VLBI satellite tracking for precise coordinate determination - a simulation study

L. Plank, J. Böhm, H. Krásná, H. Schuh

Abstract VLBI observations to satellites offer interesting new applications. The use of existing satellites like those from Global Navigation Satellite Systems (GNSS) or a dedicated new mission like the proposed Geodetic Reference Antenna in Space (GRASP) mission for co-location in space are possible concepts. In this contribution, key parameters of such observations are investigated, as for example the station network, the observation interval, or the accuracy of derived coordinates, as determined in a global solution for one week of observations. We use simulated VLBI observations which account for noise, clock errors, and tropospheric disturbances and focus on the position errors in the estimated station coordinates. Both regional and global networks are investigated, considering the potential height of the observed satellite and the attendant restrictions on common visibility. Facing the troposphere as the main error source, changing the observation interval and the possibility of additional observations to quasars in order to increase the sky coverage for each station are found to be proper means to reach the expected accuracies of a few millimeters 3D station root mean square (rms).

Keywords VLBI satellite tracking, co-location in space, GRASP

1 Introduction

Soon after the first VLBI experiments, the potential of this technique for satellite tracking and orbit determination was recognized (e.g. Preston et al., 1972; Rosenbaum, 1972; Counselman and Gourevitch, 1981). While the advance of alternative tracking methods dominated developments in the past, recently the option of VLBI observing satellites came back into the geodesists' focus (e.g. Dickey, 2010). Whether it is an experiment on observations to GNSS satellites (e.g. Tornatore et al., 2011) or the proposal of a particular satellite mission like GRASP (Geodetic Reference Antenna in Space; Nerem and Draper, 2011), several scenarios are investigated at the moment. The driving force behind these activities is an aspired improvement of inter-technique frame ties, the backbone of the International Terrestrial Reference Frame (ITRF) as a combined product of four techniques, namely VLBI, GNSS, SLR and DORIS. At co-location sites, the antenna positions of different geodetic techniques are usually tied together by local measurements. However, the measured local tie vectors often do not fit the ones derived from the TRF solution at the expected accuracies and future ITRF improvement resides in improving the consistency between them (Altamimi et al., 2011). The idea followed in this contribution is illustrated in Fig. 1. A satellite which can be tracked by several space geodetic techniques (e.g. VLBI, GNSS, SLR) shall serve as a space-tie, directly connecting the frames determined by the different techniques.

2 Procedure

Goal of this simulation study is to investigate expected accuracies of derived antenna positions in dependence of different observing strategies. Therefore we use simulated observations that are based on the common stochastic error sources of geodetic VLBI today. The actual technical realization of VLBI observations to satellites with sufficient precision is disregarded in our study. The simulations were done using the Vienna

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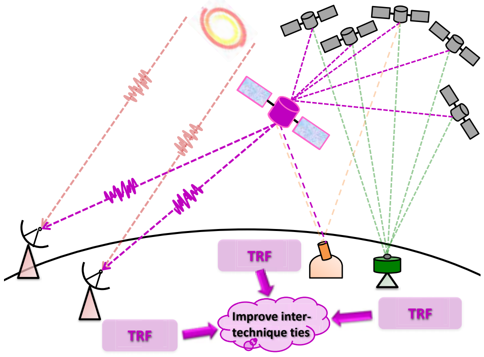

Fig. 1 Concept of co-location in space. A satellite that can be tracked by several space geodetic techniques (e.g. VLBI, SLR, GNSS) realizes a space-tie, directly connecting the frames determined by the different techniques.

	height h	inclination i	eccentricity e
GRASP	2000 km	104.89°	0.0001
GPS	20200 km	$\sim 55°$	nearly circular

Table 1 Orbital elements of the simulated satellites.

VLBI Software VieVS (Böhm et al., 2012), including a number of adaptations for this special processing. Main steps of the processing are the scheduling of observations, the simulation of them and the estimation of station coordinates with a corresponding statistical interpretation.

