Lower Atmospheric Sources of Longitudinal Variability in the Quiescent Ionosphere

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Overarching Question:

How do nonmigrating tides of tropospheric origin affect the geomagnetically undisturbed middle & upper atmosphere?

nonmigrating tide - global scale wave
period is harmonic of a solar day
propagates horizontally faster or slower than the motion of the Sun

…excited by latent heat release

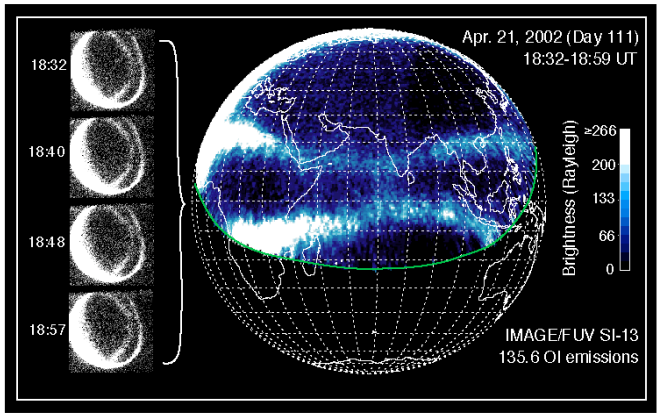
Outline

- Motivation: IMAGE satellite observations of 4-peaked longitudinal variations in the ionosphere
  - 135.6 nm airglow brightness (*Immel et al.*, 2006)
- NCAR thermosphere-ionosphere-mesosphere-electrodynamics general circulation model (TIME-GCM) results that capture the salient features of the IMAGE satellite observations [after *Hagan et al.*, 2007]
- New TIME-GCM results that further explore equatorial ionization anomaly (EIA) "wave 4" variations under different geophysical conditions
  - FORMOSAT-3/COSMIC electron density (*Lin et al.*, 2007)

IMAGE-FUV Observations of the equatorial ionization anomaly (EIA) during March 2002 equinox with eastward propagating zonal wavenumber 3 diurnal temperature perturbations at 115 km from the NCAR global-scale wave model (GSWM)

Geophysical Research Letters
10 August 2006
Volume 8 Number 88

Far-Ultraviolet Ionospheric Emissions

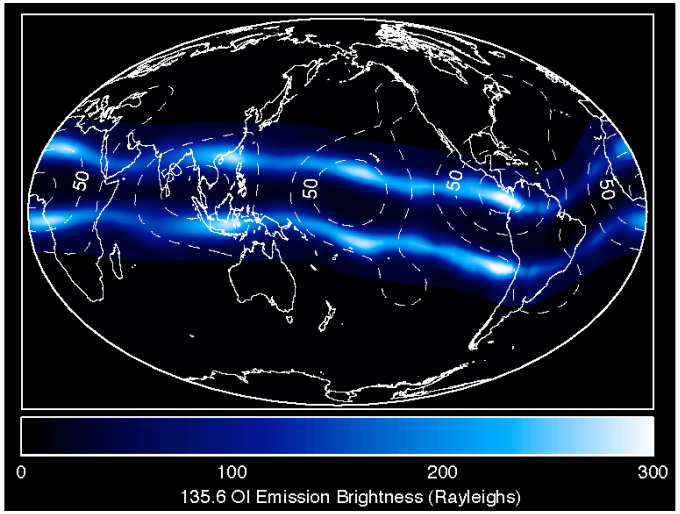


***Immel et al.*, 2006**

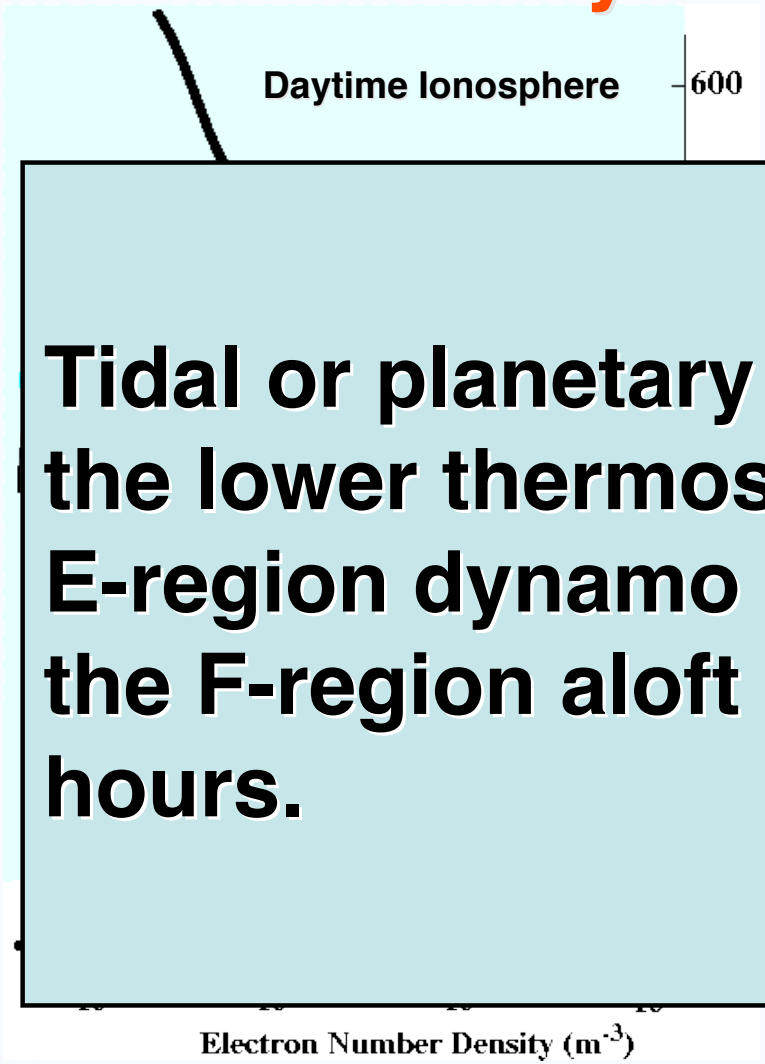
$e + O^+ \rightarrow O^*$
(135 nm)

$I = \alpha \int n_e^2 \, ds$

Diurnal Tidal Temperature Amplitude at 115 km Altitude (°K)



Coupling into the Low & Middle Latitude Daytime Ionosphere



Tidal or planetary wind perturbations in the lower thermosphere may affect the E-region dynamo process and impact the F-region aloft during daytime hours.

