Investigating atmosphere-ionosphere coupling using GPS RO observations

Nick Pedatella
COSMIC Program Office
University Corporation for Atmospheric Research

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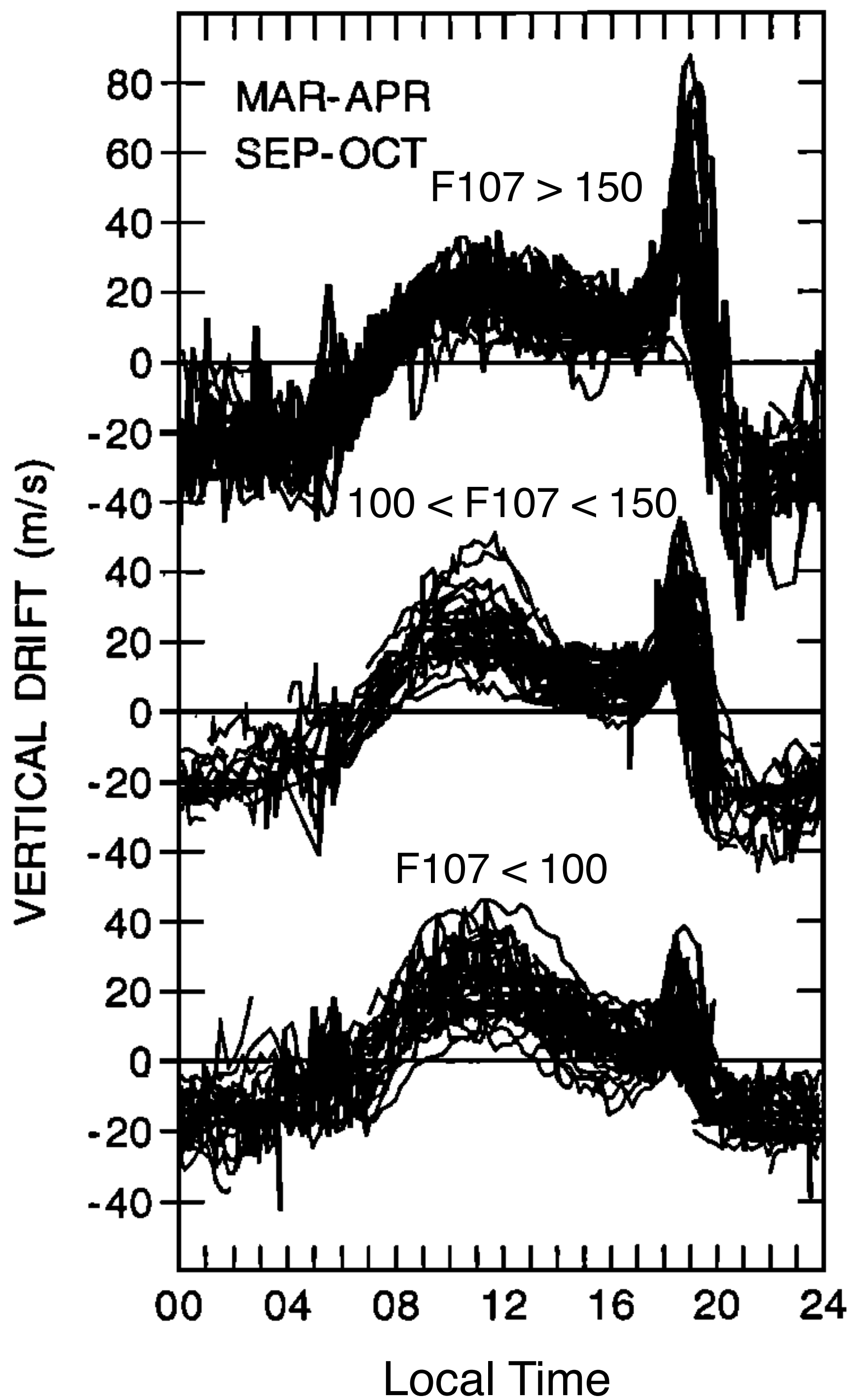
Outline

- Introduction to atmosphere-ionosphere coupling
- Investigations using GPS RO:
  - Longitude variability
  - Sudden stratosphere warmings
- Summary and Conclusions

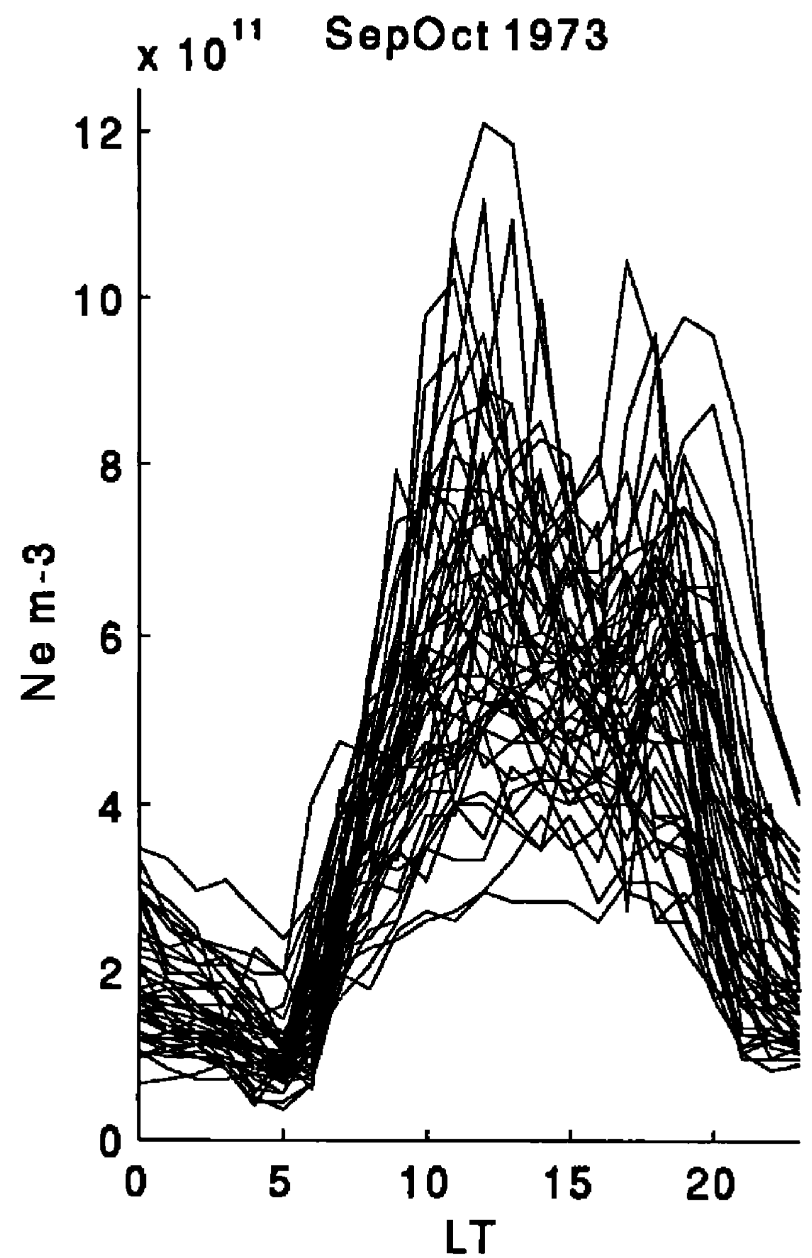
Observations show significant ionosphere variability that is unrelated to solar/geomagnetic forcing