2.1 Scheduling

The scheduling is simply based on common visibility between two antennas. With a given satellite orbit, a selected antenna network and a fixed observation interval, observations were scheduled for seven consecutive days, split into 24 hour sessions. The cutoff elevation angle was set to 5°. For our investigations we selected (a) one of the initially proposed orbits for the GRASP satellite mission idea (Nerem and Draper, 2011) and (b) a GPS satellite. The corresponding orbital parameters are given in Table 1.

VLBI satellite observations were simulated for a dense, regional network consisting of seven existing European stations (Fig. 2) and for a global artificial VLBI2010 network with 32 stations (Fig. 3).

2.2 Simulation

For the simulations, the VieVS simulator was used, following the procedure described by Pany et al. (2010).

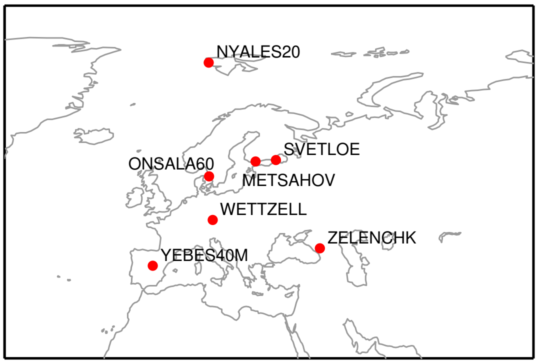

Fig. 2 European network.

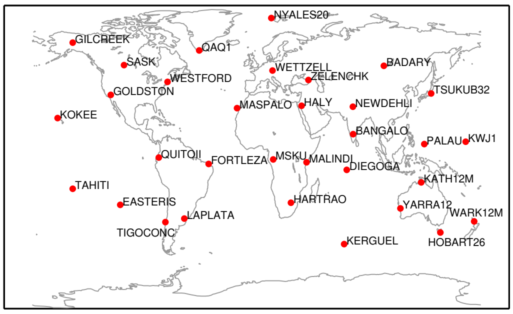

Fig. 3 Global 32 station network.

Based on Monte-Carlo simulations, the observed minus computed values are set up as the sum of the stochastical error sources due to the wet troposphere, the clock and the delay precision. We assume a turbulent troposphere with the characteristic structure constant $Cn = 2.5 \cdot 10^{-7} \mathrm{m}^{-1/3}$ and the effective height of the wet troposphere $H = 2$ km. For the clocks, an Allan standard deviation of $1 \cdot 10^{-14}$ @ 50 minutes is chosen and the delay precision is simulated as white noise of 30 picoseconds. The simulations are repeated 30 times.

2.3 Station position estimation

The simulated 24-h sessions are first processed separately with the analysis settings according to Table 2.

In a subsequent global solution, seven consecutive days are combined and one set of antenna coordinates is estimated for each station, 30 times. The rms of these estimates gives a measure of the expected accuracy in a weekly solution. This is expressed either in repeatability, respectively rms for the north-, east-, and up-components, or in terms of a 3D station rms.

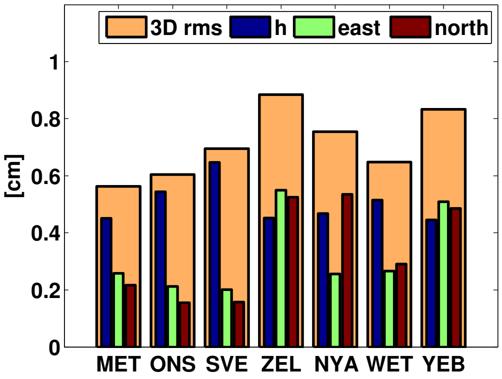

Fig. 4 Expected accuracies of station position repeatabilities if the GRASP satellite was observed in a 7-station European network in 5-min intervals.

