Searching for an Optimal Strategy to Intensify Observations of the Southern ICRF sources in the framework of the regular IVS observing programs

Zinovy Malkin, Jing Sun, Johannes Böhm, Sigrid Böhm, Hana Krásná

Abstract The quality of the VLBI-derived ICRF in the southern hemisphere is much worse than in the northern hemisphere. The main reason is that only about 3% of the observations have been made of the sources at declinations below –30 deg due to the relatively small number of VLBI stations located in the southern countries. In this paper, we investigated a possibility to increase the number of observations of the existing and prospective southern ICRF radio sources by inclusion of more such sources in the regular IVS sessions like R1 and R4. We tested the influence of adding supplementary southern sources to the IVS R1541 (12JUL09XA) session on EOP and baseline length repeatability with Monte Carlo simulations. We found that adding more observations of southern sources to the standard schedule causes a slight degradation of some geodetic products and a slight improvement of others, depending on the number of added southern sources. Similar results were obtained for the IVS R1591 (13JUN24XA) session. Generally, it has been shown that it is possible to increase the number of observations of southern sources without loss of the overall accuracy of geodetic products. So, the task is to find an optimal trade-off between the maximum increasing of the number of observations of southern sources and the degradation of geodetic results.

Keywords VLBI, IVS, ICRF, scheduling

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1 Introduction

The quality of the ICRF in the southern hemisphere is much worse than in the northern hemisphere. The main reason is that the number of southern VLBI stations participating in the astrometric observing programs is much smaller than that in the northern hemisphere. As a consequence, the number of observations of the southern sources is very small. Only about 3% of the observations have been made of the sources at declinations below -30 deg (see Fig. 1). The situation improves with time, but very slowly despite new southern stations and new CRF-dedicated observing programs (see Fig. 2). The relative number of observations of most southern sources does not improve with time at all.

Deficiency of observations of southern sources leads to the following well recognized consequences:

- the number of the southern ICRF sources is much smaller than the northern;
- the number of the southern ICRF sources with reliable position and stability estimate, herein reliable core/defining sources, is much smaller than the northern;
- the position accuracy of the southern sources is generally worse than the northern.

Special CRF programs for the southern hemisphere are rare, and are often conducted on poor networks of 2-3 stations, which can deteriorate the source position accuracy because of the source structure effect. Two possible ways were proposed by (Malkin et al., 2012) to increase the number of observations of poorly observed and new prospective ICRF sources on the southern sky: inclusion of more such sources in the regular IVS sessions like R1 and R4, and implementing new scheduling strategies not requiring sky coverage for the stations. In this paper, we investigate possible strategies to force an improvement in the ICRF sources observation distribution over the sky by:

- including prospective ICRF sources in the regular IVS observing programs, such as R1 and R4;
- finding a trade-off between a slight degradation of the EOP precision and the long-term ICRF improvement.

We made use of the VieVS scheduling and simulation tools (Böhm et al., 2012) for our study.

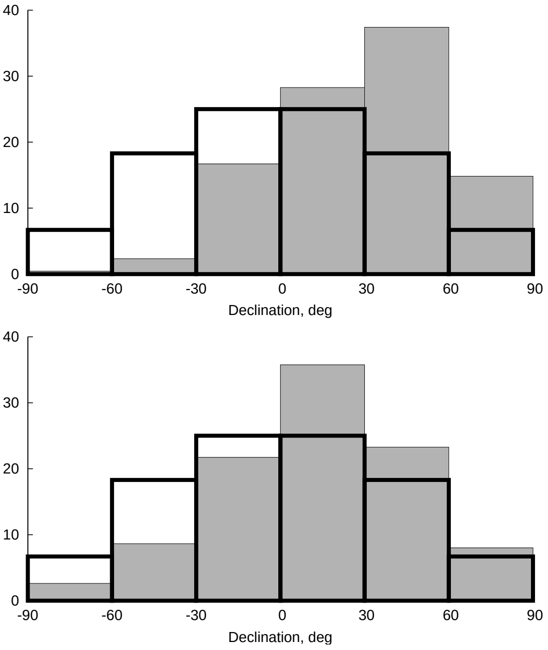

Fig. 1 Percentage of observations by DE bands (top) and percentage of the well observed sources with Nsess $\geq$ 10, Nobs $\geq$ 200 (bottom). Actual numbers of observations are shown by grey boxes, numbers of observations expected for a uniform distribution are shown by thick lines).