Jicamarca
Vertical Drift (Kp < 3)



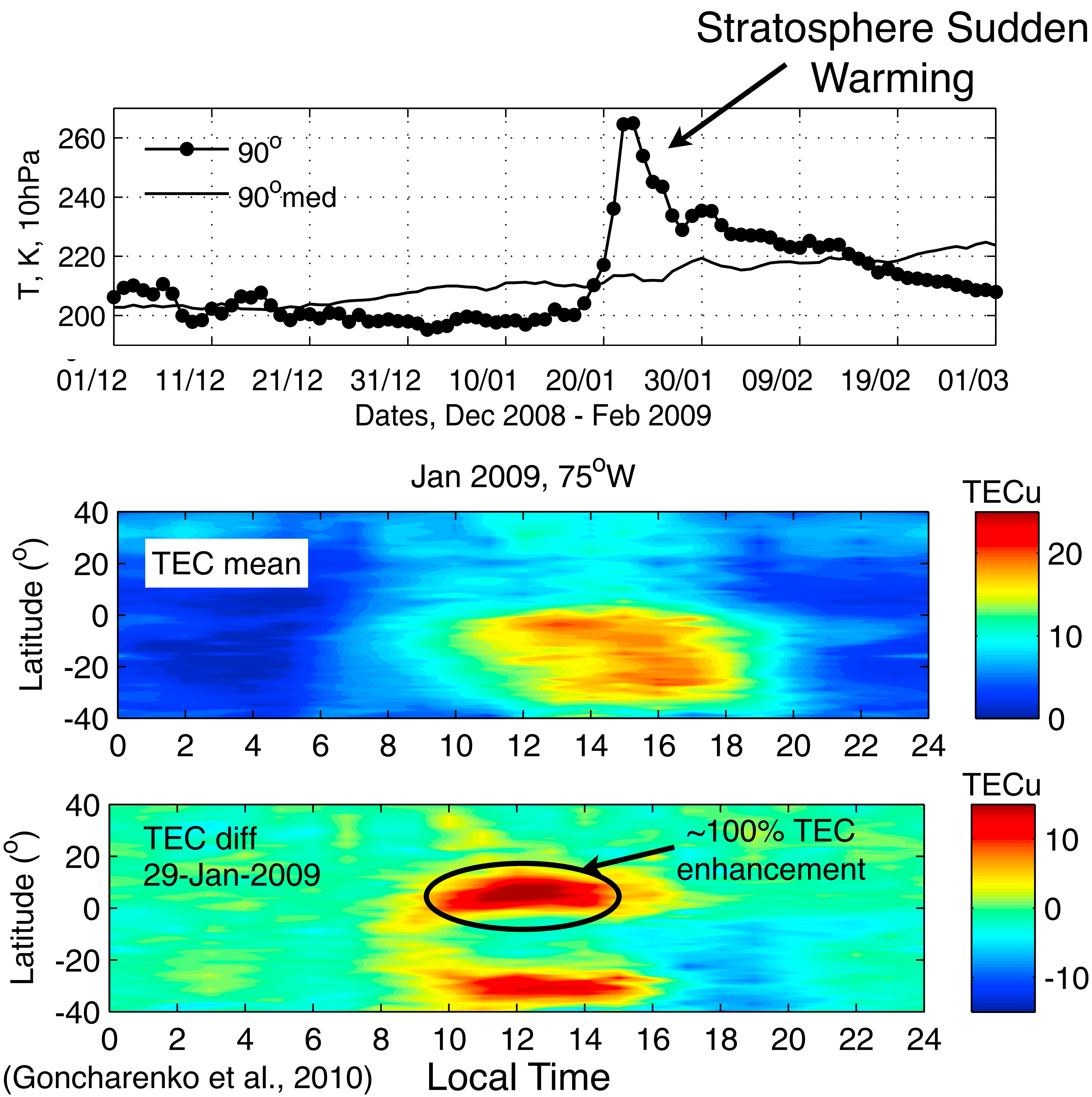
(Scherliess and Fejer, 1999)

Slough NmF2
(48°MLAT, -1°GLON)



(Rishbeth and Mendillo, 2001)

Observations have clearly linked large ionosphere variability to lower atmosphere processes



Ground-based GPS TEC observations show dramatic changes shortly after the peak of the SSW

Sources of ionosphere variability

Table 1
Possible causes of ionospheric F-layer variability (Rishbeth and Mendillo, 2001)

1. *Solar ionizing radiation*	3. *Neutral atmosphere*
Solar flares	Solar and lunar tides: generated within thermosphere or coupled through mesosphere
Solar rotation (27 day) variations	Acoustic and gravity waves
Formation and decay of active regions	Planetary waves and 2-day oscillations
Seasonal variation of Sun's declination	Quasi-biennial oscillation
Annual variation of Sun–Earth distance	Lower atmosphere weather coupled through mesopause
Solar cycle variations (11 and 22 years)	Surface phenomena: earthquakes, volcanoes
Longer period solar epochs	
2. *Solar wind, geomagnetic activity*	4. *Electrodynamics*
Day-to-day 'low level' variability	Dynamo 'fountain effect' at low latitudes
Substorms	Penetration of magnetospheric electric fields
Magnetic storms	Plasma convection at high latitudes
IMF/solar wind sector structure	Field-aligned plasma flows to and from plasmasphere and protonosphere
Energetic particle precipitation and Joule heating	Electric fields from lightening and sprites

effects. If the solar component is only about 3%, essentially all this 15% variability must be attributed to 'meteorology'.

In summary, we suggest the 'meteorological' sources of F-layer variability are comparable to the 'geomagnetic' source and much larger than the 'solar' component.

