3D Tomographic Reconstruction of Storm-Enhanced Density (SED) Plume During March 17, 2013 Storm

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Abstract

The 3DCIT technique is used to reconstruct the spatial distribution of storm enhanced density (SED) based on the GPS TEC measurements over the North American area during the March 17, 2013 storm. The reconstruction results are carefully validated with observations from ionosonde, COSMIC and the Millstone Hill ISR. It was found that the SED plume first appeared around 400 km, and then expanded downward to ~ 300 km as well as upward to ~ 500 km from 19 to 22 UT on March 17. Our study also showed that the SED plume occurred mostly above the storm-time F-layer peak height.

Introduction

Previous studies of the SED plume are usually based on either localized observations by ISR and satellites, or 2D measurements such as GPS TEC maps Although numerical models can predict the temporal and spatial variations of the 3D ionospheric electron density, the simulation results are often not consistent with observations. In order to better understand the spatiotemporal evolution of SED plume, especially its altitudinal variations, we apply the 3DCIT technique to reconstruct the ionospheric electron density distributions during the 17 March 2013 geomagnetic storm.

Data and Methodology

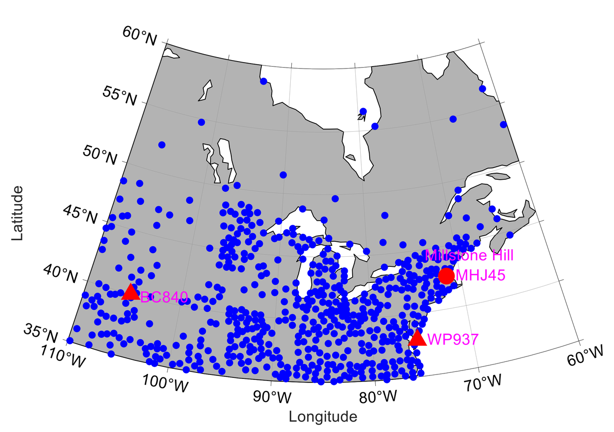

Figure 1. Distribution of ground GPS receivers (blue dots), ionosonde and stations (red triangles) and incoherent scatter radar (red dot).

Lat	35-60° N	dLat	1°
Long	60-110° W	dLong	1°
Alt	100-1000km	dAlt	10km: <420 km 50km:>420km

Table 1. The range and resolution of 3DCIT inversion region.

For calculating the electron density in each voxel, the improved constrained simultaneous iterative reconstruction technique (ICSIRT) is employed:

$$STEC^{3DCIT}_{m\times 1} = A_{m\times n} \cdot x_{n\times 1}$$

$$x_j^{k+1} = x_j^k + \frac{1}{P}\sum_{i=1}^{P} \lambda \cdot (y_i - \sum_{m=1}^{M} A_{i,m} x_m^k) \cdot \frac{x_j^k}{\sum_{m=1}^{M} A_{i,m} \cdot x_m^k}$$

NeQuick2 model is used to subtract the plasmaspheric part of the electron content above 1000 km from the GPS STEC data. Electron density values from the TIEGCM simulation of the storm are used as the initial values for the 3DCIT reconstruction. To minimize the effect of initial values on the inversion results, a multiplication factor (0.3) is applied to the TIEGCM model values.

