MARTIAN CO_2 CYCLE FROM TIME VARIABLE GRAVITY AND LENGTH-OF-DAY (LOD) OBSERVATIONS

Ö. Karatekin , *Royal Observatory of Belgium, Brussels, BE (o.karatekin@oma.be)*, **A. S. Konopliv**, **C. F. Yoder,** *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA*.

Introduction: The CO_2 seasonal mass exchange between the southern and northern caps results in changes in both time variable gravity field and rotation of Mars. These variations have been measured from the spacecraft tracking, using the data principally from Mars Global Surveyor (MGS) and Mars Odyssey missions (Yoder et al. 2003, Smith et al. 2001,2009, Balmino et al. 2005, Konopliv et al. 2006, 2010, Marty et al., 2009). The time variations of the zonal gravity coefficients and rotation provide an important constraint for the total mass involved in the exchange of mass from one pole to the opposite. In addition, it allows monitoring the global CO2 cycle; whether the process is highly regular or contains evidence of irregular climate changes. Additional constraints on the Martian icecap seasonal histories are provided by the High Energy Neutron Detection (HEND, Litvak et al., 2004, 2006), and the Neutron Spectrometer (NS, Prettyman et al., 2004, 2009) instruments aboard the Odyssey spacecraft.

Time Variable Gravity: We investigated seasonal and inter-annual changes in seasonal gravity and LOD. The solutions are compared with the GCM AMES (Haberle et al., 008) and Laboratoire de Météorologie Dynamique (LMD,) Forget et al., 1999) models and Odyssey HEND and NS data sets (see Konopliv et al. 2010). The observed MGS and Odyssey J_3 seasonal gravity solutions represent the sum of odd zonal coefficients and have the largest seasonal signature observed in Mars gravity field. The MGS J_3 history versus as a function of time (mean anomaly, M or solar longitude Ls) is presented in Figure 1. Since the observed J_3 seasonal gravity, the sum of odd zonal history through degree 25 of two GCM models (AMES and LMD) and HEND model are graphed (Karatekin et al., 2005). Although we can detect seasonal J_2 changes from spacecraft, their accuracy is limited.

The measures gravity periodic signature of J_3 is studied for different periods or cycles that represent aphelion-to-aphelion Martian years (-180° < M < 180°). For example the cycle 3 covers the time between September 21, 2002 and August 3, 2004. In Figure 2 we compare the periodic fit of cycles 3 and 4 and examine if the changes seen in NS data agree with MGS tracking results. Differencing should cancel any common modeling errors. Both NS and MGS have similar signature for the first part of the comparison. Although the presence of interannual variations is not conclusive, we cannot discount that the NS yearly change could be real. The difference can be due to a phase shift in the timing of the accretion and melting of the CO_2 ice caps that could reflect a change in overall temperature or dust content. Dust storms might contribute to such a process.

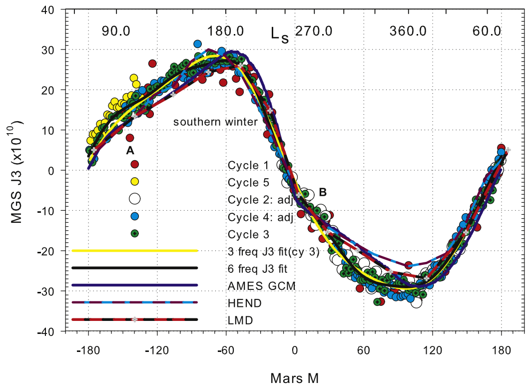

Figure 1: Comparison of measured MGS gravity harmonic J_3 history with GCM models of LMD, AMES as well as the HEND Data. The data is plotted as a function of mean anomaly (M) and solar longitude (Ls). Points A and B correspond to the end of north and south cap melting, respectively. The fits are good except at the extremes and the break at point B (end of south cap melting), especially for the AMES model (Konopliv et al. 2010).

