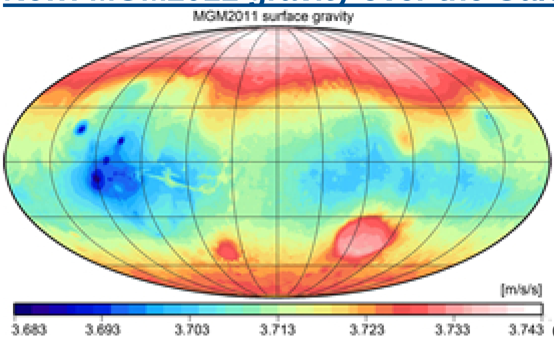
Mars Gravity Model 2011 (MGM2011)

New: MGM2011 gravity over the Gale crater (Curiosity landing site)



Click for larger image - Fig. 1 MGM2011 surface gravity accelerations over Mars' surface, unit is m s^{-2}, Mollweide projection centred to 0° longitude. Meridians and parallels are 30° apart. Click for larger image –

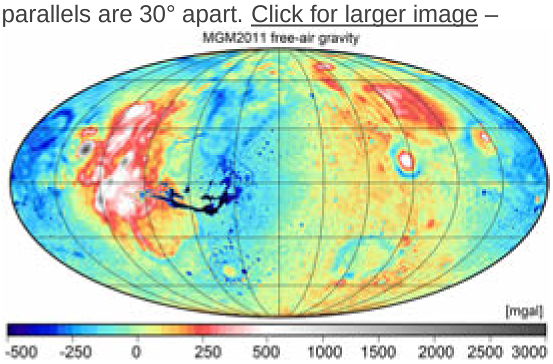
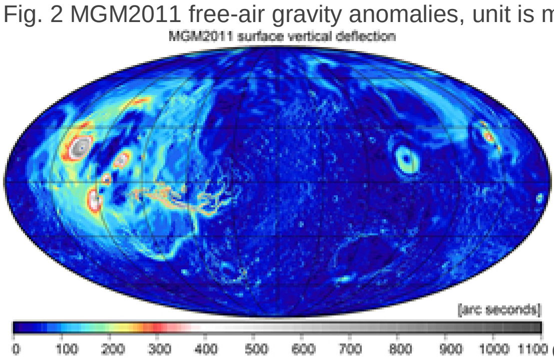
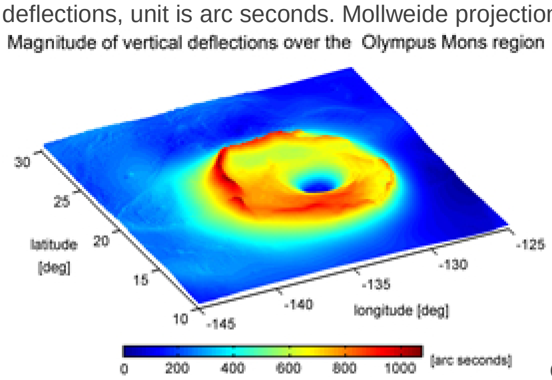


Fig. 2 MGM2011 free-air gravity anomalies, unit is m s^{-2}, Mollweide projection centred to 0°longitude.



Click for larger image - Fig. 3 MGM2011 total vertical deflections, unit is arc seconds. Mollweide projection centred to 0°longitude.



Click for larger image - Fig. 4 MGM2011 total vertical deflections over the Olympus Mons region, unit is arc seconds.

General

MGM2011 (Hirt et al. 2012a) is a gravity field model for Mars that resolves features down to km-scales. The model is constructed as a composite of a normal gravity field, a recent space-collected gravity field and Newtonian gravity forward-modelling.

- The normal gravity field approximates Mars's gravitational attraction as rotating mass-ellipsoid,
- space-collected gravity (MRO110B2, Konopliv et al. 2011) delivers anomalies of the Martian gravity field down to scales of ~125 km, and
- Newtonian forward-modelling and high-resolution Mars topography data from laser altimetry (MOLA, Smith et al. 2001) is used to derive topography-implied gravity (MRTM85) at spatial scales of ~125 km down to ~3km.

