Investigation of Earth Orientation Parameters for VLBA Calibrator Survey sessions

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Abstract About two thirds of the sources in the ICRF-2 catalog are estimated from VLBA Calibrator Survey (VCS) sessions. These sessions were carried out from 1994 to 2007 by a network of ten radio telescopes in North America with the densification of the celestial reference frame as the primary goal. A total of twenty-four VCS sessions, each with duration of 24 h, were observed in six campaigns. Coordinates estimated from these sessions have up to five times worse precision when compared to non-VCS sources from the ICRF catalog, which is to a great extent due to the limited number of observations. In the analysis of VCS sessions Earth Orientation Parameters (EOP) were estimated alongside source coordinates and other parameters. This, however, is not ideal, since the network is regional (only North American telescopes) and, therefore, not suitable for EOP estimation (EOP estimates w.r.t. IERS 08 C04 are up to 3 mas). We examine the effect of EOP estimation on source coordinates from VCS sessions and show that wrong EOP estimates generate systematic errors up to 1 mas. This is done by comparing solutions with EOP estimated in the analysis with solutions where EOP are fixed to IERS C04 08 combined series.

Keywords VLBA Calibrator Survey, Earth Orientation Parameters

1 Introduction

The ICRF2 (Ma et al., 2009) is to date the celestial catalog with the highest positional accuracy. It is derived from VLBI data up to early 2009 and consists of 3414 sources in total.The majority (2197) of the sources in the ICRF are observed by the so called VLBA Calibrator Survey (VCS) sessions. We will call sources observed only in these sessions VCS sources hereafter.The purpose of these sessions was to densify the consisting reference frame with as many sources as possible. Since observing time is limited these sources were only observed in a couple of, some only in one, sessions. This subsequently resulted in a low number of observations for these sources and, therefore, in lesser positional accuracy. Furthermore, the network used for the observations is the VLBA, see Fig. 1 for a plot of the station distribution. This network consists of ten stations across North America and is, therefore, regional in a global sense.

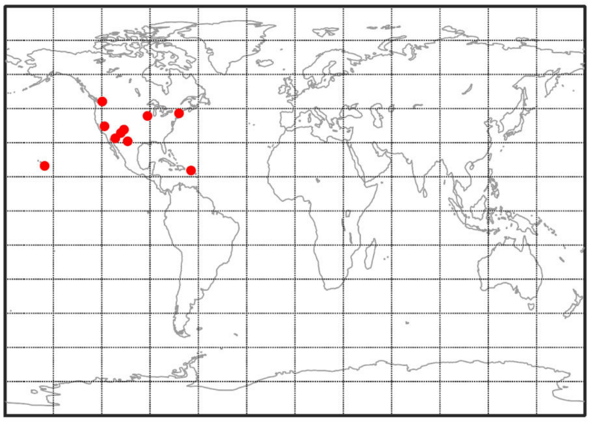

Fig. 1 Global distribution of the ten VLBA antennas.

The VCS sessions (23 in total) were separated into 6 campaigns, named VCS1 - VCS6 (Beasley et al., 2002; Petrov et al., 2003, 2005, 2006; Kovalev et al., 2007; Petrov et al., 2008), which took place from 1994 to 2007. However, recently (from end of 2014 until beginning of 2015) a second VCS campaign was conducted, the VCSII. The main aim of these new sessions was to observe the VCS sources again and increase their accuracy. However, this investigation concentrates on the old VCS sessions. No results from the new sessions are presented here.

2 Scheduling of the VCS sessions

In this section we will discuss the different scheduling techniques used for the VCS sessions. Scheduling a VCS session is a complicated task. On the one hand, as many sources as possible

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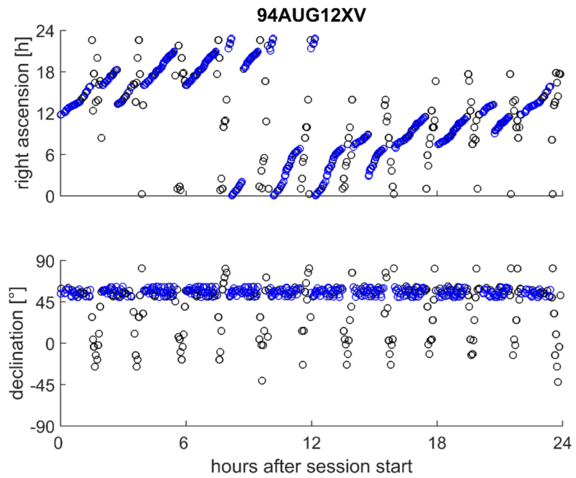

Fig. 2 Declination and right ascension of sources used in a typical schedule of the VCS1 sessions plotted from beginning to end of the session.

