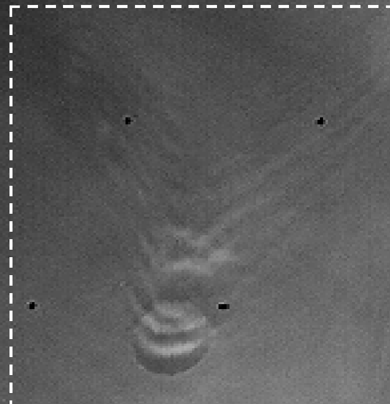
Wave Activity on Mars



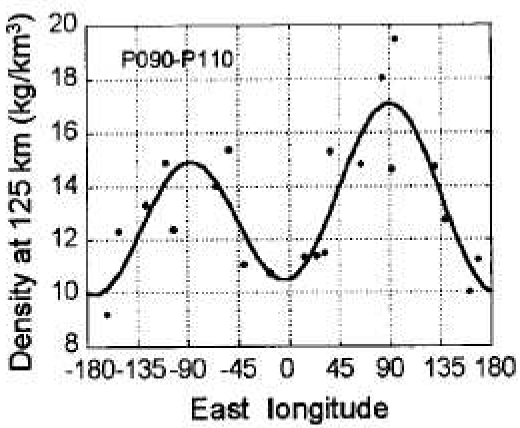
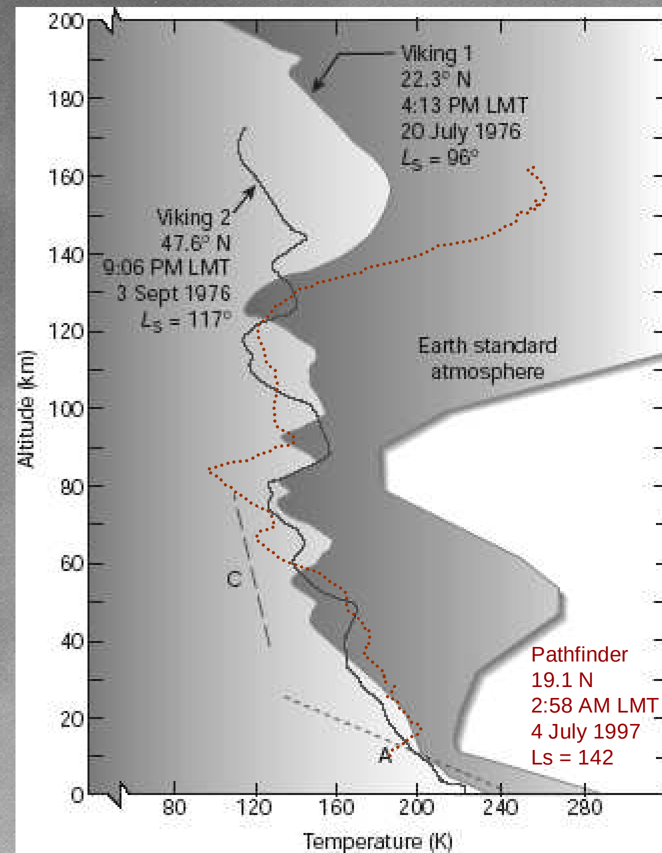


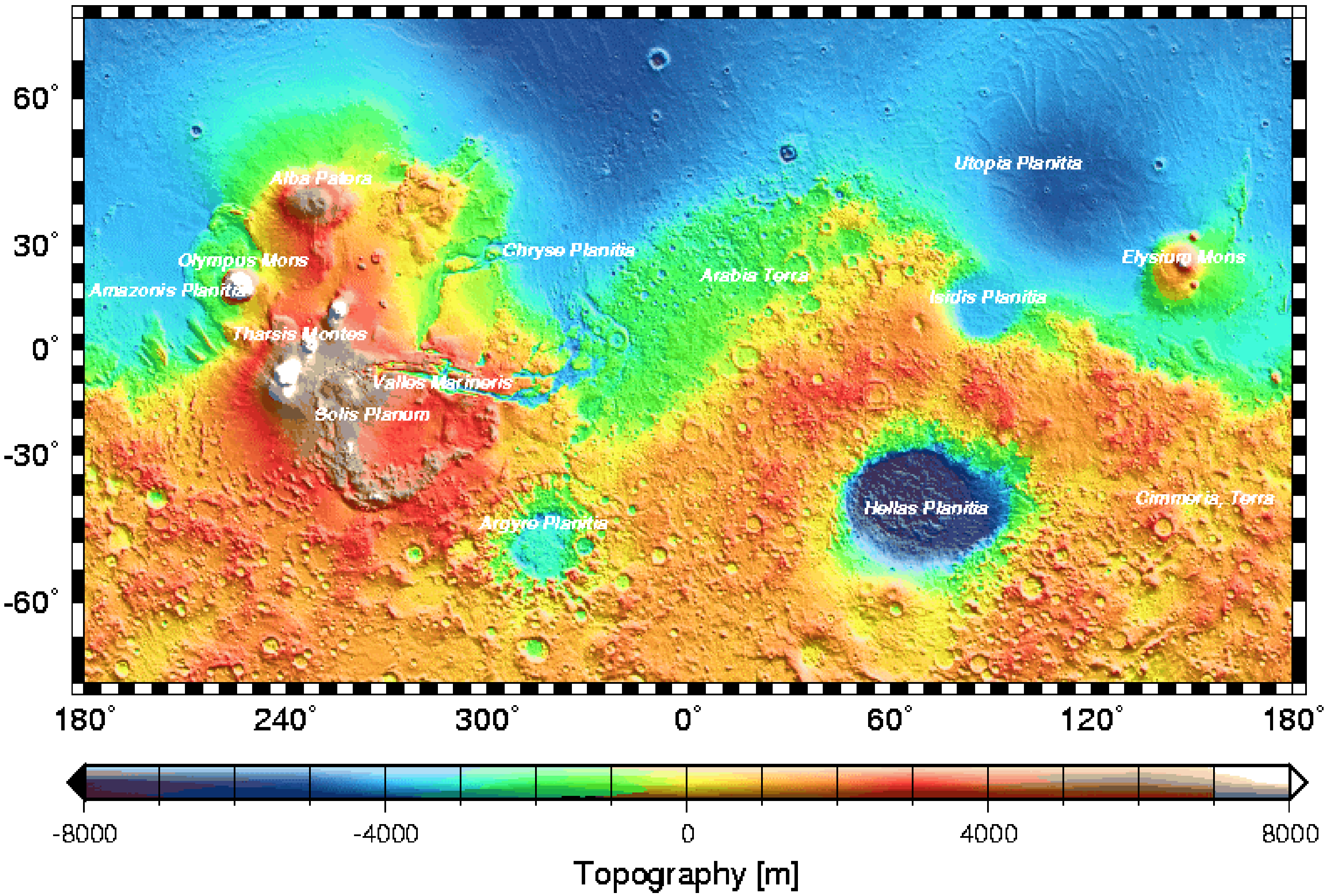
Fig. 6. Thermospheric density, normalized to 125 km, as a function of East longitude (solid circles) measured from P090 through P110 by the MGS accelerometer. The solid curve represents a least-mean-square fit solving for wave 1 and wave 2. For this case, wave 1 has an amplitude (mean to peak) of 8% of the mean and a phase (for the minimum) of 256°E, and wave 2 has an amplitude of 22% of the mean and a phase of 1°E.



