BKG/DGFI-TUM Combination Center Biennial Report 2015+2016

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Abstract This report summarizes the activities of the BKG/DGFI-TUM Combination Center in 2015 and 2016 and outlines the planned activities for 2017 and 2018. The main focus in 2015 and 2016 was submitting the IVS contribution to the ITRF2014, adding source positions to the combination procedure, and investigating the potential of a consistently combined TRF/CRF solution. Furthermore, we included additional Analysis Centers into the combined solution. In 2017 and 2018, we intend to improve the combination strategy for small station networks, to expand the consistent realization for EOP, and to evaluate the impact of the different ITRS realizations (DTRF2014, ITRF2014, and JTRF2014) 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, or BKG) and the German Geodetic Research Institute (Deutsches Geodätisches Forschungsinstitut, or DGFI). The participating institutions as well as the tasks and the structure of the IVS Combination Center are described in [8]. 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). In coordination 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 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. [6], [7]).

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 and IGS.
- Feedback to the Analysis Centers: quality control results are available at the BKG IVS Combination Center Web pages [5].
- 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) [3].
- 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)

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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. 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.
- Adhering to IERS Conventions: 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 2015 and 2016:

- 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.
- Generation of the IVS combined contribution to the ITRF2014 for the IERS ITRS Combination Centers.
- Inclusion of new ACs: Centro di Geodesia Spaziale (CGS), Italy and German Research Center for Geosciences (GFZ) into the routine rapid combination.
- Refinements of the combination procedure and implementation of source position combination.

The IVS contribution to the ITRF2014 was finalized and submitted to the IERS ITRS Combination Centers in February 2015. Figure 1 shows the VLBI station participation of the ITRF2014 submission. Overall 158 different stations observed between 1979 and 2015. The sessions on the right side of the vertical (red) line represent additional data collected since ITRF2008. Here, only stations with more than ten observations are shown. Figure 2 shows the WRMS over all stations for the combined and the individual solutions. Slightly improved statistics for the combined solution are visible for all components.

Figure 3 shows the scale of single combined sessions with respect to DTRF2008 (blue), ITRF2008 (red), and VTRF2014 (black). The VTRF2014 is a TRF which is generated from the AC submissions for the ITRF2014. An average scale offset of 0.3 ppb between DTRF2008/VTRF2014 and the ITRF2008 can be detected. Furthermore, two peculiarities around 2004 and 2014 with scale variations of about -0.6 ppb are evident. The corresponding periods contain many regional sessions with an unfavorable global station distribution for scale determination. This effect nearly vanishes if only R1 and R4 sessions are used for this comparison. We expect that improving the combination strategy for small networks will lead to a better understanding of scale variations with respect to the other space-geodetic techniques.

The combination procedure, as well as results for station coordinates and EOP, have been summarized in [1].

Source parameters have been added to the routine combination procedure. First tests show that source positions can benefit from a combined solution in a way similar to EOP and station coordinates in terms of, e.g., improved statistics. The objective is a consistent estimation of terrestrial and celestial reference frames and EOP in the near future. For our studies, we estimated a combined TRF/CRF containing 67 stations and 907 sources (including 291 ICRF2 defining sources). The resulting rotation angles A_1, A_2, and A_3 relative to ICRF2 are -12.7, 51.7, and 1.8 μas, the drifts D_α and D_δ are -67.2 and 19.1 μas/rad, and the bias B_δ is 26.1 μas. A comparison of the TRF solution with the IVS routinely combined quarterly TRF solution shows that the consistent estimation of the CRF has no significant impact on the TRF. The root mean square value of the post-fit station coordinate residuals is 0.9 cm. A detailed description was published in [2].