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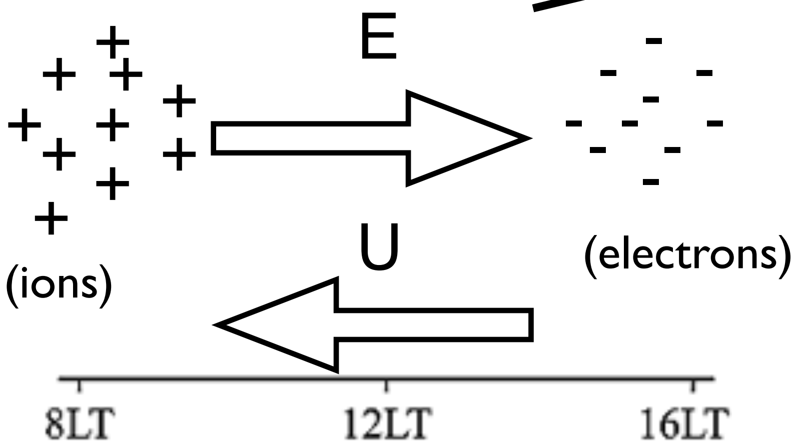
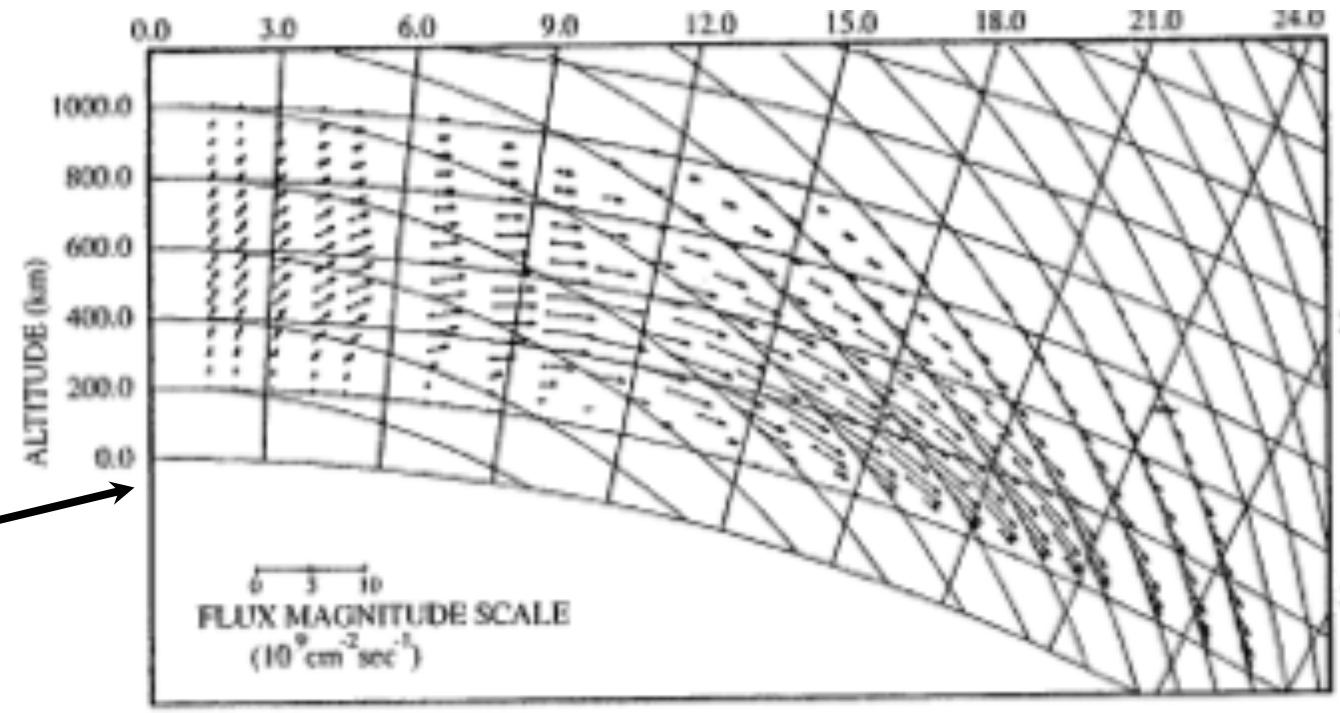
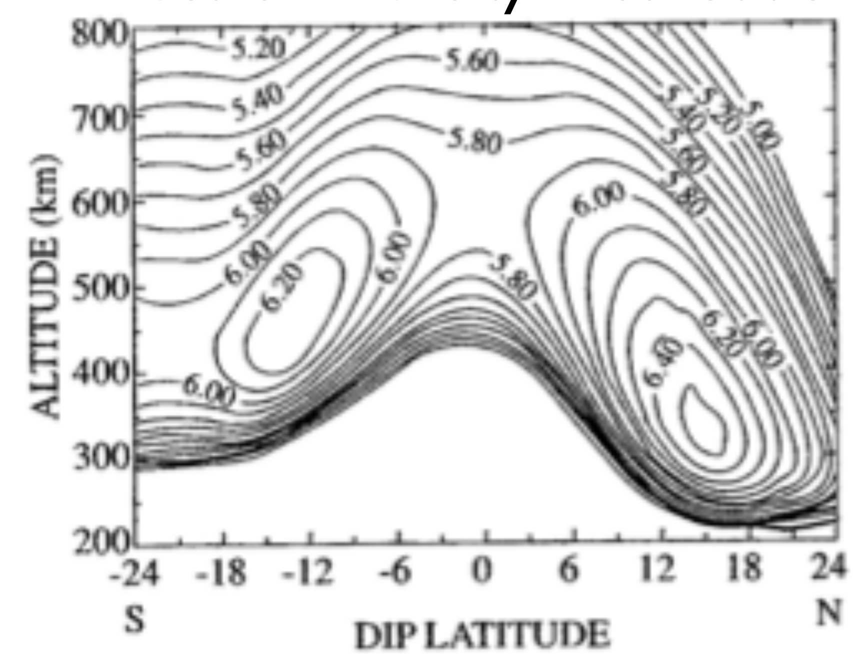
Coupling between the lower and upper atmosphere is thought to occur due to modulation of the ionosphere wind-dynamo

$$V = \frac{E \times B}{B^2}$$





Electron Density Distribution



$$\mathbf{J} = \sigma_P(\mathbf{E} + \mathbf{u} \times \mathbf{B}) + \sigma_H\, \mathbf{b} \times (\mathbf{E} + \mathbf{u} \times \mathbf{B}) + \mathbf{J}_M + \mathbf{J}_{||}$$