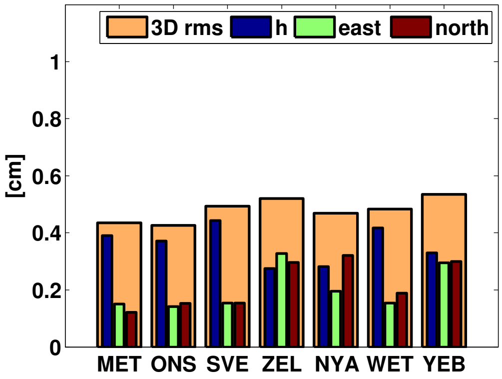

Fig. 5 Expected accuracies of station position repeatabilities if the GRASP satellite was observed in a 7-station European network in 1-min intervals.

EOP	fixed
Troposphere *zwd*	30 min pwl offsets
	0.7 ps^2/s constraints, no gradients
Clock	quadratic polynomial + 60 min pwl
	0.5 ps^2/s constraints
Station coordinates	NNT, NNR applied

Table 2 Analysis settings for the parameter estimation.

3 Observations to GRASP

In Fig. 4 the results are shown if the GRASP satellite was observed every 5 minutes. According to our simulations, the station positions can be determined in the satellite system with an accuracy of a few mm, with the height component being significantly worse than the horizontal position. This is not true for the stations Ny Ålesund (NYA), Zelenchukskaya (ZEL) and Yebes (YEB), which are located at the edges of the network. They only form baselines with the other stations more or less in one direction, causing their east- and north-components being not as well determined as for the other stations in the center of the network.

Improvement of the results is found when the observation interval is shortened from 5 to 1 min (Fig. 5). However, this improvement is not as big as probably expected and a further reduction of the interval gives no additional impact. Since the spatial and temporal correlation is included in the model applied in the simulator, additional observations into similar directions and at approximately the same time do not provide new information about the tropospheric conditions.

When going from a regional network to a global one, the results are slightly worse. In Fig. 6 the expected station position repeatabilities for the global 32-station network observing GRASP in 30 sec intervals is shown. A major reason for the worsening is the small number of possible observations, as indicated by the red line in the figure. This is a result of the longer baselines and the low satellite height reducing common visibility.

4 GPS observations

Next, we investigate VLBI observations to a single GPS satellite. Using the same approach as for GRASP in the previous section, station position repeatabilities of several cm are achieved. The reason for this is the poor sky coverage over each station, what results in an insufficient modeling of the troposphere. In Fig. 7 the sky coverage for station Wettzell is shown for one day observing the GRASP satellite in 1-min intervals (left plot) and 5-min intervals (right plot). With its low height GRASP passes the station several times per day resulting in observations well distributed on the sky. Unlike GRASP, the GPS satellite flies much higher and passes the station only twice per day, as can be seen in Fig. 8, left plot.

As a consequence, we propose to include VLBI observations to a single GPS satellite in a conventional geodetic VLBI session. As illustrated in Fig. 9, in a first step the troposphere then can be estimated using all observations and subsequently the antenna positions are determined using the GPS observations only. With this 2-step procedure the stations are determined in the satellite system, which further on can be directly compared to the station positions determined from VLBI observations to radio sources. Deviations between both determined station positions represent the difference between the satellite and the VLBI system and can help

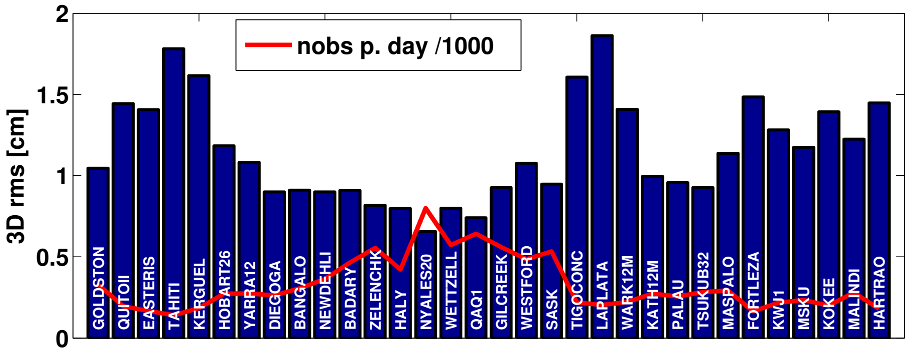

Fig. 6 Expected accuracies of station position repeatabilities if the GRASP satellite was observed in an artificial 32-station global network in 30 sec intervals. The red line indicates the mean number of observations per day.

