Comparison of Space and Ground based observations of equatorial electron density irregularities

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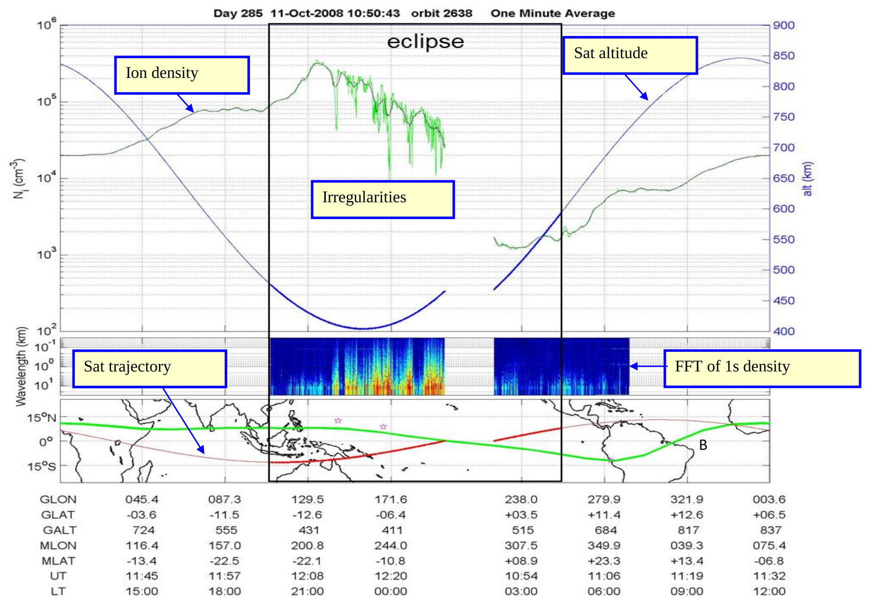
1. Introduction:

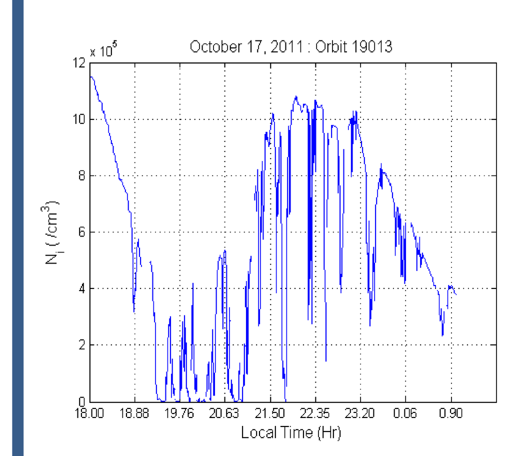
Equatorial Spread F is the most severe natural space weather phenomenon known to occur on a regular basis. It is characterized by large-scale instabilities in the post-sunset low-latitude ionosphere and the subsequent formation of medium to small scale irregularities over large regions. The responsible mechanism for Spread F, formally identified as the gravitational Rayleigh-Taylor Instability, drives large-scale electron density structures known as depletions or low density plasma "bubbles" that originate at the magnetic equator and expand poleward as the perturbation electric fields map along magnetic field lines. In this paradigm the meridional extent of the disturbances is wholly determined by the height of the bubbles at the equator. We present an investigation of the occurrence and altitudes of bubbles as a function of solar flux from in situ observations in the context of ground based scintillation measurements. We analyze electron density data from the Communication/Navigation Outage Forecasting System (C/NOFS) satellite developed by the Air Force Research Laboratory. The investigation presented here will identify the regions affected by low-latitude scintillation, enhance our ability to model radio occultation results and provide insight into the growth mechanism and longitudinal variability of equatorial spread F. We also present preliminary work on comparison between ground station scintillation observations and satellite observations of the ion density irregularities. We believe this will allow us to gain new insight into the flux-tube expansion mechanism of equatorial plasma bubbles.

