SOURCE POSITIONS FROM VLBI COMBINED SOLUTION

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ABSTRACT. The IVS Combination Center at BKG is primarily responsible for combined Earth Orientation Parameter (EOP) products and the generation of a terrestrial reference frame based on VLBI observations (VTRF). The procedure is based on the combination of normal equations provided by six IVS Analysis Centers (AC). Since more and more ACs also provide source positions in the normal equations - beside EOPs and station coordinates - an estimation of these parameters is possible and should be investigated. In the past, the International Celestial Reference Frame (ICRF) was not generated as a combined solution from several individual solutions, but was based on a single solution provided by one AC. The presentation will give an overview on the combination strategy and the possibilities for combined source position determination. This includes comparisons with existing catalogs, quality estimation and possibilities of rigorous combination of EOP, TRF and CRF in one combination process.

1. INTRODUCTION

More and more IVS Analysis Centers (AC) are providing source positions in their Sinex files, beside EOPs and station coordinates. The task of the IVS Combination Center is to combine regular 24h-sessions of VLBI observations in a routine process. Currently, six IVS ACs are contributing to the combined solutions, among them 4 also provide source positions. Two different products are regularly submitted to the IVS data center: the rapid combination twice per week comprises EOP series and the quarterly solution every three month comprises EOP series and additionally station positions and a VTRF (terrestrial reference frame based on combined VLBI observations). Until now source positions have not been included in the routine combination process. With regard to the upcoming ITRF2013, where the IVS is highly encouraged to provide quasar coordinates, the combination procedure has been extended for these parameters. With regard to the upcoming ICRF3, the generation of a combined VLBI catalog with combined quasar coordinates based on based on combined VLBI data (VCRF) are investigated.

2. COMBINATION APPROACH

For the combination of source positions, all available VLBI 24h-sessions between 1984 and 2013 have been combined. Figure 1 shows a histogram which shows the distribution of the number of observations of sources. It can be seen (without going into details), that there is a large number of sources with very few observations and few number of sources which are regularly observed.

The combination is done on the level of datum free normal equations. The general combination approach for source positions is the same as for EOPs and station coordinates (ref. Böckmann et al. 2010). Thus, the additional implementations which are necessary for the combination of the source parameters can be embedded into the existing software, which allows to use approved modules for outlier test and weighting strategies (ref. Bachmann and Lösler 2012). The source parameters - right ascension (RA) and declination (DE) - of the individual ACs are transformed into equal apriori values, which are taken from the ICRF2. The general model of VLBI observations is based on the hypothesis, that the observed quasars and radio galaxies are situated very distant in space that they seem to be fixed observation targets. As a consequence, the ICRF does not contain velocities for source positions and no source velocities are estimated within the combination process. For the computation of equal apriori values, the common formula for apriori value transformation is applied (ref. Seitz 2009). Given two observations equations 1 and 2 the transformation can be formulated as follows:

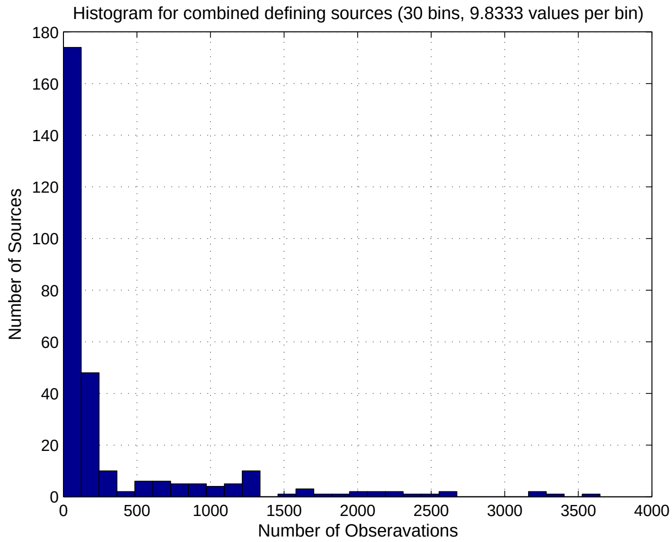

Figure 1: Observations of sources.

$$A_i x_i = b_i + v_i \quad \text{with} \quad x_i = p - p_{0i} \quad (i = 1, 2)$$
$$x_2 = p - p_{01} + p_{01} + p_{02} = x_1 + (p_{01} - p_{02}).$$

Where A_i denotes the design matrix (or coefficient matrix) of observations i, x_i denotes the vector of variables of observation i, b_i the expected value and v_i the correction of observation i.

As the source positions are supposed to be time-independent, a shift of the epoch is not applied.