Validation of the 3DCIT results

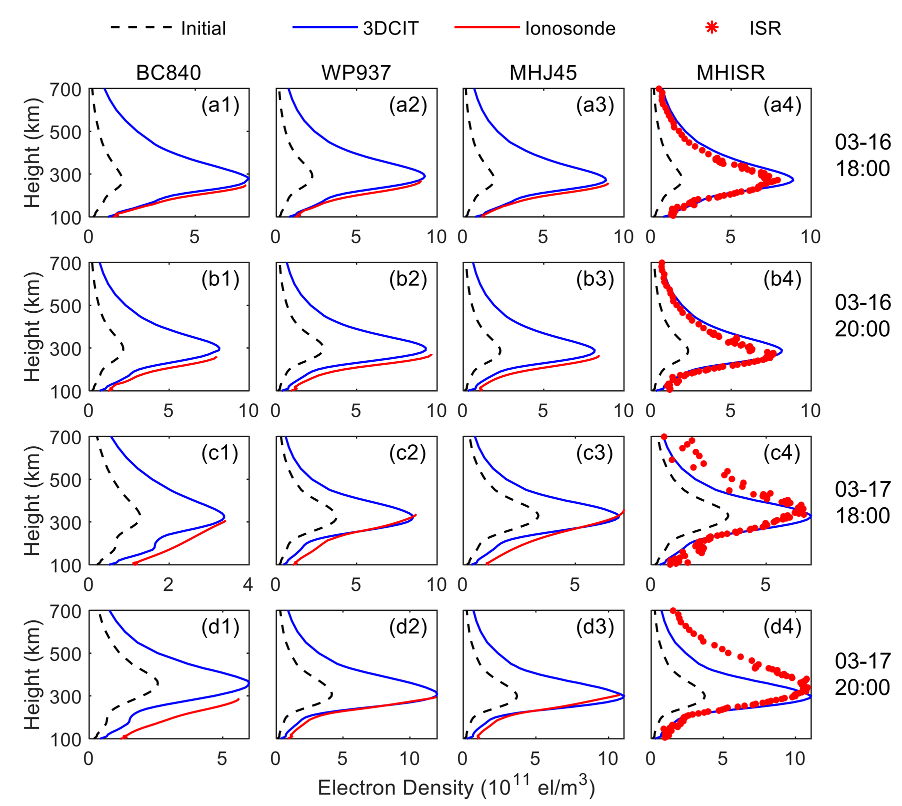

Figure 2. Comparison of 3DCIT electron density profiles with initial value, ionosonde and ISR observations.

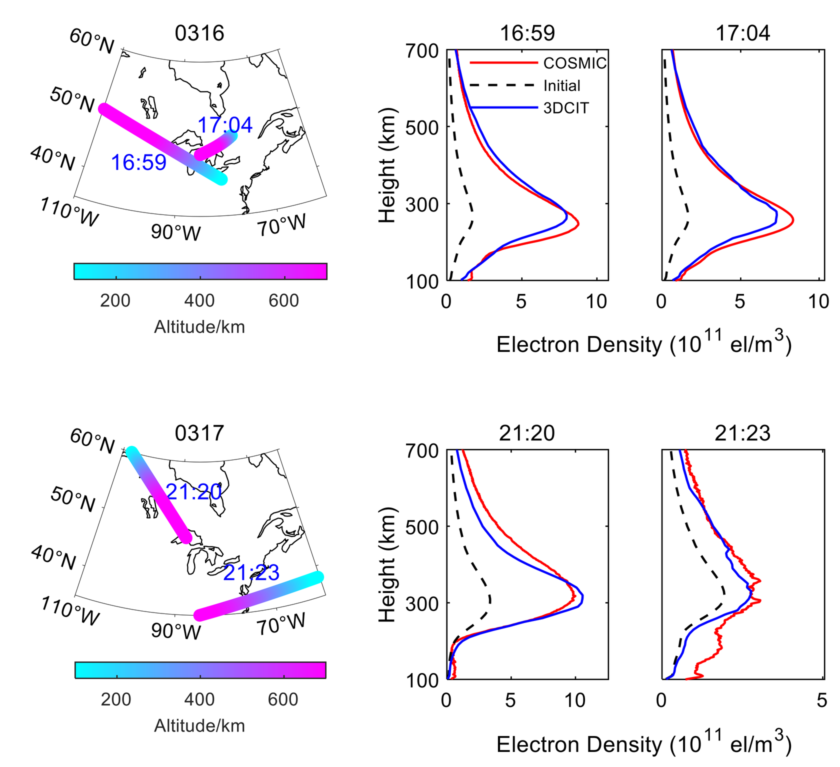

Figure 3. (left column) Projection of the COSMIC occultation tangent points. (middle and right columns) Comparison of the initial electron density profiles, the 3DCIT profiles, and the COSMIC observations.