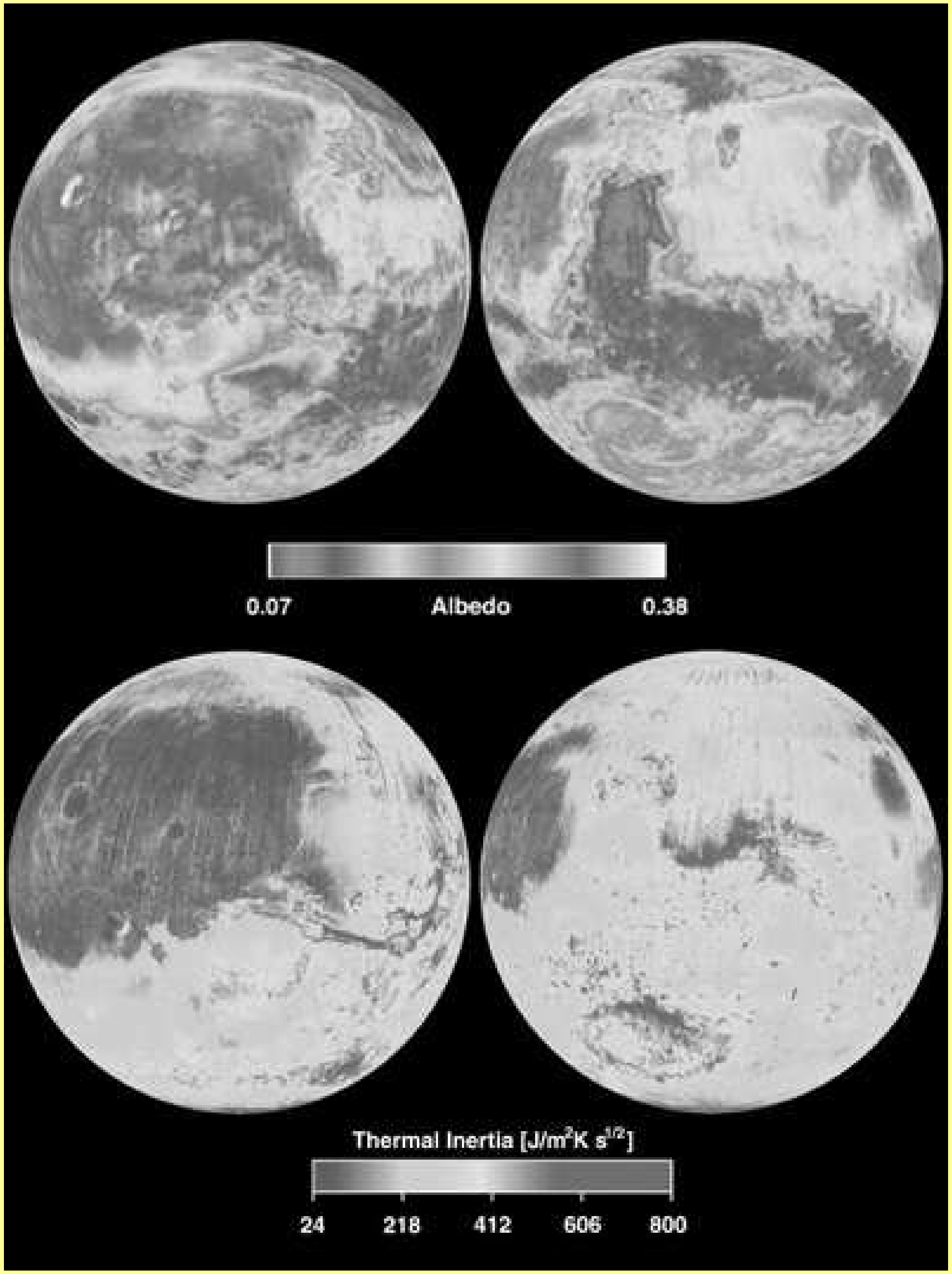
Viking Orbiter Images
Viking temperature profiles: Leovy 2001
MGS thermospheric densities: Keating et al, 1998

