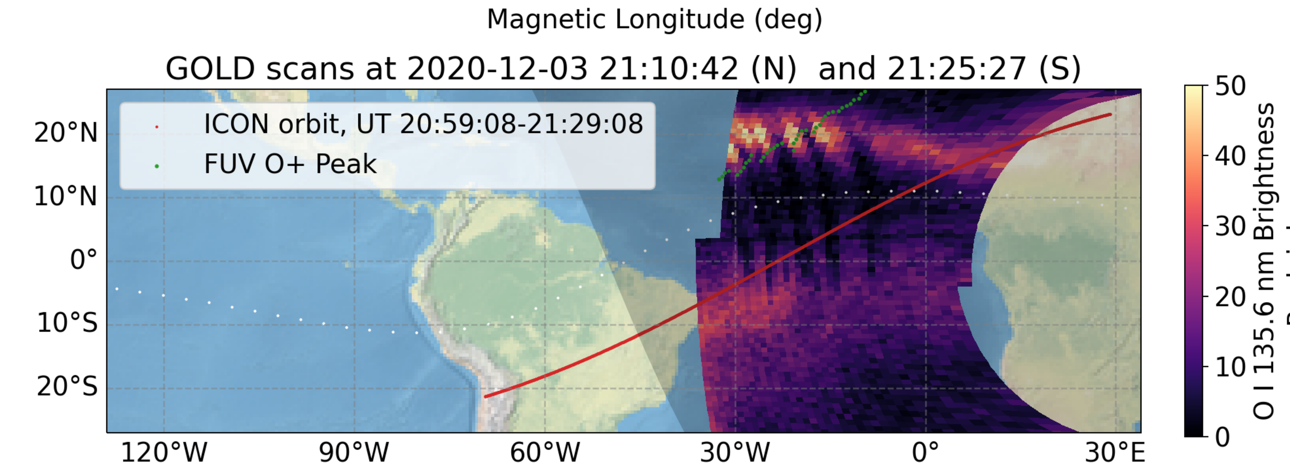
GOLD images show the large-scale horizontal structure of the bubbles as well as their temporal evolution.

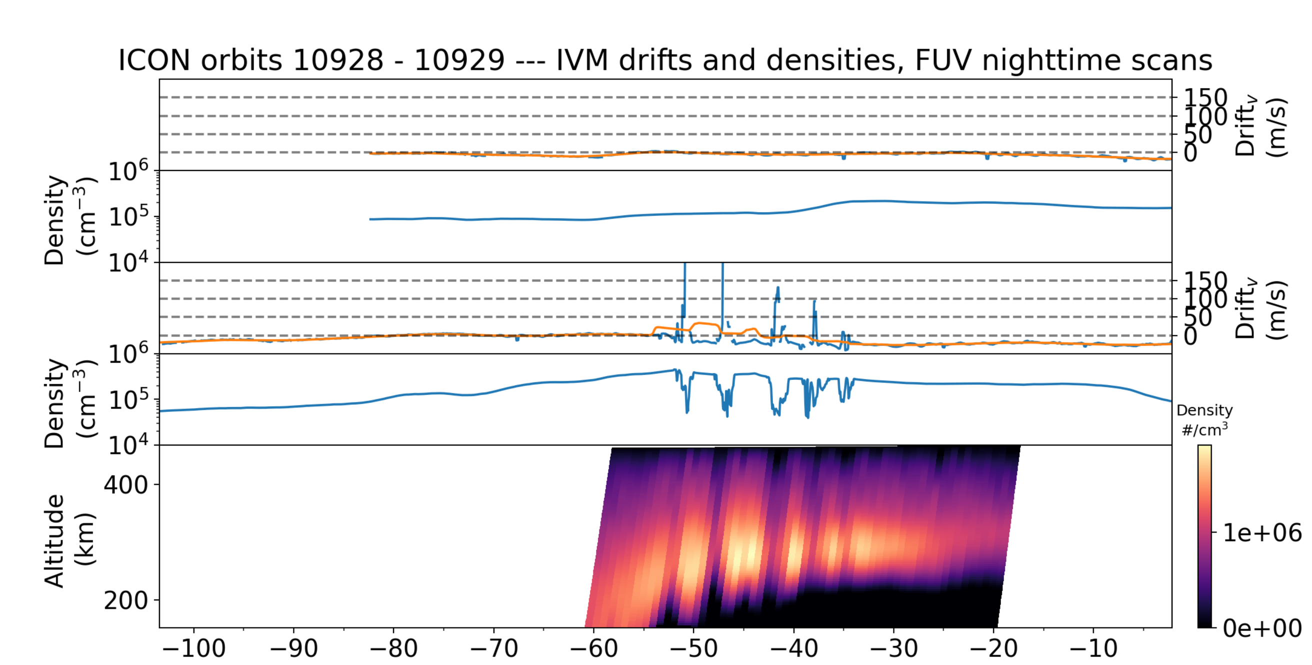
141 EPB occurrences with PRE identifications and coincident GOLD and FUV images. One event is shown to the right (this is the same event as shown above). ICON and FUV data is now plotted vs geomagnetic longitude.

