Non-migrating Tides From the Ground and From Space

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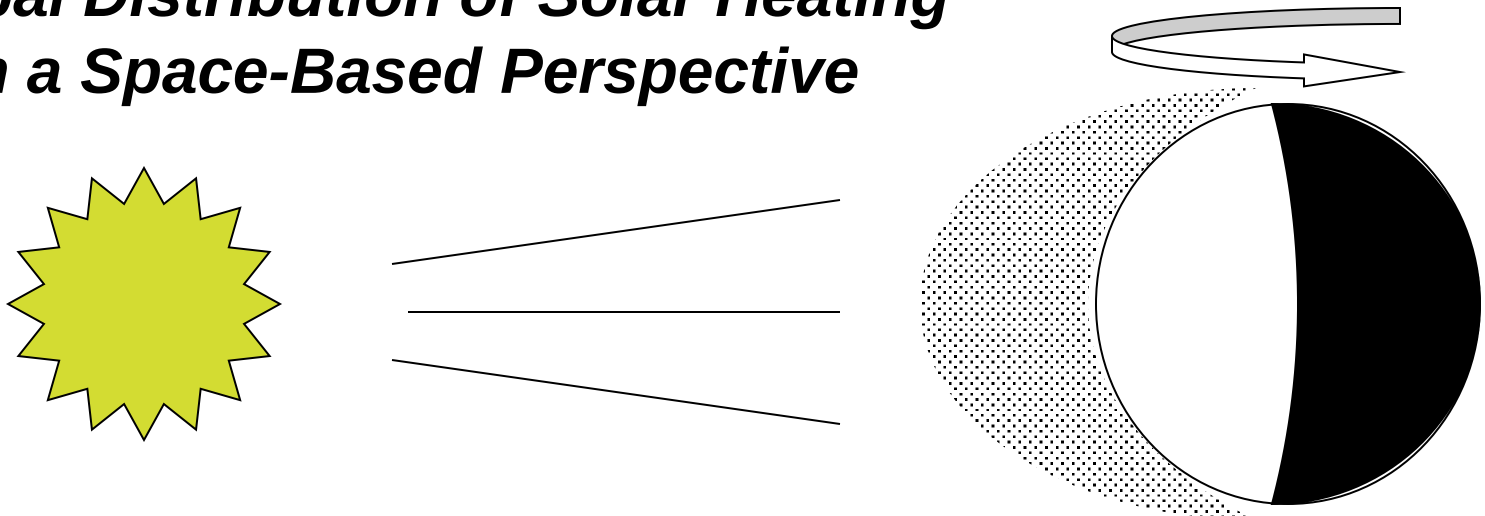
What distinguishes nonmigrating tides from migrating tides?

How are they excited?

What do they look like in space-based (satellite) observations? (a.k.a What are they talking about when they say "wave-4"?)

Global Distribution of Solar Heating from a Space-Based Perspective



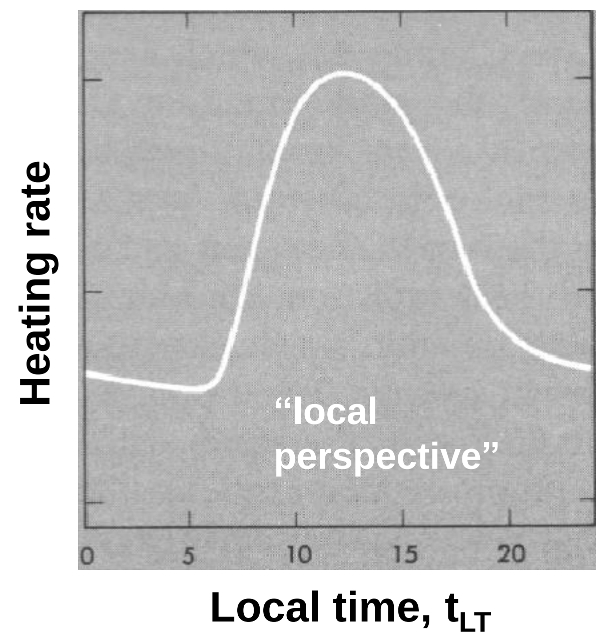
To an observer in space, it looks like the bulge is fixed with respect to the Sun, and the planet is rotating beneath it.

In the local (solar) time frame, the heating may be represented as

$$\text{heating} = Q_o + \sum_{n=1}^{N} a_n \cos n\Omega t_{LT} + b_n \sin n\Omega t_{LT}$$

$$= Q_o + \sum_{n=1}^{N} A_n \cos(n\Omega t_{LT} - \phi) \qquad \Omega = \frac{2\pi}{24}$$

diurnal, (n = 1), semidiurnal (n = 2), etc. tides



Converting to universal time $t_{LT} = t + \lambda/\Omega$, we have

$$\text{heating} = Q_o + \sum_{n=1}^{N} A_n \cos(n\Omega t + n\lambda - \phi)$$

Implying a zonal phase speed $$C_{ph} = \frac{d\lambda}{dt} = -\frac{n\Omega}{n} = -\Omega$$

To an observer in space, it looks like the bulge is fixed with respect to the Sun, and the planet is rotating beneath it.

To an observer on the ground, the bulge is moving westward at the apparent motion of the Sun. It is sometimes said that the bulge is 'migrating' with the apparent motion of the Sun with respect to an observer fixed on the planet.

Since this thermal forcing is periodic, it can excite a wave, called a "thermal tide", that can propagate from the lower atmosphere up into the upper atmosphere where it is dissipated.

This is what things look like if the solar heating is the same at all longitudes.