		Earth	Mars
Radius	km	6380	3390
Solar constant	W/m^2	1373	591
Orbital inclination	deg.	23.5	25.2
Eccentricity		0.03	0.093
Magnetic dipole moment (wrt Earth)		1	$2.5 \cdot 10^{-5}$
Surface gravity	m/s^2	9.81	3.72
Surface Pressure	mb	1000	6
Specific gas constant	$m^2 s^{-2} K^{-1}$	287	191
Specific heat at constant pressure		1000	860
Mean Temperature (lowest scale height)	K	260	200
Bulk radiative timescale (lower atmos.)	days	16	2
Thermal equilibrium timescale (thermos.)	days	2-5	0.2-0.5
Typical zonal wind at jet level	m/s	30	80
Mean Scale Height		7	10
Exobase height	Km	450 (H)	170 (H,H2, O)
Homopause height (dayside)		100	125
Dayside exospheric temperature		900-1500	200-350
Max. diurnal near-surf. Temp. change	K	30	60
Max. seasonal near-surf Temp. change		50	90
Dry adiabatic lapse rate	K/km	9.8	4.3
Average lapse rate (lowest scale height)		6.5	2.5

Mars Topography from MGS



Mars Surface Properties from MGS



Tides

Earth

- Lower atmosphere (0-20 km)
  - NIR (H_2O)
  - Latent heat release of deep convection
- Middle atmosphere (30-60 km)
  - UV (O_3)
- Upper Atmosphere (above 90 km)
  - UV (O_2)
  - EUV (O_2, N_2, O)
  - Exothermic ion and neutral gas chemistry
  - Collisional heating
  - Auroral heating
  - Joule dissipation of ionospheric currents
  - Molecular dissipation of upward propagating waves

Mars

- Visible radiation by ground
- Lower atmosphere (0-50 km)
  - IR (Dust)
  - Solar (Dust)
- Middle atmosphere (50-100 km)
  - NIR (CO_2)
- Upper Atmosphere (above 100 km)
  - UV (CO_2, O_2)
  - EUV (CO_2,O_2, O)

Tidal component of the circulation plays a more important role on Mars due to its reduced atmospheric mass (about two orders of magnitude less than that on Earth)

Doppler shifts of the tides by the mean winds are expected to be larger on Mars than on Earth.

Phase speed = 450 m/s Earth
250 m/s Mars

Non-migrating Tides

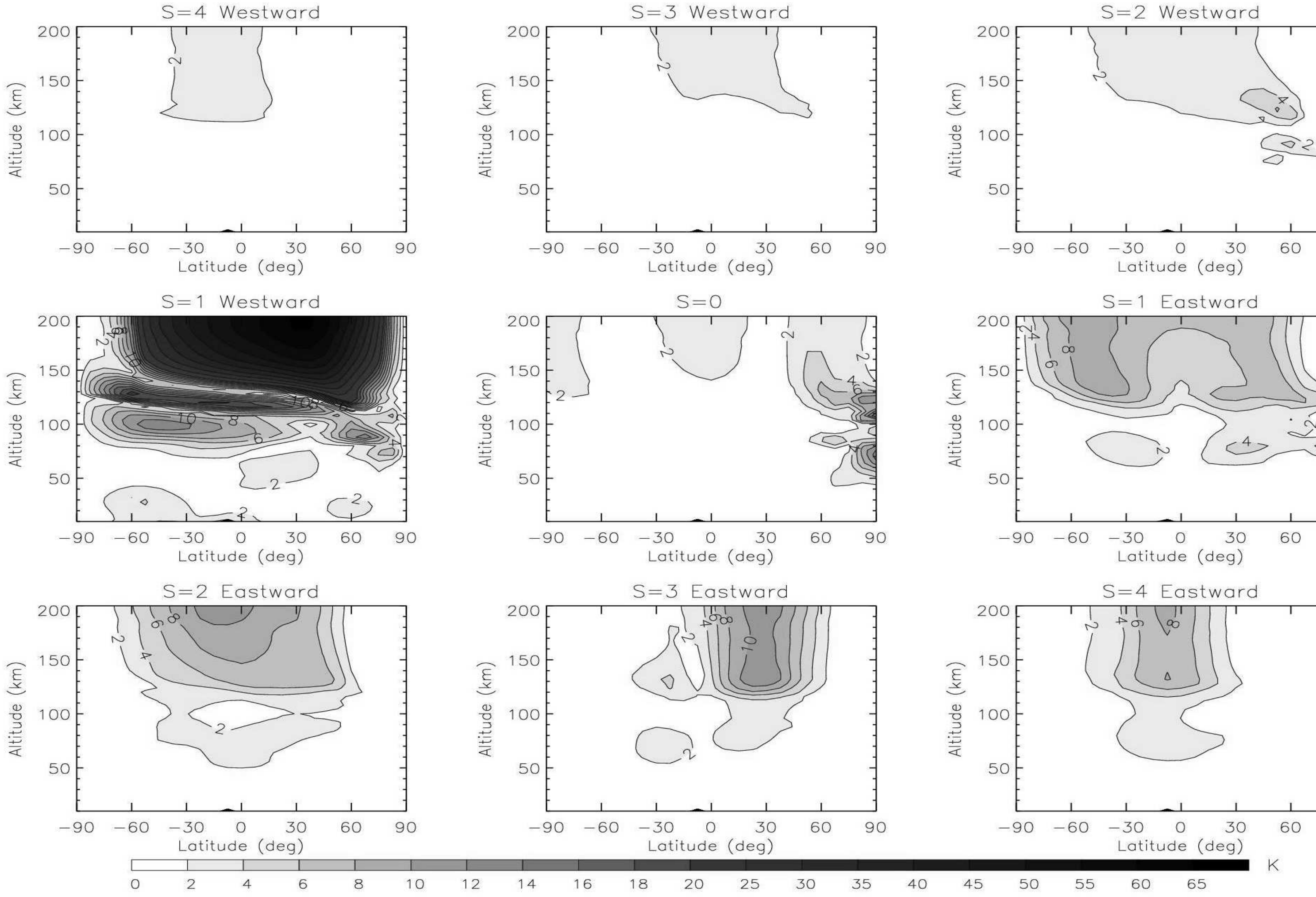
- Longitudinal Inhomogeneities Solar Forcing
  - Spatial distribution of absorber
  - Topography

