Observations of thermal tides in the middle atmosphere of Mars by the SPICAM instrument

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Thermal tides

$$\sum_n \sum_s A_{n,s}(z,\theta)\cos\left(n\Omega t + s\lambda - \phi_{n,s}(z,\theta)\right)$$

General tidal equation

$$\sum_n \sum_s A_{n,s}(z,\theta)\cos\left(n\Omega t_{LST} + (s-n)\lambda - \phi_{n,s}(z,\theta)\right)$$

$$\cos\left(s_X \Omega t_{LST} + (s_X - s_X)\lambda - \phi_{s_X,s_X}\right)$$

Migrating tide has s=n
Here replaced by s_x

$$\cos\left(m\lambda - \phi_m\right)$$

Topographic or other variations can interact with migrating tides

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$$\cos\left(s_X \Omega t_{LST} + ((s_X - s_X) \pm m)\lambda - (\phi_{s_X,s_X} \pm \phi_m)\right)$$

Produce non-migrating tide with zonal wavenumber in fixed LST frame that is independent of migrating tide
Period depends on migrating tide

Lower and upper atmospheric observations of thermal tides

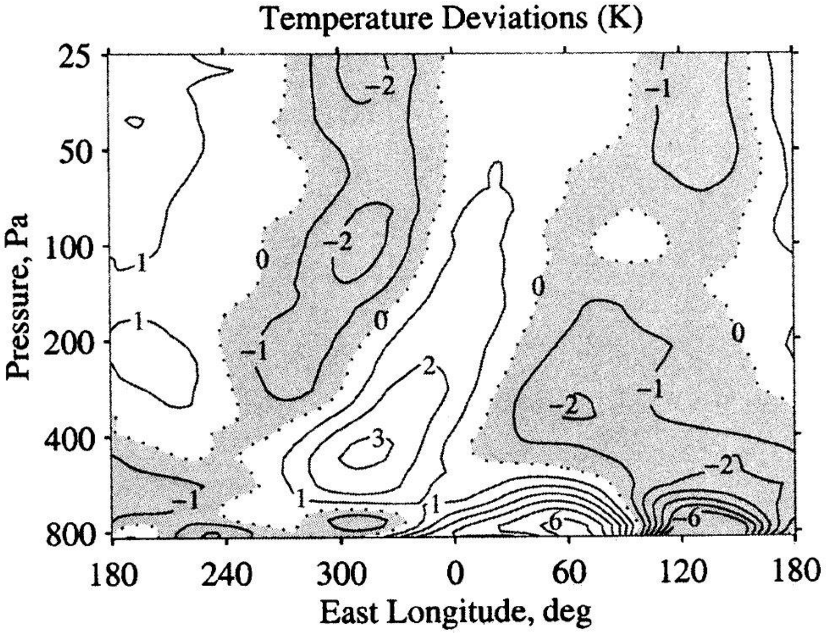


Fig 6 of Hinson et al. (2001)
Temperature deviations from zonal mean
66^{o}N, Ls=75^{o}, LST = 0400
MGS radio occultation data

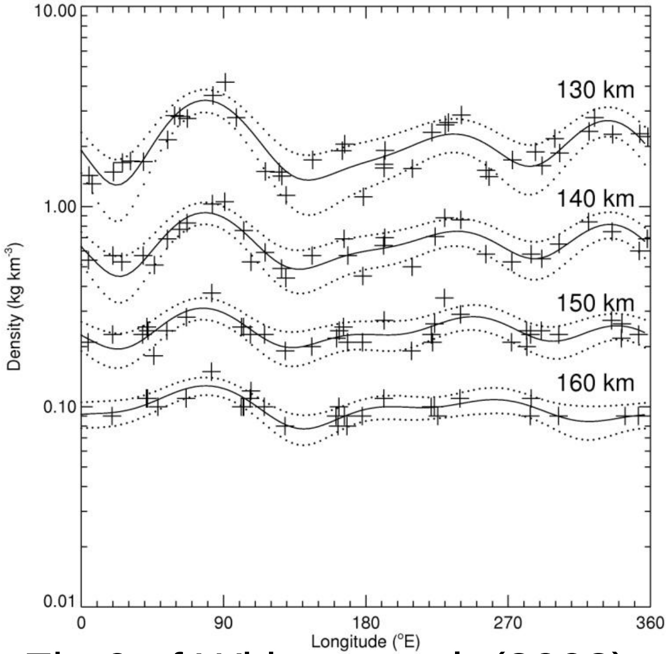
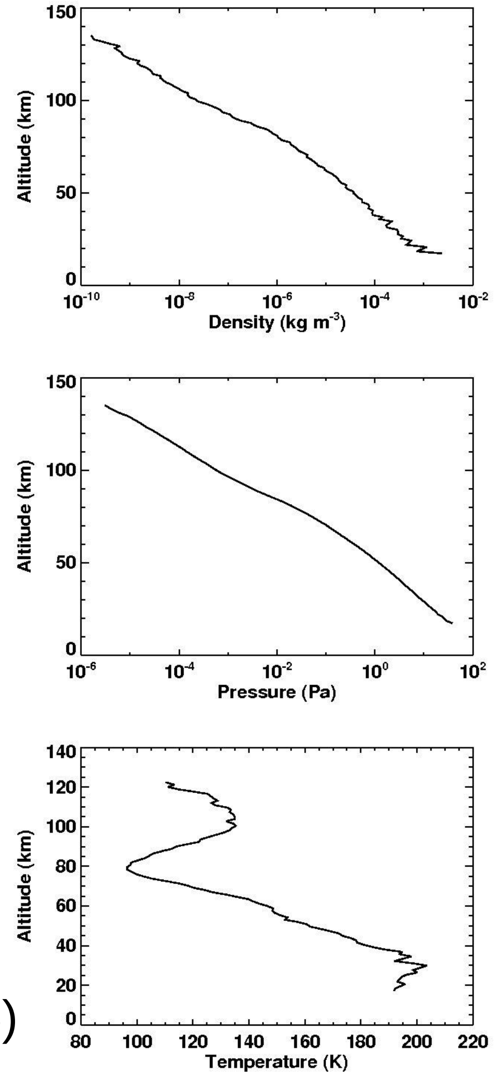


