Inter-Calibration of Ionospheric Density Data From IVM and TGRS

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Introduction

As operational mission for weather and space weather F7/COSMIC 2 mission has an urgent need to calibrate the IVM (Ion Velocity Meter) ion density data. We used a new differential GNSS TEC method to derive the electron density at the satellite height and compared with the IVM in-situ ion density measurements. The F7/COSMIC 2 IVM ion density was calibrated. We found that the IVM ion densities are about 10 to 15% lower at high orbits (710 km) and 5% lower at lower orbit (540 km). Linear correction has been applied to the IVM density and we believe we have removed the bias in the ion density data, which is ready for operational use.

Differential TGRS Slant TEC Data Derived Density

The key to the differential slant TEC method is to find the instance when the GNSS satellite is either right in front or behind in the direction the COSMIC satellite moving direction. Under those conditions, the changes in the TEC is mainly due to the variations in distance between the GNSS satellite and COSMIC2. By taking differential of the varying TEC and distance, we obtain the local electron density. Figure 1 shows the geometry and selection parameters for this method.

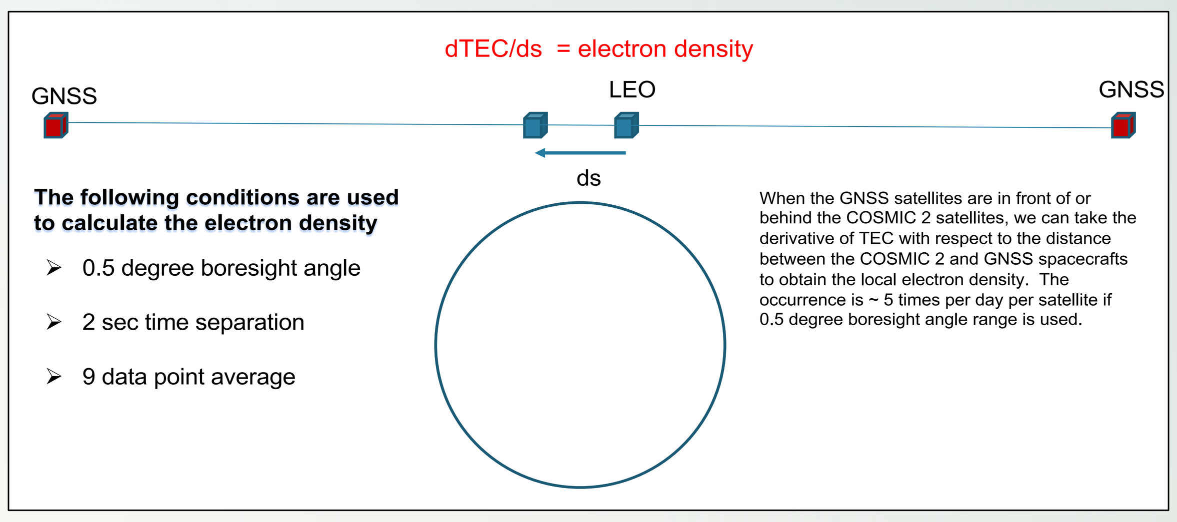

Figure 1. Geometry for differential TGRS slant TEC measurements of the orbital height electron density. The GNSS satellite can be in front or behind of the F7/C2 satellite as the F7/C2 has two POD antennas viewing both forward and backward. Any passing of the GNSS in both direction with the 0.5 boresight angle can be used to derive the electron density. The distance traveled by the LEO is exaggerated to illustrate the method.

