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

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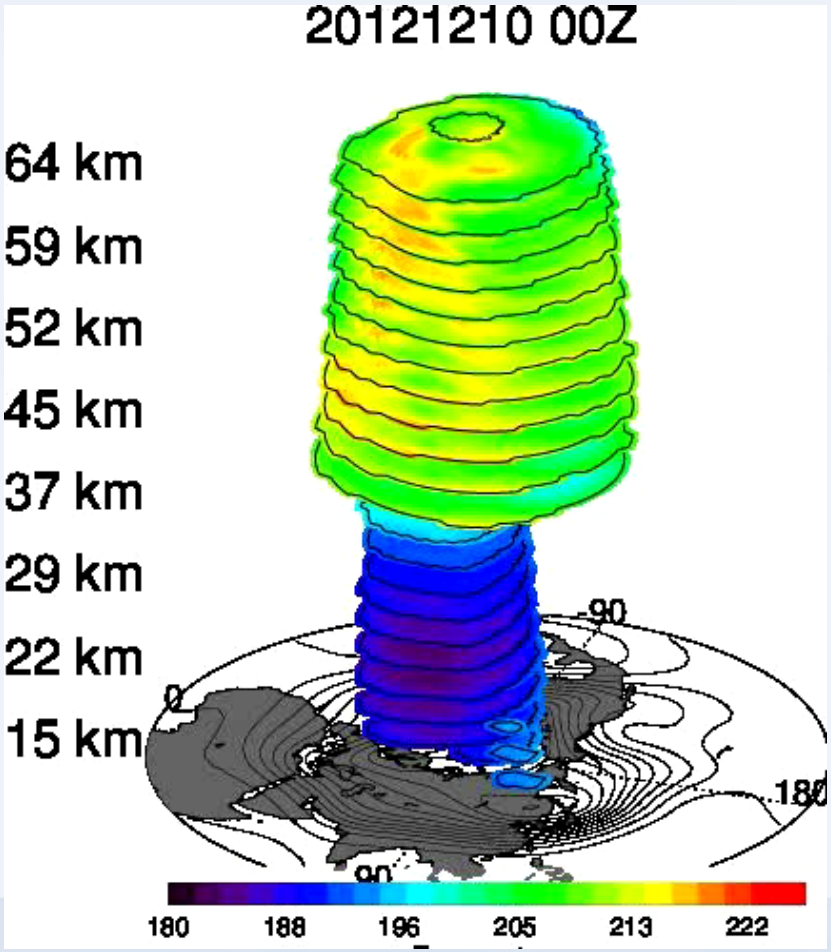
Outline

1. What is a SSW event?
2. Atmosphere-ionosphere coupling during SSW events
3. Project Motivation and Objectives
4. Ionosphere-Plasmasphere Electrodynamics (IPE) Model
5. Model Comparisons
6. SSW vs. no SSW IPE runs
7. January 2009 SSW event runs
8. Conclusions and Further Research

What is a Sudden Stratospheric Warming (SSW) event?

- Abrupt disturbance in the northern Stratospheric westerly winds
  - Break down and/or direction change of polar vortex over a few days
  - Increase in Stratospheric temperature
  - Abnormal conditions in upper atmosphere

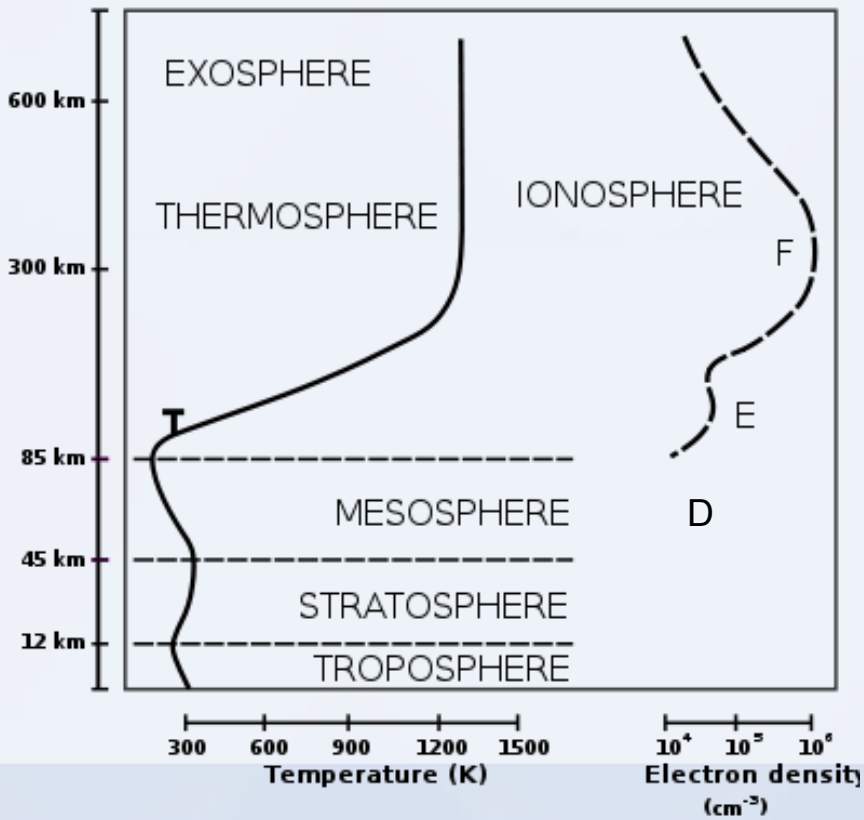
Polar vortex reversal



L. Harvey, CEDAR Workshop 2013

Atmosphere-Ionosphere Coupling during SSW Events

- Indirect coupling via the ionospheric E-region dynamo



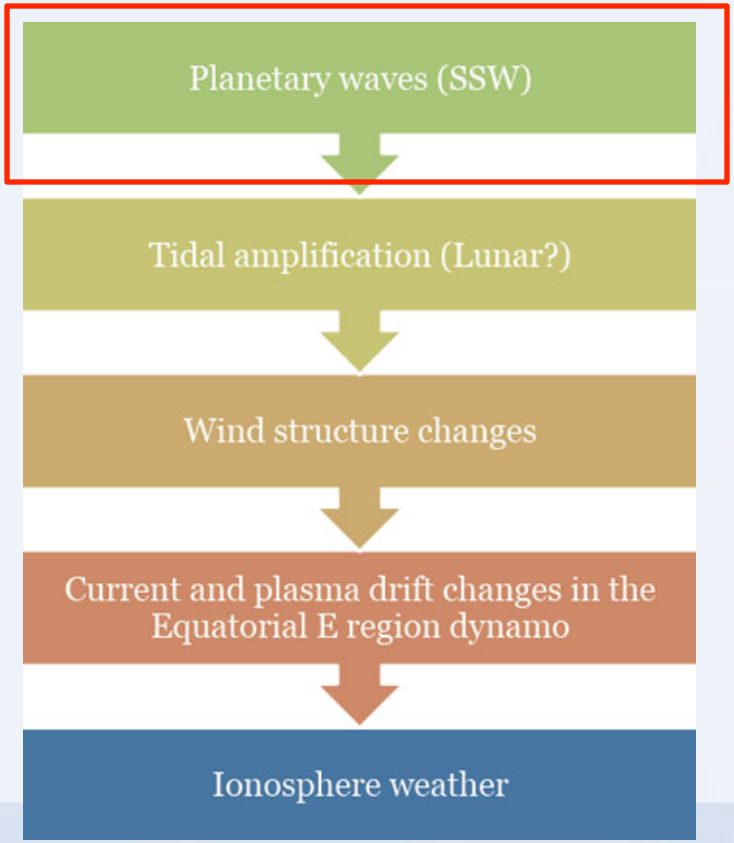
http://en.wikipedia.org/wiki/Ionosphere

Atmosphere-Ionosphere Coupling during SSW Events

- Indirect coupling via the ionospheric E-region dynamo

<u>Planetary waves</u>: longer-period global oscillations which are either stationary (fixed to the Earth) or zonally propagating in either direction

Upward propagating effects of planetary waves interact nonlinearly with zonal (latitudinal) winds (Matsuno 1971)

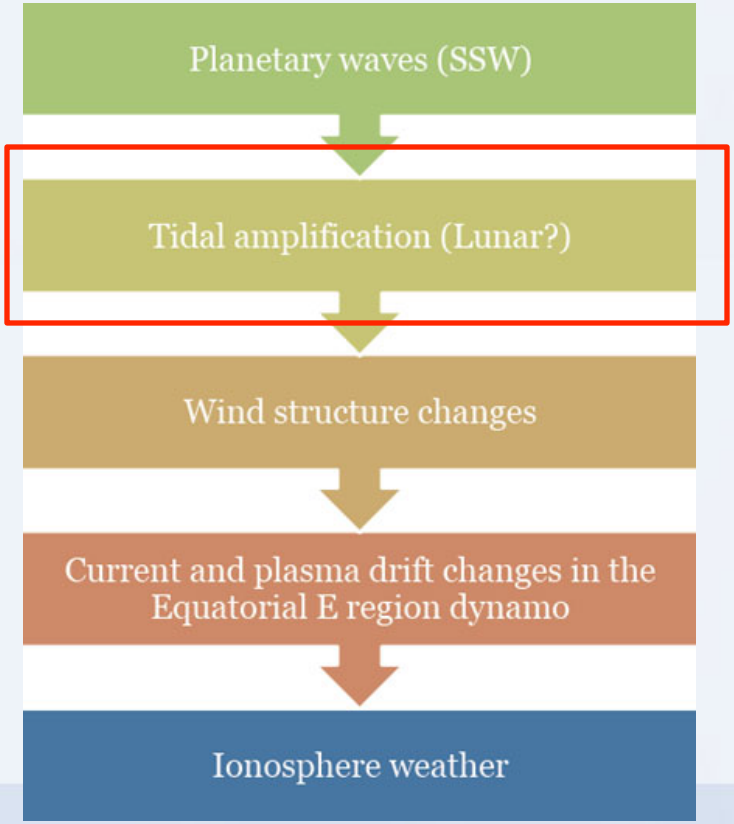


Chau et al. 2011

Atmosphere-Ionosphere Coupling during SSW Events

- Indirect coupling via the ionospheric E-region dynamo

Solar atmospheric tides are caused by the periodic heating of the atmosphere by the Sun
-Migrating/non-migrating do/don't propagate with the Sun's apparent motion
Lunar tides are migrating with the apparent motion of the moon