The innovation of MGM2011 lies in the use of topography-implied gravity (MRTM85) to augment Mars space-collected gravity at medium and short-scales. MGM2011 surface gravity accelerations (Fig. 1) and free-air anomalies (Fig. 2), and vertical deflections (Fig. 3) are provided at 0.05° resolution (3600 x 7200 = 25.92 million points) over the entire surface of Mars.

New high-resolution views on Mars gravity

MGM2011 is the first model to resolve the (expected) Martian gravity field down to km-scales. MGM2011 surface gravity accelerations are maximum with 3.7426 m/s^2 at the bottom of the Jojutla crater (81.6°N, 169.3°W) in the low-lying Northern plains. The minimum of 3.6838m/s^2 is at the rim of Arsia Mons (8.4°S, 121.4°W), the southernmost of the Tharsis shield volcanos (Fig. 1). The average MGM2011 surface gravity acceleration is 3.7208 m/s^2 with a global range of ~0.059m/s^2 or 1.6 %.

MGM2011 vertical deflections, the angle between the ellipsoid normal and the plumb line, exhibit notable variability (Fig.3.), specifically over the Tharsis region. Maximum values are encountered near (18°N, 136°W), West of Olympus Mons. The gravitational pull of Mars's famous ~22 km high shield volcano deflects the plumb line by more than 1000 seconds of arc (~ 0.28°) from the ellipsoidal normal (Fig. 4).

Fig. 5 shows detail perspective views of the MGM2011 gravity modelling for Valles Marineris, Mars's largest Canyon system of ~3500 km length. In this most rugged area, MRTM85 gravity (Fig. 5a) adds much detail that is not resolved by the space-collected MRO110B2 (Fig. 5b). Views of MGM2011 free-air gravity, computed as MRTM85 plus MRO110B gravity (Fig. 5c), and MGM2011 surface gravity accelerations (Fig. 5d) provide a good impression about the ruggedness of Mars's gravity field down to km-scales.

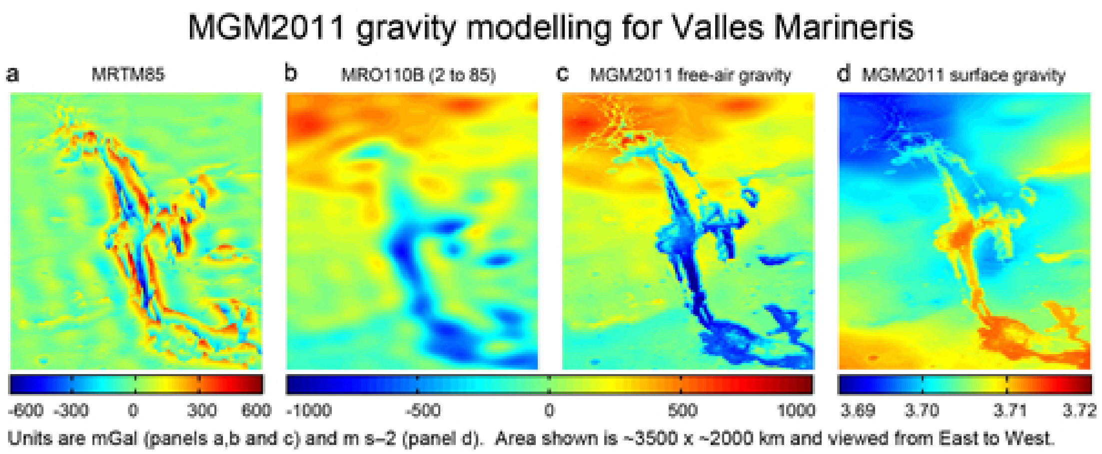


Fig. 5 Detail views of MGM2011 gravity modelling for Valles Marineris

Click for Larger Image

MGM2011 gravity over the Gale crater (Curiosity landing site)

Fig. 6 shows the topography (panel A) and gravity field (panels B, C) over the Gale crater, where NASA's Mars rover Curiosity http://en.wikipedia.org/wiki/Curiosity_rover was successfully landed on 6th August 2012.

The MGM2011 gravity acceleration at the landing site (-4.5919S 137.4403E) is about 3.7133 ms^{-2}, also see Fig. 6B for the variation of surface gravity accelerations over Curiosity's investigation area. From Fig. 6C, the direction of gravity (with respect to the Mars ellipsoid) changes up to 250 seconds of arc within 30 km radius around the landing site.

