

Simulations of Minimum Elongation from the Sun

Jing Sun^{1,2}, Harald Schuh³, Geshi Tang¹

Abstract Based on the typical IVS (International VLBI Service for Geodesy and Astrometry) networks, we evaluate how the minimum elongation angle from the Sun affects the estimation of the Earth orientation parameters (EOP). In particular, we investigate the better sky coverage and the uniform distribution of radio sources in the sky if sources closer to the Sun than 15 degrees are included in the schedule, i.e., if the minimum elongation angle is set to 4 degrees. In addition to thermal measurement noise and clock errors, tropospheric turbulences are simulated based on realistic station-dependent turbulence parameters derived from GPS time series of zenith wet delays. The improvement in the estimation of EOP is investigated by Monte Carlo simulations, which are realized by running a sequence of different solutions using the VieVS software (Vienna VLBI Software).

Keywords Elongation, schedule, Monte Carlo simulations, VieVS

1 Introduction

The quasar's elongation is the angle between the Sun and the quasar, as viewed from the Earth. As seen from Figure 1, the elongation is the angle α . In the history of IVS (International VLBI Service for Geodesy and Astrometry) geodetic VLBI observations, the minimum

elongation was set to 15 degrees between 2002 and November 2013; before 2002 it was 5 degrees.

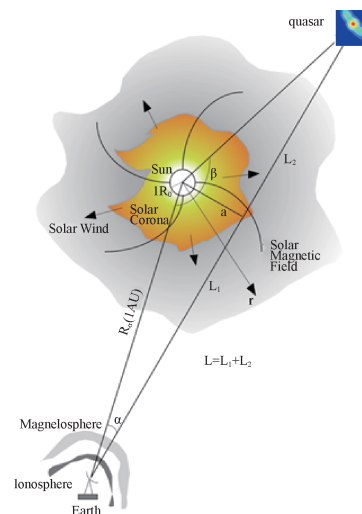


Fig. 1 The definition of quasar's elongation angle from the Sun.

If we schedule VLBI observations closer to the Sun, one of the disadvantages is the possible loss of observations because of stronger solar wind, plasma, and corona. Even worse, observations too close, e.g., on the limb of the Sun, could have an impact on antenna hardware. On the other hand, we can benefit a lot from the observations closer than 15 degrees to the Sun. Based on the data from RDV (R&D sessions with the VLBA stations) and VCS (VLBA Calibrator Survey) experiments, Lambert and Poncin-Lafitte [1] expected that the inclusion of sources closer to the Sun can improve the determination of the post-Newtonian parameter γ by 15% (even with a modest number of observations below 15 degrees per session; for instance, one to two

1. National Key Laboratory of Science and Technology on Aerospace Flight Dynamics, China
2. Shanghai Astronomical Observatory, China
3. GFZ German Research Centre for Geosciences, Germany

observations per session). Secondly, the observations closer to the Sun would be helpful to probe the solar corona as demonstrated by Soja et al. [2].

In this paper, we study the improvement of Earth orientation parameter (EOP) determination by observations closer to the Sun using Monte Carlo simulations, which are realized by running a sequence of different solutions of the VieVS software (Vienna VLBI Software) [3].

2 Scheduling Parameters

Two networks are employed here to evaluate the influence of the minimum elongation angle from the Sun. The first network is a typical nine-station network used for IVS-R1 sessions (see Figure 2). The second network is artificial and only used for this study; it includes eight stations (see Figure 3).

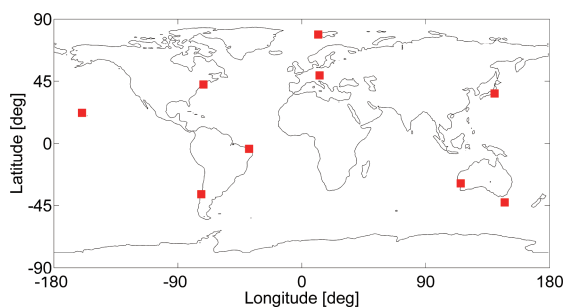


Fig. 2 A typical IVS-R1 nine-station network.

