Ionosphere Topside Tomography Performance Based on CMONOC GNSS Observations

Shuli Song[1], Zhe Yang[1], Wenhai Jiao[2], Guangming Chen[3], Junchen Xue[1], Weili Zhou[1], Wenyao Zhu[1]

[1]Shanghai Astronomical Observatory, Chinese Academy of Sciences. Shanghai, China

[2]Beijing Institute of Tracking and Telecommunication Technology, Beijing, China

[3]Beijing Aerospace Control Center, Beijing, China

The work was supported by the National Natural Science Foundation of China

(Grant No. 10603011, 11273048, 41474131)

Abstract

In China, a regional GNSS network known as the Crustal Movement Observation Network of China (CMONOC) has been established since late 2000, initially only operating 25~30 GNSS tracking stations. In the second phase of the CMONOC, the number of stations has been increased to about 260. These ground-based GNSS stations provide large volumes of continuous measurements from different directions over long periods. In this study, we will take the advantage of this dense GNSS tracking network of the CMONOC to conduct an experiment of GNSS ionospheric imaging over China.

The objective of this study is to quantitatively analyze how the tomographic reconstruction performs in the topside ionosphere. To carry out this analysis, the comparison is made against the plasma densities measured by the Defense Meteorological Satellite Program (DMSP) satellites. China spans widely in both longitude and latitude directions, so there should be a large amount of DMSP measurements available for the analysis. This study will allow to know the quantitative performance of GPS ionospheric tomography in the topside ionosphere.

Data and Method

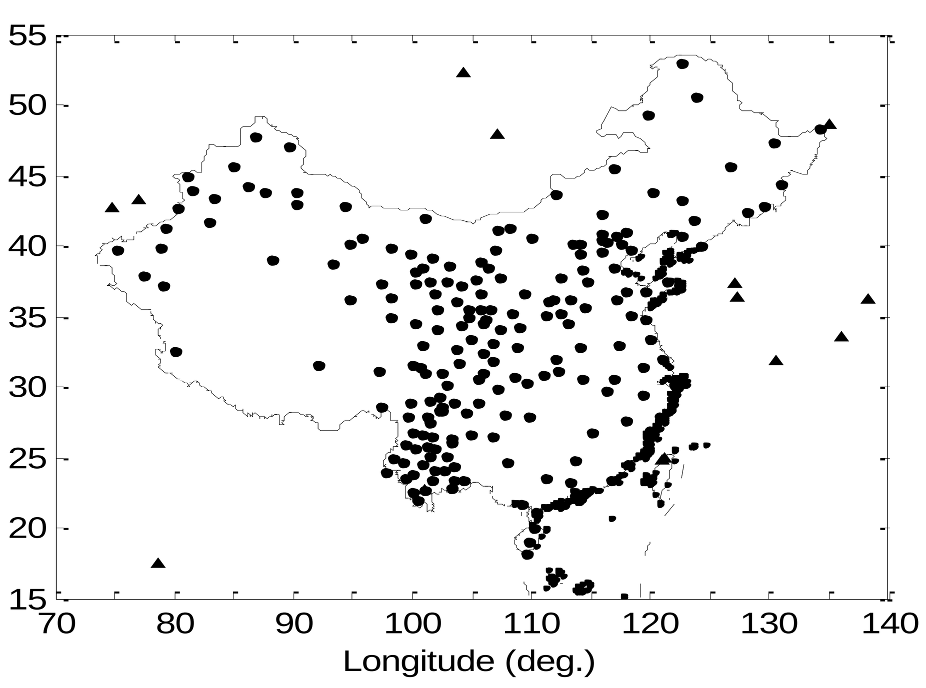

Figure 1. Locations of GNSS stations used for this study

The CMONOC is a large scale and high precision GNSS-based network. The scientific objective is hazard mitigation while at the same time providing geodetic support. Since 2010 there have been about 260 permanent GNSS tracking stations in the CMONOC, producing data with sampling intervals of 30 seconds.

Figure 1 shows the locations of GNSS stations of the CMONOC. These stations almost cover the entire mainland of China although in some regions they are less dense.

