The Influence of the background ionospheric density on the Irregularity parameter characterizing the Equatorial Ionospheric Irregularities

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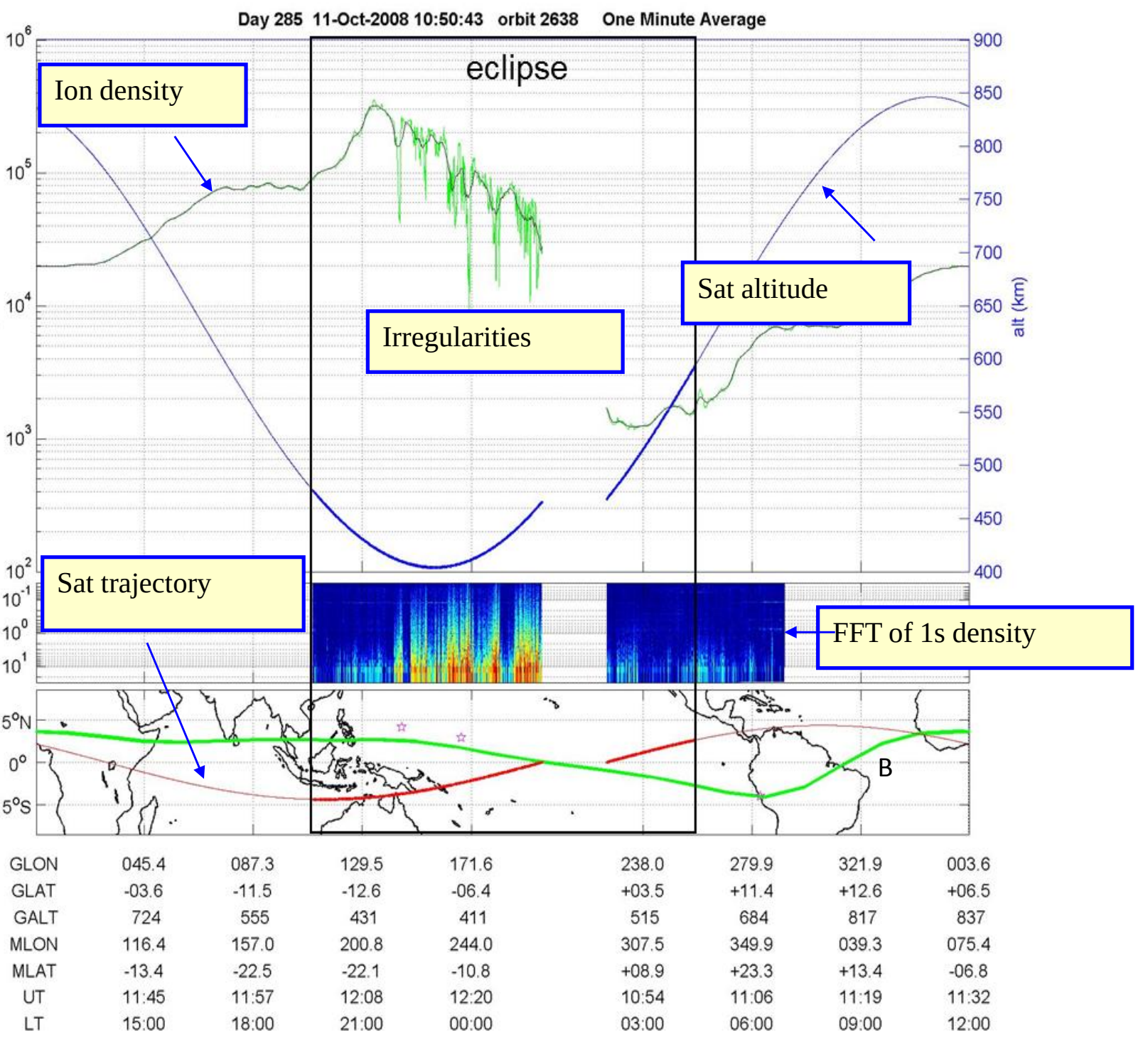
1.

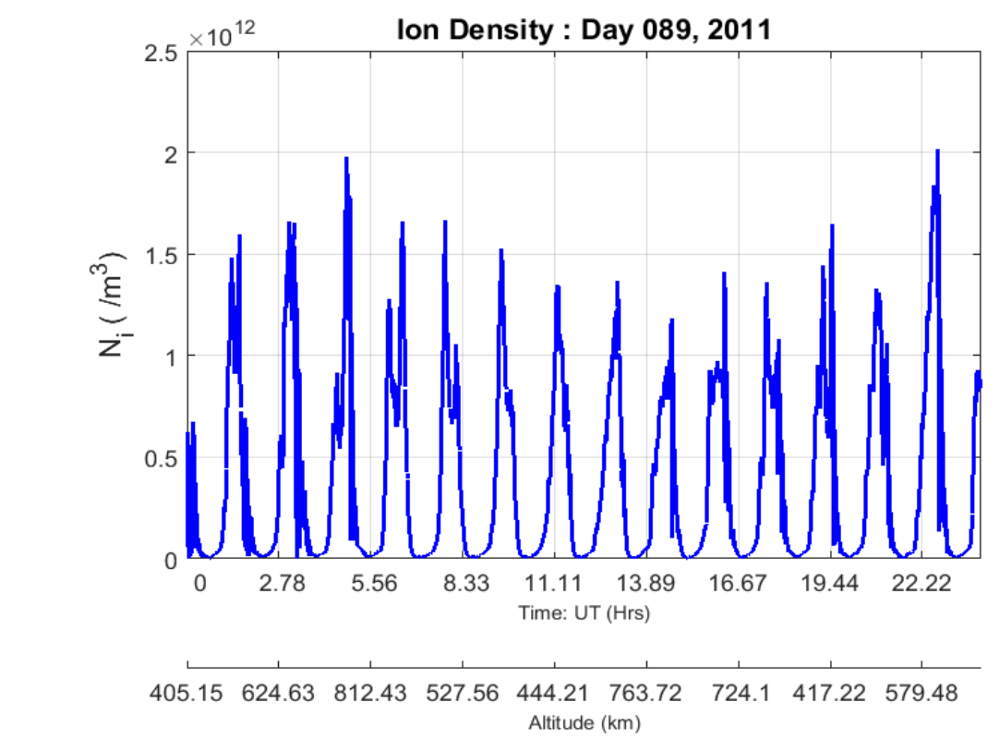
Introduction: The low-latitude ionosphere is characterized by large-scale instabilities in the post-sunset hours due to the distinct geometry of the earth's magnetic field lines at the equator. The magnetic field lines are horizontal at the equator contributing to the high vertical drift velocity of the plasma bubbles growing from the bottomside of the ionospheric F-region. The phenomenon, commonly known as equatorial spread F, is an important problem in aeronomy as it can cause radio wave scintillation effects representing the most critical impacts of space weather on man-made technologies, such as satellite communications and global navigation satellite systems (GNSS). Here, we seek to characterize the spatial distribution of equatorial ionospheric irregularities and try to understand the dependence of the peak heights of the irregularities at the magnetic equator on solar flux by analyzing in-situ observations made on-board the Communications/Navigations Outage Forecasting System (C/NOFS) satellite mission. Since the irregularities map along the magnetic field lines, their height above the magnetic equator determines the spatial extent of the irregularities in latitude allowing us to identify regions affected by space weather impacts. In this investigation, we seek to understand the possible influence of the background ionospheric density on the irregularity parameter characterizing the equatorial ionospheric irregularities. This is a critical examination of the parameter to confirm our results on the peak-height distributions of the irregularities at the magnetic equator and also several other studies which have employed similar definition of the irregularity parameter