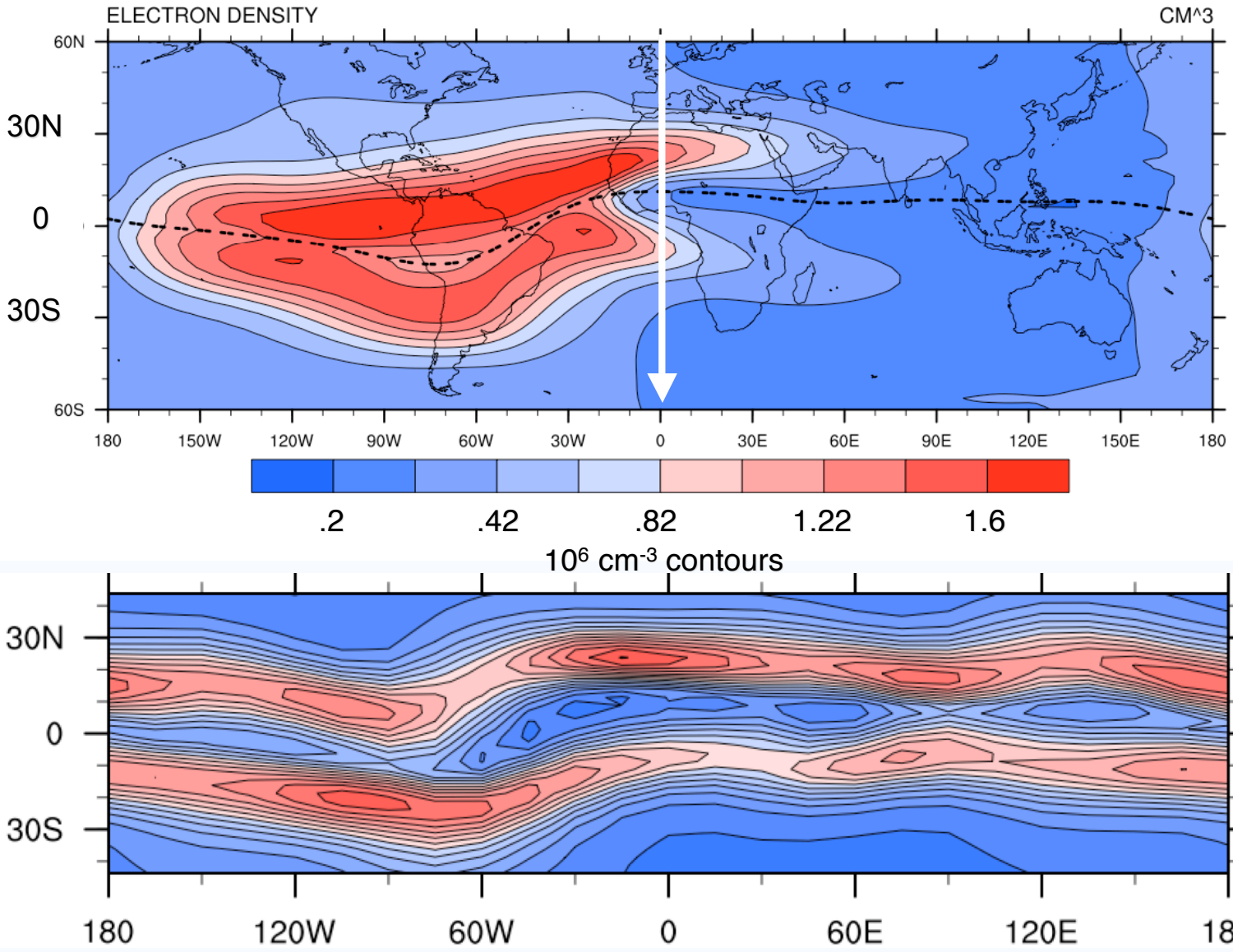
TIME-GCM

- First-principles global model
  - self-consistent dynamics, chemistry, electrodynamics
  - ~30 - 500 km; 2.5^{o} x 2.5^{o}; 4 grid points per scale height
  - parameterized sub-grid-scale gravity waves
  - cross-polar-cap potential drop = 30 kV

Hagan et al. [2007] Results:

- Geomagnetically quiescent vernal equinox moderate solar conditions
  - 10.7-cm solar radio flux ($F_{10.7}$) = 75
  - hemispheric power = 8 GW
  - cross-polar-cap potential drop = 30 kV
- Lower boundary condition (LBC)
  - Climatological tidal perturbations from the GSWM - March
  - horizontal winds, temperature, geopotential height