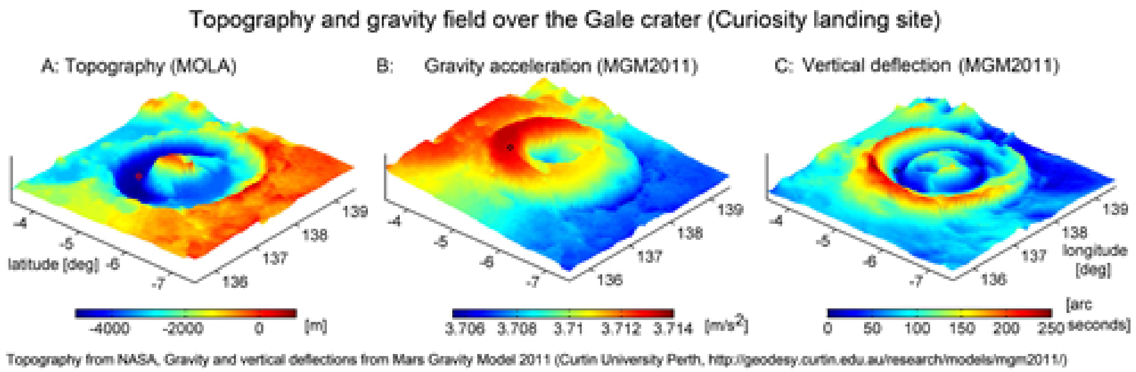


Fig. 6A: MOLA ellipsoidal heights of the Gale crater region, B: MGM2011 gravity accelerations, C: MGM2011 vertical deflections (lateral pull of gravity). Circle shows Curiosity's landing site, area shown approximately 300 km x 300 km in size.

Click for Larger Image

Applications

By virtue of MRTM85, the high-frequency topography-implied component from Newtonian forward-modelling, MGM2011 provides a more accurate and more complete description of Mars's gravity field than truncated space-collected models alone. In gravity field modelling, MGM2011 can be used

- as a background model for the inversion of spacecraft data,
- for the design and planning of any future Mars satellite gravimetry mission,
- and for gravity field statistical analysis.

In the context of engineering-driven applications, MGM2011 can be used to correct for the irregularities of Mars's gravity field. Application examples requiring spectrally complete information on the gravity field may include

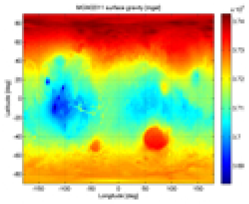
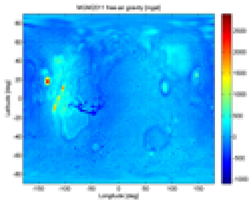
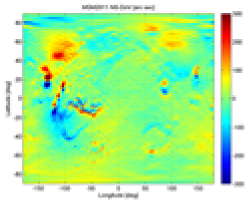
- high-resolution topographic mapping (where the areoid takes the role of a height reference surface),
- landing missions (prediction of gravity at future landing sites), and
- inertial navigation at or above the Martian surface (requiring vertical deflections).

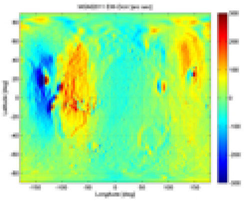
At spatial scales shorter ~125 km, MGM2011 is not recommended for direct geological interpretation of gravity field anomalies, because the MRTM85 component originates from constant mass-density Newtonian forward-modelling, and assumes the residual topography as uncompensated.

MGM2011 Products, input data and software

MGM2011 Products

MGM2011 products are surface gravity accelerations, free-air gravity, and the North-South and East-West vertical deflection components at the Martian surface.