	Diurnal	Semidiurnal
s = 4	s = 3 s = -5	s = 2 s = -6
s = 2	s = 1 s = 3	s = 0 s = -4

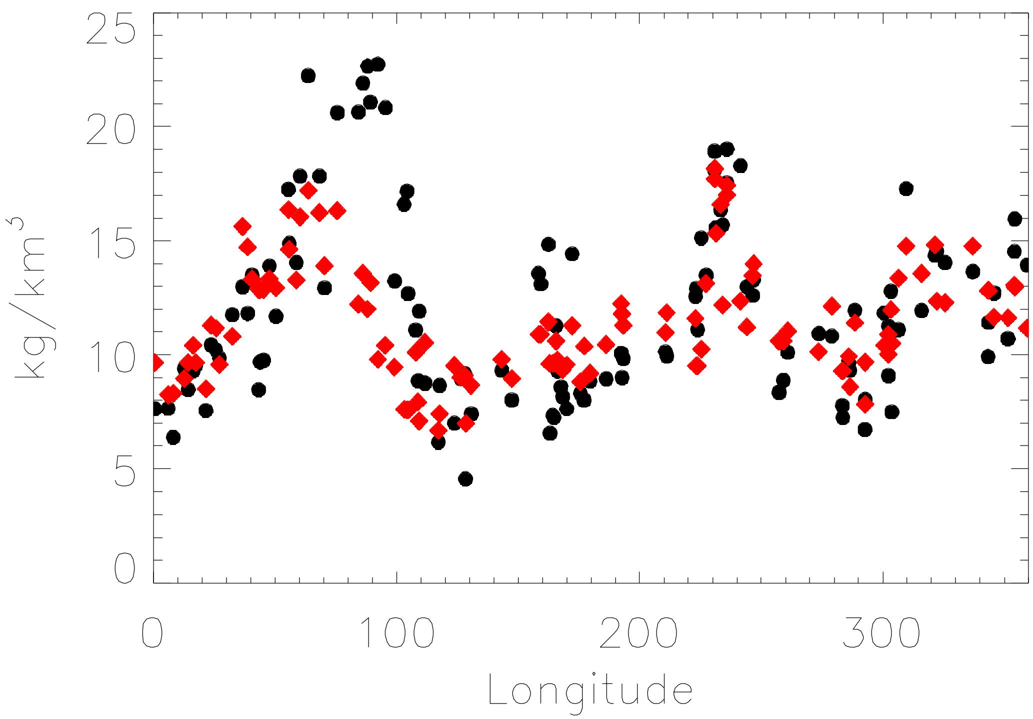
- Non-linear Wave Interactions

Diurnal Temperature Amplitudes

Ls=300, LMD GCM



Density Comparison: LMD GCM vs. MGS Data
Ls = 65, Z = 115, Lat = (-10°, 20°), Lt = 15



Wave in a local time frame of reference:

$$A \cdot cos[(s + 24/p)\,\lambda - \sigma\, t_{LT} - \Phi]$$

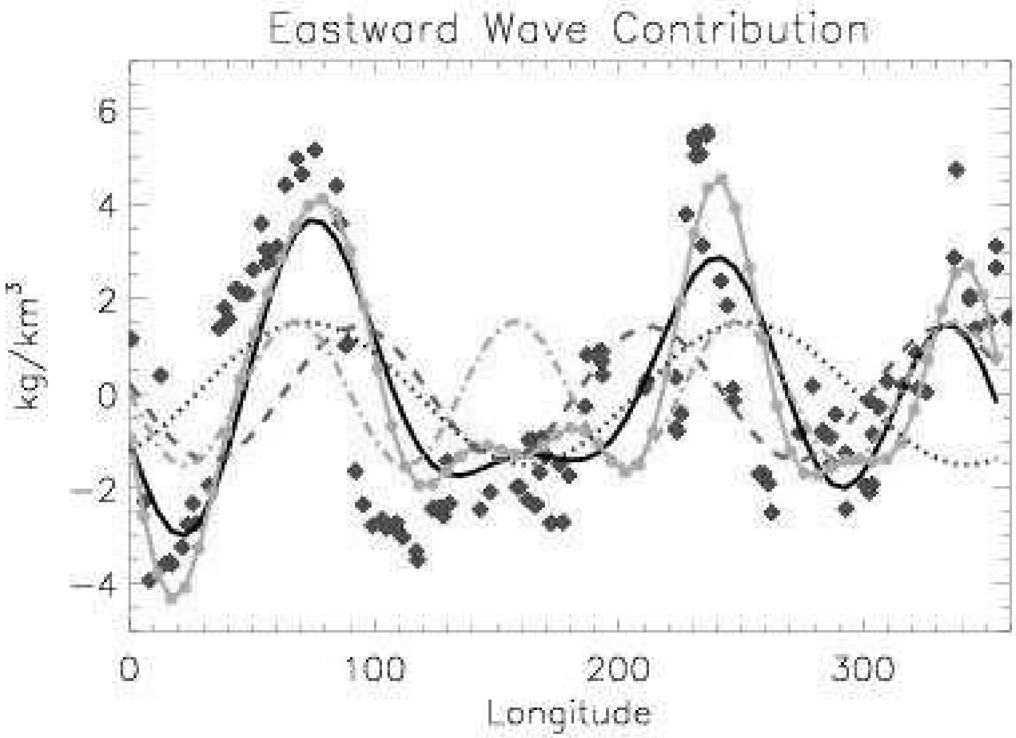
$$A \cdot cos[\, s_{LT}\,\lambda - \sigma\, t_{LT} - \Phi]$$