In order to reduce the border effect in the tomography process, some IGS GPS stations are included, shown as triangles in Figure 1. In this study, GPS data from CMONOC and IGS recorded in October 2011 are used for the ionospheric tomographic reconstructions.

We use the pixel-based ionospheric imaging method to reconstruct ionospheric electron density (IED). Regarding this method, the mapped region of the ionosphere should be firstly discretized into numerous small pixels. Assuming the electron density within each pixel is constant during the reconstruction period, the inversion of IED can be expressed as:

$$\mathrm{STEC}_i = \sum_{j=1}^{n} A_{ij} x_j + e_i \quad i = 1, 2, \dots\ m$$

In the present work, the MART (Multiplicative Algebraic Reconstruction Technique) algorithm is used for image reconstruction, and the IRI-2012 (International Reference Ionosphere) model is adopted to provide initial values of IED for the algorithm. In our tomography the contribution of the plasmasphere to the GPS TEC is removed by employing the NeQuick 2 model.

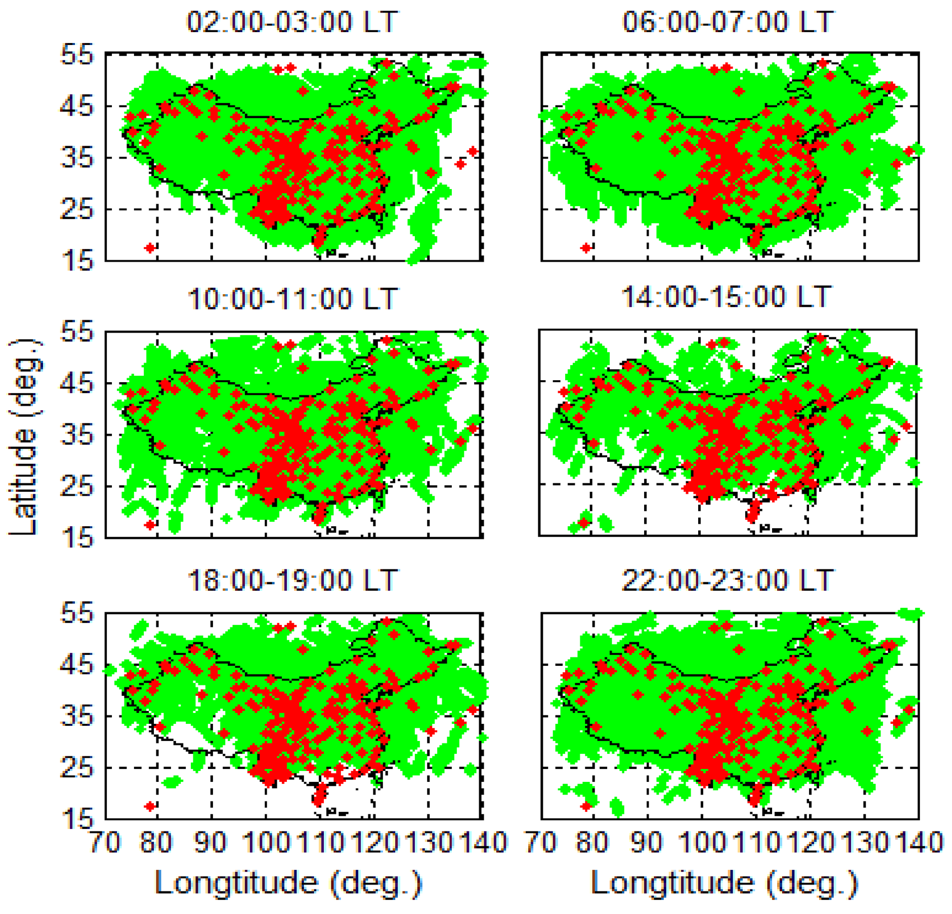

Figure 2. Distribution of the Ionospheric Pierce Points during one hour period on October 17 2011 (red point represents GNSS stations and green point represents IPPs)

As a horizontal illustration of available GPS raypaths, Figure 2 shows the distribution of Ionospheric Pierce Point (IPP) corresponding to each GPS observation collected during one-hour period on October 17, 2011.