$$\mathbf{U} = \overline{\mathbf{U}} + \mathbf{U}'$$

Mean wind

Perturbation

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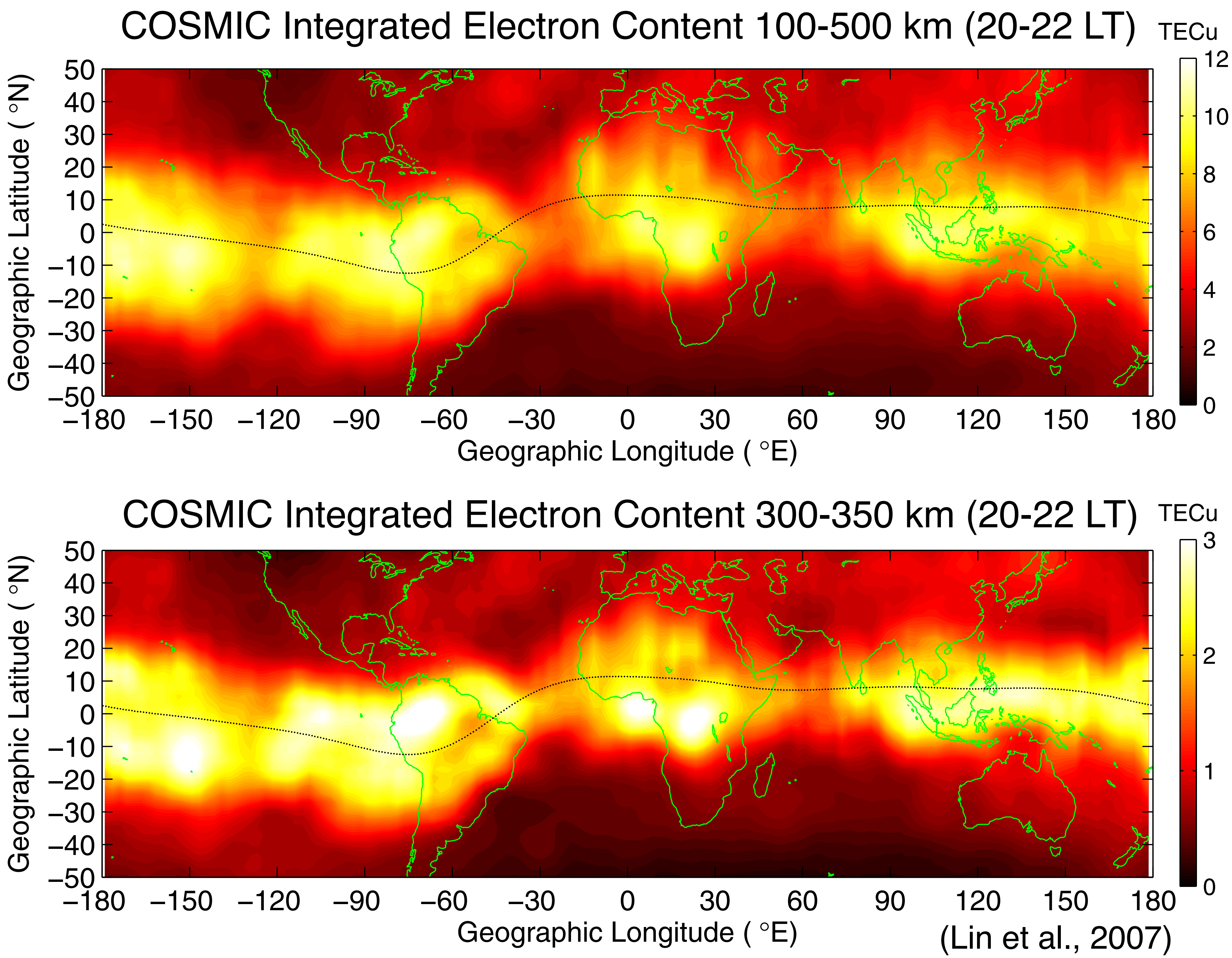
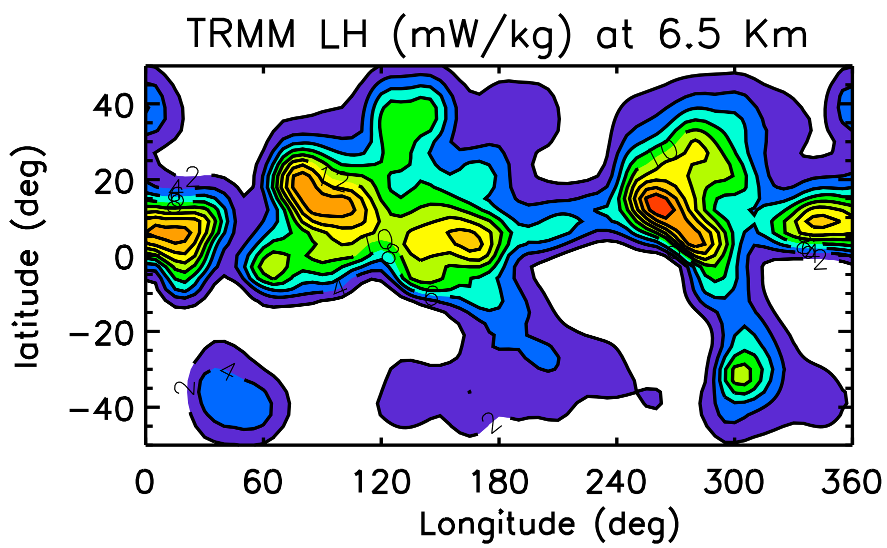
When viewed from a fixed local time perspective, the ionosphere exhibits a distinct longitudinal structure

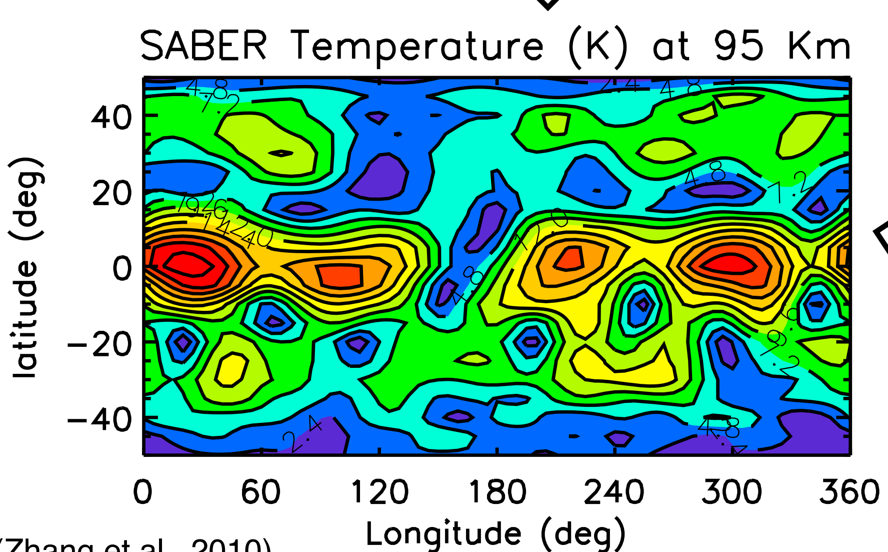


(Lin et al., 2007)

The ionosphere longitude variability is attributed to upward propagating tides of tropospheric origin, which are generated by tropospheric convection

