Polar cap plasma transport during geomagnetic superstorm

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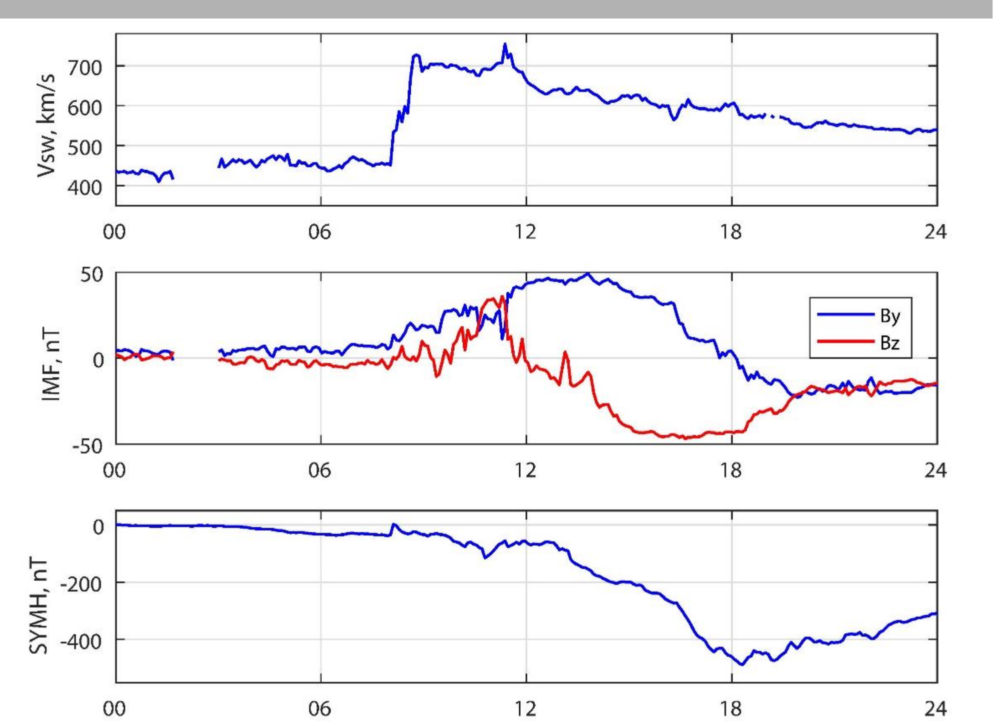
Abstract

Positive plasma anomalies appear during the main phase of geomagnetic storms at (sub)auroral latitudes, extending across the polar cap as tongue of ionisation (TOI). Physical mechanisms of TOI, including electrodynamic plasma transport and neutral wind forcing, are simulated with TIE-GCM during the superstorm of Nov. 2003. The simulations are compared with TEC observations and GNSS tomography. The electrodynamic transport (vertical ExB component in particular) is identified as the main mechanism controlling TOI anomaly during great storms (Dst < -300 nT). This makes the choice of high-latitude convection model critical for simulations.