As displayed, the IPP distribution almost covers the whole land area of China, as a result of the dense network of GNSS stations in the CMONOC.

It is also found that the voxels without GPS raypaths passing through are mainly near the border where there lack GPS stations. For these regions, the tomography has to rely on the priori information provided by the IRI-2012 model.

We intend to use the database of total ion densities observed by the sensor SSIES on the DMSP's F16, F17 and F18 satellites to test the quality of tomography in the topside ionosphere.

The quantitative comparison is made between the reconstructed plasma density (PD) and observations from the spacecrafts F16, F17 and F18, respectively. The plasma density of spacecrafts' measurements is compared with the reconstructed result on the nearest grid point.

The bias and standard deviation (STD) as measure of performance of the imaging results are defined by:

$$\mathrm{Bias} = < \mathrm{PD_{meas}} - \mathrm{PD_{cit}} >$$

$$\mathrm{STD} = \sqrt{< (\mathrm{PD_{meas}} - \mathrm{PD_{cit}} - \mathrm{Bias})^2 >}$$

where < > denotes a mean on a given period of the specified expression. PDcit represents the value of plasma density reconstructed by the tomography. PDmeas represents the in situ plasma measurements by the DMSP SSIES.

Results and Discussions

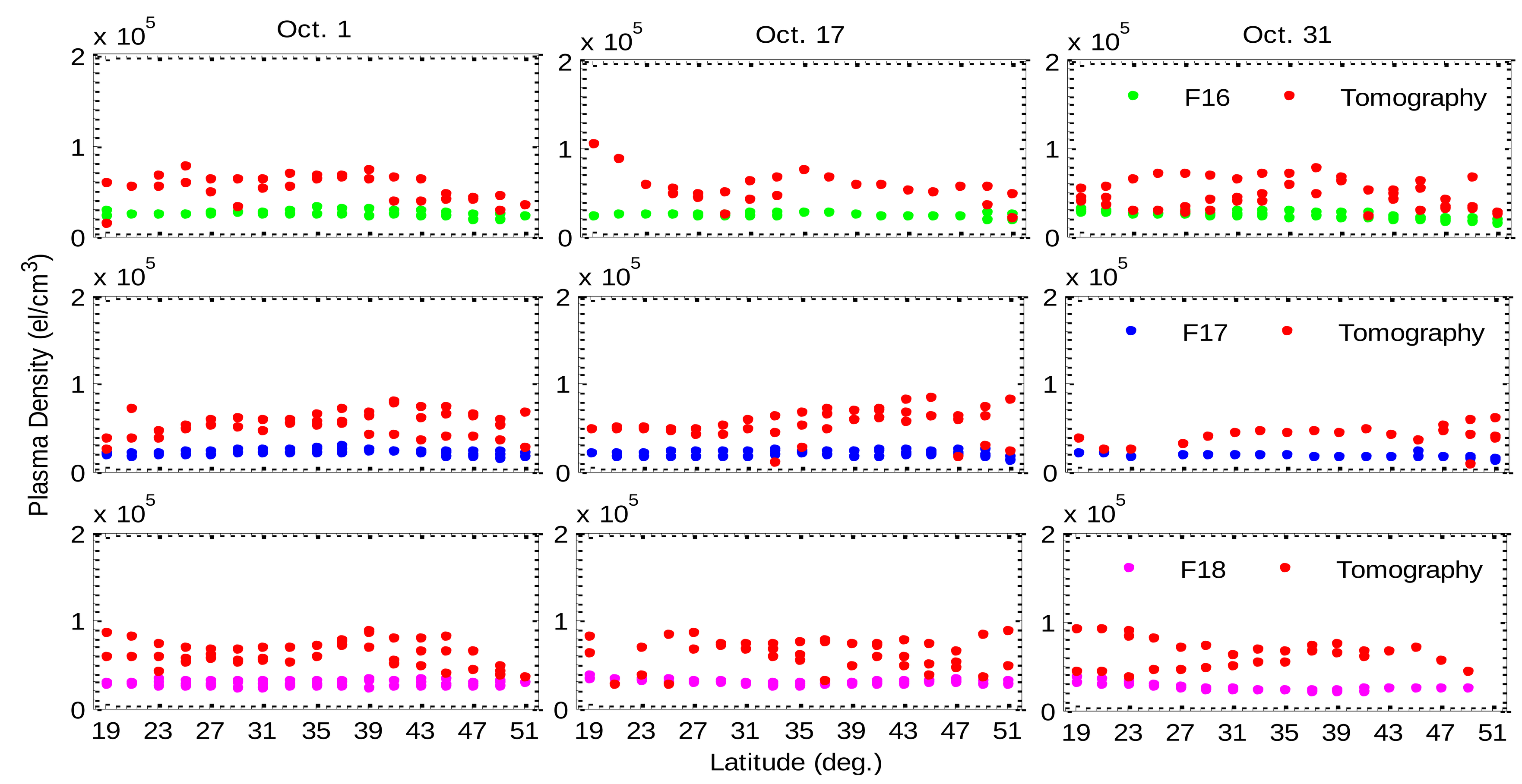

Figure 3. Comparisons of plasma densities between the tomographic reconstruction and the DMSP spacecrafts with descent trajectories on October 1, 17, and 31, 2011. Results for the tomography are presented in red; results for the F16, F17 and F18 are represented in green, blue and magenta, respectively.