Fig 6 of Withers et al. (2003)
Zonal density variations
10-20^{o}N, Ls = 90, LST = 1500
MGS aerobraking data

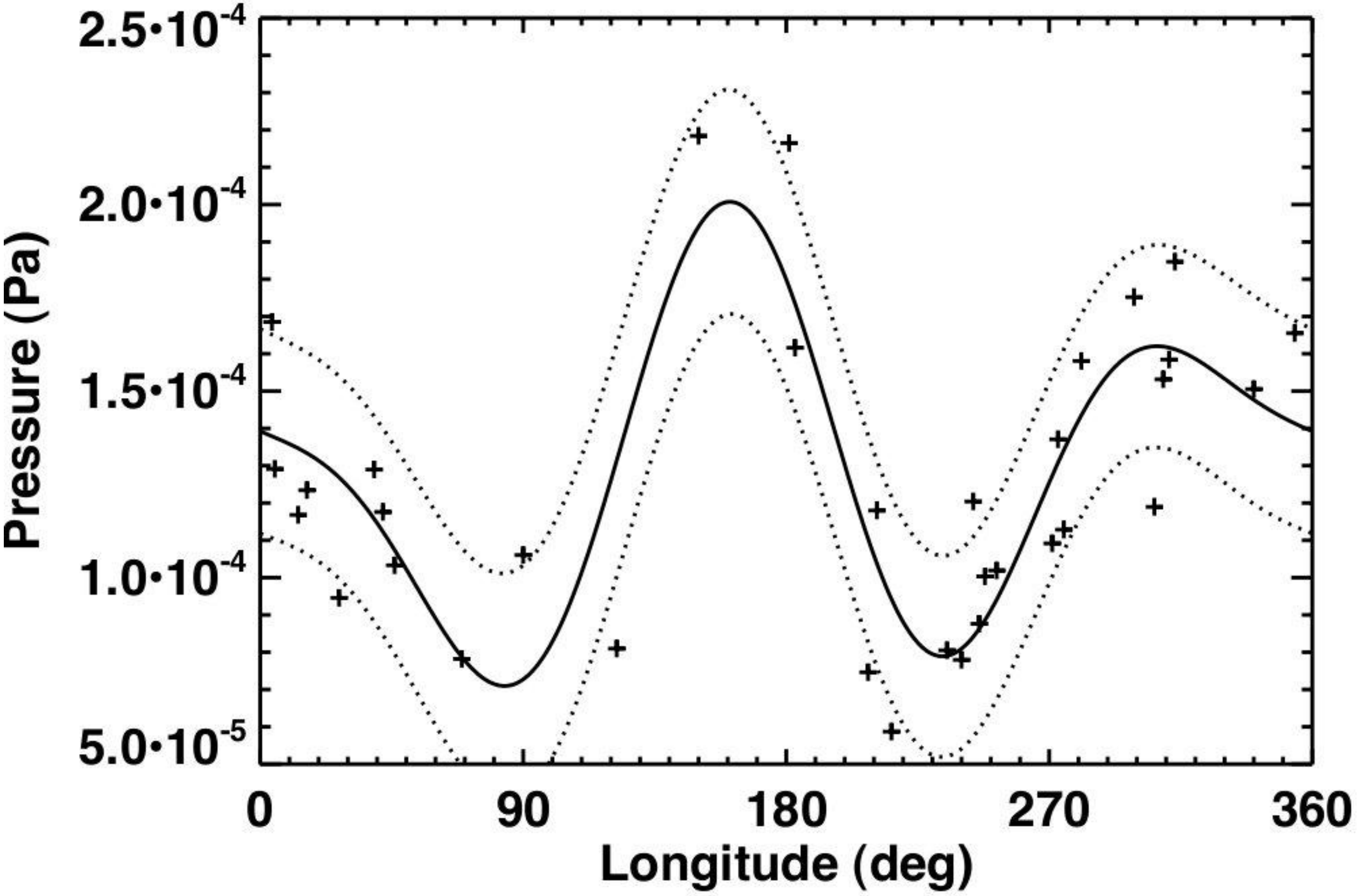
Diurnal Kelvin wave 1 (DK1) is common
Long vertical wavelength, minimally damped
Broad meridional extent, wave 2 in fixed LST data