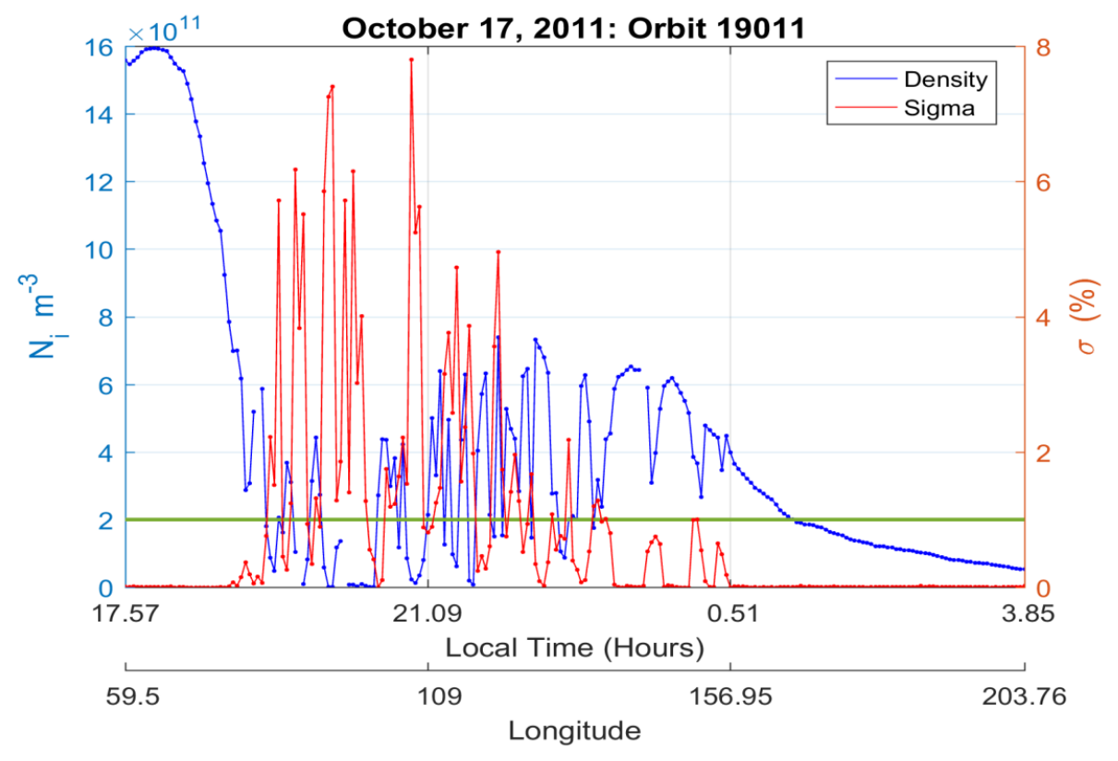
C/NOFS Mission Parameters:

- 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. Equatorial Plasma Irregularities (EPI)

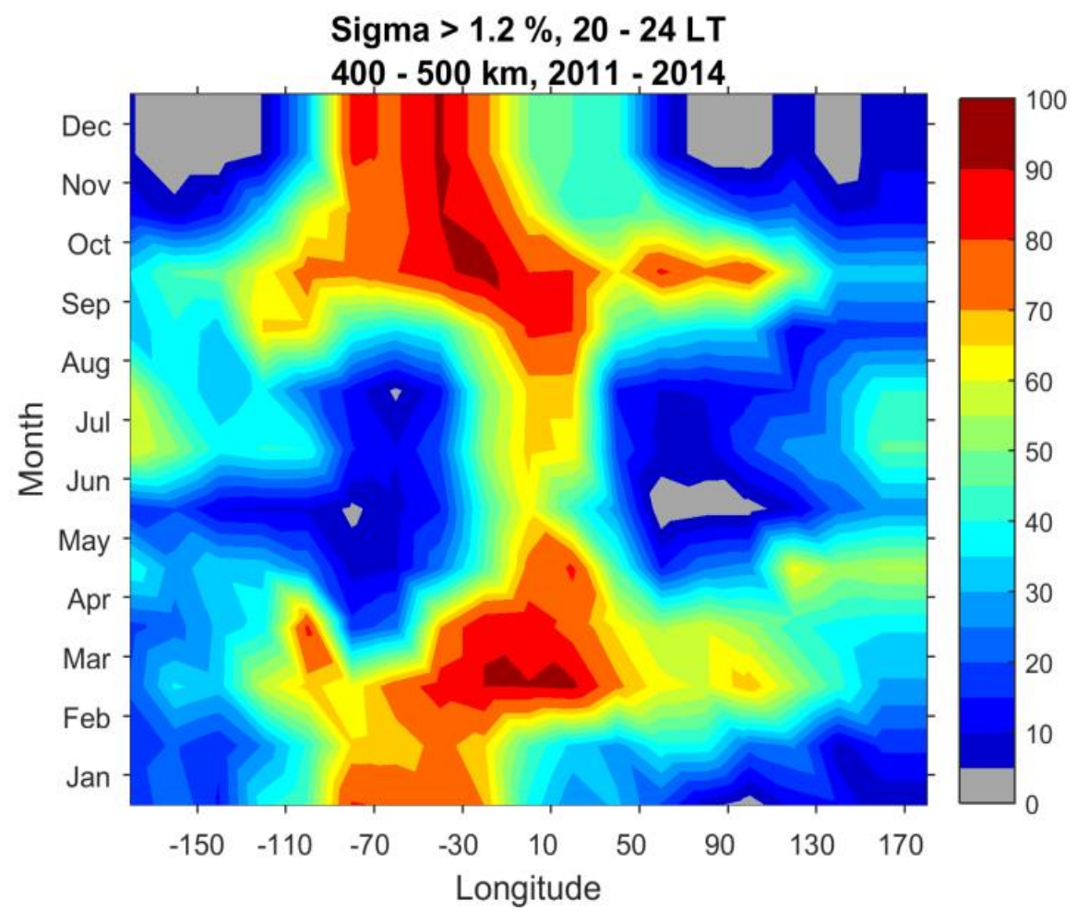


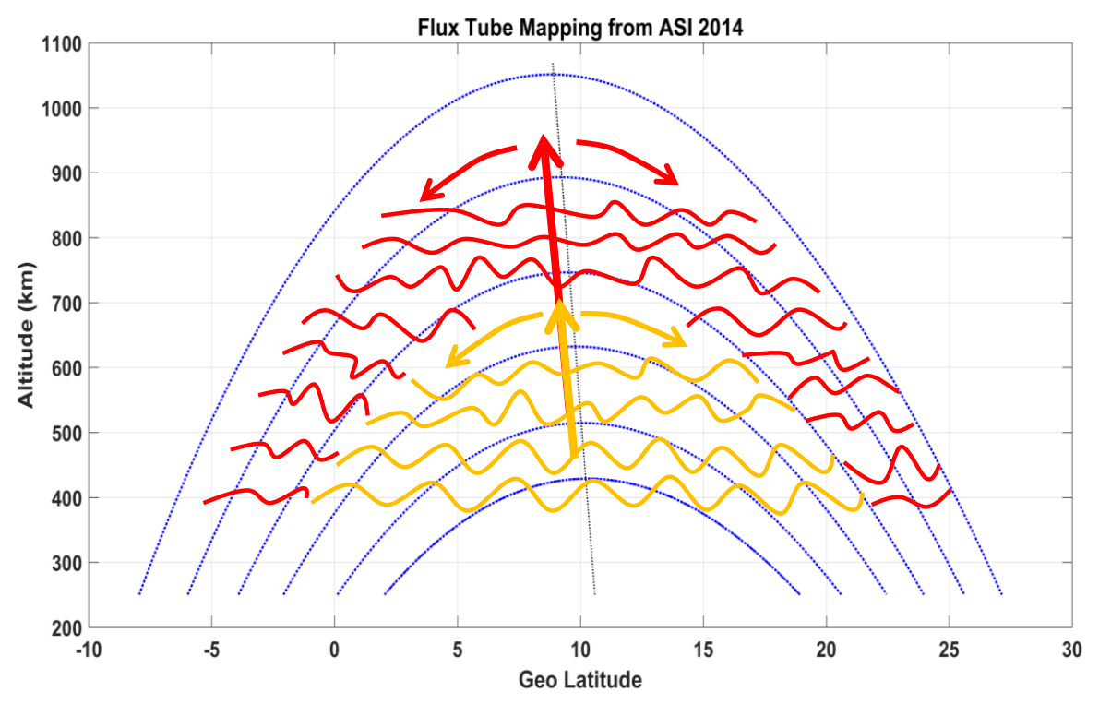


We define an irregularity parameter, σ as :

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

- The above equation represents the standard deviation of ion density variations in logarithmic scale divided by the mean of ion density in logarithmic scale.
- Consistent with other studies, the occurrence probability is generally high in equinoctial months and low around June solstice, maximizes in the longitude sector from 280°E to 10°E.
- The mapping of large-scale electric fields along magnetic field lines suggests that the meridional extent of spread F structures can be estimated from the altitude distribution of equatorial bubbles.





