Dynamical Coupling in the Earth's Upper Atmosphere

Outstanding Challenges for DASI

Maura Hagan
High Altitude Observatory
National Center for Atmospheric Research

Outline

- Motivation
  - Context: thermosphere-ionosphere space weather
- Observational evidence of ionospheric variability during geomagnetically quiet conditions
  - 1-σ variations in NmF2 during quiet times
  - IMAGE & FORMOSAT-3/COSMIC observations of 4-peaked longitudinal ionospheric variations
- Concluding Remarks

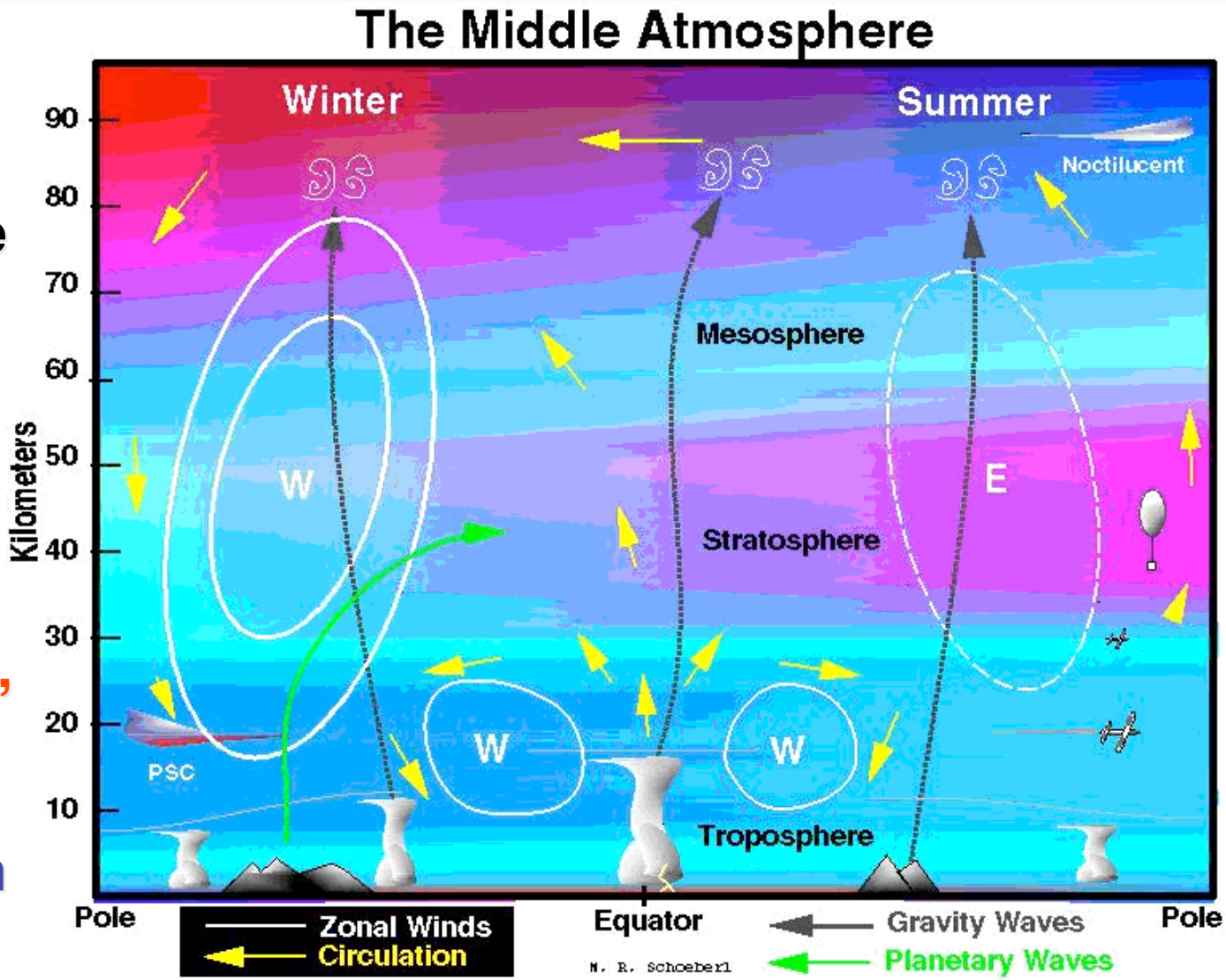
Motivation

- Quiescent variability of thermosphere-ionosphere
  - unresolved research topic
  - potential sources - lower atmosphere 
    residual disturbance effects
- Increasing insight into the impact of lower atmospheric sources on the mesopause region
  - 2007 CEDAR tutorials
- One system - the atmosphere doesn't "know" about the boundaries that we impose on it
  - models
  - funding
  - observations
- The mesopause is the "gateway" to the thermosphere-ionosphere

Macro-Scale Effects of Micro- & Meso-Scale Variations

The TI Gateway: The Mesopause Region

Gravity Waves: sources, evolution, dissipation, effects
➔ ???? penetration into the TI



Natural Variability of the Quiescent Ionosphere (after *Mendillo et al.*, 2002)

daily predictions coupled CCM3 TIME-GCM

peak density vs. UT

1σ: monthly mean ionosonde data

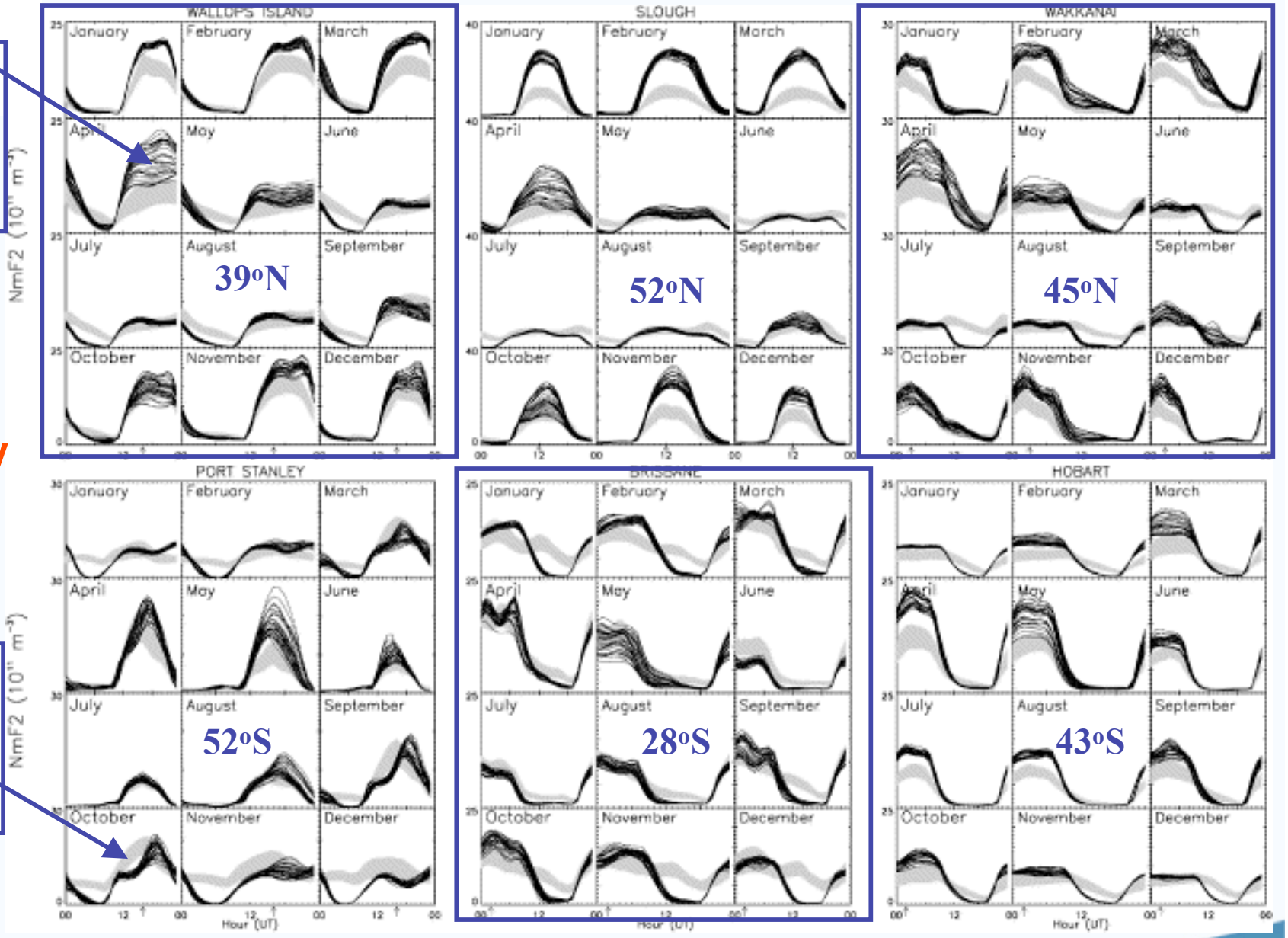


IMAGE-FUV observations of the equatorial Ionization anomaly (EIA) during March 2002 equinox with DE3 115-km temperature perturbations from the NCAR global-scale wave model (GSWM)