SPICAM on Mars Express

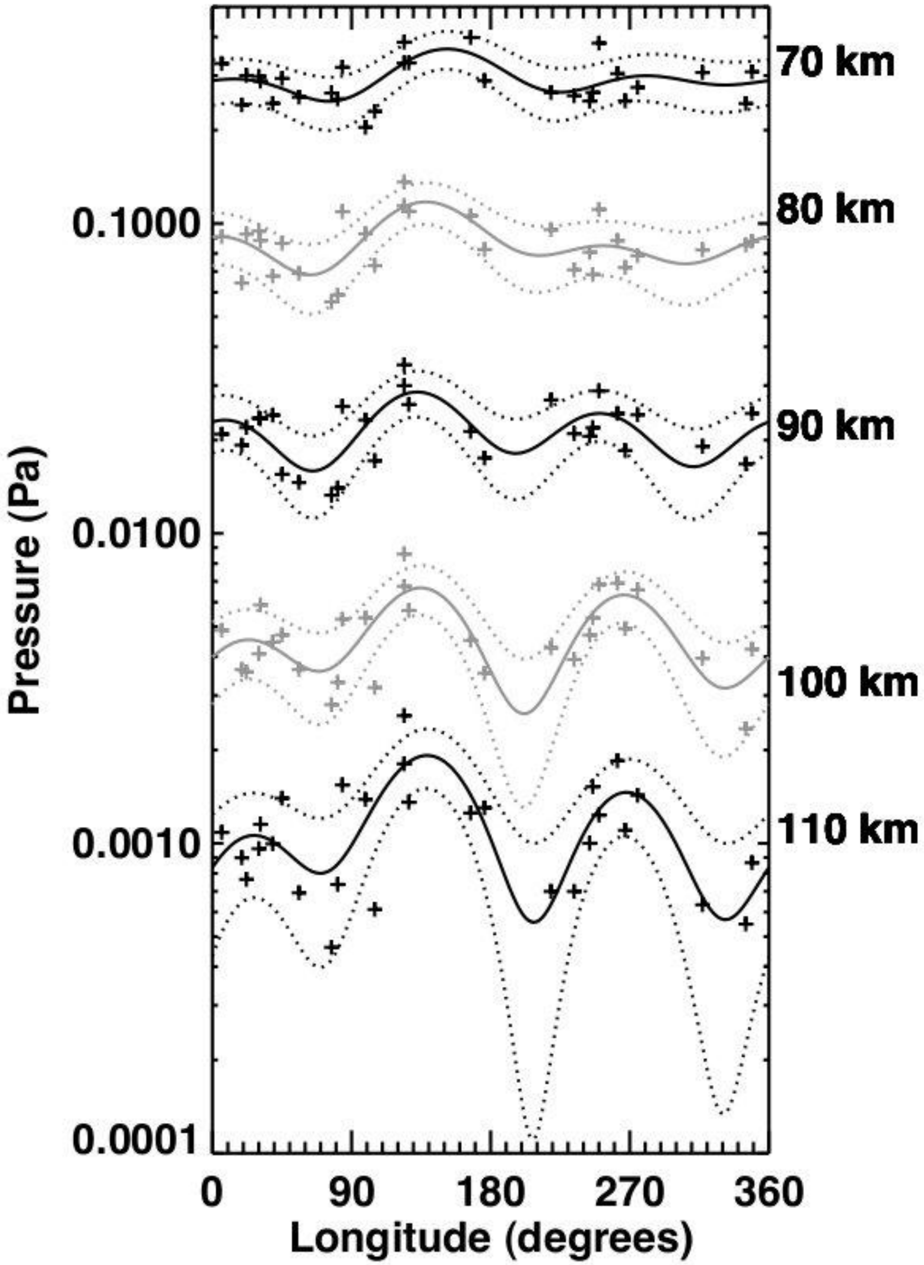
- UV spectrometer observes stellar occultations
- Produces ρ, p, T(z) profiles at ~50-120 km
- We select 29 profiles at 20-10^{o}S, Ls=90-120^{o}, LST = 0200-0500, then examine zonal variations
- Other cases not reported today



Example SPICAM profile (orbit 0906)
42^{o}S, Ls=96^{o}, LST =0300



Pressure at 110 km for **<u>different</u>** latitude/Ls/LST (**<u>best case</u>** illustration)
Wave-3 harmonic fit shown here and in subsequent figures
Wave-2 component is strong, presumably DK1