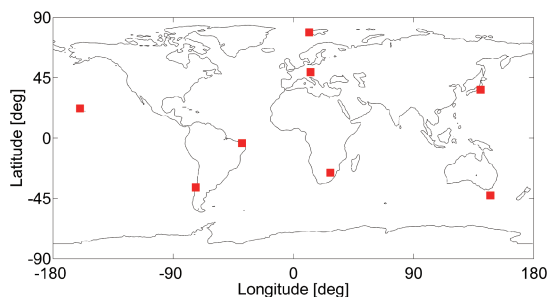


Fig. 3 An artificial eight-station network.

All the antennas are assumed to be identical in this study. The slew rate parameters are 3 deg/s and 2 deg/s

in the azimuth and elevation axes, respectively. The slew acceleration in both axes is 3 deg/s². The same SEFD (System Equivalent Flux Density) of 2500 is used for all the antennas. The data rate is 512 Mbps. SNRs of 20 at X-band and 15 at S-band are used for all stations. A cutoff elevation angle of 5 degrees is used.

The pre-selected source list is established considering the strength, compactness, and distribution, which includes 61 suitable radio sources in total (see Figure 4). Three out of 61 sources have an elongation angle from the Sun less than 15 degrees, i.e., source 1958–179 (13.9 degrees), source 1921–293 (8.0 degrees), and source 1920–211 (4.5 degrees). As seen from Figure 4, the distribution of observed sources on the celestial sphere is improved if we consider more sources closer to the Sun.

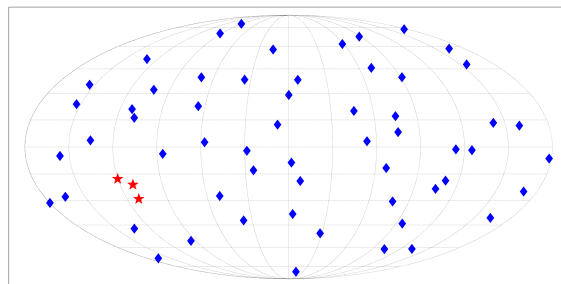


Fig. 4 Distribution of all 61 radio sources (blue diamonds) on the celestial sphere, including the three special radio sources (red stars) having an elongation angle from the Sun less than 15 degrees.

The source-based scheduling strategy of Vie_Sched (scheduling package of VieVS) with fill-in mode was employed, and one source was scheduled each time to generate all the schedules in this study [4]. The same source was not observed again within 30 minutes.

For either network, two schedules were generated with different thresholds of elongation angles. The first schedule (Schedule1) considered a minimum elongation angle of 15 degrees. The other one (Schedule2) included three special radio sources having elongation angles less than 15 degrees (the minimum elongation angle was set to 4 degrees). It is found from Schedule2 that all the stations except NYALES20 have observations on these three radio sources.

3 Simulation Parameters

In this paper Monte Carlo simulations are employed to study how the minimum elongation angle from the Sun affects the estimation of the EOP.

The Vie_Sched is directly connected to the other packages of VieVS and the simulation studies are realized by running a sequence of different packages of VieVS. Simulated VLBI observables are generated taking into account the three most important stochastic error sources in VLBI, i.e., wet troposphere delay, station clock, and measurement error [5]. In order to simulate the wet delays as realistically as possible, the turbulence theory with a dedicated strategy proposed by Nilsson and Haas [6] is applied. Those wet delays following turbulence theory take into account the covariance information between all observations at a station, and a particular series of equivalent zenith wet delays is triggered by random numbers. The turbulent troposphere is modeled using site-dependent structure constants C_n [7], effective wet heights H , and components of wind velocity (V_n and V_e). The zenith wet delay at the beginning of the time series (zwd_0), the correlation interval ($dhseg$), and the height increment for the numerical integration (dh) are set to standard values. Stochastic errors of station clocks can be simulated as the sum of random walk and integrated random walk stochastic processes. Our simulations are performed with power spectral densities corresponding to Allan Standard Deviations (ASD) of 1×10^{-14} at 50 minutes, which is a typical frequency stability of current H-masers. The contribution of the measurement error to the simulated delay observables is small compared to the contributions of troposphere and clock. In our simulations a white noise (WN) of 8 ps 1-sigma Gaussian random variable is used to represent all system errors. The simulation parameters are summarized in Tables 1 and 2.

