

# BKG/DGFI-TUM Combination Center Report

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**Abstract** This report summarizes the activities of the BKG/DGFI-TUM Combination Center in 2023 and 2024 and outlines the planned activities for 2025 and 2026. The main focus in 2023 and 2024 was the generation of the IVS contribution to the first update of ITRF2020 (called ITRF2020-u2023), which comprised three years of data from 2021.0 to 2024.0. Furthermore, we included additional Analysis Centers into the combined solution. In addition to the session-wise combination of R1 and R4 sessions, we implemented a similar operational process for combining the VGOS 24-h sessions. In 2025 and 2026, we intend to improve the combination strategy for small station networks, expand the consistent EOP realization, and evaluate the impact of the different ITRS realizations (DTRF2020, ITRF2020, and JTRF2020) on the combined EOP.

## 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 German Geodetic Research Institute of TU Munich (Deutsches Geodätisches Forschungsinstitut der TU München, DGFI-TUM). The participating institutions as well as the tasks and the structure of the IVS

1. Federal Agency for Cartography and Geodesy (BKG)
2. Technische Universität München, Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)

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Combination Center are described in [12]. 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, EOP). In close cooperation with the IVS Analysis Coordinator, the combination results are released as official IVS products. The Combination Center is also expected to generate and contribute the official IVS input for any ITRF activities.

The BKG/DGFI-TUM Combination Center performs a combination of session-based input by the IVS ACs on an operational basis. The combination strategy is based on the combination of normal equations and was adopted from the combination process developed and performed by the IVS Analysis Coordinator (cf. [10, 11]).

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 AC-specific results, and comparison of the results with external time series provided by the IERS, IGS, and ILRS.
- Feedback to the ACs: Quality control results are available on the BKG IVS Combination Center web pages [8].
- Generation of high-quality combination products and timely archiving and distribution: Combination products are created by using the Combination and Solution library DOGS-CS of DGFI-TUM's software package DOGS (DGFI Orbit and Geodetic parameter estimation Software) [3].
- Submission of official IVS combination products to the IERS: The products are submitted to the responsible IERS components to be used for IERS prod-

uct generation (e.g., for EOP rapid products and the EOP series IERS C04).

- Generation of the official IVS input to ITRF and ITRF updates considering the specific requirements for ITRF input data (e.g., non-tidal loading displacements are not applied): The combined session products are submitted for ITRF computation in the form of session-wise normal equations in SINEX format. This work is also supported by the staff of the IERS Central Bureau hosted by BKG.
- Archiving: 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.

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

- Developing state-of-the-art combination procedures taking into account new observation types, models, and parameters. These activities are closely linked to the ITRS Combination Center at DGFI-TUM.
- Conducting scientific research aimed at the consistent realization of the ICRS and the International Terrestrial Reference System ITRS.
- Updating the DGFI-TUM's DOGS software according to the developed combination procedures and by implementing new models and functions to ensure compliance with IERS Conventions.

## 2 Activities During the Past Years

At BKG, the following activities were performed in 2023 and 2024:

- Integration of the new DOGS-CS software components into the IVS combination process.
- Generation of a combined solution for IVS 24-h rapid sessions twice a week.
- Generation of a combined solution for IVS VGOS sessions (approximately once per 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 IERS Conventions (2010).

- Generation of the IVS combined contribution to the ITRF2020-u2023 to be used by the IERS ITRS Combination Centers.
- Validation of the ITRF2020-u2023 solution and investigation of the scale behavior as a contribution to the IVS Working Group 9 on VLBI scale.
- Inclusion of two new ACs, i.e., Geoscience Australia (AUS) and University of Alicante, Spain (UAV), into the routine rapid and VGOS combination.
- Refinements of the combination procedure and implementation of source position combination.

For the operational rapid combination, the contributions of two additional ACs (i.e., AUS and UAV), both using the analysis software VieVS, were introduced into the combination procedure. This increases the number of ACs that regularly contribute to the combined IVS solution to 13.

At DGFI-TUM, the following activities were carried out in 2023 and 2024:

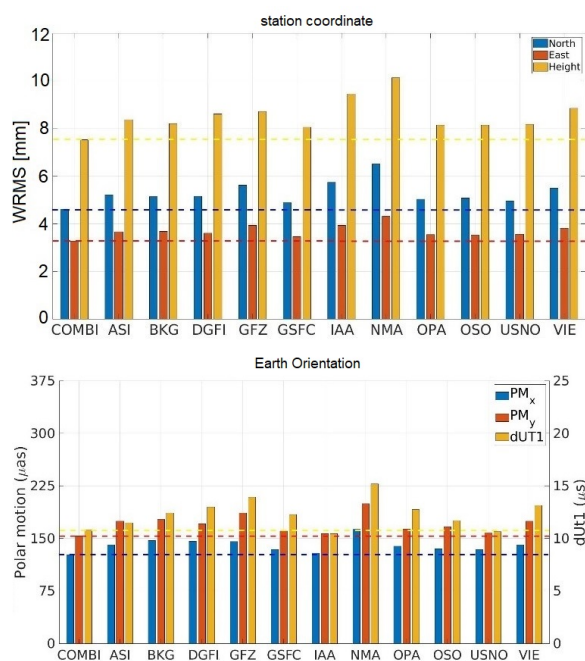
- Construction and integration of restitution equations.
- Update of the similarity transformation program.
- Analysis of combined session solutions including EOP, station coordinates, and source coordinates.