3. Simulation I : Estimation of Peak EPI Apex-Altitude Distributions

- The True Peak EPI Apex-Altitude Distribution can be estimated from the Observed Apex-Altitude Distribution based on the physical reality that all higher altitude bubbles at the magnetic equator pass through the lower altitudes beneath them. Mathematically,

$$M_{zo} = \int_{z_o}^{\infty} N(z)\,dz\ ,$$

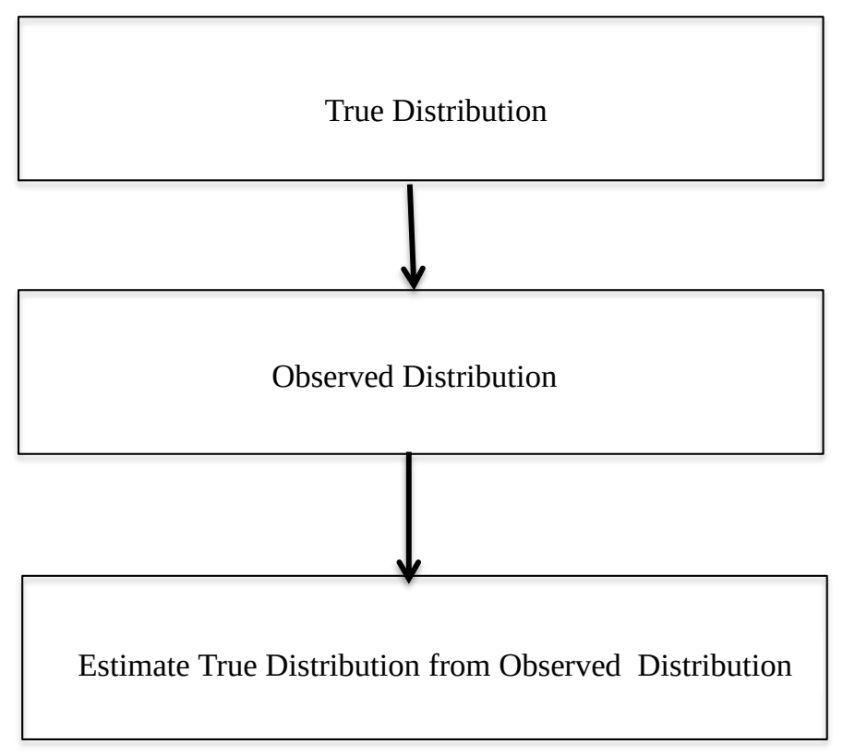
where, M_{zo} is observed distribution,

$N(z)$ is true distribution.