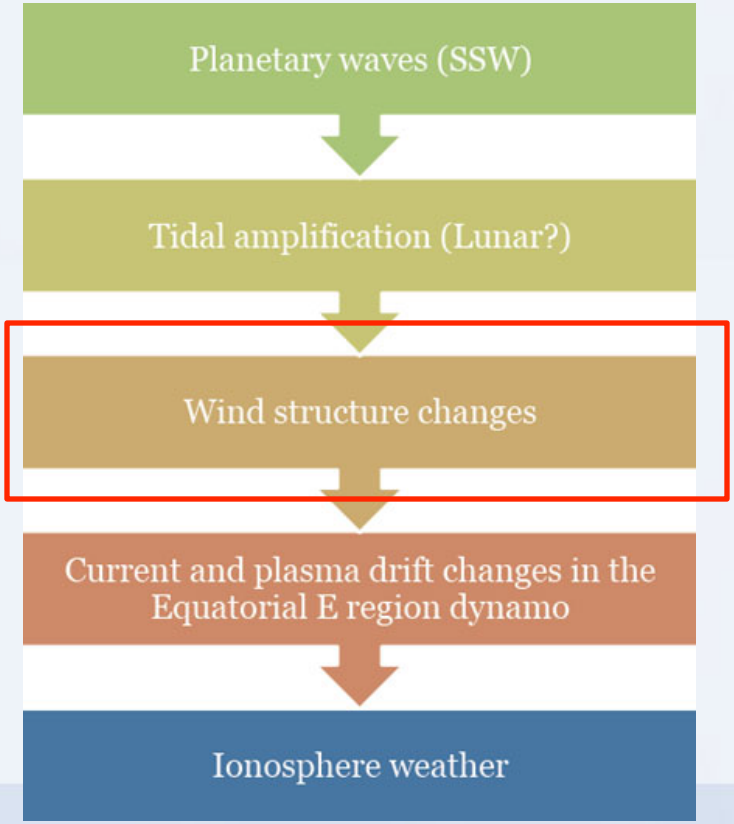


Chau et al. 2011

Atmosphere-Ionosphere Coupling during SSW Events

- Indirect coupling via the ionospheric E-region dynamo

Changes in tides perturb neutral Thermospheric winds

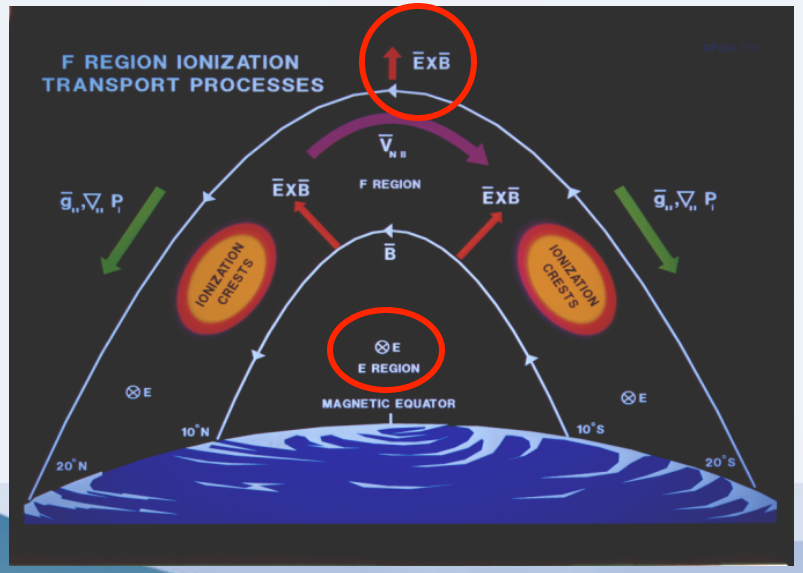


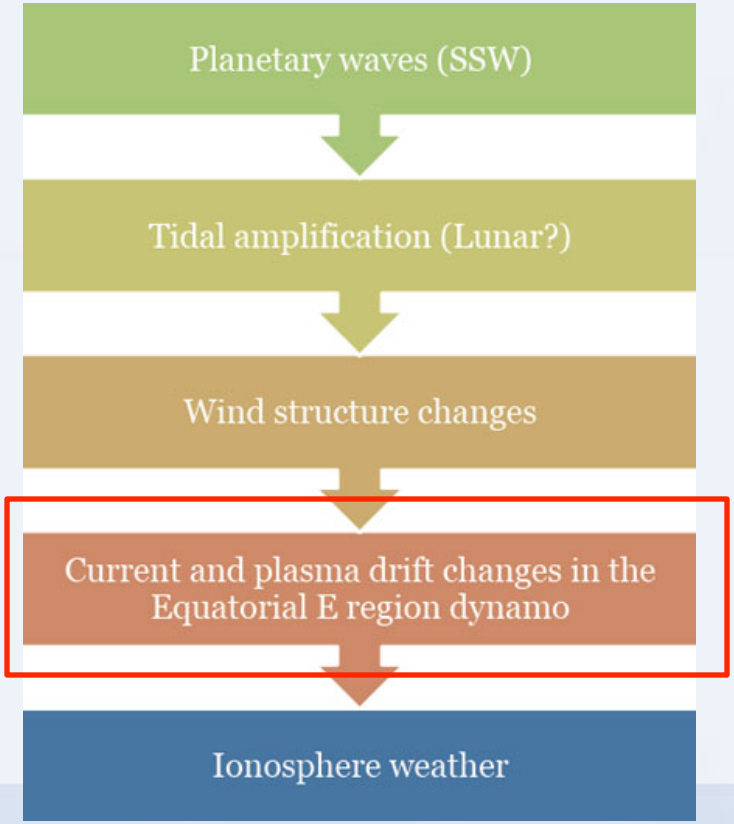
Chau et al. 2011

Atmosphere-Ionosphere Coupling during SSW Events

- Indirect coupling via the ionospheric E-region dynamo

Neutral Thermospheric winds produce E-region electric field, which yields ionospheric plasma drifts.



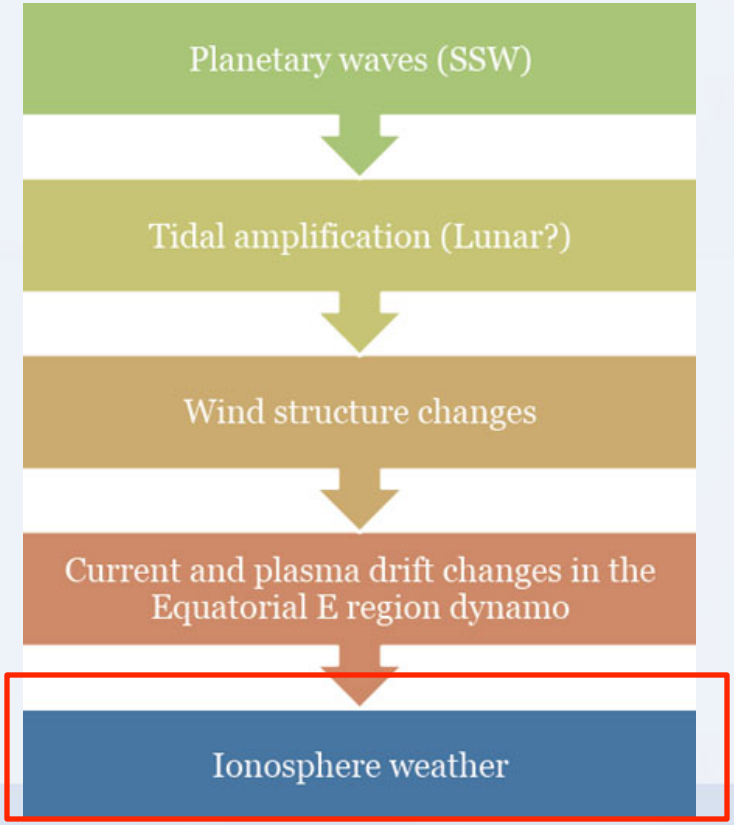


Chau et al. 2011

Atmosphere-Ionosphere Coupling during SSW Events

- Indirect coupling via the ionospheric E-region dynamo

Changes in plasma drifts leads to deviations in primary ionospheric characteristics.



Chau et al. 2011

Motivation and Objectives

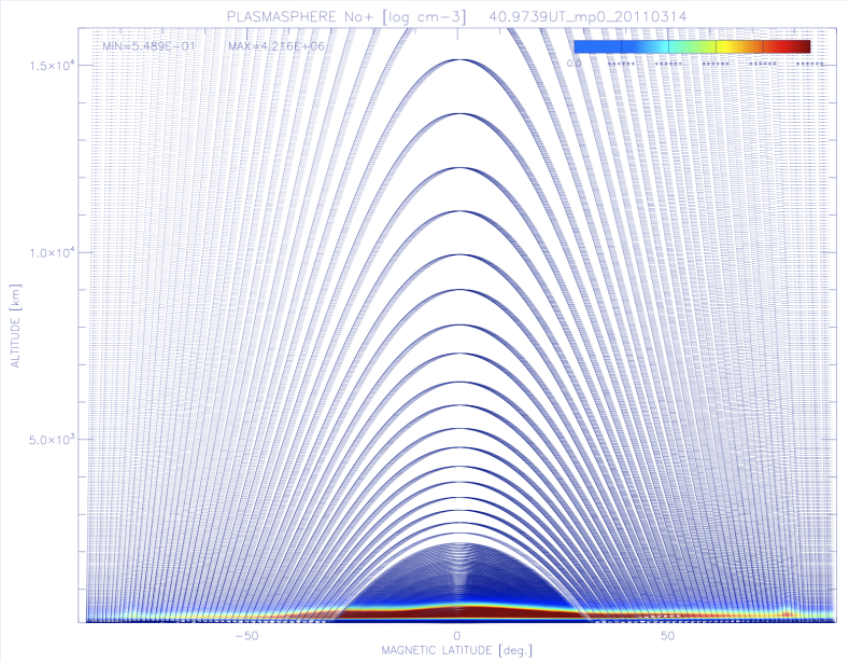
- Other models have worked to simulate the ionospheric forcing/response from SSW events, but it has been difficult to quantitatively reproduce the observed ionospheric response
- Investigate the ionospheric response to the observed ExB drift during the January 2009 SSW event
- Evaluate the role of ionosphere-plasmasphere coupling in the observed ionospheric response

Ionosphere-Plasmasphere Electrodynamics (IPE) Model

- Global ionosphere-plasmasphere model recently developed at NOAA SWPC (Maruyama et al. 2013)
- Based on the Field Line Interhemispheric Plasma Model (FLIP, Richards and Torr, 1996)
  - Ion densities and parallel velocities from equations of continuity and momentum
  - Electron and ion temperatures from energy equations
- Global potential dynamo solver (Richmond et al. 1992)
  - Calculates ionospheric currents
- APEX magnetic field coordinate system based on the International Geomagnetic Reference Field (IGRF, Richmond 1995)

IPE Model: Key Features

- Self-consistent coupling between ionosphere and plasmasphere
- Flux tube coordinate system
- Realistic model of Earth's magnetic field (IGRF)
- Thermosphere temperature, composition, and wind from empirical models
- Self-consistent photoelectron flux calculation