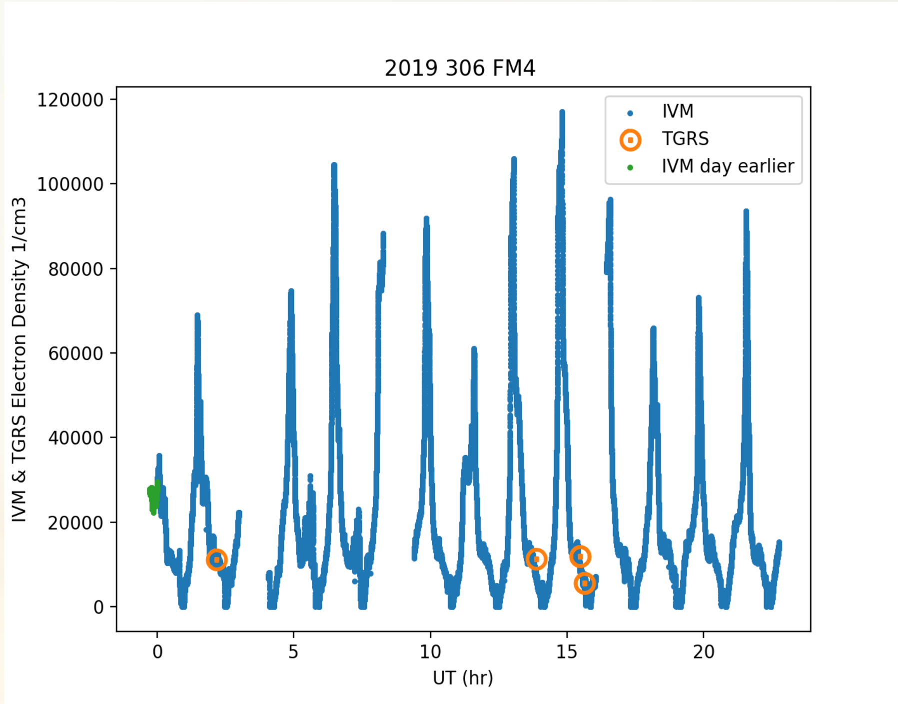

Figure 2. 2019 Day 306 FM4 IVM (blue dots) and TGRS derived density (orange circles) comparison. Good agreement between the two measurements is apparent. IVM data from day earlier is shown as green dots. The IVM density has 1 sec temporal resolution.

Precision of the Differential TGRD Derived and IVM Density

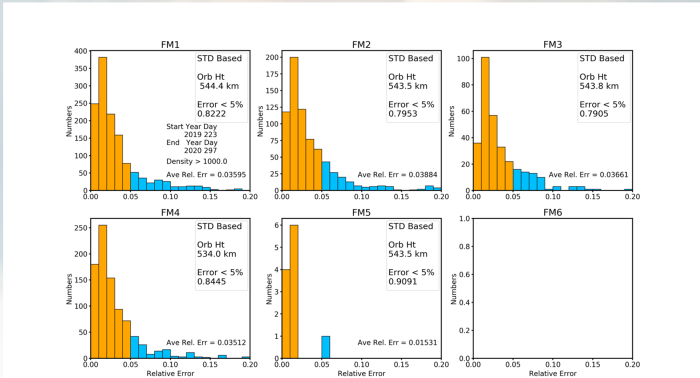

Figure 3. The precision of the TGRS derived density based on the STD of 9 point used for averaging. Because we used 9-sample average the precision is divided by a factor of 3 (square root of 9). The orange color marks the bins with less 5%, which is a requirement for the IVM density. The more than ~80 percent of time the precision is much better than 5%.

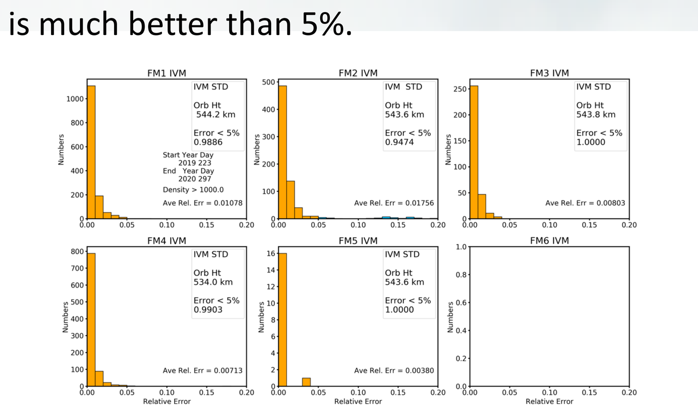

Figure 4. Precision of the IVM density based on the standard derivation of the 9 samples used to calculate the averaged value. The precisions of the IVM densities are less than 1.7 %.