For discrete data,

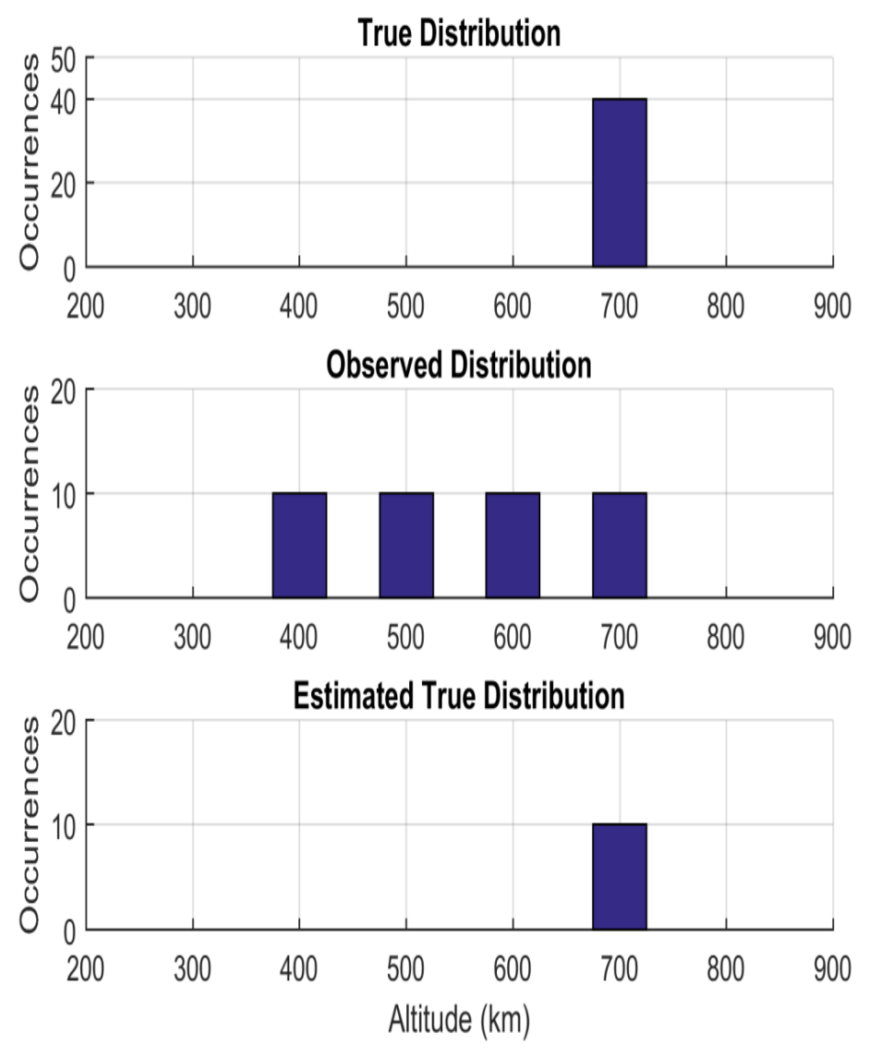
$$M_{zo} = \sum_{z_o}^{\infty} N(z)$$

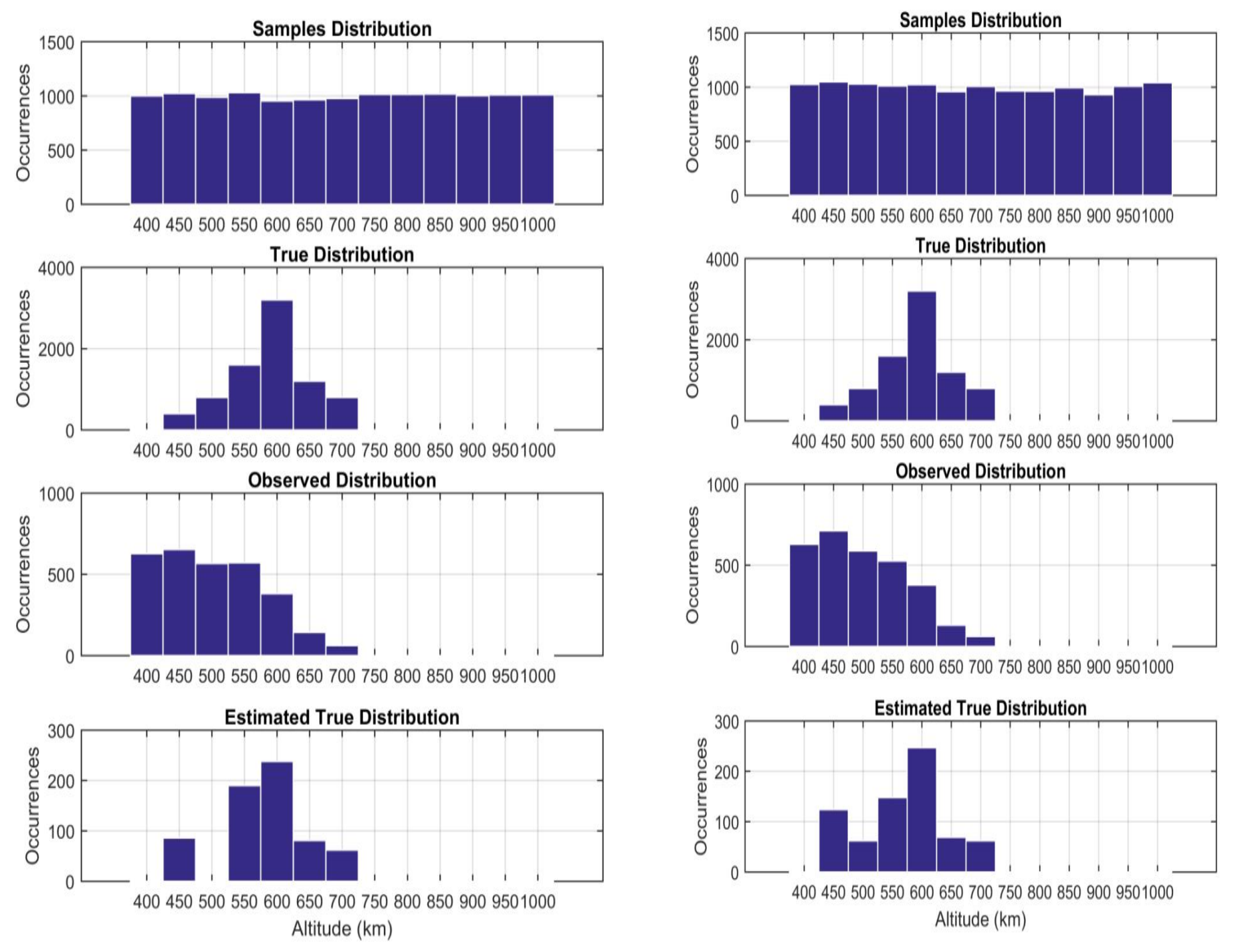
- The flow-chart and simulation (top panel) illustrate a simple example of the estimation of a true distribution from the 'Observed Distribution'. The estimated true distribution resembles the pre-defined 'monochromatic' true distribution .
- Two runs (bottom panel) of another simulation to estimate the true distribution of bubble activity from an initially assumed true distribution. The estimated true distribution is 'similar' to the true distribution .


True Distribution

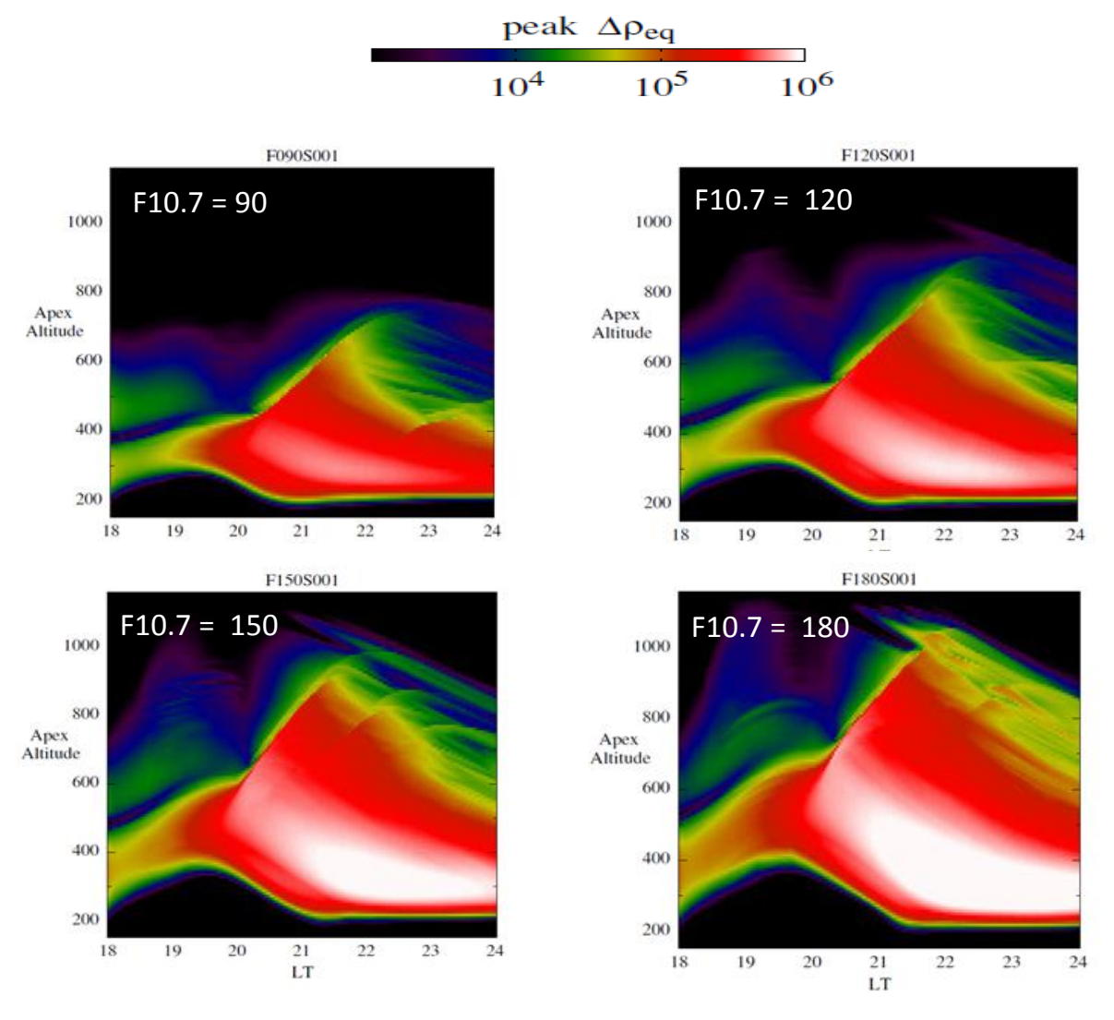
Observed Distribution

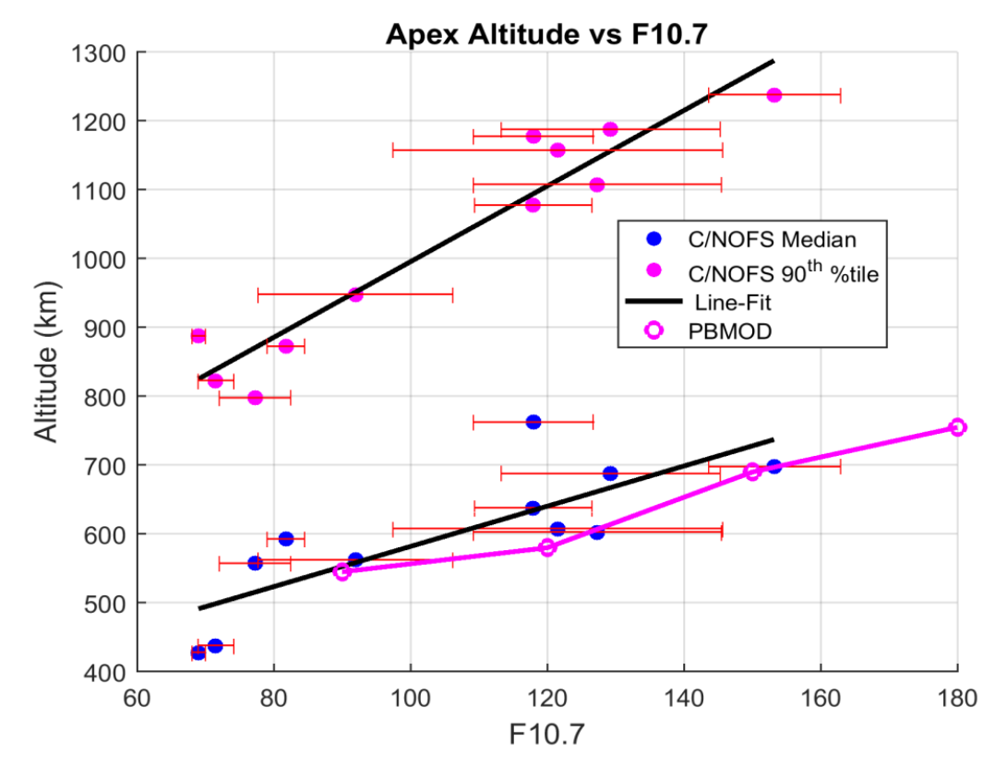
Estimate True Distribution from Observed Distribution