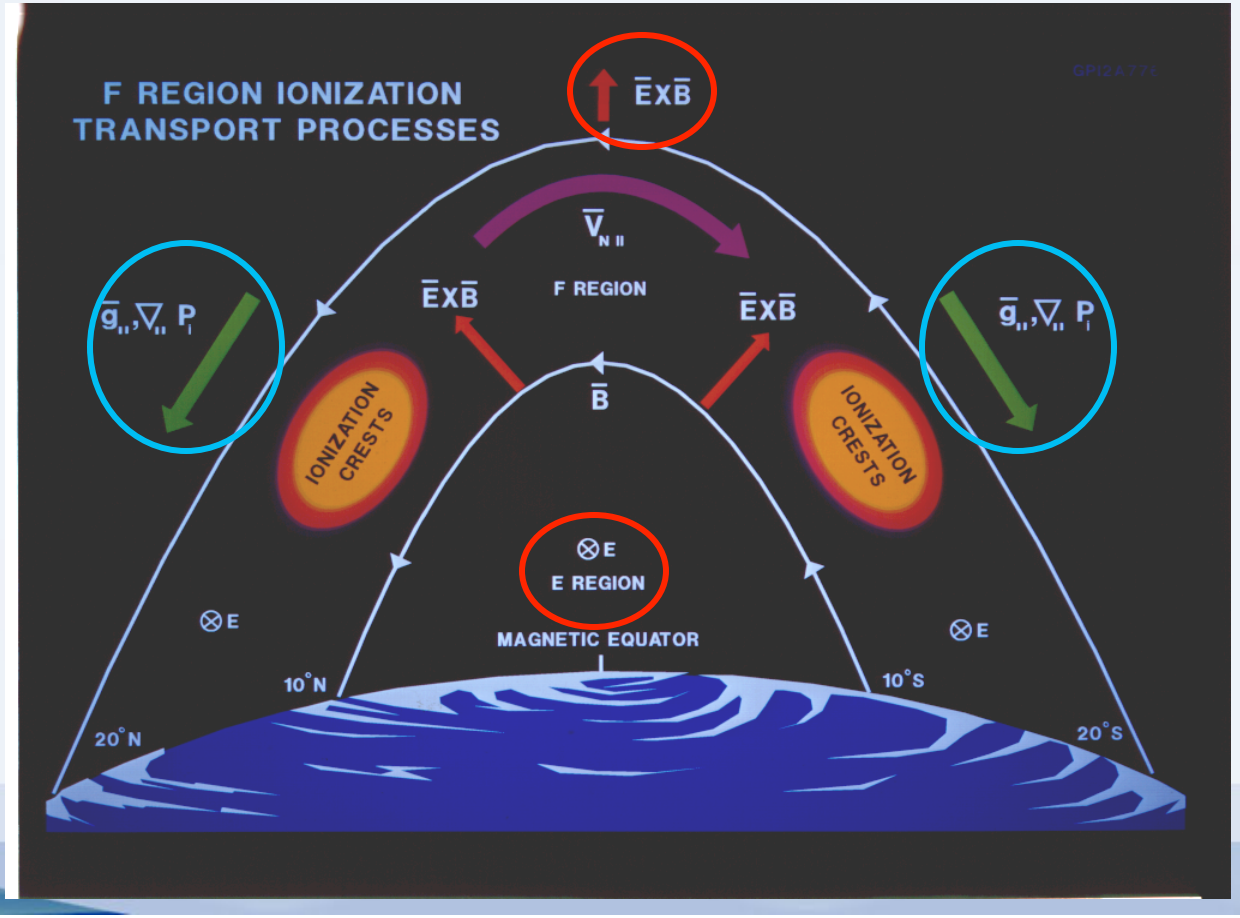


IPE flux tube coordinates

Ionospheric F-region Dynamics:

2 Main Drivers

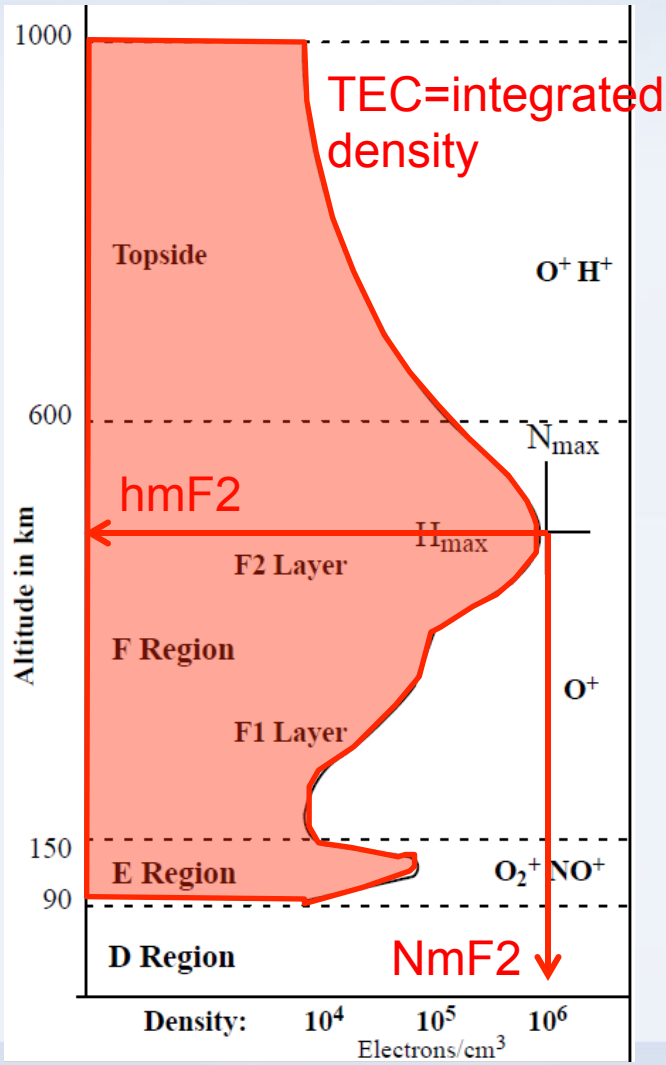
- Main drivers of F-region dynamics are electric field (ExB drifts) and neutral wind



Model Comparisons

- Must first validate IPE before running SSW events
  - TIME-GCM: Thermosphere Ionosphere Mesosphere Electrodynamics Global Circulation Model
  - IRI 2012: International Reference Ionosphere
  - COSMIC data: Constellation Observing System for Meteorology, Ionosphere, & Climate

Ionospheric Parameters



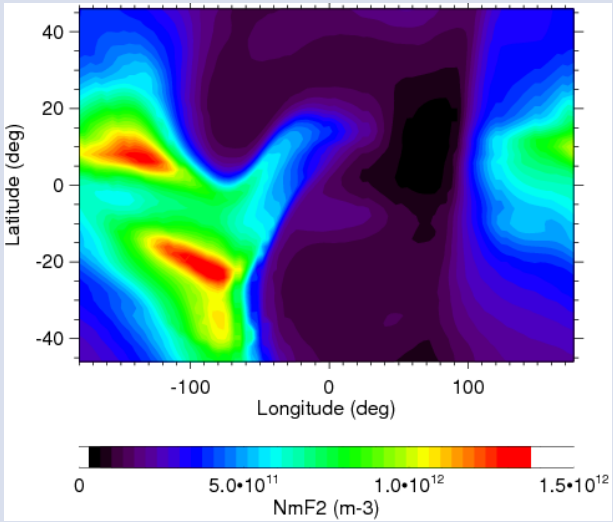
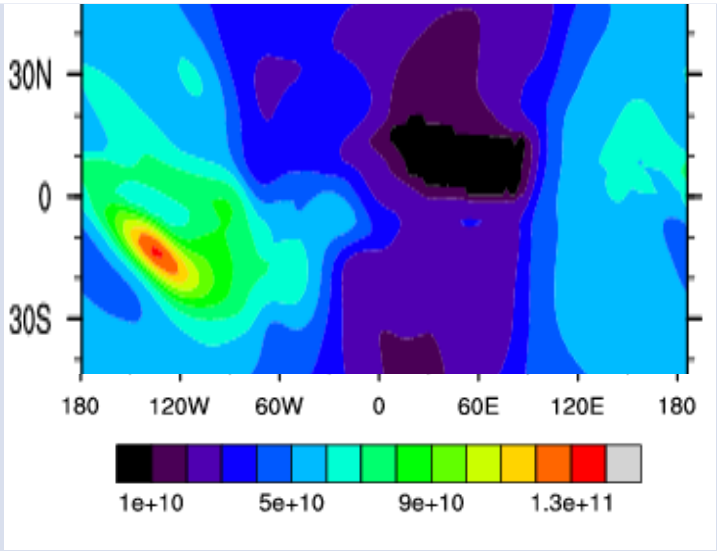
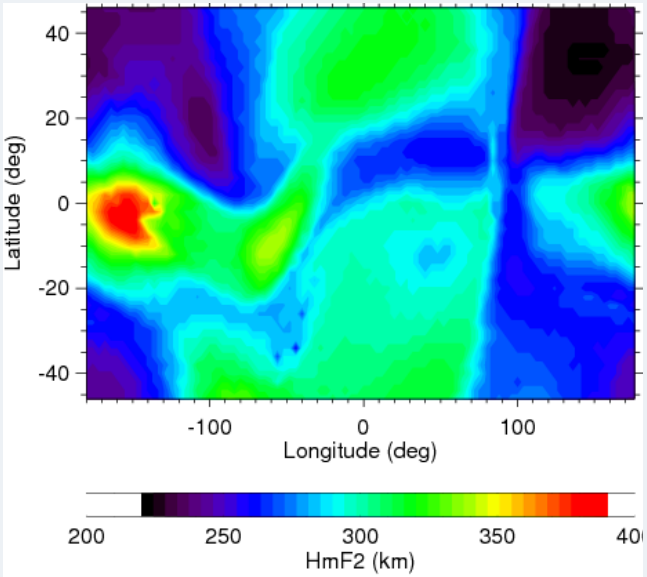
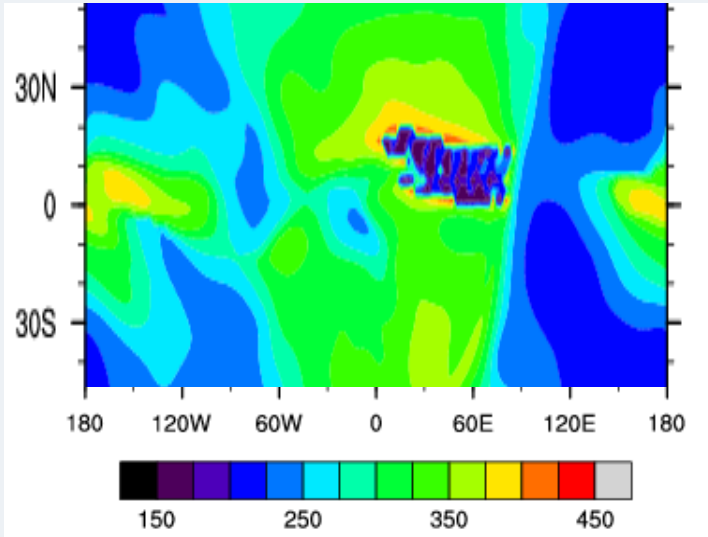
http://www.swpc.noaa.gov/info/Iono.pdf