Concerning the operational rapid combination, contributions of two additional ACs were added. CGS using Calc/(nu)Solve and GFZ using VieVS@GFZ were introduced in the combination routine. This

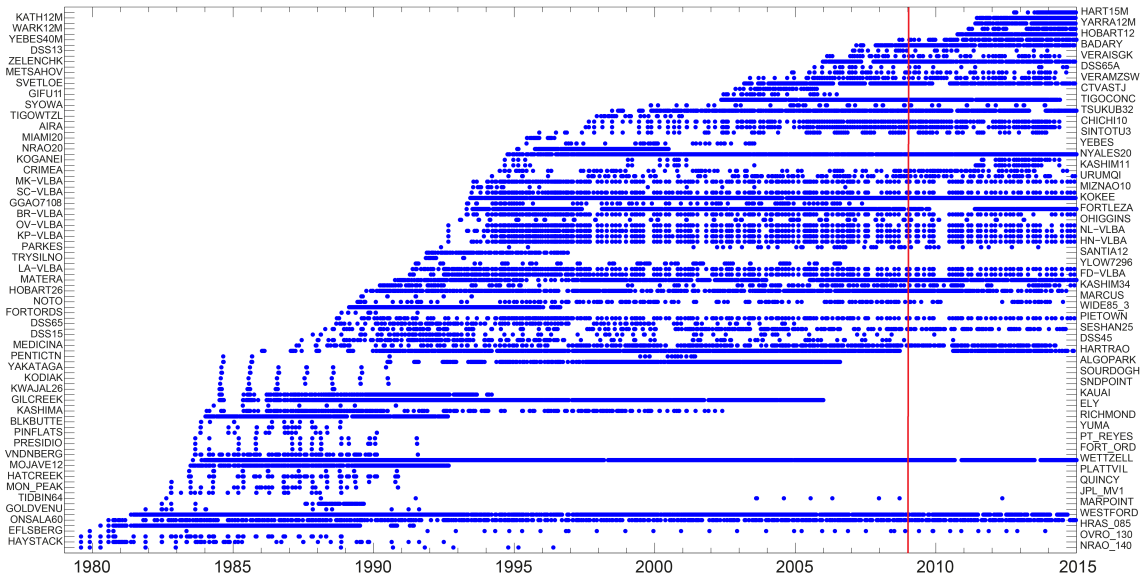

Fig. 1 VLBI station participation for ITRF2014. Only stations with more than ten observed sessions are shown, resulting in 158 different stations. On the right side of the vertical (red) line, additional sessions are shown that were not considered for the previous ITRF2008.

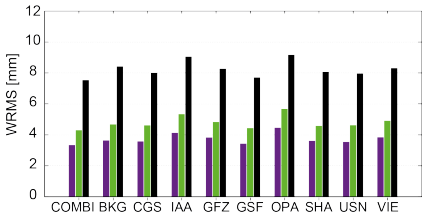

Fig. 2 Station coordinate WRMS of all stations in North (purple, left bar), East (green, middle bar), and Up (black, right bar).

increases the number of regularly contributing ACs to eight.

In 2016, the IVS Combination Center (CCIVS) revised its Web site. A predefined content management system was implemented to standardize the CCIVS Web presence. New features such as combination protocols, an interactive observatory map (see Figure 4), and more combination details were added to the available information about station coordinates, EOP, baselines, and combination results. The implementation changed the system structure and improves the administrative handling. It simplifies the workflow and allows a fast intervention in the system procedure. Results of the combination are published automatically and updated regularly. The revised Web site is accessible at http://ccivs.bkg.bund.de.

At DGFI, the following activities were performed in 2015 and 2016:

- Construction and integration of restitution equations.
- Update of a similarity transformation program.

3 Staff

The list of the staff members of the BKG/DGFI-TUM Combination Center in 2015 and 2016 is given in Table 1.

More details about the IVS Combination Center at BKG can be found in an interview for the IVS Newsletter [4].