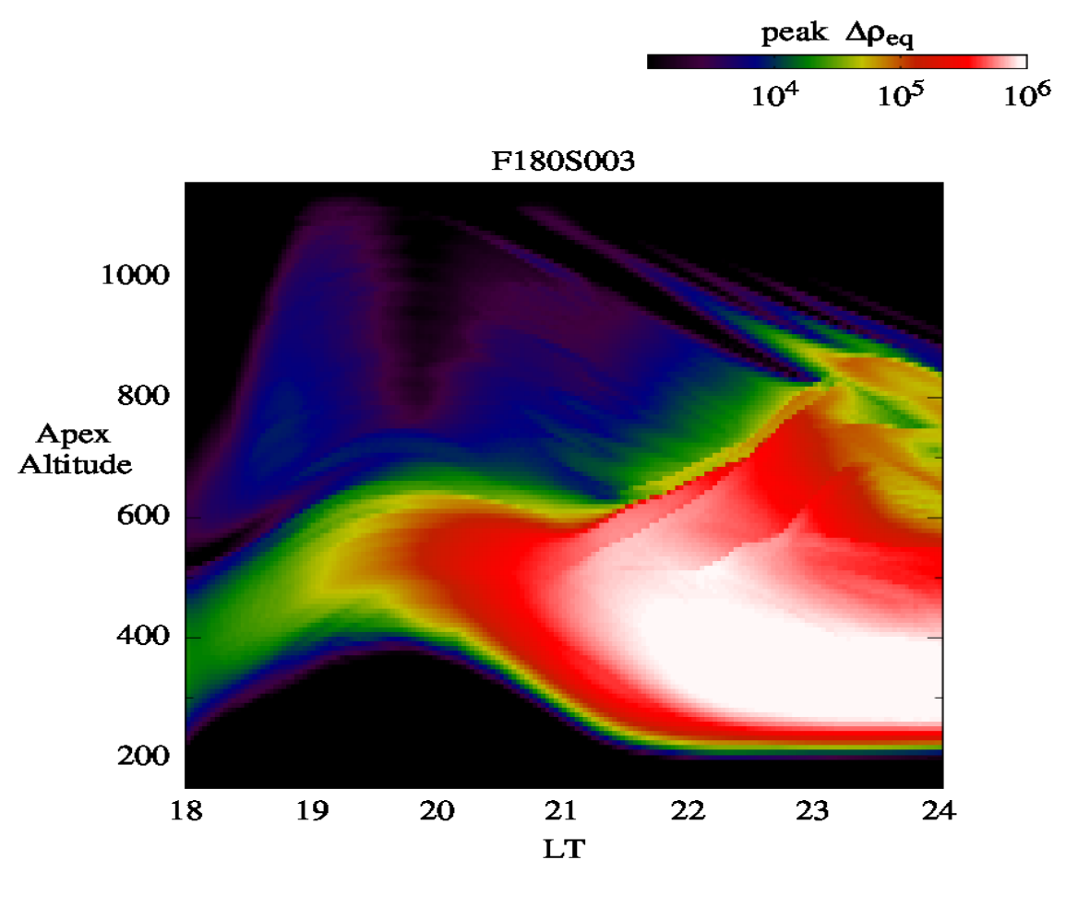


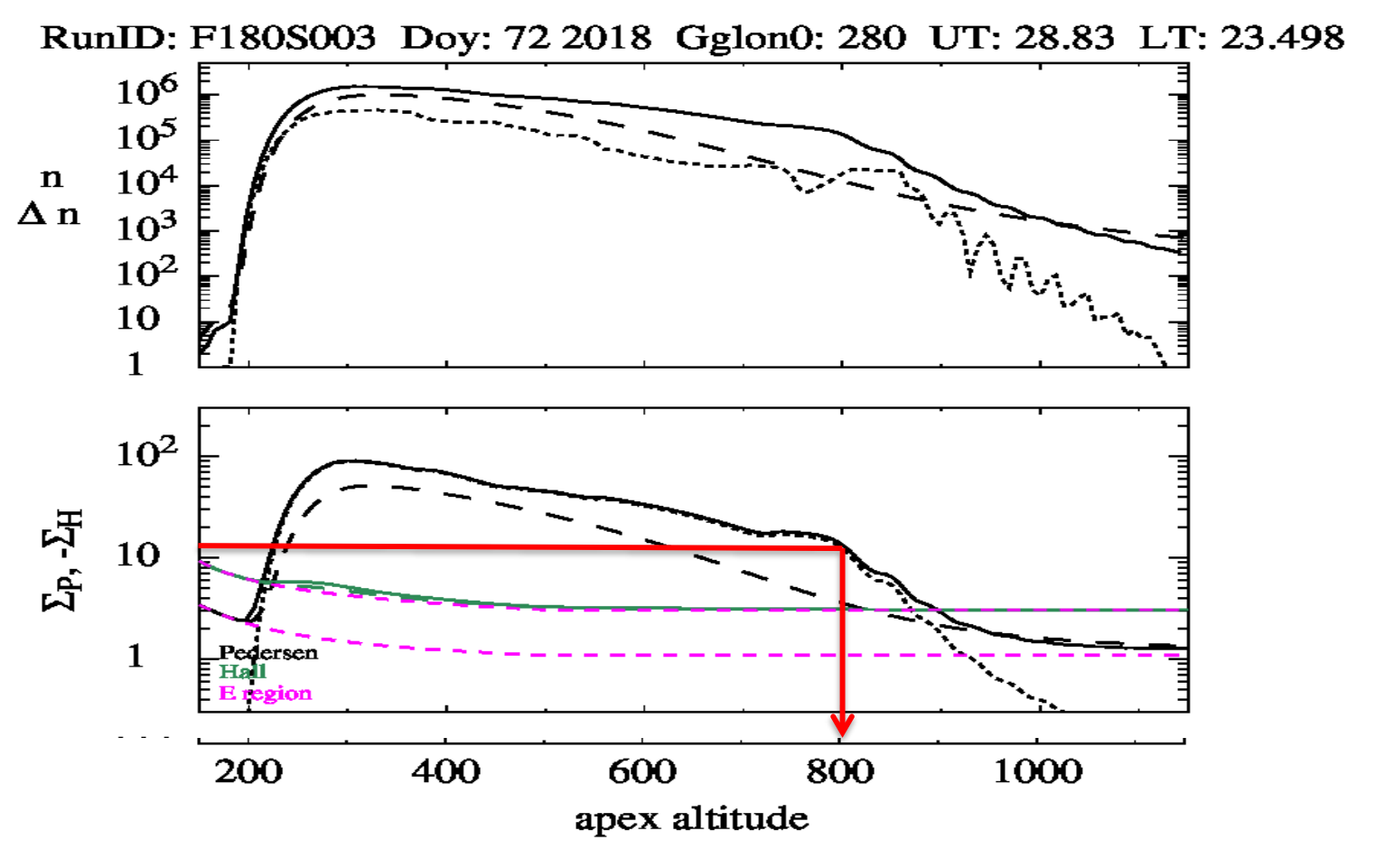
4. Peak-Altitude : Modeling and Data Analysis Results