- Top two panels show consecutive ICON orbits with the vertical drift plotted as in the previous figure along with ion density measurements.
- Third panel shows FUV data
- Fourth panel shows coincident GOLD images. ICON orbit track is in red, location of peak O+ density from FUV is in green. White dots show the geomagnetic equator
- Note that the plasma depletions throughout the F layer are oriented vertically in geomagnetic longitude compared with the previous FUV plot in UT.
- The first two bubbles observed by the FUV not seen in the IVM data, likely due to EPBs not reaching ICON apex height, which is higher as ICON is at latitudes farther away from the equator.

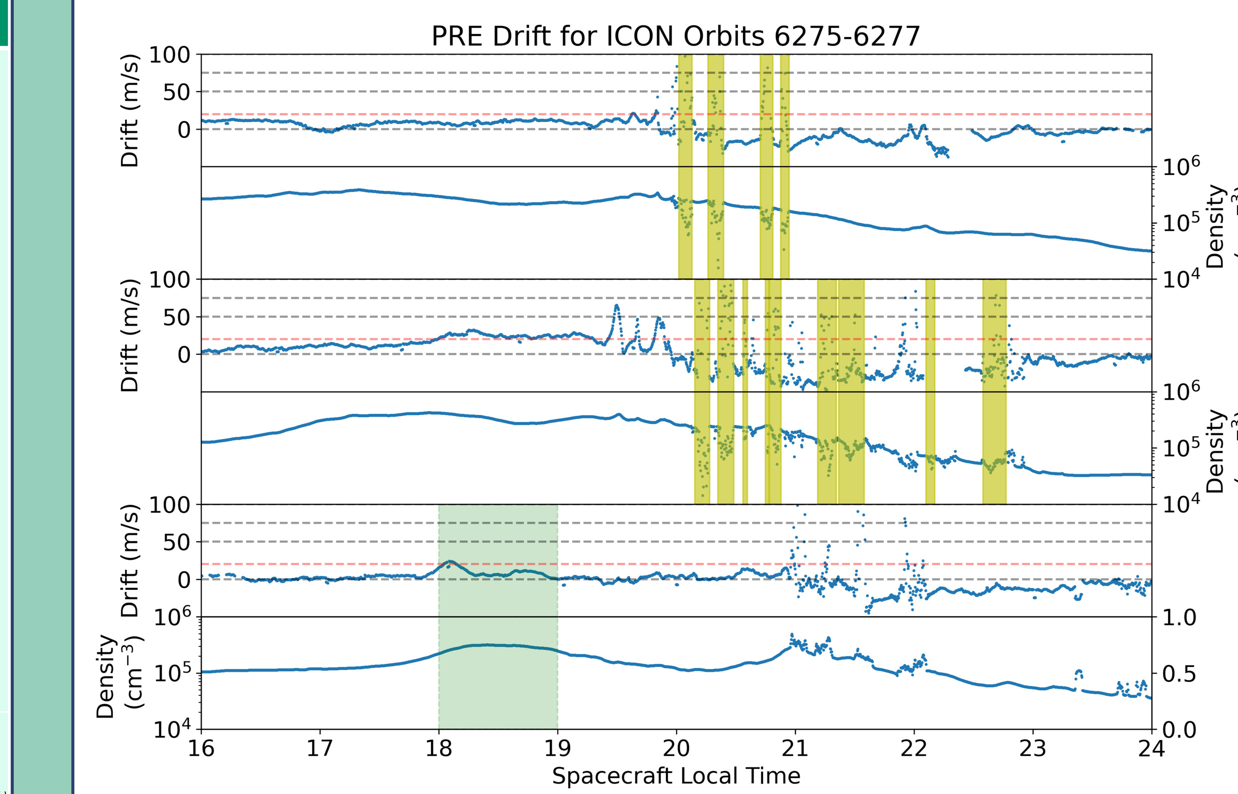
Another event is shown to the right. All EPBs here are observed in both IVM and FUV data. This is due to the EPBs reaching ICON heights as the satellite is closer to the equator.