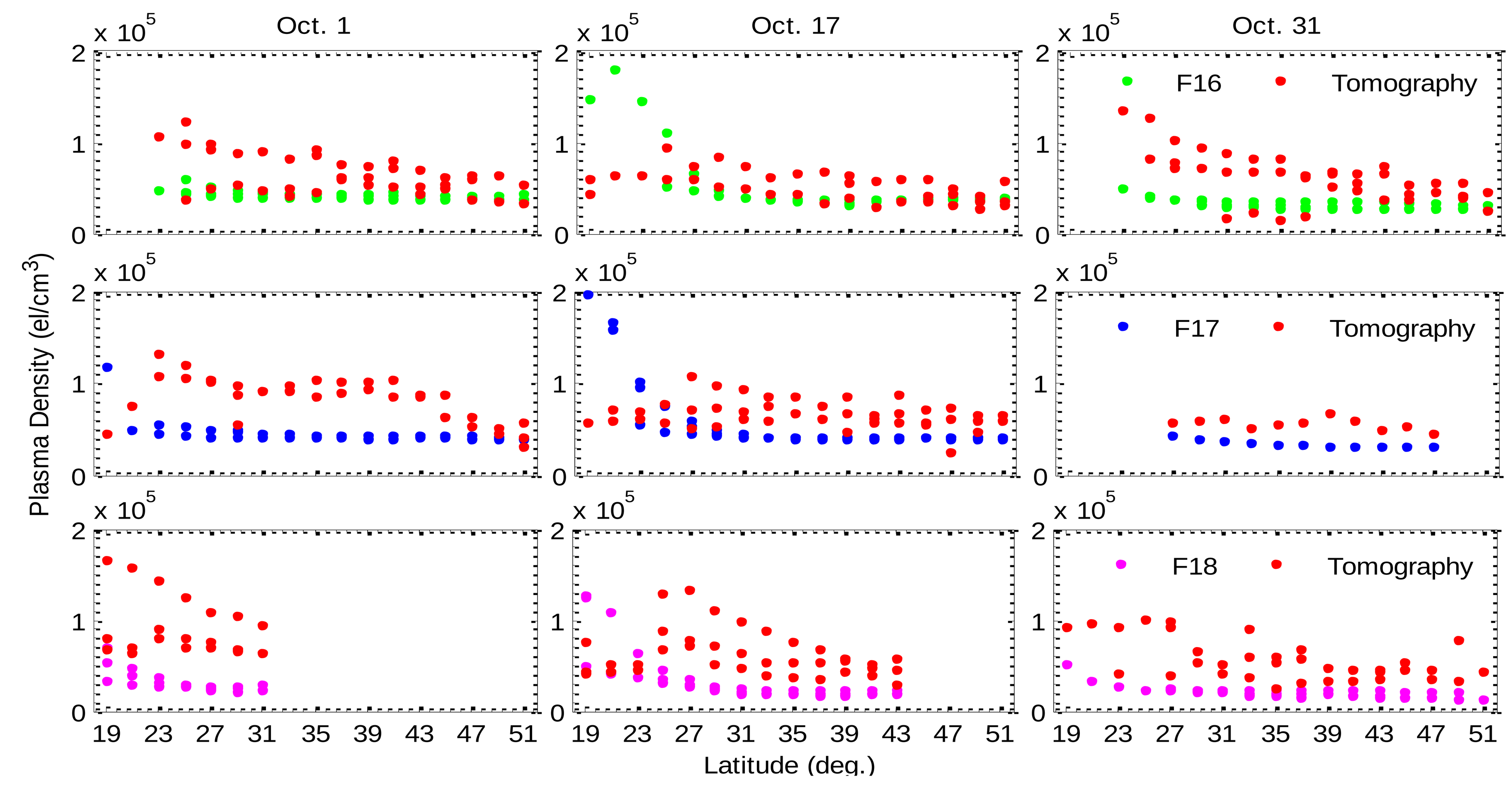

Figure 4. Comparisons of plasma densities between the tomographic reconstruction and the DMSP spacecrafts with ascent trajectories on October 1, 17, and 31, 2011. Results for the tomography are presented in red; results for the F16, F17 