### 2.1 IVS Contribution to the First Update of ITRF2020 (ITRF2020-u2023)

The IVS contribution to ITRF2020-u2023 was finalized, evaluated, and submitted to the IERS ITRS Combination Centers in March 2024. Altogether twelve ACs contributed with their reprocessed series, using six different software packages. The reprocessed series contain altogether 668 sessions, i.e., 568 legacy sessions and 100 VGOS sessions. Overall, 54 different telescopes (42 legacy telescopes and 12 VGOS telescopes) observed between the corresponding time frame between 2021.0 and the end of 2023. The regular observation of VGOS sessions allows, for the first time, estimation of reliable station coordinates for the new VGOS telescopes.

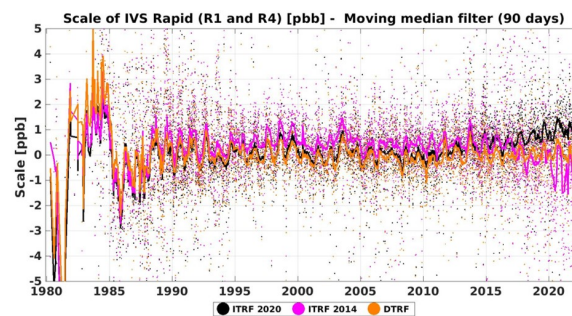
For the evaluation of the combined contribution, various investigations were made in order to ensure the high quality of the submitted products. Figure 1 shows

the quality of the station coordinates and the Earth's rotation (Polar Motion, dUT1) for the combined and the individual AC solutions. For the station positions we show the WRMS of the coordinate residuals w.r.t. an average mean position and linear trend. In case of the EOPs, the WRMS of the residuals w.r.t. the IERS C04 series is shown. As expected, an improvement for the combined solution compared to any single AC solution is evident. More details on the combined IVS contribution can be found in [4] and [6].



**Fig. 1** Upper figure: WRMS of station coordinate residuals w.r.t. linear approximation (average over all stations). Lower figure: WRMS of Polar Motion and dUT1 residuals from comparison with IERS C04.

Figure 2 shows the scale parameter derived from each single combined session with respect to three different reference solutions: DTRF2020 preliminary (orange), ITRF2014 (magenta), and ITRF2020 (black). As expected, an improvement for ITRF2020 compared to ITRF2014 is clearly seen. However, the behavior for the most recent years still needs to be understood, and it is currently discussed within the newly established IVS Working Group 9 on VLBI scale.



**Fig. 2** Scale between single combined sessions and DTRF2020 preliminary (orange), ITRF2014 (magenta), and ITRF2020 (black).

### 3 Staff

The list of the staff members of the BKG/DGFI-TUM Combination Center in the years 2023 and 2024 is given in Table 1. There were changes in BKG's staff during these years. Hendrik Hellmers left BKG in October 2023 and has been replaced by Alexander Kehm since October 2024. Sadeh Modiri moved in August 2024 from the IVS Combination Center to BKG's IVS Analysis Center.

### 4 Current Status

By the end of 2024, 13 IVS ACs (namely ASI, AUS, BKG, DGFI-TUM, GFZ, GSFC, IGE, NMA, OPA, OSO, UAV, USNO, and VIE) contributed regularly to the IVS combined rapid and quarterly product (see [8]). The combined rapid EOP solution only covers 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. In addition to the combined EOP series, session-wise combined SINEX files are generated.

The VGOS 24-h sessions are regularly combined on a session-wise level in a similar way as the R1 and R4 sessions. The provision of a combined EOP series for VGOS along with session-wise combined SINEX files has been started in 2024.

Long-term series are generated at quarterly intervals and include all 24-h sessions since 1984. The quarterly series include long-term EOP and station posi-

**Table 1** Staff members of the BKG/DGFI-TUM Combination Center during 2023+2024.

Name	Affiliation	Function	E-Mail
Sabine Bachmann	BKG	ITRF2020-u2023; Combination procedure	sabine.bachmann@bkg.bund.de
Hendrik Hellmers	BKG	Combination procedure; Scientific aspects	hendrik.hellmers@bkg.bund.de
Alexander Kehm	BKG	ITRF2020; Combination procedure	alexander.kehm@bkg.bund.de
Sadegh Modiri	BKG	ITRF2020; Operational combination	sadegh.modiri@bkg.bund.de
Sandra Schneider-Leck	BKG	Operational combination	sandra.schneider-leck@bkg.bund.de
Sonja Geist	BKG	IVS CC web pages	sonja.geist@bkg.bund.de
Daniela Thaller	BKG	Scientific and strategic advice	daniela.thaller@bkg.bund.de
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Manuela Seitz	DGFI-TUM	Combination strategies	manuela.seitz@tum.de

tions and velocities. Furthermore, a VLBI-only TRF is generated and submitted to the IVS Data Center.

The IVS combined EOP series have been submitted in the new EOP format version 3 since the beginning of 2023.

The results of the combination process are archived by the BKG Data Center. The IVS Combination Center website [8] is currently undergoing a major review and update, and it will be online again in the first half of 2025.

## 5 Future Plans

In 2025 and 2026, the work of the BKG/DGFI-TUM Combination Center will focus on the following aspects:

- Implementing the new master file format.
- Transitioning to ITRF2020-u2023 in the first months of 2025.
- Generating the IVS combined contribution to the second yearly update of ITRF2020, i.e., ITRF2020-u2024.
- Setting up a session-wise combination for all session types (in analogy to R1, R4, and VGOS).
- Investigating the impact of different ITRS realizations (DTRF2020, ITRF2020, and JTRF2020) on the combined EOP.
- Including new ACs into the routine rapid and quarterly combinations as soon as the ACs become available.
- Improving the combination strategy and making the combination procedure more robust and flexible.
- Re-launching the IVS Combination Center website.
- Establishing EOP predictions based on IVS combined EOP products.

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