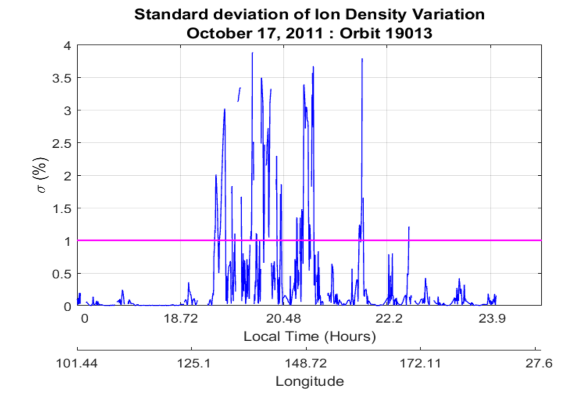
C/NOFS Mission Parameters:

- Perigee – 400 km
- Apogee – 850 km
- Inclination – 13 degrees
- Period – 97.3 minutes
- Six sensor payload measures
  - Ion density
  - Vector E-field
  - Neutral wind
  - Temperature
- Ground-based instruments
- Models (PBMOD)



2. Plasma Occurrence Probability :





We define an irregularity parameter, σ as follows:

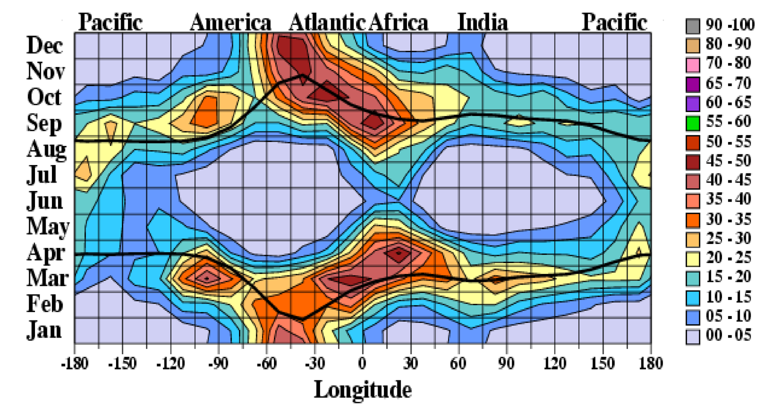
$$\sigma\ (\%) = 100\ \mathrm{x}\ \frac{\left[\frac{1}{11}\sum_{i=1}^{11}\left(\log N_i - \log N_{0i}\right)^2\right]^{1/2}}{\frac{1}{11}\sum_{i=1}^{11}\log N_{0i}}$$

The above equation represents the standard deviation of ion density variations in logarithmic scale divided by the mean of ion density in logarithmic scale.

The top figure shows the ion density measured by CNOFS on October 17, 2011. Density variations during a single orbit are shown in the figure below on the left. The figure to the right (below) shows the corresponding value of σ, the index for plasma irregularities. The magenta line represents a threshold of 1% and the structures that exceed this value correspond to post-sunset equatorial plasma bubbles. A more conservative and robust threshold for the detection of bubbles (2%) was used for the subsequent analysis shown here.

