Deutsches Geodätisches Forschungsinstitut
Technische Universität München
(DGFI-TUM)

Recent developments of the VLBI analysis software DOGS-RI at DGFI-TUM

Matthias Glomsda, Michael Gerstl, Younghee Kwak, Detlef Angermann, Florian Seitz (matthias.glomsda@tum.de)

Introduction

After many years of using OCCAM (see Titov et al. [2004]) as the main Very Long Baseline Interferometry (VLBI, see Figure 1) analysis software, DGFI-TUM started to implement and apply a proprietary library called DOGS-RI (Radio Interferometry). It is part of the general DGFI Orbit and Geodetic parameter estimation Software (DOGS, see Gerstl et al. [2000]) package and intended to ensure a consistent combination of VLBI with other space geodetic techniques. In this contribution, we will provide an overview on DOGS-RI and compare its results to those of other softwares used within the International VLBI Service for Geodesy and Astrometry (IVS).

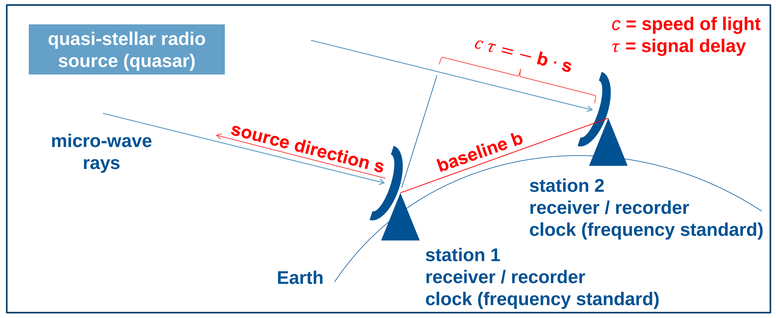

***Figure 1**: Very Long Baseline Interferometry (VLBI).*

DGFI Orbit and Geodetic parameter estimation Software (DOGS)

The software package DOGS consists of three major parts:

- **DOGS-RI** (Radio Interferometry) processes VLBI experiments,
- **DOGS-OC** (Orbit Computation) performs Precise Orbit Determination (POD) based on satellite observations (currently mainly Satellite Laser Ranging (SLR)), and
- **DOGS-CS** (Combination and Solution) aggregates the distinct results of space geodetic techniques on the normal equation level.

The combination conducted by DOGS-CS is not restricted to VLBI and SLR. Normal equations of other observation techniques, for example the Global Navigation Satellite System (GNSS) or Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), can also be added via SINEX files. Figure 2 presents a schematic overview of DOGS. As its components share common models and functionalities, we obtain a consistent treatment of the individual techniques.

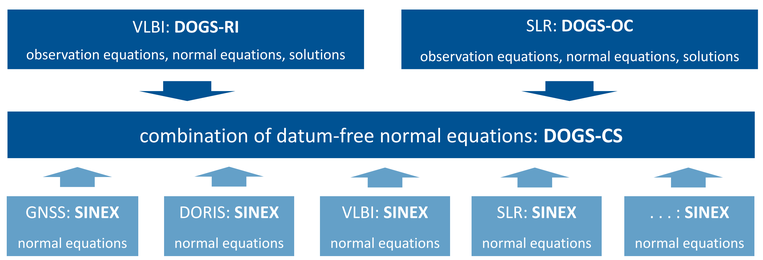

***Figure 2**: Consistent combination of various space geodetic techniques with the DGFI Orbit and Geodetic parameter estimation Software package (DOGS). Lightblue boxes refer to external data.*

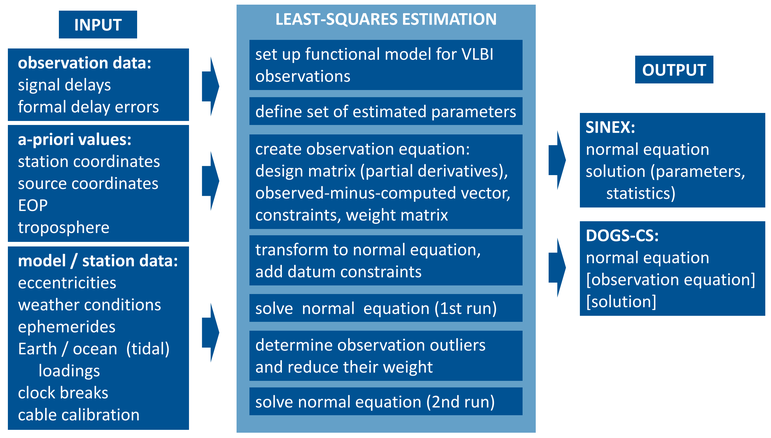

***Figure 3**: Schematic workflow of processing VLBI data with DOGS-RI.*

Features of the VLBI analysis component DOGS-RI

- DOGS is written in FORTRAN and can hence adopt standard procedures and subroutines already available for geodetic and astronomical applications.
- DOGS-RI offers great flexibility by containing a wide range of geophysical and signal delay models of previous and current IERS Conventions (see Petit and Luzum [2010]).
- Both, the classic NGS-card (MK3) and the new vgosDB data format can be used for input of VLBI observation data.
- The estimated variables comprise station and source coordinates, Earth Orientation Parameters (EOP), troposphere and station clock parameters.
- For a-priori station positions, all major TRFs (ITRF, JTRF, DTRF) can be chosen. The standard for DOGS-RI is the ITRF2014.
- With respect to EOP, celestial pole offsets dX, dY are now implemented for nutation next to $d\psi$, $d\varepsilon$.
- Parameter estimation can also be based on a conjunction of several single sessions.