and F18 are represented in green, blue and magenta, respectively.

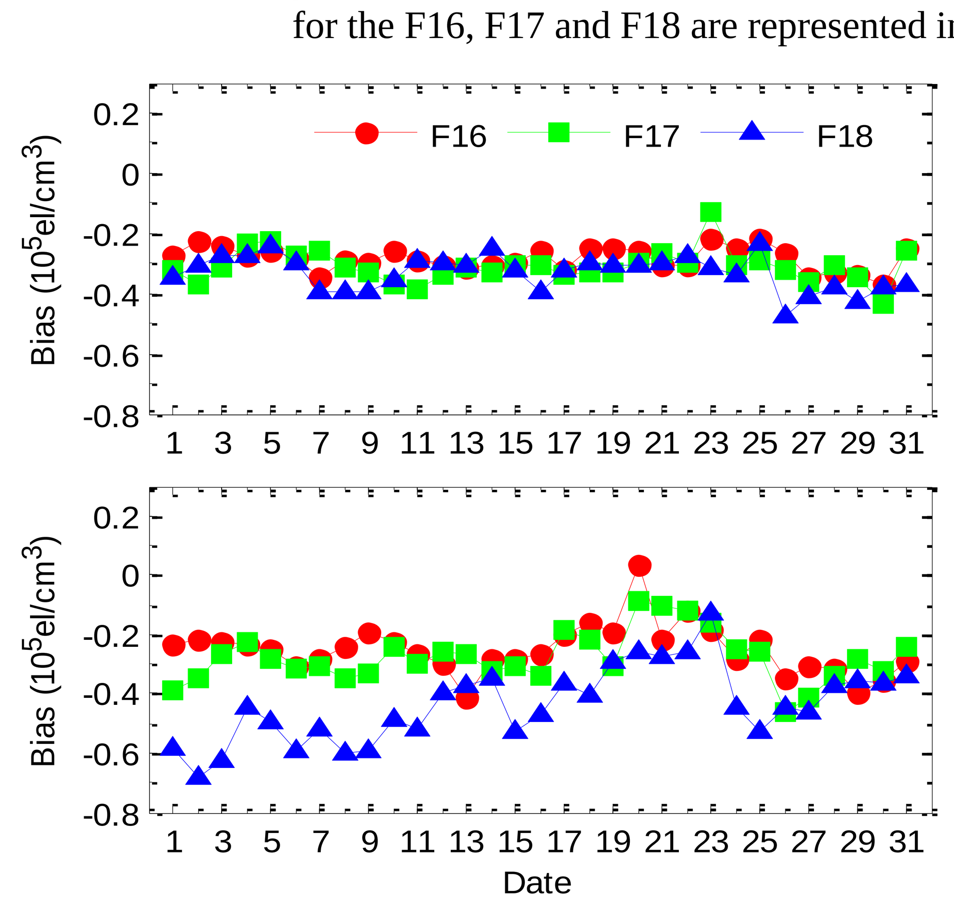

Figure 5. Daily biases of the reconstructed plasma densities with respect to F16, F17 and F18 measurements during the daytime (top) and nighttime (bottom) in October 2011