Angelats i Coll, M., et al, 2004

LMD Simulation

Ls = 65, Z = 115, Lat = (-10°, 20°), Lt = 15

(without longitudinal mean)

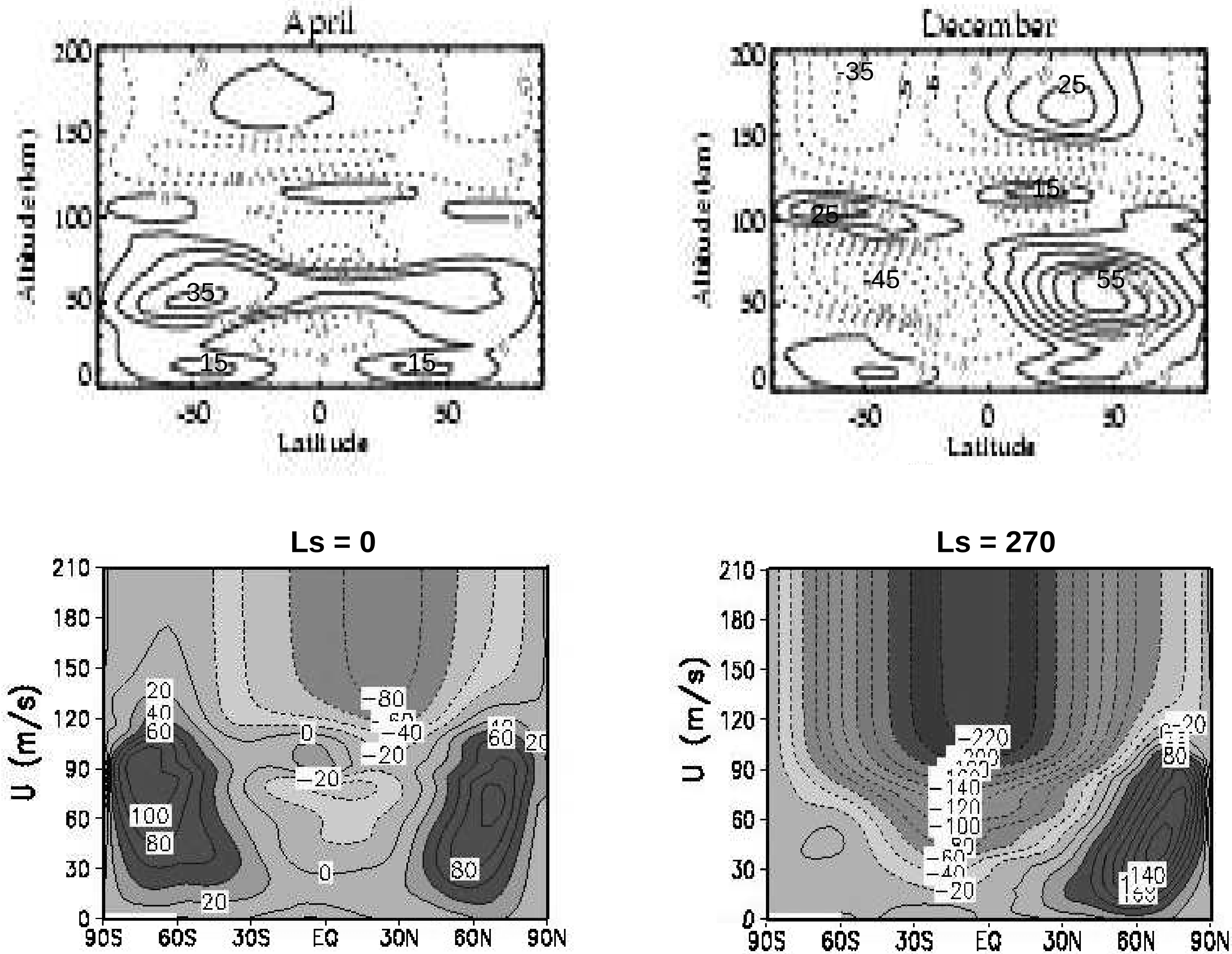


(1/24, 1) + (1/24, 2) + (1/24, 3)

(1/12, 2) + (1/12, 3) + (1/12, 5) + (1/24, 5)

