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# VLBI Solution DGFI01R01 Based on Least-Squares Estimation Using OCCAM 5.0 and DOGS-CS

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**Abstract**

The latest International Terrestrial Reference Frame realisation (ITRF2000) includes solutions of all space-geodetic techniques. All three VLBI solutions contributing to the ITRF2000 are computed using the CALC/SOLVE software package. Therefore a solution based on a different software should provide an insight in the reliability of VLBI results and could provide a higher reliability to a VLBI-determined terrestrial reference frame.

This paper presents the first DGFI VLBI solution computed with OCCAM 5.0 and DOGS-CS using the least-squares method (DGFI01R01). It is based on observation data from 2067 VLBI sessions between 1984 and the end of 2000, available from the IVS and CDDISA. The solution strategy is discussed. Comparisons of the coordinates and velocities of the 47 stations of the DGFI01R01 and other VLBI solutions with the ITRF2000 indicate that it is a competitive VLBI solution but needs still further improvement.

## 1. Solution Description

### 1.1. Observation Data

The observation data used for the solution was selected from 3400 sessions taken from NASA's CDDISA server as well as the IVS data servers. To reach a reasonable homogeneity of the data, we used only 24 h or longer sessions with at least three participating stations observing at least 250 times. Only non-mobile telescopes with sufficient observations during an adequate time span are included in order to obtain reliable velocities. If a telescope had less than 100 observations during a session, its observations were not used for this session. These strict criteria led to a basis of 2067 sessions between 1984 and the end of 2000 with 47 stations observing 1,933,748 group delays to 684 sources. The observation data is, in particular in its temporal evolution, quite inhomogeneous. This is due to varying objectives of geodetic VLBI as well as technological progress. For example, only 8 of the 47 stations in the solution have more than 400 sessions, 18 stations have between 400 and 50 sessions and 8 stations in the solution have less than 20 sessions. Further statistics concerning yearly averages of VLBI observation data used can be found in Figures 1 to 4.

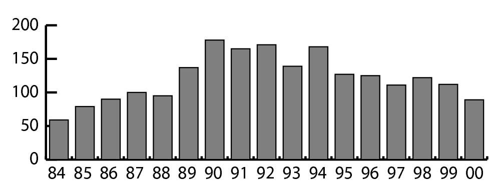


Figure 1. Number of sessions per year.

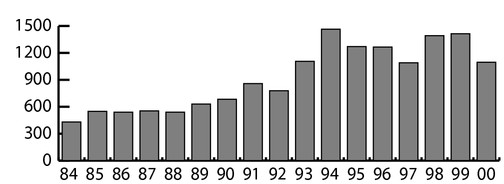


Figure 2. Yearly avg. # observations per session.

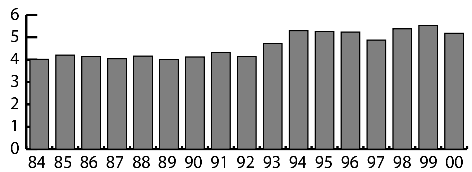


Figure 3. Yearly avg. # stations per session.

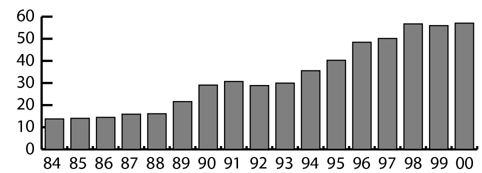


Figure 4. Yearly avg. # sources per session.

## 1.2. Solution Strategy

In a first step, datum-free normal equations for each single session were set up using OCCAM 5.0 LSM and transferred to the DOGS-CS software, which is beeing developed at the DGFI to accumulate and to solve normal equations. The normal equations included station coordinates at epoch 1997.0, velocities, EOP and auxiliary parameters such as clocks and troposphere. After the EOP and the auxiliary parameters were reduced from the original normal equations, they were accumulated to one datum-free normal equation system. To avoid distortion of the geometry of the solution and to provide a connection to existing terrestrial reference frames, the datum defect was removed by applying NNT and NNR conditions for coordinates and velocities to 10 well-determined stations w.r.t. ITRF2000 (see [1]) (Kauai, Kokee, Fairbanks, Westford, Fortaleza, Onsala, Wettzell, Hartebeesthoek, Kashima, Hobart).