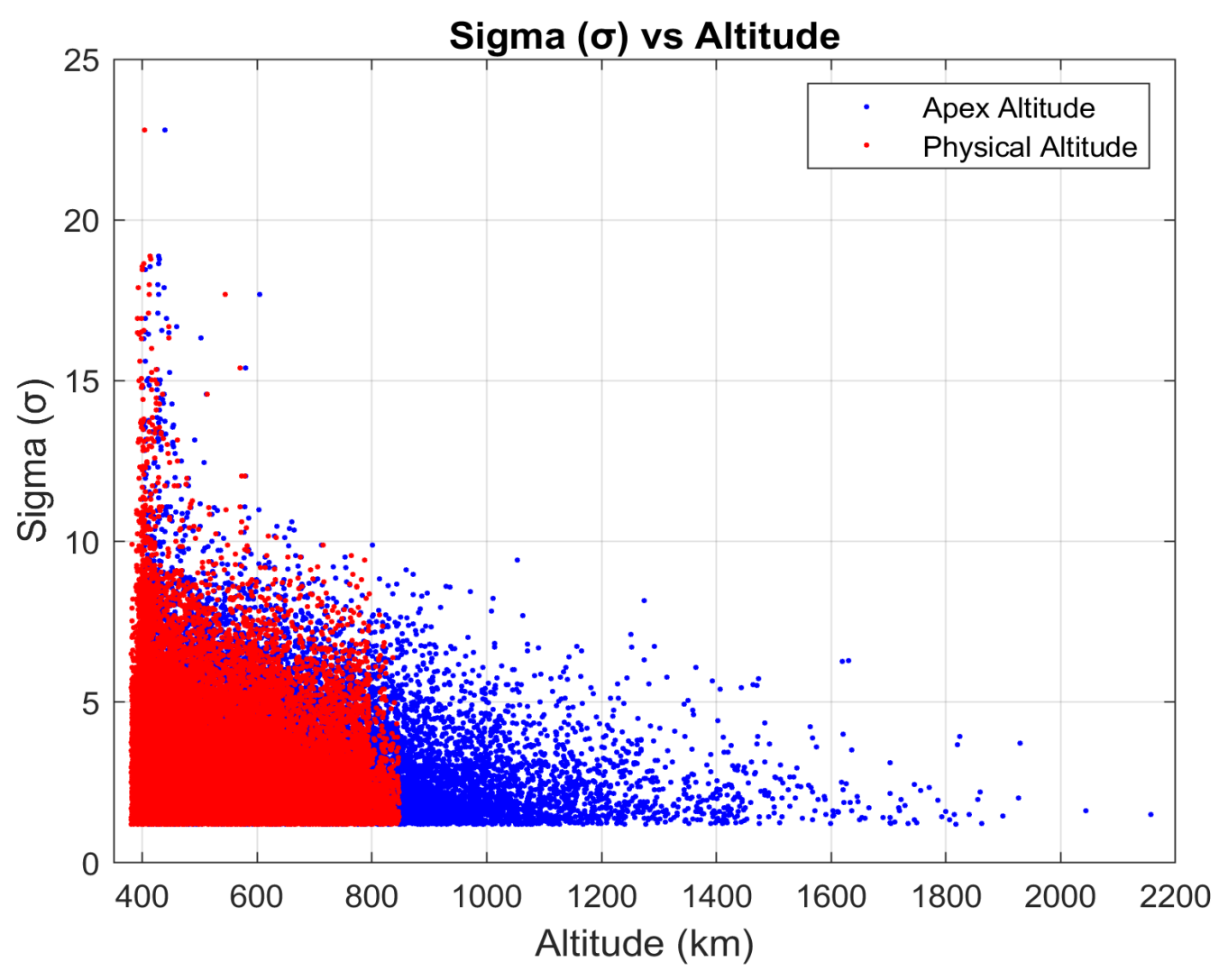


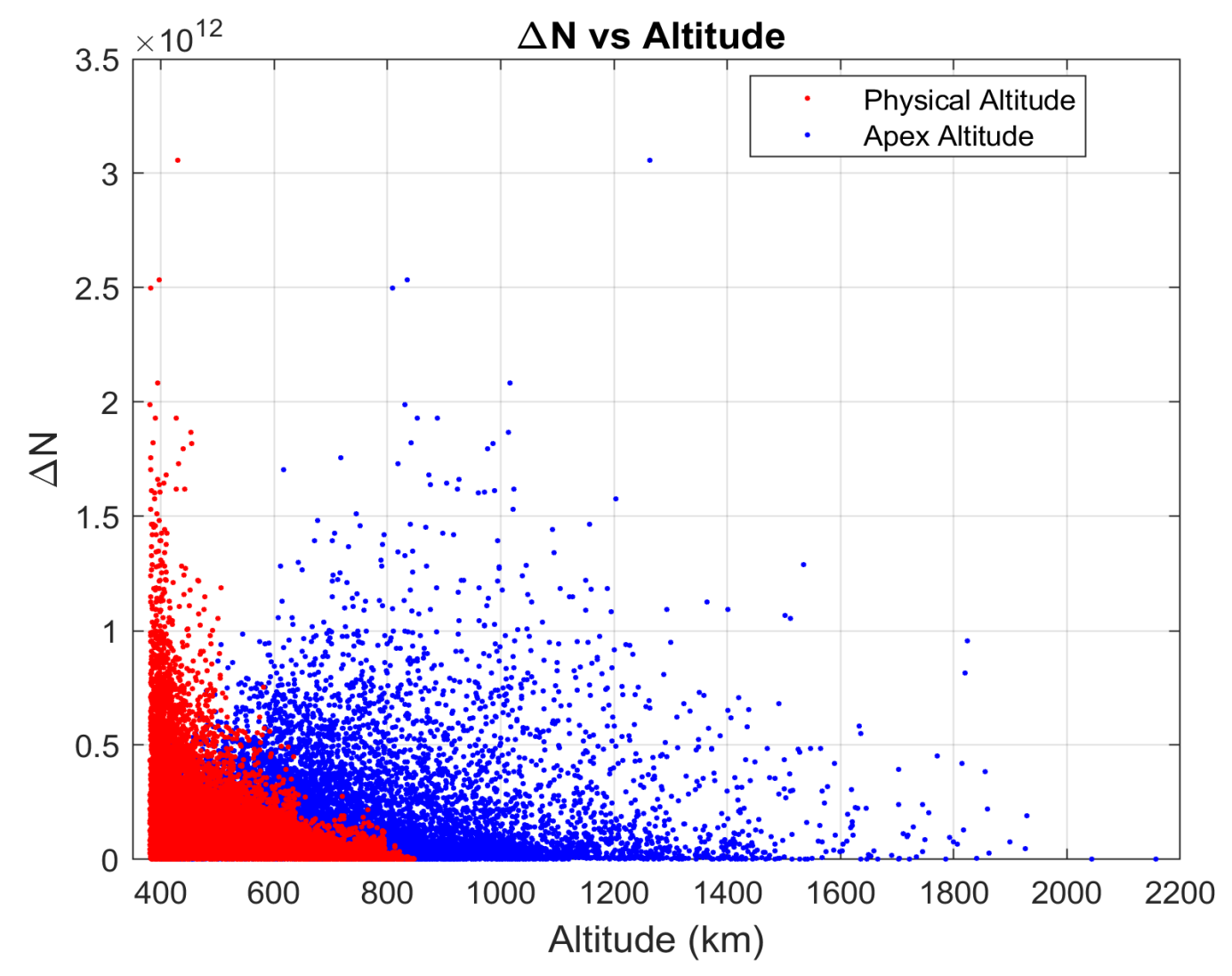
- The images (top panel) show a history of the peak magnitude of the deviation of density in the equatorial plane across the zonal direction as a function of apex altitude and local time in the PBMOD (Physics Based MODels) results. The equatorial plasma bubbles rise to higher apex altitudes with increasing solar flux.
- The evolution of the median peak apex altitudes from low solar activity year 2008 to high solar activity year 2014 (middle panel). The line fit shows that the irregularities rise from about 491 km at solar minimum to 737 km during solar maximum. The PBMOD results for the variation of the plasma bubble apex altitude with solar flux matches closely with that of the median values of the apex-altitude distributions from C/NOFS observations.
- In the profile of Pedersen conductivity (bottom panel) at the time of maximum extent of the plume, the height where the conductance equals the conductance initially just below the F layer (12 mhos) is about 800 km, close to the maximum height of the plume containing the plasma initially from that place.

