Overview of Middle Atmosphere Tides

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What are atmospheric tides?

Global-scale oscillations, periods are 1/n of solar day:

24 hours: Diurnal
12 hours: Semidiurnal
8 hours: Terdiurnal

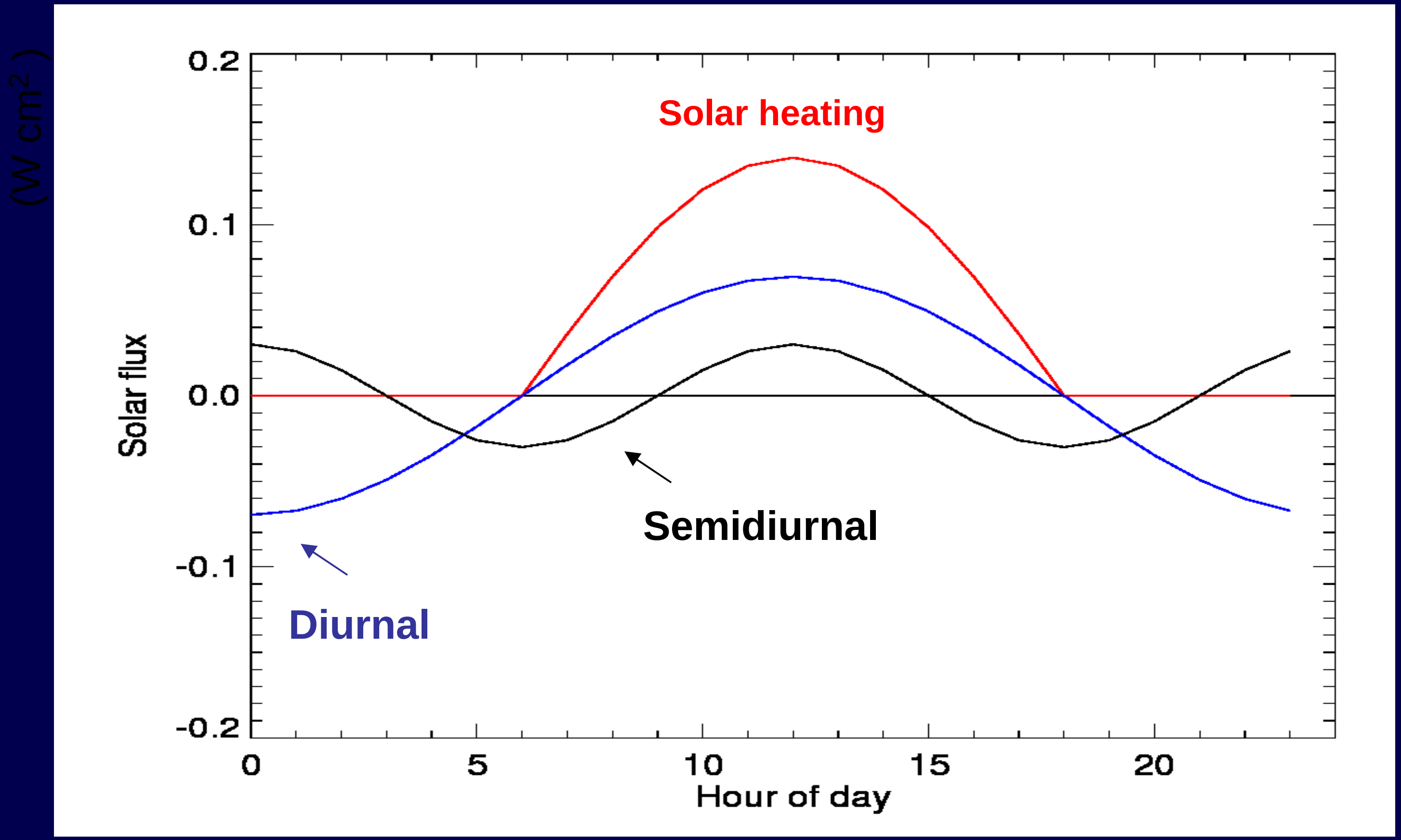
Migrating **: Angular phase speed $c = \Omega$ (2π rad/d).**

Diurnal: $m = 1$ westward ($c = \Omega/1$).
Semidiurnal: $m = 2$ westward ($c = 2\Omega/2$).

Nonmigrating: **Angular phase speed $c \neq \Omega$.**

Diurnal: all eastward, westward $m \neq 1$
Semidiurnal: all eastward, westward $m \neq 2$

Why do atmospheric thermal tides exist?



Because the sun illuminates the Earth only during daylight hours.