The 3DCIT Ne profiles at 18:00 and 20:00 UT on 16 March are very close to the ionosonde and ISR observations. On the storm day of 17 March, the 3DCIT results are also generally consistent with the ionosonde and ISR observations except the underestimation of the topside at 20:00 UT at ISR station. 3DCIT Ne profiles also show a good agreement with COSMIC occultation Ne profiles. The 21:20 UT occultation crossed the SED plume and the topside, NmF2 and hmF2 values of 3DCIT are very close to the COSMIC data.

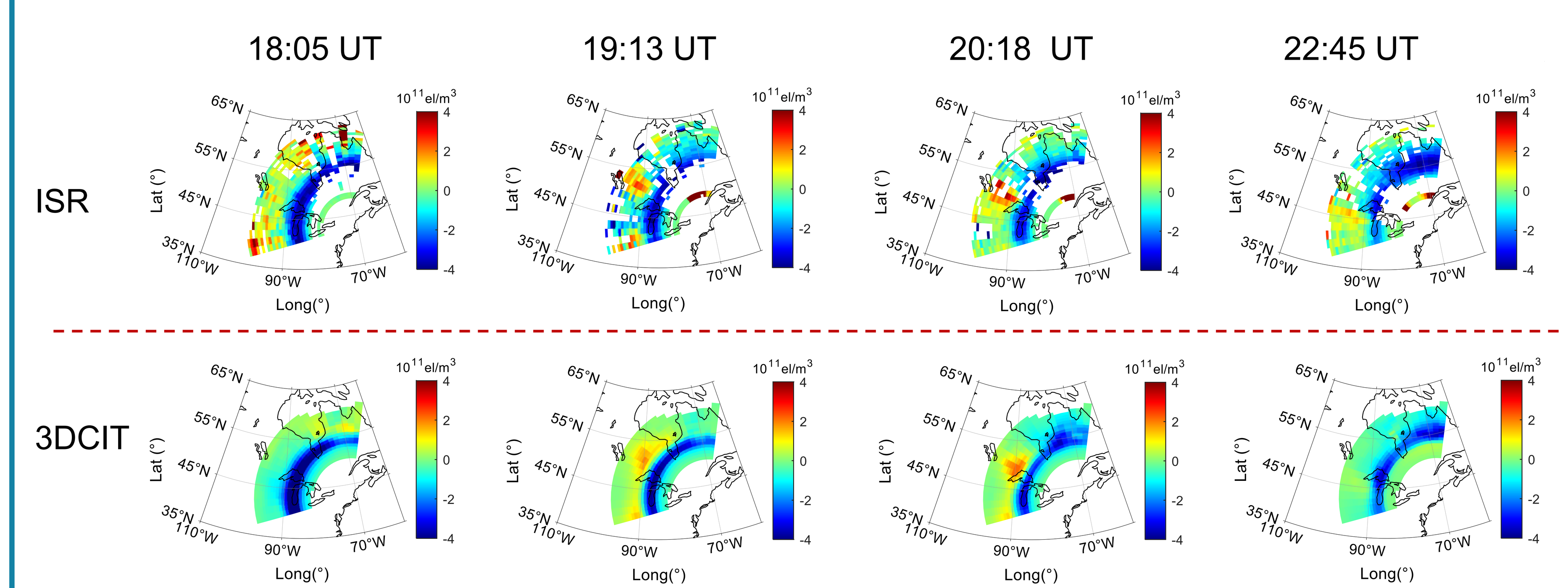

Figure 4. Ne difference plots between storm time (17 March) and quiet time (16 March).

At 18:05 UT, there is an obvious density depletion zone in both the radar and 3DCIT Ne difference plots, and no SED plume was discernible. At 19:13 UT, an increased Ne structure can be seen around 48°N and 95°W in the radar plot, and a similar structure is also shown in the 3DCIT plot at the same location. The SED structure moved southward slightly at 20:18 UT in both the radar and 3DCIT Ne difference plots. By 22:45 UT, the SED structure had nearly disappeared.

