Long-duration depletion in the topside ionospheric total electron content during the recovery phase of the March 2015 strong storm

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Abstract

Topside ionospheric total electron content (TEC) observations from multiple low-Earth orbit (LEO) satellites have been used to investigate the local time, altitudinal, and longitudinal dependence of the topside ionospheric storm effect during both the main and recovery phases of the March 2015 geomagnetic storm. The results of this study show, for the first time, that there was a persistent topside TEC depletion that lasted for more than 3 days after the storm main phase at most longitudes, except in the Pacific Ocean region, where the topside TECs during the storm recovery phase were comparable to the quiet time ones. The observed depletion in the topside ionospheric TEC was relatively larger at higher altitudes in the evening sector and greater at local times closer to midnight. Moreover, the topside TEC patterns observed by MetOp-A (832 km) were different from those seen by other LEO satellites with lower orbital altitudes during the storm main phase and at the beginning of the recovery phase, especially in the evening sector. This suggests that the physical processes that control the storm time behavior of topside ionospheric response to storms are altitude-dependent.

Geophysical conditions of the March 2015 storm

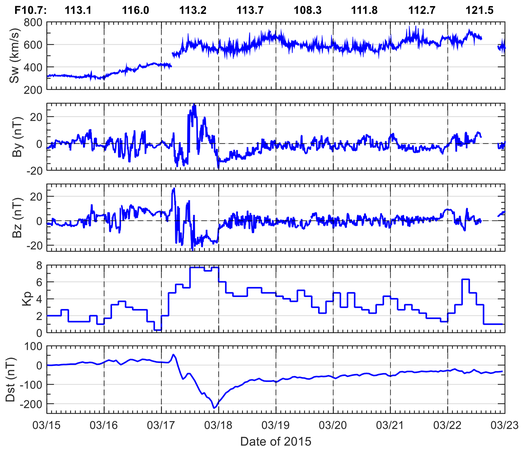

Figure 1. Variations of solar $F_{10.7}$ flux, solar wind speed, IMF B_y and B_z components, geomagnetic activity index *Kp, and* ring current index *Dst* during 15–22 March 2015.

Upward-looking TEC database

The upward-looking TECs are measured between LEO satellites and GPS satellites (20,200 km). The cutoff elevation angle of TEC is set as 40°.

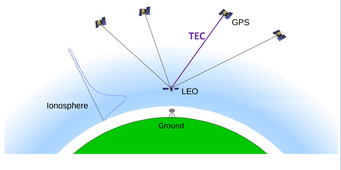

Table 1. Orbit information for LEO satellites during 15-22 March.

Satellite	Altitude	Orbit	Local Time	Inclination
GRACE	410 km	Near-polar	05:35 / 17:35	89°
TSX	520 km	Sun-synchronous	06:01 / 18:01	97.44°
Swarm-A	467 km	Near-polar	07:36 / 19:36	87.4°
Swarm-B	520 km	Near-polar	09:14 / 21:14	88°
MetOp-A	832 km	Sun-synchronous	09:31 / 21:31	98.7°