For Monte Carlo simulations, 50 sessions are simulated to detect the small difference of the EOP sigmas using the same 24-hour schedule but different realizations of noise delays, each time creating new values for zenith wet delays, clocks, and white noise. The analysis is performed for each of the simulated files, and the sample of output parameters is analyzed statistically.

Table 1 Simulation parameters.

H [m]	2000
V_n [m/s]	0.00
V_e [m/s]	8.00
zwd_0 [mm]	250
$dhseg$ [h]	2
dh [m]	200
clock ASD	10^{-14} @50 min
WN [ps]	8

Table 2 Site-dependent C_n in $m^{-1/3}$.

Station	$C_n \cdot 10^{-7}$	Station	$C_n \cdot 10^{-7}$
FORTLEZA	2.46	TSUKUB32	3.45
HOBART12	1.60	WESTFORD	2.30
KOKEE	1.39	WETTZELL	1.50
NYALES20	0.65	YARRA12M	1.76
TIGOCONC	2.08	HARTRAO	1.34

4 Results

In the least squares parameter estimation part of VieVS, most of the estimated parameters are modeled by piecewise linear offset functions. The parameters to be estimated are troposphere parameters, clock parameters, and station positions, as well as daily EOP. The main goal of the estimation process in the simulations is to investigate the impact of observations closer to the Sun on the estimation of EOP.

Tables 3 and 4 show the detailed information on the observations to the three special radio sources for the typical IVS-R1 network and the artificial network.

Table 3 Detailed information on the observations to the three special radio sources for the typical IVS-R1 network.

Source	Elongation angle	Num of scans	Num of obs
1958-179	13.9°	5	13
1921-293	8.0°	10	10
1920-211	4.5°	9	43

Table 4 Detailed information on the observations to the three special radio sources for the artificial network.

Source	Elongation angle	Num of scans	Num of obs
1958-179	13.9°	4	11
1921-293	8.0°	11	13
1920-211	4.5°	10	30

Tables 5 and 6 show the EOP results estimated from the two schedules for the two networks. Schedule2 has great advantages for providing EOP estimation, as a consequence of its better source distribution.

Table 5 EOP determination from the two schedules for the typical IVS-R1 network.

EOP Parameter		Schedule1 (elong_min = 15°)	Schedule2 (elong_min = 4°)
Mean uncertainty [μ as, μ s]	xp	25.55	24.52
	yp	24.47	24.02
	dUT	1.76	1.72
	dX	21.71	21.25
	dY	20.93	20.83

Table 6 EOP determination from the two schedules for the artificial network.

EOP Parameter		Schedule1 (elong_min = 15°)	Schedule2 (elong_min = 4°)
Mean uncertainty [μ as, μ s]	xp	22.49	21.61
	yp	25.81	25.18
	dUT	1.63	1.59
	dX	21.50	21.28
	dY	21.57	21.26

To have a closer look at the small difference, Figure 5 plots the relative improvement of EOP determination. The average improvement of EOP determination is up to 4% just by adding three radio sources that are between 4 and 14 degrees from the Sun.

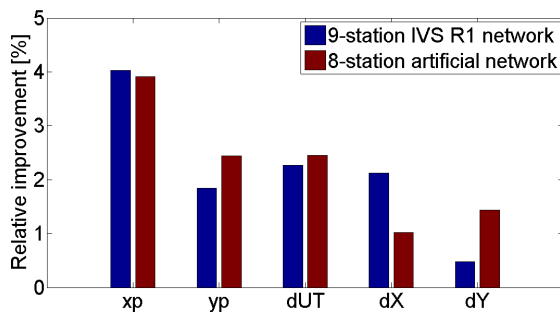


Fig. 5 Relative improvement of EOP determination.

5 Conclusions

According to the above results, a 4% improvement in the estimation of the x-pole is obtained from the second schedule. The average improvement of the pole coordinates is 3%, of the Earth rotation parameter dUT 2.4%, and of the nutation parameters 1.3%. Thus, just by adding a few radio sources with elongation less than 15 degrees to the observing schedule, an improvement of the main geodetic parameters between 0.5% and 4% is obtained. This can be explained by the better coverage of the complete sky if radio sources closer to the Sun are included in the schedule. In the future, it would also include the consideration of solar activity for the setting of minimum elongation angle.

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