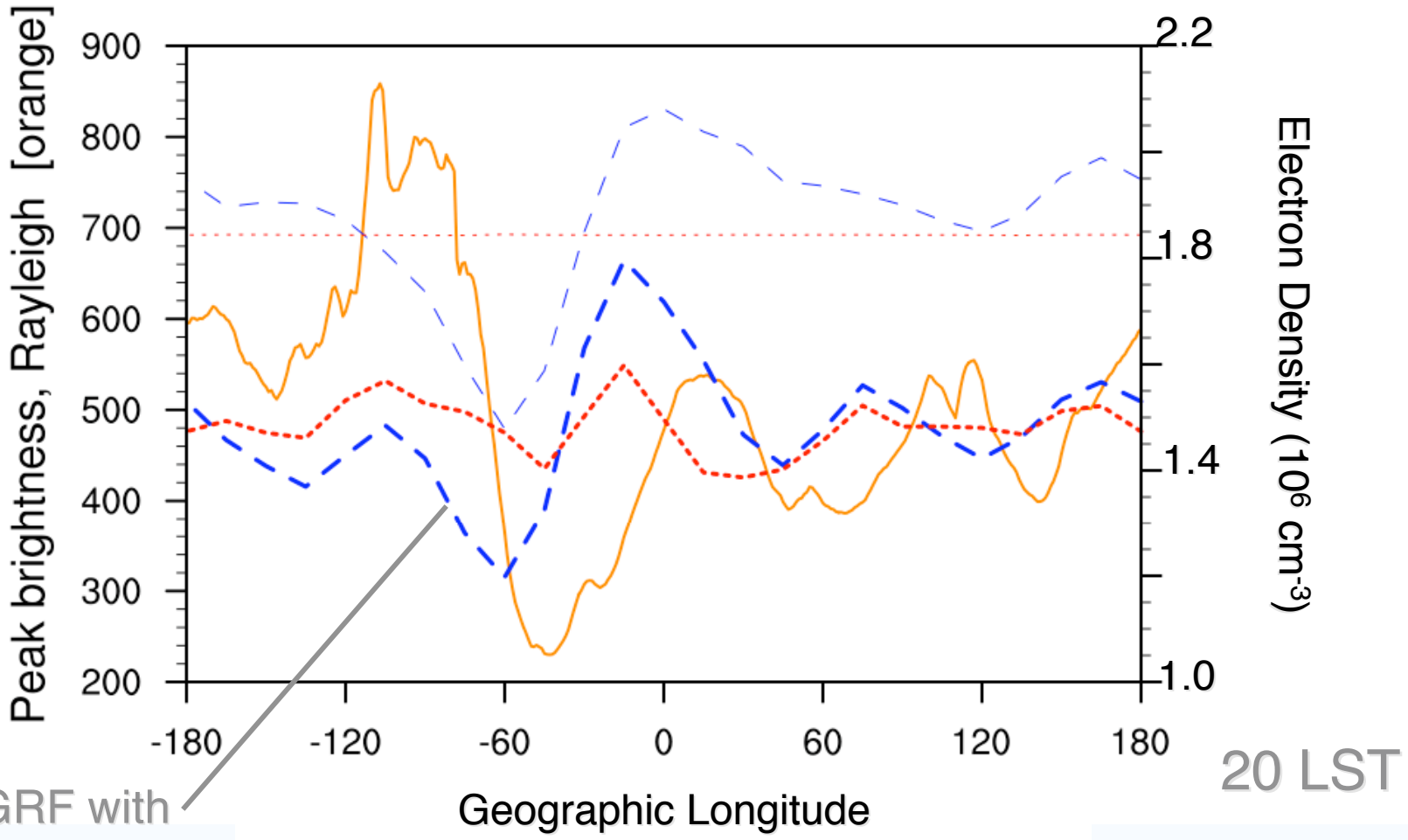
TIME-GCM Electron Density at 450 km



after *Hagan et al.* [2007]

TIME-GCM Northern Hemisphere Peak Electron Density

IMAGE FUV Northern Hemisphere Peak Brightness



after *Hagan et al.* [2007]

Hagan et al. [2007]

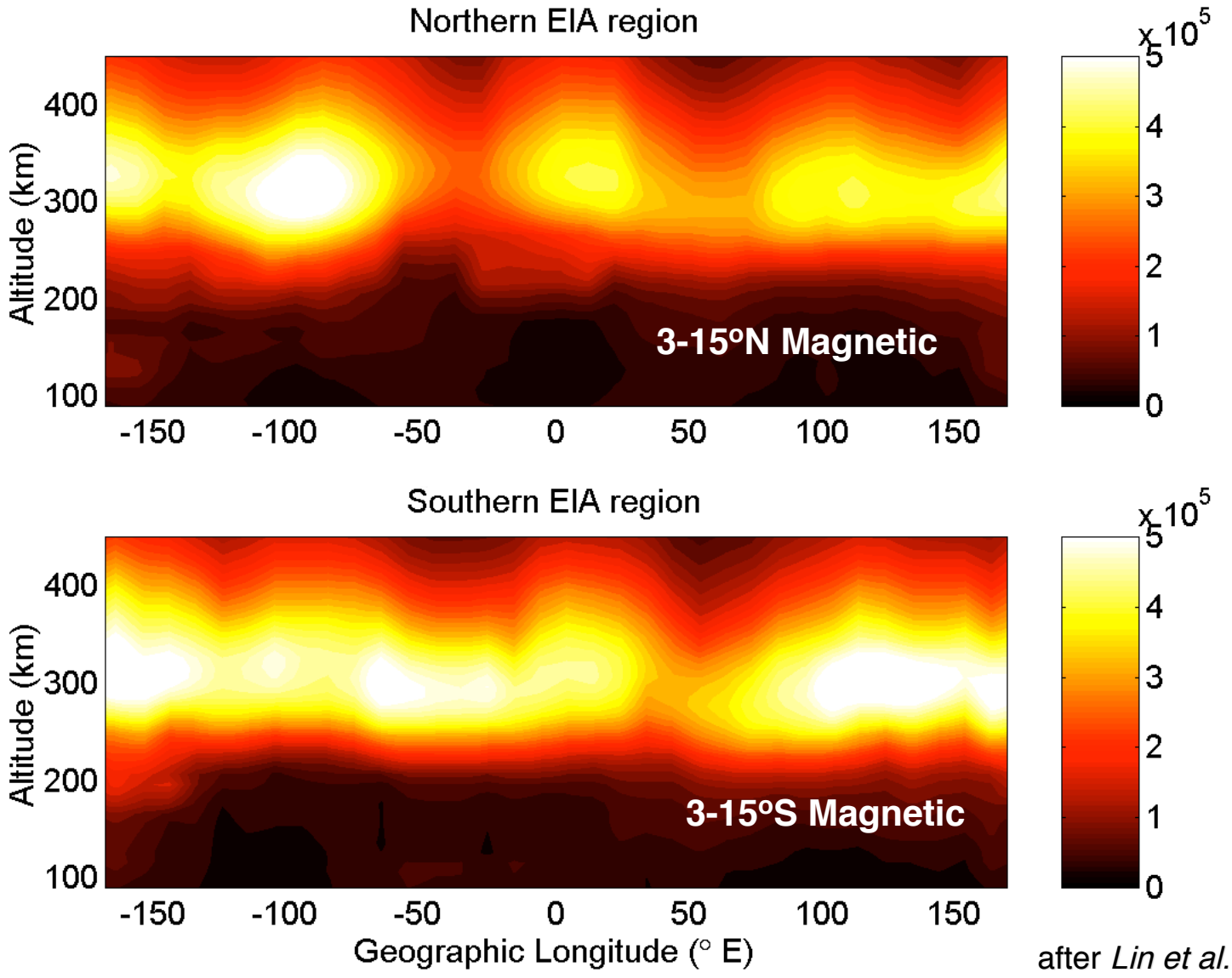
NCAR TIME-GCM simulations can replicate 4-peaked ionospheric longitudinal variations observed by IMAGE only when GSWM eastward propagating zonal wavenumber 3 diurnal (DE3) tidal forcing is included at the model lower boundary.