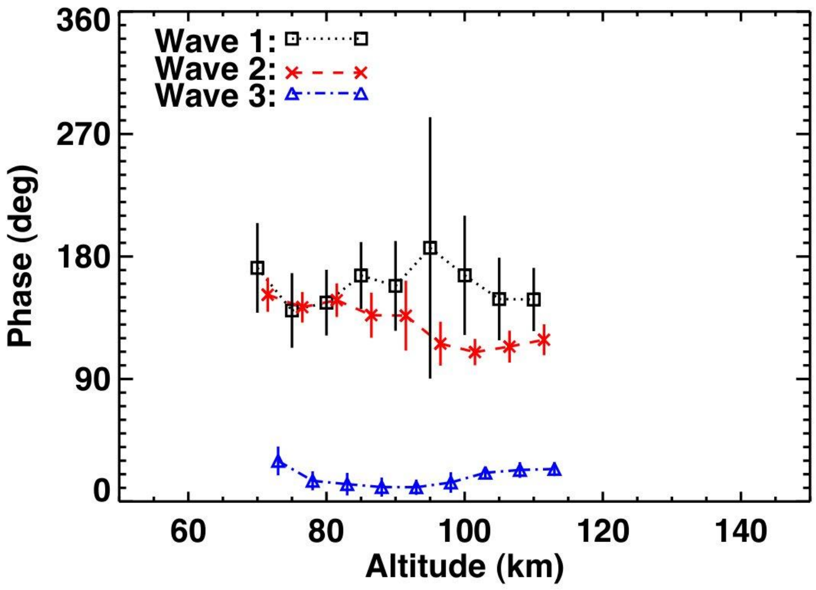
Pressure at 70-110 km for **<u>selected</u>** range of latitude/Ls/LST

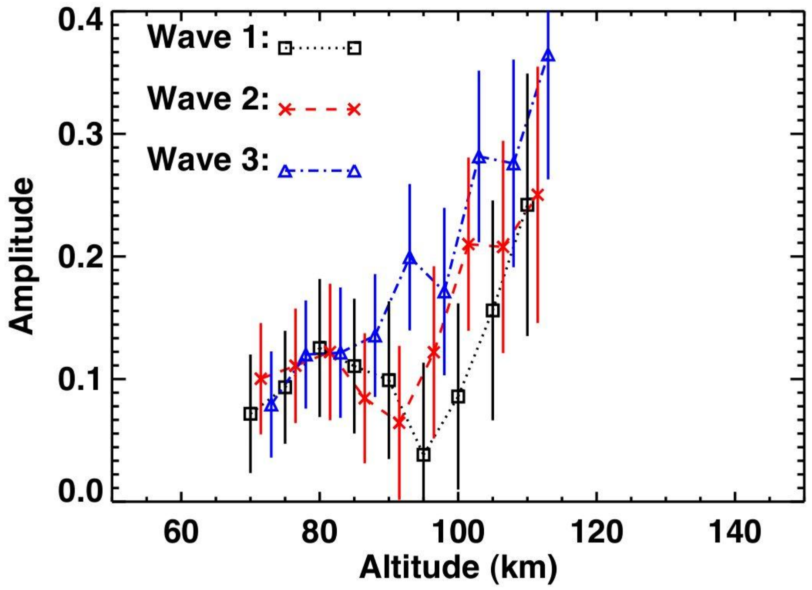
Zonal structure is persistent over wide vertical range

Normalized amplitudes of pressure harmonics increase with increasing altitude

Phases of peaks and troughs are mostly constant with altitude

Pressure phases and amplitudes versus altitude





Phase

Wave 2 phase is fairly stable, drifts slightly westward with increasing altitude

Normalized amplitude

Wave 2 amplitude has local maximum at 80 km, local minimum at 90 km, then grows steadily

Pressure-temperature relationships

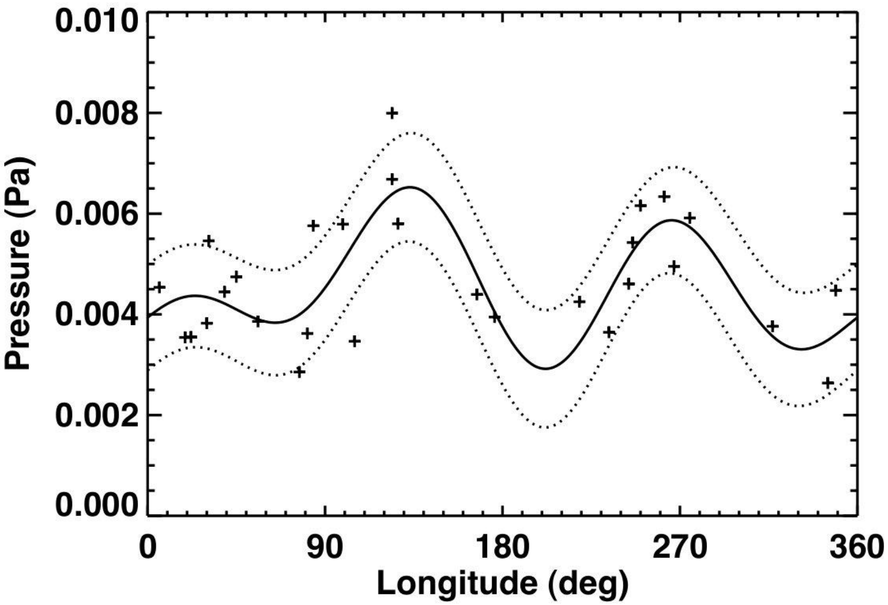
$$p = p_0(z)\left(1 + w_p(z)\, f(\lambda)\right)$$

