BKG/DGFI-TUM Combination Center Biennial Report 2017+2018

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Abstract This report summarizes the activities of the BKG/DGFI-TUM Combination Center in 2017 and 2018 and outlines the activities planned for 2019 and 2020. The main focus in 2017 and 2018 was to generate operationally combined session-wise rapid solutions as well as long-term quarterly solutions. Furthermore, we tested and included additional Analysis Centers into the combined solution. We investigated the impact of different ITRS realizations on combined Earth Orientation Parameter (EOP) and scale and developed a combination strategy for IVS Intensive sessions. In 2019 and 2020, we intend to continue testing new AC contributions, to include source positions operationally in the routine combination products, and to establish a product of combined Intensive sessions. Additionally, we will provide the IVS combined contribution to the next ITRF.

1 General Information

The BKG/DGFI-TUM Combination Center was established in October 2008 as a joint effort of the Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie [BKG]) and the Deutsches Geodätisches Forschungsinstitut at the Technical University of Munich (DGFI-TUM), which is responsible for the development and the maintenance of the combination software. The participating institutions as well as the tasks and the structure of the IVS Combination Center are described in [11]. The tasks comprise quality control and a timely combination of the session-based intermediate results of the IVS Analysis Centers (ACs) into a final combination product (e.g., Earth orientation parameters). In cooperation with the IVS Analysis Coordinator, the combination results are released as official IVS products. The Combination Center is also expected to contribute to the generation of the official IVS input to any ITRF activities.

The BKG/DGFI-TUM Combination Center performs an operational session-based combination of contributions from the IVS ACs. The strategy for the combination is based on the combination of normal equations and was adapted from the combination process as developed and performed by the IVS Analysis Coordinator (cf. [9, 10]).

At BKG, the following tasks are performed:

- Quality control of the AC contributions: checking the format of the contributions and their suitability for combination, identification, and reduction of outliers, inter-comparison of the Analysis Centers' results, and comparison of the results with external time series provided by IERS, IGS, and ILRS.
- Feedback to the Analysis Centers: quality control results are available at the BKG IVS Combination Center Web pages [7].
- Generation of high-quality combination products and timely archiving and distribution: combination products are created by using the combination part DOGS-CS of DGFI-TUM's software package DOGS (DGFI orbit and geodetic parameter estimation software) [6].
- Submission of official IVS combination products to the IERS: the products are submitted to the responsible IERS components to be used for IERS prod-

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uct generation (e.g., for EOP rapid products and the EOP series IERS C04).
- Generation of the official IVS input to the ITRF: the combined session products (from 1984 to present) are submitted for ITRF computation in the form of normal equations in SINEX format. This work is also supported by the staff of the IERS Central Bureau hosted by BKG.
- Final results are archived in the BKG Data Center and mirrored to the IVS Data Centers at Observatoire de Paris (OPAR) and Goddard Space Flight Center (GSFC). This work is assisted by the staff of the BKG Data Center in Leipzig.

DGFI-TUM is in charge of the following Combination Center functions:

- DGFI is developing state-of-the-art combination procedures.
- The software DOGS-CS is updated by implementing and documenting the developed state-of-the-art combination procedures.
- Adhering to IERS Conventions: the DGFI-TUM DOGS software package is continuously updated to be in accordance with the IERS Conventions.

2 Activities During the Past Years

At BKG, the following activities were performed in 2017 and 2018:

- Generation of a combined solution for IVS 24-h rapid sessions twice a week.
- Generation of a combined long-term solution of IVS 24-h sessions every three months.
- Ensuring that the combination process is in agreement with the IERS2010 Conventions.
- Inclusion of new ACs: Norwegian Mapping Authority (NMA), Norway was added to the routine rapid combination.
- Performing combination tests for individual contributions from IGE (Spain), BEV (Austria), and ESA (Germany).
- Investigations into the impact of different ITRS realizations on VLBI-based EOP and scale.
- Refinements of the combination procedure and implementation of source position combination.
- Development of a combination strategy for IVS Intensive sessions.

2.1 Impact of Different ITRS Realizations

For our investigations into the impact of different ITRS realizations (DTRF2014 [12], ITRF2014 [2], and JTRF2014 [1]) on combined EOP and scale, we used them as a priori station information for the combination process. We found TRF-induced variations in station coordinates, such as slight offsets and seasonal variations originating from different handling of non-tidal atmospheric loading corrections (see Figure 1, left side). Furthermore, Helmert transformation parameters between the three ITRS realizations and the respective combined solution were calculated. The results show offsets in the magnitude of -0.01 ppb w.r.t. DTRF2014, -0.38 ppb w.r.t. ITRF2014, and $+0.19$ ppb w.r.t. JTRF2014. The scale parameter time series (smoothed) are shown in Figure 1 (right side).

