USING RANGE OBSERVATIONS OF SPACECRAFTS VIKING-1, VIKING-2, MARINER-9 FOR IMPROVEMENT OF ORBITAL ELEMENTS OF PLANETS AND PARAMETERS OF MARS ROTATION

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Abstract. The extremely precise observations of spacecrafts VIKING-1, VIKING-2 (1972-1982), MARINER-9 (1971-1972) were used for improvement of orbital elements of Mars and Earth and parameters of Mars rotation.

The ranging observations near conjunction were corrected for the solar corona with simultaneously determinations of parameters of corona model. These range data were combined with radar observations made at Haystack and Goldstone in 1971 (corrected for topography of Mars) to improve of orbital elements of Mars and Earth. The precision of the least-squares adjustment is rather high, for example formal standard deviations of semi-major axis of Mars and Earth were $0.''000004$ for da_M/a_M and $0.''000002$ for da_E/a_E.

Tracking data from planet landers allow to study precession and nutation of the spin axis that would provide a better understanding of planet geophysics. In the present work the rate of Mars rotation, the mean node and inclinations of the martian equator upon the mean orbit, their variations and Mars precession constant were improved from VIKING Landers observations.

Keywords : range observations of spacecrafts, ephemerides of planets, parameters of Mars rotation

1. Observations

A set of quite precise range measurements of two martian landers VIKING-1 and VIKING-2 was obtained by the Jet Propulsion Laboratory of the USA during the years 1976-1982 (2462 ranges). Up to now they surpass in accuracy any other planet radar range observations (a priory errors in the distance are about 7 meters). With MARINER-9 tracking data they have contributed the most to the accuracy of the well known JPL ephemerides of the DE series. By the courtesy of Dr. M. Standish we have got these observations to our disposal and now are going to combine them with the data set of $\sim$ 10000 planet radar observations (1961-1992, both Soviet and American ones) that have been already used for constructing our original planet ephemerides (Krasinsky et al., 1993).

It may be thought that the direct radar ranging to planet surfaces becomes useless because the observations of this type considerably concede in accuracy to the VIKING and MARINER data. And indeed they are seriously corrupted by

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peculiarities of the planet relief. That is why they practically were not used while constructing the DE ephemerides. Nevertheless we believe that these observations still keep their value until now due to 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 observations of radar ranges cover time interval of 30 years whereas the VIKING and MARINER data are restricted to 7 years interval.

In this paper we present results of the first stage of the project when the VIKING and MARINER data were processed simultaneously with radar ranging observations of Mars made in Goldstone and Haystack in 1971. All set of the data used is given in the Table I.

TABLE I

Observations used in the ephemeris solutions.

Type of observations	Date	Number	A priory 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	04.1971-02.72	2046	0.07-7km
Goldstone Mars radar ranging	06.1971-10.71	761	~ 0.5km

It should be mentioned that the accuracy of MARINER-9 observations drops near a conjunction with Sun and the accuracy of VIKING-1 data falls off after 1979; so the observations need a careful reduction.

2. Reduction of Range Measurements

Reduction of range measurements was made by a standard manner, including relativistic corrections for time conversion and Shapiro's effect. The location of the stations in the inertial reference frame were computed in ordinary way, taking into account precession, nutation, variations of Universal Time and polar motion.

We have also corrected the observations for effects of propagation of electromagnetic signals in the Earth troposphere as well as in the solar corona. The Earth's tropospheric effect was computed according to the model of Murray (1983).

The largest effect of the solar corona delay (τ_{cor}) reaches its maximum at superior conjunctions of the planet. This delay may be computed by the formula (see Muhleman and Anderson, 1981) :

$$\tau_{cor} = K \int_{p}^{r_E} \frac{N_e(r) r dr}{(r^2 - p^2)^{1/2}} + K \int_{p}^{r_P} \frac{N_e(r) r dr}{(r^2 - p^2)^{1/2}} , \qquad (2.1)$$

where the integral is taken along the ray path; p is a range ray impact parameter; r_E, a position of station on the Earth; r_P, a position of a point of reflection on observed object; $N_c = 1.240 \times 10^4 f^2(MHz)$ cm^{-3}, the critical density; $K = 1/2cN_c(f)$, $N_e(r)$, the electron density at r.