$$\frac{d \ln p_0}{dz} = \frac{-1}{H_0}$$

$$H = H_0\left(1 + H_0 \frac{dw_p(z)}{dz} f(\lambda)\right)$$

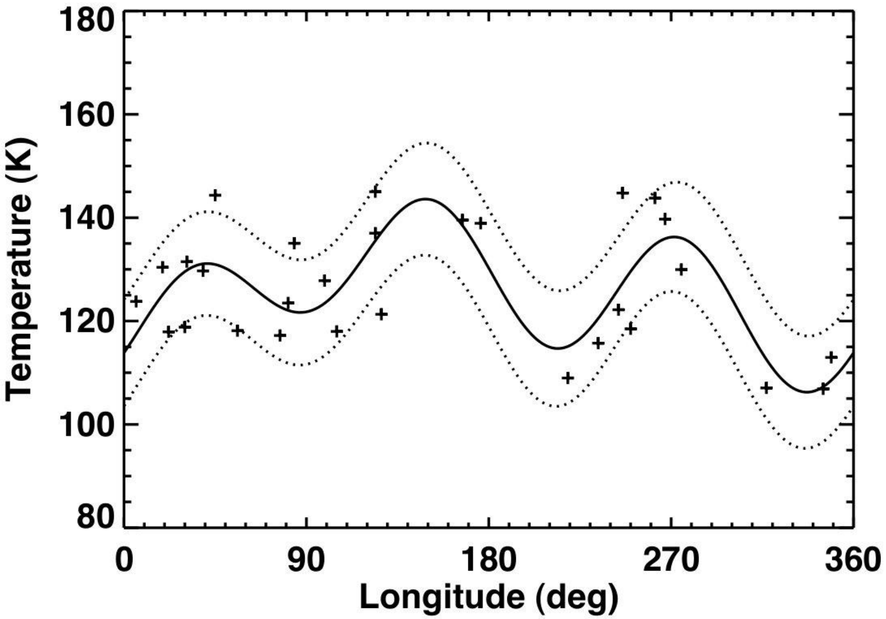
Changes in amplitude of pressure variations determine temperature variations

Pressure and temperature variations at 100 km



Pressure (Pa)

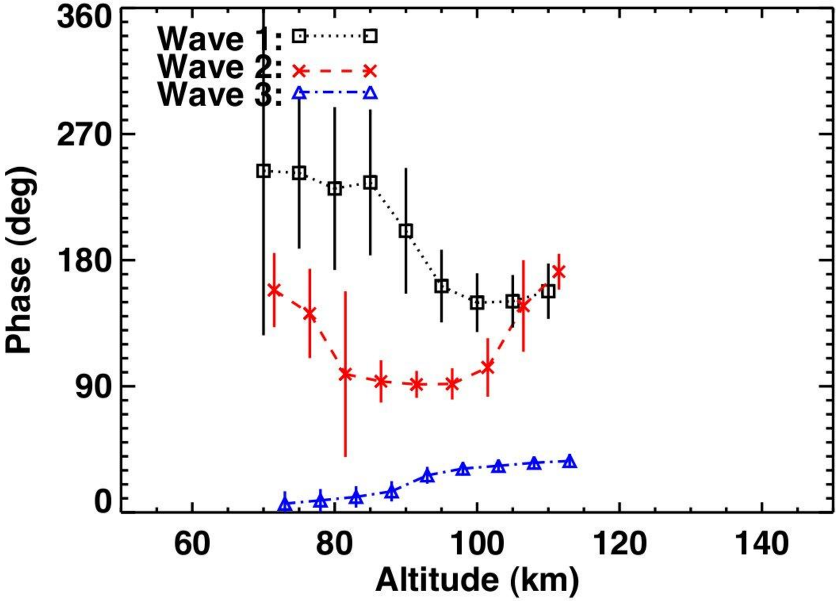
Similar appearance, phases of zonal variations likely to be similar



Temperature (K)

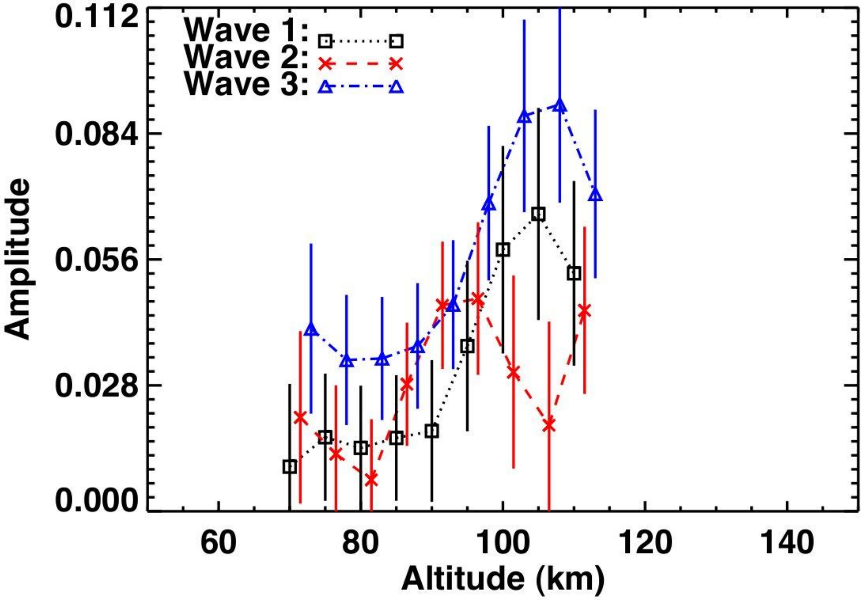
Dominant temperature harmonics are not simply the same as the dominant pressure harmonics