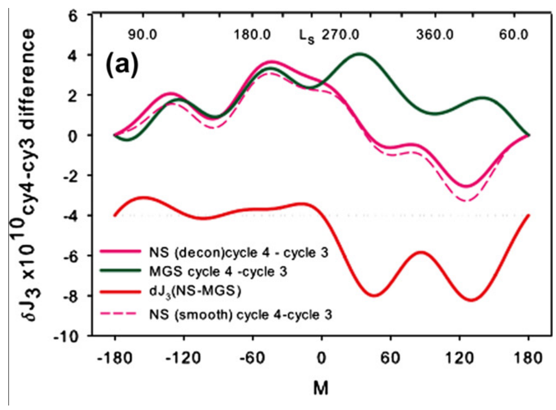

Figure 2: Search for inter-annual signature in NS and MGS cycles 3 and 4 by comparing the cycle 4 minus cycle 3 residuals. Also included is the differenced residual using the smoothed NS data.

Length-of-Day (LOD) Variations: The parameters of the rotation of Mars have been determined using radio Doppler and ranging measurements from the Viking landers (Yoder and Standish, 1997) and Mars Pathfinder (Folkner et al., 1997). These measurements were performed from an Earth tracking station to a lander on Mars and had a signature on the measured radio signal due to the rotation of Mars about its spin axis and to the changes in Mars' orientation. Accurate radio tracking of Mars orbiters is being performed nearly continuously since the arrival of Mars Global Surveyor in 1997. Since then, the radio science data from orbiters (Mars Global Surveyor, Mars Odyssey, and Mars Reconnaissance Orbiter) combined with the data from Viking and Mars Pathfinder landers has been continuously improving the determination of the Mars rotation parameters (Konopliv et al., 2006, 2010).

The changes in Mars rotation parameters are mainly caused by the condensation/sublimation of the CO_2 atmosphere at seasonal scales. Several authors (Cazenave and Balmino, 1981; Defraigne et al., 2000; Van den Acker et al., 2002; Sanchez et al., 2003, 2004; Karatekin et al., 2006) estimated the seasonal variations of LOD from Viking lander surface pressure measurements as well as from GCM data, which includes the wind contribution as well. The discrepancy between the observed and modeled LOD variations has decreased with time thanks to the continuous measurements of Martian orbiters as well as to the developments in numerical modeling of the Martian atmosphere. Figure 3 shows that there is a good agreement between the observed and modeled ΔLOD.

In Table 1 we compare the LOD variations from AMES and LMD GCM data with the previous solutions that used earlier versions of the same GCM. Total ΔLOD deduced from AMES and LMD GCM is in good agreement with the previous studies. The ΔLOD annual and semi-annual amplitudes of Sanchez et al. (2003) based on sum of axial atmospheric angular momentum and cap's inertia (see Fig. 14 of Sanchez et al. (2003)) are very close to those deduced from the current AMES GCM run which simulates more closely the Viking lander pressure variations (Haberle et al., 2008). The load factor and the liquid core neglected in Sanchez et al. (2003) have a combined effect of less than few percent (Karatekin et al., 2006). Similarly the ΔLOD amplitudes reported by Defraigne et al. (2000) and Van den Acher et al., 2002 using earlier LMD GCM simulations, are in line with the present LMD GCM solutions except the large semi-annual component given by Defraigne et al. (2000

We can also expect that the tracking of present and future orbiters around Mars will be pursued to improve the present knowledge of the rotation state of Mars. Besides constraining the CO_2 cycle, in synergy with the time-variable gravity measurements, the variations of the zonal wind can be estimated. Seasonal zonal winds which are the primary cause of ΔLOD on Earth, are less important on Mars but still significant. Because of the lack of direct measurements, they are only estimated from Martian GCMs, which suggests, nevertheless, annual amplitudes as large as one third of the total ΔLOD. In our calculations, the total signature and the annual and semi-annual signatures have about the same amplitude. This is contrary to an earlier study that found that the wind component is primarily semi-annual (Van den Acher et al., 2002). Also, AMES GCM predicts zonal winds that are about 30% larger than the LMD GCM. This also holds true for the mass component and total amplitude. In future, Martian meteorological data assimilation (e.g. Montabone et al., 2006) can be used to estimate the wind variations. ΔLOD amplitudes with an accuracy better than 2% were shown to be necessary to determine whether or not the core is liquid, and even better (<0.5%) to constrain the core size (Karatekin et al., 2006). This kind of accuracy can be obtained more easily with Martian landers having direct radio (see Dehant et al., 2010). Observing polar motion and nutation would provide a step forward in our understanding of Mars, exactly as it did for the Earth a couple of decades ago. Compared to LOD variations, it is more challenging to detect the rotation variations associated with polar motionand nutations, principally due to their smaller signature. Nevertheless, an upper bound for the polar motion of Mars is given by Konopliv et al. (2006) from radio tracking of Mars orbiters and landers.