For the estimation of the individual solution of each AC, source positions are estimated applying No-Net-Rotation (NNR) constraints to the parameters of the "Defining sources", which are assigned to be reliable sources of radiation due to their position stability and their source structure index (ref. Fey et al. 2009 (IERS TN 35)). Applying NNR conditions on spherical coordinates contains no rotation with respect to a reference and no change in the orientation with respect to a reference frame is carried out ($r_0 \times dr$). Practice showed that applying NNR conditions for station source positions and does not suffice to solve the datum problematic of the normal equations system. Additionally, station coordinates are kept fixed when source coordinates are estimated.

The classification of sources also comprises "Special handling sources". These sources have been identified as unstable sources. Within the ICRF2 determination, they have been identified by applying various statistics on their parameters (right ascension RA and declination DE) like weighted root mean square (WRMS) variation about the mean and χ^2 tests per degree of freedom. Within the combination of source positions, special handling sources are threaten as free parameters without applying any constraints (thus no NNR condition). Within the ICRF2 determination, 39 special handling sources have been defined overall.

After the generation of individual solutions, outlier tests are applied on the parameter. The outlier test for source positions is similar to the outlier test of EOP and station coordinates. A Least Median of Squares (LMS) estimation is applied. The median is equal to the observation where the square residual is minimal ($med(v_i^2) \to \min$). The variance factor is than estimated by

$$\sigma_{LMS} = 1.4826 \left(1 + \frac{5}{n-u}\right) \sqrt{\min\ med(v_i^2)}$$

following Rousseeuw/Leroy 2003. An outlier (∇_i) is detected, if the test value is larger than a given threshold k within the data set. Supposed $k = 3$ - according to the three-sigma-rule - this is leading to

$$\nabla_i = \begin{cases} \text{false, if } |v_i| \le k\sigma_{LMS} \\ \text{true, else.} \end{cases}$$

An outlier is identified if the difference of the value and the median is bigger than three times the standard deviation of the LMS estimator.

The combined solution is estimated by stacking the individual normal equations with equal apriori source positions. The individual weight of the contributing solutions is determined by a variance component estimation (VCE). Within the VCE, observation groups are composed and variance factors for each group are introduced. In order to compensate an over-weighting of individual contributions which are all using the same software package, the groups within the VCE are arranged by software packages (one package per group). The resulting weighting factors are then used to scale the individual normal equations before they are stacked to generate the combined solution. The stacked NGL is solved by fixing station coordinates and EOPs and applying NNR conditions on defining sources.

Figure 2 shows the individual solutions and the combined solution for session 13OCT24XE (R4608).