The DE3 is excited by parameterized latent heat release associated with raindrop formation in deep tropical convective clouds in the GSWM.

These results provide strong evidence of a connection between persistent global meteorological weather patterns and quiescent space weather.

<u>Will this effect evolve with solar cycle, local time, season</u>?

FORMOSAT-3/COSMIC Electron Density 20-22 LST - Sep 2006



after *Lin et al.* [2007]

New TIME-GCM Simulations

- Geomagnetically quiescent solar minimum conditions
  - 10.7-cm solar radio flux ($F_{10.7}$) = 75
  - hemispheric power = 8 GW
  - cross-polar-cap potential drop = 30 kV

Two Realistic Simulations:

- March & September
- 13 wavenumber diurnal and semidiurnal perturbations
- westward wavenumber 6 through eastward wavenumber 6

Three Diagnostic Simulations:

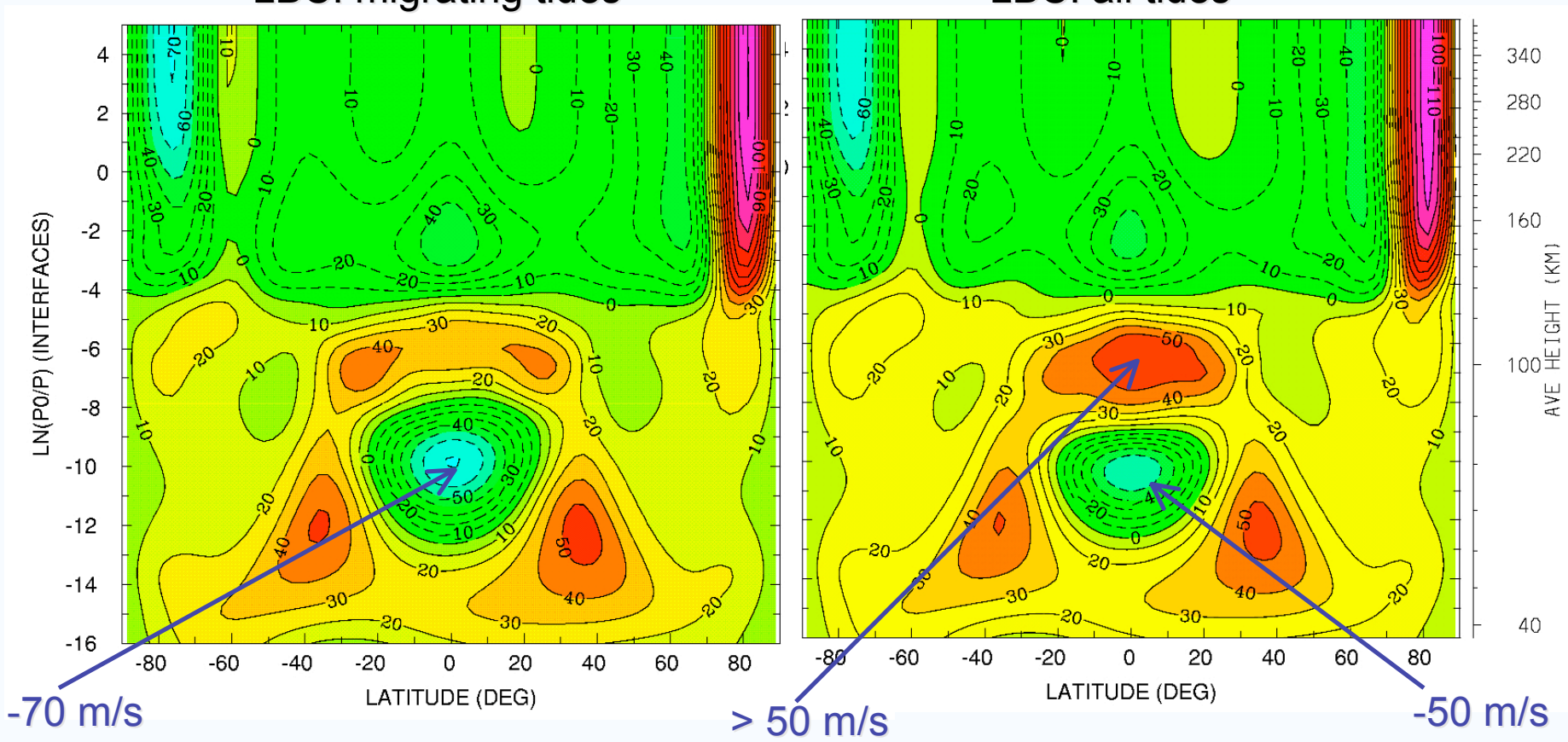
- LBC migrating tides; March & September
- LBC migrating + diurnal nonmigrating tides; March