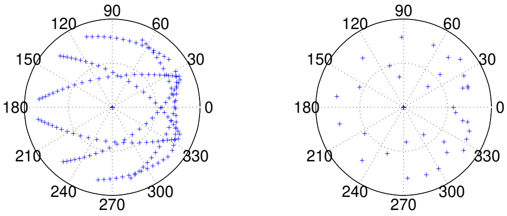

Fig. 7 1-day skyplot for station Wettzell observing GRASP in 1 min intervals (left) and 5 min intervals (right).

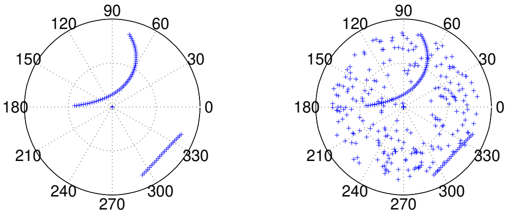

Fig. 8 1-day skyplot for station Wettzell observing one GPS satellite in 5 min intervals (left). On the right the corresponding skyplot is shown for the combined approach, including observations to radio sources.

to identify and remove possible inadequacies of the two frames.

Applying this combined approach (with the corresponding sky plot shown in Fig. 8, right plot), station rms of a few mm are achieved, as shown in Fig. 10. This is an improvement by a factor of 10 compared to the GPS-only solution. With a good estimation of the troposphere, the determined station errors are dominated by the geometrical conditions due to the stations' positions in the network and the satellite orbit, resulting in a significantly better determined height component than the horizontal components.

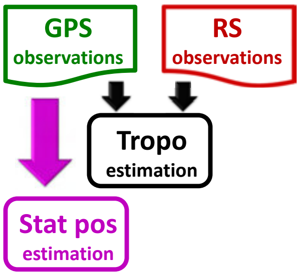

Fig. 9 Concept of combined GPS and radio source (RS) observations.

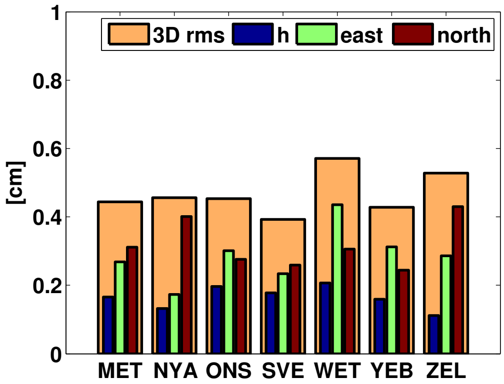

Fig. 10 Station position repeatabilities using the GPS combined approach. The results shown are from a weekly global solution where a GPS satellite was observed in 5 min intervals, flanked by VLBI observations to radio sources.

5 Conclusions

With the goal to improve inter-technique ties, we investigate VLBI observations to satellites. Based on simulated observations, strategies are found to precisely determine antenna positions on ground in the satellite system with accuracies of 5 – 10 mm 3D rms. This is possible for either very low (h = 2000 km) or GPS satellites, in a dense, regional antenna network. For a global network the results are worse by a factor of about 2 due to the longer baselines and limited common visibility. The optimal observation interval varies for satellites at different heights as no additional information is gained through consecutive observations in similar directions. For higher satellites like those from the GPS we propose to include the observations into standard geodetic VLBI sessions in order to successfully resolve the troposphere.

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