<u>For solar heating that varies with longitude</u>, a spectrum of tides is produced that consists of a linear superposition of waves of various frequencies (n) and zonal wavenumbers (s):

$$\sum_{s=-k}^{s=+k}\sum_{n=1}^{N} A_{n,s}(z,\theta)\cos\left(n\Omega t + s\lambda - \phi_{n,s}(z,\theta)\right)$$

Similarly, at any given local time, we have a sum of waves that defines the longitude dependence of heating at that local time.

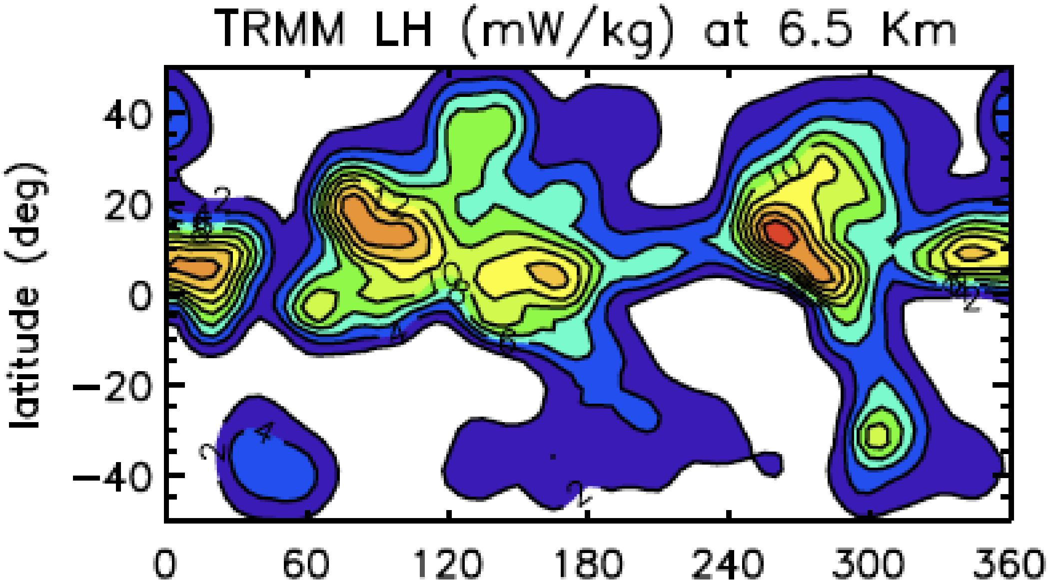
At any given longitude, we have a sum of waves that defines the local time pattern of heating, as before; however, this pattern now changes with longitude.

observer.

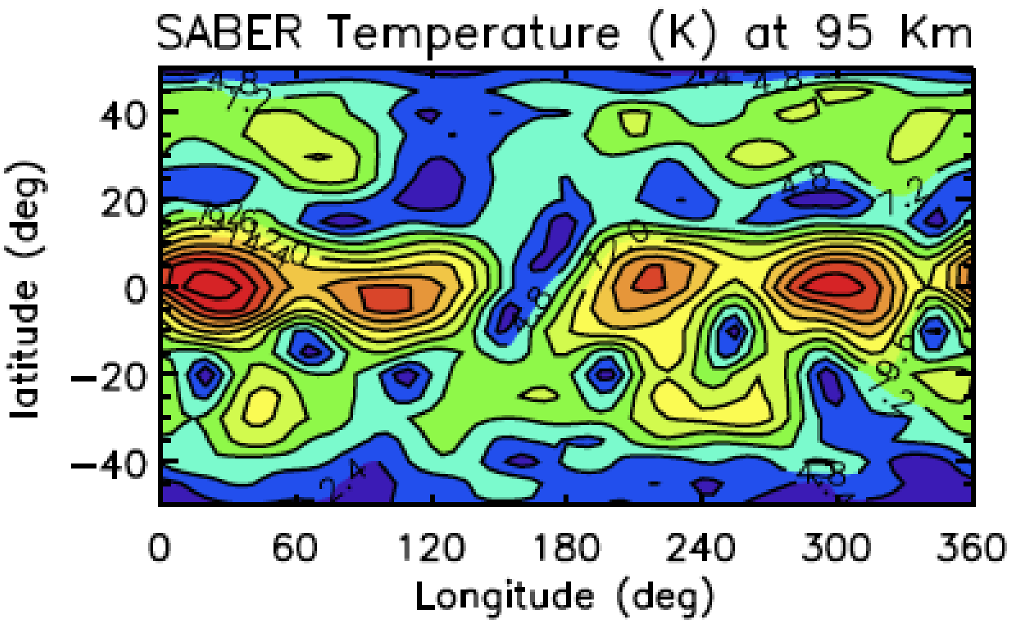
Transforming back to local time:

$$\sum_{s=-k}^{s=+k}\sum_{n=1}^{N} A_{n,s}(z,\theta)\cos\left(n\Omega t_{LT} + (s-n)\lambda - \phi_{n,s}(z,\theta)\right)$$

Diurnal Latent Heating and Lower Thermosphere Response



"Decomposition" of the diurnal heating rates yields a spectrum of diurnal waves, which, when superimposed, yields the pattern to the left.