TIME-GCM Zonal Mean Zonal Winds during March

Solar Minimum Geomagnetically Undisturbed Conditions

LBC: migrating tides

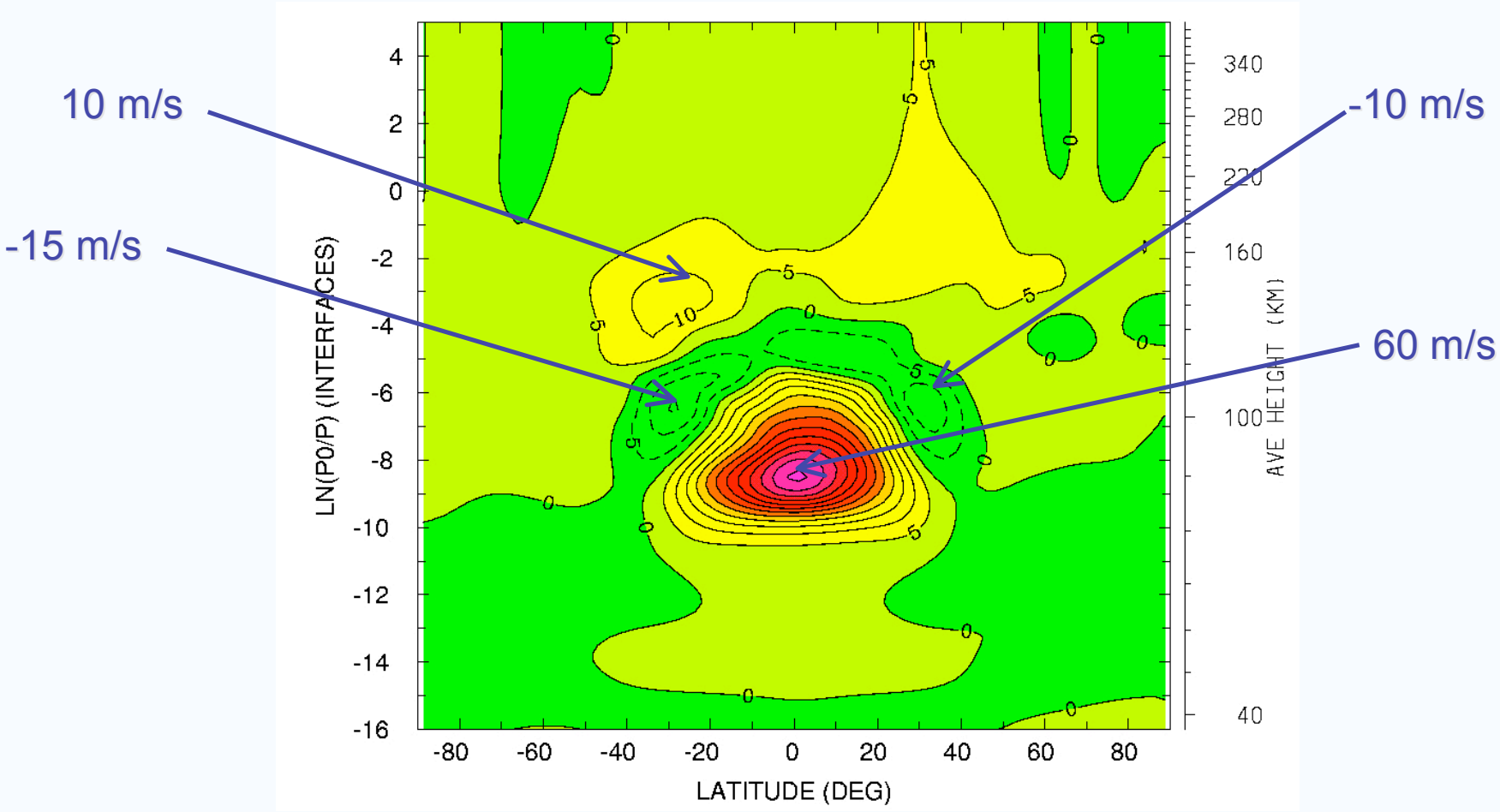
LBC: all tides



Note change in altitude and magnitude of equatorial jets

TIME-GCM Zonal Mean Zonal Wind Differences

all tides - migrating tides

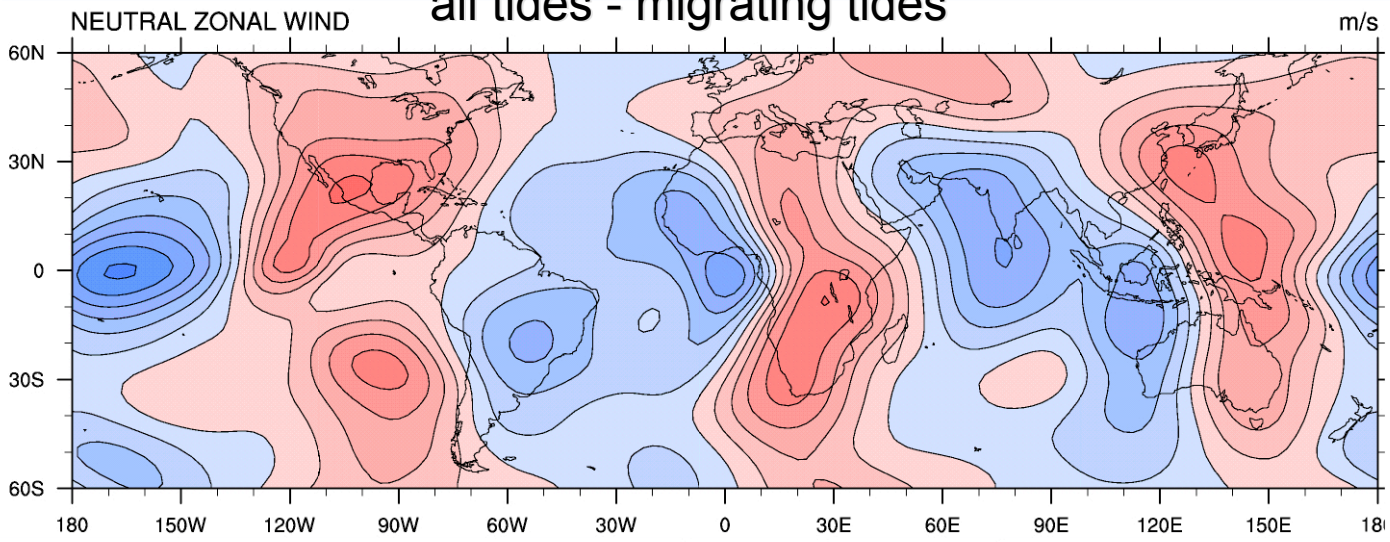


Nonmigrating tidal dissipation profoundly affects the zonal mean circulation in the upper mesosphere and lower thermosphere.