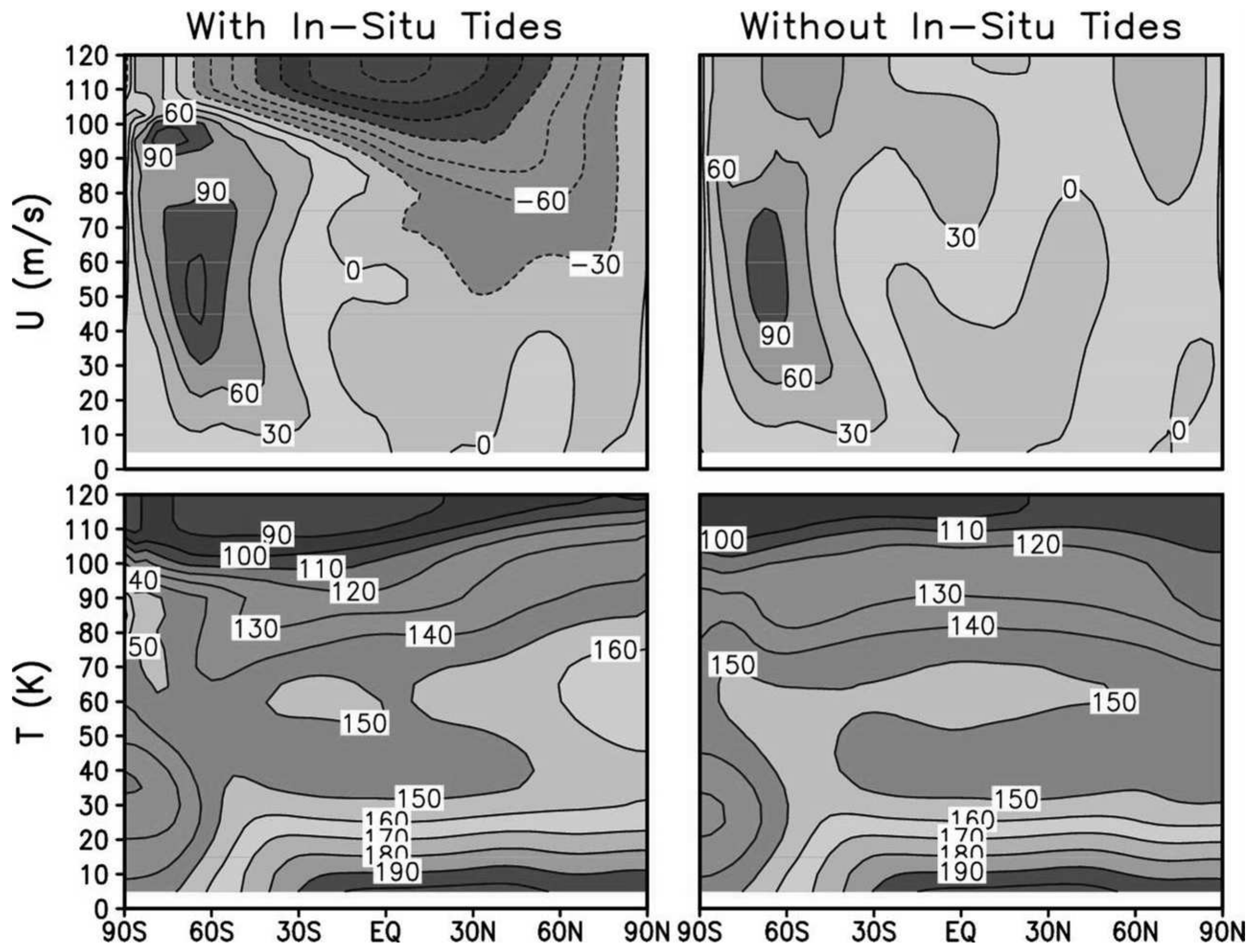
Angelats i Coll, M., et al, 2004

Zonal Mean Winds



Zonal Means for Ls = 65

Temperature and Zonal Wind



Angelats i Coll, M., et al, 2004

Winter Polar Warming

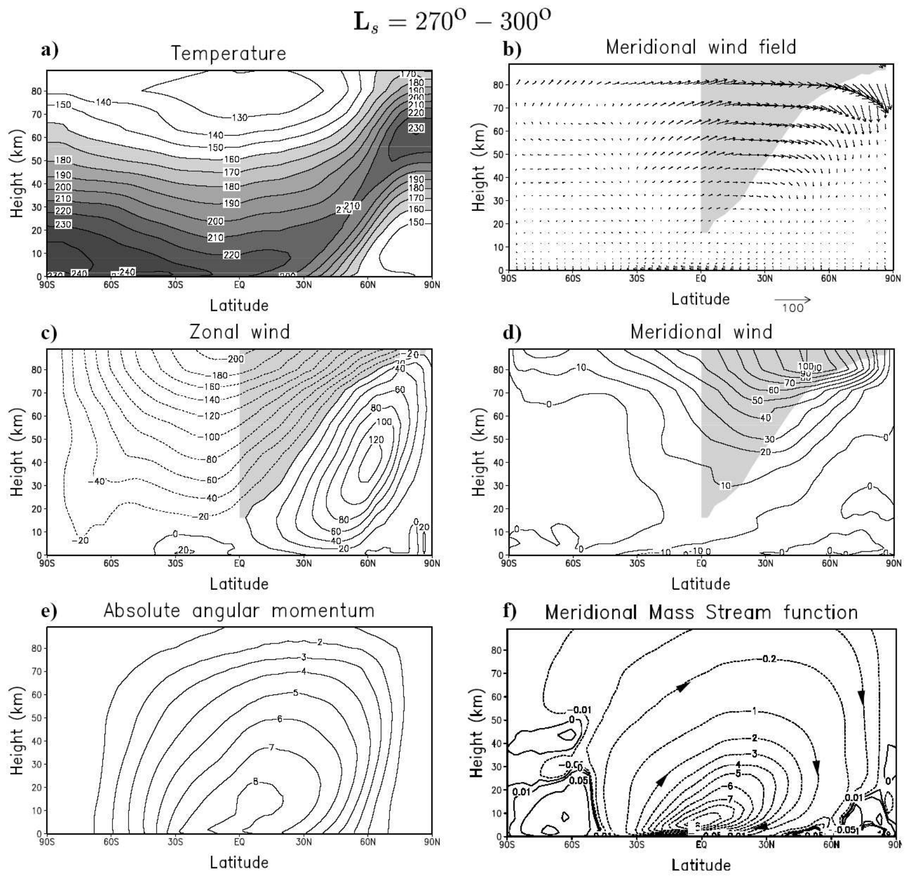


Figure 7. Time-mean section of zonal-mean temperature (K), zonal wind, meridional wind (m s^{-1}), absolute angular momentum (10^8 kg m^2 s^{-1}) and meridional stream function (10^9 kg s^{-1}) during early northern winter ($L_s = 270° - 300°$) as simulated with the grid point model. The spectral model gives almost exactly the same mean results for this season. Shaded areas in Figures 7b-7d show where the Coriolis and centrifugal