The GFZ VLBI Solution: Characteristics and First Results

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Abstract At GFZ, we have created a contribution for ITRF2013 following the analysis configuration specified by the IVS Analysis Coordinator. The models mostly comply with the IERS Conventions (2010). For the sake of consistency, the ICRF2 defining sources were fixed on their catalog positions. The positions of other sources, including the special handling sources, were estimated together with the coordinates of the terrestrial network stations and the Earth orientation parameters. The standard auxiliary parameters—clock, tropospheric zenith delays and gradients—were estimated as well, applying a 1-h resolution for clock and zenith delays and a 6-h resolution for gradients. The resolution of auxiliary parameters was changed, if the density of observations demanded it. The solution contains 5,813 24-h VLBI sessions between 1979 until the end of 2013. The analyses were done with the VieVS VLBI software.

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1 Introduction and General Characteristics

At the IVS Associate Analysis Center (AC) at GFZ Potsdam, a VLBI solution has been obtained using the VLBI analysis software VieVS (Boehm et al., 2012). With this effort the AC GFZ aims to contribute to the upcoming realization of the International Terrestrial Reference System (ITRS), the International Terrestrial Reference Frame ITRF2013. Currently, the GFZ VLBI solution starts at the post-processing level with the NGS file (`http://lacerta.gsfc.nasa.gov/mk5/help/dbngs_format.txt`), which is created from the database format vers. 4 or higher. At this stage, the ambiguities from broadband synthesis have been fixed and the ionospheric delays have been determined. We have downloaded the complete historical archive available from IVS Data Centers, more specifically from the BKG Data Center (`ftp://ivs.bkg.bund.de/pub/vlbi/ivsdata/ngs/`). By the end of February 2014 when the GFZ VLBI solution was completed, the archive contained 5,984 non-Intensive sessions. The GFZ solution includes 5,813 of those sessions (97%). The neglected sessions mainly suffer from larger numbers of bad observations due to a variety of reasons, e.g., radio frequency interference, or from bad station or baseline performances due to sub-ambiguities.

In general, the number of observations per session has been increasing since 1979 (Figure 1). In the middle of the 1990s a smaller group of sessions significantly exceeds the mainstream: the sessions featuring the VLBA (`http://www.vlba.nrao.edu/`). Those sessions generally have many more observations than the average and also include the session with the most observations: 99DEC20XA (30,510 observations), a session observed by the ten VLBA antennas plus a global network of ten IVS antennas.

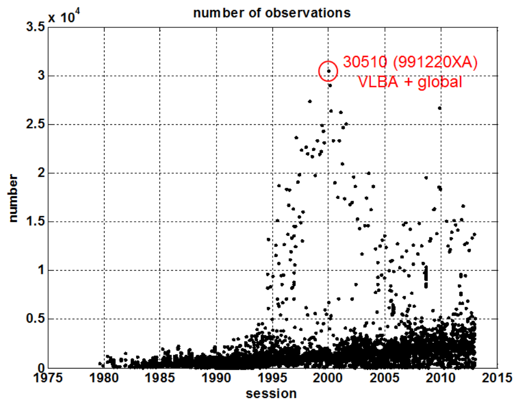

Fig. 1 GFZ VLBI solution: the number of observations per session has been increasing since the beginning in 1979.

The generally increasing number of stations per session (Figure 2) does not exceed 20, with one exception: the International Year of Astronomy (IYA) session, 09NOV18XA (`http://ivscc.gsfc.nasa.gov/program/iya09/`). With 32 stations, this individual session features the largest number.