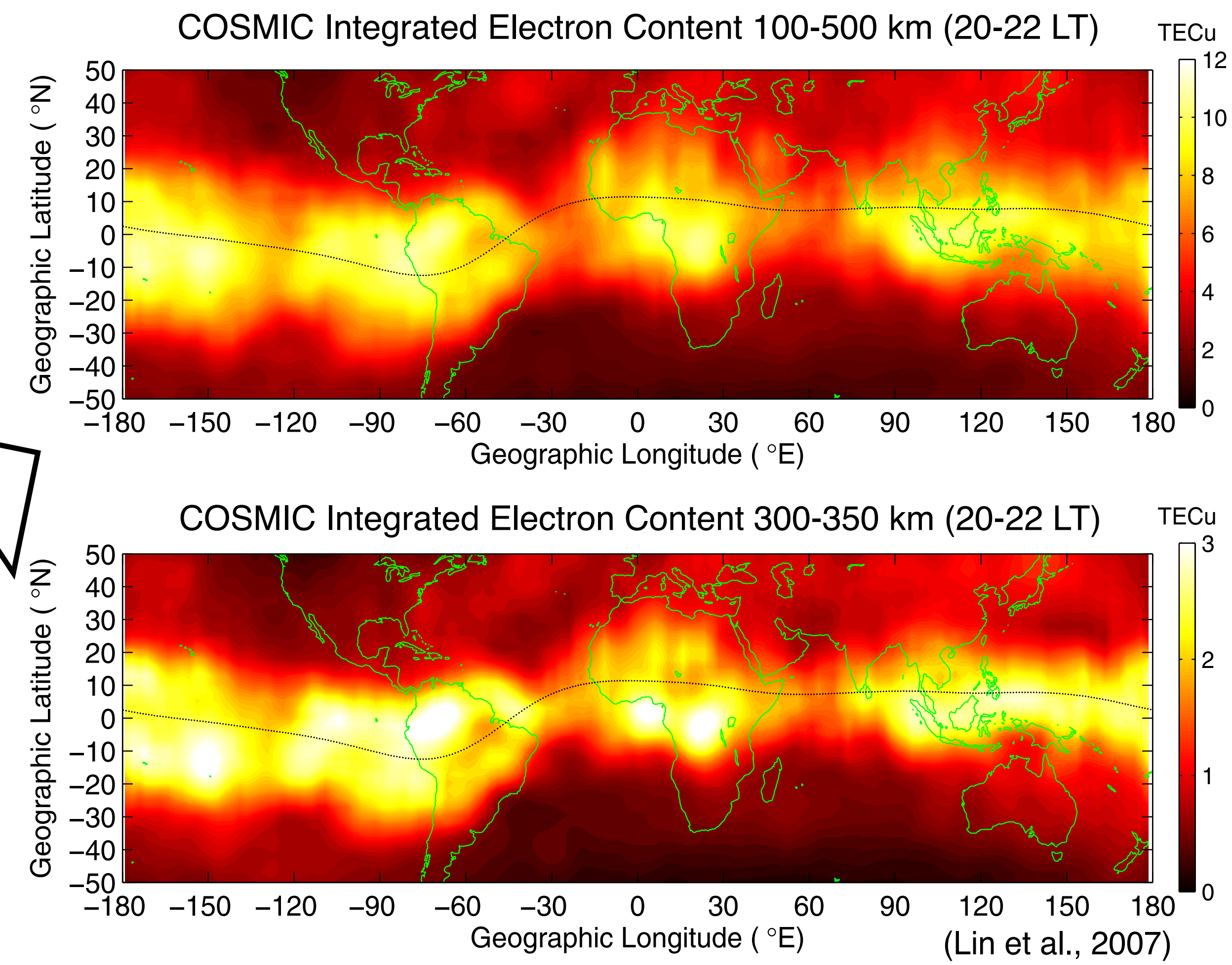


vertical propagation
&
amplitude growth



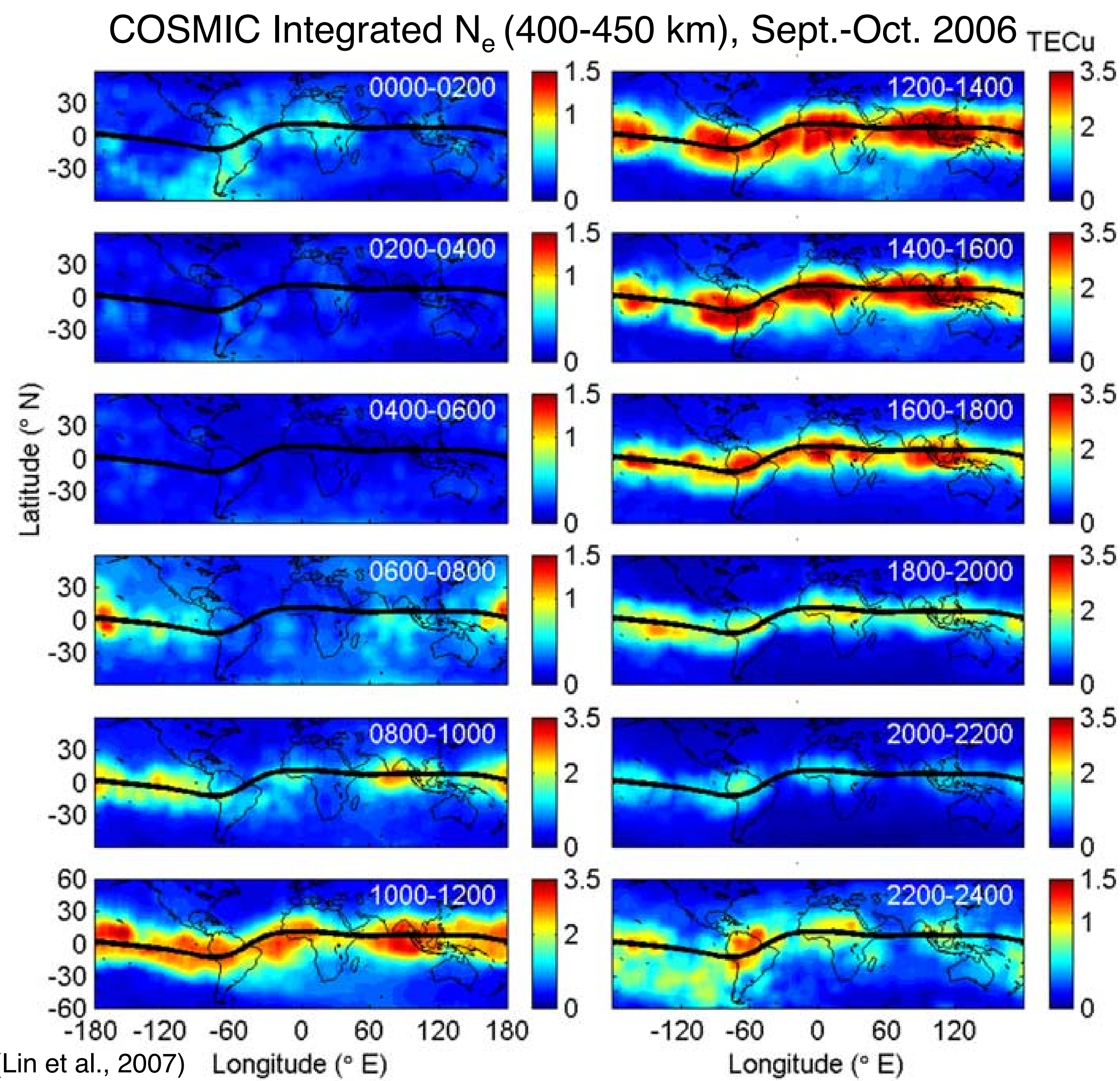
(Zhang et al., 2010)