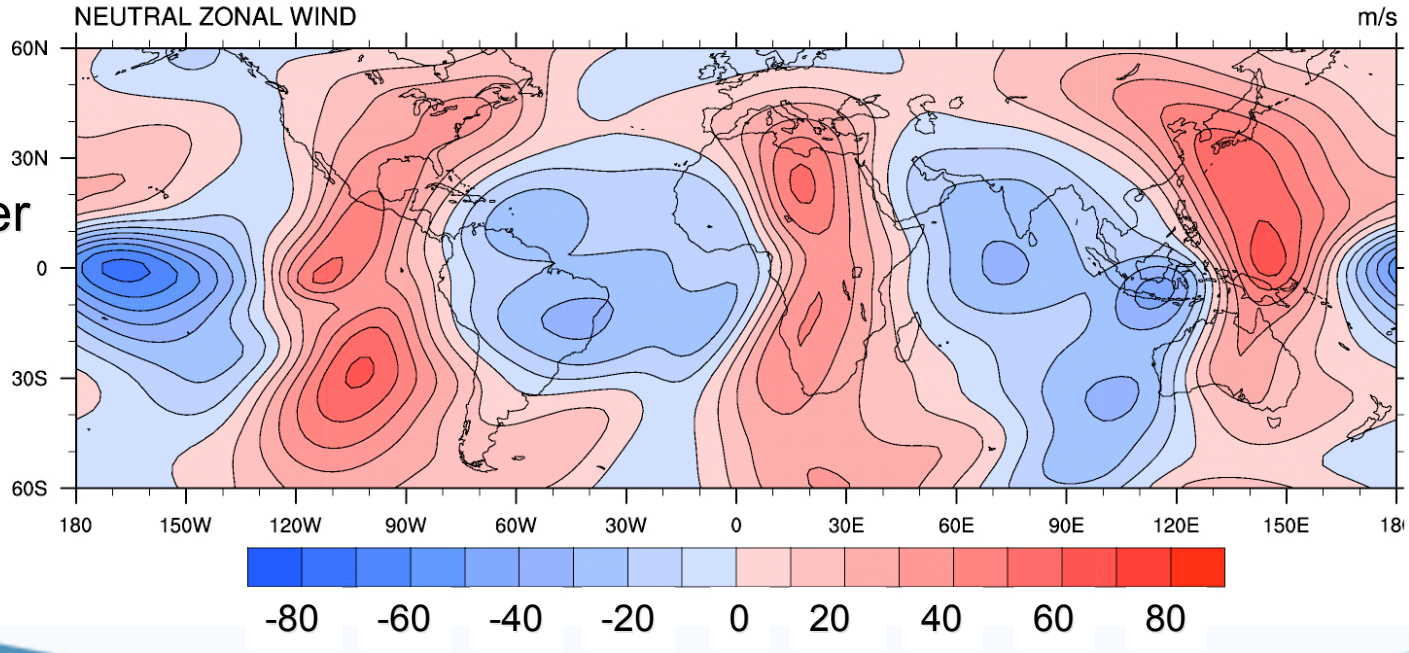
Zonal Wind Differences (m/s) near 120 km at 15 UT