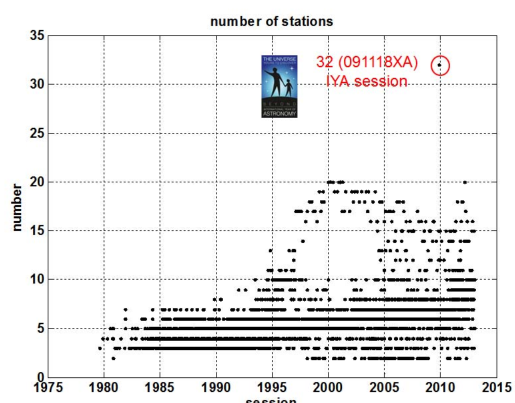

Fig. 2 GFZ VLBI solution: the number of stations per session does not exceed 20 with only one exception: the IYA session.

Figure 3 shows the number of sources observed per session. In the first years from 1979 until about 1989, one can see that there were not more than about 20 radio sources observed in a single 24-h VLBI session. Then, in 1990, the number of sources started to increase until about 2002 when the average number of sources per session settled roughly around 50. Some groups of sessions contain significantly larger numbers of sources. The session type with the largest number of sources is the VLBA Calibrator Survey (VCS). Among them we find the session with the most radio sources observed, 05JUL09XV, a VCS-5b session (Kovalev et al., 2007) with 268 sources.

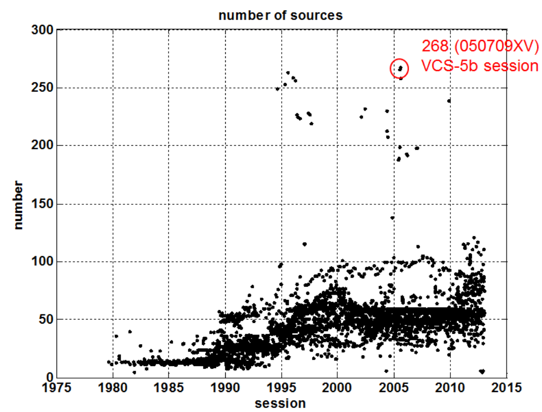

Fig. 3 GFZ VLBI solution: the number of sources per session.

The duration of the sessions has not varied a lot from 1979 until the end of 2013. With a few exceptions, it has stayed around 24-h. With 62-h, the longest session is also the earliest of our archive: 79AUG03XX. While the duration mostly stays the same, the starting time of the sessions varies significantly, in particular in the early years. Since about 1995, well-defined starting times of individual session types have been introduced mainly varying between 12:00 and 18:30 UTC (Figure 4). With its starting time at 0 h UTC since 2008, the CONT (`http://ivscc.gsfc.nasa.gov/program/cont08/`) type of session is an important exception. CONT05 has also been re-correlated to provide sessions between integer UTC days. Because the observation period fits to the ones of the other space geodetic techniques and due to the superior quality, the CONT type of session is specifically suitable for comparisons with other space geodetic techniques.

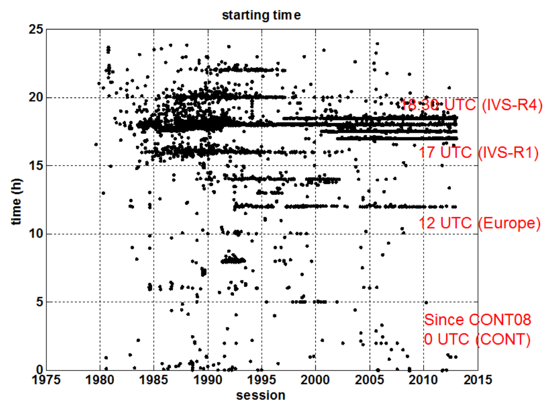

Fig. 4 GFZ VLBI solution: the starting time of the sessions.

