SEMIANNUAL OSCILLATIONS IN THE ATMOSPHERE OF MARS. A. S. Medvedev[1] , T. Kuroda[1], P. Hartogh[1] and M. Takahashi[2], [1] Max Planck Institute for Solar System Research, Katlenburg-Lindau, 37191 Germany (medvedev@mps.mpg.de), [2] Centre for Climate System Research, University of Tokyo, Kashiva, Chiba, Japan .

Abstract: We report on the first detection of the semiannual oscillation (SAO) in the Martian atmosphere. The semiannual periodicity is found in the difference between day- and night-time atmospheric temperatures, a good proxy for solar tides, measured from Mars Global Surveyor. Simulations with a general circulation model proved that this modulation of tidal amplitudes is a manifestation of the SAO of zonal winds in Martian tropics. Our numerical experiments revealed significant differences in driving mechanisms of the SAO between Mars and Earth. On Mars, unlike on Earth, equatorial Kelvin waves supply only small retrograde torque to the mean circulation. Instead, thermal tides and quasi-stationary planetary waves induced by flow over Martian topography contribute strongly to the prograde (super-rotation) acceleration.

SAO signal in the MGS-TES data: To date, there are virtually no measurements of the equatorial wind on Mars except for some sparse data with very low resolution. In mid- and high latitudes, the wind can be estimated from numerous temperature profiles acquired with the Martian orbiters using the so-called thermal wind relation, as, for instance, was done for the Thermal Emission Spectrometer aboard Mars Global Surveyor (MGS-TES). Unfortunately, this relation breaks down and of little use in low latitudes.

However, if the SAO in the Martian atmosphere exists, the seasonally varying tropical wind must necessarily modulate the propagation of solar tides. Following this assumption, we analyzed the temperature difference between the day- (local time ~2:00 pm) and night-time (local time ~2:00 am) retrieved from the MGS-TES limb measurements during Mars Years 24 and 25 (MY24-25). The absolute value of this difference is proportional to twice the amplitude of the diurnal sun-synchronous tide [1]. Figure 1a shows a clear semiannual signal between 0.5 and 0.05 mb (approximately 25-50 km) with the peak values ΔT~6-8 K near the equinoxes (the solar longitudes L_s=0 and 180^o) and minima around the solstices (L_s=90 and 270^o).

Simulation with a general girculation model: To find out if the observed tidal signature is really caused by the SAO, we applied our Martian general circulation model (MGCM) [2] to simulate long period variations of the tropical wind. The model is based on the CCSR/NIES terrestrial GCM, and has a comprehensive suite of physical parameterizations for the Martian atmosphere. The model accounts for the realistic topography, albedo and thermal inertia on the surface, and for the CO_2 condensation/sublimation including the change of the air mass and the surface CO_2 snow cover. It computes the radiative effects of CO_2 (under the LTE) and of airborne dust in the solar and infrared wavelengths. The vertical grid has 30 σ-levels with the model lid at ~80 km, and the horizontal resolution is set to about 5.6˚×5.6˚ (~333 km at the equator).

The simulations were carried out for 7 model Martian years starting with the initial isothermal and windless state, and the output from the last 5 years was used for the analysis in the form of composite cycles. To match the meteorological conditions of the MY24-25, we prescribed the seasonal and latitudinal variations of the dust opacity in accordance with the MGS-TES retrievals during the same time (TES2 dust scenario in [2]). This was a period with a "minor" dust storm during the southern spring with the increased dust opacity in the visible wavelength ~0.7-1.5, and ~0.2 in other seasons. The simulated seasonal change of the temperature difference at 2 pm and 2 am of local time over the equator in Fig. 1b shows a remarkable agreement with the observations in Fig. 1a including the semiannual signal around 0.1-0.3 mb.

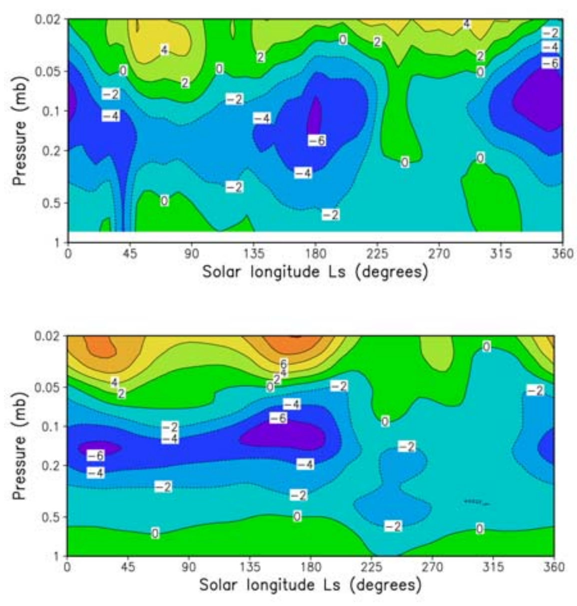

Figure 1. (a) Temperature difference between local day and night divided by 2, $(T_{2PM}-T_{2AM})/2$, averaged between 10˚S and 10˚N from the MGS-TES limb observations. The data in this plot are for the period from L_s=125° in Mars Year 24 (April 1999) to L_s=125° in Mars Year 25 (March 2001). The contour interval is 2 K. (b) Same as above but from the

MGCM run with the seasonally varying dust opacity (TES2 scenario) corresponding to the period of observations in (a).