The EOPs resulting from the test series vary very little, except for dUT1. dUT1 variations calculated using DTRF2014, ITRF2014, JTRF2014, and VTRF2015q2 as a priori station coordinates with fixed datum stations are shown in Figure 2. The left panel illustrates the dUT1 comparison with respect to the IERS 14C04 series [5] showing different offsets for the three ITRS realizations and a scatter around zero for the comparison using VTRF2015q2. A different situation is given when comparing to the (previous) IERS 08C04 series, showing a discontinuity around the year 2000. A detailed description of the impact of ITRS realizations on combined EOP and scale is given in [3].

2.2 Development of a Combination Procedure for Intensives

Routinely, we generate combined EOP products using IVS 24-h sessions. Starting in 2018, we developed a combination routine for IVS 1-h Intensive sessions. These sessions are dedicated to determining dUT1 on a daily basis. Combining IVS Intensives requires a different combination approach than 24-h sessions due to the reduced set of parameters and the associated adapted datum definition and weighting strategy. Overall we tested the Intensives combination procedure using one year of Intensive sessions and a set of four AC contributions in the form of datum-free normal equa-

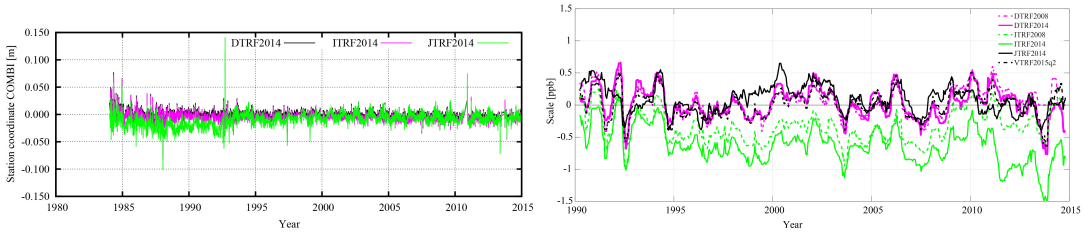

Fig. 1: Left: Station height of Wettzell (Germany) when using different TRFs as a prioris. Right: 90 day median-smoothed scale between the different ITRS realizations and the session-wise VLBI combined solution: DTRF2008 (light blue), DTRF2014 (dark blue), ITRF2008 (light red), ITRF2014 (dark red), JTRF2014 (black), and VTRF2015q2 (ocher).

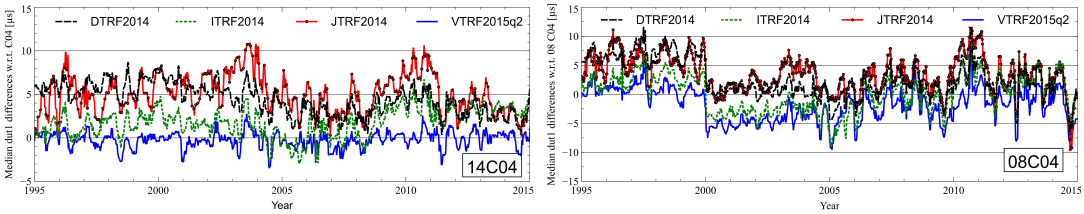

Fig. 2: dUT1 differences between the solutions based on the different TRFs and IERS 14C04 (left) and IERS 08C04 (right). 90 day median smoothed values are shown.

tions provided in SINEX files. A more detailed description of the Intensives combination procedure and the test results is published in [4]. The results of dUT1 for the individual and the combined solutions in comparison to the IERS 14C04 series are shown in Figure 3.

The results show a good agreement between the individual contributions and the combined solution, with a reduced RMS of the combined solution compared to the individual solutions: the RMS of the combined solution is 32.0 µs, while the RMS values of the individual solutions range between 38.6 µs and 33.4 µs (as can be seen in Table 1). We are optimistic that also IVS Intensives can benefit from a combined product in terms of improved repeatability, as combined 24-h sessions have already proved. In order to move forward in this respect and work on establishing an IVS combined product also for the Intensives, all ACs are encouraged to analyze Intensive sessions and provide SINEX files with datum-free NEQs containing station coordinates and all five EOPs, for instance, similar to the 24-h sessions.

Table 1: RMS and offset for dUT1 w.r.t. the IERS 14C04 series using 258 Intensive sessions from 2017 (only sessions available for all ACs are taken into account).

AC	RMS [µs]	Offset [µs]
BKG	36.9	5.1
SHAO	37.3	7.7
USNO	38.6	10.9
VIE	33.4	1.9
COMBI	32.0	5.6

2.3 Other Activities

Concerning the operational rapid combination, contributions of one additional AC were added: NMA using software “Where” was introduced in the combination routine. This increases the number of regularly contributing ACs to nine.