This wave spectrum propagates upward, and evolves with height since the various waves are affected differently by background winds and dissipation. They superimpose at high altitudes to give a pattern like the one to the left

Spectrum of Diurnal Tides Excited by Latent Heating Due to Tropical Convection, Modulated by Land-Sea Contrast

Dominant zonal wavenumber representing low-latitude land-sea contrast on Earth is m = 4

diurnal harmonic of solar radiation

n = 1

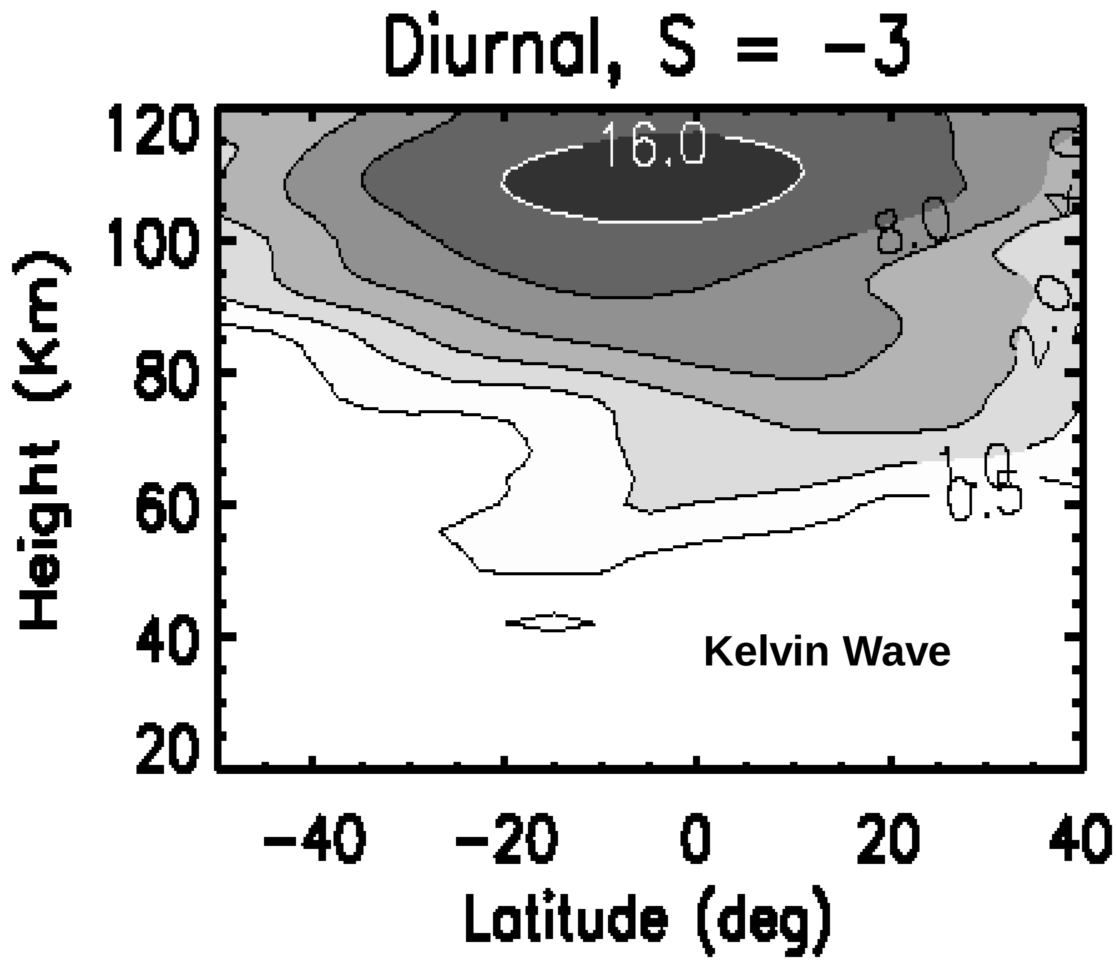
s = n = 1

Modulation by dominant zonal wavenumber m = 4

$$\cos(n\Omega t + s\lambda) \times \cos(m\lambda)$$

$$C_{ph} = -\frac{n\Omega}{s} = -\Omega$$

DE3 Temperature Amplitude Distribution, August 2002, from TIMED/SABER Measurements



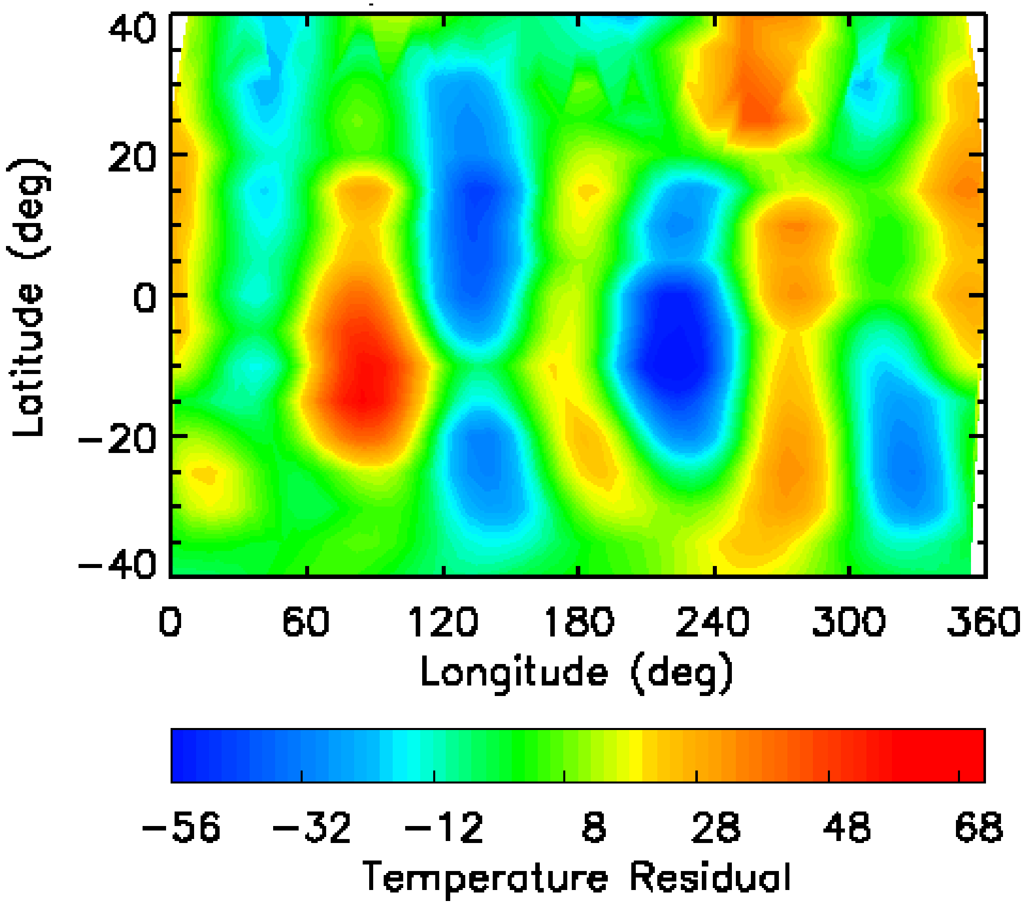
How Does the Wave Appear from Sun-Synchronous Orbit?