Temperature phases and amplitudes versus altitude



Phase

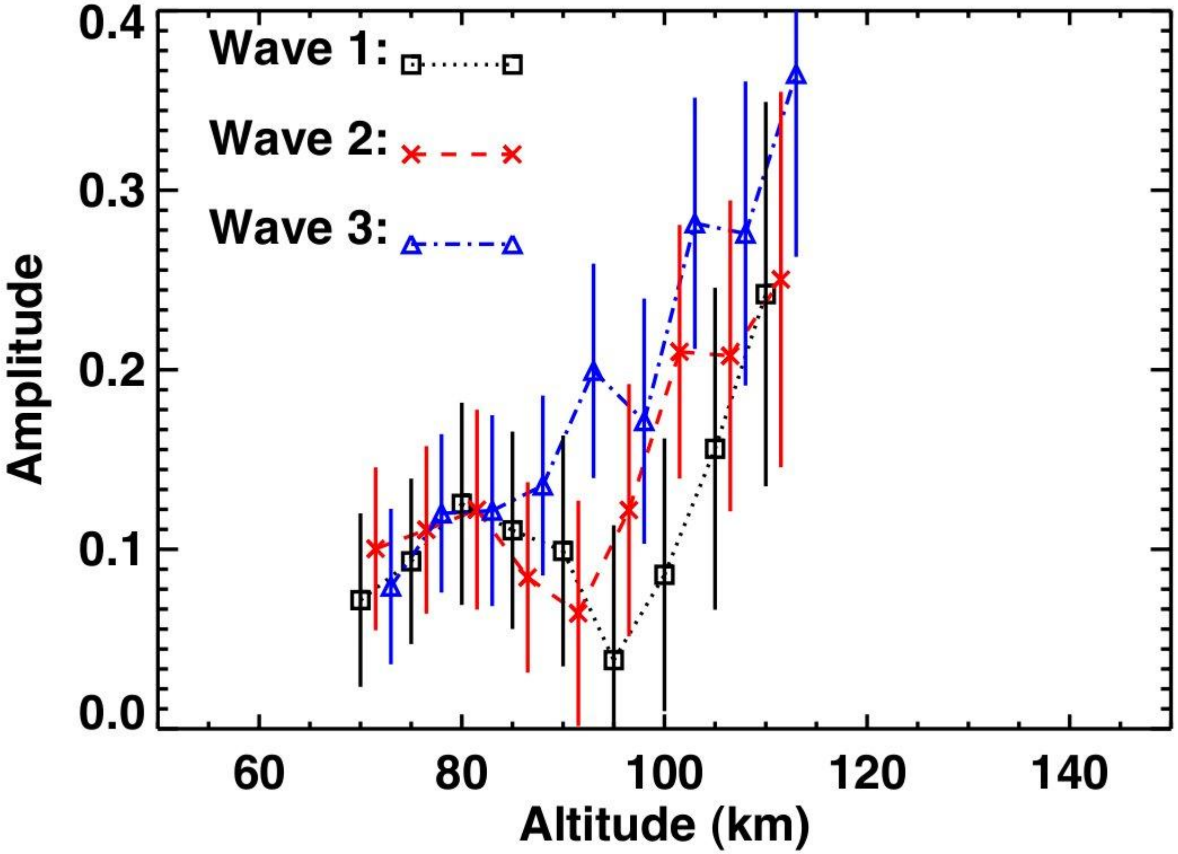
More variable than pressure phases



Normalized amplitude

Much noisier than pressure amplitudes

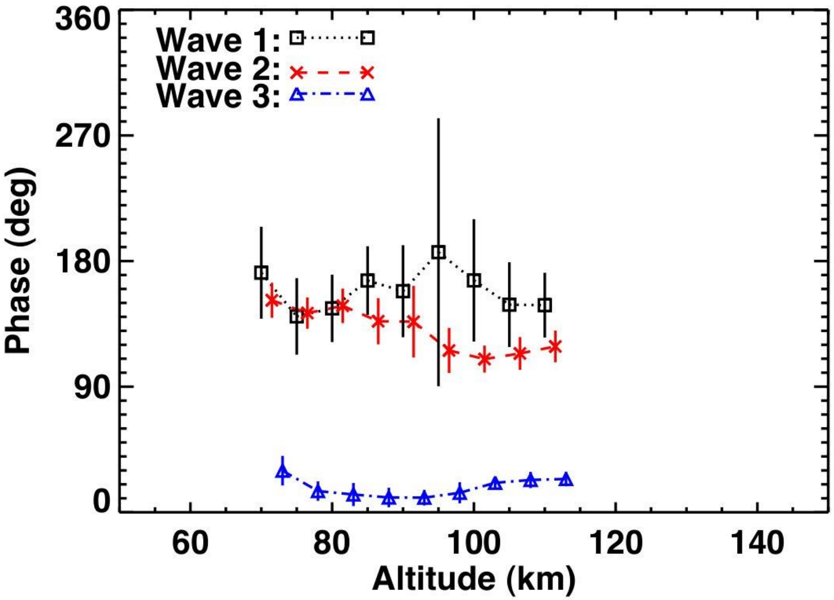
Wave 2 pressure amplitude versus altitude



