

# BKG/DGFI-TUM Combination Center 2019+2020 Biennial Report

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**Abstract** This report summarizes the activities of the BKG/DGFI-TUM Combination Center in 2019 and 2020 and outlines the planned activities for 2021 and 2022. The main focus in 2019 and 2020 was the continuous generation of combined products for the rapid sessions R1 and R4, as well as generating quarterly solutions based on all 24-hour sessions since 1984. Additional IVS Analysis Centers were included in the combination as soon as their contributions were validated. We started a major update and re-design of the combination software as well as the combination procedures in order to become more flexible and more user-friendly. Furthermore, the planning and testing of the IVS combination for generating the official IVS input to the ITRF2020 started, and the session-wise IVS combined SINEX files will be submitted to the ITRS Combination Centers in early 2021.

## 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 (Deutsches Geodätisches Forschungsinstitut) at the TU Munich (DGFI-TUM). The participating institutions as well as the tasks and the structure of the IVS Combination Center are de-

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scribed in [9]. 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, or EOP). There are two types of combined products: (1) a rapid product as a session-wise combination of the R1 and R4 sessions and (2) the so-called Quarterly combination accumulating all 24-hour sessions over approximately 40 years now. In close 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 realization.

The BKG/DGFI-TUM Combination Center performs a combination of session-based results of the IVS ACs on an operational basis. The strategy for the combination is based on the combination of normal equations and was adopted from the combination process as developed and performed by the IVS Analysis Coordinator (cf., [7, 8]).

At BKG, the following tasks are performed:

- Quality control of the AC results: checking the format of the results and their suitability for combination, identification and reduction of outliers, comparison of the Analysis Centers' results with each other, and comparison of the results with external time series provided by the IERS (International Earth Rotation and Reference Systems Service), IGS (International GNSS Service), and ILRS (International Laser Ranging Service).
- Feedback to the Analysis Centers: quality control results are available at the BKG IVS Combination Center website [6].
- 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) [4].

- Submission of official IVS combination products to the IERS: the products are submitted to the responsible IERS components to be used for IERS product 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 at BKG.
- Archiving of final results: Final results are archived in the IVS Data Center at BKG and mirrored to the IVS Data Centers at Observatoire de Paris (OPAR) and the Goddard Space Flight Center (GSFC). This work is assisted by the staff of BKG's IVS Data Center in Leipzig and Frankfurt.

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

- DGFI is developing state-of-the-art combination procedures. This work, as well as the following item, is related to the ITRS Combination Center at DGFI and DGFI's efforts within the IERS WG on Combination at the Observation Level (COL).
- The software DOGS\_CS is updated by implementing and documenting the developed state-of-the-art combination procedures.
- The DGFI 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 2019 and 2020:

- Integration of the new DOGS\_CS software into the IVS combination process.
- Generation of a combined solution for IVS 24-hour rapid sessions twice a week.
- Generation of a combined long-term solution of IVS 24-hour sessions every three months.

- Ensuring that the combination process is in agreement with the IERS2010 Conventions.
- Preparing the IVS combined contribution to the ITRF2020 for the IERS ITRS Combination Centers.
- Inclusion of new ACs: National Geographic Institute of Spain (IGE) and Onsala Space Observatory, Sweden (OSO) into the routine rapid combination.
- Testing of potential new ACs: Instituto Geografico Nacional, Argentina (IGN) and European Space Agency (ESA).
- Refinements of the combination procedure and implementation of source position combination.

Concerning the operational rapid combination, contributions of two additional ACs were added. IGE using the software Where and OSO using `ivg::ASCOT` were introduced into the combination routine. This increases the number of regularly contributing ACs to twelve.

At DGFI-TUM, the following activities were performed in 2019 and 2020:

- Full re-design of software handling.
- Construction and integration of restitution equations.
- Update of the similarity transformation program.
- Handling of the new SINEX block with the loading corrections.

## 3 Staff

The list of the staff members of the BKG/DGFI-TUM Combination Center in 2019+2020 is given in Table 1.

## 4 Current Status

By the end of 2020, up to twelve IVS ACs (ASI, BKG, DGFI-TUM, GFZ, GSFC, IAA, IGE, NMA, OPA, OSO, USNO, and VIE) contributed regularly to the IVS combined rapid and quarterly product (see [6]). The rapid solutions contain R1 and R4 sessions only, 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 usually in a quarterly

**Table 1** Staff members of the BKG/DGFI-TUM Combination Center.

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sequence and include all 24-hour sessions since 1984. The quarterly series include long-term EOP, station positions, and velocities. Furthermore, a VLBI TRF is generated and published.