The integration depends on an accepted model of the solar corona. The main term of all models is B/r^2, it shows that the electron density profile falls off as the inverse square of the distance. We have chosen a simple model :

$$N_e(r) = \frac{A}{r^6} + \frac{B}{r^2}, \tag{2.2}$$

such a model was used by Standish (1990) while constructing of the planetary ephemerides DE. The parameter A varies by the factor of 2 or 3, depending on a solar activity; the parameter B is much less variable. For the available observations the minimum impact parameter achieves only 13 $R_\odot$ (for MARINER-9), the contribution of the first term in (2) is insignificant and it cannot be estimated from these observations. So we set $A = 1.22 \cdot 10^8$cm^{-3} according to the paper by Standish (1990). For the value of parameter B estimated from the observations we have :

$$B = (0.618 \pm 0.018) \cdot 10^6 \text{ cm}^{-3}.$$

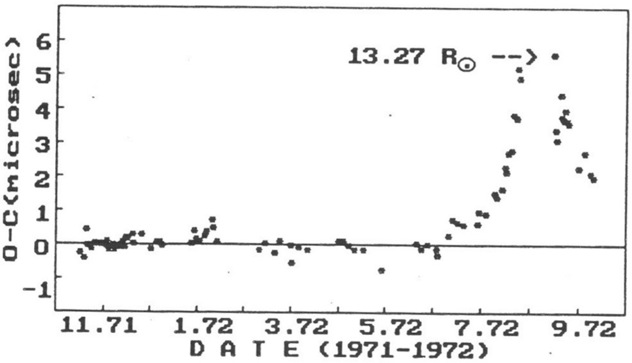

Fig. 1 The MARINER-9 residuals before a correction for solar corona.

The residuals of MARINER-9 data before and after the reduction for solar corona are shown in Figures 1,2. The observation with the minimum impact parameter $p = 13.27 R_\odot$ is marked by an arrow. Fig.1. shows that the maximum delay due to the solar corona may exceed 5 μs. From Fig.2. one can see that the effects of solar corona are completely taken into account by this method.

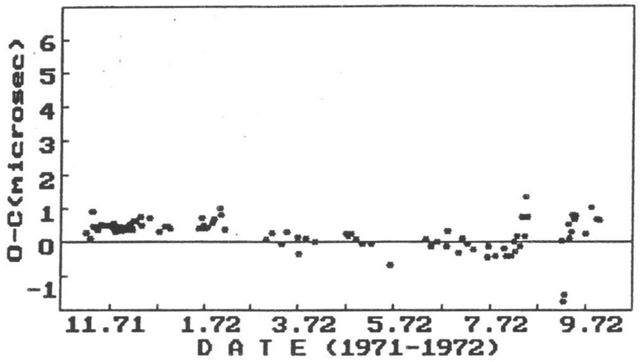

Fig. 2 The MARINER-9 residuals after a correction for solar corona.

During Lander VIKING mission the solar corona was calibrated by dual frequency measurements of the VIKING Orbiters. For observations after the end of the work of the orbiters (Aug 7, 1980) the model of solar corona derived mainly from MARINER-9 data was used to reduce the delay from the solar corona.

Great attention was given to the reduction of radar observations for 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 presentation of global topography of Mars by an expansion to 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 these areas. As an example, the residuals of radar ranging for the data ($5^h - 11^h$, 16 Aug, 1971) obtained at Goldstone are given on Figures 3,4 (before and after topographic reduction). These observations correspond to mountain region of Tharsis Montes.

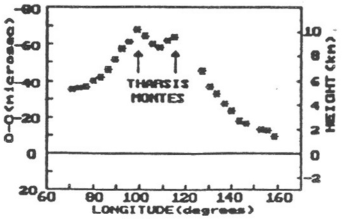

Fig. 3. Mars residuals before a correction for topography.

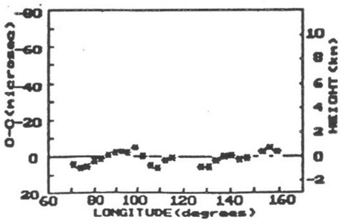

Fig. 4. Mars residuals after a correction for topography.

The reduction for topography allowed us to diminish the relief errors of normal places for every-day Mars radar observations to the level ~ 100 m.

The position of the lander, expressed in the inertial frame, is given (after Standish,1990) by the basic angles expressed as linear functions in time :

$$\vec{r} = \mathbf{R}_x(-\varepsilon)\mathbf{R}_z(-\Omega)\mathbf{R}_x(-I)\mathbf{R}_z(-\Omega'_q)\mathbf{R}_x(-I'_q)\mathbf{R}_z(-V')\vec{r}_o\ , \tag{2.3}$$

where the angle ε is the obliquity of the ecliptic; Ω and I, the node and inclination of the mean martian orbit upon the ecliptic; Ω_q and I_q, the mean node and inclination of the martian equator upon the mean orbit; V, the longitude of the martian prime meridian; $\mathbf{R}$, the turn matrices on corresponding angles.

$$\Omega'_q = \Omega_q - \Delta\psi_M\ ,\ \ I'_q = I_q + \Delta\varepsilon_M\ ,\ \ V' = V + \Delta\psi_M \cos I_q , \tag{2.4}$$

where $\Delta\psi_M$ and $\Delta\varepsilon_M$ express the nutation of Mars, computed from the formulation of Lyttleton et al.(1979).

3. Results and Discussion

Tracking data from planet landers allows not only to improve the orbital elements of planets, but also to study procession and nutation of the spin axis, that would provide a better understanding of planet geophysics.