$$T_{n,s}\cos\left[n\Omega t + s\lambda - \phi_{n,s}\right]$$

becomes

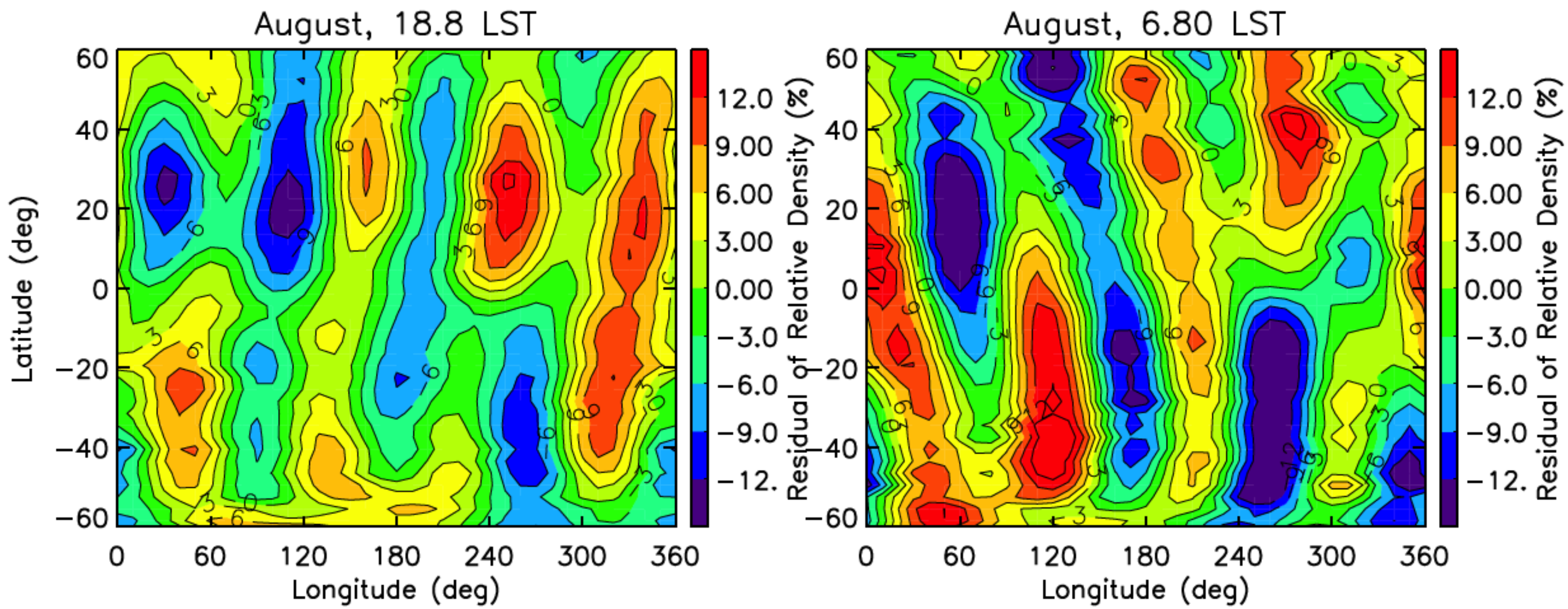
$$T_{n,s}\cos\left[n\Omega t_{LT} + \underbrace{(s - n)}_{\textbf{= 4 for DE3}}\lambda - \phi_{n,s}\right]$$