modulation of E-region dynamo and equatorial electric fields

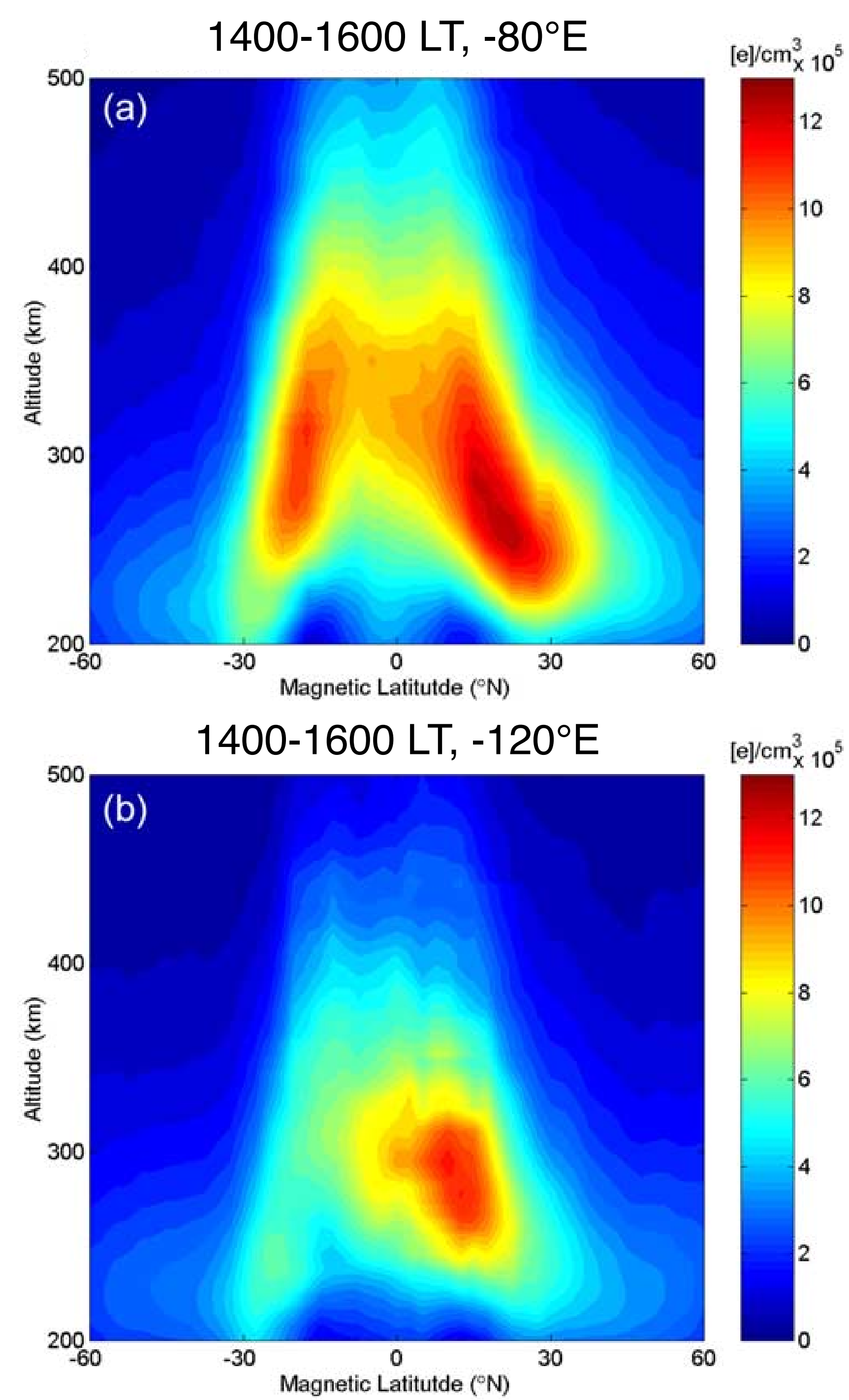


(Lin et al., 2007)

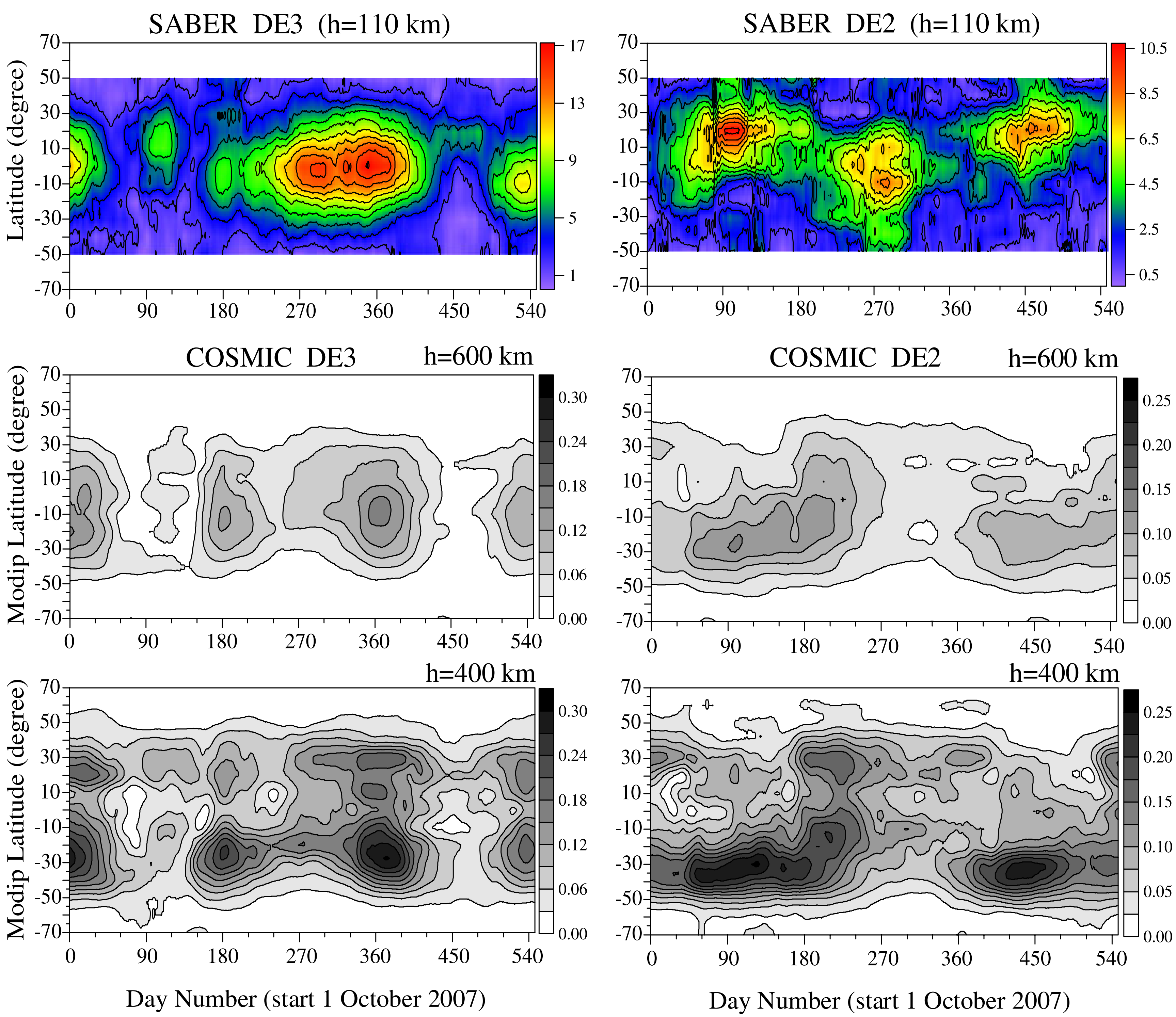
Global sampling at all local times permits investigations of the longitudinal variability of the ionosphere in terms of its temporal evolution and altitude structure



(Lin et al., 2007)



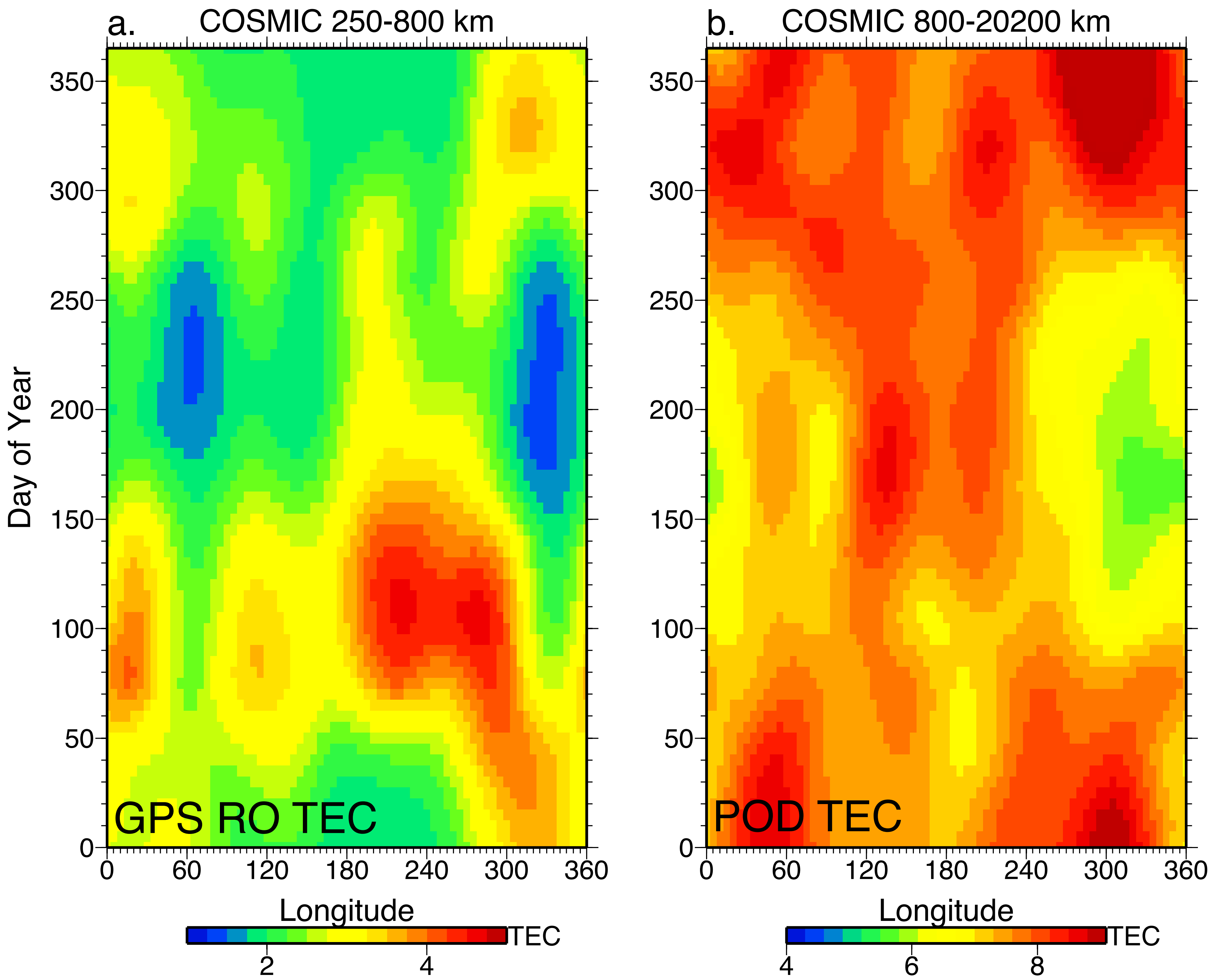
GPS RO sampling permits decomposition into tidal modes, which can be used to connect ionosphere variability with vertically propagating waves