3. High Solar Activity Years

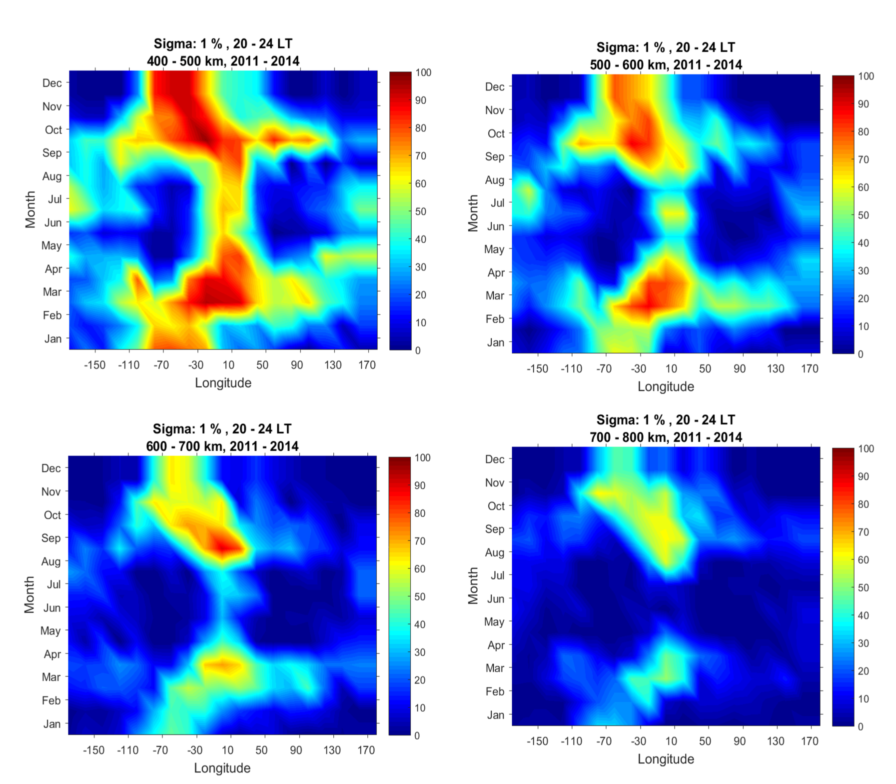
DMSP Observations Solar Cycle 23



During the high solar flux period from 1999-2002 in solar cycle 23, Gentile et al. (2006) detected bubbles using sun-synchronous DMSP satellites and mapped percent occurrence by longitude and day of year, shown above. DMSP flew at a fixed altitude of approximately 830 km. Peak occurrence rates ≥ 50% were observed during active periods in the American-African longitude sectors. Because the satellite altitude is fixed, we cannot estimate the height distribution of bubbles using DMSP. During solar minimum the lower detection rates are undoubtedly due to a combination of lower bubble occurrence and lower bubble altitudes.

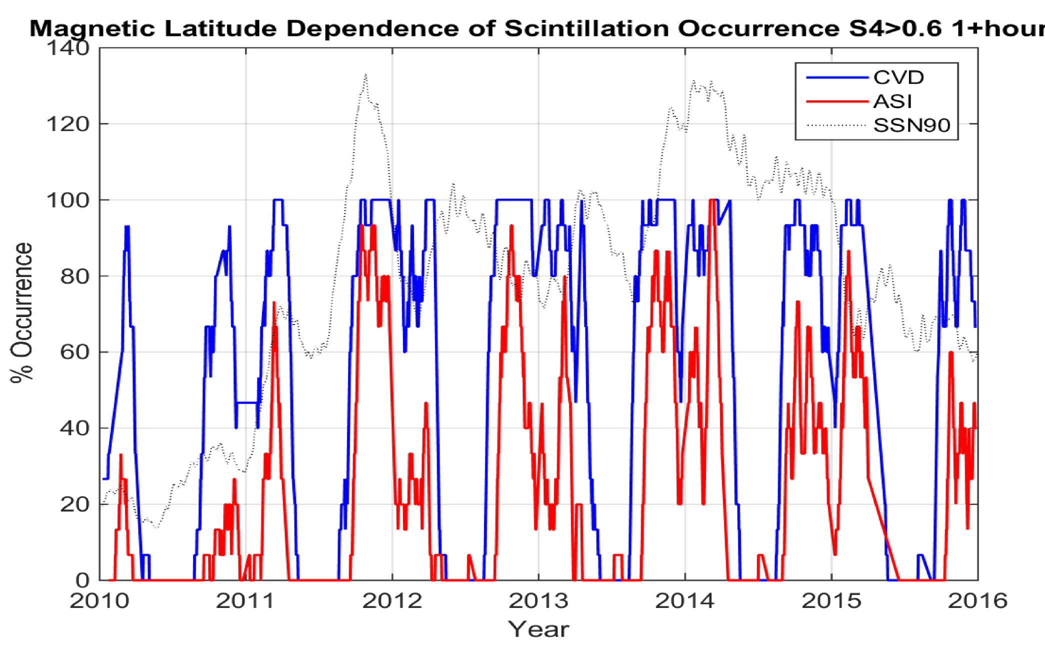
*See, e.g., Gentile et al., 2006; Huang et al., 2014;