NmF2: peak electron density in F2 region

hmF2: altitude of peak electron density

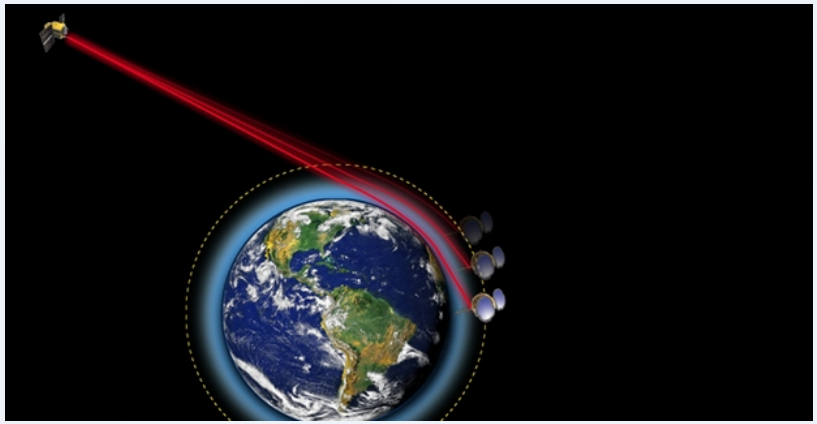
TEC: integral of electron density from satellite to ground

IPE vs. TIME-GCM: F10.7=70, Day=1-19-2009 (beginning of SSW event), UT=0

	IPE	TIME-GCM
NmF2		
hmF2		

IPE vs. COSMIC data

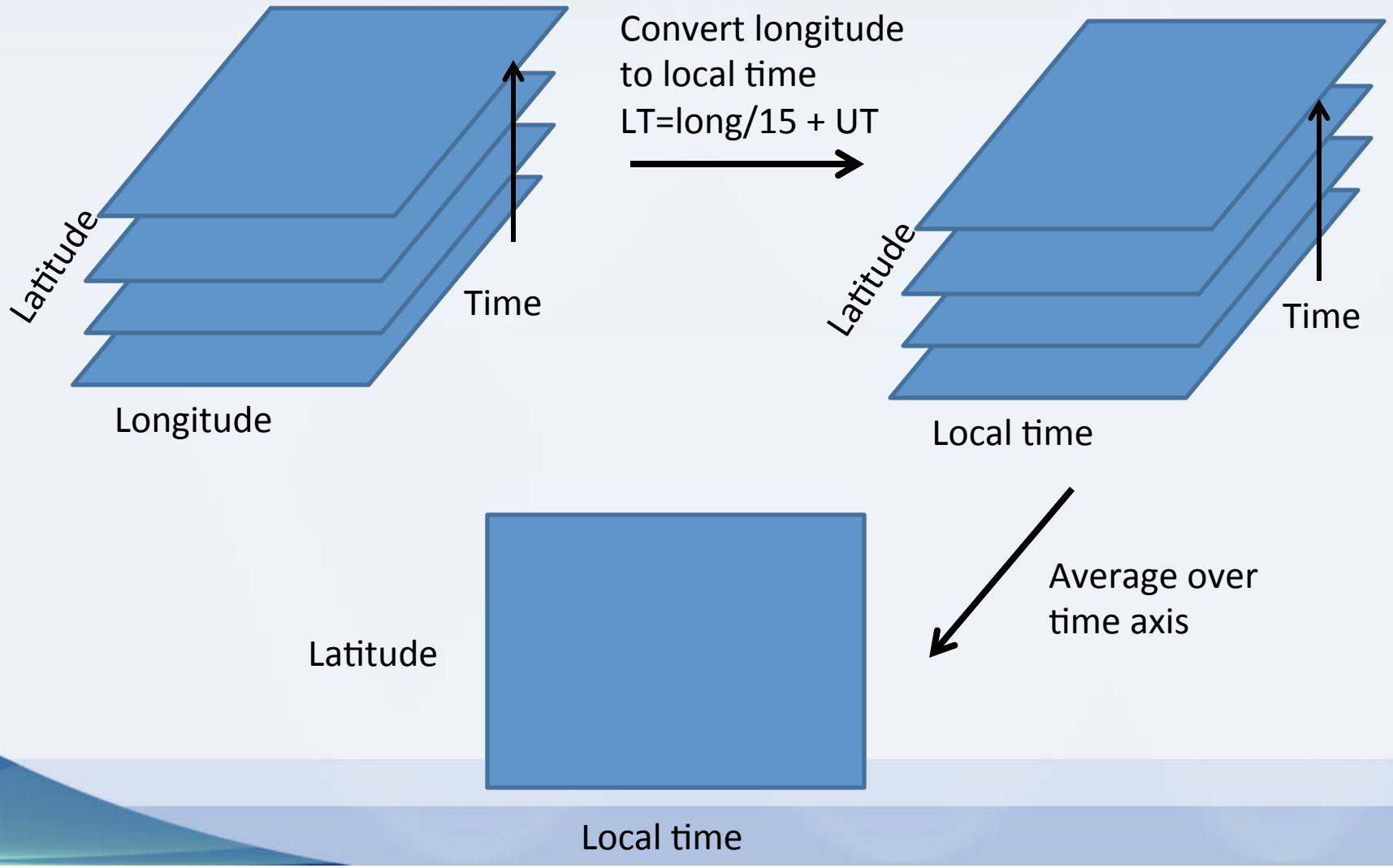
- Constellation Observing System for Meteorology, Ionosphere, & Climate
  - Set of 6 satellites taking radio signals from GPS as they pass through Earth's atmosphere



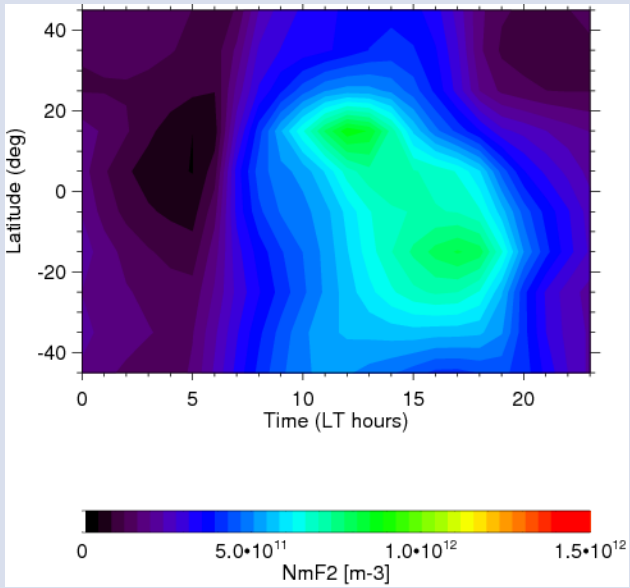
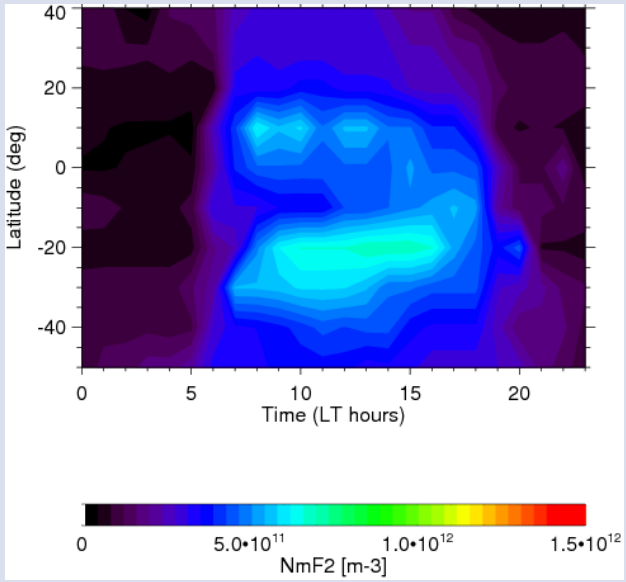
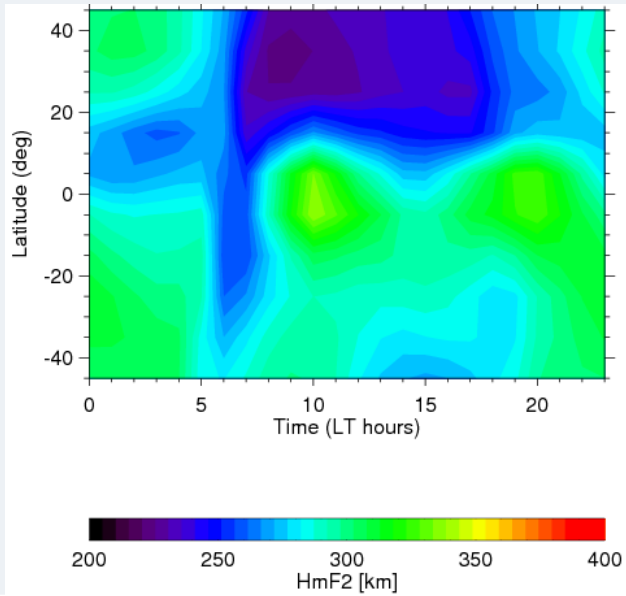
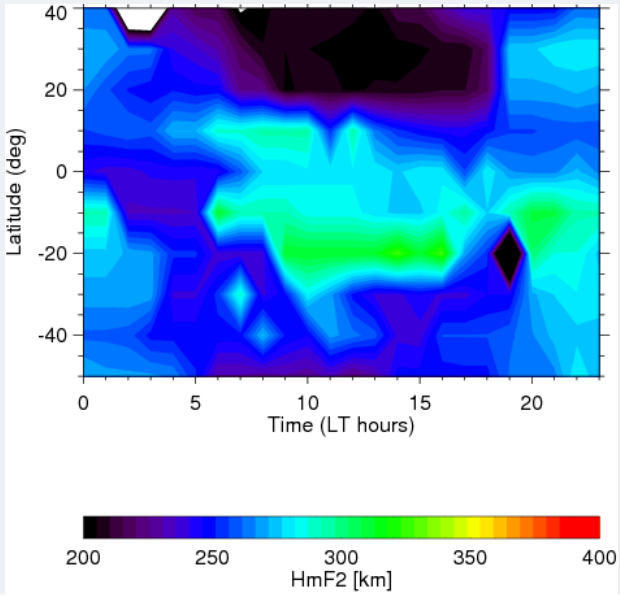
http://www.cosmic.ucar.edu/index.html

- IPE data binned and longitudinally averaged to same resolution as COSMIC data
- January 17-31, 2009 during SSW event