all tides - migrating tides

March



September

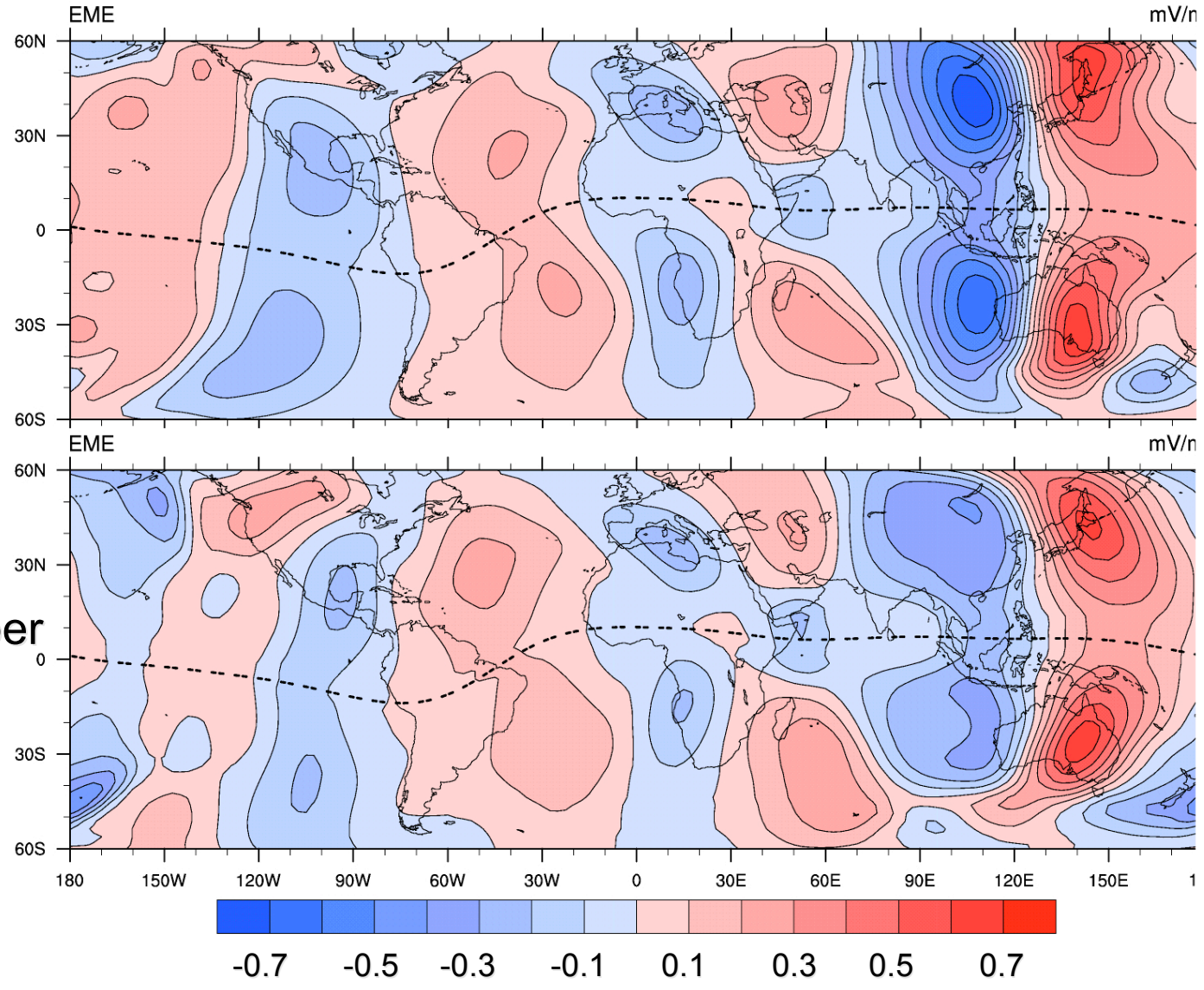


Electric Field Differences (mV/m) near 120 km at 15 UT

all tides - migrating tides

March

September

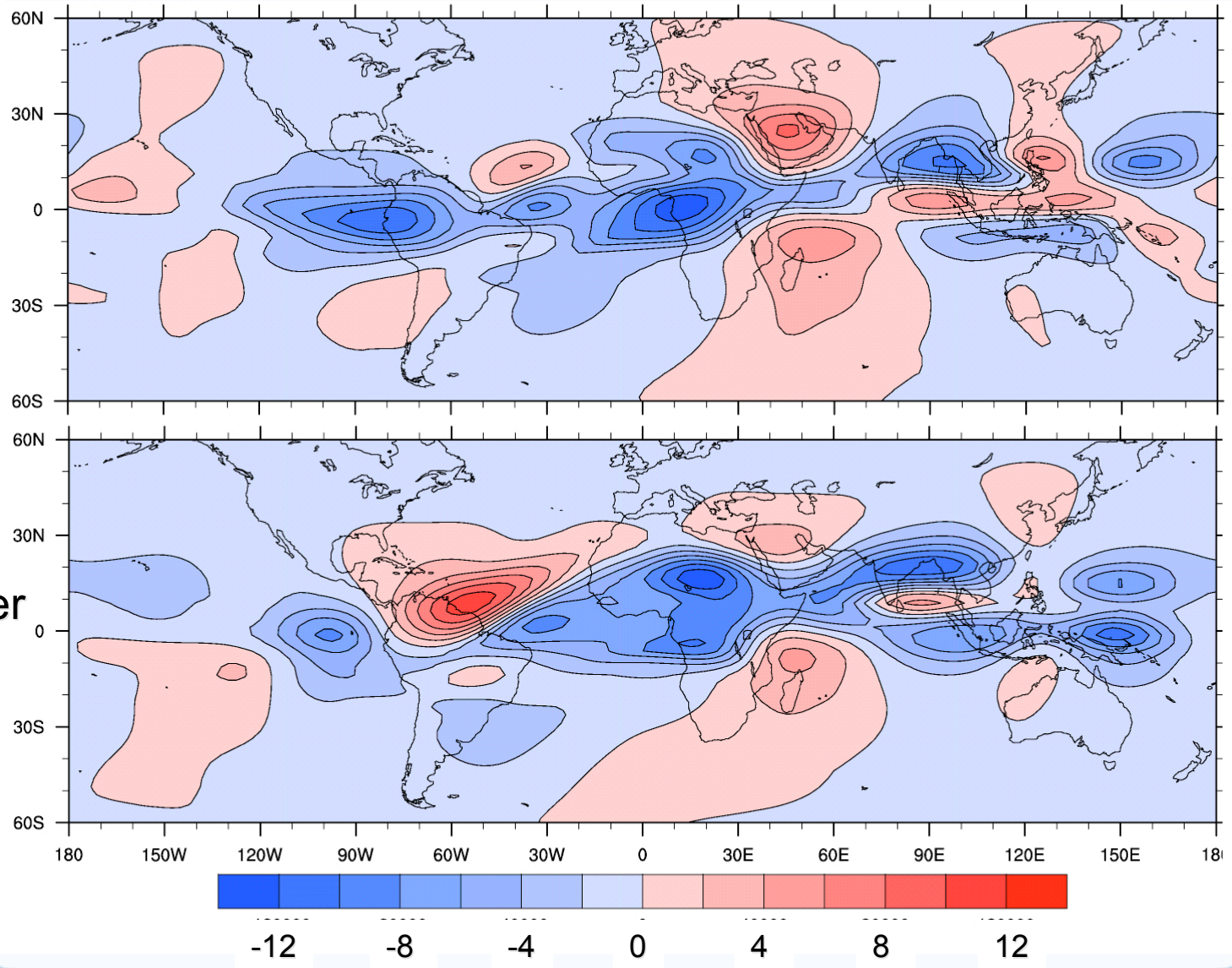


Electron Density Differences (10^4cm/s) near 350 km at 15 UT

all tides - migrating tides

March

September



Equinoctal Variability of Equatorial Zonal Wind Tidal Amplitudes (m/s) during Solar Minimum