2 Analysis Options and Parameterization

The analysis options applied for the GFZ VLBI solution follow the specifications given by the IVS Analysis Coordinator for contributions to ITRF2013 (`http://lupus.gsfc.nasa.gov/IVS-AC_ITRF2013.htm`). Most of the applied models are valid for several space geodetic techniques and are thus specified by the IERS Conventions (Petit & Luzum, 2010). Those will not be discussed explicitly here. This section focuses on the analysis options which are not specified by the IERS Conventions or are treated in a different way. The Conventions recommend a model of S1-S2 tidal atmosphere pressure loading. For the sake of consistency, atmosphere pressure loading is not applied because the IGS contribution to ITRF2013 does not consider it. Apart from the Conventions, which recommend the use of APG a priori gradients (Boehm et al., 2013), an updated version of the DAO a priori gradient model (MacMillan & Ma, 1998) was specified for the ITRF2013 contribution. The axis offset correction is based on axis offset lengths given in the updated list (`http://lupus.gsfc.nasa.gov/files_IVS-AC/gsfc_itrf2013.axo`) provided by GSFC. For the antenna thermal expansion model (Nothnagel, 2008) some of the dimensions of the antennas (`http://vlbi.geod.uni-bonn.de/Analysis/Thermal/antenna-info.txt`) have been added; others have been revised.

The most prominent difference between a standard solution and this ITRF2013 contribution is the handling of the radio sources. The positions of the ICRF2 (Fey et al., 2009) defining sources were fixed on ICRF2 catalog values, while the positions of ICRF2 special handling and other sources were estimated (and reduced from the reported normal equations). Coordinates of all terrestrial stations are estimated as session-wise offsets. For the EOP, the 24-h sessions of the ITRF2013 contribution fall into two categories:

- > 3 station networks, for which standard EOP parameterization including adjustments to the celestial pole coordinates X and Y, terrestrial pole coordinates x-pole and y-pole, UT1–UTC, and their first time derivatives has been applied, or
- the 2–3 station networks, for which a limited parameterization has been applied for EOP: x-pole, y-pole, and UT1–UTC.

These and other technical solution characteristics are summarized in a document (`http://lupus.gsfc.nasa.gov/files_IVS-AC/ITRF2013_checklist_v2014Feb07.pdf`) issued by the IVS Analysis Coordinator.

With the version of VieVS modified at GFZ it was possible to follow the specified solution requirements. However, the EOP parameterization in VieVS is a linear spline with equally spaced supporting points at integer UTC days, labeled by some authors as piece-wise linear function, while the IVS requirements for ITRF2013 specify the offset and rate parameterization referring to an epoch close to the middle of the VLBI session. In addition to these two parameterizations, the ITRF2013 input for EOP of the other space geodetic techniques (GNSS, SLR, and DORIS) refers to 12 h UTC. For ITRF2013, the IVS Combination Center at BKG will transform both VLBI EOP parameterizations to the offset and rate representation at 12 h UTC. Consequently, for the first time the IVS input to ITRF2013 will be at the same epoch as the other space geodetic techniques. Since the EOP determined by several VLBI groups refer to an epoch close to the middle of the session, the large differences of the starting times (Figure 4) may cause an inconsistency of the EOP if the parameter definition epoch is not exactly considered. In the future, AC GFZ intends to contribute to ICRF, ITRF, and EOP time series solutions within the framework of IVS, IERS, and IAU.

3 GFZ VLBI Solution: First Results

In this section we present a selection of results obtained with the GFZ VLBI solution.

The GFZ VLBI solution includes in principle all IVS stations, currently 157, which have ever participated in an astrometric or geodetic IVS session. Since some of the VLBI sessions are observed by networks of rather low numbers of antennas, the terrestrial constraints are most reliable if the maximal number of stations is included. Thus, all available ITRF2008 VLBI stations were used for the session-wise NNR and NNT constraints. In the cases where an episodic motion (earthquake, seismic event, antenna repair) had significantly affected a station, the station was excluded from the constraint after the event but kept before. Figure 5 shows such an event, the Tōhoku earthquake, which affected the coordinate time series of adjacent sites, for example the time series of the 32-m antenna in Tsukuba, Japan. A big advantage of ITRF2013 compared to ITRF2008 will be that it will contain many more stations located in the southern hemisphere. Figure 6 exemplarily shows the time series of coordinate adjustments of the new VGOS antenna KATH12M in Katherine, Australia, where the time series are now long enough to reliably estimate velocities.