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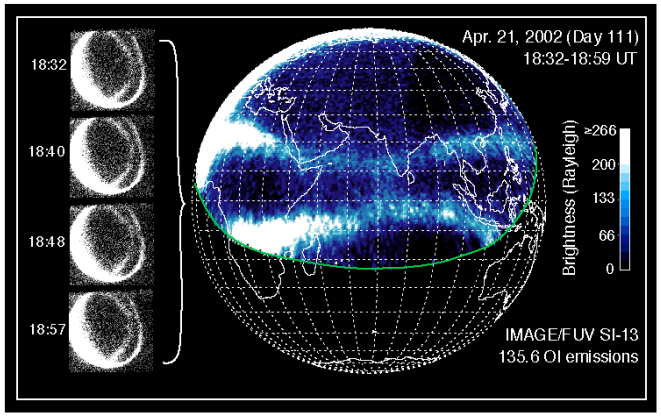
Volume 8 Number 88

Far-Ultraviolet Ionospheric Emissions

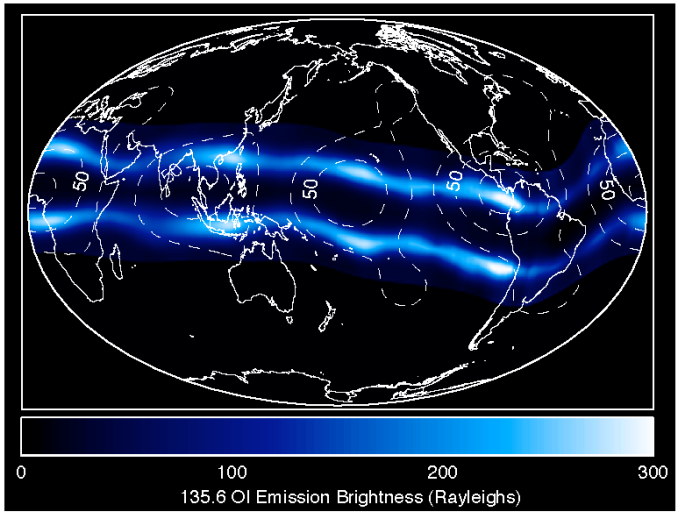


***Immel et al.*, 2006**

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

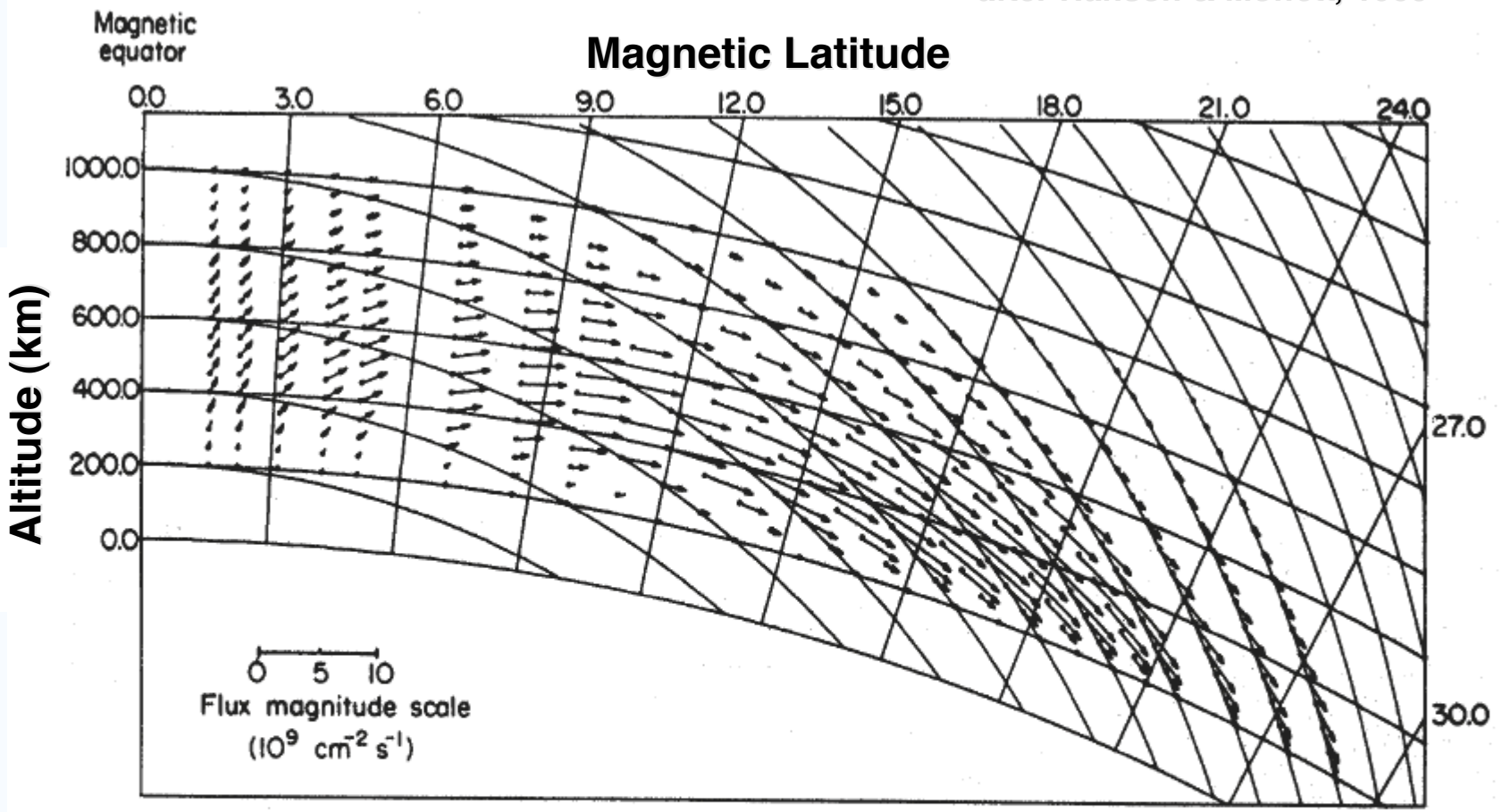
$I = \alpha \int n_e^2 \, ds$

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



Equatorial Ionospheric Anomaly - The Fountain
Flux in the Magnetic Meridian Plane

after *Hanson & Moffett*, 1966

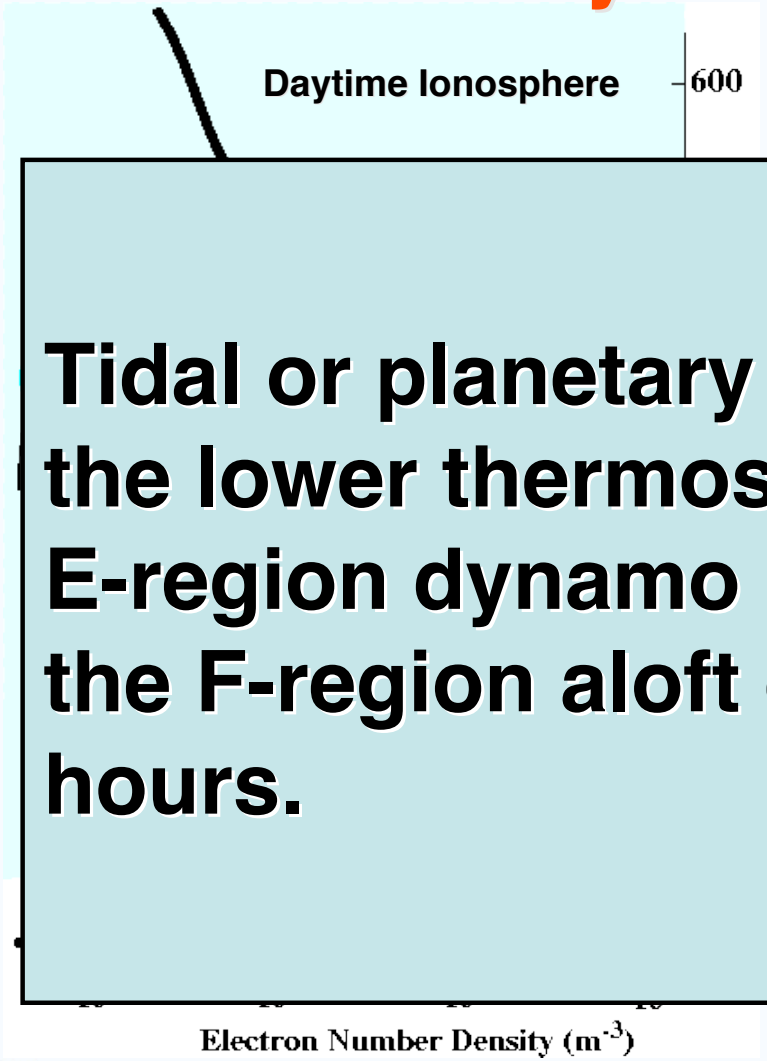


Combined effects of:

Upward drift (eastward E)

Plasma diffusion along B

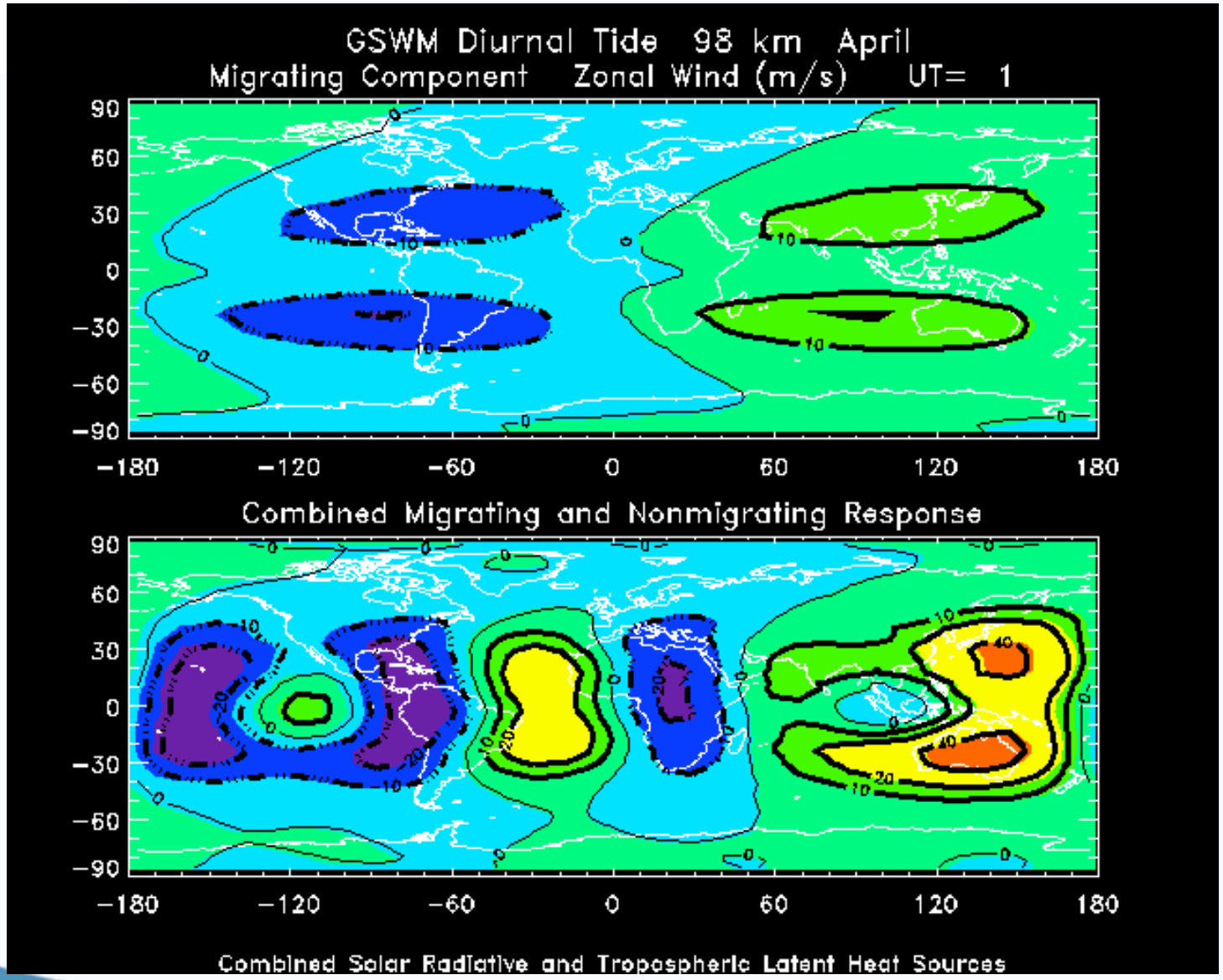
Coupling into the Low & Middle Latitude Daytime Ionosphere



E-region Dynamo

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.

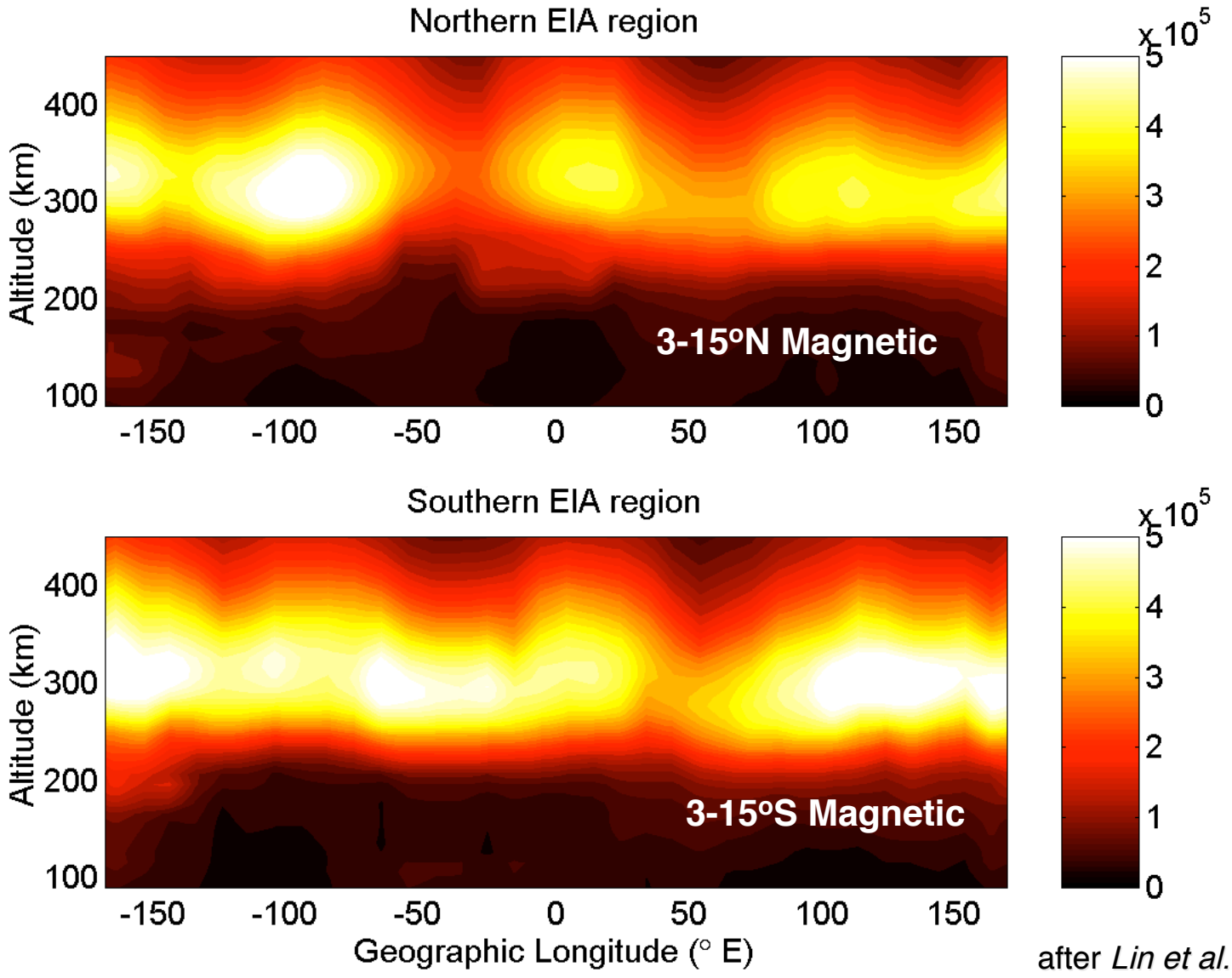
GSWM Diurnal Zonal Wind - 98 km



GSWM-00 migrating tide

GSWM-02 = GSWM-00 + latent heat response

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



after *Lin et al.* [2007]

Snapshot

synoptic map - universal time (t_{UT}) perspective

tidal perturbation, f', at a given latitude -

$$f' = \Sigma A_{s,n} \cos[\omega_n(t_{UT} - \phi_{s,n}) - s\lambda]$$

s = zonal wavenumber; λ = longitude

n = harmonic - 1=diurnal; 2=semidiurnal, etc.