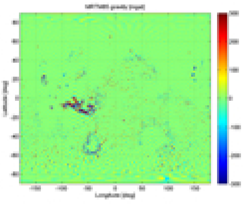
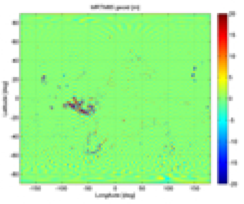
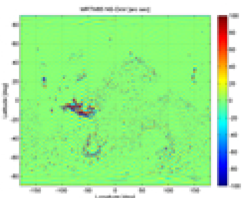
-  Click for larger image MGM2011 surface gravity accelerations (computed as MRO110B2 spectral band 2 to 85 gravity disturbances + MRTM85 gravity + MGM2011 normal gravity), unit in 10^{-5} ms^{-2}. Note: a constant value of 370000 x 10^{-5} ms^{-2} must be added to this data set.
-  Click for larger image MGM2011 free-air gravity(MRO110B2 spectral band 2 to 85 gravity disturbances + MRTM85 gravity) unit 10^{-5} ms^{-2}.
-  Click for larger image MGM2011 North-South surface vertical deflection (MRO110B2 spectral band 2 to 85 + MRTM85 NS vertical deflection), unit is seconds of arc.

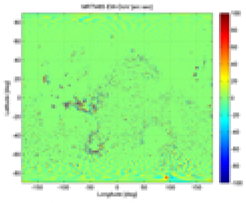
-  Click for larger image MGM2011 East-West surface vertical deflection (MRO110B2 spectral band 2 to 85 + MRTM85 EW vertical deflection), unit is seconds of arc.

MGM2011 Input Data Sets

MRTM85 Functionals

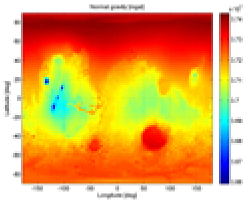
MRTM85 (Mars RTM gravity field with the spectrum to degree 85 removed) are a set of gravity field functionals from Newtonian forward-modelling using MOLA residual topography. MRTM85 complements any Mars spherical-harmonic gravity model beyond harmonic degree 85. Those users who wish to use MRTM85 gravity field functionals can download following files:

-  Click for larger image MRTM85 gravity accelerations, unit 10^{-5} ms^{-2}.
-  Click for larger image MRTM85 areoid undulations, unit 10^{-1} m. This file can be used to augment the Mars areoid from space-craft data beyond spherical-harmonic degree 85.
-  Click for larger image MRTM85 NS vertical deflection, unit seconds of arc.

-  Click for larger image MRTM85 EW vertical deflection, unit seconds of arc.

MGM2011 Normal Gravity

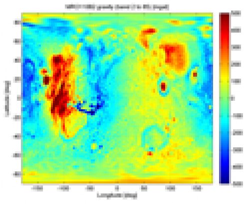
Those users who wish to use the MGM2011 normal gravity field can download following file:

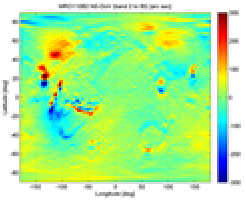
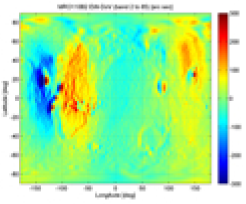
-  Click for larger image MGM2011 normal gravity, unit 10^{-5} ms^{-2}. Note: a constant value of 370000 x 10^{-5} ms^{-2} must be added to this data set.

The MGM2011 normal gravity field takes into account the gravitational attraction of Mars, approximated as rotating ellipsoid of constant mass-density. MGM2011 normal gravity includes the gravitational attraction of Mars's total mass, the effect of Mars's ellipticity and the decay of gravity with height. MGM2011 normal gravity is based on Mars Geodetic Reference System (MGRS) and refers to the physical surface of Mars, as represented by the MOLA topography.

MRO110B2 Functionals

Those users who wish to use the MRO110B2 (Konopliv et al. 2011) functionals used in the construction of MGM2011 can download following files:

-  Click for larger image MRO110B2 gravity disturbances (MRO110B2 spectral band 2 to 85, evaluated at the MOLA topography), unit 10^{-5} ms^{-2}.

-  Click for larger image MRO110B2 NS vertical deflection (MRO110B2 spectral band 2 to 85, evaluated at the MOLA topography), unit seconds of arc.
-  Click for larger image MRO110B2 EW vertical deflection (MRO110B2 spectral band 2 to 85, evaluated at the MOLA topography), unit seconds of arc.

