Modeling Sudden Stratospheric Warming Events Using the Ionosphere-Plasmasphere Electrodynamics Model

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I. Abstract

Sudden Stratospheric Warming (SSW) events are large meteorological disturbances where the northern winter stratospheric westerly winds slow down or reverse direction. The perturbation is associated with a breakdown in the northern polar vortex, a rise in stratospheric temperature by several tens of degrees, as well as various anomalies in the atmosphere at higher altitudes, including the ionosphere. This is an important area of study in order to understand the connection between the terrestrial and space weathers during these events. Previous studies have used ionospheric simulations to investigate the effect on the ionosphere due to the forcing from SSW events. However, it has been difficult to quantitatively reproduce the observed ionospheric response.

In this work, the Ionosphere-Plasmasphere Electrodynamics (IPE) model has been used to investigate the response of the ionosphere during SSW events. We first illustrate the model's validity by comparison with other models and observations. We then demonstrate the ability of the IPE model to reproduce to first order the observed ionospheric response to the large SSW event of January 2009. We study the direct impact of the equatorial drift deviations during the SSW event on the variations of main ionospheric parameters and investigate the role of the coupling between ionosphere and plasmasphere in reproducing the observations.

II. The IPE Model

IPE is a physics-based ionosphere-plasmasphere model recently developed at NOAA SWPC (Maruyama et al. 2013).

Model components:
❖ Global ionosphere-plasmasphere model based on the Field Line Interhemispheric Plasma Model (Richards and Torr, 1996)
❖ Ionospheric potential solver (Richmond et al. 1992)
❖ APEX magnetic field coordinate system based on the International Geomagnetic Reference Field (Richmond 1995)

Major outputs of the model:
❖ Plasma densities and parallel velocities (continuity and momentum eqs.); ion and electron temperatures (energy eqs.)

Key features of the IPE model:
❖ includes coupling between ionosphere and plasmasphere
❖ combines flux tube coordinate system with IGRF coordinate system
❖ includes self-consistent calculation of photoelectron flux

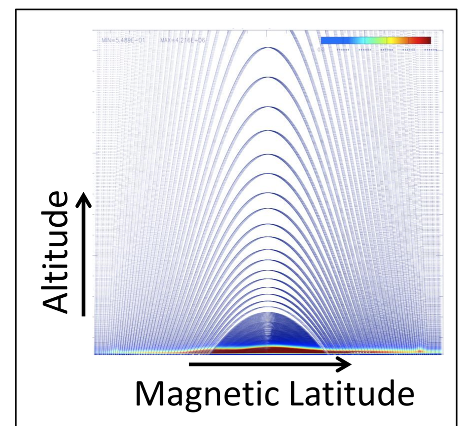

Fig. 1: IPE plot of electron density in the plasmasphere illustrating magnetic field coordinates.

III. Model Validation

IPE was qualitatively compared with:
❖ Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation Model (TIME-GCM)
❖ International Reference Ionosphere (IRI) empirical model
❖ Constellation Observing System for Meteorology, Ionosphere, & Climate

Ionospheric parameters used for comparison:
❖ Peak electron density in the F2 region of the ionosphere (NmF2)
❖ The height at which the peak electron density occurs (hmF2)
❖ Total Electron Content (TEC)