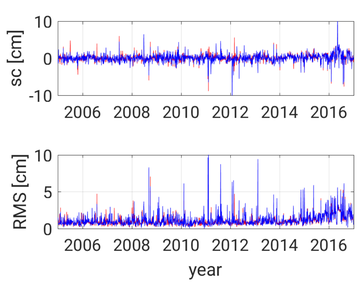

***Figure 4**: Scale parameters (upper part) for Helmert transformations of station coordinates computed with OCCAM (red) and DOGS-RI (blue) to those of the DTRF2014. The lower part shows the RMS of the coordinate residuals for these Helmert transformations (same color code).*

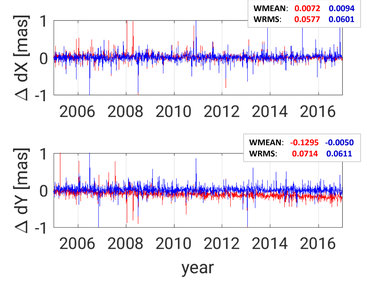

***Figure 5**: Differences between the IERS 14 C04 nutation parameters dX, dY and those obtained by OCCAM (red) and DOGS-RI (blue). With OCCAM, there is an unexpected drift for dY, which is not observed with DOGS-RI.*

Validation of DOGS-RI results

Kwak et al. [2017] conducted a quality assessment of the VLBI solutions generated by DOGS-RI. It consists of both

- internal comparison to OCCAM solutions based on reprocessing past sessions,
- and external comparison to the results of other Analysis Centers (AC) by examining IVS combined solutions.

Figures 4 and 5 exemplarily show that DOGS-RI provides station positions and EOP in good agreement with those of OCCAM. The authors further acknowledge the external analysis of DOGS-RI's solutions, which was kindly performed by the IVS Combination Center (CCIVS) *Bundesamt für Kartographie und Geodäsie* (BKG). The results confirmed the competitiveness of DOGS-RI (see Figure 6), and the AC DGFI-TUM hence started contributing VLBI solutions to the IVS based on its new software.

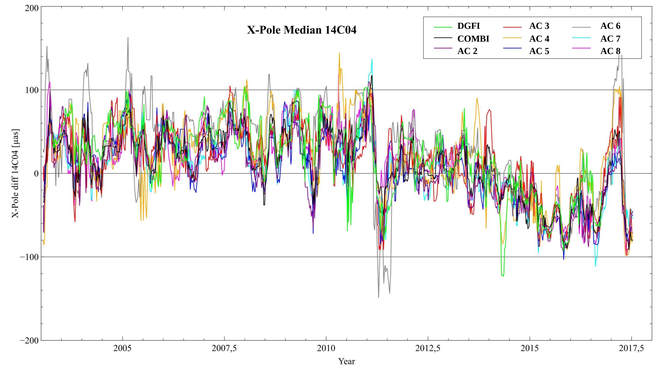

***Figure 6**: Differences between the EOP x-pole as calculated by the Analysis Centers (and the IVS Combination Center BKG) and as provided by the IERS 14 C04 series. Courtesy of S. Bachmann, BKG.*

Ongoing development

Being an operationally stable VLBI analysis software, the various features of DOGS-RI will be further tested and developed. Examples for current projects are:

- VLBI observations are still suffering from jumps in the stations‘ frequency standards (clock breaks). The manual detection shall be replaced by an automatic approach.
- The classic least-squares estimation (Gauss-Markov model) is vulnerable to observation outliers. The existing identification routines (data snooping, BIBER, see Titov et al. [2004]) shall be refined and extended. One approach is to use robust estimators such as the minimization of the sum of absolute (residual) values. For these, outliers are less disruptive and more clearly attributable to residuals with exceptionally high values.

References

Gerstl M., Kelm R., Müller H., Ehrnsperger W. (2000): **DOGS-CS - Kombination und Lösung großer Gleichungssysteme**. Internal Report, DGFI-TUM, München.

Kwak Y., Gerstl M., Bloßfeld M., Angermann D., Schmid R., Seitz M. (2017): **DOGS-RI: new VLBI analysis software at DGFI-TUM**. Proceedings of the 23rd EVGA Meeting, Gothenburg, Sweden.

Petit G., Luzum B. (2010): **IERS Conventions (2010)**. IERS Tech. Note 36, Verlag des Bundesamtes für Kartographie und Geodäsie, ISBN: 978-3-89888-989-6.

Titov O., Tesmer V., Böhm J. (2004): **OCCAM v.6.0 software for VLBI data analysis**. In: N. Vandenberg, K. Baver (eds.), IVS 2004 General Meeting Proceedings, NASA / CP-2004-212255, 267–271.

European Geosciences Union (EGU), General Assembly 2018, Vienna, Austria