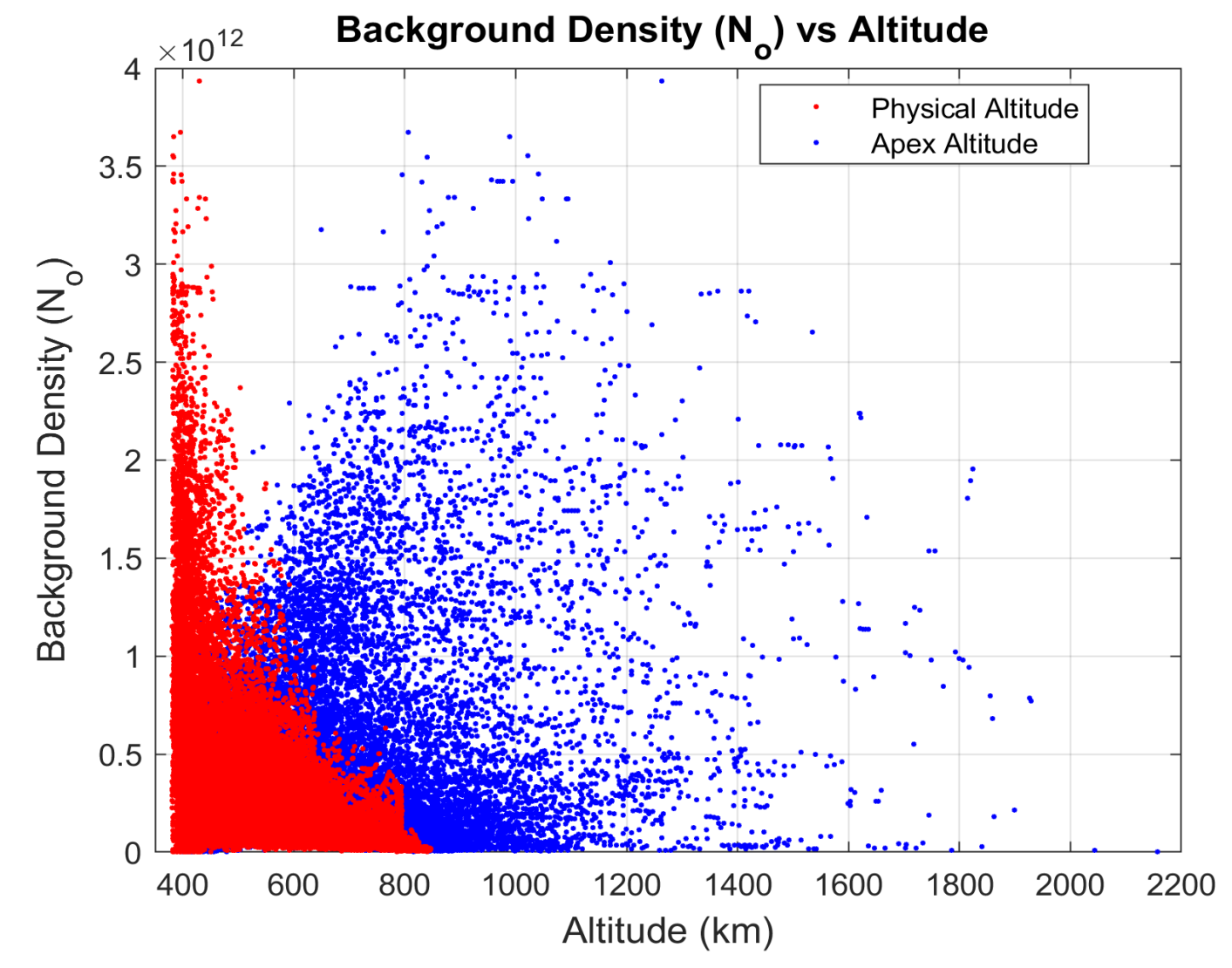


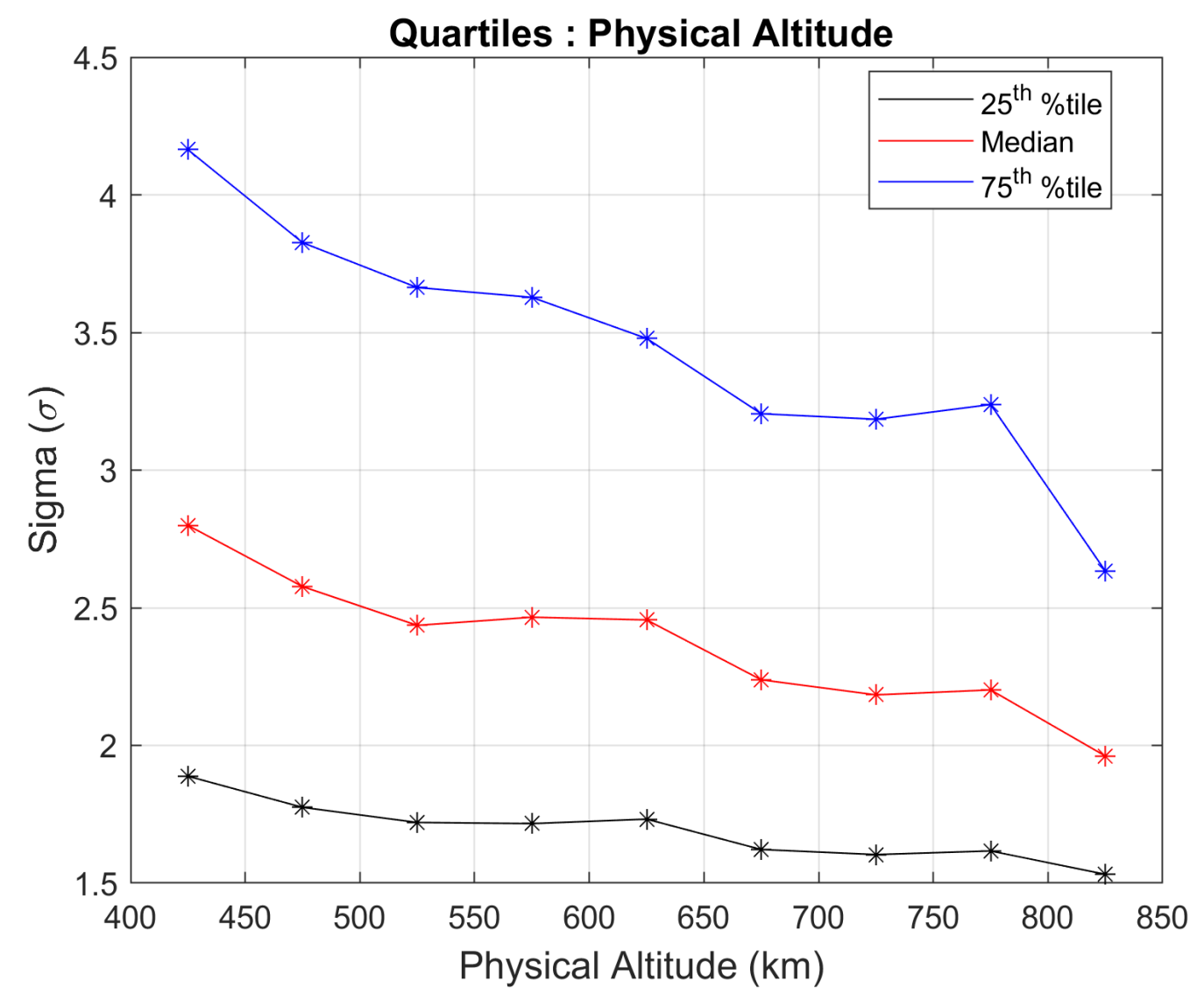


5. Altitude Dependence of the Irregularity Parameter - I



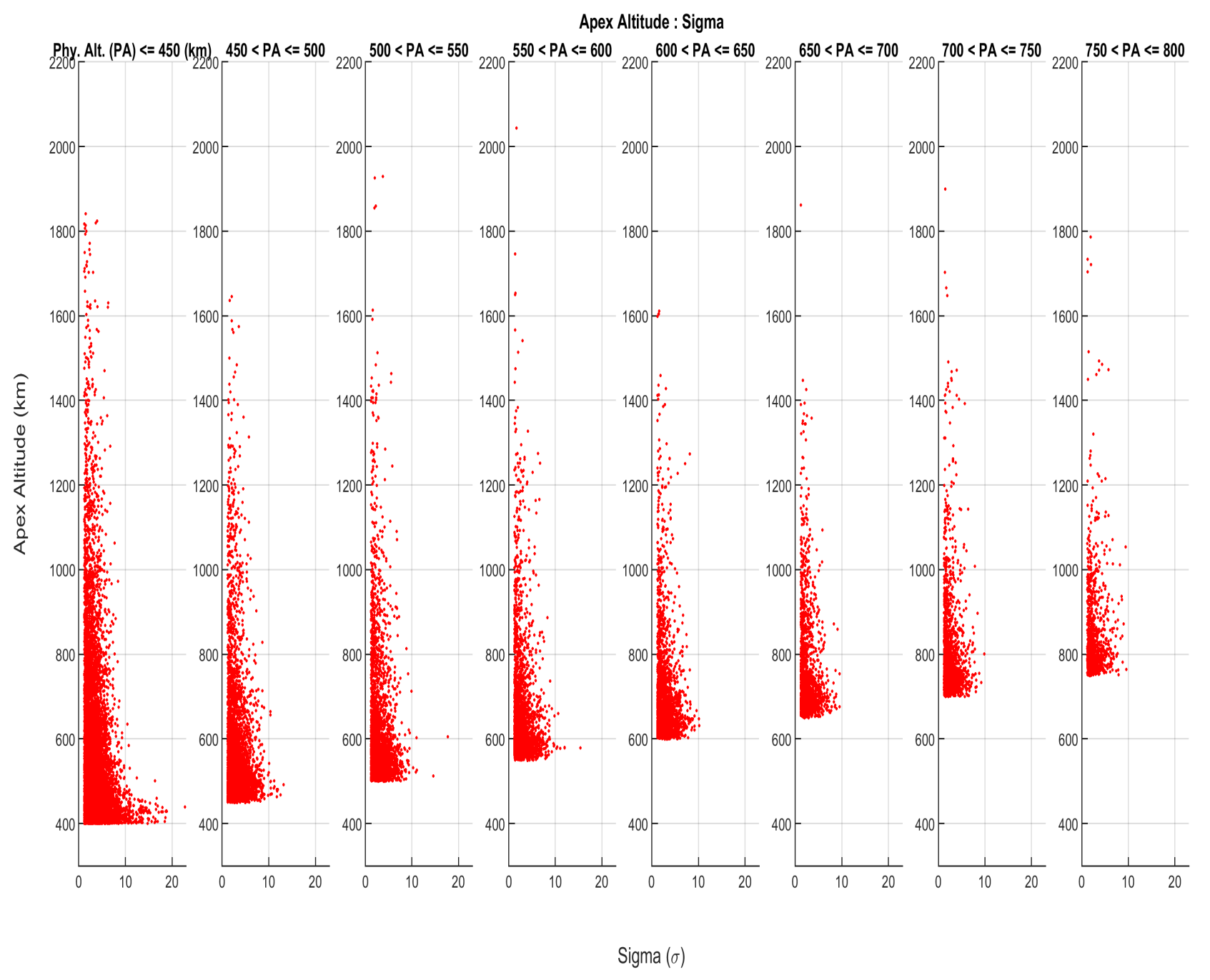


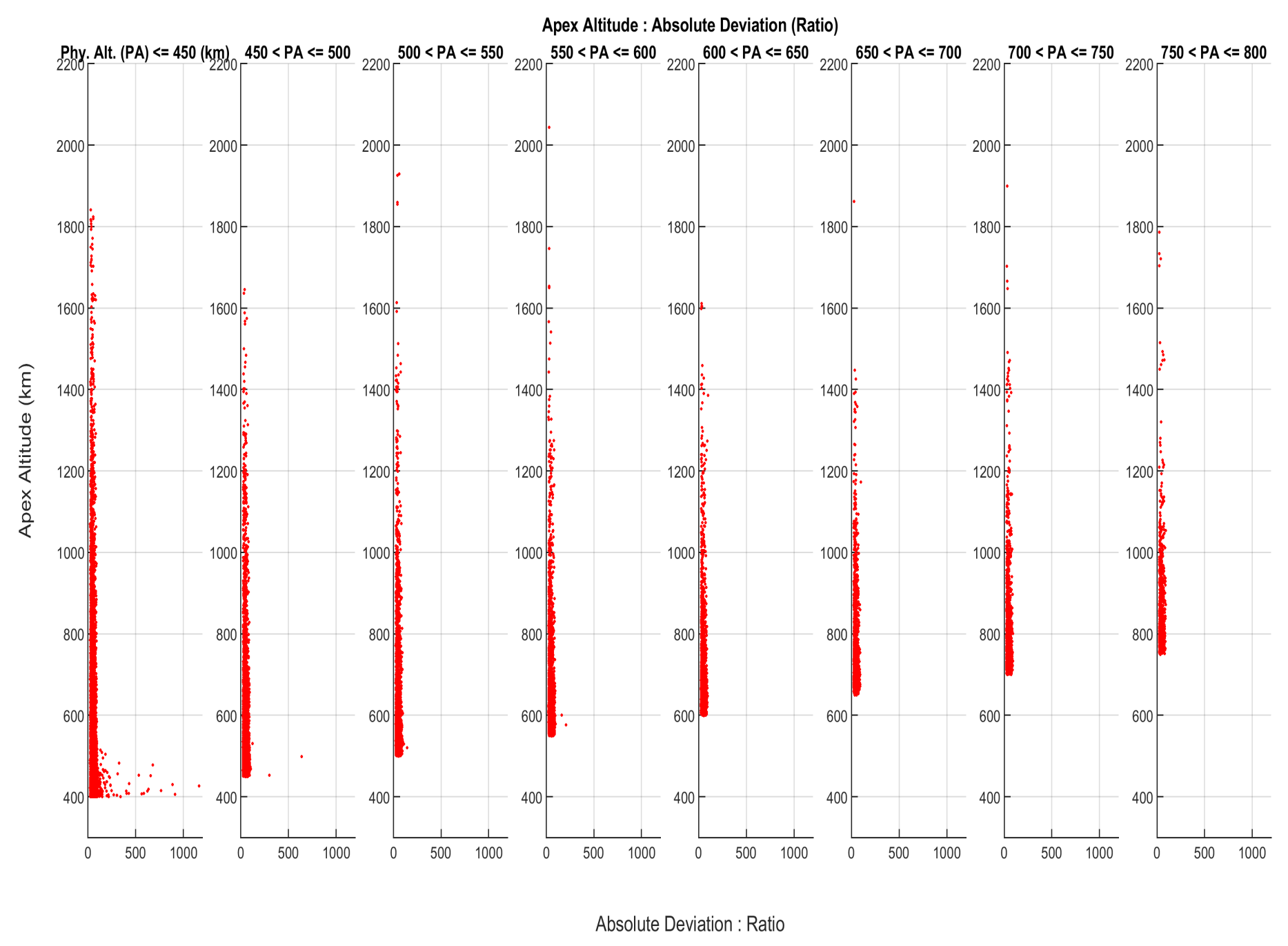




The scatter plots for the sigma, absolute deviation in linear scale and the background density in the linear scale with respect to the physical altitude all have a 'steeper' slope. Similar plots are made for the apex-altitudes. For the absolute deviation and the background density, the apex altitude varies 'randomly' as for any two similar physical altitudes, the corresponding apex-altitude can be significantly different.
But the quartile plot is not as 'steep' although the 25th percentile plot has decreased by ~ 20 percent.

6. Altitude Dependence of the Irregularity Parameter - II





The sigma values closer to the magnetic equator (low apex altitude) at lower physical altitudes are higher than those farther from the magnetic equator (high apex altitude) . But this doesn't hold true for the irregularity parameter defined in terms of the linear scale (absolute deviation ratio). So, it requires more investigation to understand the influence of background density on the irregularity parameter and while investigating this , we might as well discover the 'right parameter' to use to characterize the irregularities.

7. Conclusions:

- The C/NOFS bubble occurrence statistics are consistent with past studies.
- The simulations confirm the physical reality that all higher altitude bubbles at the magnetic equator pass through the lower altitudes beneath them.
- The median height distribution of bubbles increases linearly from about 491 km at solar minimum to 737 km during solar maximum.
- In the PBMOD model, the field-line integrated conductivity is found to be the key determinant of terminal bubble altitude.
- More investigation is required to reach towards unambiguous conclusions on the influence of background density on the irregularity parameter characterizing the ionospheric irregularities.

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