$\omega_n = 2\pi n/24$ hours

$A_{s,n}$ / $\phi_{s,n}$ = tidal amplitude / phase

Satellite Maps

asynoptic - local time (t_{LST}) perspective

$$t_{LST} = t_{UT} + 360^o\lambda/2\pi 15^o$$

$$f' = \Sigma A_{s,n} \cos[\omega_n(t_{LST} - \phi_{s,n}) - (s-n)\lambda]$$

☞ observed zonal wavenumber = $|s-n|$

IMAGE & F-3/C Signatures

☞ wavenumber 4

☞ could be DE3

s =-3, n =1

$|s-n| = 4$

TIME-GCM Simulations [*Hagan et al.*, 2007]

- Resolution: horizontal - 2.5^o x 2.5^o
  vertical - 4 grid points per scale height
- Geomagnetically quiescent vernal equinox moderate solar conditions
  perpetual day of year = 80 (March 21)
  10.7-cm solar radio flux ($F_{10.7}$) = 150
  hemispheric power = 8 GW
  cross-polar-cap potential drop = 30 kV
- Lower boundary (~ 30 km) condition (LBC):
  aggregate March global-scale wave model (GSWM) results
  diurnal and semidiurnal perturbations - 13 wavenumbers
  horizontal winds, temperature, geopotential height

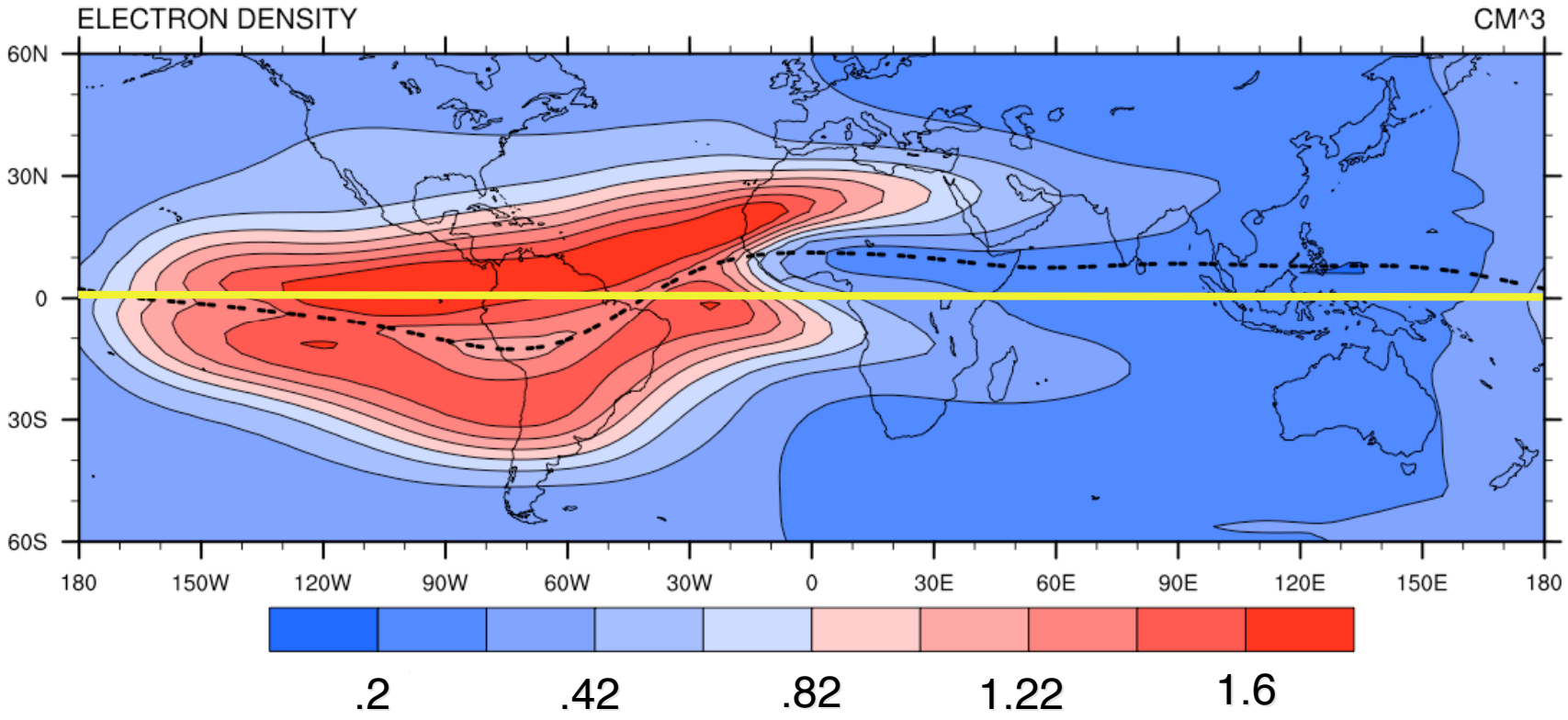
Standard Run:

International Geomagnetic Reference Field (IGRF)

Diagnostic Runs:

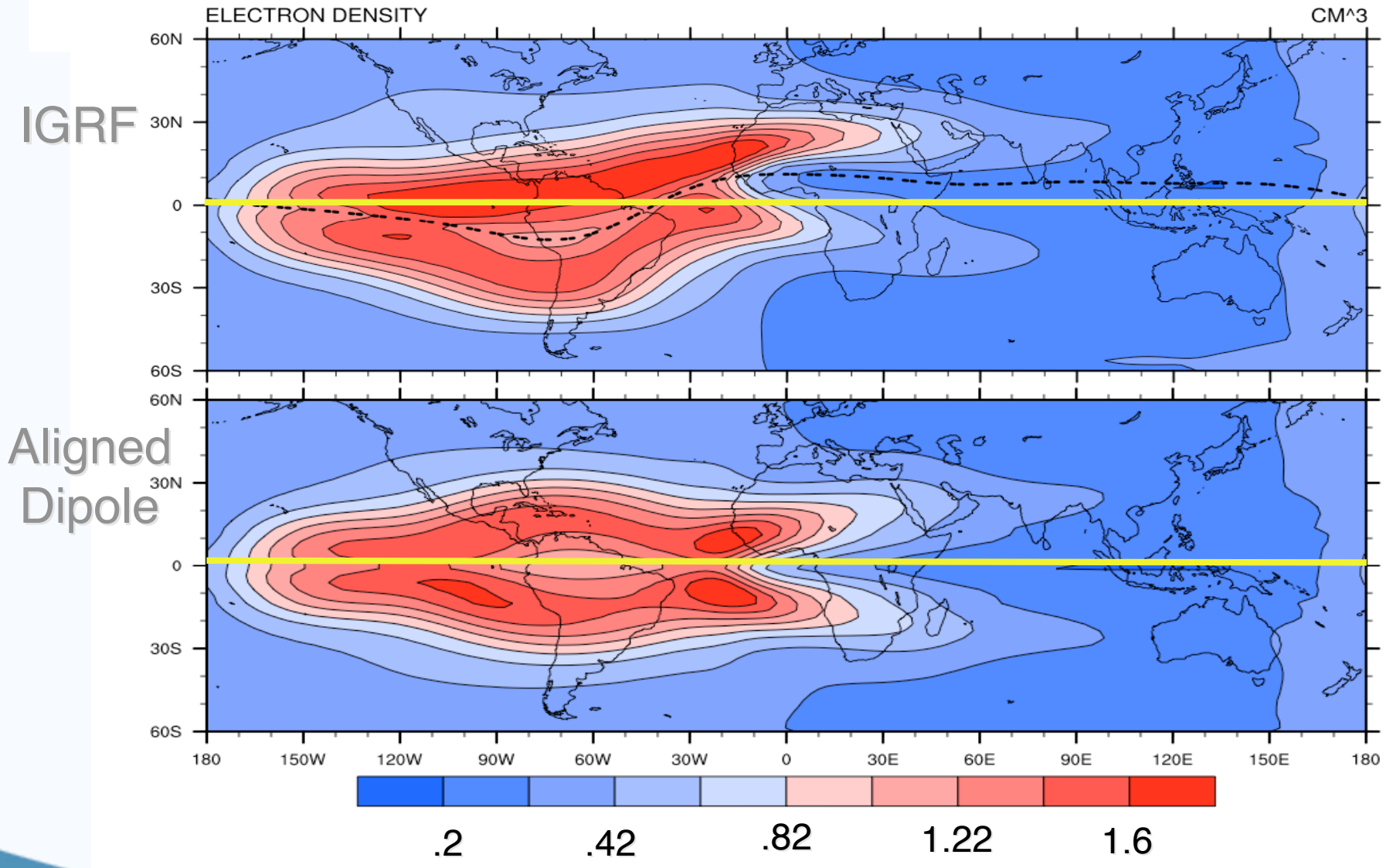
IGRF without tidal LBC ("without tropospheric tides")
Aligned Dipole geomagnetic field
Aligned Dipole geomagnetic field without tropospheric tides