IVM and TGRS Density Comparison Before Correction

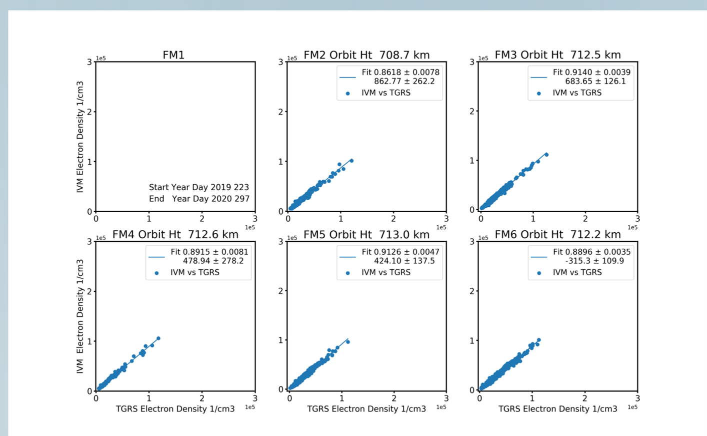

Figure 5. IVM vs TGRS density comparison for high orbit. FM1 does not have high orbit data. The linear fit lines are also plotted and fitting coefficients are given in the legends. The fitting slope shows the IVM densities are 15 to 7 precent smaller than the TGRS measurements. The plot scales are in 1.e5 /cm3.

FM	1	2	3	4	5	6
Linear coeff.	No data	1.1553	1.0943	1.1335	1.0783	1.1164
Offset	No data	292.82	798.15	278.04	1140.0	1667.4

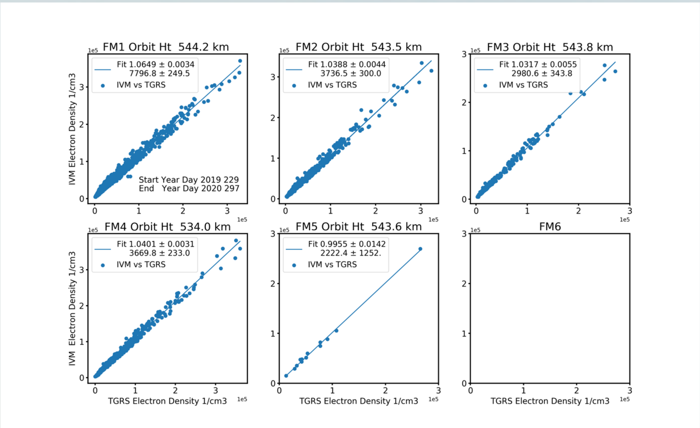

Figure 6. Same as Figure 5 but for low orbit. FM5 and 6 have very few or no data point in the time period used for the analysis. The fitting slopes show the IVM densities are about 4 to 6 percent higher than the TGRS values, which is opposite to the high orbit case.

FM	1	2	3	4	5	6
Linear coeff.	0.9422	0.9645	0.9639	0.9632	0.9642	0.9642
Offset	-7448.	-3423.	-2555.	-3492.	-2989.	-2989.

IVM and TGRS Density Comparison After Correction

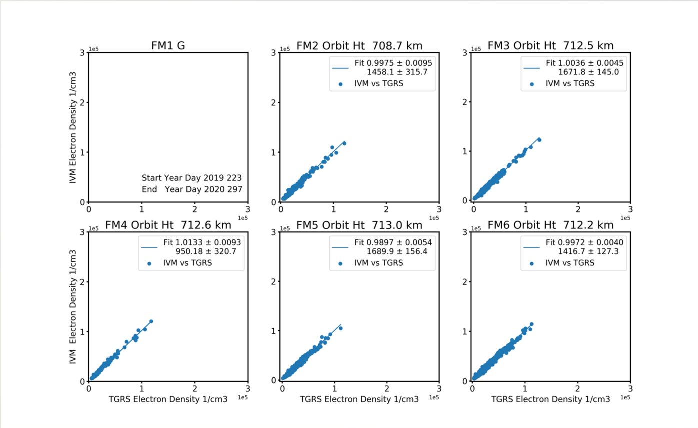

Figure 7. IVM vs TGRS derived densities after the linear correction for high orbits. The linear fit lines to the data are also plotted with coefficients provided in the legends. The slopes for each of the FM are close to 1 within 1.3 precent. Offsets are less than 1700 cm-3.