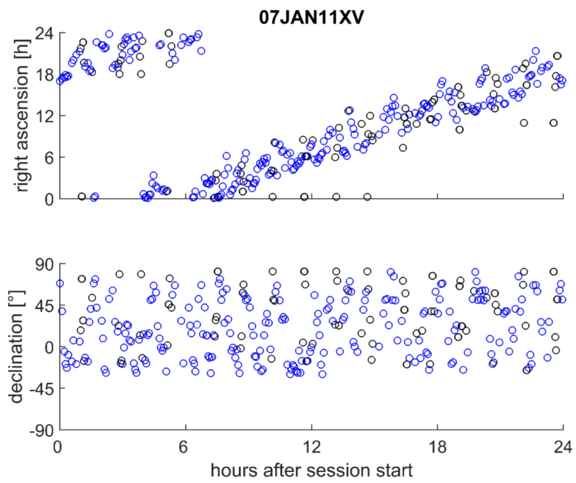

Fig. 3 Declination and right ascension of sources used in a typical schedule of the VCS2 - VCS6 sessions plotted from beginning to end of the session.

should be observed in one session, because observing time is a scarce resource. On the other hand, a good geodetic solution should be obtained in order to ensure high quality source coordinates. The problem with a geodetic solution is that many observations in different directions are needed to separate the height of the stations, clock and troposphere parameters. Therefore, a lot of time is spent on slewing. This is especially critical with the VLBA, since its telescopes have a very slow slew rate. Subsequently a compromise has to be found which provides as many observations as possible while still producing a good geodetic solution. The VCS sessions were scheduled using three different techniques.

In the first VCS sessions (VCS1) sources with a similar declination were observed on a meridian stripe, see Fig. 2 for an illustration of the schedule. This scheme was interrupted every 2 hours to observe non-VCS sources spread over right ascension and declination. This was done to ensure a good sky coverage and to observe sources which were later used to link the VCS sources to the ICRF.

For the VCS2 - VCS6 sessions the scheduling strategy was changed, see Figure 3 for an illustration of the schedule. The sources were also observed on a constant meridian but this time the declination was spread out over the whole observable sky (in this case up to approximately $-45°$ declination). Another difference to the VCS1 schedule is that the non-VCS sources (for linking the catalog to the ICRF) are included in the general strategy.

The recent VCS sessions (VCSII) are scheduled in a similar manner as the VCS2 - VCS6 sessions with the difference that sources are observed in clusters in order to keep the time a telescope slews to a minimum. Figure 4 illustrates the schedule.

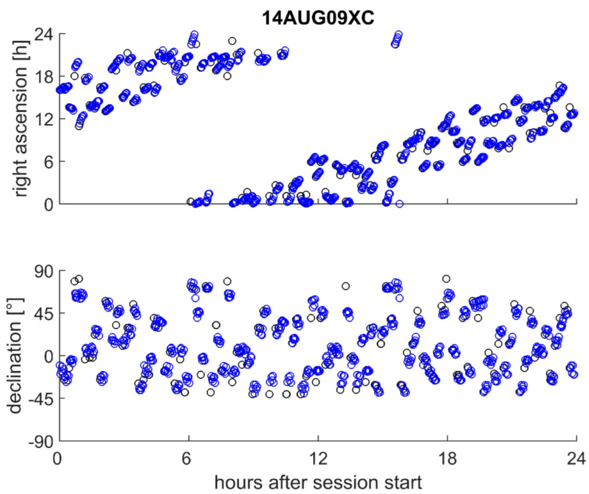

Fig. 4 Declination and right ascension of sources used in a typical schedule of the VCSII sessions plotted from beginning to end of the session.. (courtesy of David Gordon)

3 Estimating EOP from VCS sessions

When the ICRF2 was generated standard geodetic parameters, such as ZWD, clock parameters, EOP etc., were estimated alongside source coordinates. However, the quality of EOP is highly dependent on the size of the VLBI network. Therefore, EOP estimates of regional networks, such as the VLBA, are of questionable accuracy. Figure 5 depicts a series (all 23 VCS sessions in chronological order) of EOP estimates and formal errors w.r.t. the C04 08 time series (Bizouard et al., 2009; Gambis, 2004) which was used as a priori values. One can see that the estimates

