USING SPACECRAFT RANGE DATA AND RADAR OBSERVATIONS FOR THE IMPROVEMENT OF THE ORBITAL ELEMENTS OF PLANETS AND PARAMETERS OF MARS ROTATION

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Abstract. The extremely precise Viking (1972–1982) and Mariner data (1971–1972) were processed simultaneously with the radar-ranging observations of Mars made in Goldstone, Haystack and Arecibo in 1971–1973 for the improvement of the orbital elements of Mars and Earth and parameters of Mars rotation. Reduction of measurements included relativistic corrections, effects of propagation of electromagnetic signals in the Earth troposphere and in the solar corona, corrections for topography of the Mars surface. The precision of the least squares estimates is rather high, for example formal standard deviations of semi-major axis of Mars and Earth and the Astronomical Unit were 1–2 m.

A set of range measurements of the two martian landers Viking-1 and Viking-2, obtained by the Jet Propulsion Laboratory of the USA during the years 1976–1982 surpass in accuracy any planetary radar-ranging observations. With Mariner-9 tracking data they have been one of the major contributors to the accuracy of the JPL planetary ephemerides.

It may be thought that the direct radar-ranging to planet surfaces becomes useless because the observations of this type are seriously corrupted by peculiarities of the planet relief. Nevertheless we believe that these observations are valuable for two reasons. Firstly, the relief errors may be taken into account with the help of the modern planet hypsometric maps of high accuracy. Secondly, the radar range observations now cover almost

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30 years whereas the Mariner-9 (1971–72) and the Viking (1976–82) data are restricted to two short intervals of time.

In this paper we present results of the first stage of our investigation when the Viking and Mariner data, obtained from Standish (1994), were processed simultaneously with the radar-ranging observations of Mars made in Goldstone, Haystack and Arecibo in 1971–1973. Later, we intend to combine them with the all set of Russian and American radar observations, obtained during 1961–1995. The set of the data used now is given in Table 1

Table 1. Observations used in the ephemeris solutions.

Type of observations	Date	Number	A priori accuracy
Mariner-9 normal points	10.1971–09.72	645	40–400m
Viking Lander range points	07.1976–09.82	2462	7–12m
Haystack Mars radar ranging	04.1971–11.73	3490	70–7000m
Goldstone Mars radar ranging	06.1971–11.73	31274	70–500m
Arecibo Mars radar ranging	10.1973–11.73	1644	70–300m

The ranging observations near conjunctions with the Sun were corrected for the solar corona effect with simultaneous determinations of parameters of a corona model.

Great attention was given to the reduction of radar observations for the topography of Mars. This correction may be carried out by two methods. The first method makes use of hypsometric maps of Mars (Sherman, 1978). The second method uses a representation of the global topography of Mars by an expansion of spherical functions of 16–18 degrees (Bills and Ferrari, 1978). We have combined both these approaches. Usually the topographic reduction was made using spherical harmonics, but for some areas (for example, Olympus Mons) the heights were computed making use of the hypsometric map of this areas. The further details of the reduction and residuals of these observations can be founded in the paper (1995).

A least-squares solution for 23 unknowns was produced, where the unknowns were the elements of Mars and Earth (only those independent of the three-dimensional rotations), the Astronomical Unit, the scale correction to the reference surface of Mars, the parameter B of the solar corona, the lander locations, the rate of Mars rotation ($\dot{V}$), the angles of the Mars orientation (Ω_q and I_q) and their variations.

The formal standard deviations of the adjustment of the orbital parameters from the range data of Viking-1,-2, Mariner-9 and radar observations of Mars are given in Table 2.

Table 2. The formal deviations of the adjustment of orbital parameters.

Mars

$\Delta a/a$	$\Delta(\sin I \cos \Omega)$	$\Delta(\sin I \sin \Omega)$	$\Delta(e \cos \pi)$	$\Delta(e \sin \pi)$	$\Delta\lambda$
0.″000003	0.″000159	0.″000217	0.″000014	0.″000014	0.″000050

Earth-moon barycenter

$\Delta a/a$	$\Delta(e \cos \pi)$	$\Delta(e \sin \pi)$
0.″000001	0.″000009	0.″000009

ΔAU=2.135 m

As seen from Table 2, the accuracy of the least-squares estimations of the parameters is rather high. It should be remembered however, that such formal statistics tend to be highly optimistic when there are unmodeled forces; in this case, the perturbations of many small asteroids cannot be modeled precisely, since their masses are unknown.

The positions of the landers must be computed taking into account the precession and nutation of Mars. Therefore, the tracking data allow one not only to improve the orbital elements of planets, but also to study the precession and nutation of the spin axis in order to provide a better understanding of planet geophysics.

The values of Mars's orientation parameters and the Viking lander coordinates from our solution are given below:

$$V=(350^o.89198649 \pm 0^o.00000038)\ /\text{day}$$
$$\Omega_q=35^o.34746 \pm 0^o.00037$$
$$\dot{\Omega}_q=(0^o.230 \pm 0^o.014)\ /\text{century}$$
$$I_q=25^o.18231 \pm 0^o.00018$$
$$\dot{I}_q=(-0^o.0292 \pm 0^o.0080)\ /\text{century}$$

These formal standard deviations are in agreement with those of Standish (1990), notwithstanding that somewhat different observational data were used in this work.

We have an estimation of the precession constant of Mars: $(-750'' \pm 36'')$/century, which is in a good agreement with the result derived from the analyses of Viking Lander range and doppler data covering a time span of nearly four years (1976–1980) (Michael and Kelly, 1981) and also with that of $-708''$/century, predicted by Lowell (1914).

It is seen from post-fit residuals that some systematic component is present, although post-fit residuals for the measurements obtained during the first 14 months are consistent with the values from the paper by Reasenberg *et al.*(1979). Different numerical experiments were carried out in attempts to eliminate this systematic component. We tried to explain it by a polar motion of Mars or by corrections to the principal nutation terms, but all the attempts failed. Possibly, this systematic component is due to insufficiency of our dynamical modeling of the perturbations from asteroids. At present there are only the perturbations from five most massive asteroids in our model, but we are planing to take into account perturbations of asteroids in more full scale.

It would be desirable to continue such experiments and obtain new data from landers on the surface of other planets, especially on the surface of Mercury. Such observations could give an opportunity to improve not only Mercury's elements and its rotation but to estimate the variability of the gravitational constant with the standard error $10^{-12} - 10^{-13}$ per year. But only Mars landers are planned: American project MESUR and the Russian project MARS-96 (this missions will place in July 1997). We expect that including new data from these missions to Mars into our processing would improve essentially the estimate of the Mars precession constant and make it possible to determine the amplitudes of the dominant short periodic nutations. As shown by our computations the inclusion of data within a year from the MESUR lander yields the estimate of the Mars precession constant with a standard error of $10'' - -15''$/century. But if the duration of the MESUR mission is only one month the improvement of this estimate will be insignificant.

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