DE3 – produces wavenumber-4 longitude structure in ionosphere
DE2 – produces wavenumber-3 longitude structure in ionosphere

(Pancheva and Mukhtarov, 2014)

Evolution of ionosphere longitude variability in altitude can also be determined through comparison with near vertical observations from POD antennae



(Pedatella et al., 2011)

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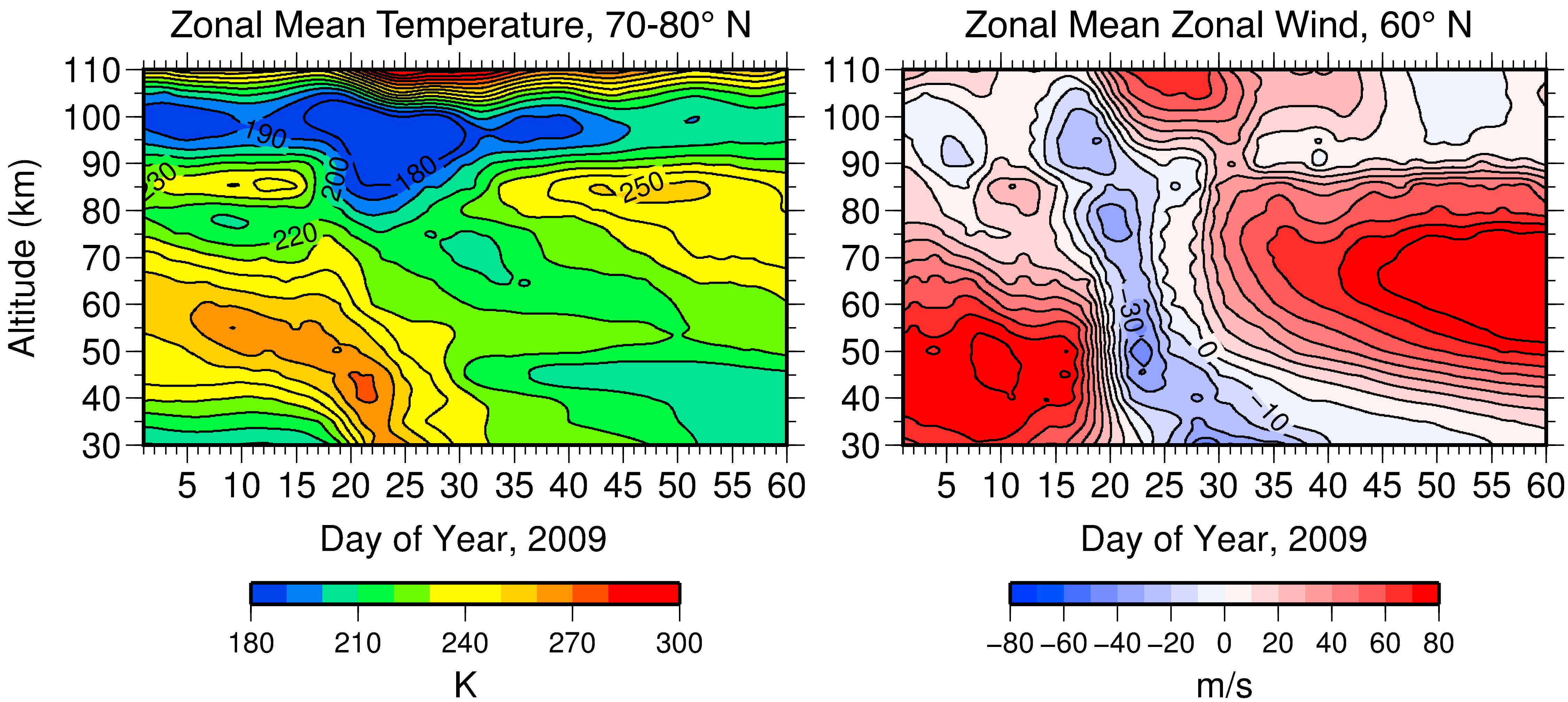
Sudden Stratosphere Warmings