Upward-looking TEC observations

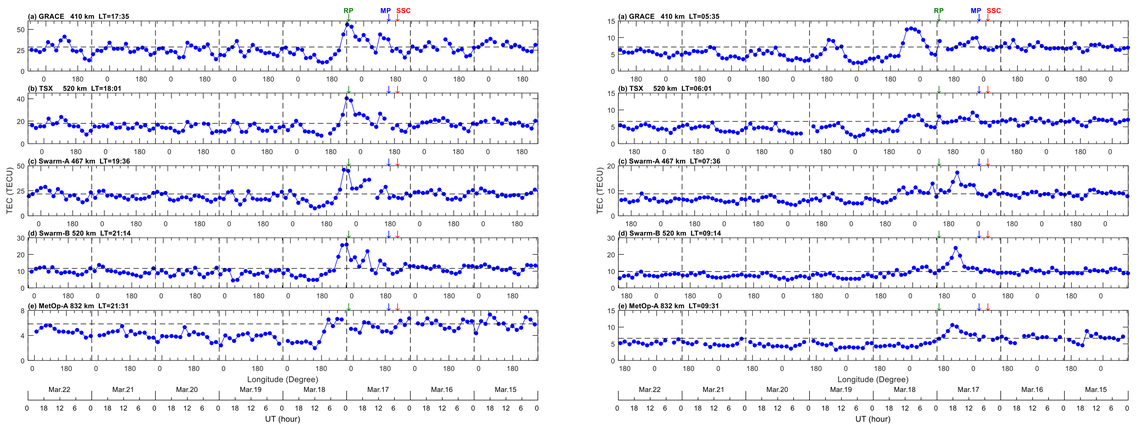

Figure 2. Variations of mean TECs as a function of equator crossing longitude and UT during 15-22 March (time from right to left). The TECs from –30° to 30° magnetic latitudes are used. The horizontal dashed lines indicate the averaged mean TEC during 15-16 March.

- **TEC depletion persisted for many days. Most of the TECs on 22 March were still below the quiet levels.**

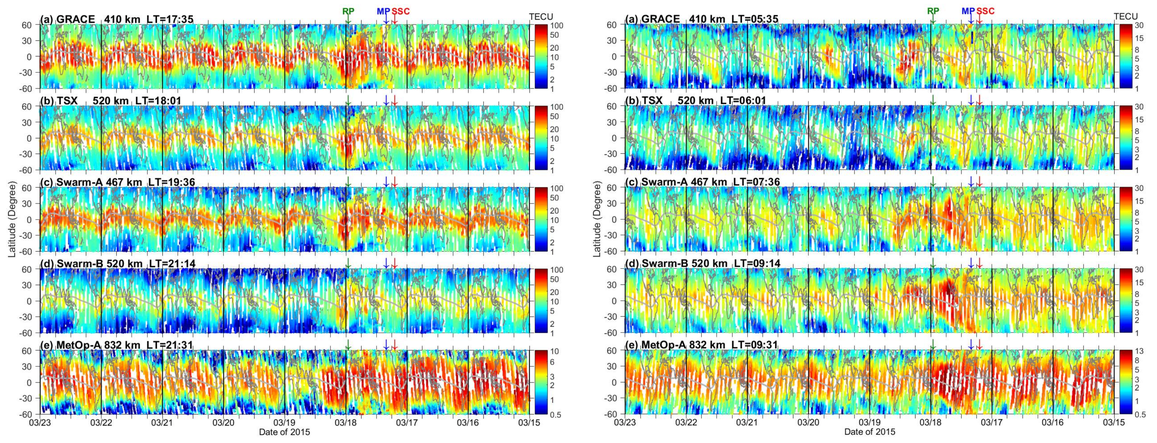

Figure 3. Variations of the upward-looking TECs as a function of latitude and longitude during 15-22 March.

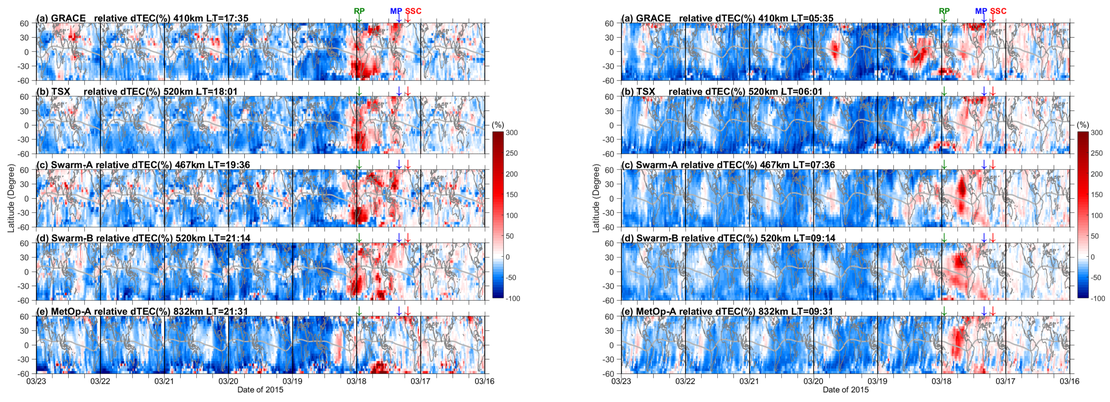

Figure 4. Percentage changes of the upward-looking TECs during 16-22 March, compared with the quiet time values on 15 March.