C/NOFS PLP Observations Solar Cycle 24

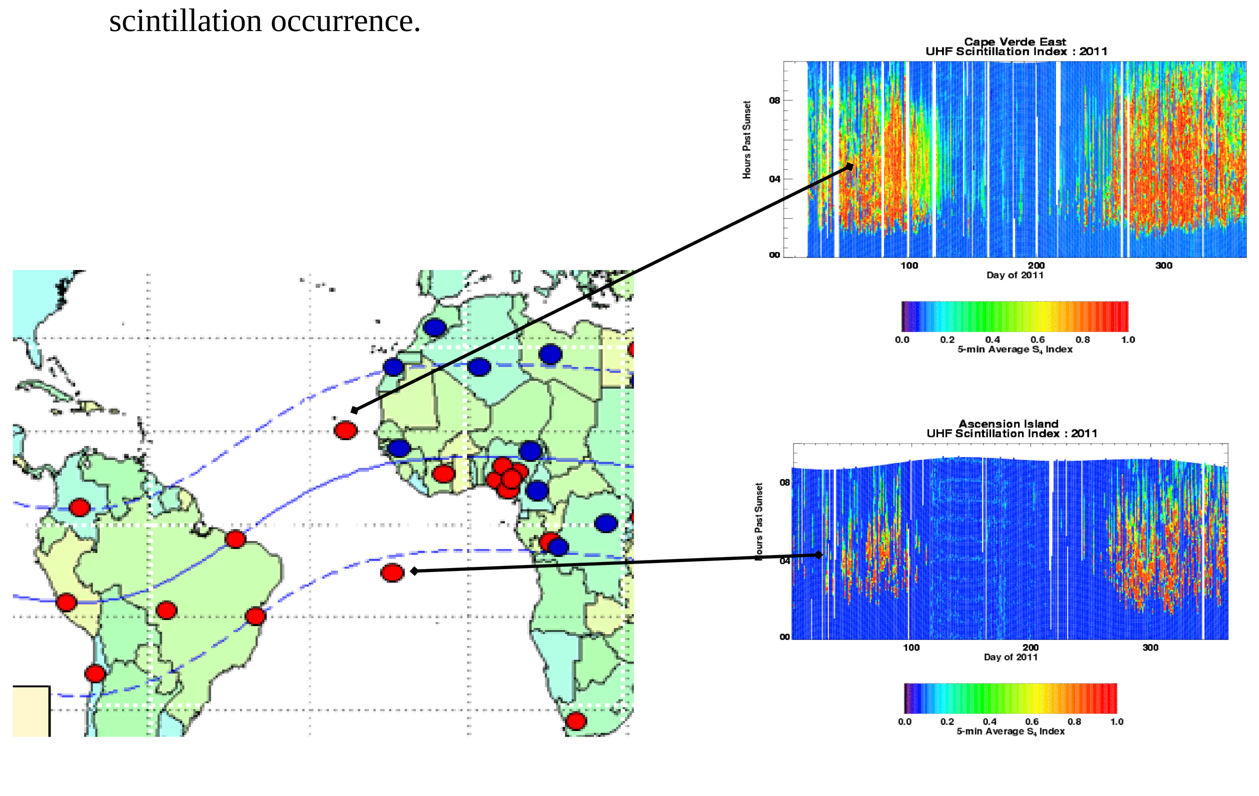


The occurrence probability of equatorial ionospheric irregularities as a function of longitude and day-of-year for four different ranges of apex altitude is shown above. σ > 1 % in the time range of 20 – 24 LT during 2011 – 2014. Occurrence probability is high in equinoctial months and low around June solstice. Both occurrence probability and altitude extent are maximum in the longitude sector from 280°E (-80°) to 30°E as has been reported in other studies*. Peak occurrence rates above 700 km are ≥ 50% , similar as observed by DMSP in the previous solar cycle maximum.