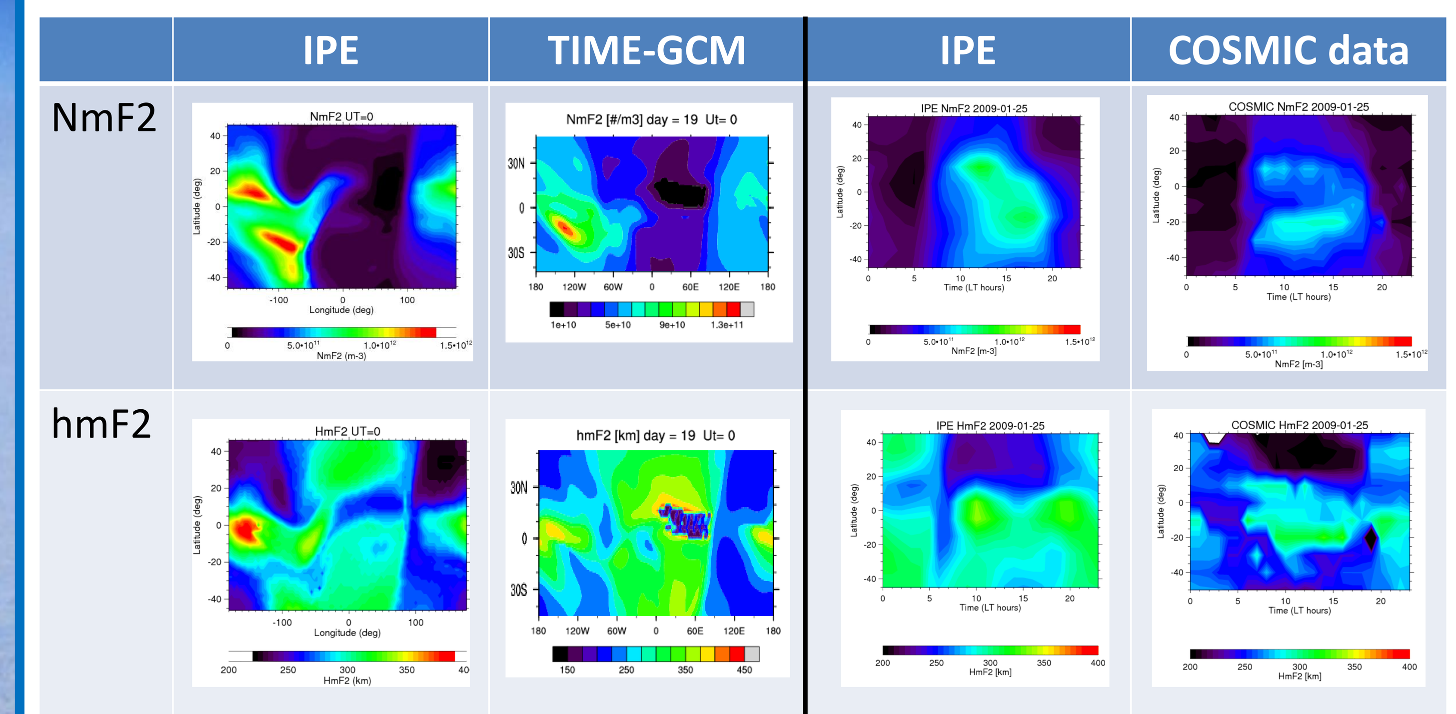

Fig. 2: Comparisons of NmF2 and hmF2 between IPE and TIME-GCM for January 19, 2009 (beginning of SSW event), UT=0, and F10.7=70 for IPE.

Fig. 3 Comparisons of binned and longitudinally averaged NmF2 and hmF2 between IPE and COSMIC data for January 25, 2009 (during SSW event), and F10.7=70.

IV. TEC Anomalies: Comparing IPE Output with Observations during the January 2009 SSW Event

Source of TEC Anomalies

Background: Equatorial vertical drift

Thermospheric winds in the dynamo region (90~ 200 km) generate electric fields. At the magnetic equator, plasma drifts upward in the ExB direction during the day (E: eastward; B: northward). Recombination of ions and electrons is slower at higher altitudes, so plasma becomes denser. Plasma eventually drifts down the field lines due to pressure and gravity forces, creating the Equatorial Ionization Anomaly (EIA).

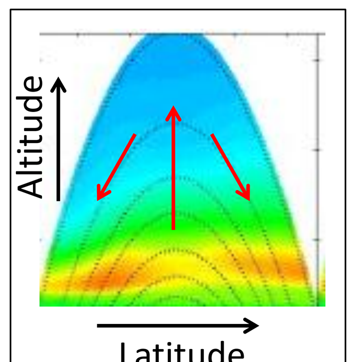

Fig. 4: Plot of electron density as a function of altitude and latitude illustrating the Equatorial Ionization Anomaly.

Effects during SSW events:

During SSW events the thermospheric winds are disturbed due to lower atmospheric forcing, which causes deviations in vertical drift and TEC. During the January 2009 SSW event, the vertical drift was higher than normal in the morning and lower than normal in the afternoon (Figure 5). Increased morning drift lifts plasma to higher altitudes where recombination is slower, so plasma density is increased. The opposite effect occurs in the afternoon.

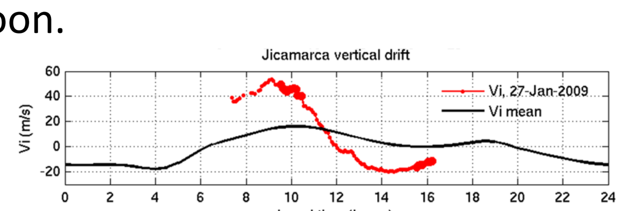

Fig. 5: Jan 27, 2009 vertical drift from Jicamarca compared to climatological drift. (Goncharenko et al 2010b)

IPE TEC Anomalies vs. Observation

The IPE model was driven with observed ExB drift data (Goncharenko et al 2010b) for January 17-31, 2009. We examined the TEC difference as a function of local time and latitude at 75°W (Figure 6).