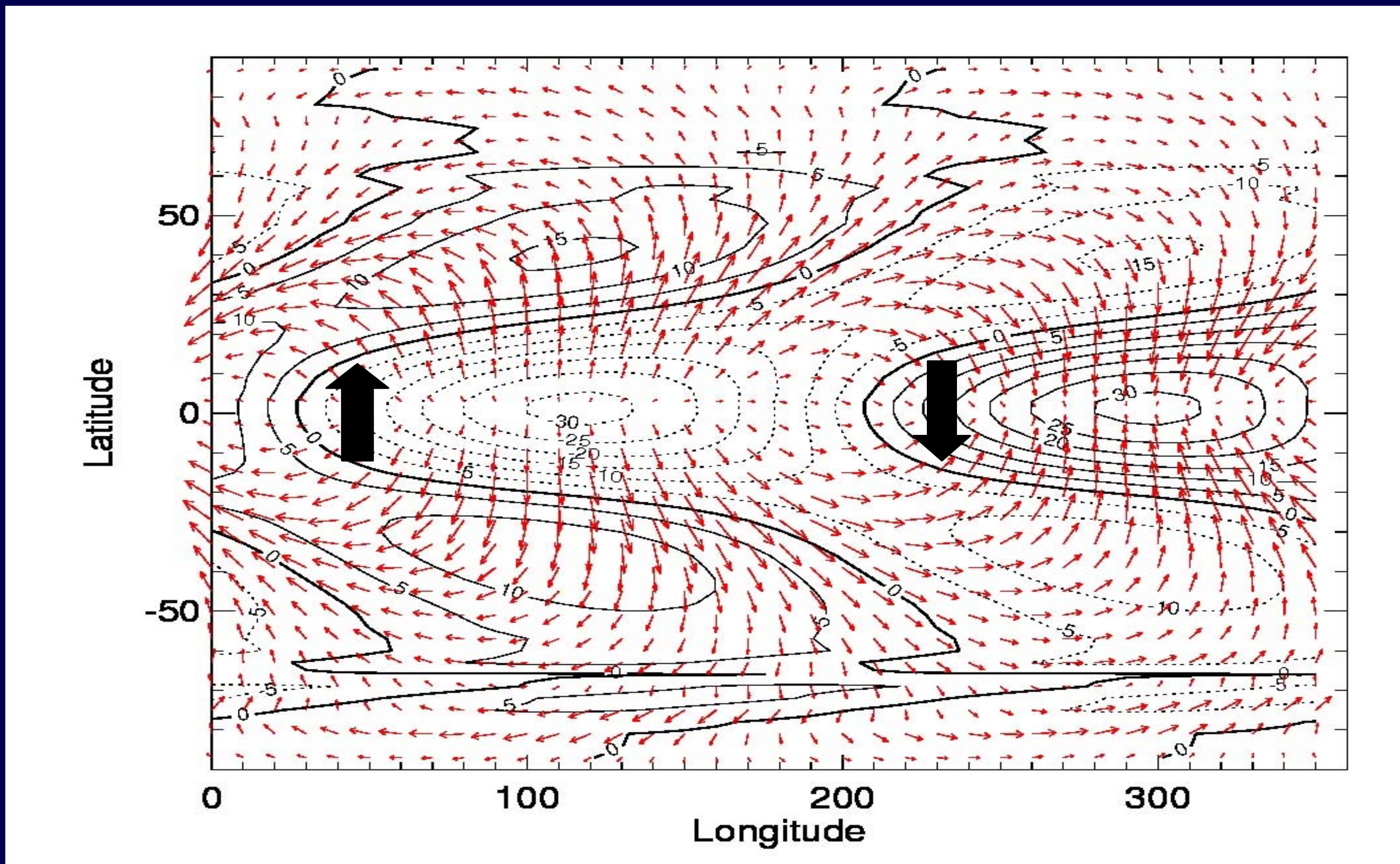
Tides are inertia-gravity waves on a sphere

$$\partial u'/\partial t - f v' + (a\cos\varphi)^{-1}\Phi'_\lambda = 0$$

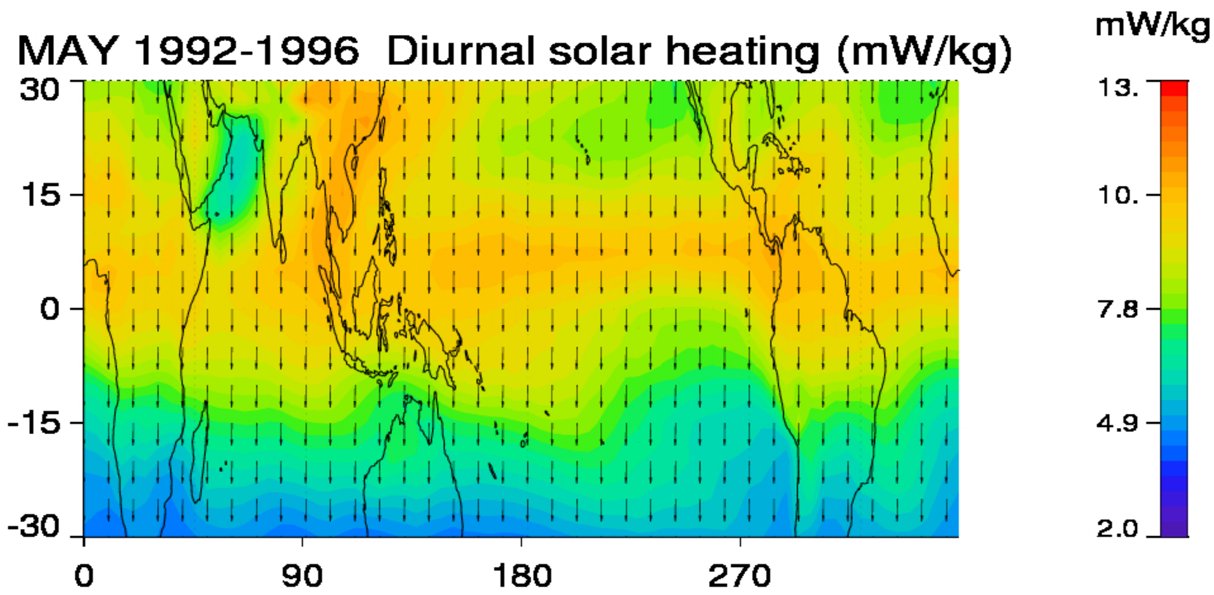
$$\partial v'/\partial t + f u' + a^{-1}\Phi'_\varphi = 0$$

$$(a\cos\varphi)^{-1}(u'_\lambda + (v'\cos\varphi)_\varphi) = \rho_0^{-1}(\rho_0 w')_z$$

