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Estimation of Mars geophysical information through Same Beam Interferometry

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Abstract

A mission deploying two or more landers on the surface of Mars would enable very accurate geodesy and geophysics experiments, by means of a tracking technique called Same Beam Interferometry (SBI). A microwave carrier is sent by a single Earth antenna towards two or more widely separated Mars landers, equipped with identical digital transponders with high long-term frequency stability, that retransmit coherently the signal back to Earth. The observable quantity is the difference between the phases of the two signals received simultaneously by the same ground antenna. The path delays due to interplanetary plasma, Earth's troposphere and ionosphere cancel out in the differential phase, as they act in nearly identical ways in both paths, contributing for less than 0.2 mm in the error budget. The cancellation does not occur for the Mars atmospheric and ionospheric delays, which however may be kept at a level respectively below 0.2 and 0.6 mm by suitable calibrations and adopting Ka-band links. Adopting Code Division Multiple Access (CDMA) technique allows to use the same frequency band for all links, thus maximizing the commonality of the delays. The envisaged overall error budget for SBI observations on Mars is better than 0.7 mm at Ka-band, so it would provide measurements of Mars tidal deformation and rotation with an unprecedented accuracy. The determination of tides and rotational state with such an accuracy will allow to focus on interior processes and provide essential constraints for models of the thermal, geochemical, and geologic evolution of Mars. Using X-band links is also an option, nevertheless a degradation of the measurement accuracy is foreseen, up to about 10 mm (mostly due to Martian ionosphere contribution). In this work we show the expected performance of SBI technique at Ka-band, in a mission scenario involving a network of three landers on Mars.

Table 1: Geophysical parameters of interest on Mars.

	Investigated parameter	Interior/Geophysical property
Nutation	– F (Core factor) – σ_0 (Free Core nutation frequency)	Size and moment of inertia of a liquid core
Precession	– Precession rate $\dot{\psi}$	Moment of inertia of the planet
Length-of-day variations	8 amplitudes (annual, semi-, 3- and 4-annual)	Atmospheric CO_2 sublimation and condensation process
Polar Motion (X and Y)	16 amplitudes (annual, semi-, 4-annual and Chandler wobble)	Atmosphere/ice caps
Tidal effect on the lander position	Love Numbers h_2, l_2 (radial and horizontal)	Interior structure

1. Configuration of the scenario

The following nominal configuration is investigated:

- 3 landers around the equator with a baseline separation of about 2000 km.
- Mission duration of 71 weeks.
- SBI data (accurate to 0.7 mm) and Doppler data (accurate to 0.07 mm/s) measurements are simulated at the same time, once per week, when the Earth is visible.

We computed the derivatives of the SBI and Doppler observables with respect to the parameters. With a covariance analysis, we can find the **a posteriori uncertainties** from the covariance matrix for each parameter of interest (Table 1) and their correlations. The least square fit is also used to estimate the parameters and get the error with respect to the assumed true value (**true error**).

2. Covariance analysis results

The summary of covariance analysis results are shown in Figure 1. After 60 weeks of mission duration, enough information is collected to obtain a satisfactory a posteriori uncertainty for all the

