THE GRAVITY FIELD OF MARS FROM MGS, MARS ODYSSEY, AND MRO RADIO SCIENCE.

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Introduction: The Mars Global Surveyor (MGS), Mars Odyssey (ODY), and Mars Reconnaissance Orbiter (MRO) missions have enabled NASA to conduct reconnaissance and exploration of Mars from orbit for sixteen consecutive years. These radio systems on these spacecraft enabled radio science in orbit around Mars to improve the knowledge of the static structure of the Martian gravitational field. The continuity of the radio tracking data, which cover more than a solar cycle, also provides useful information to characterize the temporal variability of the gravity field, relevant to the planet's internal dynamics and the structure and dynamics of the atmosphere [1].

MGS operated for more than 7 years, between 1999 and 2006, in a frozen sun-synchronous, near-circular, polar orbit with the periapsis at ~370 km altitude. ODY and MRO have been orbiting Mars in two separate sun-synchronous orbits at different local times and altitudes. ODY began its mapping phase in 2002 with the periapis at ~390 km altitude and 4-5pm Local Solar Time (LST), whereas the MRO science mission started in November 2006 with the periapis at ~255 km altitude and 3pm LST.

The 16 years of radio tracking data provide useful information on the atmospheric density in the Martian upper atmosphere. We used ODY and MRO radio data to recover the long-term periodicity of the major atmospheric constituents -- CO_2, O, and He -- at the orbit altitudes of these two spacecraft [2]. The improved atmospheric model provides a better prediction of the annual and semi-annual variability of the dominant species. Therefore, the inclusion of the recovered model leads to improved orbit determination and an improved gravity field model of Mars with MGS, ODY, and MRO radio tracking data.

Mars atmospheric model: The estimation of the variability of the Mars atmospheric constituents with radio data relies on the semi-empirical model Drag Temperature Model (DTM)-Mars [3] that is implemented in our precise orbit determination program (GEODYN II; [4]). DTM-Mars predicts density and temperatures as a function of position (altitude, latitude, local solar time), solar activity, and the Mars day-of-year. This model assumes static diffusive equilibrium of the atmospheric constituents, which is valid in the altitude range from 115-135 km to 800 km. Therefore, we estimated the long-term variability of the atmospheric partial density of the dominant species (CO_2, O, He) along ODY and MRO orbits. The results provide an accurate prediction of the O annual and semi-annual variability in the Mars atmosphere showing consistent densities with the MARS-GRAM2010 model [5].

The atmospheric model implemented in GEODYN-II does not include dust storm modeling. Therefore, we adjusted an atmospheric drag coefficient (C_D) for each spacecraft orbit. These coefficients are time-correlated within each arc (~3 days) with a time-correlation length of one orbital period. The adjusted drag scale factors (C_D) compensate for the increase of the atmospheric density due to the effects of dust storms and are good indicators of the quality of the estimated DTM-Mars model. Figure 1 shows the high correlation (~0.8) between C_D and dust opacity after the global estimation. The correlation between these two parameters with the *a priori* model is ~0.3-0.4.

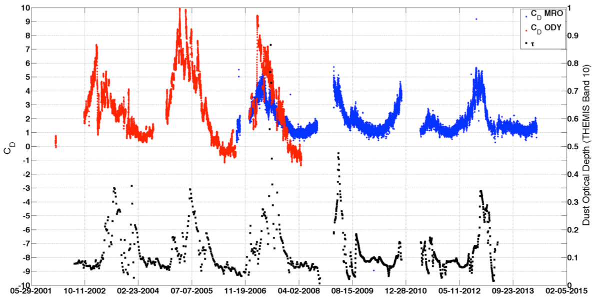

Figure 1. MRO (blue dots) and ODY (red dots) drag scale factors and dust optical depth at 1075 cm^{-1} from the ODY THEMIS instrument [6].

Results: In order to recover the Mars gravity field (especially the time-variable, long-wavelength coefficients), all the non-conservative forces acting on the spacecraft must be modeled accurately. The two major force models that limit long-wavelength and temporal gravity recovery are solar radiation pressure and atmospheric drag. The latter is computed using density values from the DTM-Mars model, as explained above, and possible mismodeling is mitigated by means of time-correlated C_Ds. To compute the effects of radiation pressure and drag, the spacecraft is modeled as a set of plates representing the spacecraft bus, the solar panels and the antenna. The orientation of each plate is determined from spacecraft telemetry and the specular and diffuse coefficients for each plate are based upon combinations of surface types. The MRO panel reflectivities and the scaling factor for the solar pressure force (C_R=1) are not estimated. We adjust two along-track periodic accelerations, at the orbital frequency (~2 hours), to account for solar radiation pressure mismodeling (self-shadowing, atmospheric dust effects, etc.).

We analyzed MGS, ODY, and MRO 2-way and 3-way coherent X-Band Doppler data. ODY data display the highest quality (~0.02 mm/s at 60s integration time), whereas MRO data are affected by some unknown transponder periodic signature (with periods near 4-5s). However, in March 2014 the MRO Navigation Team decided to change transponder, which decreased the effects of the anomaly, leading to a substantial decrease of the noise level. The latest MRO data and the updated atmospheric model allow us to provide an updated model of the Mars gravity field.

Figure 2 shows how the correlation of the gravity field with topography significantly improves when using a more accurate atmospheric model. The three gravity fields reported in the figure are: GSFC0714, which used MRO data up to January 2012 and the *a priori* DTM-Mars model; MRO110C [7], determined at the Jet Propulsion Laboratory with the Orbit Determination Program (ODP) which used atmospheric density values from the Mars-GRAM 2000 model; and MROMGM0032 [8], estimated at NASA Goddard Space Flight Center with GEODYN II, which used the Stewart-87 model [9]. The inclusion of the DTM-Mars into our precision orbit determination program improves the recovery of spherical harmonic coefficients of the Mars gravity field leading to a higher correlation with topography.

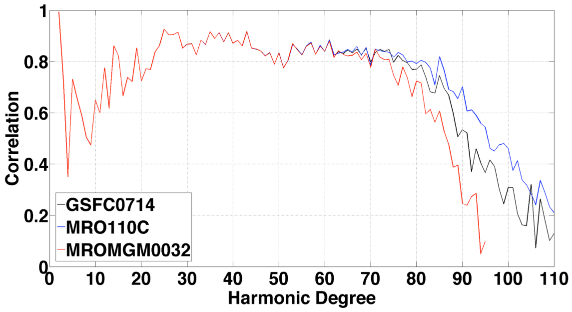

Figure 2. Correlations with topography for various gravity field models: the newly estimated field GSFC0714, MRO110C [7], and, MROMGM0032 [8].

Conclusions: We will present a global model of the Martian gravitational field using MGS, ODY and MRO data. The solution is based on 8 years of MRO radio tracking data, from August 2006 to June 2014. The determination of a Mars gravity field model from MRO radio tracking data requires an accurate upper-atmosphere model to predict the variability of the drag effect. Uncompensated drag forces on the spacecraft may affect the gravity solution, especially, the seasonal variability of the low degrees. The inclusion of the updated DTM-Mars model into our orbit determination program significantly improves the recovery of atmospheric density leading to an improved Mars gravity field model.

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