SABER Temperature Residuals, August, LST = 1300, 110 km

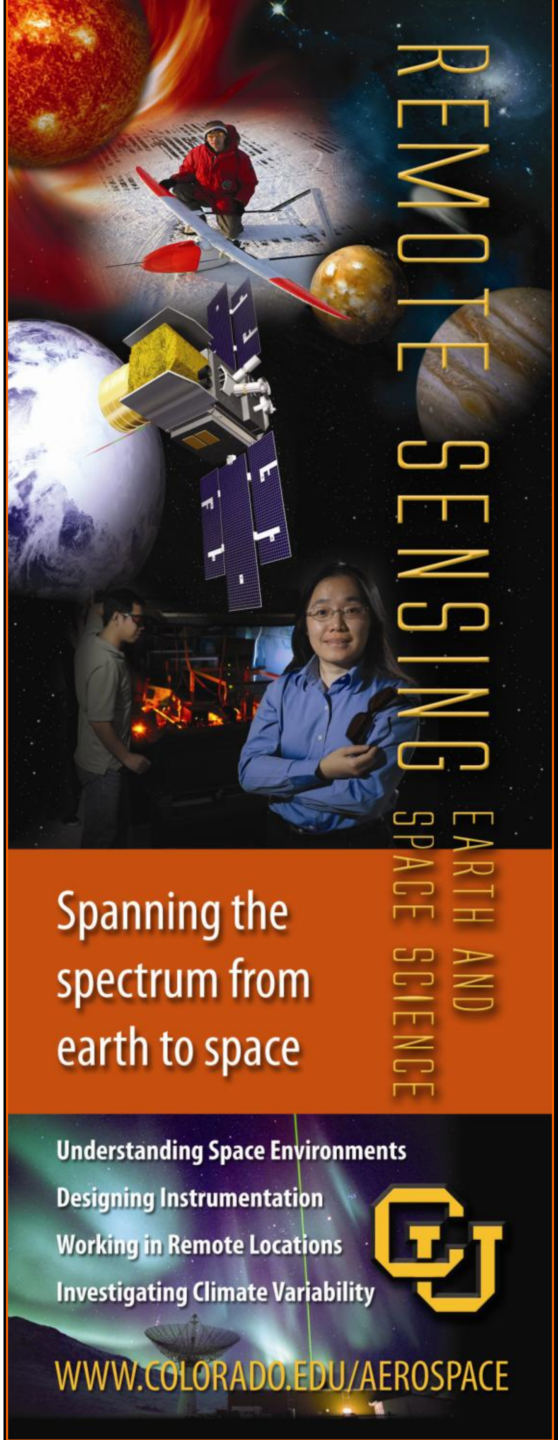


Raw temperature residuals (from the mean) exhibit the wave-4 pattern anticipated for a dominant eastward-propagating s = -3 diurnal tide.

CHAMP Neutral Densities During Solar Minimum, 7 days in August, 2008



Non-symmetric wave-4 and non-anti-phase between asc/desc parts of orbit suggests SE2, not DE3



Space Physics and Aeronomy Research

Xinzhao Chu	(lidars, MLT dynamics)