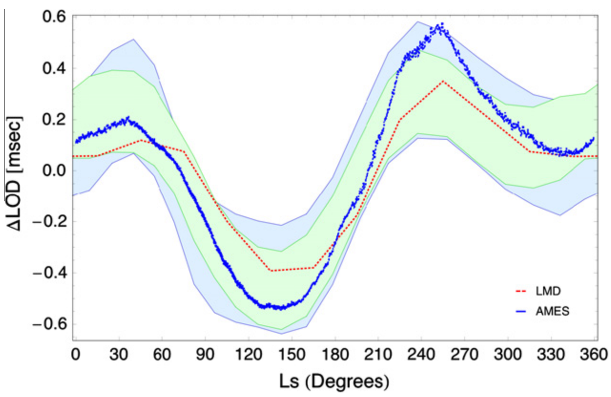

Figure 3: Seasonal LOD variations of Mars given in msec. The LOD variations computed from the GCM data (red and blue lines) compared with the observations from Konopliv et al (2006) (blue region) and Konopliv et al. (2010) (green region). The thickness of the shadowed regions corresponds to the measurement uncertainties.

Table 1: Comparison of the annual and semi-annual ΔLOD Amplitudes calculated from the outputs of GCM.

Reference	Amplitude (ms)	
	Annual	Semi-annual
Sanchez et al (2003)	0.374	0.272
Van der Acker et al (2002)	0.253	0.246
Defraigne et al. (2000)	0.223	0.375
AMES (present)	0.360	0.260
LMD (present_	0.229	0.207

References:

Balmino, G., Marty, J.C., Duron, J., Karatekin, O., 2005. Mars long wavelength gravity field time variations: A new solution from MGS tracking. In: Dynamic Planet, Proc. IAG Symposium, Cairns, Australia. Springer, Berlin, doi:10.1007/978-3-540-49350-1.

Cazenave A. and Balmino G., 1981, Meteorological effects on the seasonal variations of the rotation of Mars, Geophys. Res. Letters, 8, 245-248.

Defraigne P., de Viron O., Dehant V., Van Hoolst T., and Hourdin F., 2000, Mars rotation variations induced by atmospheric CO2 and winds, J. Geophys. Res. (Planets), 105, E10, 24563-24570.

Dehant V., et al., 2009, Lander Radioscience for obtaining the rotation and orientation of Mars, Planet. Space Sci., 57, 1050-1067, DOI: 10.1016/j.pss.2008.08.009.

Folkner W.M., Yoder C.F., Yuan D.N., Standish E.M., and Preston R.A., 1997, Interior Structure and Seasonal Mass Redistribution of Mars from Radio Tracking of Mars Pathfinder, Science, 278(5344), 1749.

Forget, F., Hourdin F., Fournier R., Hourdin C., Talagrand O., Collins M., Lewis S. R., P. L. Read P. L. and Huot J.-P., 1999, Improved general circulation models of the Martian atmosphere from the surface to above 80km J. Geophys. Res., 104, E10, pp 24,155-24,176.

Haberle, R.M., Forget, F., Colaprete, A., Schaeffer, J., Boynton, W.V., Kelly, N.J., Chamberlain, M.A., 2008. The effect of ground ice on the martian seasonal CO2 cycle. Planet. Space Sci. 56, 251–255.

Karatekin, Ö., Duron, J., Rosenblatt, P., Van Hoolst, T., Dehant, V., 2005. Mars' time-variable gravity and its determination: Simulated geodesy experiments. J. Geophys. Res. 110, E06001. doi:10.1029/2004JE002378.

Karatekin Ö., Van Hoolst T., Tastet J., de Viron O., and Dehant V., 2006, The effects of seasonal mass redistribution and interior structure on Length-of-Day variations of Mars, Adv. Space Res., 38(4), 561-828, DOI: JASR-D-04-01301R1.