4 Current Status

By the end of 2016, eight IVS ACs (BKG, CGS, DGFI-TUM, GFZ, GSFC, IAA, OPA, and USNO) contributed regularly to the IVS combined rapid and

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

Name	Affiliation	Function	E-Mail
Sabine Bachmann	BKG	Combination procedure development	sabine.bachmann@bkg.bund.de
Linda Messerschmitt	BKG	Operational combination/Web site maintenance	linda.messerschmitt@bkg.bund.de
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Ralf Schmid	DGFI-TUM	Combination strategies	schmid@tum.de

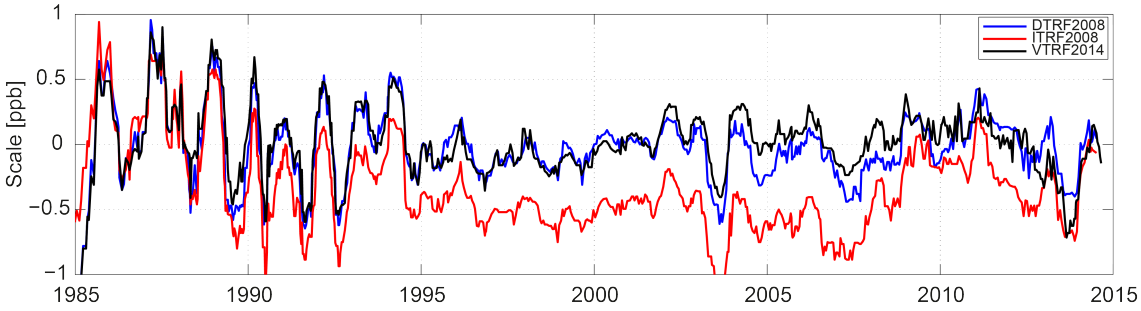

Fig. 3 Scale between single combined sessions and DTRF2008 (blue), ITRF2008 (red, bottom line) or VTRF2014 (black).

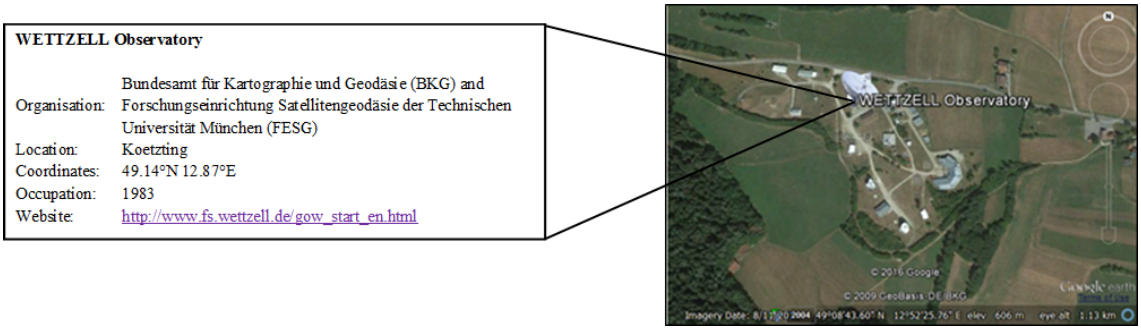

Fig. 4 Wettzell (Germany) as an example of the interactive map feature of the newly designed IVS Combination Center Web site.

quarterly product (see [5]). The AUS (Geoscience Australia) AC is currently under review and 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 source combination as well as for a consistent generation of TRF and CRF. To prepare for the transition from ITRF2008 to the ITRF2014 reference frame, several tests of new software versions are in progress. The transition is planned for early 2017. 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 [5] or via the IVS Analysis Coordinator Web site.

5 Future Plans

In 2017 and 2018, the work of the BKG/DGFI-TUM Combination Center will focus on the following aspects:

- Transition to ITRF2014 in the first months of 2017.
- Investigating the impact of different ITRS realizations (DTRF2014, ITRF2014, and JTRF2014) on the combined EOP.
- Extending the number of sources and the number of stations in the consistent TRF/CRF generation, as well as including EOP.
- 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.

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