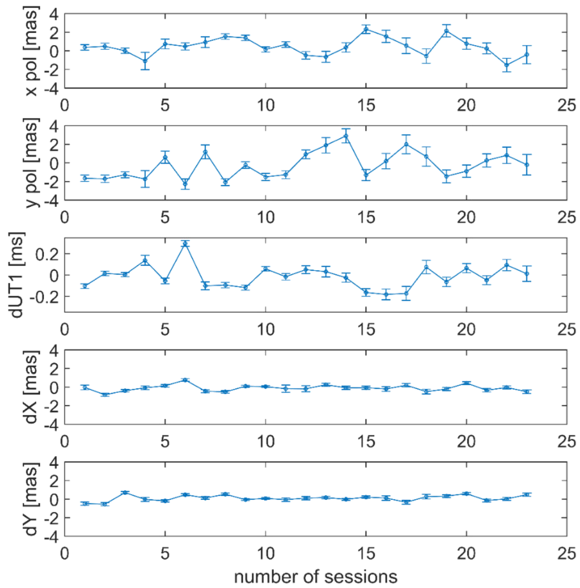

Fig. 5 EOP estimates and formal errors from 23 VCS sessions.

Table 1 RMS of the EOP estimates w.r.t. the C04 08 time series.

EOP	RMS
x-pole	0.95 mas
y-pole	1.31 mas
dUT1	0.11 ms
dX	0.34 mas
dY	0.31 mas

get quite large (up to $3mas$) at some of the sessions. RMS values for each EOP are provided in Table 1. The C04 08 is the most accurate EOP time series available, it includes polar motion data from GNSS observations.

4 Estimating source coordinates from VCS sessions

We estimated source coordinates from the 23 VCS sessions with a general geodetic parametrization:

- Station coordinates (NNR + NNT w.r.t. VTRF2008) (Böckmann et al. (2010))
- Source coordinates (NNR w.r.t. ICRF2 non-VCS sources)
- Troposphere (ZWD + gradients)
- Clock parameters
- EOP offsets

A second analysis was conducted as well, with the difference that EOP were fixed to the a priori C04 08 values. The difference in source position from both analysis strategies for the session 06DEC18XV is depicted in Figure 6. One can see a clear

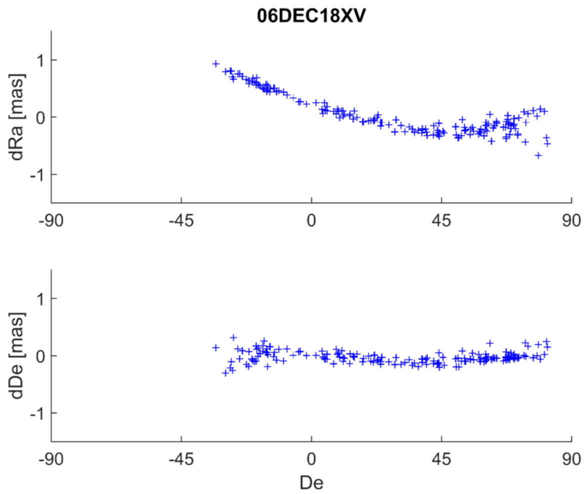

Fig. 6 Difference in source position from two analysis strategies estimated from session 06DEC18XV.

systematic effect which reaches up to 1 mas. This indicates that systematic errors might mitigate into the source coordinates.

4.1 Using different a priori EOP

Since the C04 08 EOP time series is estimated with data from different space geodetic techniques the estimates from VLBI might be a little larger due to technique dependent systematic. In order to investigate the magnitude of this effect we generated our own a priori EOP time series using interpolated EOP values from IVS-R1 and IVS-R4 sessions. These sessions were chosen because they are used to estimated EOP twice a week and are, therefore, perfectly suitable for the task. Figure 7 illustrates the interpolation for two (x-pole and y-pole) of the five EOP, with the IVS-R1 and IVS-R4 sessions being marked as 'R1' and 'R4' and the dots in between being the interpolated EOP values per day. For comparative reasons the C04 08 values (crosses) are also plotted.