Jeff Forbes	(waves, tides, solar - terrestrial interactions)
Delores Knipp	(space weather)
Xin Lin Li	(magnetosphere)
Scott Palo	(radars, MLT dynamics, small satellites)
Zoltan Sternovsky	(dust)
Jeff Thayer	(lidars radars, atmosphere dynamics, solar – terrestrial interactions)

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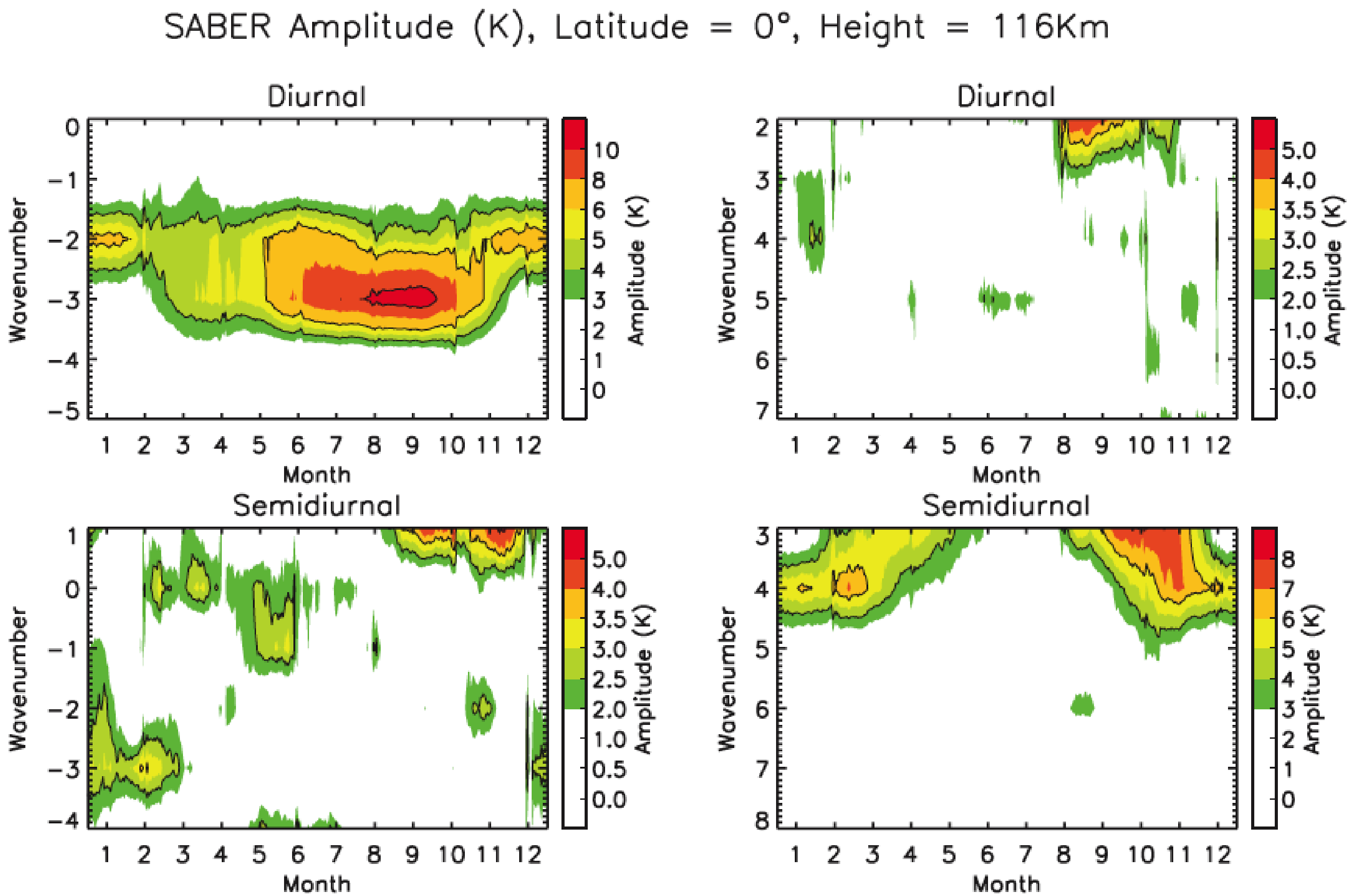
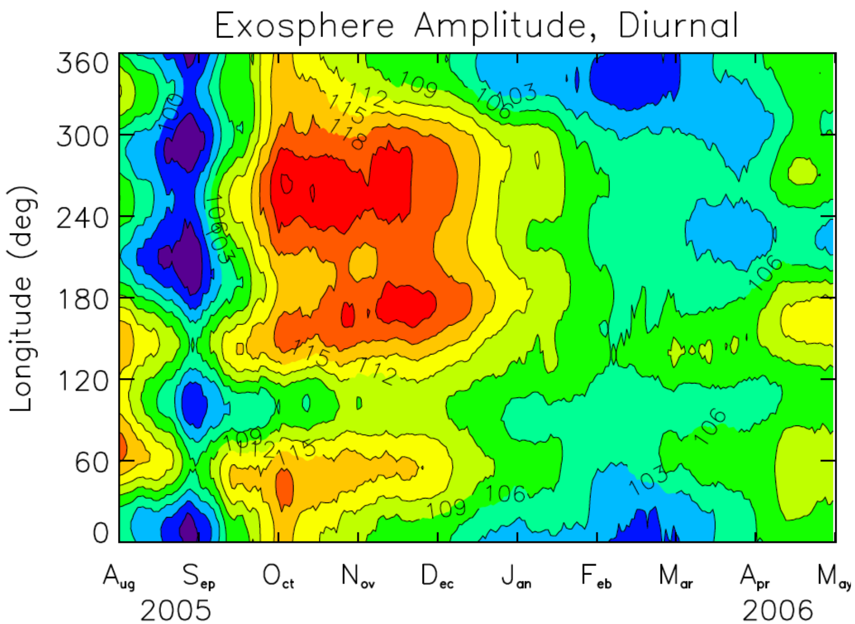
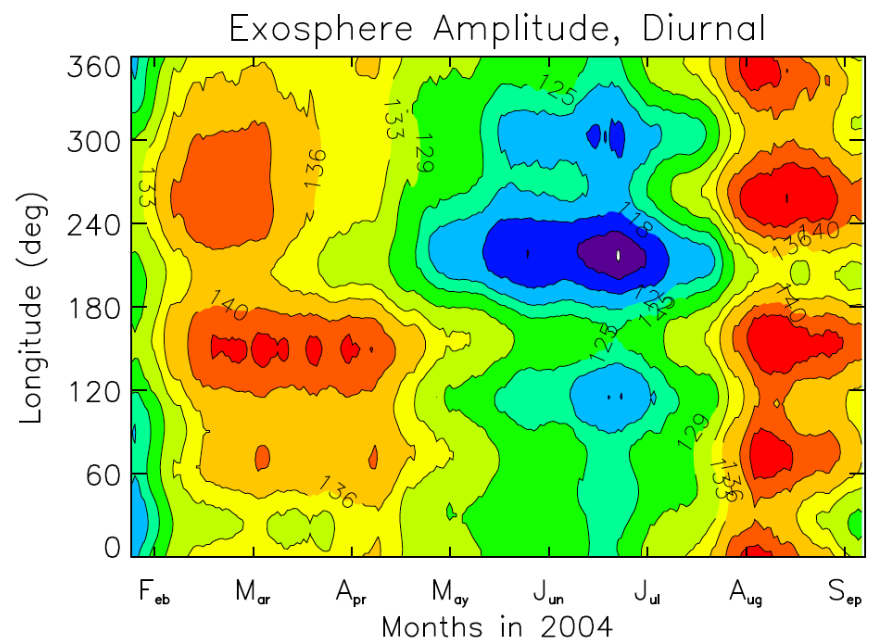
Additional & Backup Slides