Konopliv A.S., Yoder C.F., Standish E.M., Yuan Dah-Ning, and Sjogren W.L., 2006, A global solution for the Mars static and seasonal gravity, Mars orientation, Phobos and Deimos masses, and Mars ephemeris, Icarus, 182(1), 23-50, 10.1016/j.icarus.2005.12.025.

Konopliv A.S., Asmar S.W., Folkner W.M., Karatekin Ö., Nunes D.C., Smrekar S.E., Yoder C.F., and Zuber M.T., 2010, Mars High Resolution Gravity Fields from MRO, Mars Seasonal Gravity, and Other Dynamical Parameters, Icarus, doi:10.1016/j.icarus.2010.10.004.

Litvak, M.L., Mitrofanov, I.G., Kozyrev, A.S., Sanin, A.B., Tretyakov, V.I., Boynton, W.V., Shinohara, C., Hamara, D., Saunders, S., D., Drake, M., 2004. Seasonal carbon dioxide depositions on the martian surface as revealed from neutron measurements by the HEND instrument onboard the 2001 Mars Odyssey Spacecraft. Solar Syst. Res. 38, 167–177. doi:10.1023/B:SOLS.0000030856. 83622.17.

Litvak, M.L., Mitrofanov, I.G., Kozyrev, A.S., Sanin, A.B., Tretyakov, V.I., Boynton, W.V., Kelly, N.J., Hamara, D., Shinohara, C., Saunders, R.S., 2006. Comparison between polar regions of Mars from HEND/Odyssey data. Icarus 180, 23–37. doi:10.1016/j.icarus.2005.08.009.

Marty, J.C., Balmino, G., Rosenblatt, P., Duron, J., LeMaistre, S., Rivoldini, A., Dehant, V., Van Hoolst, T., 2009. Martian gravity field model and its time variations from MGS and Odyssey data. Planet. Space Sci.. doi:10.1016/j.pss.2009.01.004.

Montabone, L., Lewis, S.R., Read, P.L., Hinson, D.P., 2006, Validation of Martian meteorological data assimilation for MGS/TES using radio occultation measurements. Icarus 185, 113-132.

Prettyman, T.H. et al., 2004. Composition and structure of the martian surface at high southern latitudes from neutron spectroscopy. J. Geophys. Res. 109, E05001. doi:10.1029/2003JE002139.

Prettyman, T.H., Feldman, W.C., Titus, T.N., 2009. Characterization of Mars' seasonal caps using neutron spectroscopy. J. Geophys. Res. 114, E08005. doi:10.1029/ 2008JE00327.

Sanchez B., Rowlands D., Haberle R., and Schaeffer J., 2003, Atmospheric rotational effects on Mars based on the NASA Ames general circulation model, J. Geophys. Res. (Planets), 108, 5040.

Sanchez B., Haberle R., and Schaeffer J., 2004, Atmospheric rotational effects on Mars based on the NASA Ames general circulation model: Angular momentum approach, J. Geophys. Res., 109(E8), CiteID: E08005, DOI: 10.1029/2004JE002254.

Smith, D.E., Zuber, M.T., Neumann, G.A., 2001a. Seasonal variations of snow depth on Mars. Science 294, 2141–2146.

Smith, D.E., Zuber, M.T., Torrence, M.H., Dunn, P.J., Neumann, G.A., Lemoine, F.G., Fricke, S.K., 2009. Time variations of Mars' gravitational field and seasonal changes in the masses of the polar ice caps. J. Geophys. Res. 114, E05002. doi:10.1029/2008JE003267.

Van den Acker E., Van Hoolst T., de Viron O., Defraigne P., Dehant V., Forget F., and Hourdin F., 2002, Influence of the winds and of the CO2 mass exchange between the atmosphere and the polar ice caps on Mars' orientation parameters, J. Geophys. Res., 10.1029/2000JE001539.

Yoder C.F., and Standish E.M., 1997, Martian moment of inertia from Viking lander range data, J. Geophys. Res., 102 (E2), 4065-4080.

Yoder, C.F., Konopliv, A.S., Yuan, D.N., Standish, E.M., Folkner, W.M., 2003. Fluid core size of Mars from detection of the solar tide. Science 300, 299–303.