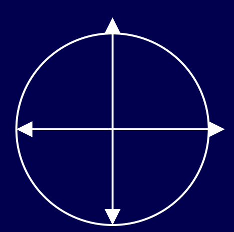
$$\Phi'_{zt} + N^2 w' = 0$$



Forcing of migrating diurnal tide

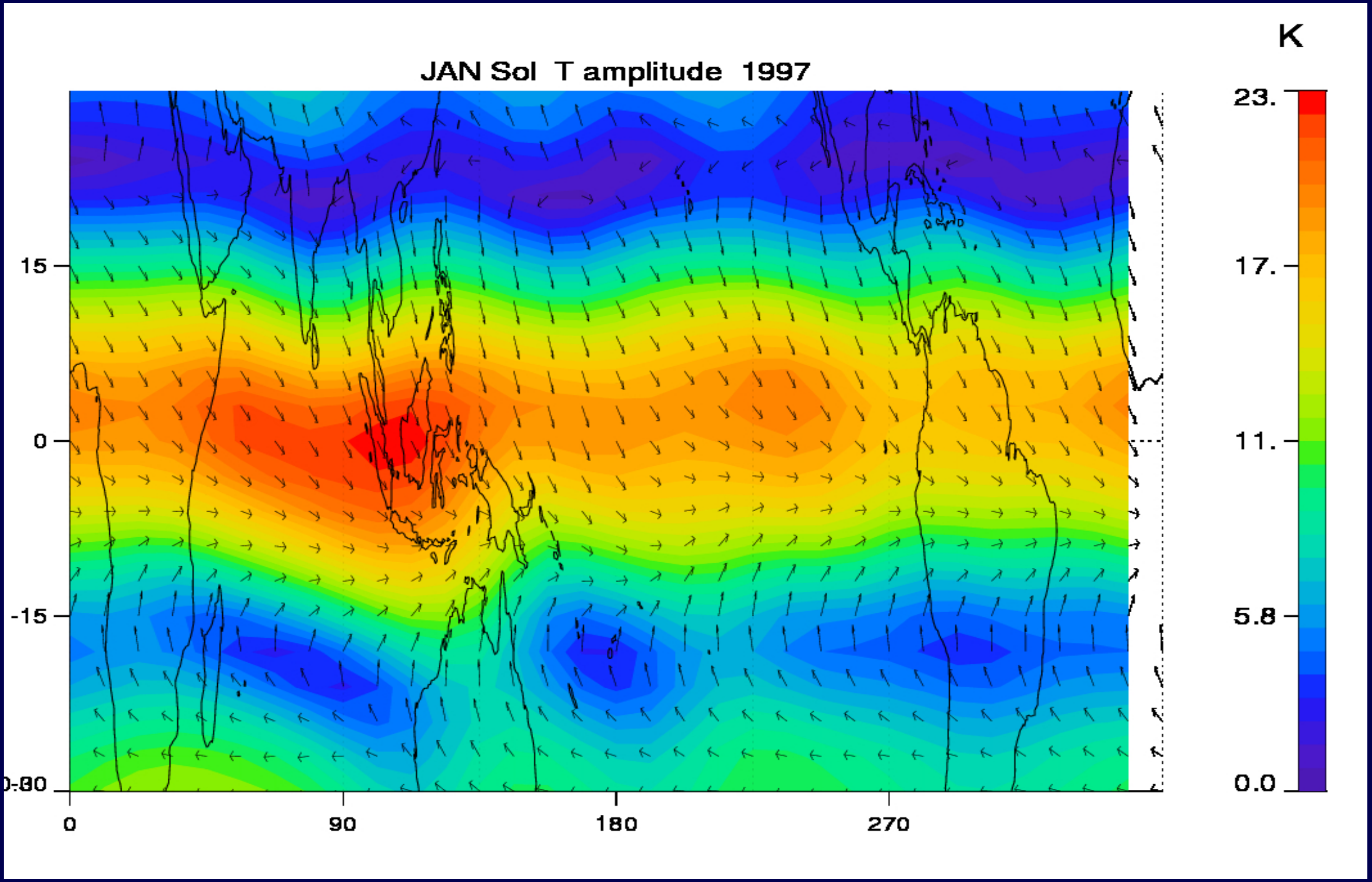


Amplitude and phase (in local time) are uniform in longitude .



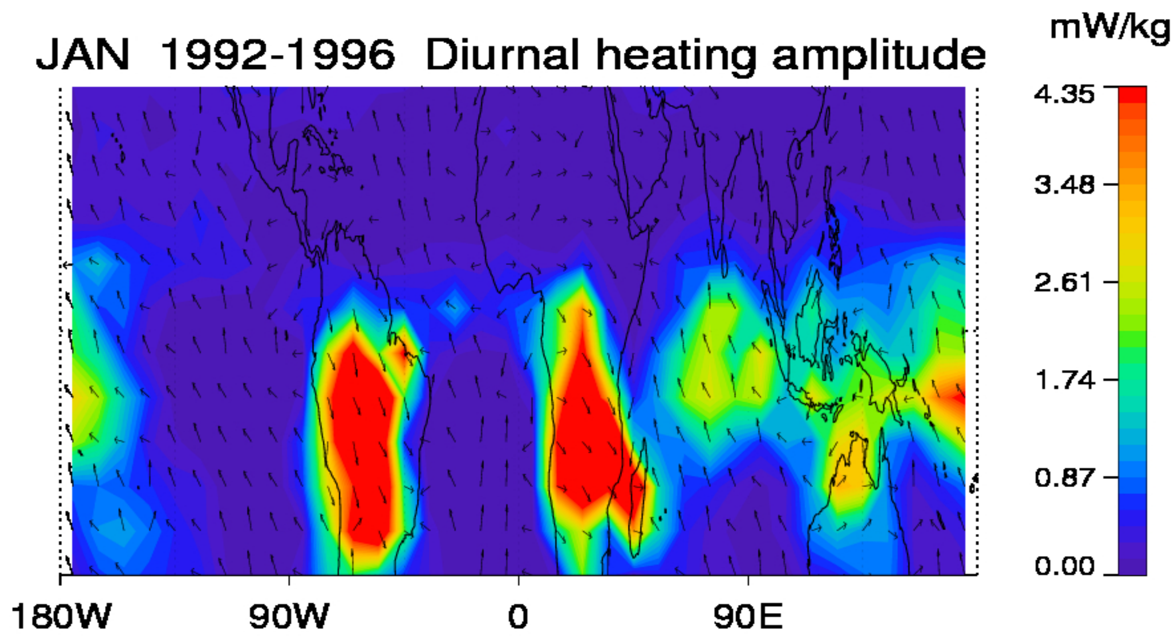
Heating is Q cos ($\lambda+\Omega t-\varphi$) = Q cos[$\Omega(t'-t'_{max})$].