4. Ground-based Scintillation Observations



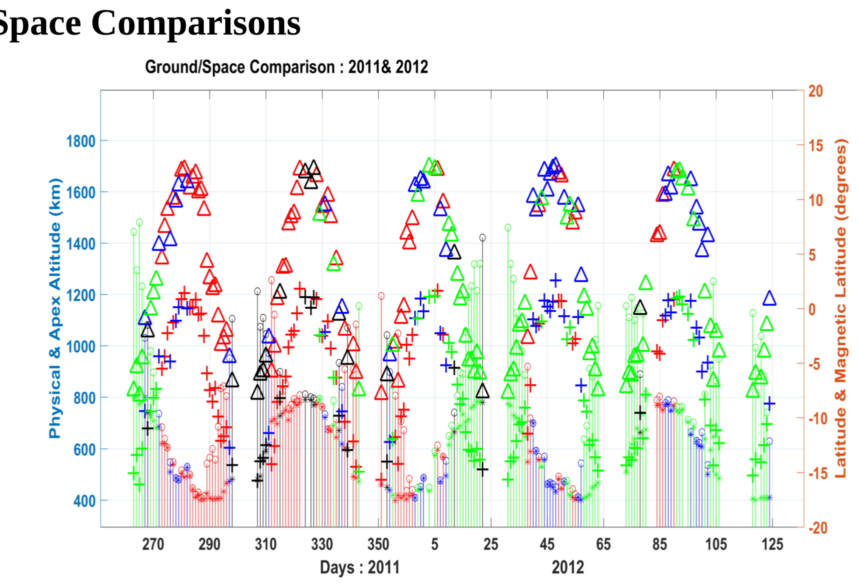
- The C/NOFS data indicates that the ionospheric irregularities occurrence rate ≥ 50 % in the apex-altitude range 700-800 km in solar cycle 24 similar as the DMSP observations in solar cycle 23. But ground-based VHF measurements show that scintillation occurrence at Ascension Island (-17° Mlat) reached 50-80% during the peak seasons between 2011-2015. Nightly occurrence rates for S4 > 0.6 for at least one hour are shown in the plot to the right for both Ascension and Cape Verde, where peak occurrence rates were essentially 100%.
- Assuming bubble height determines meridional extent, structures must rise to over 1000 km to reach Ascension, but only about 400 km to reach Cape Verde.
- The space-based occurrence rates are lower than the ground-based scintillation occurrence.



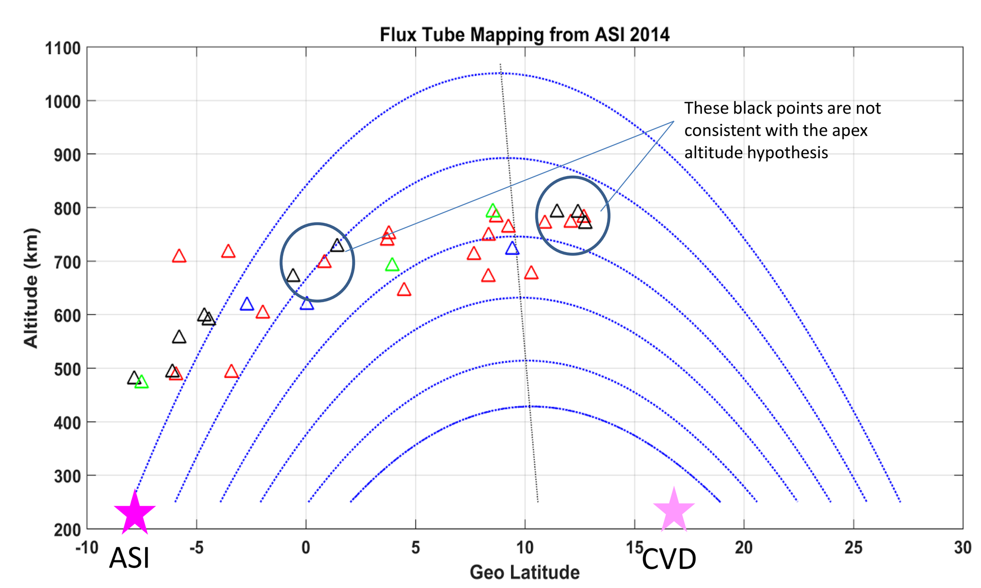
5. Current Focus: Ground and Space Comparisons