## 1.3. Results

In the following section, illustrations and a short description of the velocities of DGFI01R01 together with the site velocities of ITRF2000 can be found (Figures 5, 6). Additionally, time series of residual coordinates of single session solutions w.r.t. DGFI01R01 (Figure 7) and EOP adjustments w.r.t. IERS C04 fixing stations to DGFI01R01 (Figure 8) are presented.

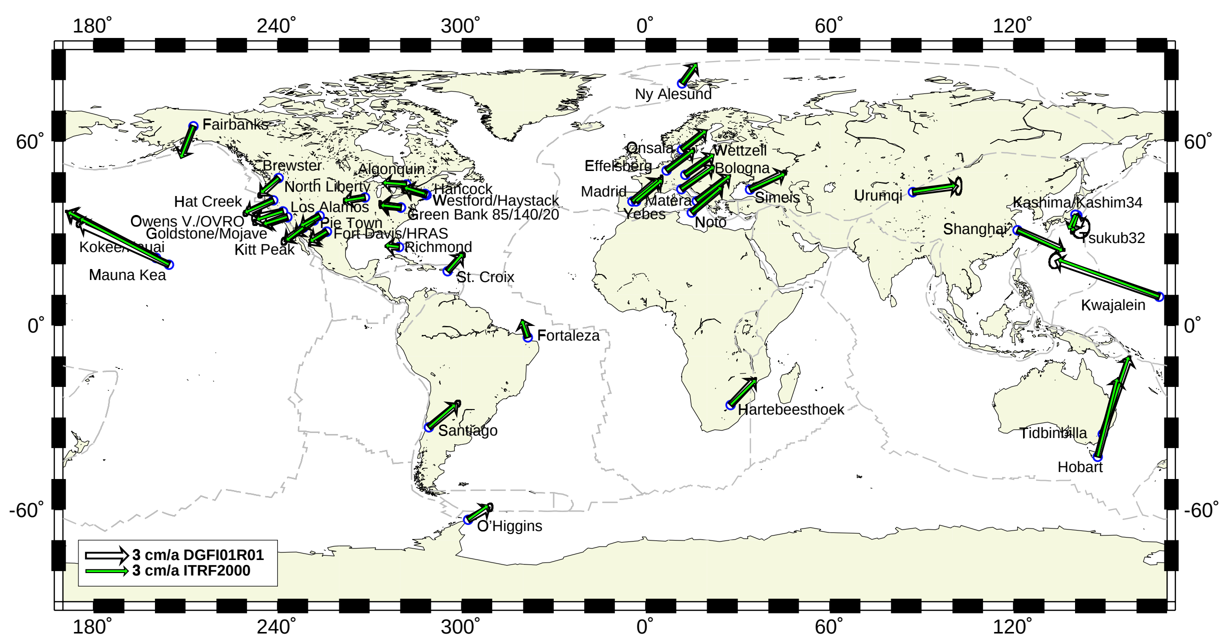


Figure 5. Comparison of horizontal site velocities from ITRF2000 and DGFI01R01.