Superstorm of Nov. 2003

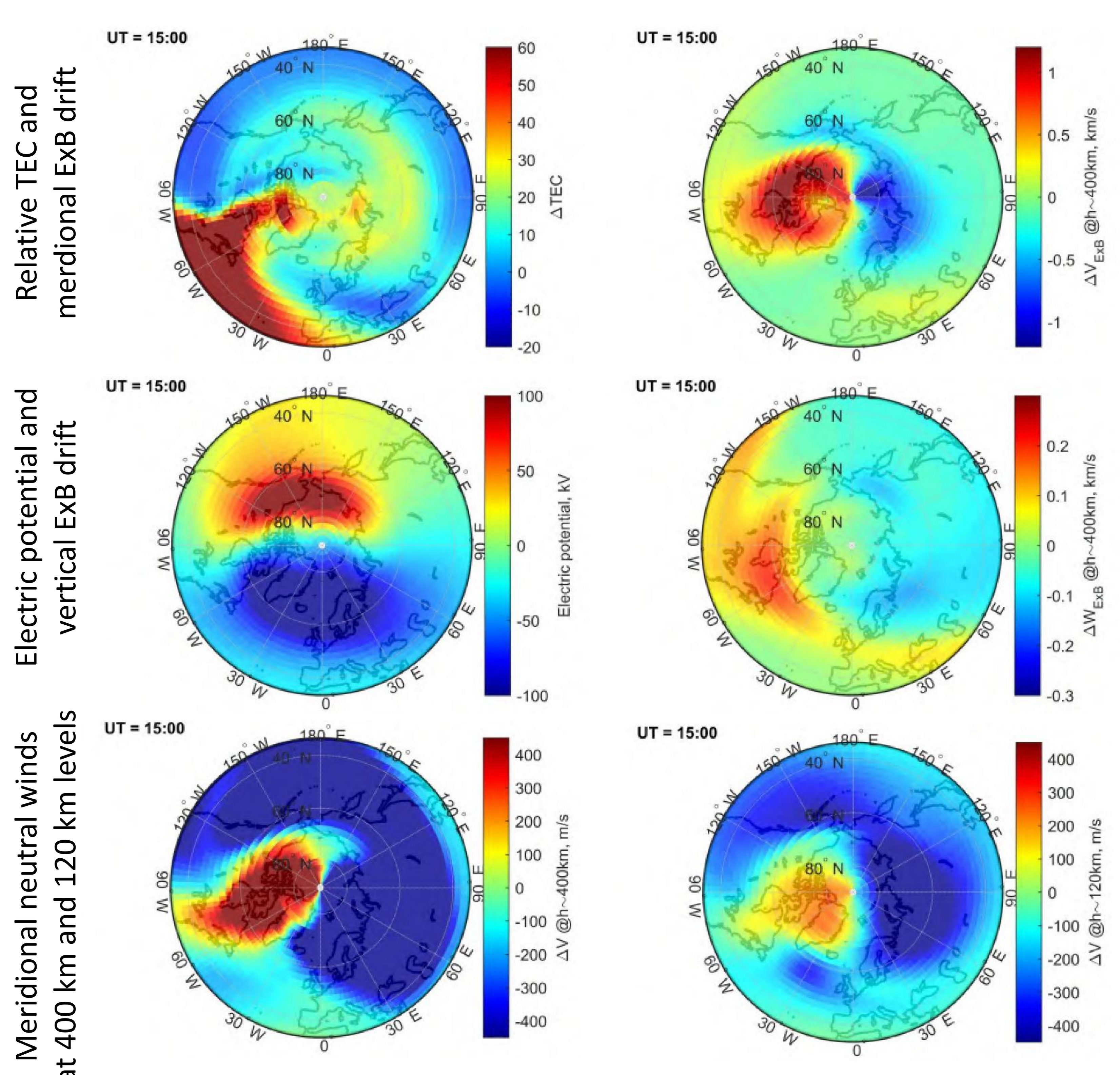
The largest storm (in Dst) recorded by modern instrumentation.

TOI dynamics studied by radars (Foster et al., 2005) and GNSS tomography (Pokhotelov et al., 2008), showing extreme ExB expansion to mid-latitudes.