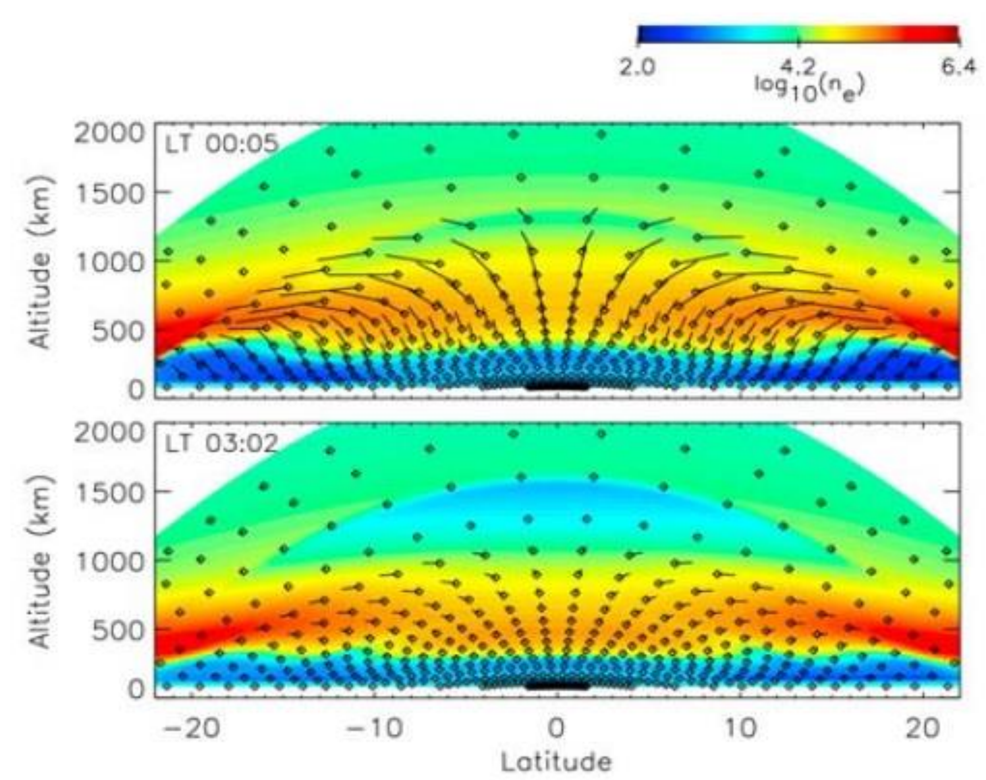
The points plotted to the right show the nightly relationship between the space and ground observations at Ascension Island. Parameters of interest include geo and apex altitude, geo and magnetic latitude.