TIME-GCM Electron Density at 20 UT and 450 km



10^6 cm^{-3} contours

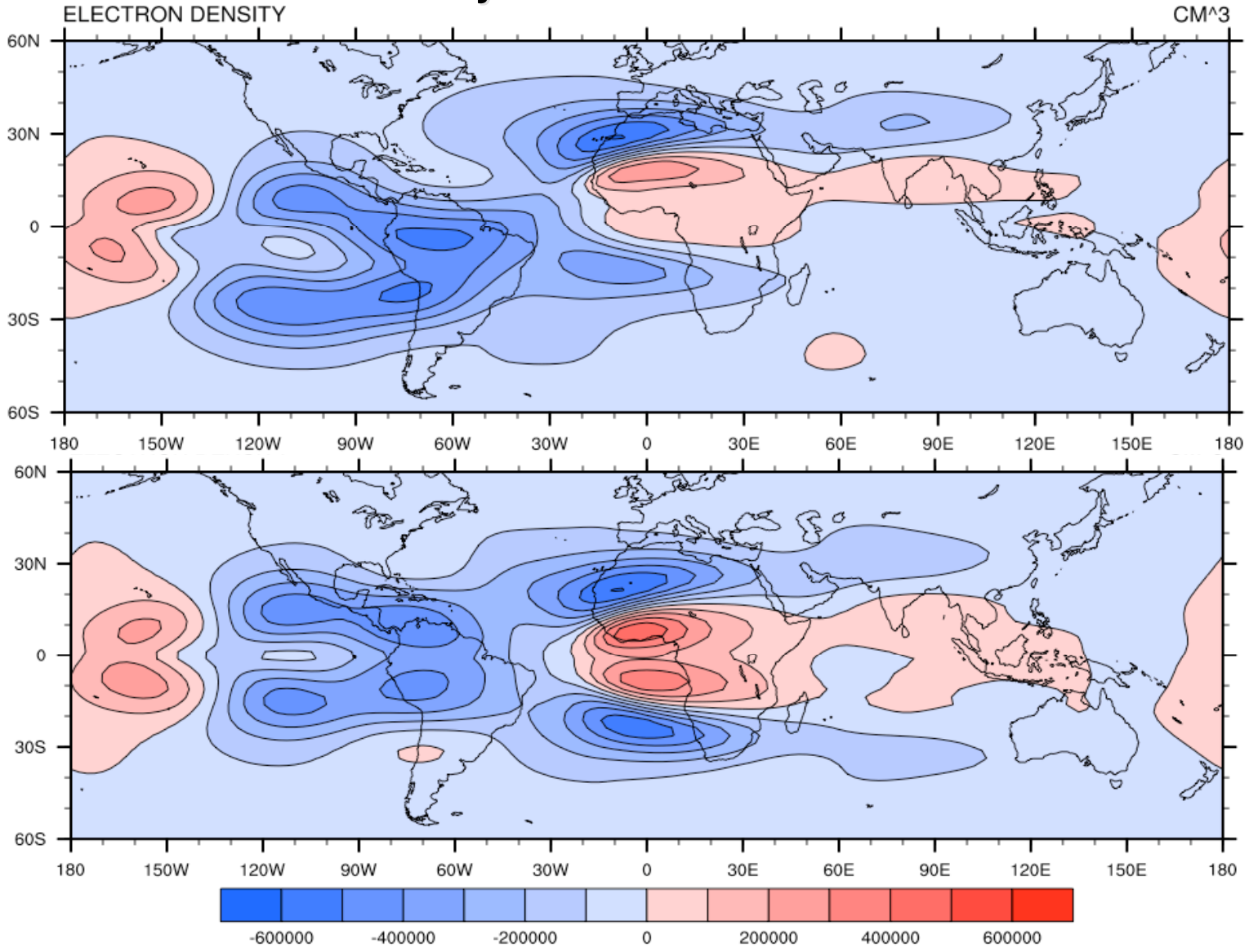
TIME-GCM Electron Density at 20 UT and 450 km