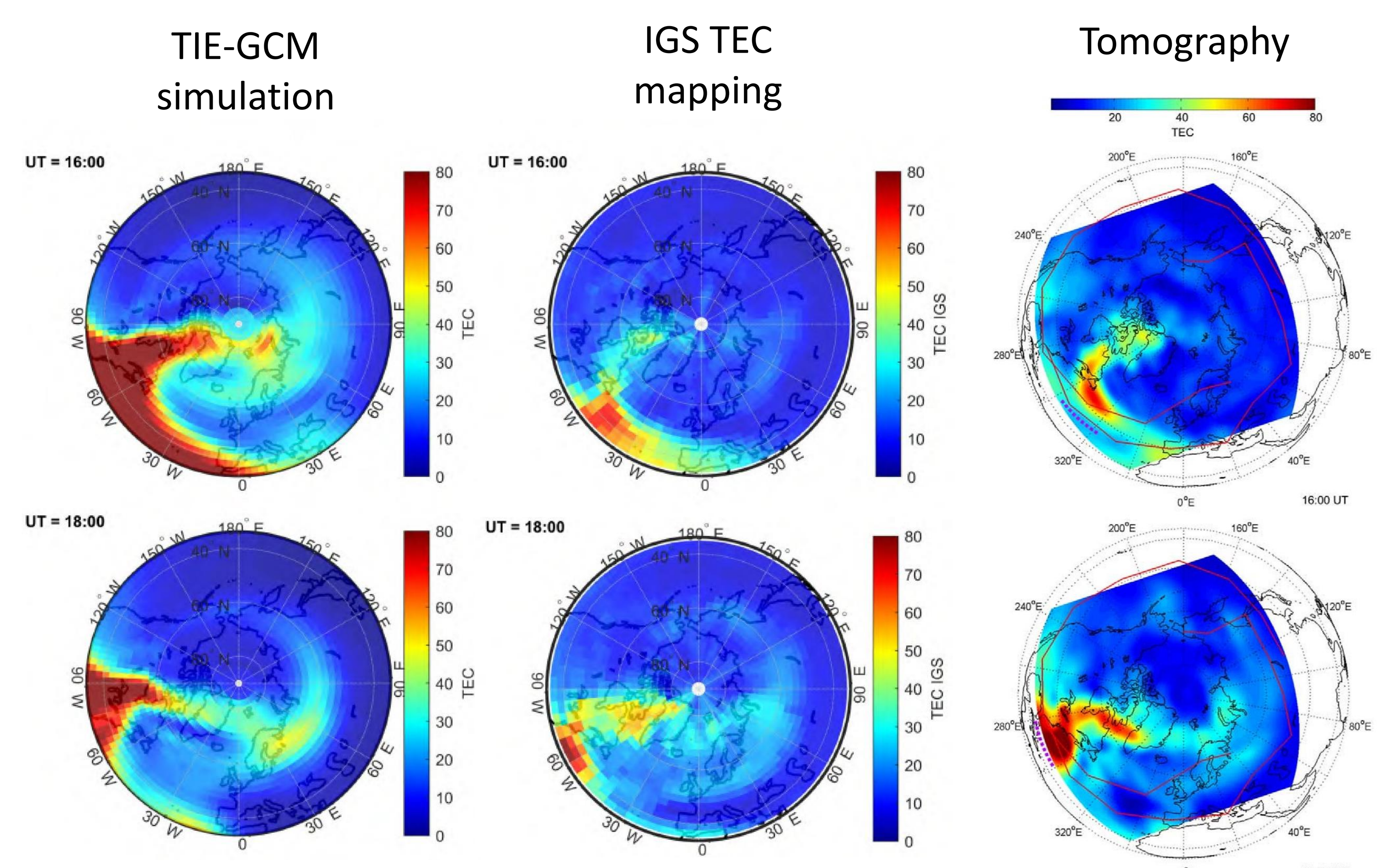


Simulations of polar cap transport

TIE-GCM is the first-principle model simulating global ionospheric dynamics at ~97 - 600 km altitudes with horizontal resolution of 2.5 deg. The ExB forcing is provided by the Wiemer model.



Relation to TEC data and tomography



MIDAS tomography and DMSP ExB observations (red lines) from Pokhotelov et al. 2008.

Conclusions

TIE-GCM with Weimer convection simulates the TOI dynamics that is generally consistent with IGS TEC and GNSS tomography. TEC magnitudes (SED and TOI) are over-estimated by TIE-GCM, as also seen in moderate storm simulations (e.g., Liu et al., 2016).

Vertical ExB component due to the convection expanded to mid-latitude (below 40° MLat) and horizontal ExB cross-polar transport are the main factors controlling the TOI formation during the superstorm.

Meridional neutral winds are enhanced by the cross-polar plasma transport but playing a passive role in the TOI formation.

The choice of plasma convection model plays a key role in the polar cap plasma transport. Simulations driven by assimilative electrodynamics (e.g., AMIE) or by storm-time ExB observations (e.g., SuperDARN) should be used for great storms.

References

Pokhotelov, D., Mitchell, C. N., Spencer, P. S. J., Hairston, M. R., Heelis, R. A.: Ionospheric storm time dynamics as seen by GPS tomography and in situ spacecraft observations, JGR, 113, do:10.1029/2008JA013109, 2008.

Pokhotelov, D., Fernandez-Gomez, I., Borries, C.: Polar tongue of ionisation during geomagnetic superstorm, Ann. Geophys., doi:10.5194/angeo-2021-19, in discussion, 2021.

Data: IGS TEC data from NASA CDAWeb. Solar wind and geomagnetic data from NASA OMNIWeb. TIE-GCM is an open-source model from NCAR HAO. MIDAS tomography software is from the Univ. of Bath.

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