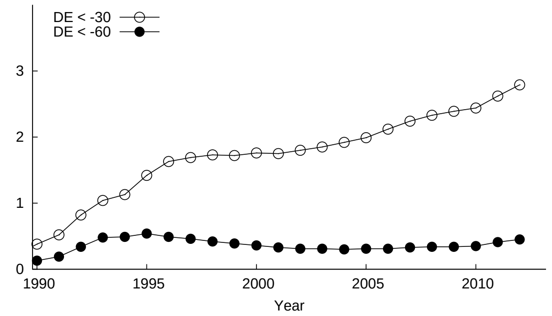

Fig. 2 Percentage of the observations of southern sources (cumulative by date).

2 Monte Carlo Simulation

The IVS R1541 (12JUL09XA) session was used for the Monte Carlo simulations in this paper. The R1541 session network includes 11 stations, 5 of them are located in the southern hemisphere (see Fig. 3). As expected, the Auscope (Australian VLBI Network), station Hartrao, station Tigo, and station Fortleza participated. The southern network size ensures large common view, and the multi-baseline observations are important to mitigate the source structure effects.

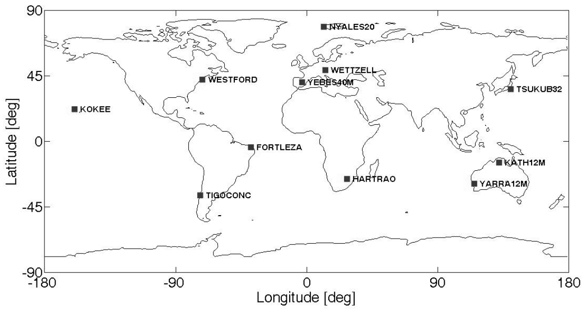

Fig. 3 11 stations network of IVS R1541 session, 5 out of 11 stations are located in the southern hemisphere.

2.1 Scheduling

The original schedule for the R1541 IVS session was generated making use of the SKED software (Gipson, 2010). There are 60 sources observed, 7 southern sources having declination less than -40 degrees. For comparisons, the supplementary southern sources are added to the original source list and experimental schedules are obtained to evaluate the trade-off between the number of southern sources and the accuracy of geodetic products.

Considering all the ICRF2 sources having the declination less than -40 degrees, they are sorted by some generalized criteria involving number of sessions, number of observations, and position uncertainty.

"The worst end" of the list shows which sources we should consider first. The strong southern sources have preference in this study.

Schedule 'R1' is achieved with the original source list. Schedule 'R1+' includes three more southern sources and schedule 'R1++' includes six more southern sources as compared with the original R1541 schedule. The three schedules for 24-hour continuous observations are generated with VieVS scheduling package (Sun et al., 2011). The distribution of observed sources is shown in Fig. 4, and detailed information on southern sources is given in Table 1.

Table 1 Number of scans/observations of southern sources in the IVS R1541 (R1) and two experimental schedules R1+ and R1++.

Source	R1	R1+	R1++
0637-752	39 / 39	42 / 48	37 / 39
0537-441	55 / 88	56 / 91	59 / 102
1104-445	16 / 18	25 / 27	19 / 23
2052-474	42 / 48	49 / 57	46 / 50
2300-683	3 / 3	1 / 1	1 / 1
0048-427	4 / 6	7 / 11	7 / 7
0308-611	4 / 4	6 / 6	2 / 2
2232-488		7 / 7	3 / 3
2204-540		9 / 9	6 / 6
2142-758		7 / 7	3 / 3
0208-512			18 / 18
0332-403			47 / 82
1424-418			42 / 67
Total	178 / 295	209 / 264	290 / 403

Except the different source list, the basic scheduling settings used in VieVS are in correspondence with the original R1541 schedule as summarized below. The optimization of source-based strategy is employed with VieVS for this study.