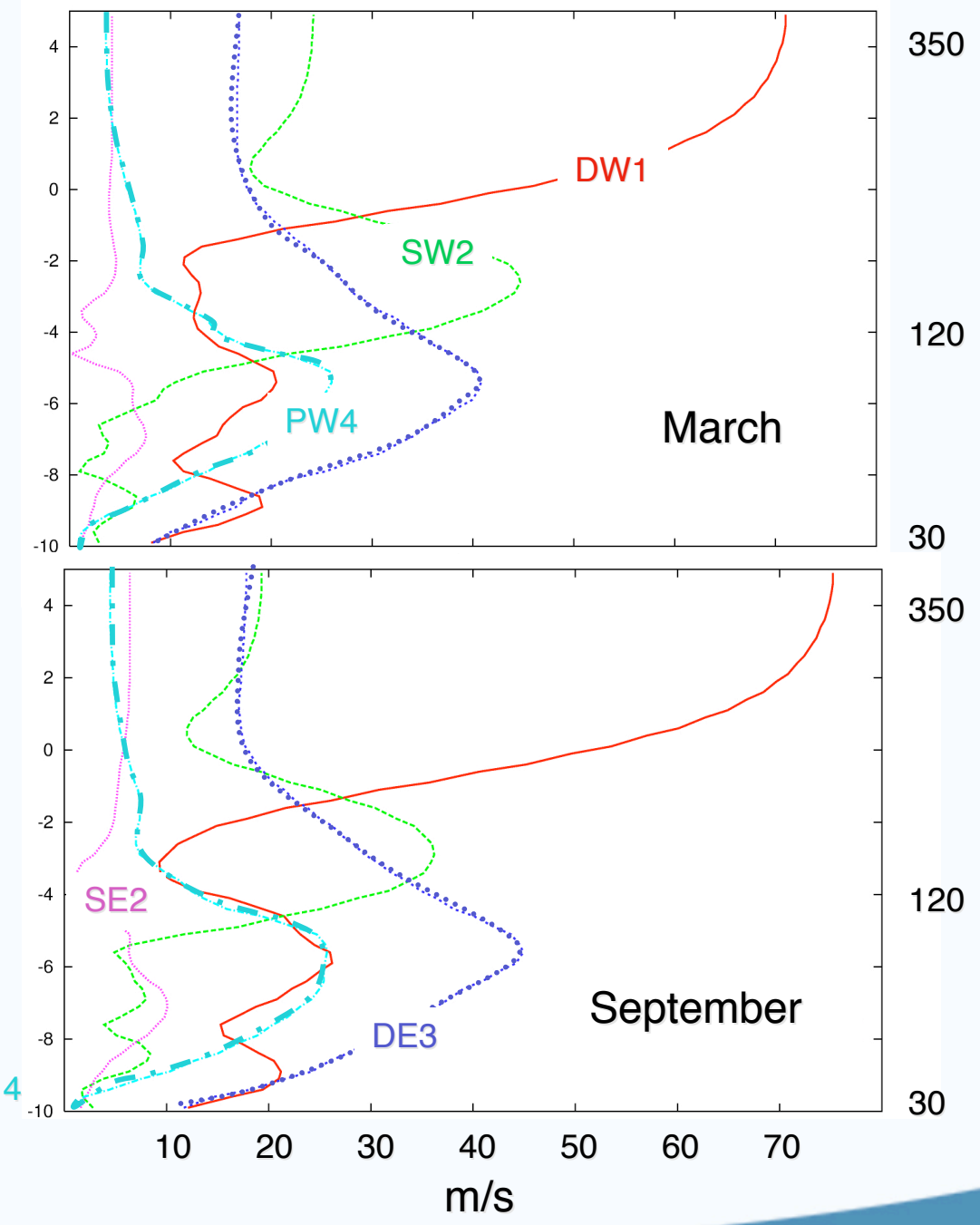
DW1 - migrating diurnal

SW2 - migrating semidiurnal

DE3 - diurnal eastward 3

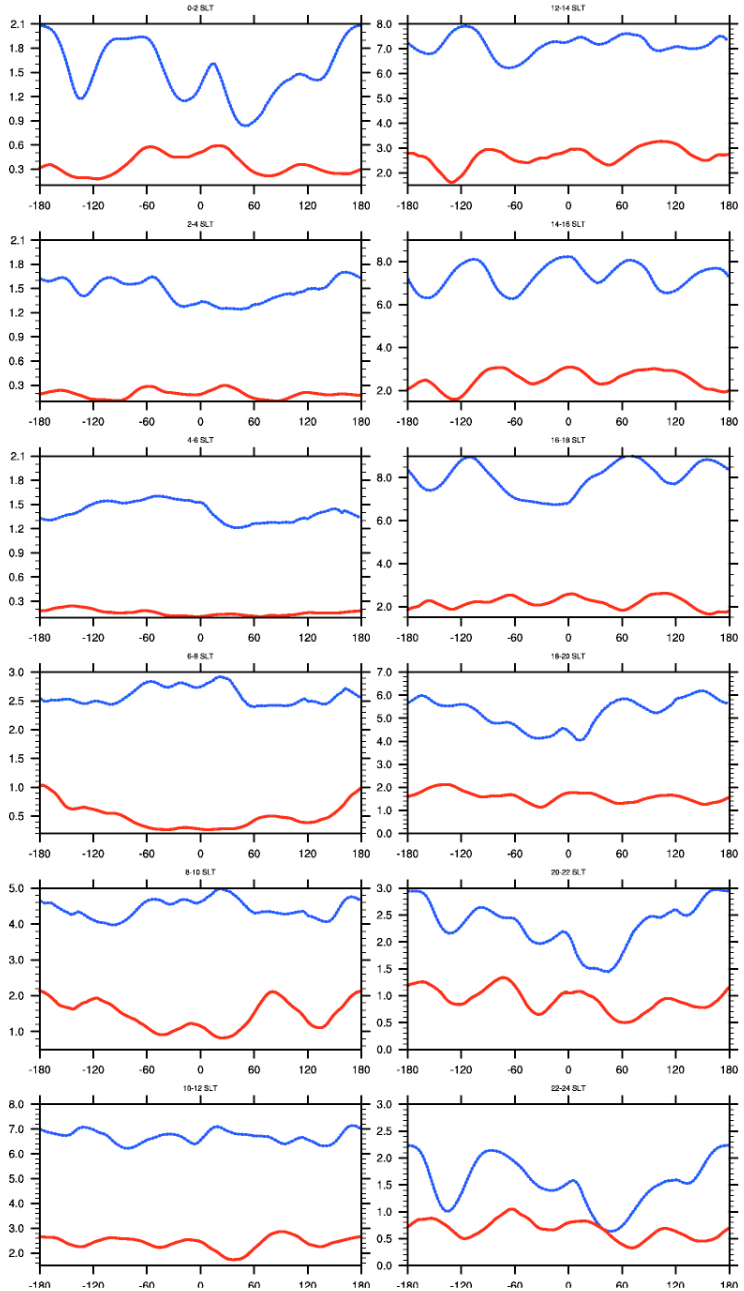
SE2 - semidiurnal eastward 2

PW4 -stationary planetary wave 4



Integrated electron density (TEC units) during September as observed by F3/C (red; after *Lin et al.*, 2007) and modeled by the TIME-GCM (blue)

+/-15° geomagnetic
F3/C: 400-450 km
TIME-GCM: 250-400 km



Discussion and Conclusions - I

- TIME-GCM replicates some salient features of the longitudinal variations observed by F3/C in the equatorial ionosphere during solar minimum conditions
- The DE3 and SW2 amplitudes dominate the equatorial tidal responses in the E-region dynamo region (ca. 90-150 km) during equinox
- The SW2, like all migrating tides, is longitudinally invariant
- PW4 is excited via nonlinear interaction between DE3 and DW1 in the TIME-GCM

Discussion and Conclusions - II

- Local time variations in the 4-peaked ionospheric structures observed by F3/C may be attributable to PW4 and a weak SE2 which modulate the DE3 signatures in the lower thermosphere
- Outstanding differences between the modeled and measured signatures remain to be explained
- Related investigations into the effects of persistent meteorological systems on space weather during solstice are underway