Top of page

About files and software

File and format description

Each file (50,625 KB) contains 7,200 x 3,600 =25,920,000 values stored in 2-byte integer big-endian format (int16, ieee-be). The grid resolution is 0.05 deg (3 arc min) and the grid is equally spaced in terms of *planetocentric* latitude and longitude. Records proceed along meridians from South to North and columns proceed from West to East. The first record is the South-West corner (-89.975° latitude,-179.975° longitude), the second record is(-89.925° latitude,-179.975° longitude) and the last record is the North-East corner (89.975° latitude,179.975° longitude).

Software to read MGM2011 data files

Here we provide a simple Matlab-script that can be used to read and display the 12 MGM2011 product and input files, and custumized by users for further use.

- Matlab-script to access MGM2011 data files

Top of page

MGM2011 development and evaluation

Mars Geodetic Reference System (MGRS)

MGM2011 is based on Mars Geodetic Reference System (MGRS), that uses four parameters (Ardalan et al. 2009)

- semimajor axis a =3395428m
- semiminor axis b =3377678m
- gravitational constant times mass GM =4.2828372 x10^{13}m^{3} s^{-2}
- angular velocity ω =7.0882181 x10^{-05} rad s^{-1}

to define the geometry and gravitational attraction of a bi-axial rotating equipotential ellipsoid (Moritz 2000).The parameter set *a,b,GM*and*w* implies MGRS parameters

- Geometric flattening f =5.227617843759x10^{-3}
- First eccentricity squared e^2 =1.042790769920 x10^{-2}
- Normal gravity at equator g_a =3.708754657884 ms^{-2}
- Normal gravity at pole g_b =3.731907392737 ms^{-2}
- m (ratio of the centrifugal acceleration to normal gravity at equator)4.568250121143x10^{-3}
- Dynamic form factor J_2 =1.955484200411 x10^{-3}

and the fully-normalized spherical-harmonic coefficients

- Coefficient $C_{2,0}$=-8.745191202090 x10^{-4}
- Coefficient $C_{4,0}$ =2.719280814521 x10^{-6}
- Coefficient $C_{6,0}$=-1.217355067691 x10^{-8}
- Coefficient $C_{8,0}$ =6.522150395570 x10^{-11}
- Coefficient $C_{10,0}$=-3.884319022342 x10^{-13}

MGRS is a replication of the GRS80 (Geodetic Reference System 1980)-concept that is routinely used in Earth geodesy (Moritz 2000).

Normal gravity

MGM2011 normal gravity accelerations at the surface of the Mars's topography (as defined by MOLA laser altimetry, Smith et al. 2001) are computed using the well-known formula of Somigliana (Torge 2001, p.106) and a second-order Taylor expansion (Torge 2001, p.110). Both Somigliana's formula and the Taylor expansion are evaluated as a function of the above MGRS parameters and MOLA ellipsoidal heights (of Mars's surface above the MGRS reference ellipsoid).

Potential Model MRO110B2

MGM2011 uses the space-collected MRO110B2 potential model (Konopliv et al. 2011) to harmonic degree 85 (equivalent to spatial scales of ~125 km) to derive gravity disturbances and vertical deflections. MRO110B2 is not used beyond degree 85 where gravity signals are not sufficiently captured (Hirt et al. 2012a). To account for the effect of gravity attenuation with height, the potential models are evaluated at Mars's topography, as defined by MOLA.

Newtonian forward-modelling (MRTM85)

Information on Mars's short-scale gravity field-that is omitted by the MRO110B2 evaluated to degree 85 - is sourced from high-pass filtered topography, also known as residual terrain model RTM (Forsberg 1984). The technique of Newtonian forward-modelling (e.g., Nagy et al. 2000, Hirt 2010) is used to compute the gravitational effects (gravity, geoid, deflections), as implied by the RTM topography. The RTM topography is constructed as as difference of the (detailed) MOLA elevation data (1/64°~1km resolution) and a long-wavelength spherical-harmonic topography. As long-wavelength topography, MarsTopo719 (Wieczorek 2007) is used up to harmonic degree 85, which removes most of the long-wavelength signals from the MOLA elevations.