Migrating solar response at 90 km

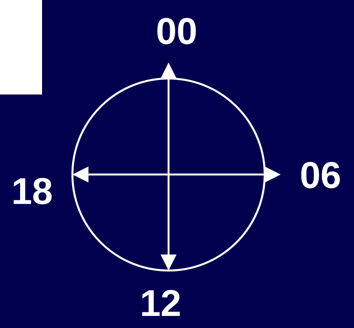


Amplitude and phase (local time) nearly uniform in longitude.

Forcing of nonmigrating tides

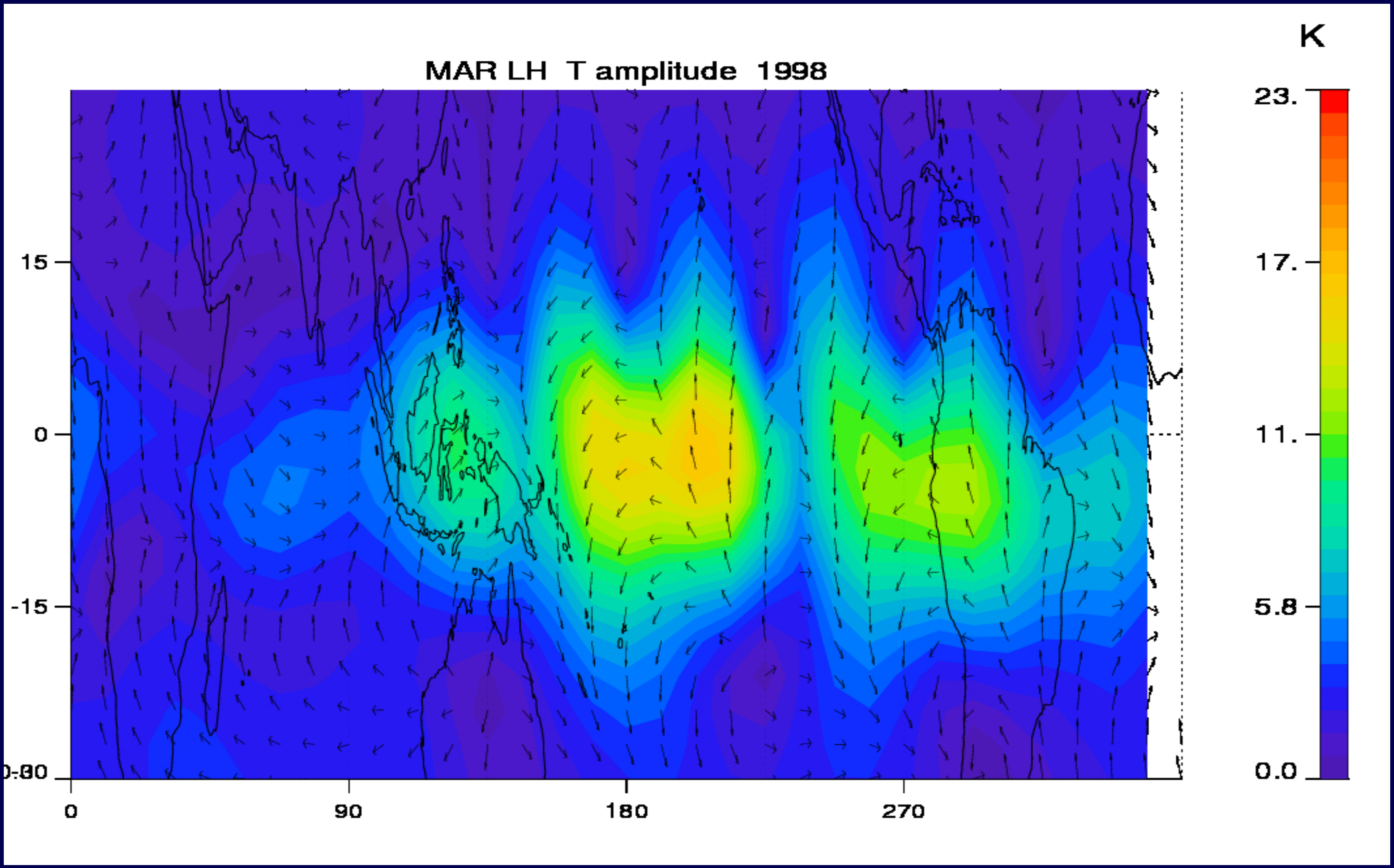


Amplitude and phase (in local time) vary with longitude .



Heating is J(λ) cos (Ωt-φ) = Σ J_m cos[Ω(t'-t_m) - mλ].