SABER Amplitude (K), Latitude = 0°, Height = 116Km
Diurnal
Diurnal
Semidiurnal
Semidiurnal
Wavenumber
Month
Amplitude (K)

CHAMP Neutral Temperatures Also Reveal Connections to Troposphere Excitation of Tidal Waves

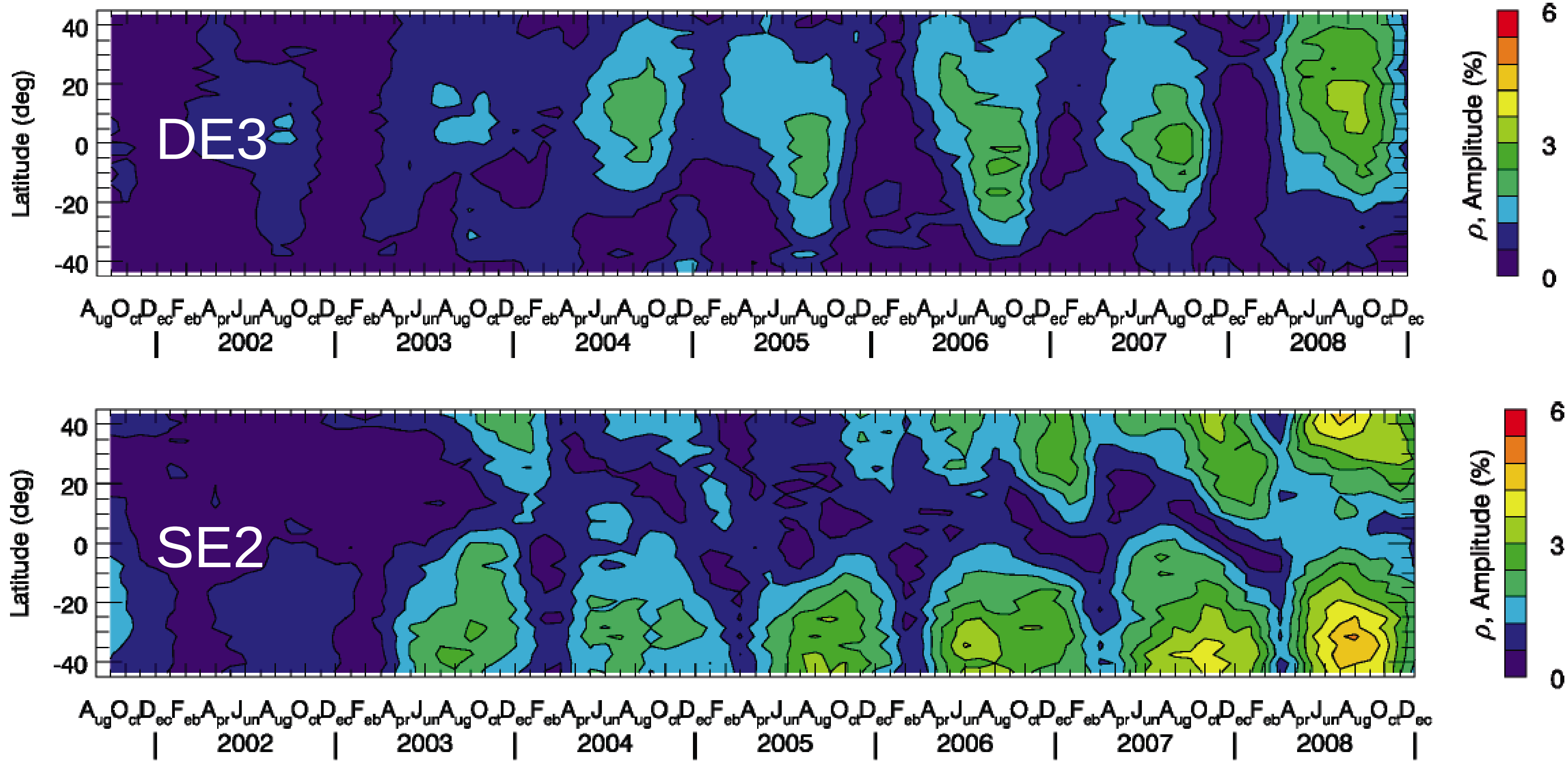




Much of the longitude variability is thought to arise from land-sea modulation of the excitation of thermal tides that propagate to the thermosphere. DE3 gives rise to a wave-4 longitude structure when interfering with the sun-synchronous tide, DW1; similarly, DE2 gives rise to a wave-3 structure when interfering with DW1.

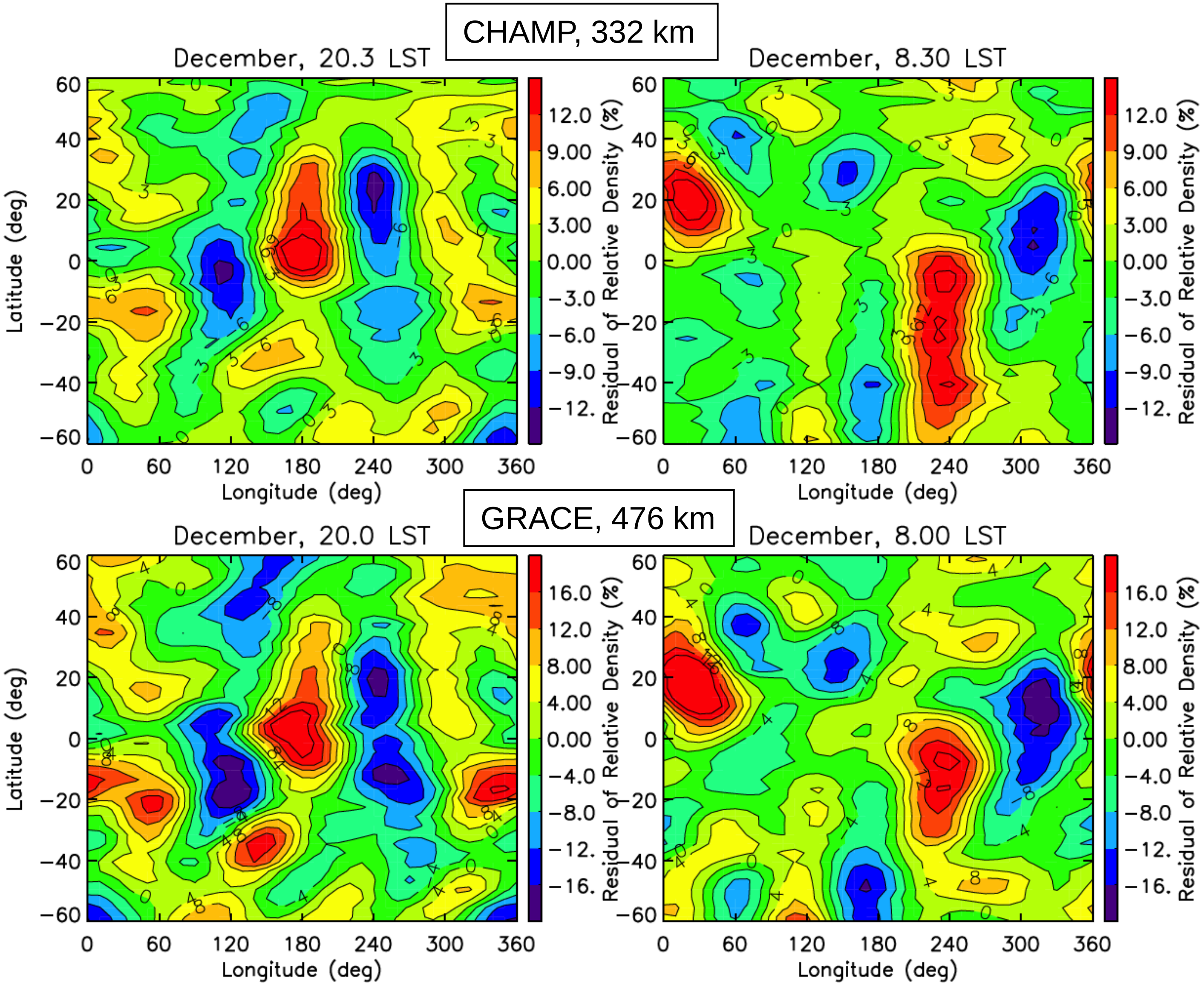
DE3 = eastward-propagating diurnal tide with zonal wavenumber = 3
DE2 = eastward-propagating diurnal tide with zonal wavenumber = 2
DW1 = westward-propagating diurnal tide with zonal wavenumber = 1 (Sun-synchronous)