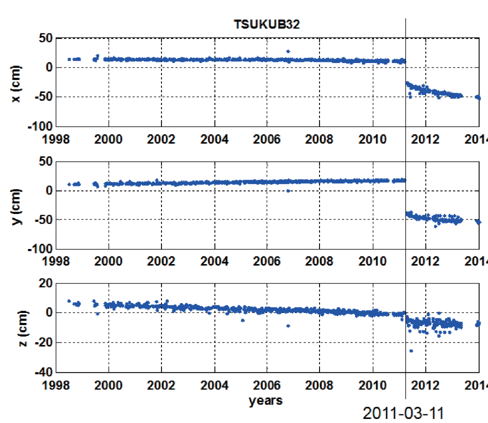

Fig. 5 GFZ VLBI solution: coordinates of TSUKUB32 relative to the respective mean value.

All of the observed radio sources were in principle included in the GFZ VLBI solution. Occasionally, for the sake of a positive redundancy, it was necessary to exclude single radio sources with insufficient number of observations from the session-wise analysis. Since the GFZ VLBI solution includes more recent sessions than the solution served for the creation of ICRF2, it is evident that the number of sources of the GFZ solution (3,559) is slightly larger than the number of ICRF2 sources (3,414). For some of the radio sources, we observed significant non-linear variations (see Mora-Diaz et al., this volume). One example is shown in Figure 7. Because the ICRF2 defining source positions were fixed to their ICRF2 catalog values (see Section 2), no local celestial NNR constraint had to be used.

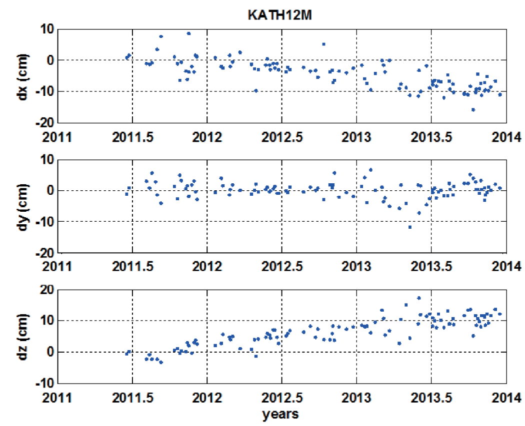

Fig. 6 GFZ VLBI solution: adjustments to the coordinates of KATH12M.

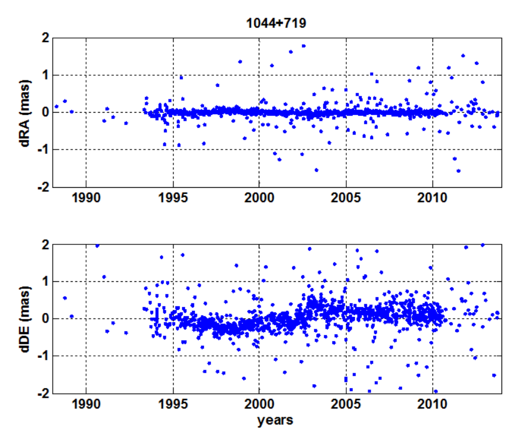

Fig. 7 GFZ VLBI solution: adjustments to the coordinates of 1044+719.

The EOP have been determined by our solution as well. We found that a large effect on the EOP is due to the relatively strong variation of the terrestrial station network. To illustrate this effect, Figure 8 shows the adjustments to the celestial pole coordinate X, color-coded for the ten most recent and black for the other session types. Depending on the type of session, large differences of the RMS can be found for all EOP. As an example, Table 1 gives the numerical results for the celestial pole X coordinate.

Table 1 RMS of the celestial pole X coordinate depending on the type of session.