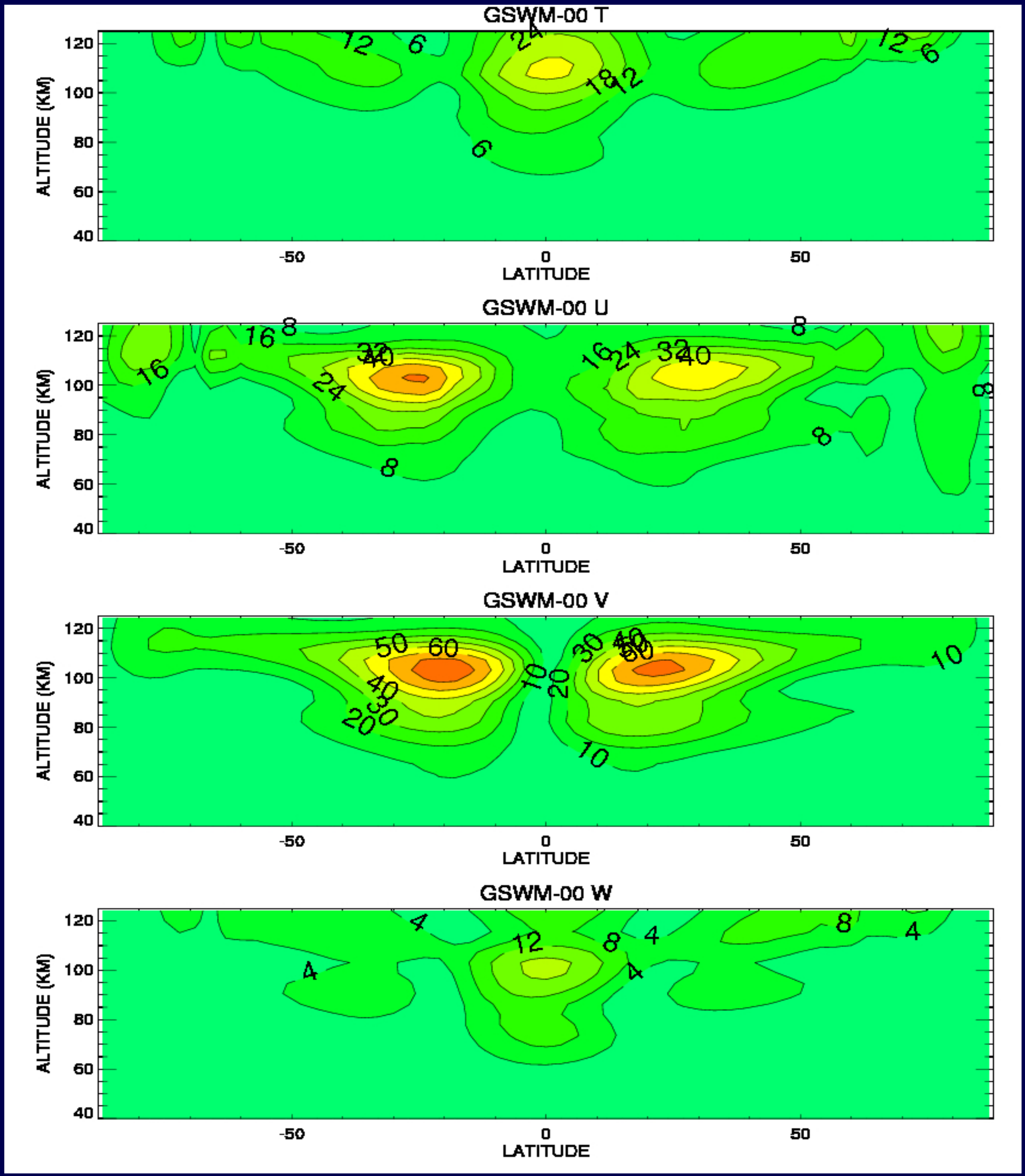
Nonmigrating T response at 90 km



Hour of maximum (local time) varies in longitude.

Why are tides important?

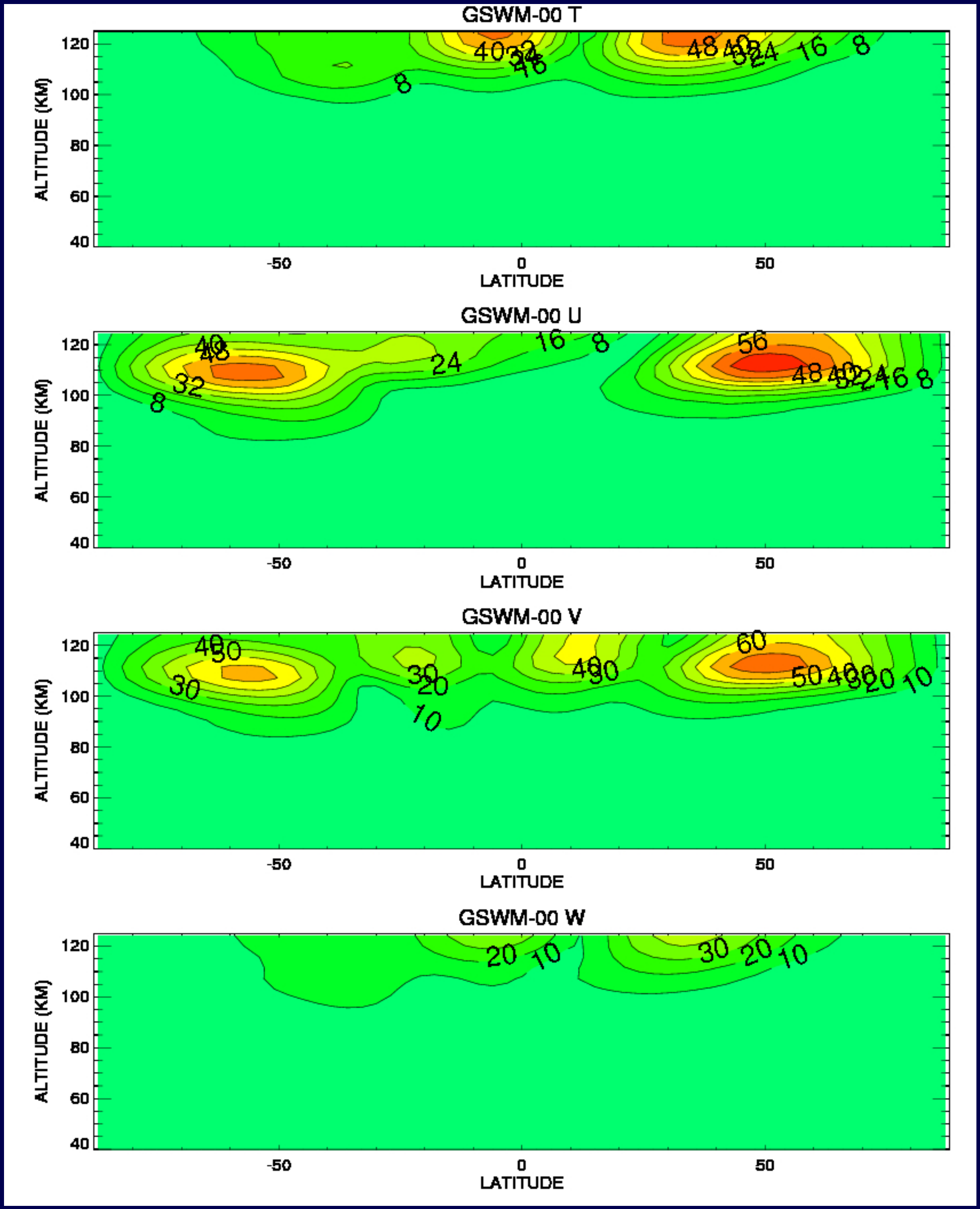
- Amplitudes increase exponentially with z $\Rightarrow$ In the MLT tidal winds are as large as zonal mean winds. Large-amplitude tides become convectively unstable, break, and transfer westward momentum to the mean flow (5-15 m/s/day).
- Tidal w' modulates various MLT constituents and molecules (e. g., OH, O_2). NO_x too?
- Long vertical wavelength (27 km) makes the tide an efficient agent of vertical coupling, and transmission of tropospheric variability into the middle atmosphere.
- Global structure of tides may facilitate cross-equatorial coupling.