The resulting RTM data is converted to gravitational effects (gravity, geoid, deflections) through numerical prism integration (Newtonian forward modelling) at a 0.05°-grid of computation points. We use a uniform mass-density of ~2900 kg m^{-3} for the residual topography, which is why local mass-density variations are not modelled. The resulting set of forward-modelled gravity field functionals is called MRTM85 (Mars RTM with the spectrum to degree 85 removed). MRTM85 provides estimates of the (expected) high-frequency gravity field, which cannot be sensed to km-scales by spacecraft observations.

MGM2011 evaluation

MGM2011 is based on tested strategies used by Curtin's geodesy group for refinement of Earth's gravity field (e.g., Hirt et al. 2010). In the absence of ground-truth gravity observations on Mars' surface, direct evaluation of MGM2011 is not possible. To indirectly evaluate MGM2011 and its modelling principles, we have performed an as-close-as-possible replication of the MGM2011 modelling approach on Earth as the planetary body with most detailed gravity field knowledge available.

Comparisons among six ground-truth data sets (gravity, vertical deflections and geoid undulations) and our "MGM2011-replication" over Europe and North America show unanimously that topography-implied gravity information improves over space-collected gravity models over rugged terrain. The improvement rates are most significant for gravity (~55% and 67%),spurious for vertical deflections (~30% to ~50%) and notable for geoid undulations (12% and 47%), cf. Hirt et al. (2012b). Given that the correlation between space-collected gravity with topography is higher for Mars than Earth at spatial scales of ~125 km, we conclude that topography-implied gravity effects are at least as dominant for Mars's as for Earth's short-scale gravity field. It is therefore reasonable to infer that the MGM2011 modelling approach is suitable for short-scale Mars gravity field improvement and that the MGM2011 gravity refinement will be most efficient over rugged parts of Mars.

Contact and Feedback

For further information or if you want to provide feedback please contact Christian Hirt

References

- Ardalan, A.A., R. Karimi, and E.W. Grafarend (2009), A New Reference Equipotential Surface, and Reference Ellipsoid for the Planet Mars, Earth Moon Planets, 106, 1-13.

- Forsberg, R. (1984), A study of terrain reductions, density anomalies and geophysical inversion methods in gravity field modelling, Report 355, Department of Geodetic Science and Surveying, Ohio State University, Columbus.
- Hirt, C. (2010), Prediction of vertical deflections from high-degree spherical harmonic synthesis and residual terrain model data,. J. Geod, 84, 179-190. pdf [2.95 MB]
- Hirt, C., W.E. Featherstone and U. Marti (2010) Combining EGM2008 and SRTM/DTM2006.0 residual terrain model data to improve quasigeoid computations in mountainous areas devoid of gravity data, Journal of Geodesy 84(9): 557-567. pdf [765 KB]
- Hirt C, Claessens SJ, Kuhn M, Featherstone WE (2012) Kilometer-resolution gravity field of Mars: MGM2011.Planetary and Space Science, Article in Press DOI: 10.1016/j.pss.2012.02.006. pdf [656 KB]
- Hirt C, Claessens SJ, Kuhn M, Featherstone WE (2012) Indirect evaluation of Mars Gravity Model 2011 using a replication experiment on Earth. Studia Geophysica and Geodetica, 56 (2012), 957-975. pdf [2 MB]
- Konopliv A.S. et al. (2011), Mars high resolution gravity fields from MRO, Mars seasonal gravity, and other dynamical parameters, Icarus, 211, 401-428.
- Moritz, H. (2000), Geodetic Reference System 1980, J Geod, 74,128-133.
- Nagy D., G. Papp, and J. Benedek. (2000), The gravitational potential and its derivatives for the prism J. Geod 74, 552-560, Erratum in J. Geod76, 475.
- Smith, D.E. et al. (2001), Mars Orbiter Laser Altimeter (MOLA): experiment summary after the first year of global mapping of Mars., J. Geophys. Res. 106 (E10), 23689-23722.
- Torge, W., (2001), Geodesy 3rd ed., de Gruyter, Berlin.
- Wieczorek, M.A. (2007), Gravity and topography of the terrestrial planets. In: Treatise on Geophysics, vol. 10. Elsevier-Pergamon, Oxford, pp. 165-206.

Disclaimer