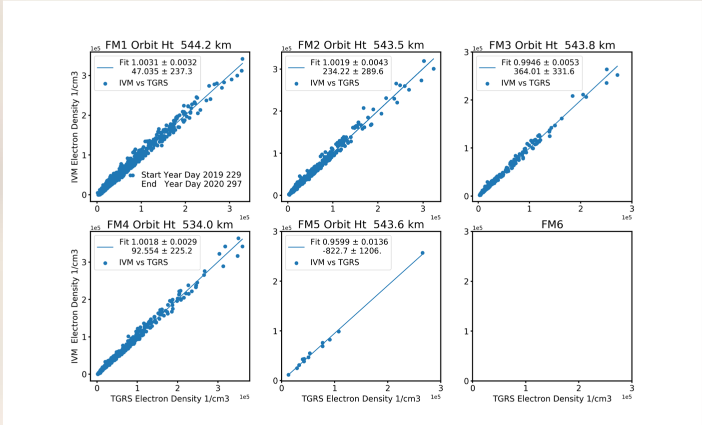

Figure 8. IVM vs TGRS derived densities after the linear correction for low orbits. Linear fit lines are also plotted with the coefficients in the legends. The slopes for FM1 to FM4 are close to 1 (within 0.5 precent). Offsets are less than 350 cm-3. FM5 does not have enough data to give a statistically significant results, whereas FM6 had no low orbit data during this time interval.

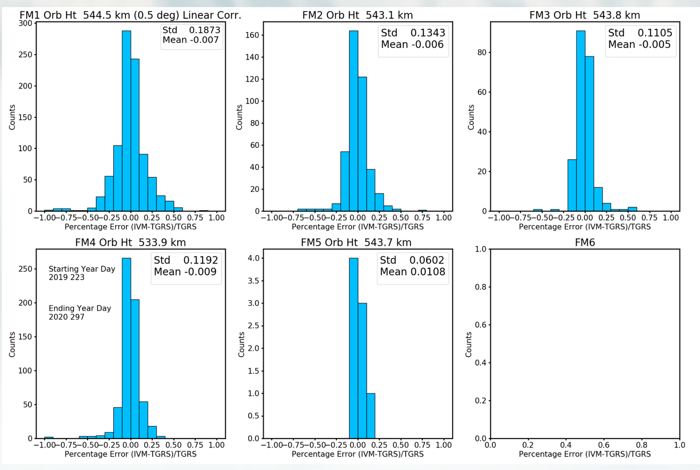

Figure 9. IVM vs TGRS percentage discrepancy distribution after the linear correction to the IVM density. The density values less 1e4 /cm3 are not included in this statistic. The mean discrepancy is mostly less than 1 percent. The standard derivation ranging from 11 to 19 percent.

Discussion

It is uncommon to have two ionospheric observations from the same satellite and even rare to have both measure the ionospheric density. There are other missions have in-situ ion density and GPS receivers, such as SWARM, but their POD antennas do not sample lower ionospheric TEC values (elevation limit at 20 deg). The F7/C2 TGRS instrument ionospheric TEC observation provides a unique opportunity to calibrate and validate the IVM ionospheric density observation with relatively high precisions. That allows us to remove the inter-satellite difference in the density data, which is critically important for study of nonmigrating tide and planetary wave features in the ionosphere. While the TGRS derived density self-determined precisions are pretty small (based on the standard deviation), the inter-instrument (IVM-TGRS) discrepancy is larger indicating there are still uncaptured variations in the observations either instrumental or geophysical origin.

Before the correction, we did find bias in the discrepancy for F7/C2 satellites and estimate the scaling factor between the two data sets. We also noted that the IVM density data at high orbits are smaller than the TGRS derived values whereas at the lower orbits, the IVM density data are slightly larger. A linear correction was applied to the IVM density data. At the moment, the cause of these opposite biases is unknown.

After the linear correction, the percentage difference between IVM and TGRS show neglectable offset between the IVM and TGRS measured densities (mostly < 1 percent). However, the standard derivations of the differences are significant ranging from 20 percent to 11 percent as shown in Figures 9 and 10 for high and low orbit respectively. As we have mentioned earlier that precision of the TGRS derived density is about 3 percent (Figure 3). We also estimated the 9-point standard derivation of the IVM data and the precision of the 9-point averaged IVM density is less than 1.7 percent (Figure 4). The spread between the IVM and TGRS could be a representation error due to the nature of the two different measurements. One based on differential value of the integrated TEC values and the other is in-situ measurement. We are still investigating the source of such a large spread between the IVM and TGRS measured values.

Summary

- We used a new differential TEC method to validate the F7/C2 IVM ion density data.
- We found that the at high orbit (~710 km) the IVM densities were about 15 to 9 percent lower than the TGRS derived density, whereas at lower orbits (~540 km) they were about 5 percent higher.
- A linear correction was applied to the IVM density, which removes the offset. We verify that the corrected IVM densities are fully consistent with the TGRS derived density afterward.
- More importantly, we also removed inter-satellite discrepancy in the IVM density, which is ready for scientific and space weather applications.

Acknowledgement

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