- frequency setup: R1 frequency setup (X/S band)
- SNR: 20/15 (15/12 for Tigo)
- recording data rate: 256 Mbps
- cut-off elevation angle: 5 degrees
- minimum scan length: 40 seconds
- extra time for settling down, calibration, correlator synchronizing

2.2 Simulating

For the Monte Carlo simulations, 50 sessions were simulated using the same 24-hour schedule but different realizations of noise delays, each time creating new values for wet zenith delay, clocks and white noise to simulate observations as realistic as possible. The random errors in delay measurement were modelled by white noise with given power spectral density (PSD). The clock rate instability was modelled using the Allan standard deviation (ASD). The turbulent troposphere was modelled using the site-dependent structure constant C_n, effective wet height H, and wind velocity V. The simulation parameters are summarized in Tables 2

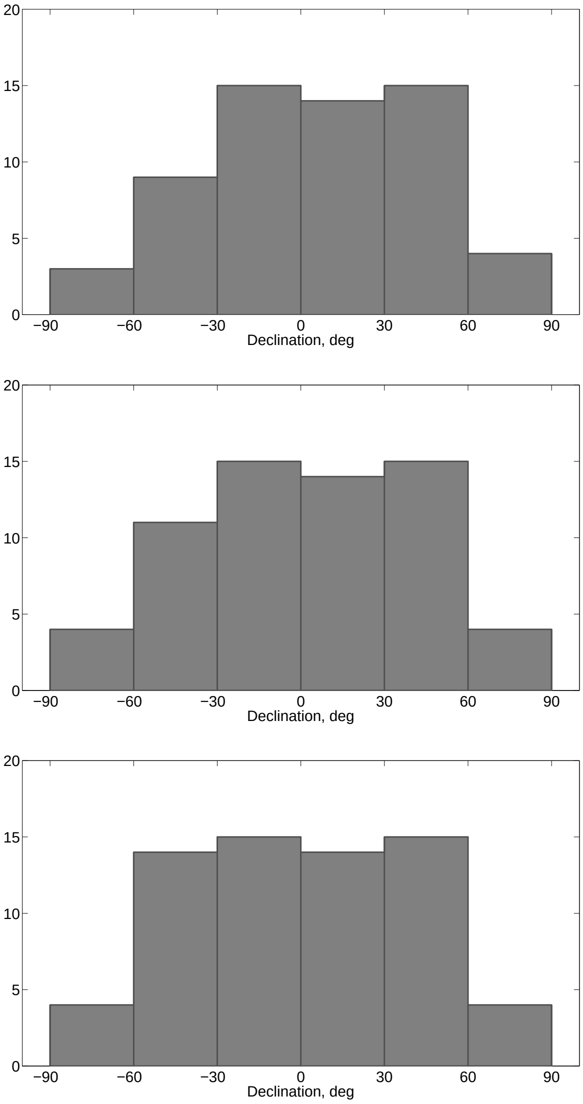

Fig. 4 Distribution of observed sources in the original R1541 schedule (top) and two experimental schedules: R1+ (middle) and R1++ (bottom).

and 3). See Sun et al., 2011 for details of the stochastic models used during simulation.

Table 2 Simulation parameters.

H [m]	2000
V_n [m/s]	0.00
V_e [m/s]	8.00
wzd_0 [mm]	250
$dhseg$ [h]	2
dh [m]	200
clock ASD	10^{-14}@50 min
WN PSD [ps]	32

Table 3 Site-dependent constant C_n, $m^{-1/3}$.

Sta name	$C_n \cdot 10^7$	Sta name	$C_n \cdot 10^7$
NYALES20	0.65	HARTRAO	1.34
ONSALA60	2.19	KATH12M	1.68
TSUKUB32	3.45	TIGOCONC	2.08
WESTFORD	2.30	WARK12M	1.94
WETTZELL	1.50	YARRA12M	1.76
YEBES40M	1.48	FORTLEZA	2.46
KOKEE	1.39		

3 Results

The simulated NGS data files are entered into the software package VieVS, which computes a classical least squares solution. All the source coordinates were fixed to the ICRF2 positions (Ma et al., 2009). The standard deviation of the 50 EOP estimates and mean formal uncertainties are listed in Table 4.

Fig. 5 shows baseline length repeatability obtained from the simulations. For the baselines shorter than ∼5,000 km the R1 schedule shows the best result, and R1+ and R1++ schedules yield worse repeatability, whereas for longer baselines the R1++ schedule is the best, and R1 is the worst. However, in fact, the results obtained with the three schedules are close to each other. The mean baseline length repeatability derived from R1, R1+, and R1++ schedules are 13.5 mm, 12.4 mm, and 11.9 mm, respectively.