IPE vs. COSMIC data: Longitudinal Average



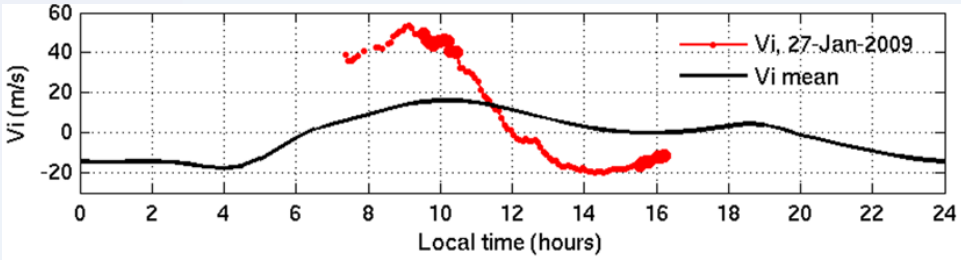
IPE vs. COSMIC data: F10.7=70, Day=1-25-2009 (during SSW event)

	IPE	COSMIC data
NmF2		
HmF2		

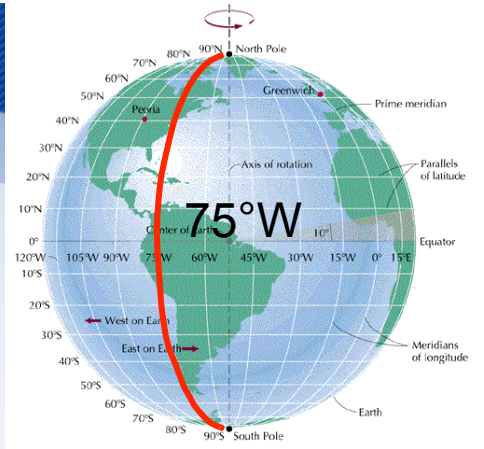
SSW vs. no SSW IPE runs

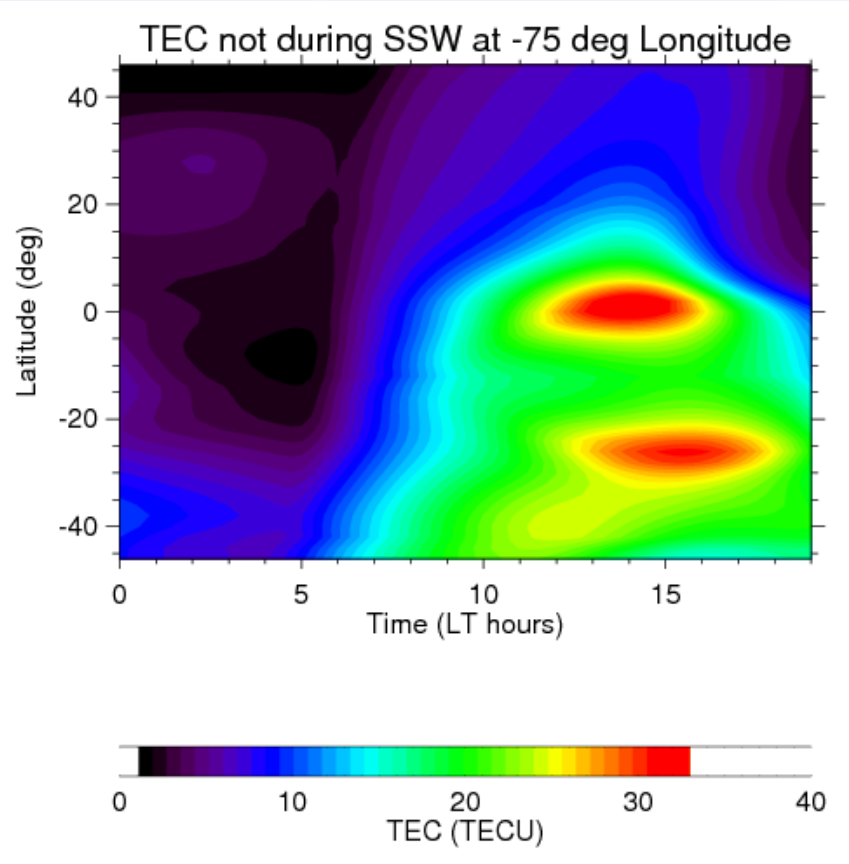
- IPE driven to simulate SSW event and no SSW event
  - Driven with observed vertical drift from 1-27-2009 for SSW run
  - Driven with climatological (normal) drift for no SSW run

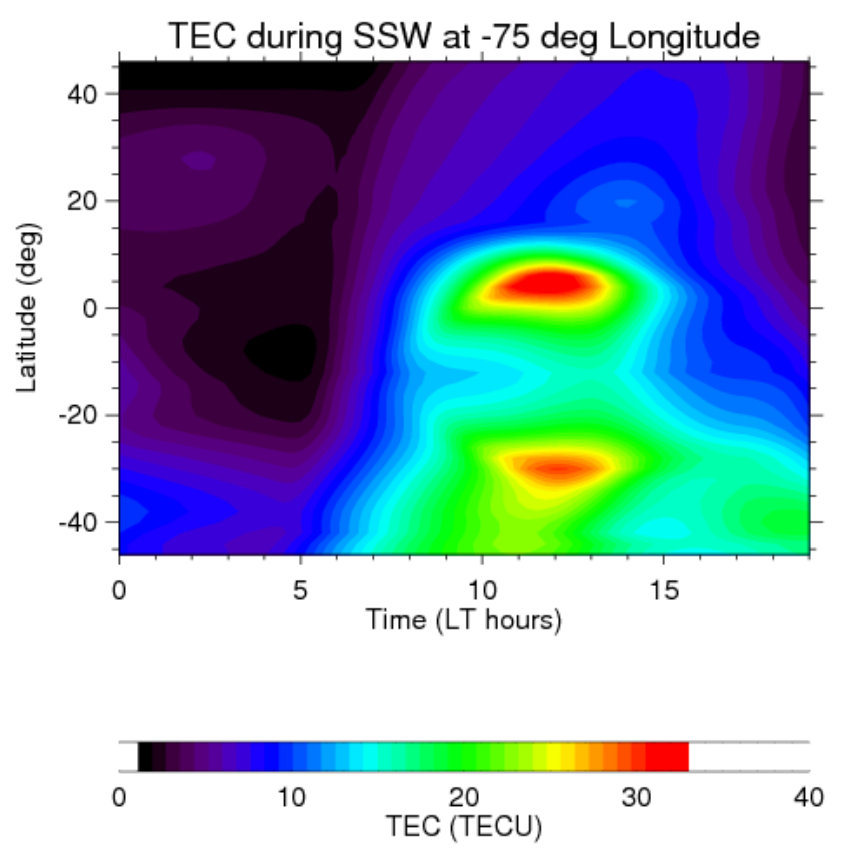
1-27-2009 Vertical Drift (Goncharenko et al 2010b)



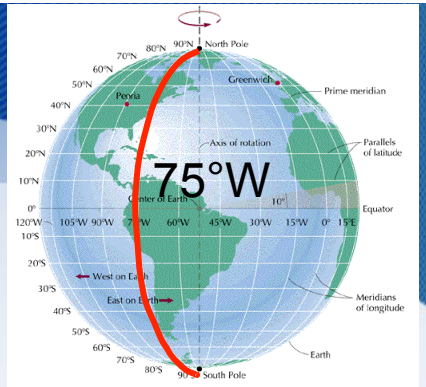
SSW vs. no SSW: TEC



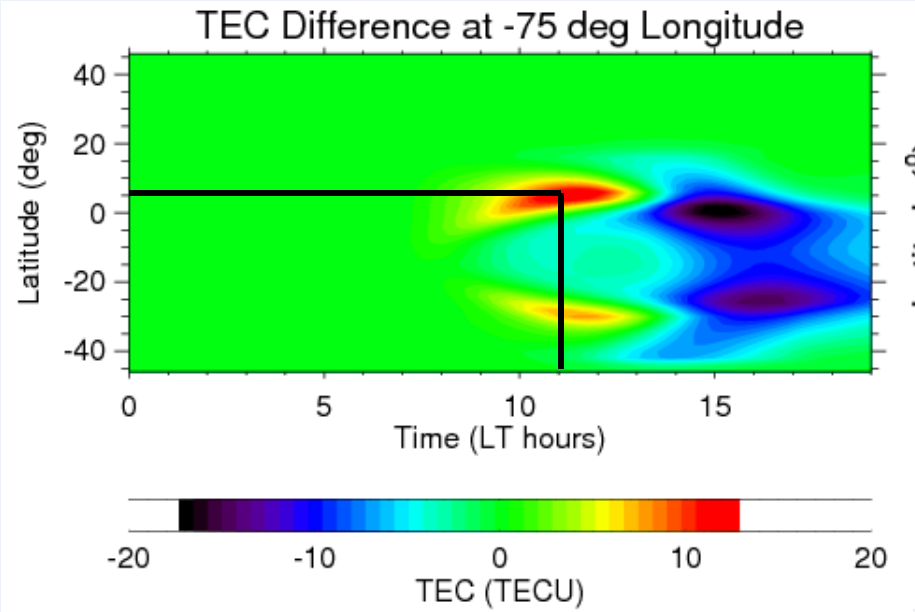




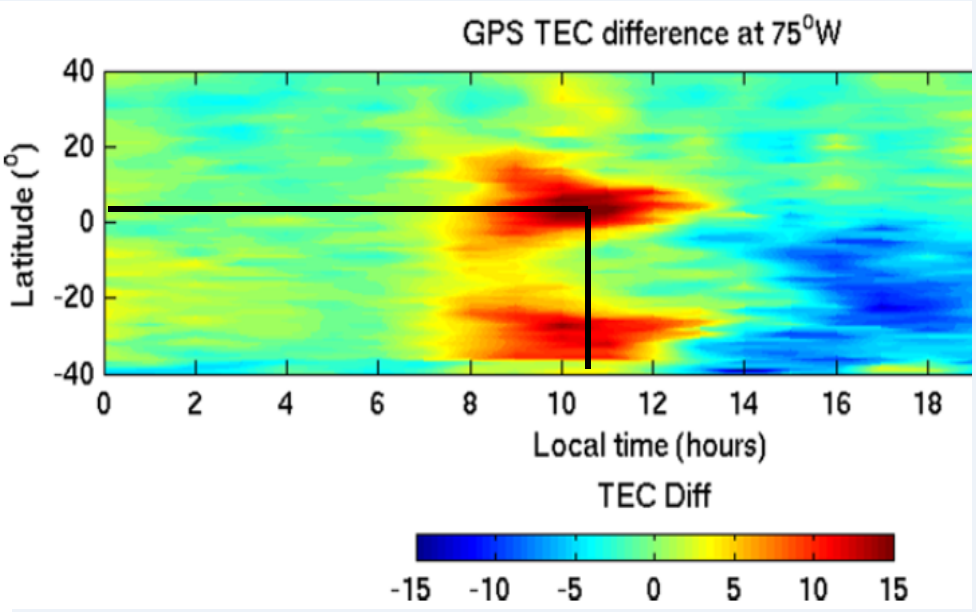
SSW vs. no SSW: TEC difference



IPE



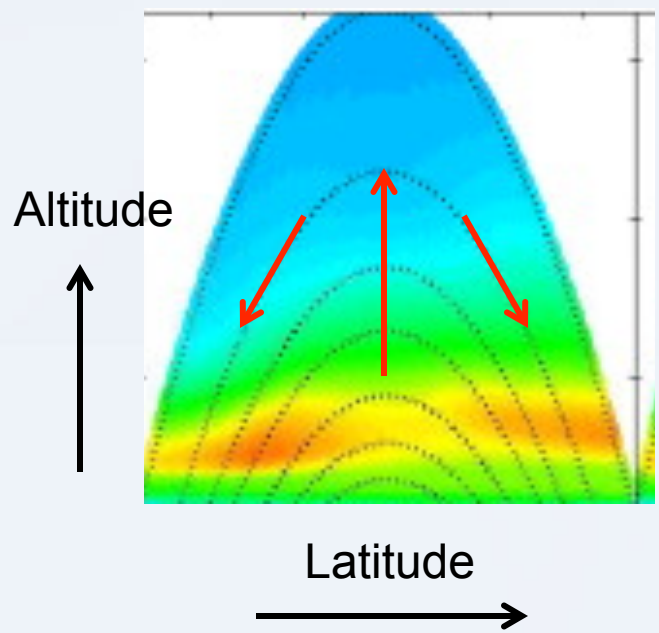
Observed (Goncharenko et al 2010b)



Why this TEC difference?