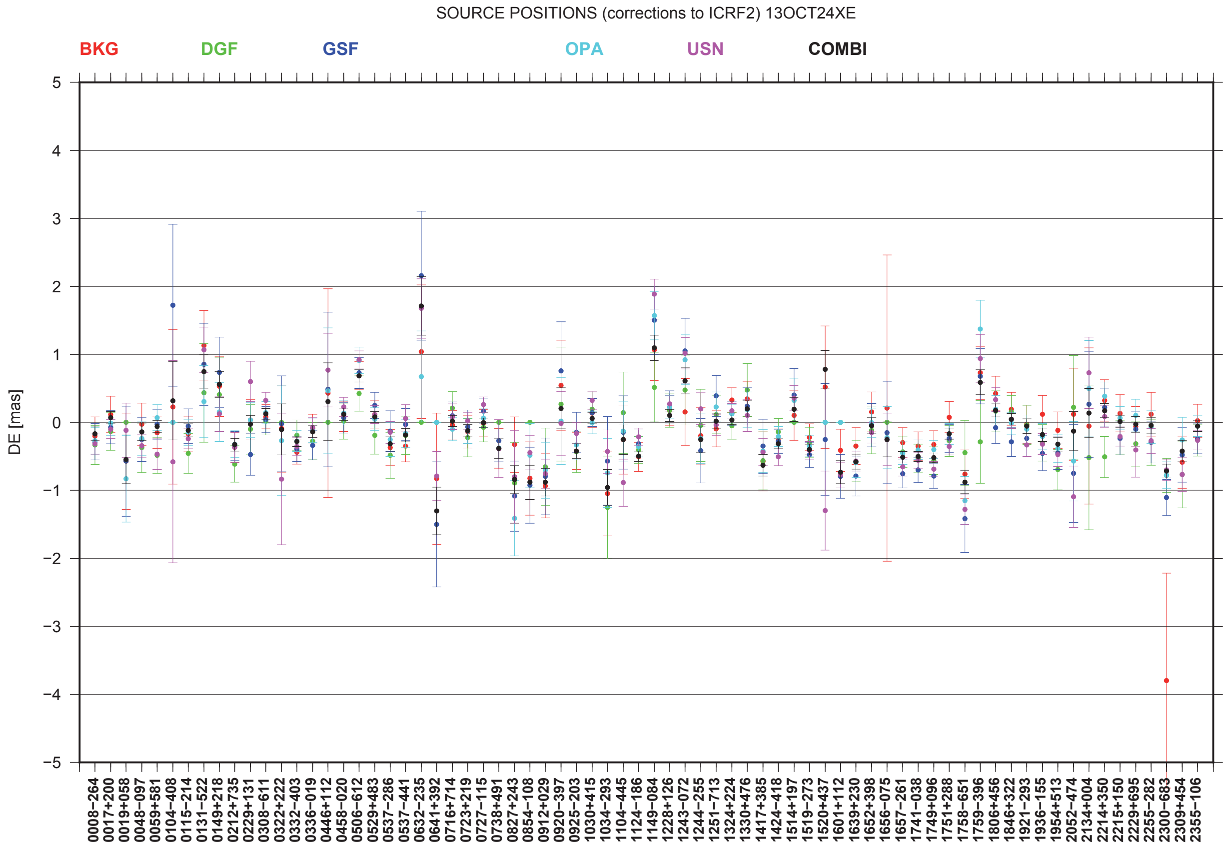

Figure 2: Source positions in declination for session 13OCT24XE

The figure shows, that the residuals for most sources are within a range of $\pm 1 mas$ for this session.

Beside the generation of time series composed of combined VLBI observations, first steps of a combined celestial reference frame as a global solution have been implemented. For this purpose, the sessions of the CONT08 campaign have been used to compile a first (very) small catalog of combined source positions. 15 24h VLBI sessions have been combined to one "celestial reference frame" containing 78 sources. Figure 3 shows the results of the combined catalog in declination and right ascension for 78 sources, which have been observed during the CONT08 campaign with respect to ICRF2. The comparison shows an agreement of the positions of ≈ 0.2 mas, which corresponds to a mean absolute difference of 0.12 mas in right ascension and 0.16 mas in declination.

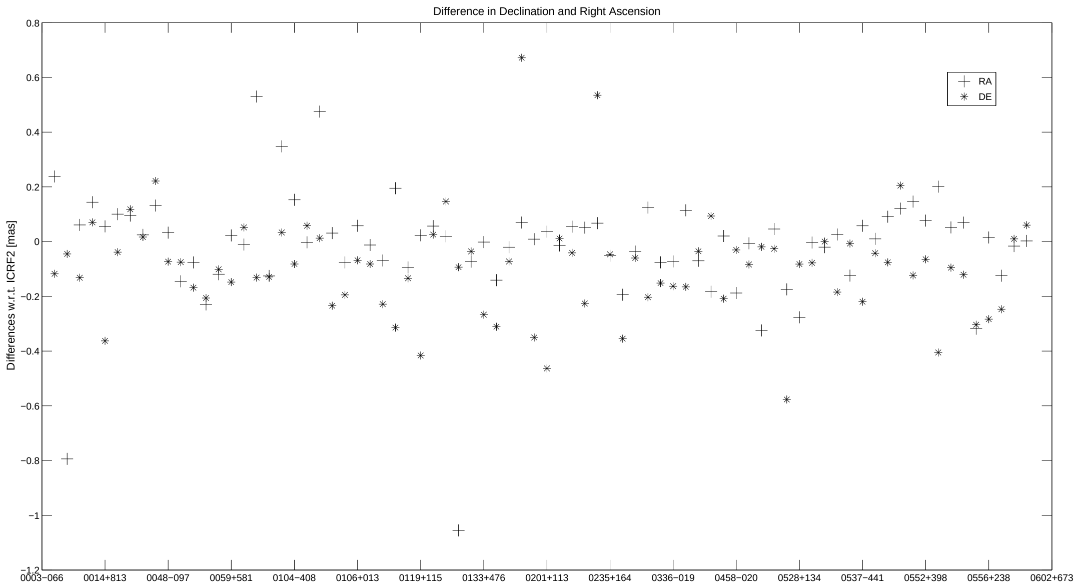

Figure 3: Differences in declination and right ascension for 78 sources of a first combined CRF.

3. SUMMARY AND OUTLOOK

The integration of sources within the routine combination process has been done successfully and first analyses look promising, for individual session combination as well as for a combined "global solution". In the near future, more Analysis Centers will provide source positions in the regular sinex contribution to the combined solution, which will be integrated into the combination process as soon as they are available. The next steps will be the analysis of the combined time series of source coordinates, to refine the combination procedure and to increase the number of sessions and sources within the combined solution. Furthermore, the number of sessions for a combined source catalog will be increased in order to include the hole time span of VLBI observations into a VCRF. Also the resulting source position stability with a complete VCRF will be studied and the results will be compared to the results of the ICRF2 generation and other catalogs.

4. REFERENCES

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