forces contribute to accelerate the meridional poleward motion instead of slowing it as on Earth. The vertical coordinate is a pseudo-altitude above the ground: $z = H \ln(p/p_0)$, where p/p_0 is the pressure normalized by its local value at the surface and H a fixed scale height $H = 10$ km.

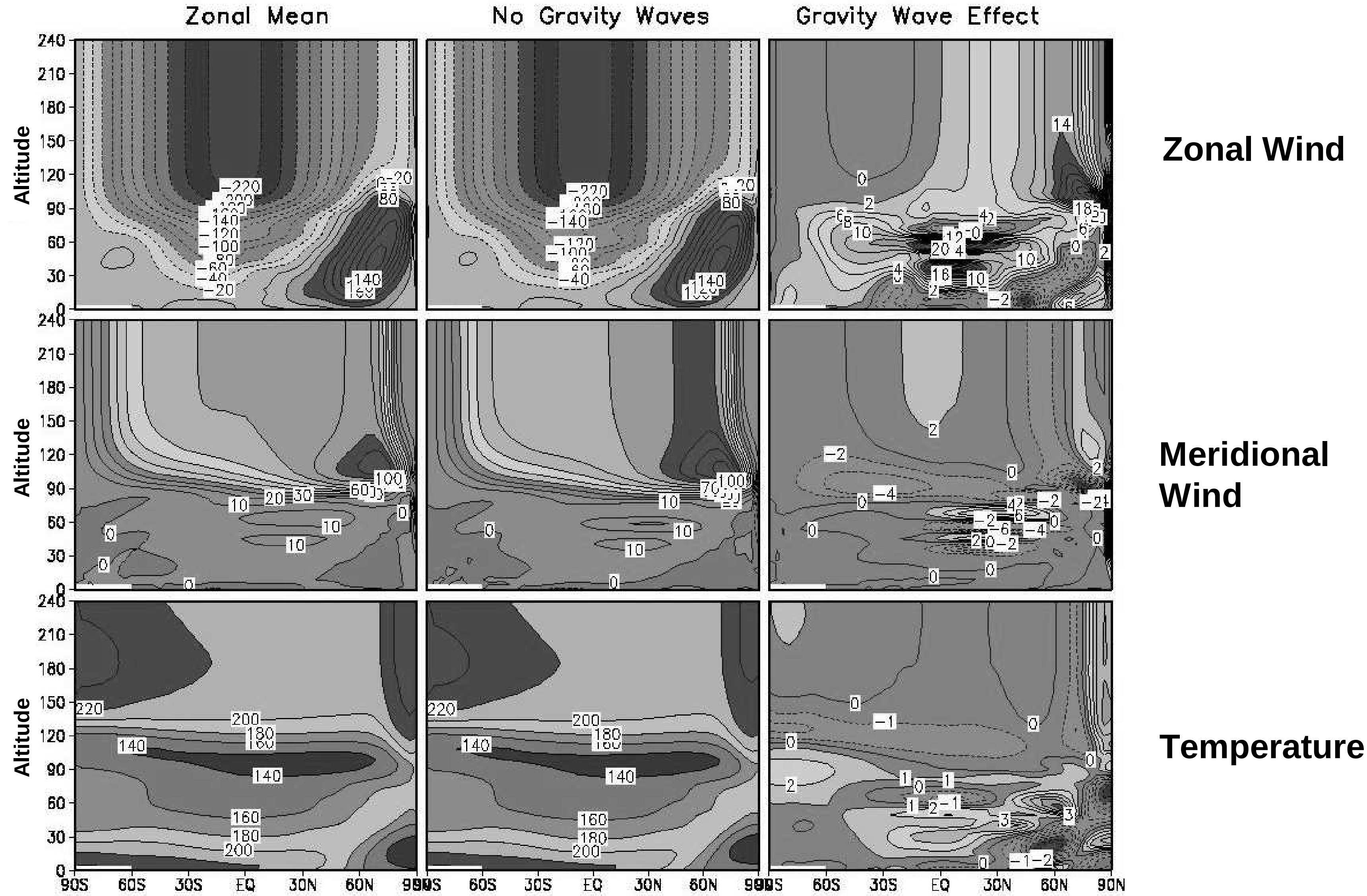
Forget, F., et al., 1999

Gravity Wave Sources

	Earth	Mars
Topography	✓	✓
Convection: Dry	✓	✓
Convection: Latent Heat Release	✓	✓
Adjustment of balanced flow (jet streams/fronts)	✓	✓
Shear instabilities	✓	✓
Body forcing by wave dissipation	✓	✓
Wave-wave interactions	✓	✓
Auroral heating	✓	
Eclipse cooling	✓	✓
Near-surface thermal contrasts	✓	✓

