**GMM-1: A 50$^{TH}$ DEGREE AND ORDER GRAVITATIONAL FIELD MODEL FOR MARS;**

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Knowledge of the gravitatational field, in combination with surface topography, provides one of the principal means of inferring the internal structure of a planetary body. The highest resolution gravitational field for Mars published thus far [1] was derived from Doppler tracking data from the Mariner 9 and Viking 1 and 2 spacecraft and is complete to degree and order 18 corresponding to a half wavelength resolution of approximately 600 km. This field, which is characterized by a spatial resolution that is slightly better than that of the highest resolution (16x16) topographic model [2], has been utilized extensively in analyses of the state of stress and isostatic compensation of the Martian lithosphere [*e.g.*. 3-5]. However, the resolution and quality of current gravity and topographic fields are such that the origin and evolution of even the major physiographic features on Mars, such as the hemispheric dichotomy and Tharsis rise, are not well understood.

We have re-analyzed the Viking and Mariner data sets and have derived a new gravitational field, designated GMM-1 (Goddard Mars Model-1). This model is complete to spherical harmonic degree and order 50 with a corresponding (half wavelength) spatial resolution of 200-300 km where the data permit. In contrast to previous models, GMM-1 was solved to as high degree and order as necessary to nearly exhaust the attenuated gravitational signal contained in the tracking data. This was possible in part due to the use of a least squares collocation solution technique [6], which stabilized the behavior of the solution at high degree and order where correlation and data sensitivities become problematic. The extension of the model to high degree and order significantly reduced errors resulting from spectral leakage coming from the omitted portion of the gravitational field beyond the limits of the recovered model. GMM-1 has a higher spatial resolution than previous iterations of the model [7,8], and in addition is fully calibrated to give a realistic error estimate from the solution covariance.

The data set consisted of 265 orbital arcs representing over 1100 days of S-band Doppler tracking data from the Mariner 9 and Viking 1 and 2 spacecraft, collected by the Deep Space Network between 1971-1978. In total over 215,000 total observations were included in the solution. The data were processed using the GEODYN/SOLVE orbit determination programs, which have previously been used in the derivation of a series of Goddard Earth gravity models, GEM, [*e.g.* 8,9] and have been adapted for the analysis of planetary tracking data [10].

The gravitational potential at spacecraft altitude was represented in spherical harmonic form as

$$V_M(\bar{r}) = \frac{GM_M}{r}\sum_{l=0}^{N}\sum_{m=0}^{l}\left(\frac{r_M}{r}\right)^l P_{lm}(\sin\phi)\ [C_{lm}\cos m\lambda + S_{lm}\sin m\lambda]$$

where $\bar{r}$ is the position vector of the spacecraft in areocentric coordinates, $r$ is the radial distance from the center of mass of Mars to the spacecraft, $\phi$ and $\lambda$ are the areocentric latitude and longitude of the spacecraft, $r_M$ is the mean radius of the reference ellipsoid of Mars, $GM_M$ is the gravitational constant for Mars, $P_{lm}$ are the normalized associated Legendre functions of degree $l$ and order $m$, $C_{lm}$ and $S_{lm}$ are the normalized spherical harmonic coefficients which were estimated from the tracking observations, and $N$ is the maximum degree representing the size (or resolution) of the field. The gravitational force due to Mars which acts on the spacecraft corresponds to the gradient of the potential, $V_M$. The origin of the field was taken to be the center of mass of Mars, which required that $C_{00}=1$ and $C_{10}=C_{11}=S_{11}=0$.

To determine the field, orbits were computed for each arc by estimating from the tracking data the initial state vector of the spacecraft, along with the atmospheric drag, solar radiation pressure, and Doppler tracking biases. After the solutions were iterated to convergence, information equations were created for each arc by evaluating the partial derivatives of the observations with respect to the arc parameters and gravity coefficients along each arc. The gravitational field was then found by adding together the information equations for each arc and solving the resulting linear system. The dominant error sources in the model are the uncertainties in the spacecraft orbits, which are affected by the tracking coverage as well as the assumed models of atmosphospheric drag and solar radiation pressure, and unmodeled spacecraft perturbations [10]. We imposed *a priori* constraints on the model using weights based on Kaula's Rule [11] rescaled to Mars, which causes poorly observed (usually high degree and order) coefficients to tend towards zero, but has little effect on coefficients that are well sensed by the tracking data [8,9].