Color Key	S4 > 0.6	σ > 1%
Red	YES	YES
Black	YES	NO
Blue	NO	YES
Green	NO	NO



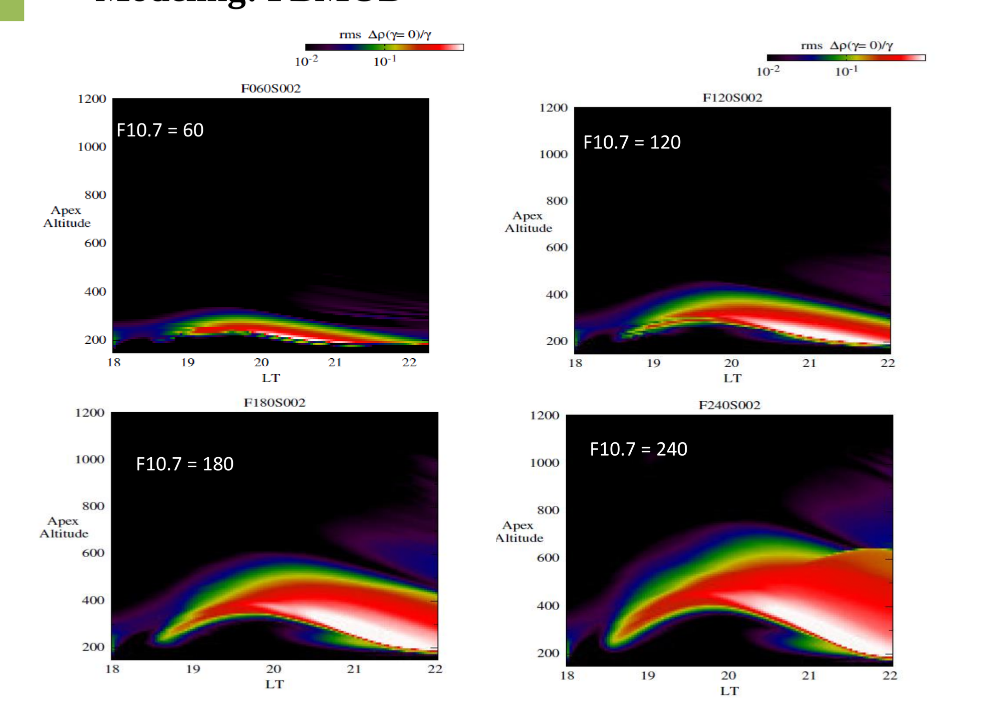
This example (image in the left) shows the distribution of points from 2011 days 307-343 above. All the points are consistent with the apex altitude hypothesis except for five black points in the circles above. These points denote scintillation observed on the ground but not in space, but the irregularities should be present there if the bubble reached 1000 km ape altitude. These anomalies ca be due to 'fossilized bubble (image in the right) a discussed by Krall,et. al Further analysis will b performed.





*see Krall, et. al., 2010;

6. Modeling: PBMOD



The PBMOD model is a system of *P*hysic *B*ased *MOD*els that describes the three-dimensional time-dependent evolution of the equatorial ionosphere on several different spatial scales: globally it provides the plasma density and composition at altitudes between 90 and 2000 km; at finer scales it describes the development of fluid plasma turbulence within this region and the resulting radio scintillation (Retterer, 2010).

PBMOD results showing the evolution of the relative density perturbation, Δρ/ρ, in apex altitude as a function of time and solar flux. Bubble height clearly increases with increasing solar flux qualitatively consistent with the PLP observations. During the period in which the data were collected average F10.7 ranged from 60 to 160.

7. Conclusions and Future Work

- The C/NOFS bubble occurrence statistics are consistent with previous work related to this topic (Huang, et al. 2012).
- The occurrence of plasma irregularities peaks in the longitude sector: 280° E to 30° E.
- Results from observations and modeling confirm the increase of apex altitude as solar flux increases; quantitative comparisons will require improved modeling.
- The apex altitude of the F-region at Ascension is over 1000 km suggesting that more bubbles should reach these altitudes.
- Currently we are comparing the space-based data with ground-observations at two sites to determine the distribution of irregularities and scintillation and consistency with the apex altitude hypothesis.
- More analysis is needed before reaching unambiguous conclusions.

References:

Huang, C.-S., O. de La Beaujardiere, P. A. Roddy, D. E. Hunton, J. Y. Liu, and S. P. Chen (2014), Occurrence probability and amplitude of equatorial ionospheric irregularities associated with plasma bubbles during low and moderate solar activities (2008–2012), J. Geophys. Res. Space Physics, 119, 1186–1199, doi:10.1002/2013JA019212.

Gentile, L. C., W. J. Burke, and F. J. Rich (2006), A climatology of equatorial plasma bubbles from DMSP 1989–2004, Radio Sci., 41, RS5S21, doi:10.1029/2005RS003340.

Retterer, J. M. (2010), Forecasting low-latitude radio scintillation with 3-D ionospheric plume models: 1. Plume model, J. Geophys. Res., 115, A03306, doi:10.1029/2008JA013839.

Roddy, P. A., D. E. Hunton, J.O. Ballenthin, and K. M. Groves (2010), Correlation of in situ measurements of plasma irregularities with ground-based scintillation observations , J. Geophys. Res., 115, A06303, doi:10.1029/2010JA015288.

Krall, J., J. D. Huba, S. L. Ossakow, and G. Joyce (2010), Why do equatorial ionospheric bubbles stop rising? Geophys. Res. Lett., 37, L09105, doi:10.1029/2010GL043128.

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