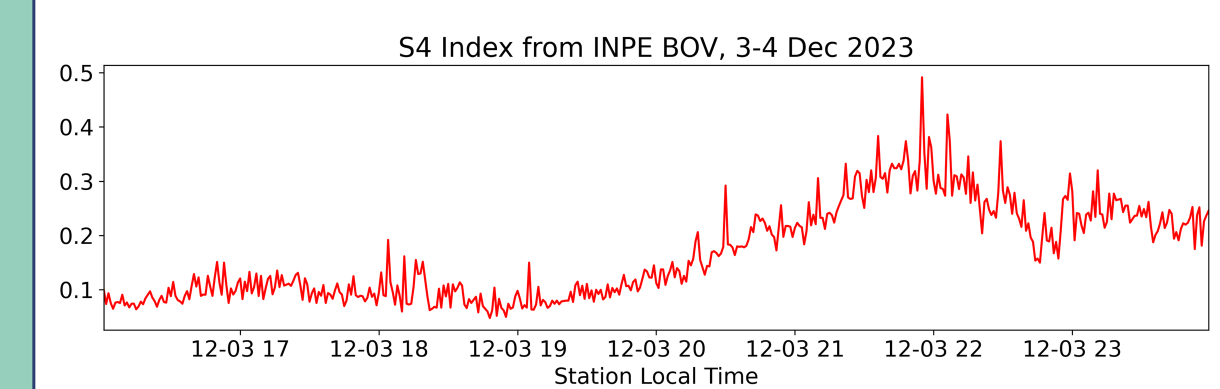






DISCUSSION





Similar to Yizengaw (2020), we find elevated S_4 indices shortly after 19 LT following low (<20 m/s) PRE drifts. Above: measurements from the same Dec 3 event as before

- Top figure shows the vertical drift over three orbits, highlighting the 18-19 LT window.
- Bottom figure shows the S_4 index from the BOV station in Boa Vista, Brazil (3 hrs behind UT) averaged over all visible GPS satellites.

With observations of low/negative PRE drift preceding bubble detection over the Atlantic sector, we reaffirm that PRE drift is not always a key factor in generating EPBs. It is assumed that another source of perturbation plays a more important role at these times.

Some suggest that one such force comes from atmospheric gravity waves (AGW) from below. Observations have been made of gravity waves during low PRE times and scintillation detection.

With these three databases we are able to further study the relationship between PRE and EPB formation. With the PRE drift database we can study its effects on scintillation. These studies can then be cross-referenced with bubble occurrences, bottomside structures, and GOLD images where data is available.

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