Solar Cycle Dependence of DE3 and SE2



SE2 produced by land-sea modulation of semidiurnal component of solar heating, but also nonlinear interaction between DE3 and DW1!

Neutral Densities During Solar Minimum, 11-17 December 2008



CHAMP & GRACE co-planar

The Ionospheric Dynamo

$$\omega_- \gg \nu_{en}$$
$$\omega_+ \gg \nu_{in}$$

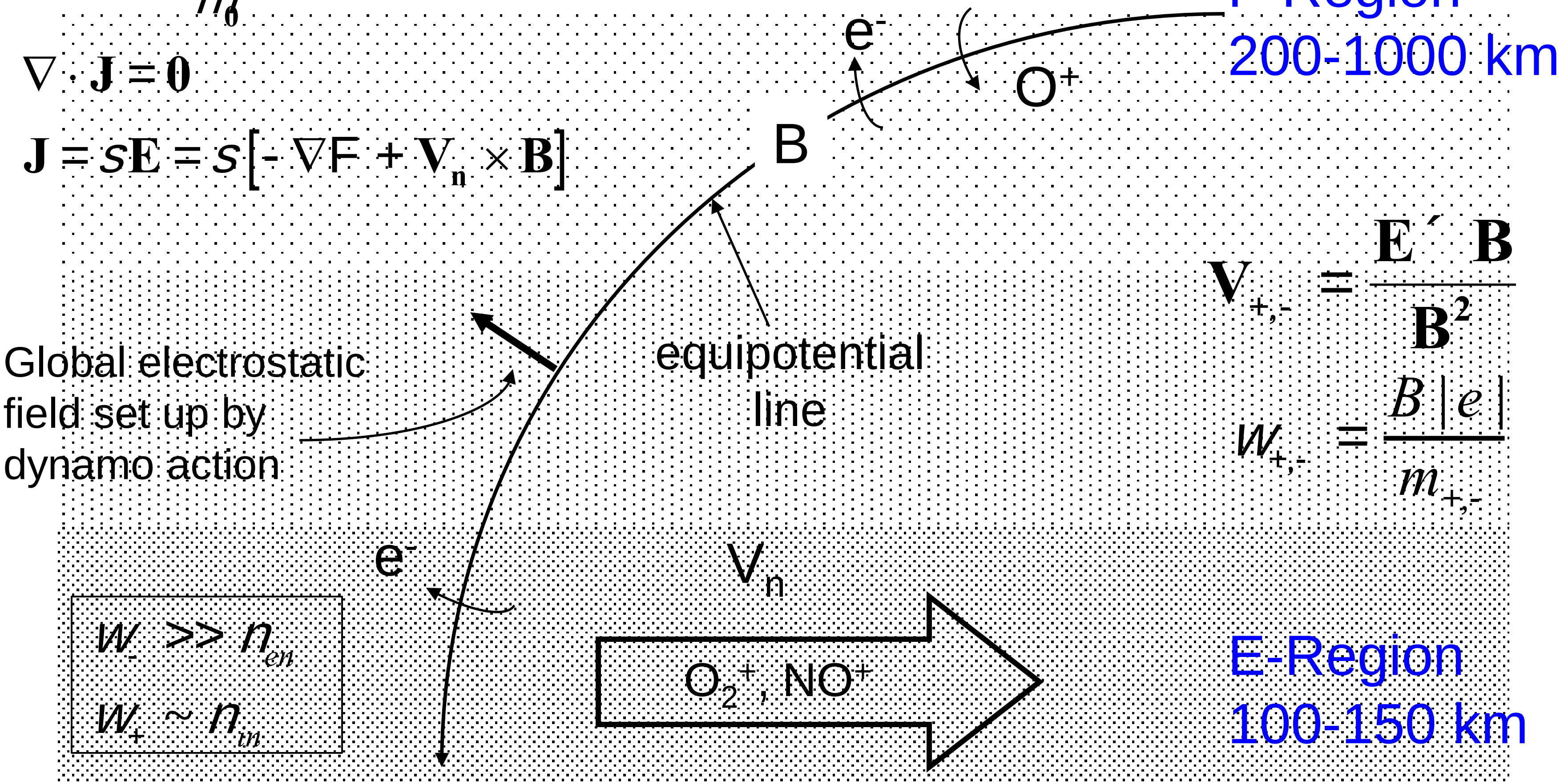
$$\nabla \times \mathbf{B} = \frac{\mathbf{J}}{\mu_0}$$

$$\nabla \cdot \mathbf{J} = 0$$

$$\mathbf{J} = \sigma \mathbf{E} = \sigma\left[-\nabla \Phi + \mathbf{V}_n \times \mathbf{B}\right]$$

$$\mathbf{V}_{+,-} = \frac{\mathbf{E} \times \mathbf{B}}{\mathbf{B}^2}$$

$$\omega_{+,-} = \frac{B\,|e|}{m_{+,-}}$$



CHAMP electron densities (~400 km) reveal wave-4 structures due to DE3 driving of the ionospheric dynamo