Free air gravity anomalies calculated at the surface from the model are plotted in Figure 1. As for previous models, the gravity anomalies correlate well with principal features of Martian topography. The model also shows a greater dynamic range of power in both the gravity anomaly field and the geoid. Probable reasons for the significant improvement achieved over previous fields include: increased computational capabilities; the application of collocation and optimum data weighting techniques in the least squares inversion for the field; and the use of longer arcs (days vs. hours) than used previously for Viking low altitude data made possible by improved force and measurement models.

The near-circular, polar orbit of the Mars Observer spacecraft, now enroute to Mars, will allow considerable improvement of the Martian gravitational field, with the greatest improvement occurring at high latitudes far removed from the Mariner 9 and Viking 1 and 2 periapsis latitudes. This gravity field, in combination with topography derived from from the Mars Observer Laser Altimeter [13], will allow detailed analyses of Mars' internal structure and mechanisms of compensation of surface topography.

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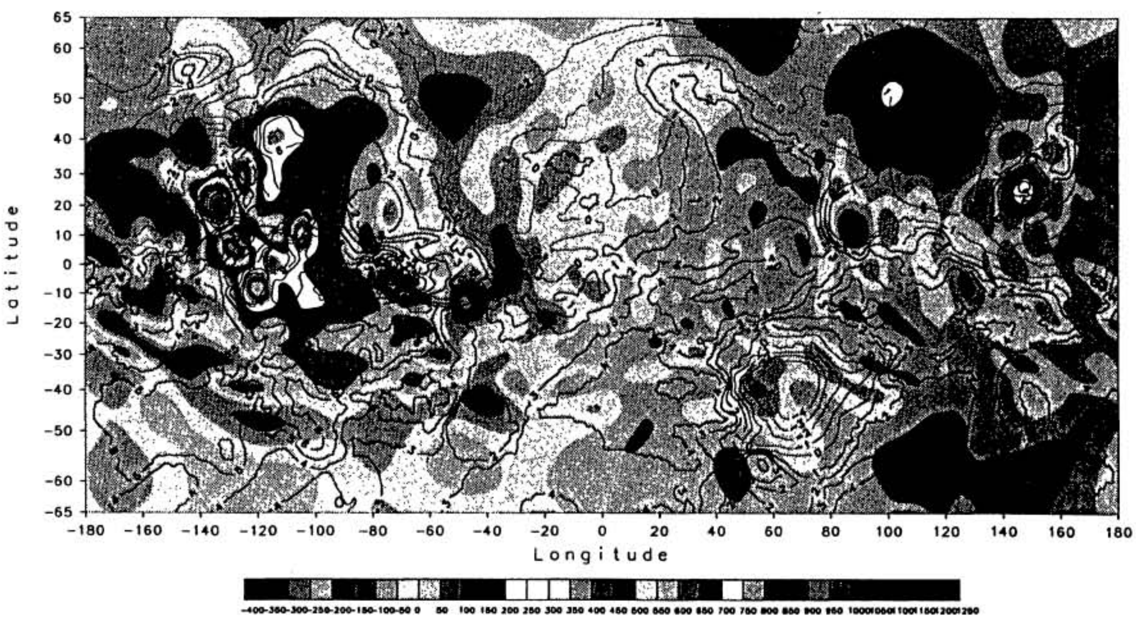


**Figure 1.** Free air gravity anomalies at the surface computed from Goddard Mars Model-1 (GMM-1) to spherical harmonic degree and order 50. The contour interval is 50 mgals. Also shown is the topographic field with a 1-km contour interval.