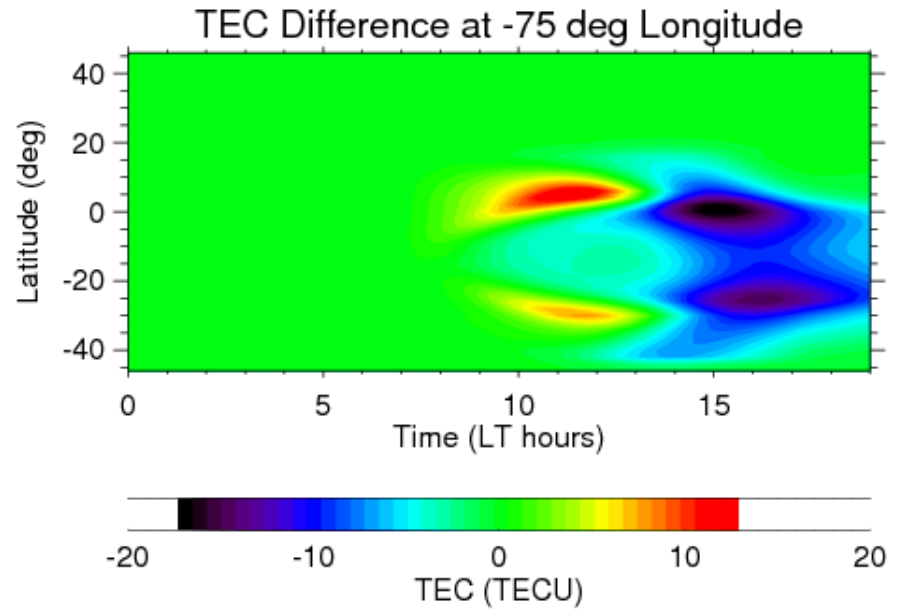
Background: equatorial vertical drift

- Thermospheric winds blowing across the magnetic field generate E-region electric fields
- Leads to upward ExB drift
- Recombination is slower at higher altitudes- plasma becomes dense
- Pressure and gravity forces cause plasma to diffuse down field lines to form the Equatorial Ionization Anomaly (EIA) on either side of the magnetic equator

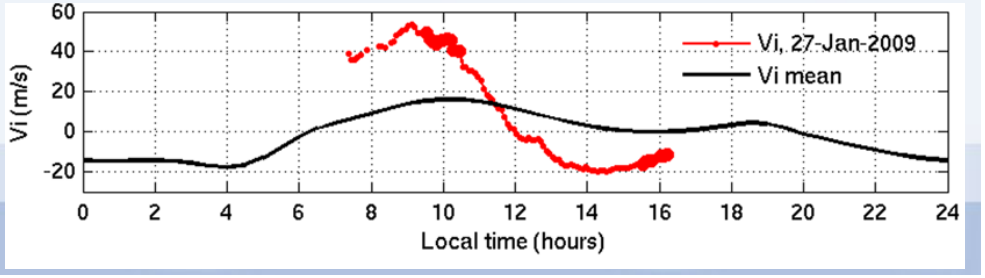


Why this TEC difference?

- Increased morning drift lifts plasma to higher altitudes where recombination is slower- increased plasma density
- Enhanced downward drift decreases plasma density by transport to lower altitudes

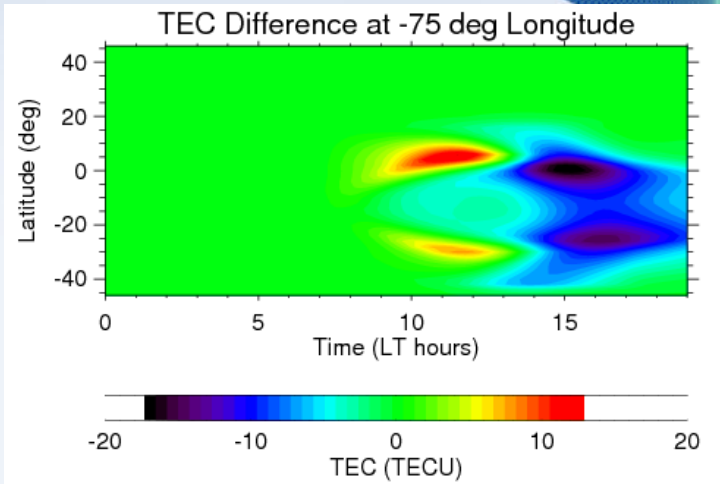


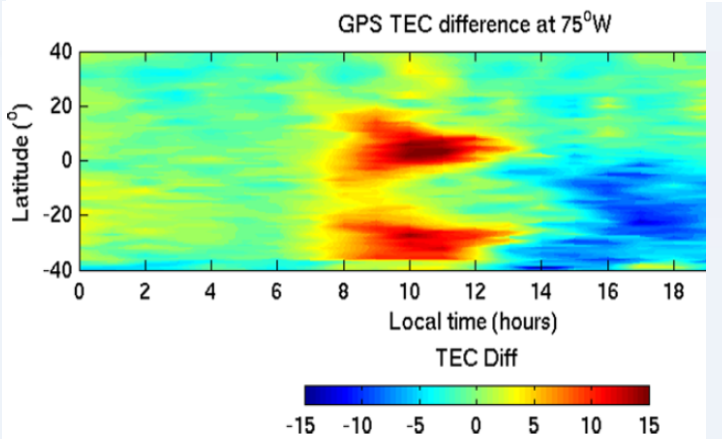
1-27-2009 Vertical Drift (Goncharenko et al 2010b)



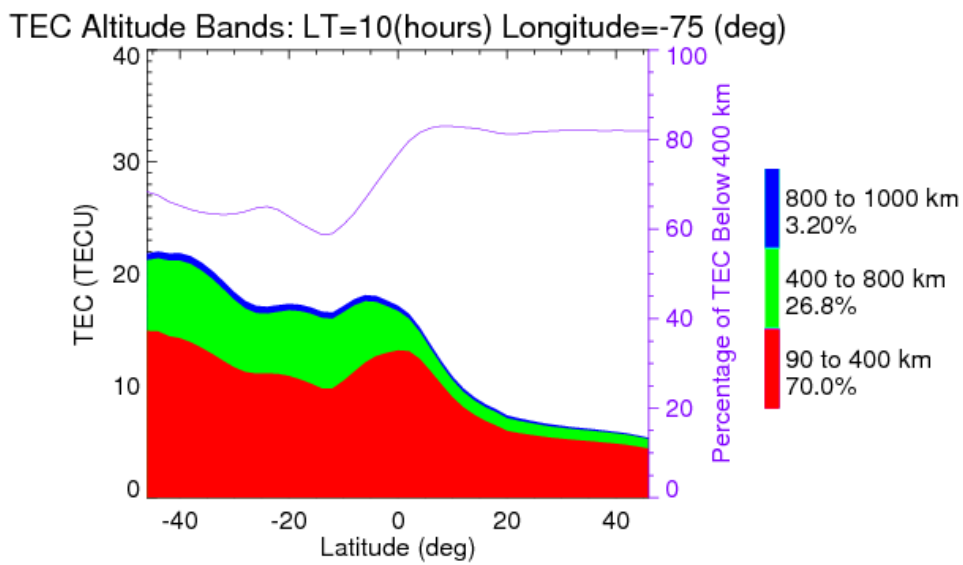
SSW vs. no SSW: TEC difference discrepancies

- TEC observed deviation starts sooner than modeled deviation and extends to a bit larger latitudinal ranges
- Limitations of drift observations
- Neutral wind uncertainty

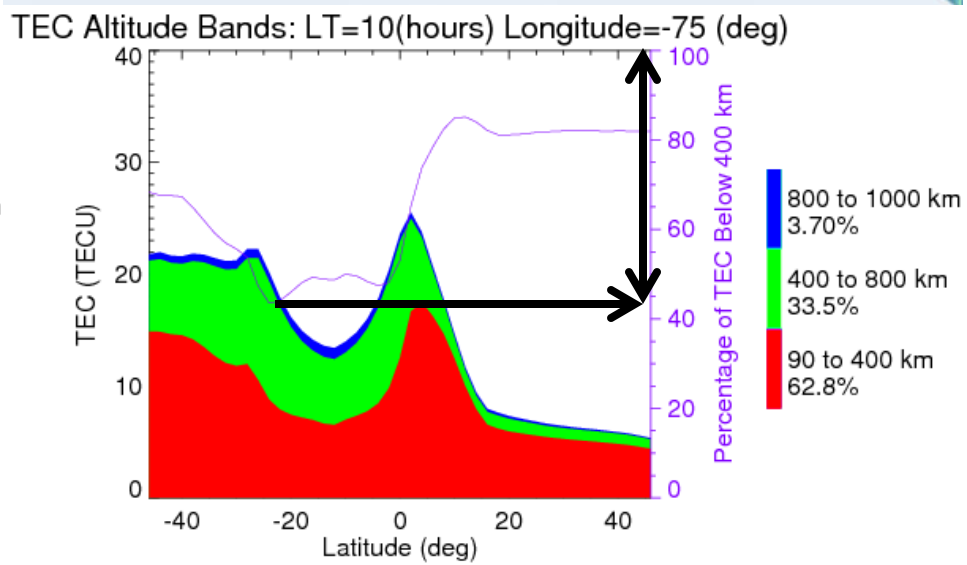




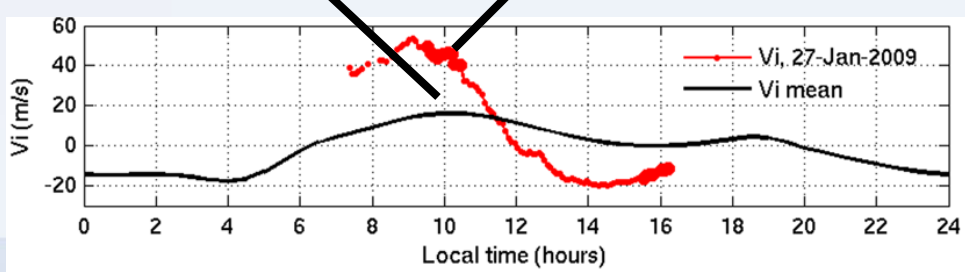
SSW vs. no SSW:
TEC altitude bands at 10 LT and 75°W