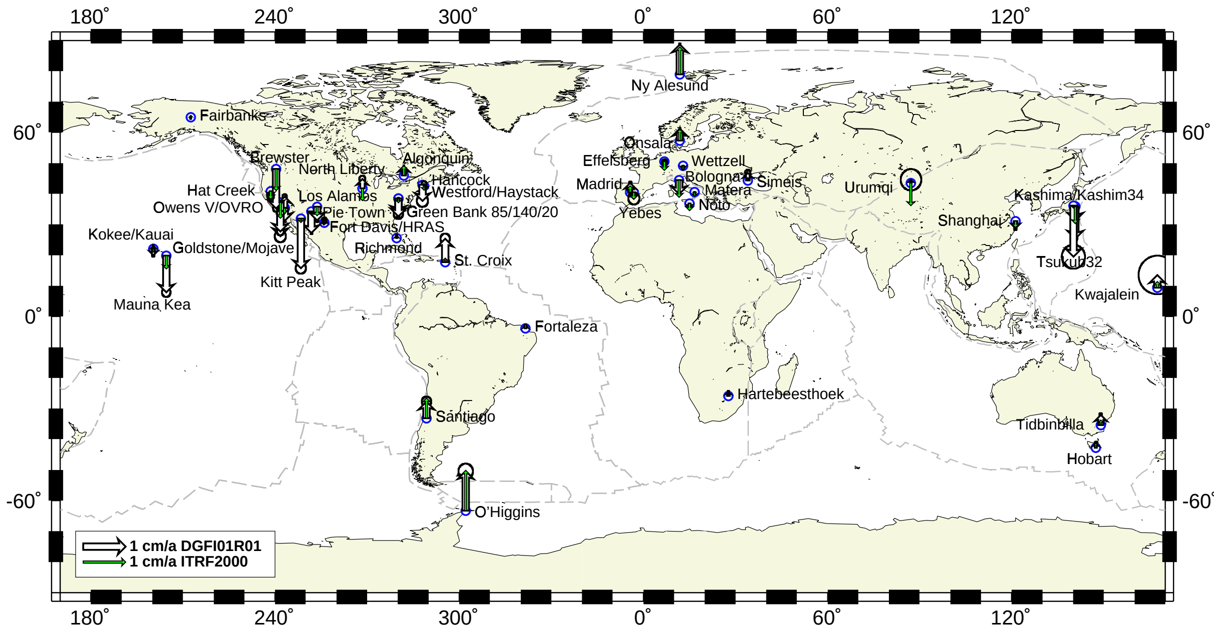


Figure 6. Comparison of vertical site velocities from ITRF2000 and DGFI01R01.

The comparison of the horizontal velocities of DGFI01R01 with the ITRF2000 (Figure 5) shows no significant differences regarding the error ellipses. The greatest differences are at the Tsukuba 32 m telescope, the Mauna Kea VLBA and O'Higgins. The problems are more obvious in the height velocities (Figure 6); they differ significantly for almost all VLBA and Tsukuba 32 m. This is supposed to be caused by the short time series of sessions for these telescopes in DGFI01R01 and an unclear modeling of a jump in height due to an antenna repair at Tsukuba in April 1999.

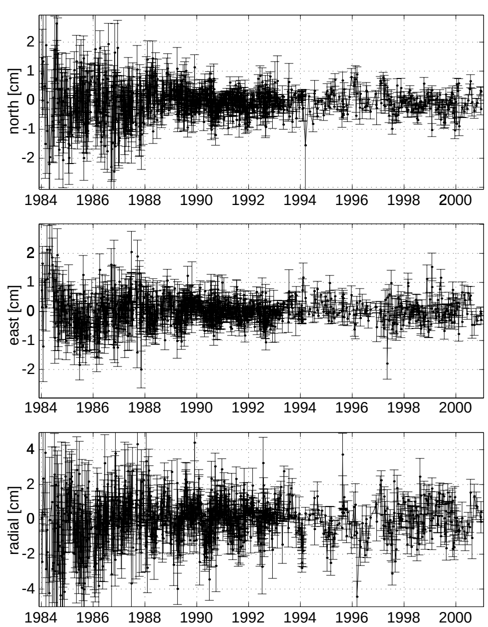


Figure 7. Residuals of WESTFORD session solutions w.r.t. DGFI01R01.