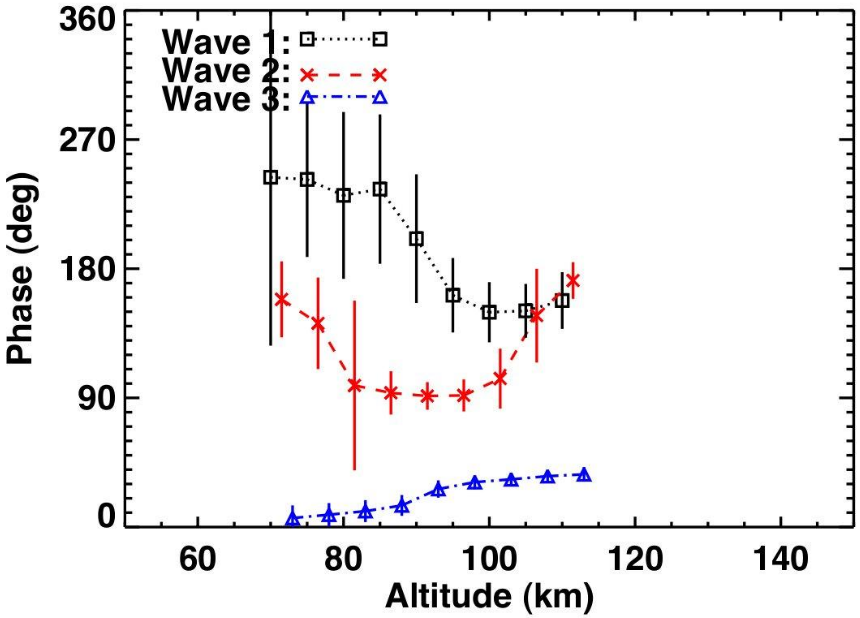
Strong increase in amplitude above 90 km consistent with minimal dissipation (DK1)

Amplitude trends below 90 km are not consistent with presence of DK1 only

Wave 2 pressure and temperature phases



Pressure phase

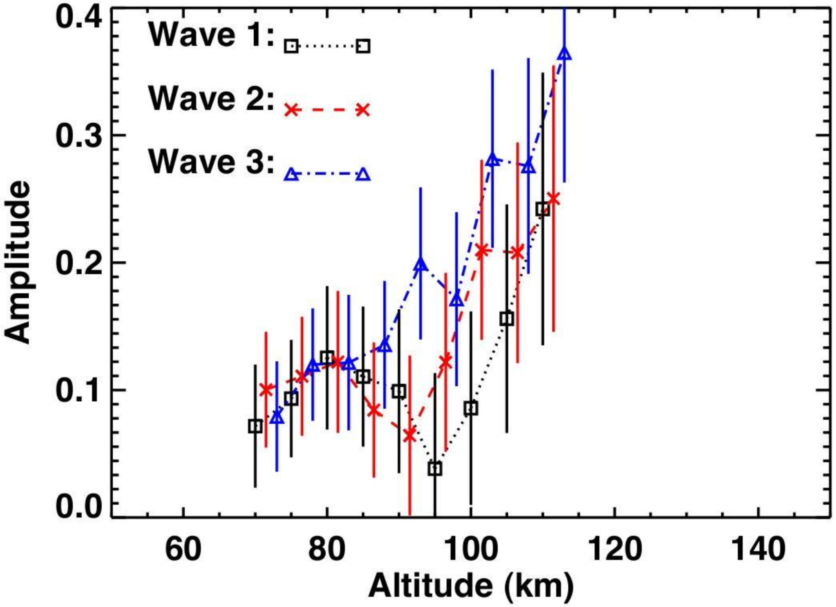


Temperature phase

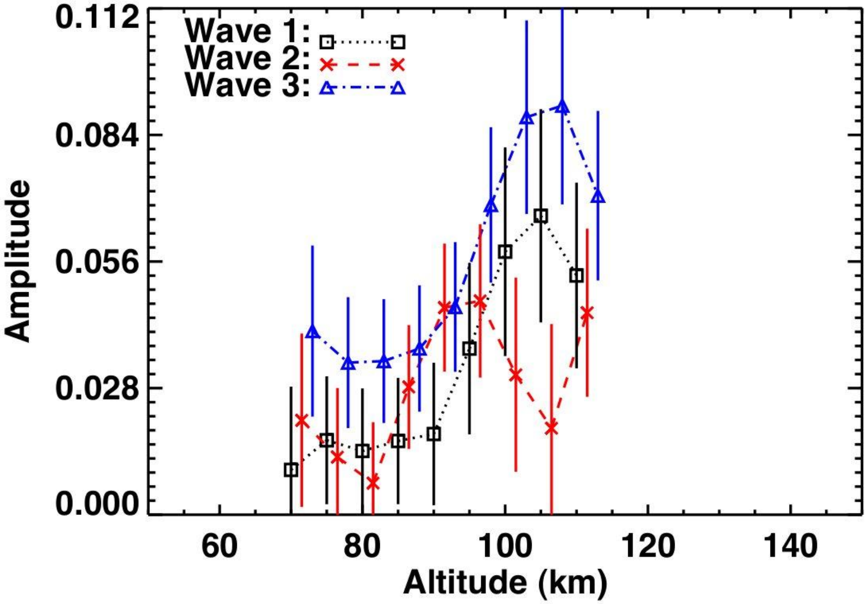
Wave 2 phases are the same at 100 km
(where pressure amplitude is increasing sharply)