No SSW



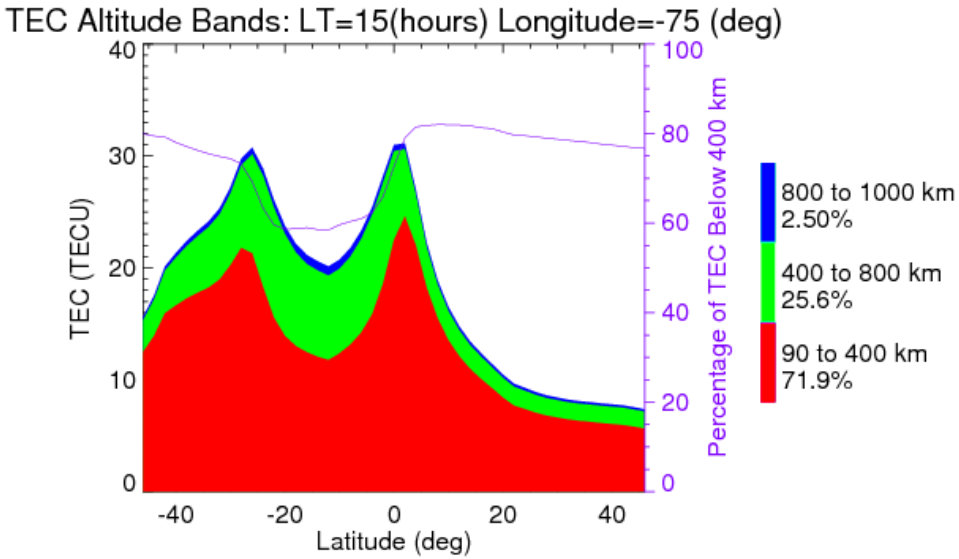
SSW

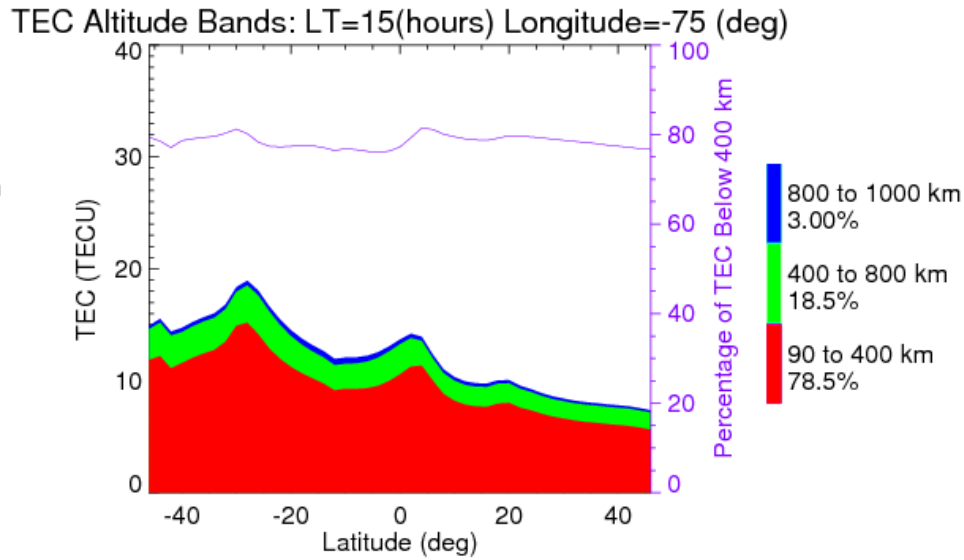


1-27-2009 Vertical Drift (Goncharenko et al 2010b)

Plasma is pushed up to higher altitudes , so the percentage of TEC below 400 km is smaller

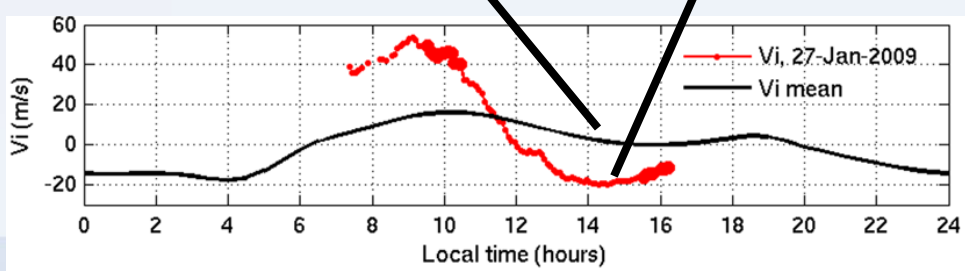
SSW vs. no SSW:
TEC altitude bands at 15 LT and 75°W





No SSW

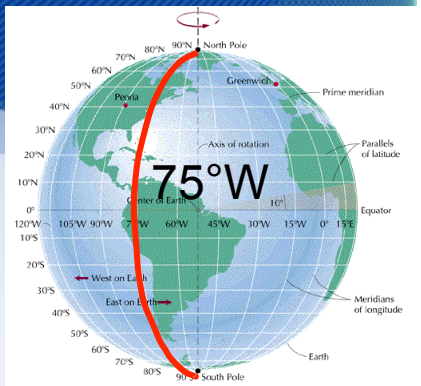
SSW

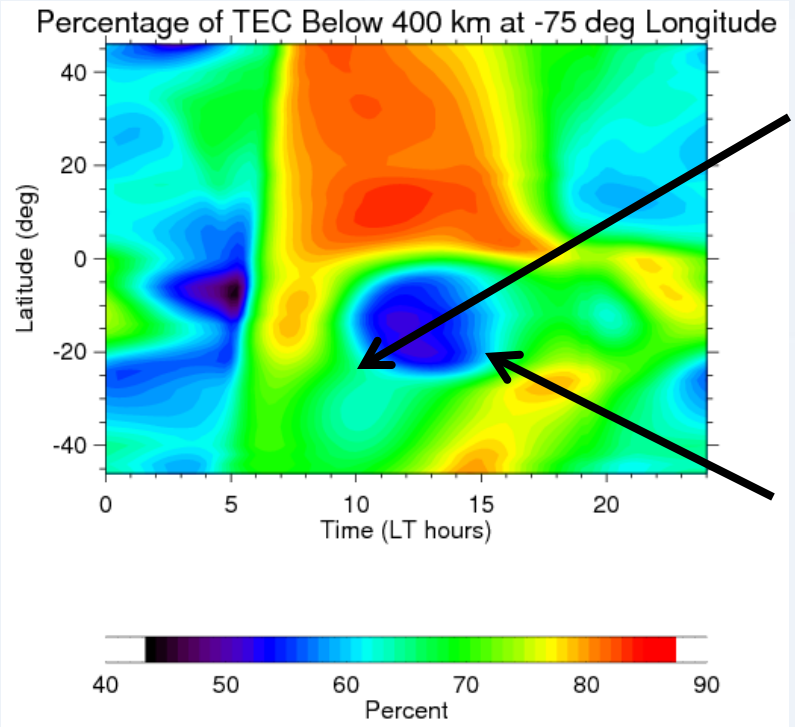


1-27-2009 Vertical Drift (Goncharenko et al 2010b)

Plasma is pushed down to lower altitudes , so the percentage of TEC below 400 km is higher