3D structure of the SED plume

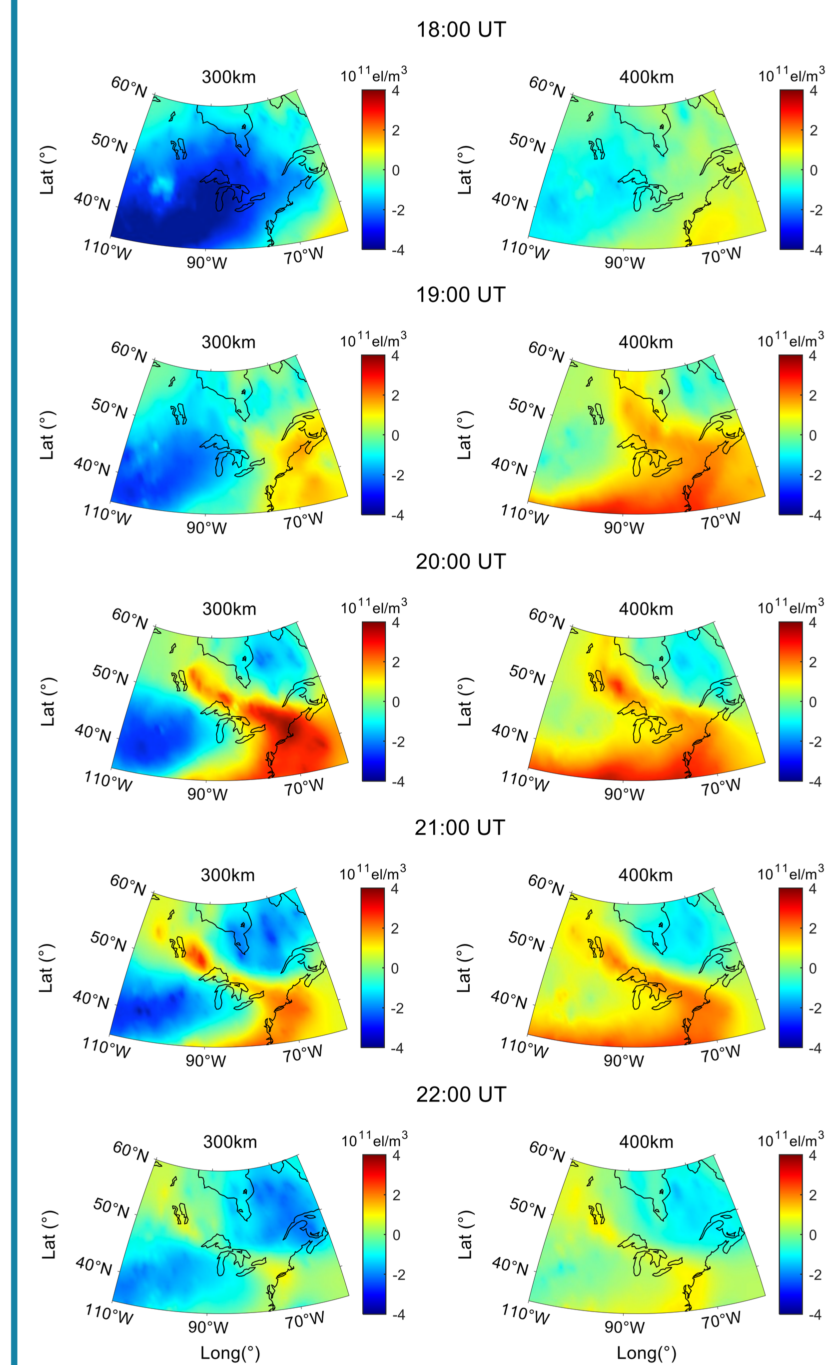

Figure 5. Latitude-longitude maps of the 3DCIT Ne difference between storm times (0317) and quiet times (0316)from 18:00 UT to 22:00 UT.