Temperature phase does not jump by half a cycle (90 degrees) when pressure amplitude has local minimum at 90 km (not consistent with simple single mode theory)

Wave 2 pressure and temperature amplitudes



Pressure amplitude

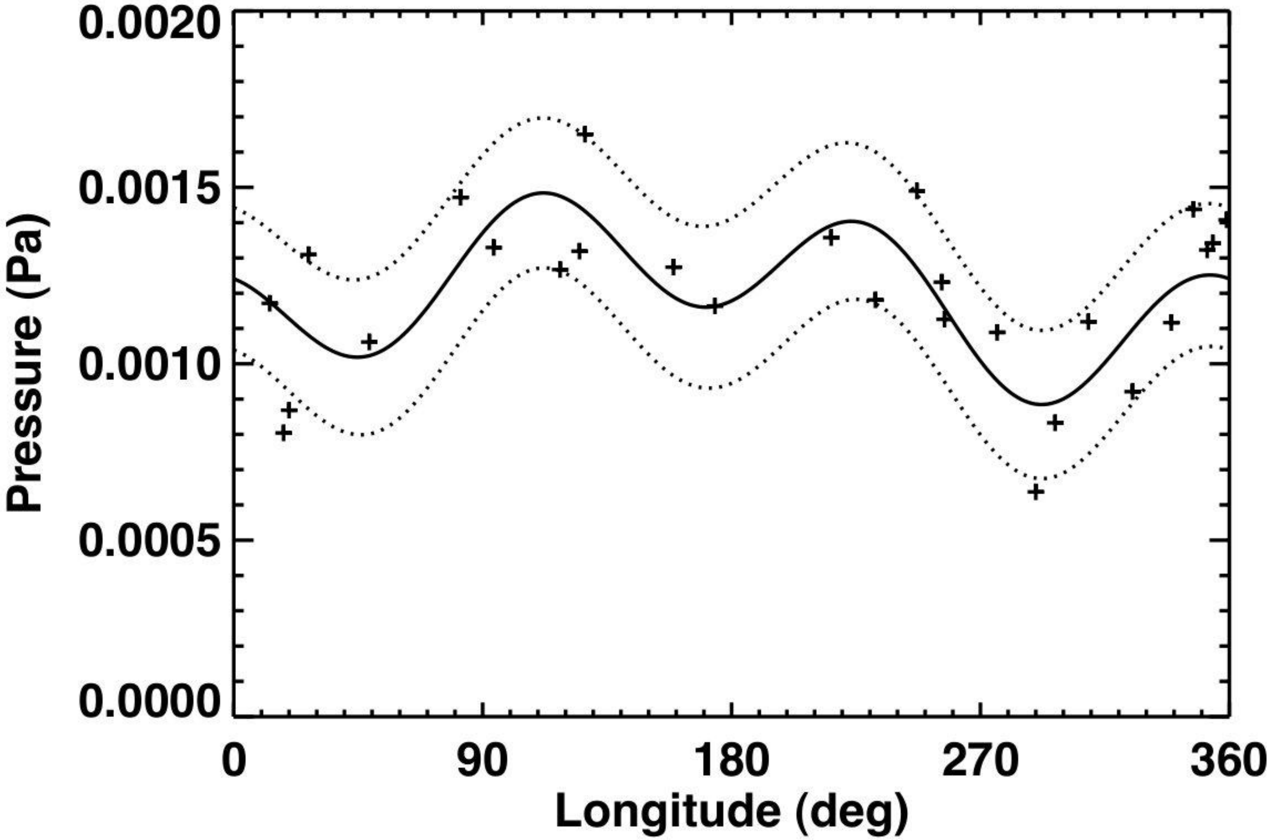


Temperature amplitude

Observed temperature amplitude near 100 km agrees with theoretical prediction (but uncertainties are large)

$$H = H_0 \left(1 + H_0 \frac{d w_p(z)}{dz} f(\lambda) \right)$$

Pressure at 110 km for different case – Vanishing DK1



Amplitude of wave 2 component is 0.013 +/- 0.047, typical amplitude=0.3

Why has DK1 vanished at 40-30ºS, Ls=150-180, LST=22-24 hrs?

Conclusions

- Zonal variations due to thermal tides are present in SPICAM pressure and temperature profiles
- Relationships between pressure and temperature variations are useful
- DK1 dominant above 90 km in selected case
- Some other tidal mode is also significant at lower altitudes
  - Banfield et al. Fall AGU analysis of MCS data identified a possible candidate

- DK1 is absent from one unusual case