The IVS combination software was extended to process source parameters for session-wise source combination as well as for a consistent generation of TRF and CRF.

The preparations for the combined IVS input to ITRF2020 started. The handling of the new SINEX block providing the loading corrections applied by the ACs has been implemented and tested within the combination procedures. The process for generating the official IVS combined contribution to ITRF2020 is set up in the following way: The session-wise combined SINEX files will include EOPs at 12:00 UTC epochs, the loading corrections by the ACs are removed so that the IVS combined solutions are free of loading corrections, and the session-wise SINEX files of the official IVS combination will contain only station coordinates and EOPs. The inclusion of radio source positions into the session-wise combined SINEX files needs further investigations, and the submission of experimental combined SINEX files is foreseen in the course of 2021.

In general, the entire combination process was updated along with the fully re-designed software in order to allow a more flexible and user-friendly operation of the IVS combination. Several tests of the new software and combination procedures are already done successfully. The complete transition from the old combination software and procedures to the new set-up was almost finished by the end of 2020 for the quarterly combination as well as for the combined contribution to ITRF2020. The transition for the rapid combination will be finished in the first half of 2021.

The results of the combination process are archived by BKG's IVS Data Center.

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 website [6] or via the IVS Analysis Coordinator website.

## 5 Future Plans

In 2021 and 2022, the work of the BKG/DGFI-TUM Combination Center will focus on the following aspects:

- Generating the official IVS combined contribution for ITRF2020 (i.e., session-wise SINEX files containing station coordinates and EOPs).
- Transitioning to ITRF2020 for the IVS combined products as soon as ITRF2020 becomes official.
- Investigating the impact of different ITRS realizations (DTRF2020, ITRF2020, and JTRF2020) on the combined EOP (in analogy to [3]).
- Generating a combined IVS product with homogeneously estimated TRF, CRF, and EOPs.
- Investigating the impact of homogeneously estimating TRF, CRF, and EOPs on the resulting parameters.
- Generating an experimental IVS combined series based on the input by the ACs for ITRF2020 (i.e., session-wise SINEX files containing also radio source positions together with station coordinates and EOPs).
- Including new ACs into the routine rapid and quarterly combination.
- Improving the combination strategy for small station networks to increase their contribution to the EOP.
- Developing strategies and processes for an automatic generation of IVS combined products.

- Improving and extending the presentation of the IVS combined results at our website.
- Embedding the IVS combination processes into BKG's quality management following ISO 9001.

## References

1. Bachmann, S., Thaller, D., Roggenbuck, O., Lösler, M., Messerschmitt, L. IVS contribution to ITRF2014. *Journal of Geodesy*, 90(7):631–654, doi:10.1007/s00190-016-0899-4
2. Bachmann, S., Thaller, D. (2016) Adding source positions to the IVS combination—First results. *Journal of Geodesy*, doi:10.1007/s00190-016-0979-5
3. Bachmann, S., Thaller, D. (2019) Impact of different TRF station coordinate parameterizations on VLBI combined EOP and scale. *IAG Symposia Series*, Vol. 149, Proceedings of the IAG Scientific Assembly, Kobe, Japan, 2017, doi:10.1007/978-3-030-12915-6
4. Gerstl, M., Kelm, R., Müller, H., Ehrnsperger, W. (2004) DOGS-CS: Kombination und Lösung großer Gleichungssysteme. Deutsches Geodätisches Forschungsinstitut, MG/01/1995/DGFI
5. Hase, H., BKG/DGFI Combination Center at Frankfurt, IVS Newsletter 36, 2–3, 2013. <http://ivscc.gsfc.nasa.gov/publications/newsletter/issue36.pdf>
6. <https://ccivs.bkg.bund.de/> IVS Combination Center website maintained by BKG
7. Nothnagel, A., Böckmann, S., Artz, T., Analysis Coordinator Report, in: *International VLBI Service for Geodesy and Astrometry 2007 Annual Report*, NASA/TP-2008-214162, D. Behrend and K. D. Baver (eds.), 16–17, 2008
8. Nothnagel, A., Böckmann, S., Artz, T., Analysis Coordinator Report, in: *International VLBI Service for Geodesy and Astrometry 2009 Annual Report*, NASA/TP-2010-215860, D. Behrend and K. D. Baver (eds.), 45–47, 2010
9. Schwegmann, W., Gerstl, M., Heinkelmann, R., BKG/DGFI Combination Center Annual Report 2008, in: *International VLBI Service for Geodesy and Astrometry 2008 Annual Report*, NASA/TP-2009-214183, D. Behrend and K. D. Baver (eds.), 250–252, 2009