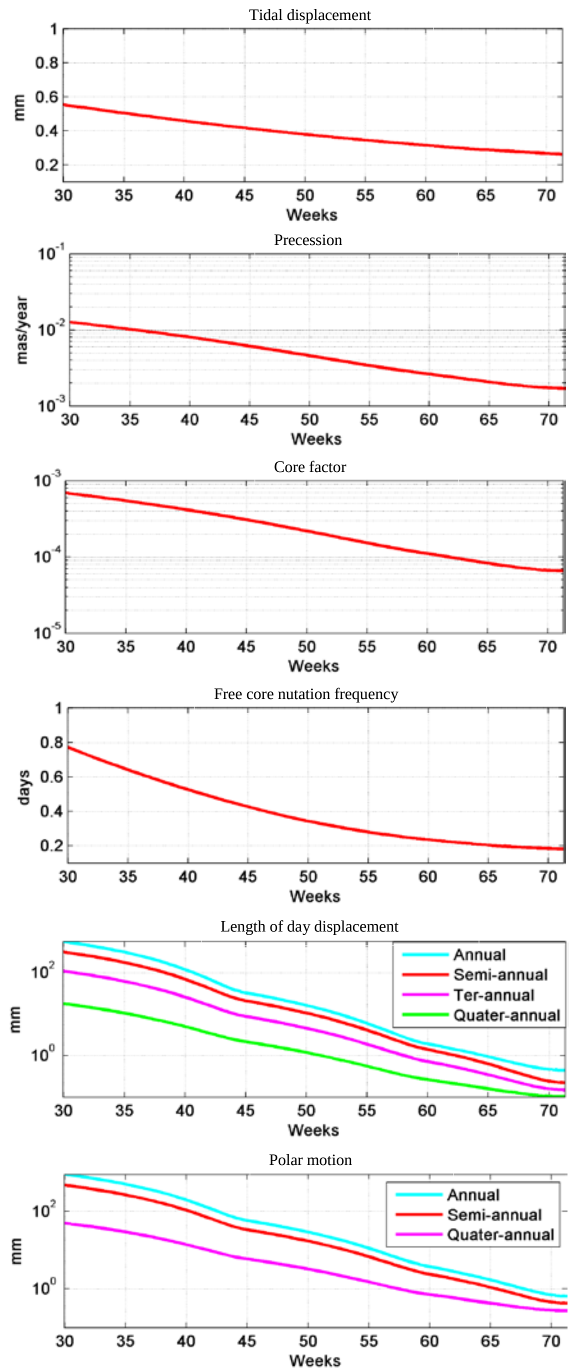

Figure 1: Postfit accuracy of the geophysical quantities of interest VS mission duration.

parameters and to grant the convergence of the least square inversion. For lower mission durations, the high level of correlation between lander coordinates and between some of the polar motion coefficients can prevent a satisfactory convergence. In the 60 weeks scenario, using simulated data, the tides, the precession, and the Free Core Nutation frequency σ_0 are estimated better than 1 σ, the core factor F and the Length of day (LOD) parameters better than 2 σ. Polar motion (PM) parameters, due to persistent correlations, are more difficult to be estimated when the Chandler's wobble (CW) frequency is not exactly determined. This latter quantity, at the moment, cannot be estimated, because its introduction prevents the convergence. The polar motion coefficients and the CW amplitudes can be estimated better than 1 σ only if the CW frequency is exactly known, otherwise PM parameters estimation degrades to better than 25 σ and CW amplitudes are not improved w.r.t. initial guess.

Table 2: A posteriori accuracies for geophysical quantities of interest (60 weeks mission).

Quantity	A posteriori accuracy σ	
Tidal displacement	0.3	mm
Precession frequency	$2.6\cdot10^{-3}$	mas/year
Core factor	$1.1\cdot10^{-4}$	
Free core nutation period	0.24	days
Length of day	1.9	mm (annual);
displacement	1.4	mm (semi-annual);
	0.7	mm (ter-annual);
	0.3	mm (quater-annual)
Polar motion	3.7	mm (annual);
	2.4	mm (semi-annual);
	0.7	mm (quater-annual)

3. Additional configurations

Different configurations and set of parameters have been investigated, changing the baseline length, the latitude of one or more landers, adding or removing some of the parameters, and using only two landers. The results obtained do not show significant improvements or degradation, except for the configurations with 2 landers, which show a general degradation of LOD parameters. The accuracy obtained for the other parameters, in the 2 landers configuration, will depend on the orientation of the baseline. No improvement in the convergence is obtained for any of the tested configurations when the CW frequency is included in the estimation, so its determination requires further analysis.

References

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