Diurnal tides acquire strongest amplitudes at ~100 km.

Diurnal tides maximize at low latitudes in T and w, and subtropical latitudes in V.

Diurnal tides propagate vertically between 30ºS-30ºN.



Semidiurnal tides acquire strongest amplitudes above 100 km.

Semidiurnal tides extend to higher latitudes.

Semidiurnal tides propagate vertically at all latitudes.

Why are tides important?

- Amplitudes increase exponentially with z $\Rightarrow$ In the MLT tidal winds are as large as zonal mean winds. Large-amplitude tides become convectively unstable, break, and transfer westward momentum to the mean flow (5-15 m/s/day).

- Tidal w' modulates various MLT constituents and molecules (e. g., OH, O_2). NO_x too???

- Long vertical wavelength (27 km) makes the tide an efficient agent of vertical coupling, and transmission of tropospheric variability into the middle atmosphere.

- Global structure of tides may facilitate cross-equatorial coupling.

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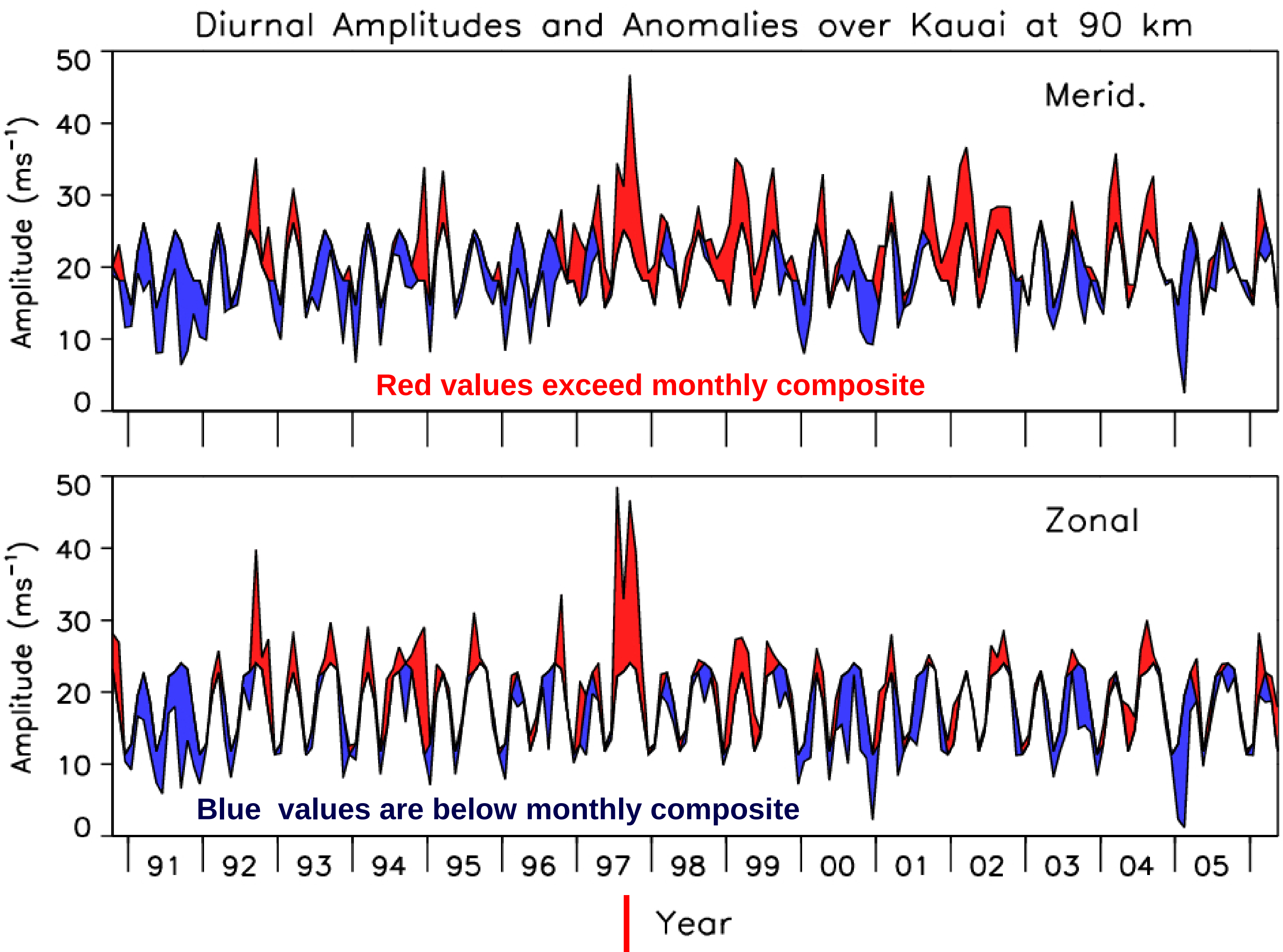
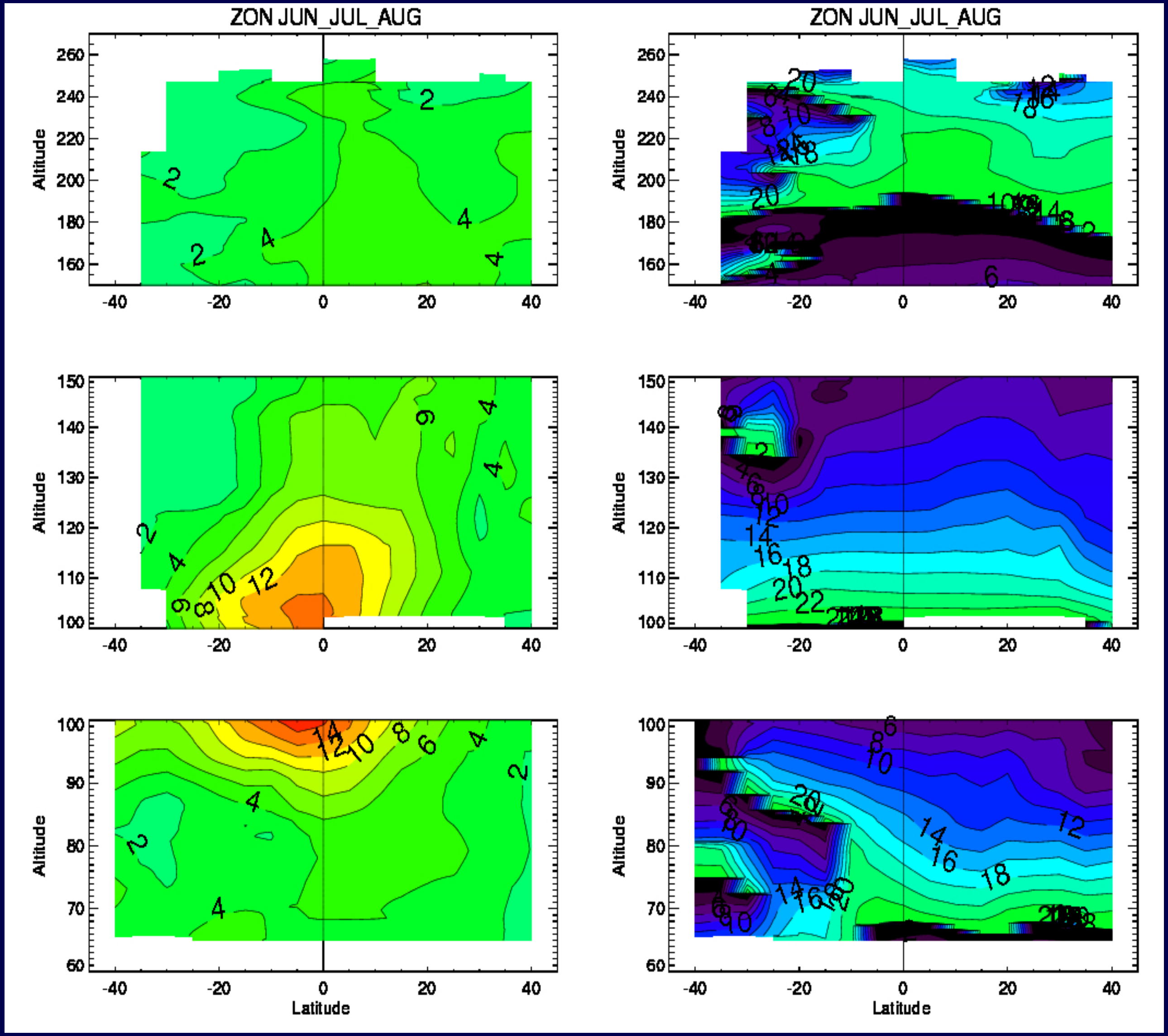


ENSO enhanced forcing of migrating diurnal tide by H_2O_v heating.