In late 2018, we implemented a new strategy for our server providing the IVS Combination Center’s Web site at https://ccivs.bkg.bund.de. The changes include

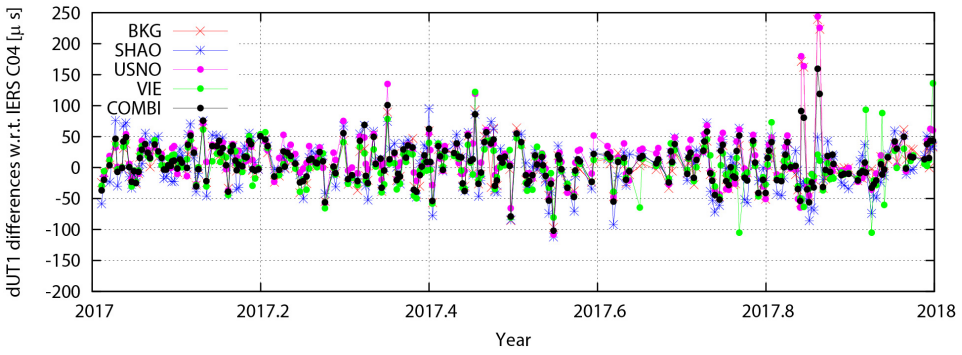

Fig. 3: dUT1 residuals w.r.t. IERS 14C04.

the separation of the test and the production system and security improvement. In the course of updating the server architecture, we revised the content of the Web site, added a new plotting tool allowing a more flexible interactive plot representation, and extended the product presentation by adding additional EOP comparisons and station coordinate representations.

At DGFI, the following relevant software developments were realized in 2017 and 2018:

- Application of non-tidal loading corrections at the normal equation level.
- Extension of similarity transformation program [8].

For more information on the DGFI-TUM VLBI activities please refer to the DGFI-TUM IVS AC report in this volume.

3 Staff

The list of the staff members of the BKG/DGFI-TUM Combination Center in 2017+2018 is given in Table 2.

4 Current Status

At the end of 2018, in total nine IVS ACs (ASI, BKG, DGFI-TUM, GFZ, GSFC, IAA, NMA, OPAR, and USNO) contributed regularly to the IVS combined rapid and quarterly products (see [7]). Several new potential ACs are currently under review: AUS (Geoscience Australia), VIE (Technical University Vienna / BEV Bundesamt für Eich- und Vermessungswesen, Austria), IGE (National Geographic Institute of Spain), and ESA (European Space Agency), which will probably become an IVS Operational AC in the near future. The rapid solutions only contain R1 and R4 sessions, and new data points are added twice a week as soon as the SINEX files of at least four IVS ACs are available. Long-term series are generated quarterly and include all 24-h sessions since 1984. The quarterly series include long-term EOP, station positions, and velocities. Furthermore, a VLBI TRF is generated and published. The software was extended to process source parameters for session-wise combination as well as for a consistent generation of TRF and CRF. For this reason, the current ICRS realization ICRF3 was implemented. The results of the combination process are archived by the BKG Data Center in Leipzig. The combined rapid EOP series, as well as the results of the quality control of the AC results, are also available directly at the BKG/DGFI-TUM Combination Center Web site [7] or via the IVS Analysis Coordinator Web site.

5 Future Plans

In 2019 and 2020, the work of the BKG/DGFI-TUM Combination Center will focus on the following aspects:

- Operationally providing consistently combined TRF, CRF, and EOP products.
- Extending the number of sources and the number of stations in the consistent TRF/CRF generation.

Table 2: Staff members of the BKG/DGFI-TUM Combination Center.

Name	Affiliation	Function	E-Mail
Sabine Bachmann	BKG	Combination procedure development and operational combination	ccivs@bkg.bund.de
Linda Janssen	BKG	Operational combination and Web site maintenance (until August 2018)	ccivs@bkg.bund.de
Sonja Geist	BKG	Web site maintenance (since August 2018)	ccivs@bkg.bund.de
Daniela Thaller	BKG	Combination strategies and strategical planning	ccivs@bkg.bund.de
Mathis Bloßfeld	DGFI-TUM	Software development and combination strategies	mathis.blossfeld@tum.de
Matthias Glomsda	DGFI-TUM	Software development and combination strategies	matthias.glomsda@tum.de

- Including new ACs into the routine rapid and quarterly combination.
- Improving the combination strategy for Intensive sessions and adding more ACs to the combined dUT1 product.
- Establishing a combined Intensive product.
- Generating the official IVS combined contribution to the upcoming ITRF2020.

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