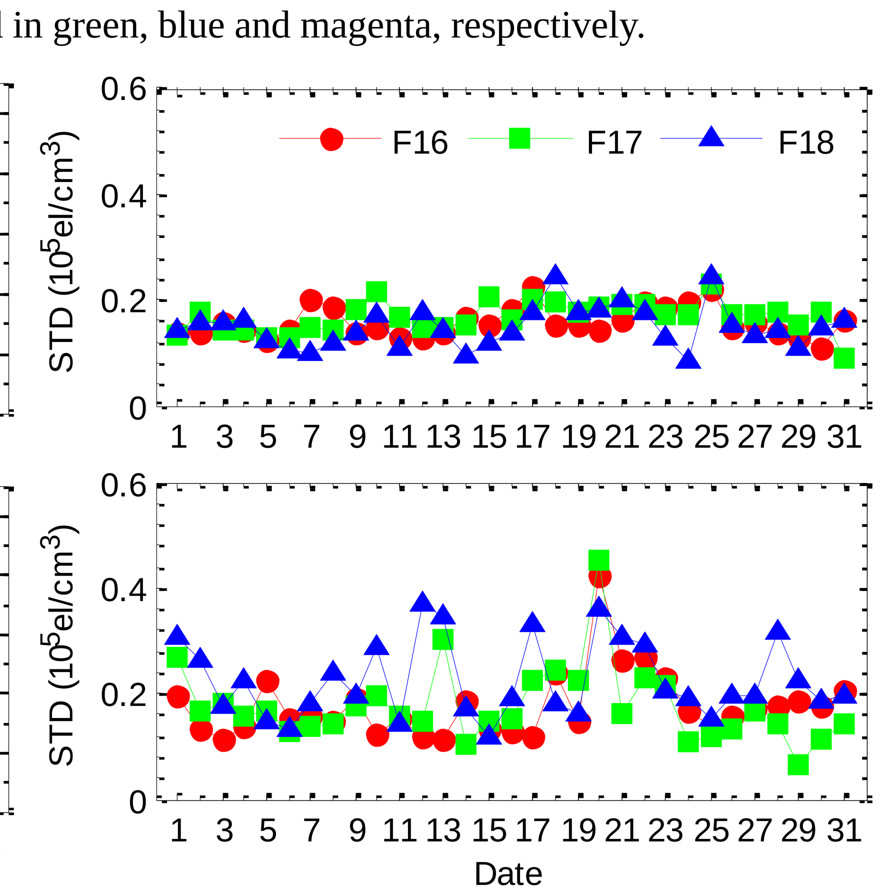

Figure 6. Daily STD of the reconstructed plasma densities with respect to F16, F17 and F18 measurements during the daytime (top) and nighttime (middle) in October 2011

Conclusions

Compared with the plasma density measured by the DMSP satellites (F16, F17 and F18) orbiting at an altitude of 830 to 880 km:

- The tomography performs an overestimation of the plasma density at the DMSP altitude, which should be caused by the low vertical resolutions for ground-based GPS measurements.
- The reconstruction is better during daytime than nighttime.
- In summary, the daytime bias is on average from $-0.32\times10^5/\mathrm{cm}^3$ to $-0.28\times10^5/\mathrm{cm}^3$ while the nighttime bias is between $-0.37\times10^5/\mathrm{cm}^3$ and $-0.24\times10^5/\mathrm{cm}^3$, and the standard deviation at daytime and at nighttime are respectively $0.082\times10^5/\mathrm{cm}^3$ to $0.244\times10^5/\mathrm{cm}^3$ and $0.086\times10^5/\mathrm{cm}^3$ to $0.428\times10^5/\mathrm{cm}^3$.