SSW vs. no SSW: Percentage of TEC below 400 km

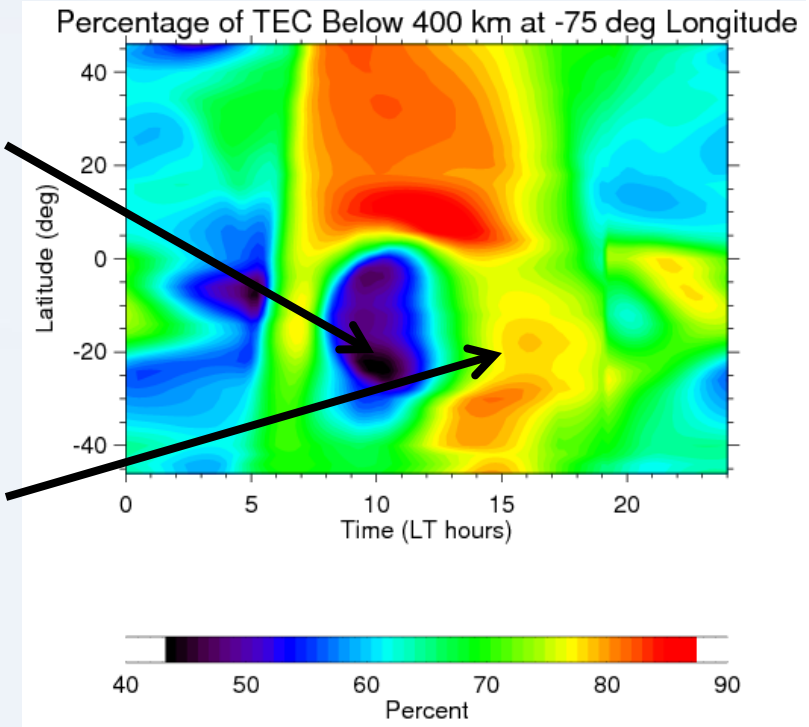




No SSW

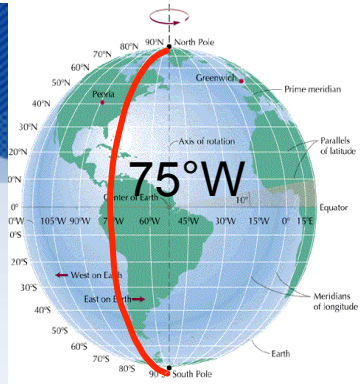
Decreased in the morning

Increased in the afternoon

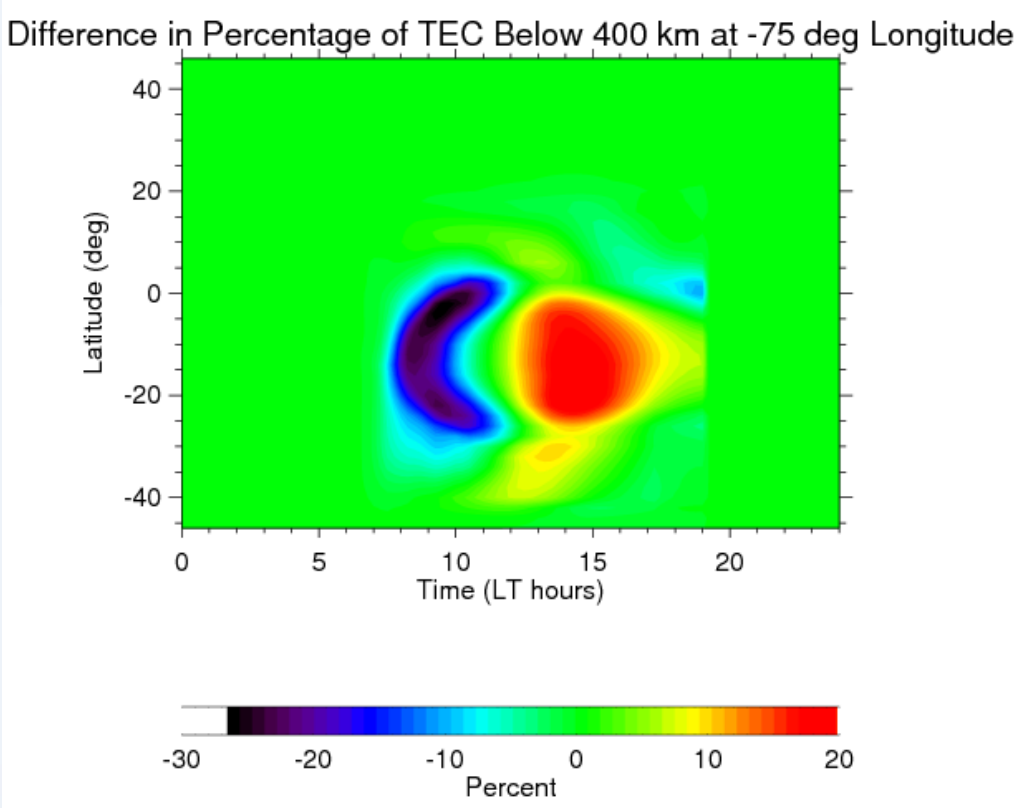


SSW

SSW vs. no SSW: Difference in percentage of TEC below 400 km

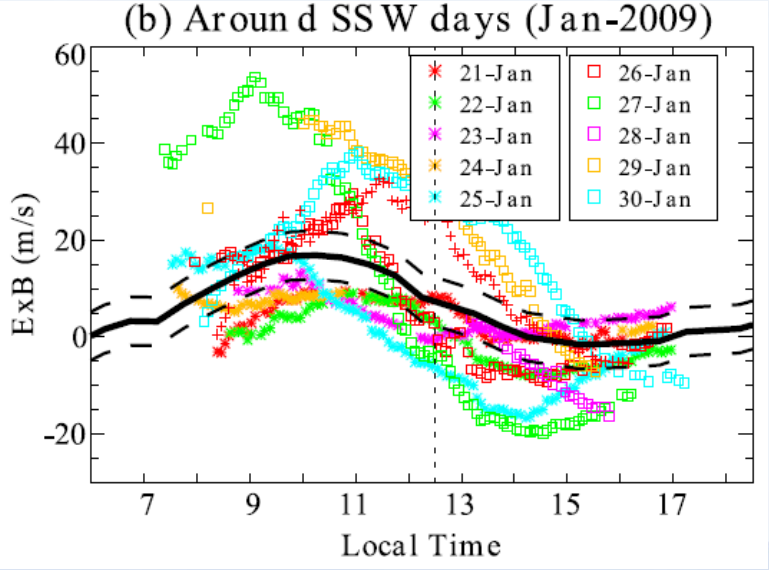


- Drift is higher in the morning, so plasma is pushed up, and there is less below 400 km
- Drift is smaller in the afternoon, so plasma comes down and there is more below 400 km



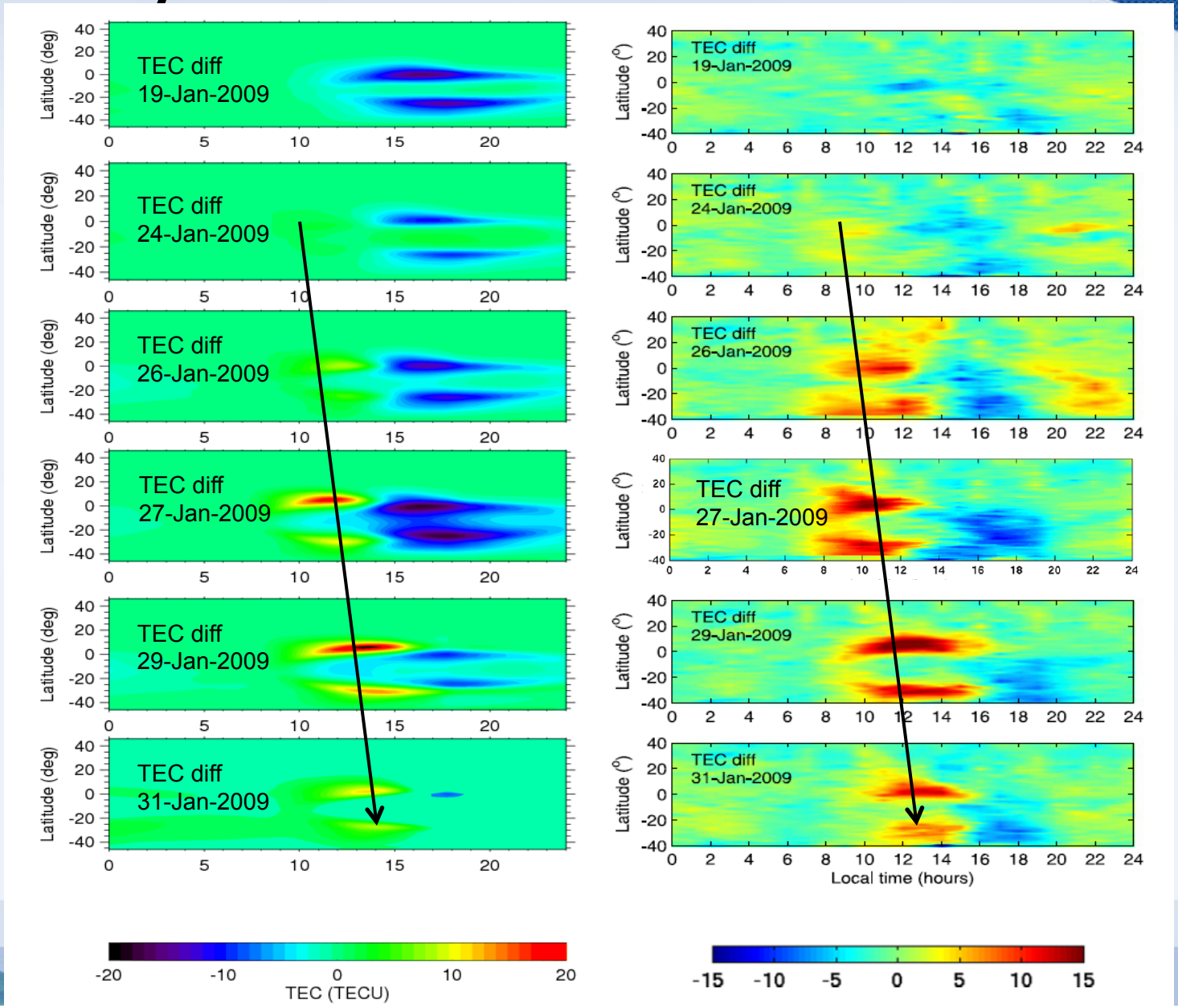
January 2009 SSW event runs

- Instead of one event day and one non-event day, looked at 14 days during the SSW event
- IPE driven with observed drift for January 17-31, 2009



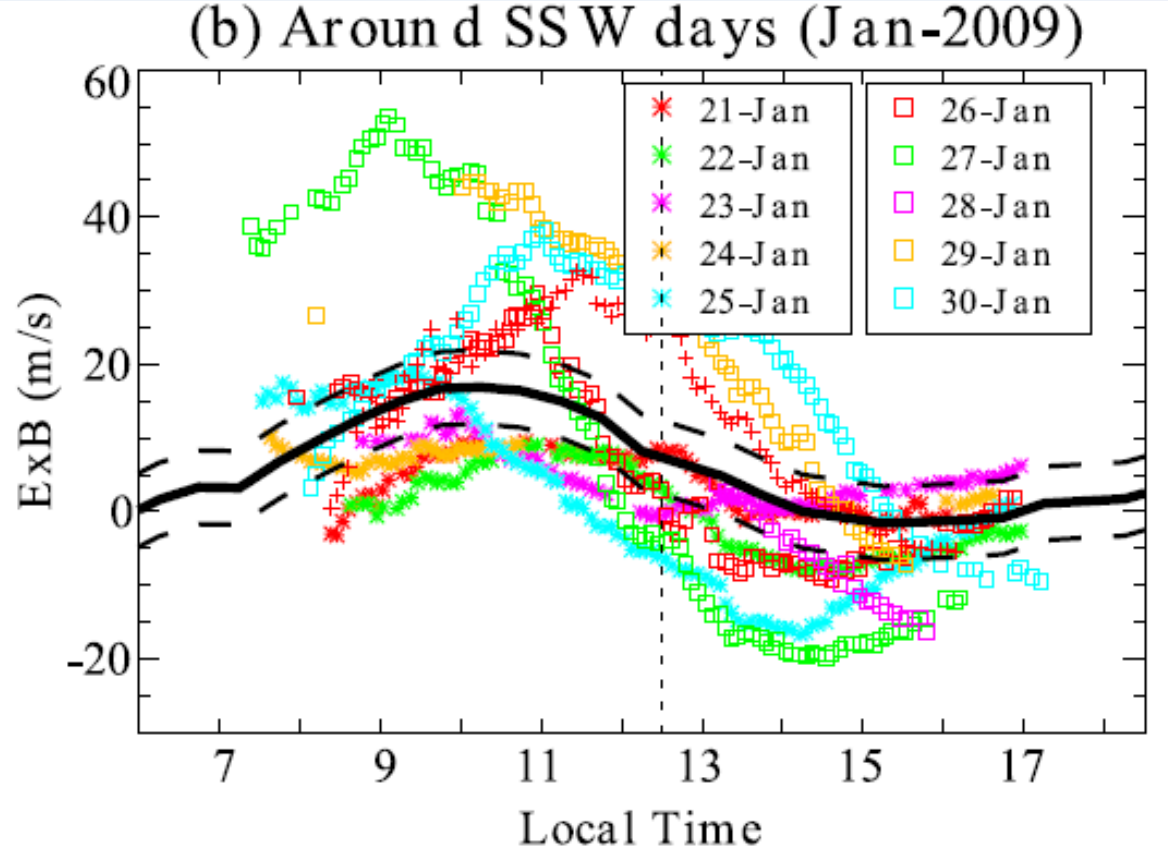
150 km echoes, Chau et al. 2011

January 2009 SSW: TEC differences



January 2009 SSW: TEC differences

- 150 km echoes (measure of ExB drift) around SSW



Chau et al. 2011

Conclusions

- Reasonable agreement with other physics based model and observation
- IPE captures day-to-day variability of ionospheric response during the Jan. 2009 SSW event
- Importance of plasmaspheric coupling during SSW event

Future Work

- Investigate relative contribution between neutral wind and ExB drift
- Drive IPE with global drift and wind data
- Investigate other SSW events

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