TIME-GCM Electron Density Differences* at 20 UT and 450 km

IGRF

Aligned Dipole

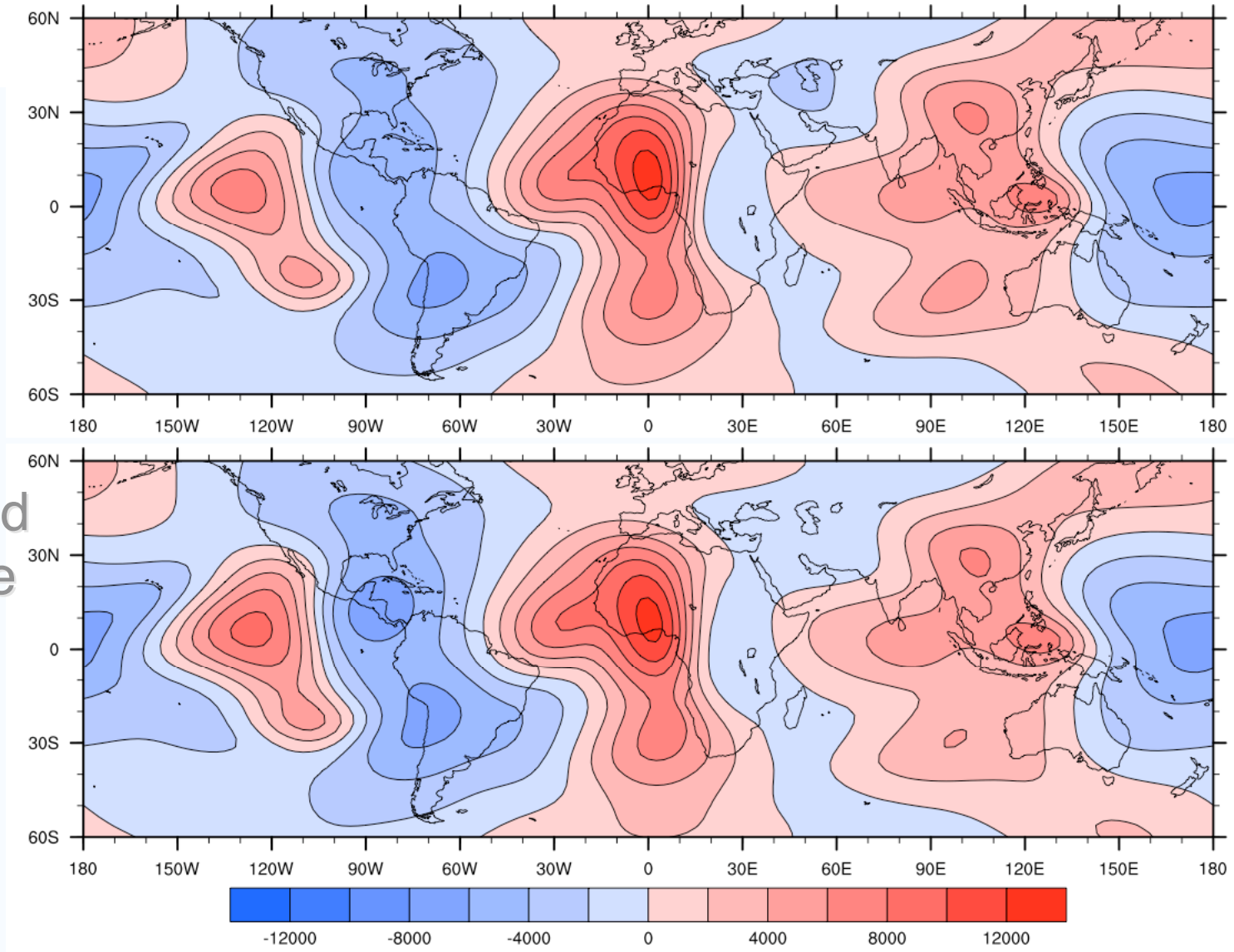


*with - without tropospheric tides

TIME-GCM Zonal Wind Differences* at 20 UT and 110 km

IGRF

Aligned Dipole

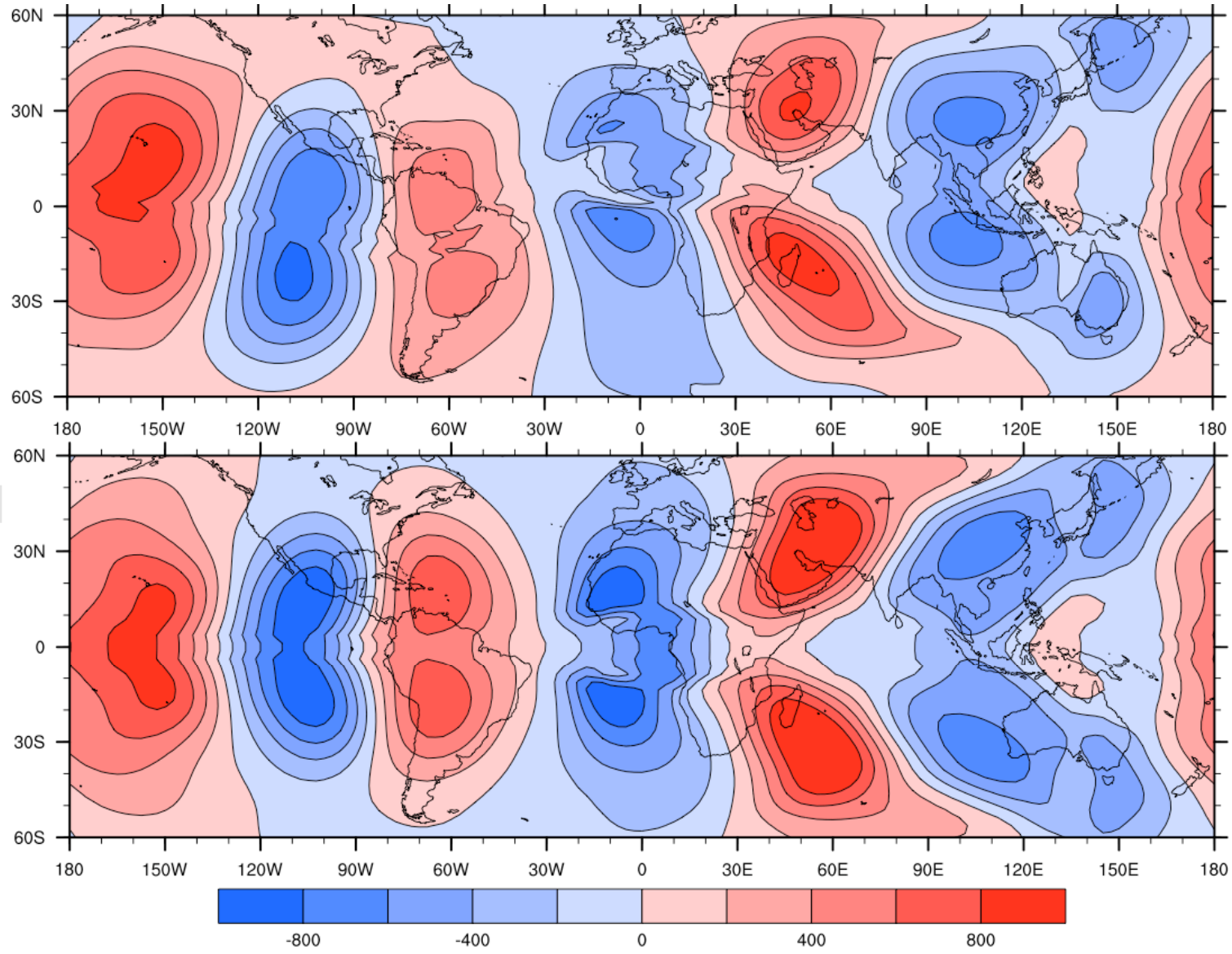


*with - without tropospheric tides

TIME-GCM Vertical ExB Drift Differences* at 20 UT and 110 km

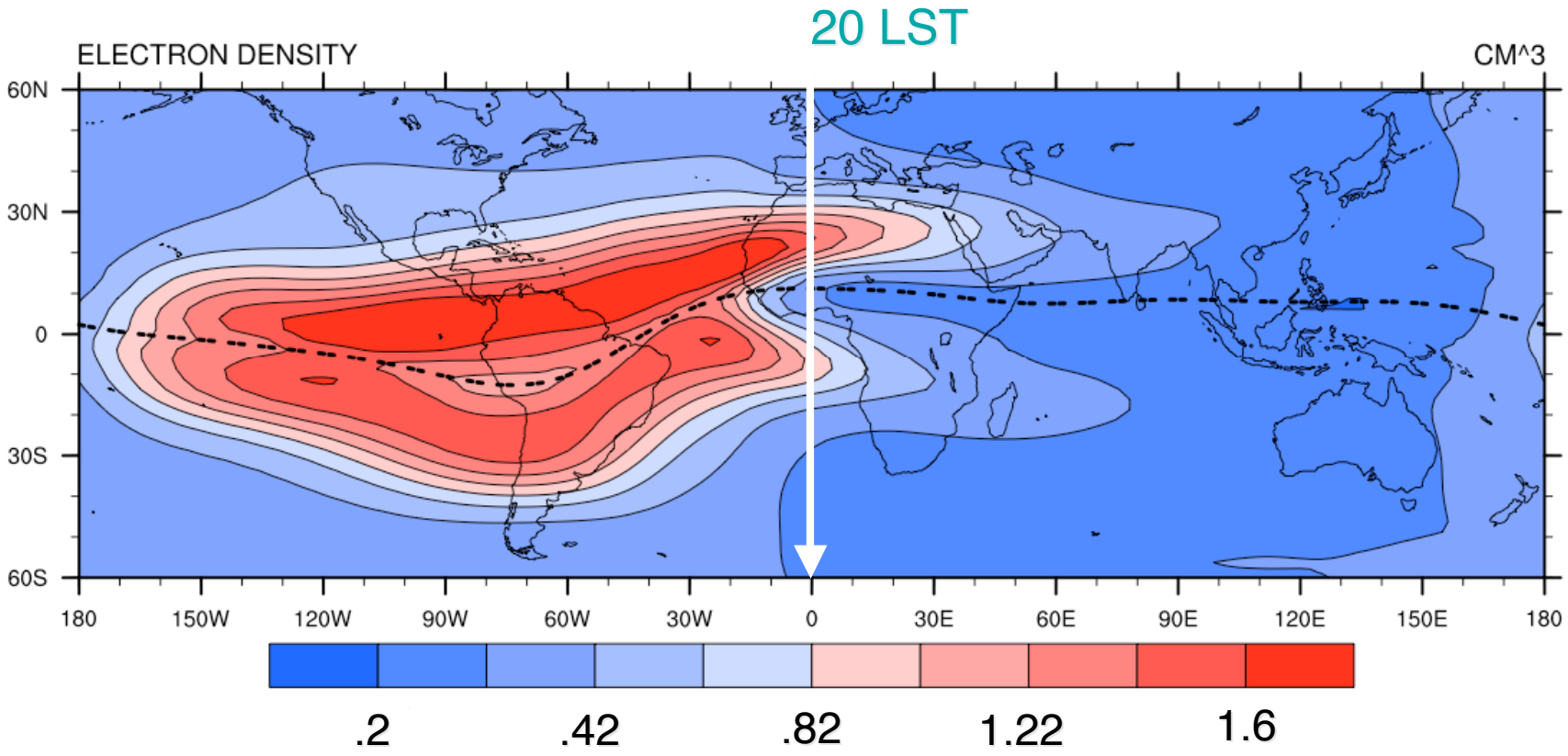
IGRF

Aligned Dipole



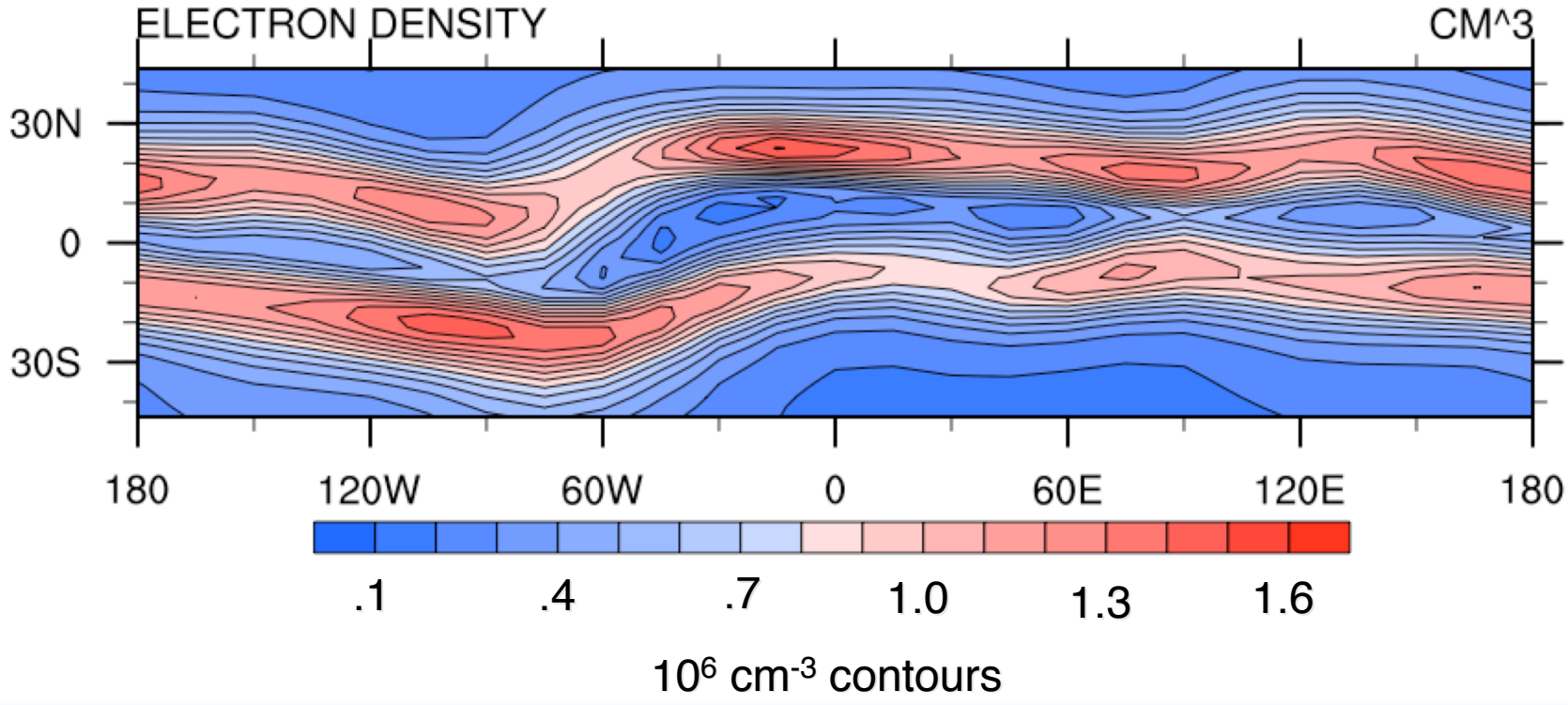
*with - without tropospheric tides

TIME-GCM Electron Density at 20 UT and 450 km

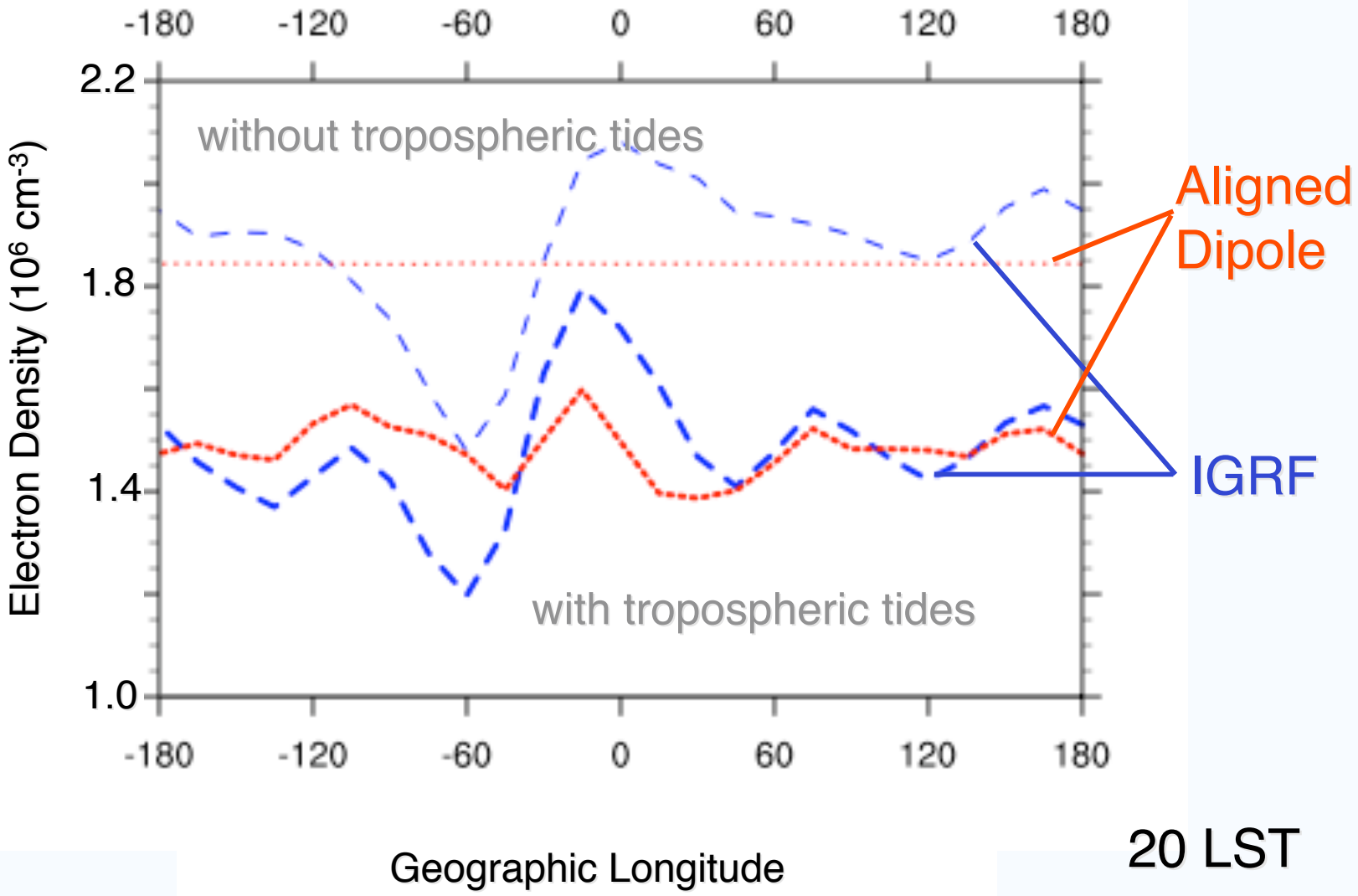


10^6 cm^{-3} contours

TIME-GCM Electron Density at **20 LST** and 450 km

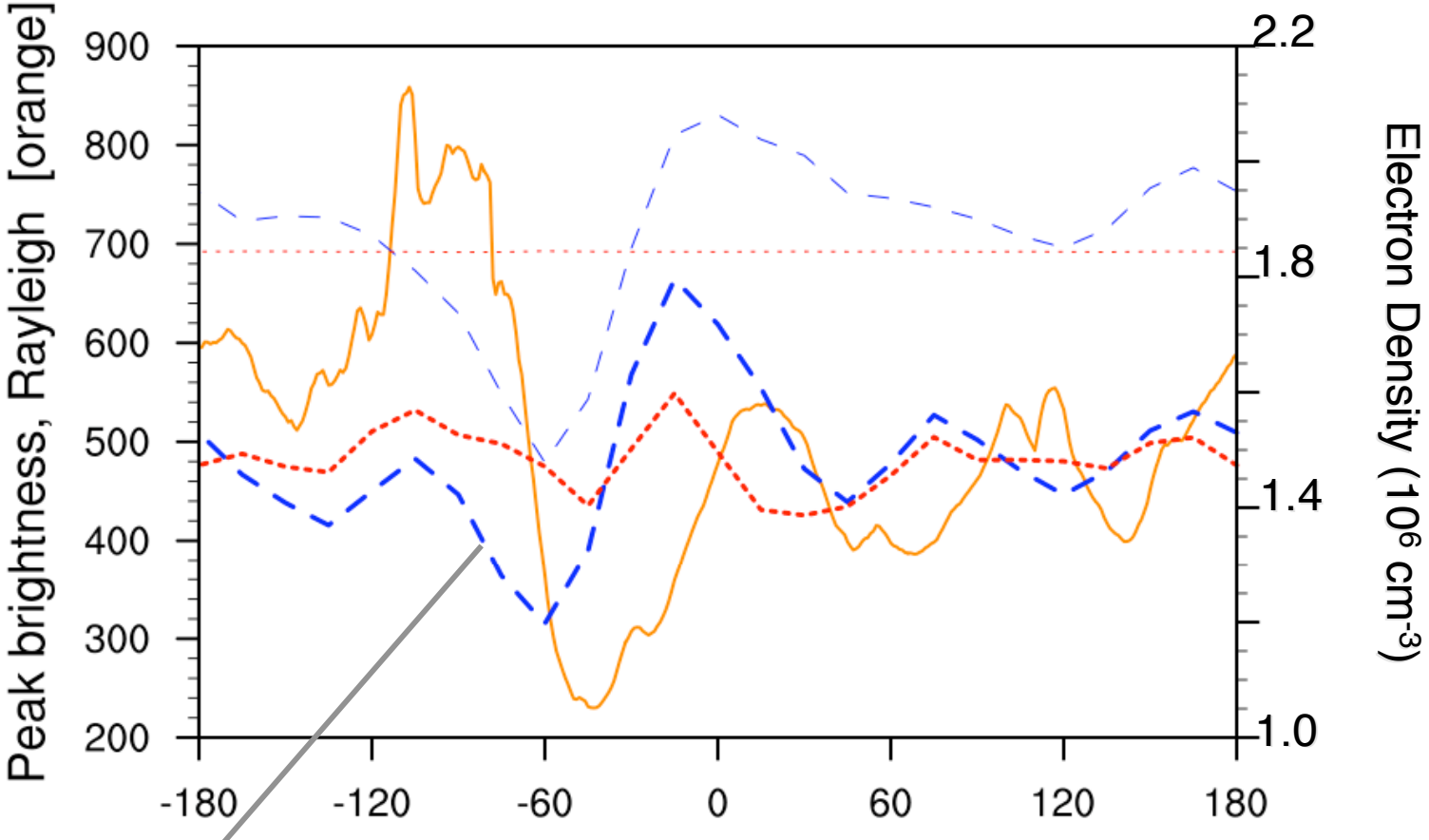


TIME-GCM Northern Hemisphere Peak Electron Density



TIME-GCM Northern Hemisphere Peak Electron Density