The residuals were computed for the planetary ephemeris DE200. As it was shown in our preceding paper (Krasinsky et al., 1993), the elements of planets of the DE200 need some corrections. It is also evident from Figure 5, where a sinusoidal signature, due to Mars orbital errors is seen.

The least-squares solutions for 26 unknowns was produced : they are elements of Mars and Earth, Astronomical Unit, the scale correction to the reference surface of Mars, the parameter B of the solar corona, lander locations; $\dot{V}$, the rate of Mars rotation; Ω_q and I_q, the angles of the Mars orientation, and their variations.

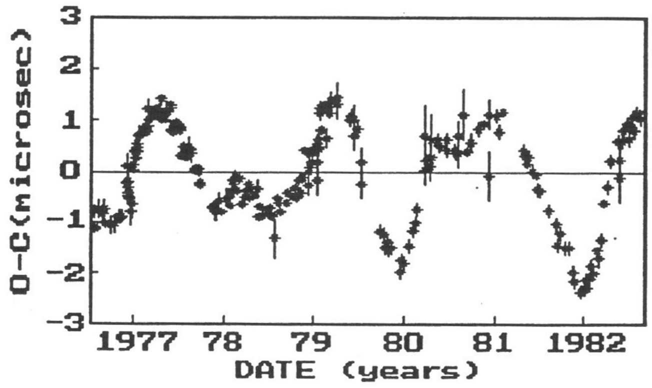

Fig. 5. The VIKING residuals before solution.

The accuracy of the least-squares estimations of the parameters is rather high, for instance, the formal standard deviations of semi - major axis of Mars and Earth are 0.″000004 for da_M/a_M and 0.″000002 for da_E/a_E, the error of determination of the Astronomical Unit is 2.6 m.

The values of Mars orientation parameters and VIKING lander coordinates from our solution are given in Table II.

TABLE II

The solutions parameters from VIKING lander observations (Ω_q, I_q in degrees, $\dot{V}$ in degrees/day, $\dot{I}_q$, $\dot{\Omega}_q$ in degrees/century).

I_q	25.19022 ± 0.00018	PX_1 [km]	3136.5158 ± 0.0042
$\dot{I}_q$	0.0102 ± 0.0080	PY_1 [km]	1284.234 ± 0.025
Ω_q	35.32462 ± 0.00037	l_1 [deg]	311.78247 ± 0.00038
$\dot{\Omega}_q$	0.102 ± 0.014	PX_2 [km]	2277.3754 ± 0.0068
$\dot{V}$	$350.89198959 \pm 0.00000038$	PY_2 [km]	2499.935 ± 0.029
		l_2 [deg]	134.01428 ± 0.00043

The formal standard deviations of this parameters are in agreement with those from the paper by Standish (1990), not with standing that somewhat different observation data were used in these works.

The estimated rotation rate corresponds to the following value of the sidereal period of Mars :

$$P = 24^h 37^m 22^s.661911 \pm 0^s.000096.$$

From determination of the parameter $\dot{\Omega}_q$ we have estimated the precession constant of Mars :

$$p = (-1034'' \pm 49'')\ /\text{century}. \tag{3.1}$$

This estimation was obtained from simultaneous determination of Ω_q and $\dot{\Omega}_q$, which are strongly correlated. When only $\dot{\Omega}_q$ is evaluated we have an estimation

$$(-750'' \pm 36'')\ /\text{century},$$

which is in a good agreement with the result derived from the analysis of range and doppler VIKING lander data covering a time span of only four years (1976-1980) (Michael and Kelly, 1981).

The post-fit residuals of VIKING data are plotted in Figure 6. It is seen from the plot that a some systematic component is present. 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. Probably, these observations have some systematic errors, that does not allow to realize its high a priory accuracy.

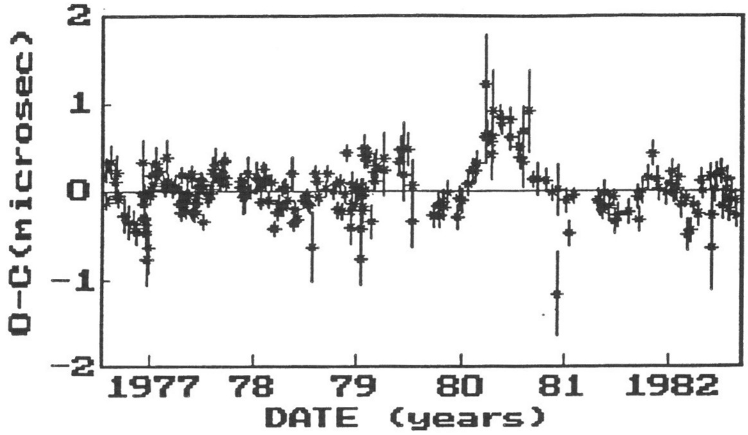

Fig. 6. The post-fit residuals of VIKING data.

We expect that including into our processing new data from planned American and Russian missions to Mars would improve essentially the estimate of the Mars precession constant and make it possible to determine amplitudes of the dominant short periodic nutations.

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