It has been found that further increasing of the number of southern sources (cf. R++ and R+ schedules) leads to a small degradation of baseline length repeatability for short baselines, and small improvement for long baselines. Errors in some EOP become smaller with inclusion of more southern sources, and some EOP show small degradation in the accuracy.

Table 4 Repeatability and standard deviation of EOP for the IVS R1541 and two experimental schedules R1+ and R1++.

Parameter		R1	R1+	R1++
Number of scans		1258	1351	1375
Number of observations		3905	3813	3997
EOP repeatability	Xp	143.2	125.5	98.2
[μas, μs]	Yp	98.2	79.1	96.8
	UT1	5.6	4.6	5.9
	dX	36.2	42.8	39.1
	dY	45.0	39.5	37.2
Mean EOP uncertainty	Xp	94.8	95.6	93.4
[μas, μs]	Yp	77.2	77.3	74.8
	UT1	4.4	4.6	4.7
	dX	29.8	30.9	29.5
	dY	29.1	29.6	28.1

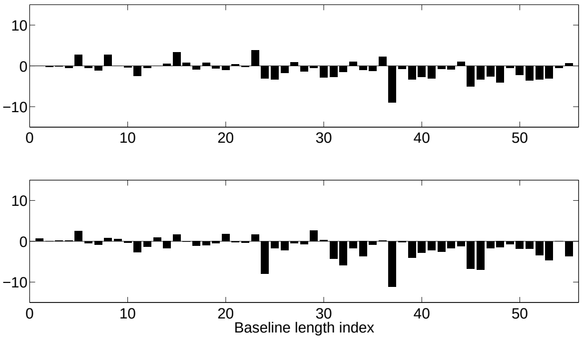

Fig. 5 Differences in baseline length repeatability [mm] between two schedules: R1+ minus R1 (top) and R1++ minus R1 (bottom). The horizontal axis represents the 55 baselines with the shortest one WETTZELL–YEBES40M (1575 km) on the left and the longest one TIGOCONC–TSUKUB32 (12401 km) on the right.

4 Summary

Including more southern sources in the regular IVS sessions may be a practical way to force an improvement of the VLBI-based ICRF in the southern hemisphere. In this paper, we studied a trade-off between the small degradation of the EOP precision and the ICRF improvement using the source-based scheduling algorithm (Sun et al., 2011). We found no degradation of the overall accuracy of main geodetic products, such as EOP and baseline length repeatability after the inclusion of several supplementary southern sources.

Although the number of southern sources added and the number of their observations are not large with respect to the standard scheduling algorithm, regular inclusion of selected sources needed for densification and accuracy improvement of the ICRF in the southern hemisphere will provide a valuable contribution to the next VLBI-based ICRF. Having quarterly observations during two years will give us a good preliminary estimate of both average source position and its stability. Rotating the list of supplementary sources between sessions, e.g., on the quarterly basis, we could substantially increase the number of reliably observed southern sources. The latter is, in particular, very important for selection of new ICRF core (defining) sources.

We tested a new approach to the scheduling using two IVS sessions R1541 (12JUL09XA) and R1591 (13JUN24XA). The results obtained with the first session are described in this paper in detail; the results obtained with the second session are very similar. However, a serious problem for schedule optimization is that southern stations are equipped with relatively small antennas, which makes it difficult to observe the weak sources. However, the much greater recording rate (as compared with the present R1/R4 operations) planned for the VLBI2010 observation mode (Behrend et al., 2008) can mitigate this problem.

The results of our work presented in this paper have shown that it's possible to add more observations of southern sources without degradation of the tested geodetic products, such as EOP and baseline length repeatability. Indeed, more study is needed to find an optimal trade-off between the quality of geodetic and astrometric (CRF) products. More detailed investigations are anticipated for different R1, R4, and other IVS network configurations and an extended list of southern sources. In particular, inclusion of non-ICRF sources shall be considered at the next stage, as well as sources near the southern polar cap. Also, testing with VLI2010 recording parameters would be useful for future scheduling.

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