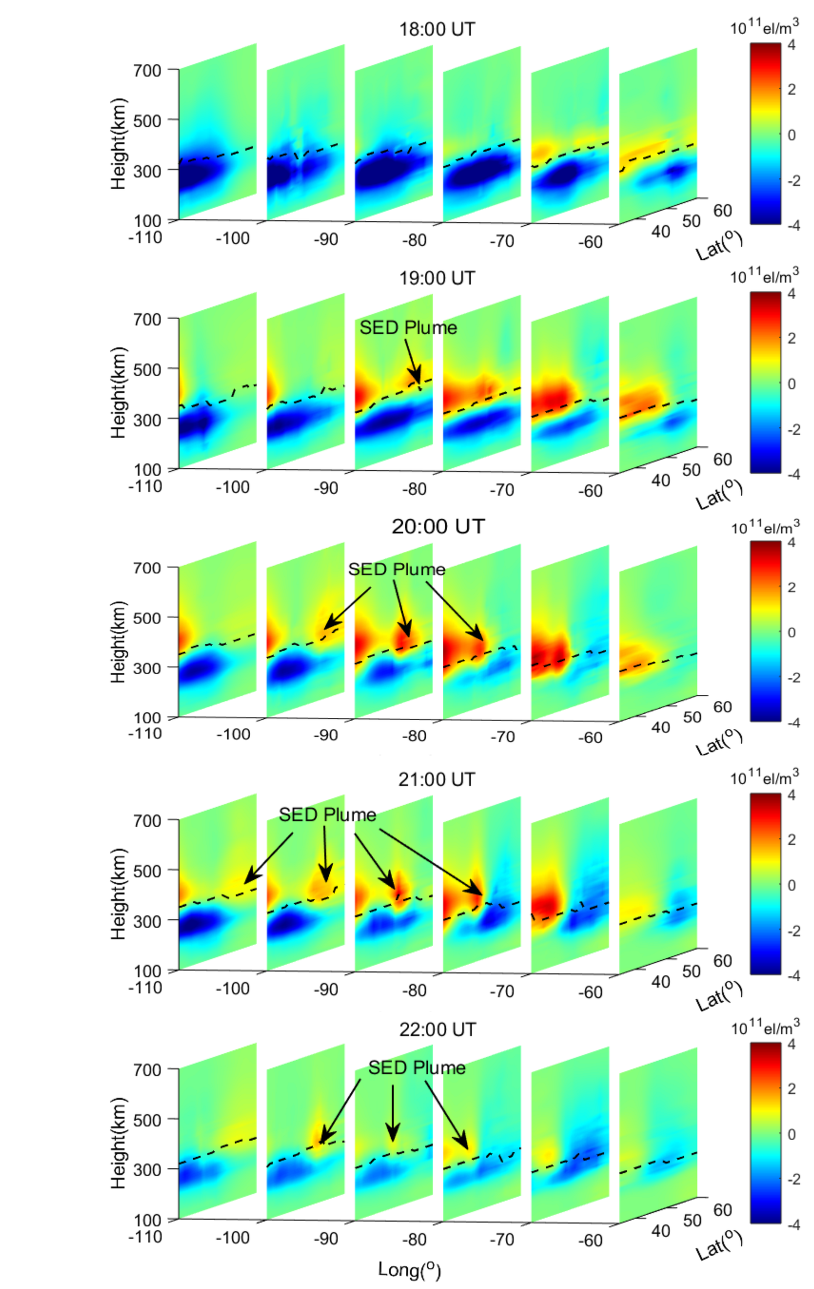

Figure 6. Altitude-latitude slices of 3DCIT results of Ne differences between storm times (0317) and quiet times (0316) from 18:00 UT to 22:00 UT. Black dashed lines denote the hmF2 position of the storm time 3DCIT results

In Figure 5, At 19:00 UT, a SED plume structure is noticeable at 400 km height. At 20:00 UT, the SED plume extended down to 300 km and was shifted westward at 400 km. By 21:00 UT, the northwest part of the SED plume at 300 km was enhanced while the intensity of the middle part as well as the base of the plume. In Figure 6, from 18:00 UT to 22:00 UT, the Ne difference was negative below 300 km. The SED plume is formed mainly above the storm-time F-region peak height as indicated by the black dotted lines.

Conclusion

1. 3DCIT technique and TEC observations from more than 500 GPS receivers over the north American sector were employed to reconstruct the 3D configuration of the SED plume.
2. 3DCIT results were carefully validated with observations 3 ionosonde stations, ISR and the COSMIC radio occultation.
3. SED plume first appeared around 400 km at 19:00 UT, and was enhanced and extended downward to 300 km height at 20:00 UT.
4. SED plume occurred mostly above the F-layer peak height.

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