In order to test the new a priori values the session 05JUN30XV was analyzed in a similar manner to Section 4. Once the interpolated a priori EOP values were used and once the C04 08 a priori EOP values were used. The comparison can be seen in Figure 8. On the left side the general approach with the C04 08 a priori EOP values is depicted. The systematics, here up to ˜1.8 mas, are clearly visible. The plot on the right side depicts the approach were a priori EOP values from IVS-R1 and IVS-R4 sessions were used. One can see that the systematic effect is reduced. However, the systematic effects do not disappear.

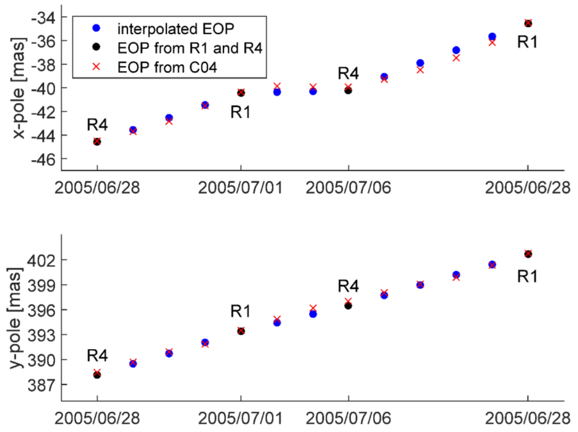

Fig. 7 Interpolation of EOP between solutions of IVS-R1 and IVS-R4 sessions.

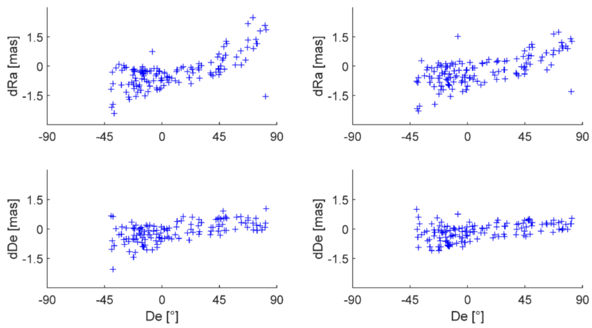

Fig. 8 Comparison of solutions with different a priori EOP. On the left the C04 05 time series was used as a priori and on the right the interpolates EOP from IVS-R1 and IVS-R4 sessions were used.

5 Difference in arc-length

In order to test if the systematic errors affect the relative position of sources, the difference in arc-length for each source with each other source was calculated for session 07JAN11XV, the result is illustrated in Figure 9. One can see that the distribution of differences is random. We can conclude that the errors are resulting in a rotation of the whole frame and have, therefore, no systematic effect on relative source position.

6 Conclusion

The VCS sources are observed by the VLBA network, which is located in North America, in only a couple of sessions. This network is not global but regional and, therefore, not suitable for high accuracy EOP estimation.

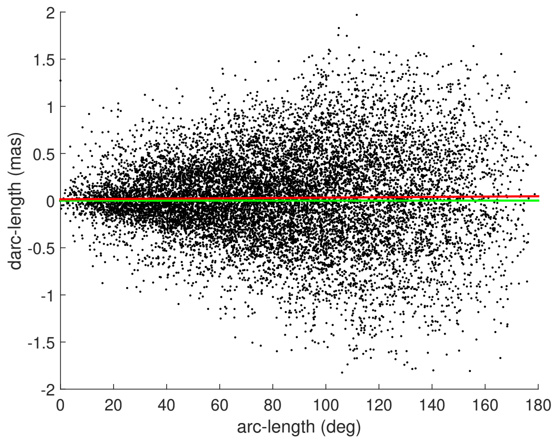

Fig. 9 Difference in arc-length of sources estimated from session 07JAN11XV.

When estimating EOP with these sessions, the offsets are larger than expected (up to approx. 3 mas). This offset is higher than one would expect for a precise a priori EOP time series such as C04 08 and is, therefore, an indication that the estimation process should be revised.

Systematic effects (up to 1 mas) can be found when comparing the source coordinates from a normal geodetic solution (estimated are: station coordinates, source coordinates, EOP, troposphere and clock parameters) to a geodetic solution where the EOP are fixed to the a priori values. Using EOP time series which are derived from VLBI observations only (EOP estimated from IVS-R1 and IVS-R4 sessions) as a priori values reduces the effect, but doesn't eliminate it. Since the arc-length is not affected systematically we can assume that the effect resembles a rotation of the whole frame which would leave the relative source position in tact.

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