Lower Atmosphere Effects: Gravity Waves

Ls=270, Solar Medium Conditions



Wave Dissipation

- Molecular diffusion
- Molecular viscosity and conductivity
- Ion drag
- Radiative damping
- Eddy viscosity and conductivity

Given comparable values for mean winds, those on Mars Doppler-shift the wave frequencies by two-fold.

Time constant for dissipation in comparison with wave's period tells us the possible effect of dissipation on the wave. If the time constant for dissipation is shorter than the period, then dissipation has an effect on the wave.

Atomic oxygen collisions are especially effective in exciting CO_2 vibrational states and thus in enhancing the radiative cooling where NLTE prevails. This effectiveness depends on O densities and $k_{CO2\text{-}O}$ collisional energy transfer rate coefficient

$$\sigma_D = \sigma - \frac{sU}{a\cos\theta}$$

Dissipation Effects		
	U > 0	U < 0
S > 0 Eastward	$\sigma_D < \sigma$ ↑	$\sigma_D > \sigma$ ↓
S < 0 Westward	$\sigma_D > \sigma$ ↓	$\sigma_D < \sigma$ ↑

Dust Storm

MGS Thermal Emission Spectrometer (TES) data

Hellas Basin: 9-km deep impact crater

Lower-atmosphere Influences: Dust Storms

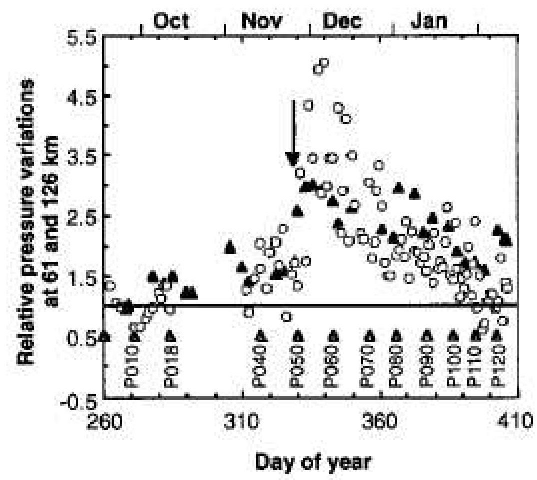


Fig. 3. Change in pressure with time (and MGS orbit number) at reference altitudes of 61 and 126 km and normalized to values on 26 September 1997, as derived from ground-based Mars disk-averaged microwave data (*15, 28*) (solid triangles), also normalized by surface pressure estimates. The microwave data are compared to 126 km MGS accelerometer data (open circles). Arrow indicates first detection of Noachis dust storm by MGS. Open triangles indicate even-numbered periapsis pressures and are labeled below the symbol.

Keating, G., et al., 1998

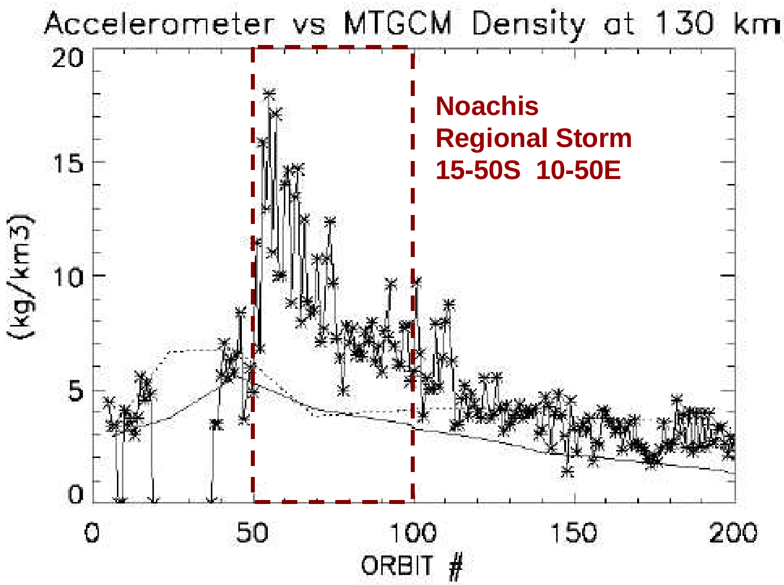


Fig. 2. MGS ACC data vs. MTGCM simulations of densities at 130 km over Phase 1 orbits P005-200. MTGCM curves are as follows: dotted ($\tau = 1.0$) and solid ($\tau = 0.3$) [4].

Modified from Bougher, S., et al., 1999

Some Outstanding Issues

- Relative contribution of various tidal forcing
- Tidal contribution to the zonal mean structure
- Gravity wave spectrum and its effect on the upper atmosphere
- Interactions between tides, planetary waves and gravity waves
- Molecular dissipation of tides and its effects on the zonal mean structure of the thermosphere
- Effects of nonmigrating tides on the mean circulation, thermal and compositional structure of the thermosphere
- Nonlinear wave interactions as a source for nonmigrating tides
- Limited measurements of [O] to constrain radiative damping in the models
- No wind measurements in the upper atmosphere