- **Topside ionospheric depletion was relatively larger at higher altitudes and at local times closer to midnight.**
- **The MetOp-A TECs on 17-18 March showed quite different variations from other TECs.**

O/N_2 ratio observations

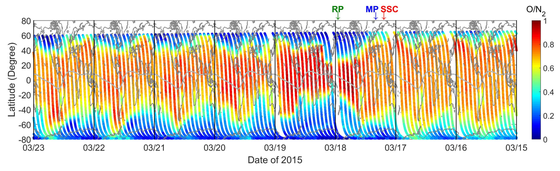

Figure 5. Variations of O/N_2 from GUVI as a function of latitude and longitude during 15-22 March.

- **Long-duration depletion of O/N_2 at high latitudes.**
- **F_2 peak region is affected by neutral composition.**

Structure of geomagnetic field line

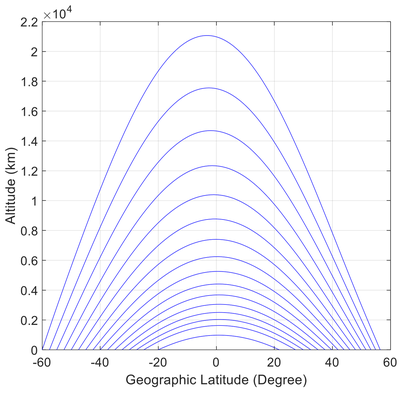

Figure 6. Variations of geomagnetic field line from IGRF as a function of altitude and latitude around 195° longitude.

- **The topside ionosphere is connected to the F_2 peak region at higher latitudes.**

Longitudinal pattern of TEC

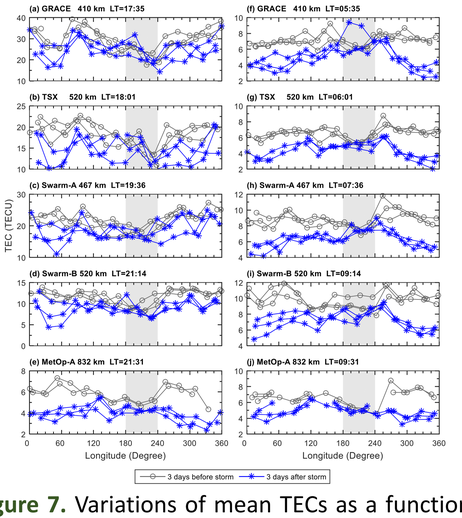

Figure 7. Variations of mean TECs as a function of equator crossing longitude for 14-16 March (grey) and 19-21 March (blue). The TECs from –30° to 30° magnetic latitudes are used.

- **TECs over the Pacific Ocean were not depleted.**

Conclusions

1. **The topside ionospheric TEC depletions lasted for many days at low and middle latitudes at most longitudes except those corresponding to the Pacific Ocean during the entire storm recovery phase. Since the magnetic field lines in the topside ionosphere are connected to the F_2 peak region at higher magnetic latitudes, the field-aligned plasma diffusion effect and the long-lasting low O/N_2 ratio in the F_2 peak region at higher latitudes might play significant roles in producing the long-duration TEC depletion in the topside ionosphere.**
2. **During the recovery phase, the topside ionospheric depletion depended on local time during the recovery phase; the depletion was relatively stronger at local times closer to midnight.**
3. **The MetOp-A TEC (832km) showed a quite different pattern compared with other TECs measured by lower altitudes satellites during the main phase and at the beginning of the recovery phase. This suggests that the physical processes that control the storm time behavior of topside ionospheric response to storms are altitude-dependent.**
4. **The combined observations also reveal that the topside ionospheric TEC recovery rate is strongly dependent on longitude. During the long recovery, the upward-looking TECs over the Pacific Ocean region were not depleted, and roughly comparable to the quiet-time ones, especially in the morning sector.**

Zhong, J., W. Wang, X. Yue, A. G. Burns, X. Dou, and J. Lei (2016), Long-duration depletion in the topside ionospheric total electron content during the recovery phase of the March 2015 strong storm, *J. Geophys. Res.*, *121*, doi:10.1002/2016JA022469.