Type of session	RMS [μas]
IVS-R1	394
IVS-R4	232
IVS-T2	314
APSG	486
VLBA & global + VLBA	183
CRF	1420
R&D	422
EUR	1051
JADE	2147
CONT	144
Other	1378

The RMS varies between 144 μas for the various CONT sessions and 2,147 μas for the JADE type of session. In general, it can be found that spatially limited networks, e.g., national (JADE) and regional (EUR) networks, cause large RMS values, while networks with a global extension (IVS-R1, IVS-R4, and CONT) result in smaller RMS values for the EOP. Session types in which the EOP are not among the original scientific purposes, e.g., CRF sessions, also do not provide good RMS values. The CONT RMS is about half as large as the respective values of the standard IVS types of session (IVS-R1, IVS-R4), which is due to the larger number of observations obtained by a denser network. This shows that with the future VGOS networks and schedules, one can expect further improvement for the EOP RMS. Note that from the celestial pole coordinates, which were derived w.r.t. the conventional IAU2000/2006 models, the free core nutation model has not been considered. Thus, the RMS derived and discussed here can only be compared and interpreted relative to each other, and they do not reflect the current accuracy capability of VLBI for the determination of EOP.

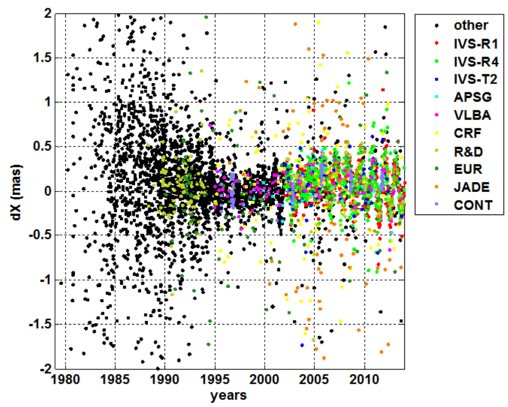

Fig. 8 GFZ VLBI solution: adjustments to the celestial pole X coordinate.

References

1. Boehm J., S. Boehm, T. Nilsson, A. Pany, L. Plank, H. Spicakova, K. Teke, & H. Schuh. The new Vienna VLBI software. In S. Kenyon, M. C. Pacino, and U. Marti (eds.) International Association of Geodesy Symposia, 136, doi:10.1007/978-3-642-20338-1_126, 1007–1011, 2012
2. Boehm J., L. Urquhart, P. Steigenberger, R. Heinkelmann, V. Nafisi, & H. Schuh. A priori gradients in the analysis of space geodetic observations. In Z. Altamimi, and X. Collilieux (eds.) International Association of Geodesy Symposia, 138, doi:10.1007/ 978-3-642-32998-2_17, 105–109, 2013
3. Fey A.L., D. Gordon, & C.S. Jacobs. The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry. IERS Technical Note. 35, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, 2009
4. Kovalev Y.Y., L. Petrov, E.B. Fomalont, & D. Gordon. The fifth VLBA calibrator survey: VCS5. *The Astronomical Journal*, 133, doi:10.1086/511157, 1236–1242, 2007
5. MacMillan D.S., & C. Ma. Using meteorological data assimilation models in computing tropospheric delays at microwave frequencies. *Phys. Chem. Earth*, 23, 97–102, 1998
6. Mora-Diaz J.A., V. Raposo-Pulido, R. Heinkelmann, M. Xu, T.J. Nilsson, M. Karbon, L. Liu, B. Soja, C. Lu., & H. Schuh. Modeling special handling source positions in the GFZ VLBI solution. in Proc. of the 8th IVS General Meeting, this volume
7. Nothnagel A.. Conventions on thermal expansion modelling of radio telescopes for geodetic and astrometric VLBI. *Journal of Geodesy*, 83, doi:10.1007/s00190-008-0284-z, 787–792, 2008
8. Petit G., & B. Luzum. IERS Conventions (2010). IERS Technical Note. 36, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, 2010