IMAGE FUV Northern Hemisphere Peak Brightness

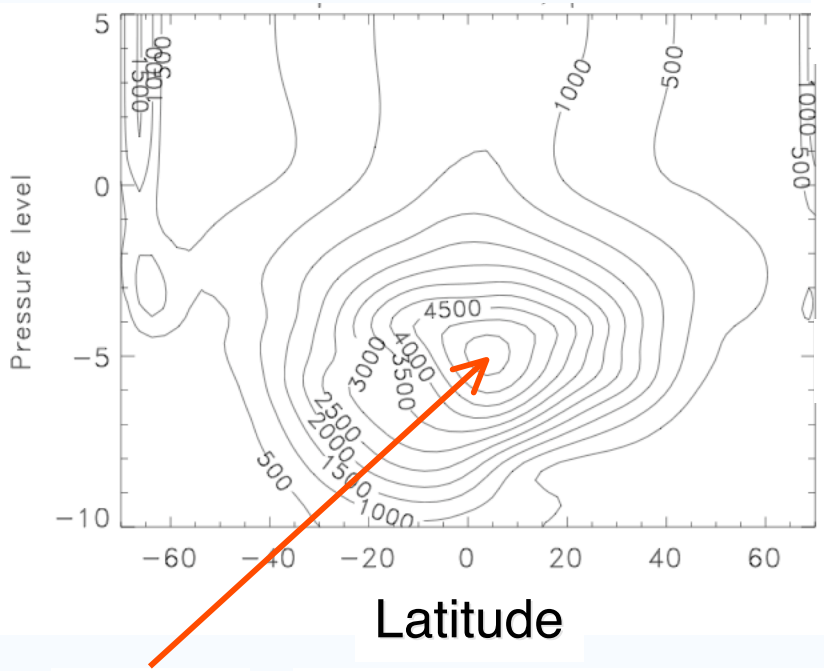


IGRF with tropospheric tides

20 LST

TIME-GCM Zonal Wind DE3 Perturbations
Standard IGRF Run

Amplitude (cm/s)



Latitude

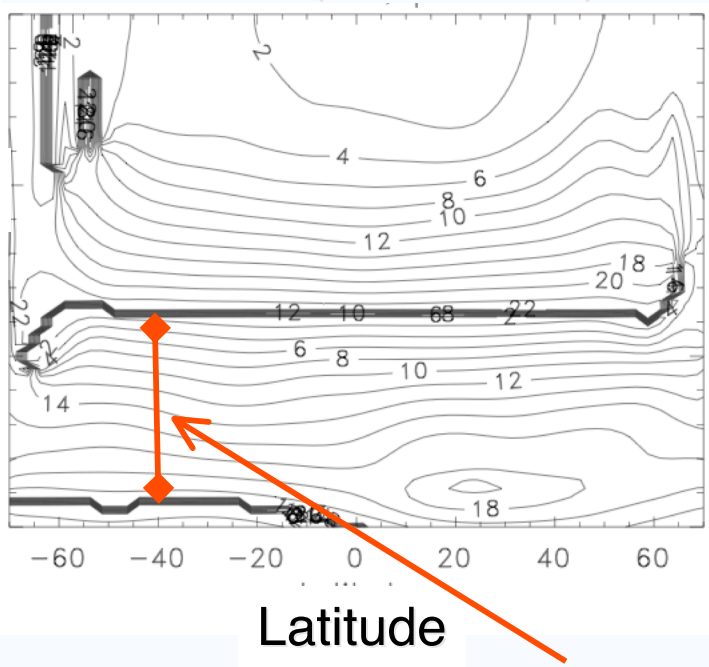
500 km

225 km

100 km

30 km

Phase (local hours)



Latitude

55 m/s

λ_z ~ 75-85 km

Peak amplitude is stronger than
- GSWM prediction (Hagan and Forbes, 2002)
- UARS/HRDI analysis result (Talaat and Lieberman, 1999)
- TIMED/TIDI analysis result (Oberheide et al., 2006)

λz is longer than
- GSWM prediction (Hagan and Forbes, 2002)

Conclusions - *Hagan et al.*, 2007

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

NCAR TIME-GCM simulations can replicate observed 4-peaked ionospheric longitudinal variations only when GSWM DE3 forcing is included at the lower boundary.

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

DASI Science Challenges

- **Select Quiescent Variability Science Questions**
  - what are the magnitudes & sources of global quiescent thermosphere-ionosphere (TI) variations?
  - does the quiescent global variability "pre"condition the TI response to space weather events?
- **Diagnostic Wish List**
  - global Tn, Un, Vn, ρ, Ne, Ti, Ui, Vi, Wi, ΔH, ΔD, ΔZ, (?)
  - leverage existing ground-based & space-borne resources
  - correlative analyses to quantify wave sources and signatures
- **Modeling Component**
  - develop/assess data assimilation (DA) models (e.g., GAIM); use DA to quantify optimum data requirements (quality-location-cadence) for fielding new instruments
  - correlative/interpretive numerical modeling efforts