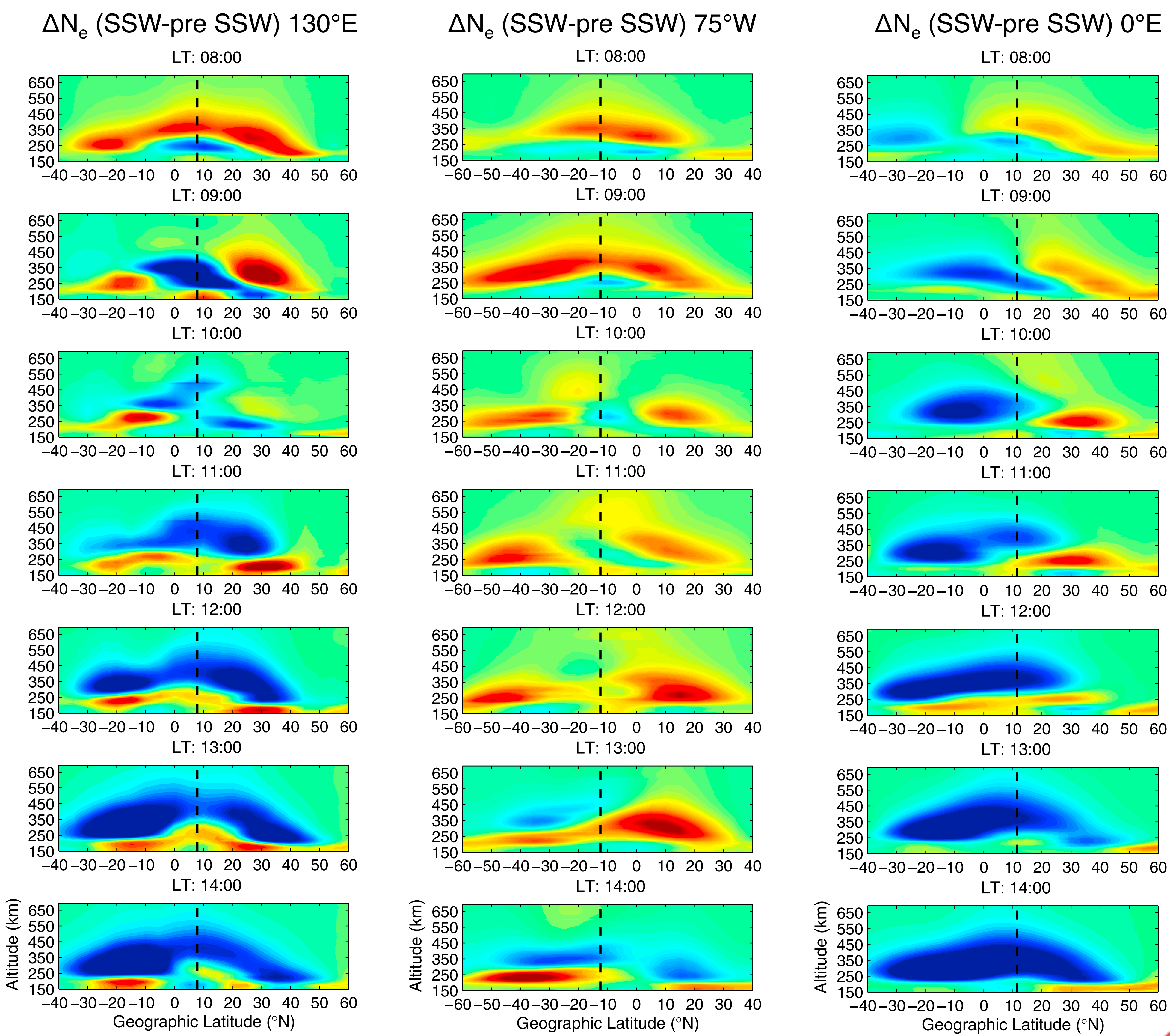


- Sudden Stratosphere Warming (SSW): warming of the high-latitude winter stratosphere; associated with dramatic changes in temperatures and winds in the middle atmosphere at high-latitudes

- Recent studies have shown large (~100%) ionosphere variability during SSWs

(Pedatella et al., 2014)

Spatial and temporal variability during SSWs can clearly be observed from COSMIC GPS RO observations. This is not possible with any other current observations.



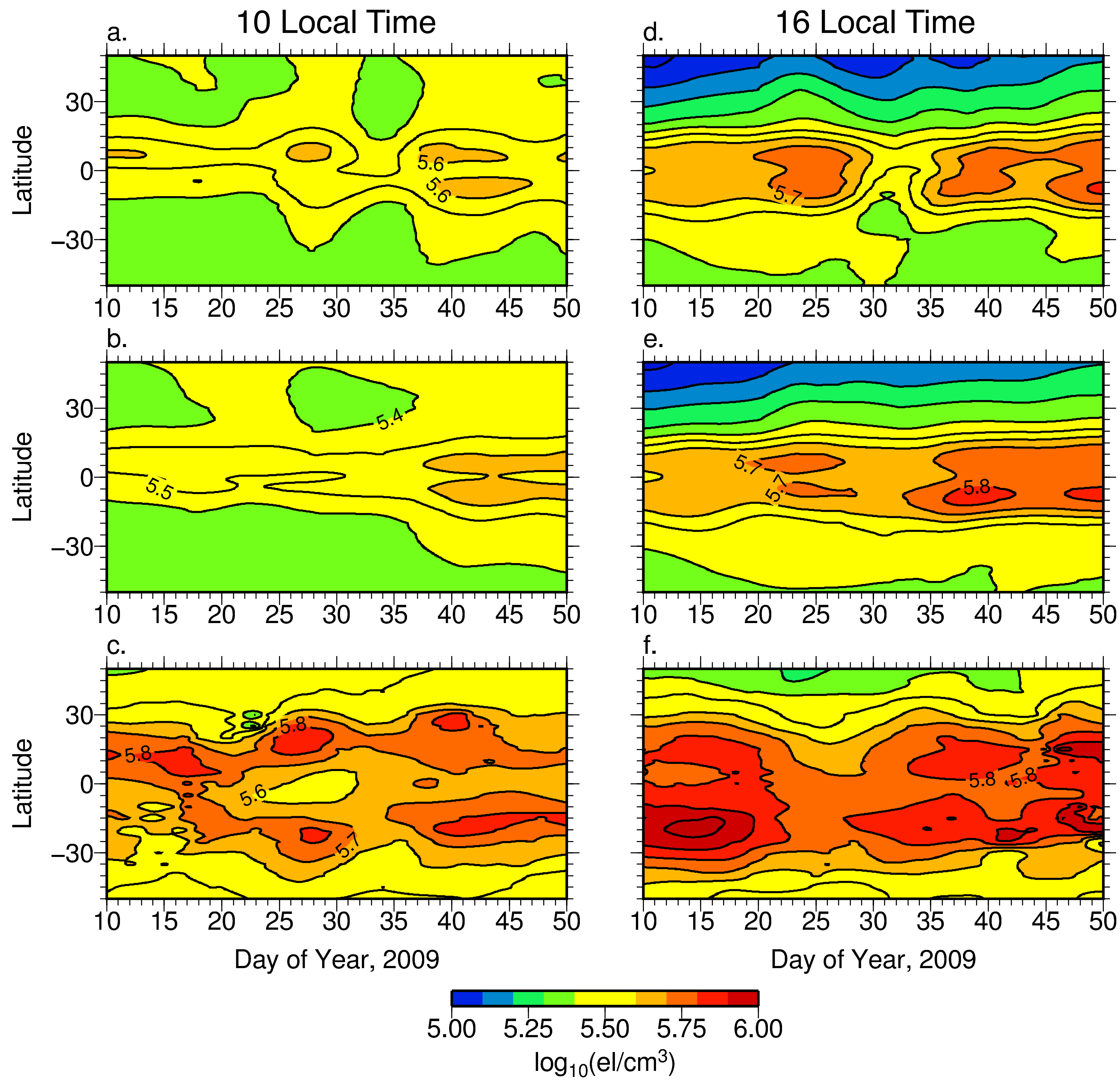
(Lin et al., 2012)

COSMIC GPS RO observations are also useful for comparison model simulations of SSWs

TIME-GCM with lunar tide

TIME-GCM without lunar tide

COSMIC Obs. (zonal mean)



(Pedatella et al., 2014)

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Summary and Conclusions

- During geomagnetic quiet time periods the lower atmosphere is a significant source of ionosphere variability.
- Lower atmosphere can introduce variability on the order of ~100%, and it is thus not an insignificant source of ionosphere variability.
- Global and diurnal sampling of ionosphere GPS RO observations makes them well-suited for studying coupling between the lower and upper atmosphere
- Note that I have only presented an overview, and GPS RO can be used to study other aspects (e.g., gravity waves) of vertical coupling.
- Increased observation density in the future will enable additional studies, particularly with regards to short-term ionosphere variability.
- Studies of atmosphere-ionosphere vertical coupling would benefit significantly from increasing the altitude of neutral atmosphere retrievals.

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