UARS/WINDII Diurnal E3

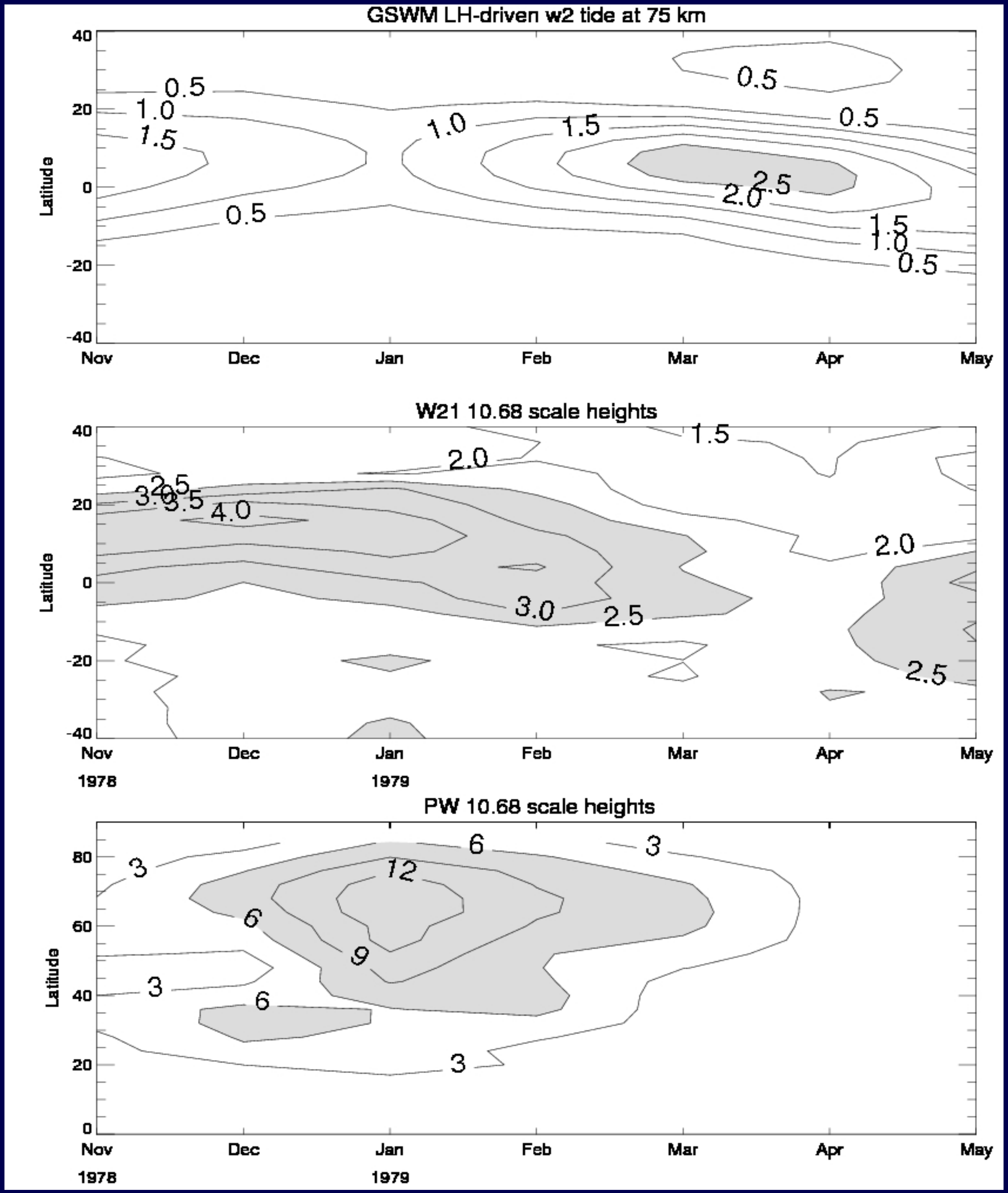


Deep tropical convection projects strongly onto an eastward-propagating zonal wavenumber 3 component (DE3).

DE3 propagates into the thermosphere.

Why are tides important?

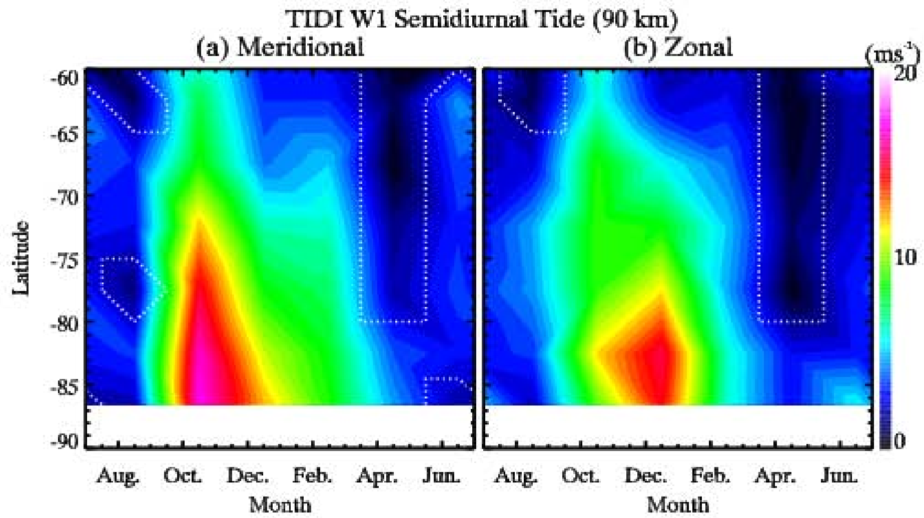
- Amplitudes increase exponentially with z $\Rightarrow$ In the MLT tidal winds are as large as zonal mean winds. Large-amplitude tides become convectively unstable, break, and transfer momentum to the mean flow. Contribute to time-mean westward winds in equatorial lower thermosphere.
- Tidal w' modulates various MLT constituents and molecules (e. g., OH, O_2). NO_x too?
- Long vertical wavelength (27 km) makes the tide an efficient agent of vertical coupling, and transmission of tropospheric variability into the middle atmosphere.
- Global structure of tides may facilitate coupling between low and high latitudes.



Nonlinear interaction between migrating diurnal tide (m = 1) and SPW 1 yields diurnal tides with wavenumbers 0 and 2.

Support for this interaction seen in TIME-GCM (Hagan and Roble (2001).

Some observational support in LIMS satellite temperatures (Lieberman et al., 2004).



Nonlinear interaction between migrating semidiurnal tide m = 2 and SPW 1 yields semidiurnal tides 1 and 3.

Seen in numerical models (Angelats i Coll and Forbes , 2002).

Possible evidence of this mechanism and cross-equatorial influence reported by Smith et el. (2007) in NH, and Imura et al. (2009) at Antarctica.

Optimal observing conditions

Global-scale data coverage, to discern zonal wavenumbers.

24-hour sampling, especially above 90 km where semidiurnal and diurnal tides have comparable amplitude.

Precession cycle no longer than 30 days, to capture tidal variability, and minimize aliasing with quasi-stationary planetary waves.

Short cuts:

> 12-hour differences are a proxy for the diurnal tide at a fixed phase. Phase information can be recovered from the vertical structure of propagating tides (Lieberman and Hays, 1994; Oberheide et al., 2002).