IPE reproduces the qualitative day-to-day variability during the SSW event.

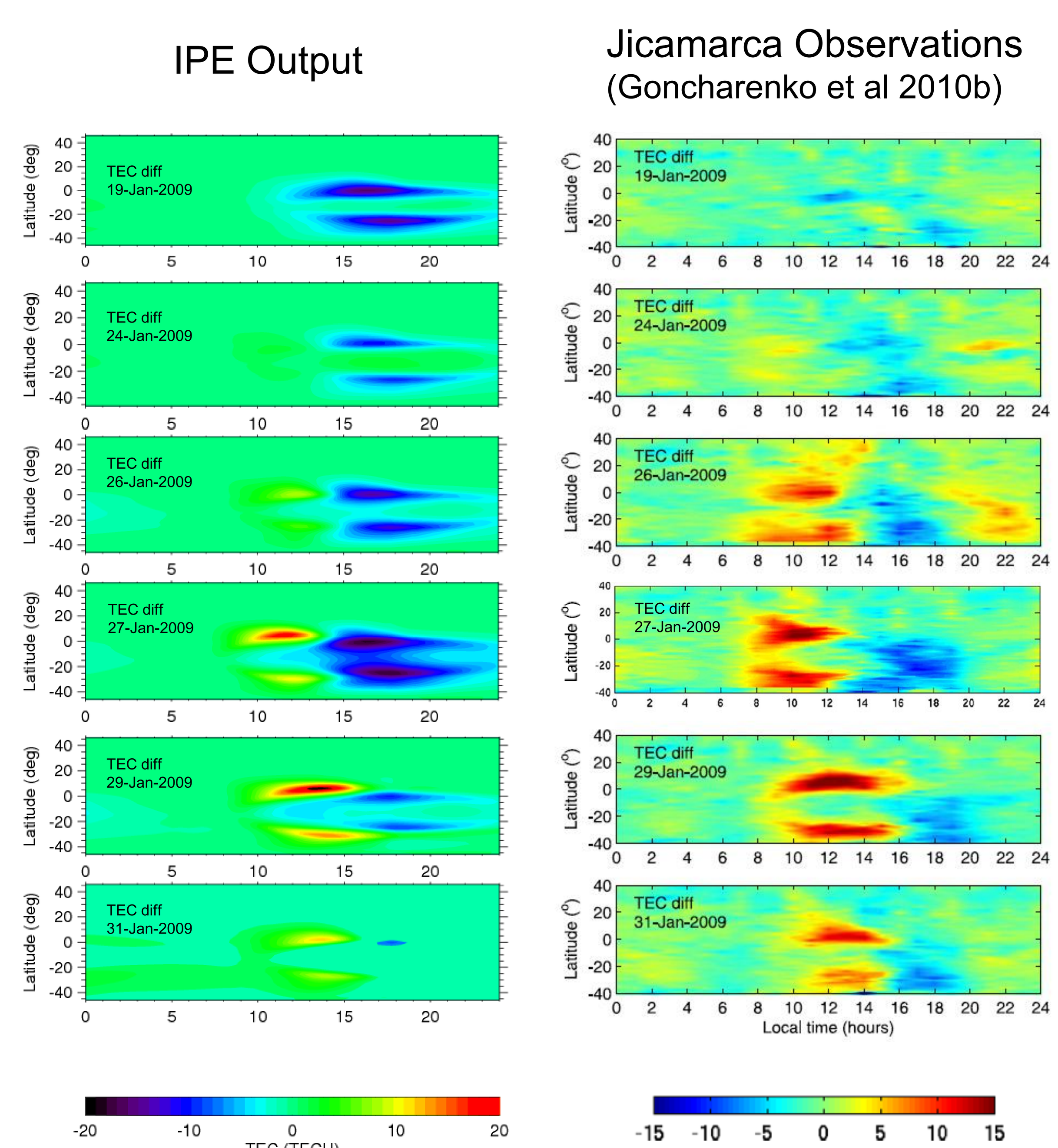

Fig. 6: Comparison of TEC differences as a function of latitude and local time at 75°W from IPE output (left) and Jicamarca observations (right) for select days during the January 2009 SSW. The difference was taken from January 17th for the IPE output and from a 10-day mean prior to the SSW event for the observed TEC differences.

