GLOBAL AND LOCAL GRAVITY FIELD MODELS OF MARS WITH MGS, MARS ODYSSEY, AND MRO. Antonio Genova1,2, Sander Goossens3,2, Frank G. Lemoine2, Erwan Mazarico2, Gregory A. Neumann2, David E. Smith1 and Maria T. Zuber1. 1 Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA (genova@mit.edu); 2 Planetary Geodynamics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; 3 Center for Research and Exploration in Space Science and Technology, University of Maryland, Baltimore County, Baltimore, MD 21250, USA.

Introduction: The NASA radio science investigations for the determination of global high-resolution global gravity fields of Mars began with the Mars Global Surveyor (MGS), and continued with the Mars Odyssey (ODY) and Mars Reconnaissance Orbiter (MRO).

MGS operated between 1999 and 2006 in a sun-synchronous near-circular polar orbit with the perilapiss altitude at ~370 km and the dayside equatorial crossing at ~2pm Local Solar Time (LST).

ODY and MRO, which started their mapping phases in February 2002 and November 2006, respectively, are still orbiting Mars. Both spacecraft are in sun-synchronous near-circular polar orbits but with different configurations. ODY is in a higher ~400 km orbit with the dayside equatorial crossing at ~4-5pm LST. MRO is in a lower 255x320 km orbit with a different crossing time at the ascending node (3pm LST).

Before entering these mapping phases, all three spacecraft collected radio tracking data at lower altitudes (~170-200 km) that help improve the resolution of the gravity field of Mars in specific regions.

The latest gravity field solution of Mars, MRO110C, released on the NASA Planetary Data System (PDS) was determined by the Jet Propulsion Laboratory in 2012 with the entire MGS radio tracking data set, and ODY and MRO radio data until December 2010 and May 2011, respectively [1].

We analyzed and processed an extended data set that includes the latest ~4 years of ODY and MRO data until 2015. We recovered the global gravity field of Mars to degree and order 120, the seasonal variations of gravity harmonic coefficients $C_{20}$, $C_{30}$, $C_{40}$, and $C_{50}$, and the Love number $k_2$ by analyzing the radio tracking data of the three NASA orbiters MGS, ODY, and MRO.

Data and Methods: We used 2- and 3-way Doppler data collected by the radio-sub-systems onboard these spacecraft, capable of providing X-band radio links for geodetic tracking to the Deep Space Network station complexes.

MGS, ODY, and MRO radio tracking data were processed dynamically over a continuous span of time using a batch least-squares algorithm through the NASA GSFC GEODYN II software [2]. All observations were combined to adjust the estimated parameters by minimizing the discrepancies between the computed observables and actual measurements. Therefore, the accurate modeling of forces that perturb the spacecraft trajectories is necessary for the orbit and gravity determination.

The gravity field of Mars is modeled as a spherical harmonic expansion [3]. We also include the time-varying gravity harmonic coefficients $C_{20}$ and $C_{30}$ that account for the redistribution of mass associated with the CO$_2$ seasonal cycle. The tidal perturbation of Phobos and the Sun is taken into account with the Love number $k_2$.

We separate the contribution of Mars atmospheric pressures on the surface of the planet from the seasonal and static gravity coefficients. Surface pressure grids from the Mars-GRAM 2010 atmospheric model, with 2.5° x 2.5° spatial and 2-h time resolution (Figure 1), are converted into gravity spherical harmonic coefficients [4]. Consequently, the gravity contribution of the atmosphere is excluded from the retrieved gravity model.

Figure 1 Pressure field at the surface of Mars from the Mars-GRAM 2010 atmospheric model.

Non-conservative forces (i.e. atmospheric drag, solar radiation pressure) are accurately modeled to reconstruct a high-fidelity spacecraft trajectory. In our processing software, the spacecraft are modeled as consisting of separate plates, each with different area and optical properties. The modeling of solar, albedo, and thermal radiation pressure account for the material properties of each spacecraft surface.
The largest perturbation acting on MRO because of its low-periapsis orbit is the atmospheric drag. For this reason, we implemented the Drag Temperature Model—Mars [5] in GEODYN II, to provide accurate predictions of atmospheric total and partial densities in the computation of the atmospheric drag acceleration [6].

**Results:** The analysis of the MGS, ODY, and MRO range rate data resulted in a model of degree and order 120, called **Goddard Mars Model (GMM)-3** [7]. The global gravity field was retrieved using a Kaula power law constraint of $15 \times 10^{-5}/f^2$, applied only at degrees $l$ greater than 90.

Figure 2 shows the correlation between gravity as predicted by the MOLA surface topography (using a constant crustal density) and two gravity field solutions: GMM-3 and MRO110C. The GMM-3 solution shows improvements in correlations up to degree 100 compared to MRO110C.

![Figure 2](image)

**Figure 2** Correlation between a MOLA topography-based gravity field and gravity solutions GMM-3 (blue) and MRO110C (black).

The improved correlation between gravity and topography clarifies local regional analyses that enable a better understanding of the crust and the interior structure. Figure 3, for example, shows the GMM-3 free-air gravity anomalies and the MOLA topography in the region between Acidalia Planitia and Tempe Terra. The higher resolution of the GMM-3 solution reveals a sharper definition of the negative gravity trough that was already detected by previous models [8].

The estimated global gravity model includes the adjustment of the seasonal variation of the long-wavelength gravity coefficients that represent the variations in the surface mass transport. We used MRO radio tracking data to determine the time-variable odd harmonic coefficients $C_{30}$ and $C_{50}$.

We also recovered a Mars Love number $k_2=0.1697\pm0.0009$ (largely consistent with earlier estimation, e.g. [1]), which is suggestive of a molten core and perhaps lower mantle.

**Conclusions:** We have developed a new global model of the Mars gravity field **GMM-3** using Doppler tracking data from MGS, Mars Odyssey and MRO.

Refinements to the atmospheric modeling in our orbit determination program and the additional years of radio tracking data allowed us to improve the resolution of the static gravity field.

The estimated static and time-variable gravity field harmonics, and the Love number $k_2$ account only for the solid planet. Indeed, the gravity contribution of the atmosphere was modeled separately by deriving spherical harmonics from surface pressure grids of the Mars-GRAM2010 model.

We also developed local gravity solutions determined by analyzing the line-of-sight derivatives of the Doppler data.