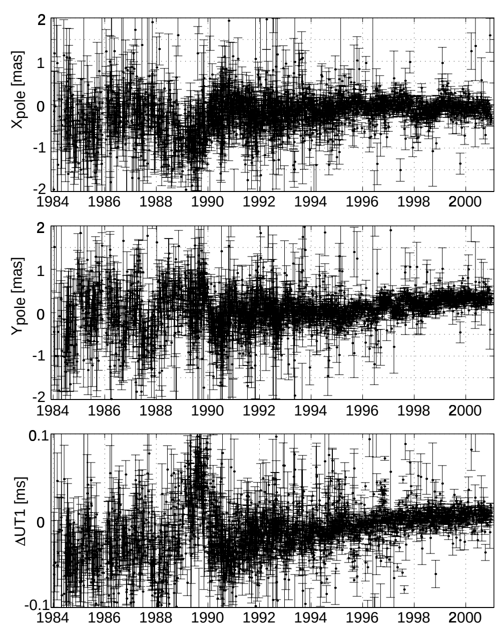


Figure 8. DGFI01R01 EOP adjustment w.r.t. IERS C04.

Figure 7 shows a coordinate time series of DGFI01R01 for the Westford telescope. It is computed by minimizing the translation and rotation components of all stations in each single session w.r.t. DGFI01R01. Neither was the inner geometry distorted nor the single session scale affected. Three results are valid for almost all coordinate time series of all stations in the solution. Firstly, the results of sessions before 1989 are at least twice as noisy than after 1988, which is probably caused by technological reasons such as uncooled receivers. Secondly, the residual horizontal coordinates after 1988 are smaller than ± 1 cm, the vertical components smaller than ± 2cm. Thirdly, many components show an annual signal with different orders of magnitude for each station and additionally for horizontal and vertical components.

In Figure 8, EOP adjustments w.r.t. to IERS C04 are presented. They were obtained from single session solutions fixing the DGFI01R01 coordinates and velocities. All sessions in the solution were used for their determination, including non-global networks like the EUROPE series, which are not sensitive for the Earth's orientation in space. Some systematic differences between the DGFI01R01 series and IERS C04 are obvious. Between 1996 and the end of 2000, the two series agree quite well at the order of magnitude of 0.5 mas for pole coordinates and 0.03 ms for $\Delta$UT1 respectively. More scatter is between 1991 and 1996, and the values of $\Delta$UT1 seem to have a linear trend w.r.t. IERS C04. The epoch before 1991 shows big systematic bumps with amplitudes comparable to bumps in other VLBI EOP series, but a with different pattern.

## 2. Comparisons of DGFI01R01 and other VLBI Solutions with ITRF2000

To get a closer insight in the qualities of DGFI01R01, it is reasonable to compare it together with other VLBI solutions to the actual terrestrial reference frame ITRF2000. More than 20 years of high-precision VLBI observables allow determination of very stable velocities for at least 40 telescopes. Therefore, deficiencies of DGFI01R01 as well as systematic differences between VLBI solutions and the ITRF2000 should easily be detected. Table 1 summarises some characteristics of the three compared VLBI solutions, the DGFI solution DGFI01R01, BKGTRA00 by the BKG, Leipzig, and GSFC's GLB2001cn (see [2]). They differ partially, e.g. in the modeling of the celestial reference frame. Please note that two independent software packages were used.

Table 1. Solution characteristics.

| | **DGFI01R01** | **BKGTRA00** | **GLB2001cn** |
|---|---|---|---|
| **Software** | OCCAM5.0 LSM/DOGS-CS | CALC/SOLVE | CALC/SOLVE |
| **# sessions** | 2067 | 2376 | 3208 |
| **data span** | 1984 - 2000 | 1984 - 2000 | 1979 - May 2000 |
| **# stations** | 47 | 51 | 137 |
| **cel. frame** | fixed to ICRF-Ext1 | NNR of 209 sources w.r.t. ICRF-Ext1 | estimated |
| **EOP** | estimated | estimated | estimated |
| **datum, coordinates** | NNR+NNT of 10 stations w.r.t. ITRF2000 | NNR+NNT of 12 stations w.r.t. ITRF97 | NNR+NNT of 12 stations w.r.t. ITRF2000 |
| **datum, velocities** | NNR+NNT of 10 stations w.r.t. ITRF2000 | NNR+NNT of 5 stations w.r.t. ITRF97 | NNR of 5 stations w.r.t. ITRF2000 + minimized hor. ajd. of 5 st. w.r.t. NUVEL-1A |