Role of the Plasmaspheric TEC Content

We investigated the amount of TEC within altitude bands and the percentage of TEC below 400 km (at the top of the thermosphere during the period) (Essex et al. 1998). During the event, the contribution of plasmaspheric content (above 400 km) of TEC reached up to more than 50% at 10 LT but decreased to 25% with little latitudinal variation at 15 LT.

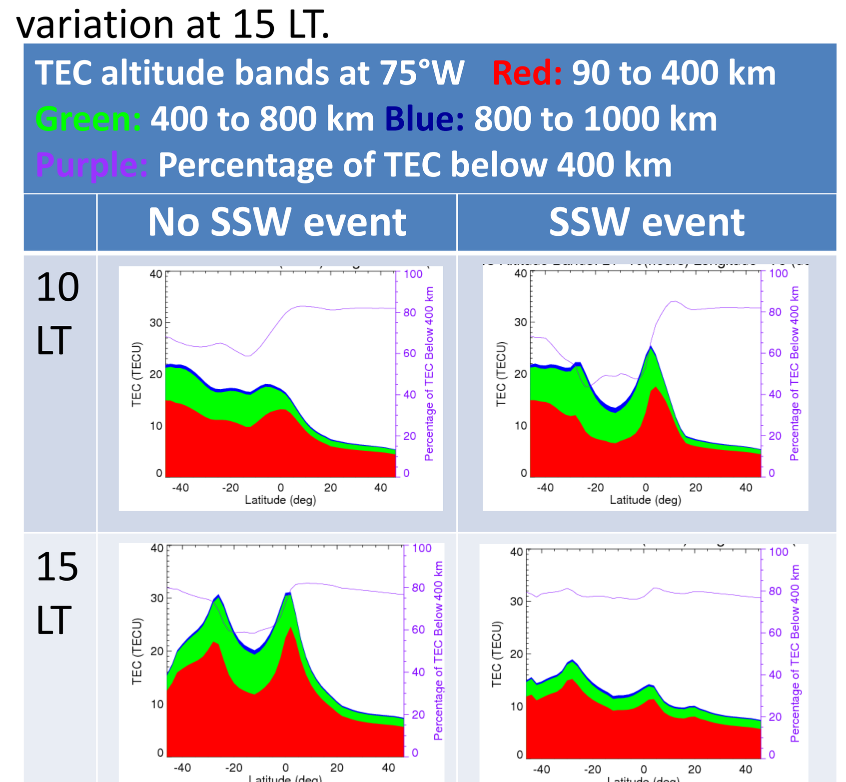

Fig. 7: Electron content contributions from 90 to 400km, 400 to 800km, and 800 to 1000km and percentage of TEC below 400 km as a function of latitude at 75°W. Plots are shown for 10 LT and 15 LT during the January 27, 2009 event and non-event.

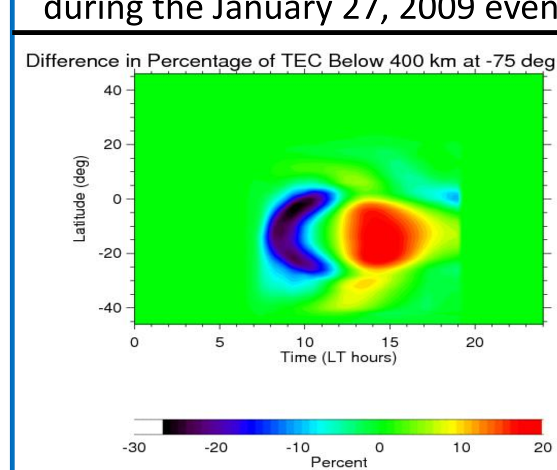

Fig. 7: Difference in percentage of TEC below 400 km (event minus non-event) as a function of latitude and local time at 75°W.

V. Conclusions and Further Research

IPE was driven with Jicamarca observed drift to study the ionospheric response during the January 2009 SSW event. The IPE results demonstrated:
❖ IPE ionosphere has reasonable agreement with other models and observation
❖ IPE captured the day-to-day variability of the ionospheric response during the SSW event
❖ the importance of plasmaspheric content in reproducing the ionospheric response

Future work:
❖ Investigate relative contribution between neutral wind and ExB drift
❖ Study other SSW events as observation becomes available

VI. References

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VII. Acknowledgements

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