Indeed, the modeled annual cycle of the mean zonal wind averaged between 10˚S and 10˚N (Fig. 2a) demonstrates a clear SAO with alternating westerlies (super-rotation, prograde wind) in equinoxes and easterlies (retrograde wind) in solstices between 0.2-1 mb (~20-35 km). Its phase is similar to the stratospheric SAO on Earth [3,4], but an unexpectedly large seasonal asymmetry is seen between the northern (~-30 $m\ s^{-1}$) and southern (~-120 $m\ s^{-1}$) summers. Partly, it is related to the occurrence of the dust storm. When the run was repeated with the seasonally and spatially uniform dust opacity ~0.2 in the visible wavelength (Fig. 2b), the magnitudes of the wind in both solstices became approximately equal, and the phase reversal above ~0.05 mb (~45 km) turned out to be more reminiscent of the terrestrial mesospheric SAO. Nevertheless, some seasonal asymmetry (westerly wind at 1-4 mb during northern summer solstices and easterlies below ~0.05 mb in southern summers) remains.

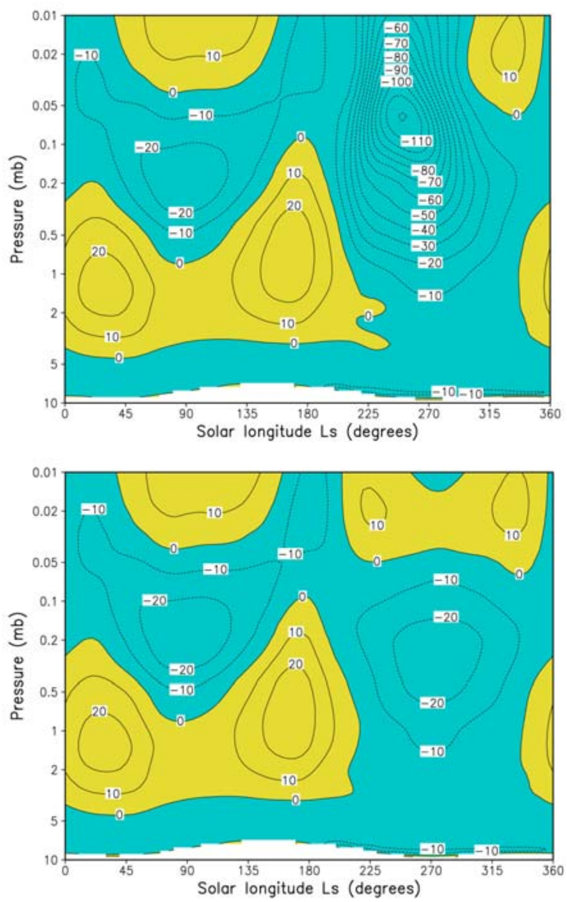

Figure 2. (a) The composite annual cycle of the simulated mean zonal wind averaged between 10˚S and 10˚N from the run with TES2 dust scenario. Westerly wind is shaded with yellow. (b) is the same as (a), except from the run with the seasonally uniform dust opacity ~0.2. The run with the circular Martian orbit yielded little difference in the wind distribution suggesting that the eccentricity of the orbit plays no role in the seasonal asymmetry of the SAO. However, a remarkable change occurred when we replaced the real topography with the flat surface: the asymmetry strongly diminished, and the westerly phase almost disappeared. Apparently, the SAO is closely related to the strength of the meridional Hadley circulation, which, in turn, is determined by the global south-north tilt of the Martian topography.

Driving mechanism of the Martian SAO: We evaluated the forcing by the vertical and meridional advection, and by various eddy components. Only three types of non-zonal disturbances contribute appreciably to the acceleration: 1) quasi-stationary planetary waves (SPW) with periods longer than 30 sols, 2) westward-propagating diurnal-period harmonics associated with the thermal tide, and 3) eastward-traveling diurnal-period Kelvin waves. As on Earth, the meridional advection supplies mainly the easterly momentum, especially in solstices. The vertical advection contributes mainly to the westerly wind acceleration. It occurs due to the enhancement of the upward flow over the equator and the negative vertical wind shear.

The momentum supplied by SPW is mostly opposite to that by the meridional advection. These waves are induced by the flow over topography with a distinct zonal-wave-number 2 structure at the equator. They provide the westerly torque to the mean flow, especially during southern summers in the lower atmosphere. This is opposite to the role of planetary Rossby waves on Earth, which transport the easterly momentum from the winter midlatitudes to the equator.

The westward-moving tide has large amplitudes in equinoxes. The associated forcing has a clear semiannual structure. Together with the vertical advection, the diurnal sun-synchronous tide is the main driver of the prograde phase of the SAO during equinoxes.

Eastward propagating Kelvin waves produce weak easterly acceleration throughout all seasons and at all heights. This is different from Earth, where Kelvin waves are excited by the equatorial moist convection in the troposphere, break higher, and strongly contribute to the westerly phase of the SAO.

Conclusion: The found SAO signature in the equatorial atmosphere of Mars and our diagnostics indicate that the SAO is not a result of peculiar terrestrial conditions, but an ubiquitous atmospheric phenomenon of fast-rotating planets. Recent detection of the SAO in the Saturnian atmosphere [*5*] provides a strong argument in favor of the latter conclusion.

References: [1] Banfield D. et al. (2003) *Icarus, 161*, 319-345. [2] Kuroda T et al. (2005) *J. Meteorol. Soc. Japan, 83,* 1-19. [3] Garcia R. et al (1997) *JGR, 90,* 26019–26032. [4] Medvedev A. S. and G. P. Klaassen (2001) *GRL, 28*, 733-736. [5] Orton, G. S. et al. (2008), *Nature, 453*, 196-199.