All three VLBI solutions were subject to a 14 parameter Helmert transformation w.r.t. the ITRF2000, using almost the complete set of 47 stations of the DGFI solution as identical ones. As the twelve translation and rotation parameters are degrees of freedom, only the scale and its rate can be considered as objective information. The difference in scale is -1.05 ppb and -0.04 ppb/y for the DGFI solution corresponding to a 7 mm decrease of the radial component in DGFI01R01 compared to the ITRF2000, which is significant and not negligible. The parameters were -0.26 ppb and -0.04 ppb/y for BKGTRA00 and +0.29 ppb and -0.05 ppb/y for GLB2001cn, which are only marginally significant.

Most interesting are the residual coordinates and velocities of the three VLBI solutions w.r.t. the ITRF2000 after the transformation. The residual horizontal velocities of VLBI solutions are usually less than 1 mm/y, almost all are less than 2 mm/y. The vertical components differ by less than 1.5 mm/y for most stations, almost all differ by less than 3 mm/y. Comparing the residual coordinates, most horizontal components differ by less than 5 mm, almost all differ by less than 10 mm in all VLBI solutions. The residual vertical coordinates are usually less than 15 mm, almost all are less than 20 mm. The only stations with greater residuals are the very weakly determined Owens Valley 130, Green Bank 140, Urumqi and the Tsukuba 32m telescope.

Systematic differences of the VLBI solutions w.r.t. ITRF2000 appear for the height of the Green Bank 20 and 85 telescopes, whose velocities differ consistently and significantly by about 3 mm/y in all VLBI solutions, but were set equal in ITRF2000. The height coordinates of stations in the very south and north, O'Higgins and NyAlesund differ consistently and significantly by up to 20 mm from the ITRF2000, the Australian DSS 45 and Hobart by about 10 mm in all components.

Additionally, the DGFI solution shows great differences up to 25 mm and 10 mm/y, respectively, for almost all VLBA telescopes, which is supposed to be caused by a considerably smaller amount of RDV sessions in this solution.

## 3. Conclusions

DGFI01R01, the first VLBI solution of the DGFI is a competitive non-CALC/SOLVE solution, but obviously needs partial improvements. In particular, adding the observational data of the year 2001 and some RDV sessions should stabilise the results of the VLBA and the Tsukuba 32m telescopes. Further investigations must be carried out concerning the scale of DGFI01R01 and its EOP series, which show different "bumb-patterns" w.r.t. IERS C04 than other VLBI solutions.

The comparisons of three VLBI solutions with the ITRF2000 can be summarized as follows: VLBI solutions do not have explicit systematic differences w.r.t. each other. Considering only well-determined stations, VLBI solutions have very few non-systematic differences greater than 25 mm and 5 mm/y resp. Furthermore, VLBI solutions have some non-negligible systematic differences w.r.t. ITRF2000, which should be subject to extensive intra-VLBI investigations.

This research has made use of NASA Goddard Space Flight Center's VLBI terrestrial reference frame solution GLB2001cn, 2001 May. The author thanks the GSFC and the IVS for the observation data, the BKG and GSFC for their solutions BKGTRA00 and GLB2001cn, respectively.

## References

[1] Webpage of the ITRF2000, http://lareg.ensg.ign.fr/ITRF/ITRF2000

[2] NASA Goddard Space Flight Center VLBI Group, 2001 May. Data products available electronically at http://lupus.gsfc.nasa.gov/global/glb.html