# KTU-GEOD IVS Analysis Center Report

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**Abstract** This report summarizes the activities of the KTU-GEOD IVS Analysis Center (AC) in 2019 and 2020 and outlines the planned activities for the years 2021 and 2022. Our specific interests and focused subjects for 2019 and 2020 were as follows; (1) implementing new outlier detection methods to the least squares (LS) module of the GFZ (GeoForschungsZentrum, Potsdam, Germany) version of VieVS software, (2) estimating the velocity field of the Alpine Himalayan Earthquake Zone from GNSS and VLBI observations, and (3) estimating the $M_2$ tidal constituent of the ocean loading displacements from the observations of the IVS CONT14 campaign.

## 1 General Information

The IVS [1, 2] KTU-GEOD Analysis Center (AC) [3] is located at the Department of Geomatics Engineering, Karadeniz Technical University, Trabzon, Turkey. The Department of Geomatics Engineering, at Hacettepe University in Ankara supports the activities of the KTU-GEOD IVS Analysis Center (AC), for instance, through analyzing the VLBI observations.

## 2 Staff at KTU-GEOD Contributing to the IVS Analysis Center

Members who have contributed to the research and activities of the KTU-GEOD IVS Analysis Center (AC) in 2019 and 2020 are listed in Table 1 (in alphabetical order) by their main focus of research and working location [3, 4, 5].

**Table 1** Staff.

| Name | Working Location | Main Focus of Research |
|---|---|---|
| Emine Tanır Kayıkçı | Karadeniz Technical Univ., Dept. of Geomatics Eng., Trabzon, Turkey | responsible person from AC, parameter combination |
| Kamil Teke | Hacettepe University, Dept. of Geomatics Eng., Ankara, Turkey | data analysis |
| Özge Karaaslan | Gümüşhane University, Dept. of Geomatics Eng., Gümüşhane, Turkey | data analysis, velocity estimation |

**Fig. 1** A photo during Emine Tanır Kayıkçı's presentation at GFZ Potsdam in July 2019.

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1. Karadeniz Technical University, Department of Geomatics Engineering
2. Hacettepe University, Department of Geomatics Engineering
3. Gümüşhane University, Department of Geomatics Engineering

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## 3 Current Status and Activities

During 2019, we implemented new approaches to the LS module of the GFZ (GeoForschungsZentrum, Potsdam, Germany) version of VieVS (Vienna VLBI and Satellite Software, [6]) to detect outliers within the research stay of Emine Tanır Kayıkçı at GFZ Postdam. The research project addressed the performance of standard outlier detection methods used in the GFZ version of VieVS by looking at the accuracy obtained for the Earth Orientation Parameters. In our work, we intend to investigate problems connected with outlier detection and elimination in VLBI data analysis [7, 8]. For this purpose, the impact of using different outlier detection criteria was assessed.

The detection and elimination of outliers in VLBI observations is an important pre-processing step for VLBI parameter estimation. A common technique to handle this problem is based on a so-called k-sigma Criteria Method. The so-called k-sigma Criteria is a commonly used technique for the detection and elimination of outliers in the observations. It is standard in the VLBI data processing using the GFZ version of VieVS software.

The main idea is to compare each residual with standard deviation of unit observation with factor k (typically $k = 3$ or $k = 5$) or with a standard deviation of residual with factor k. In case the i-th observational residual is greater than the compared standard deviation, the corresponding observation is detected as an outlier and eliminated. Otherwise, it is kept. This procedure removed the impact of outlier observation on the estimated parameter.

In outlier detection and elimination of VLBI data analysis, the analyst has to decide between removing, down-weighting, or retaining incorrect data which may negatively affect the results. Removing data seems to be the least desirable action as it leads to losing information or even to lack of the solution (due to the singularity of normal equations). Moreover, excluding any station causes disability to determine coordinates of this site and changes in the geometry of the network. On the other hand, if we want to improve the solution, retaining bad data is not an option. The most appropriate solution seems to be down-weighting observations, as it allows saving the required data [9].

The down-weighting practically eliminates the impact of the observation on the estimated parameters. With the standard outlier detection method [10] used in VieVS, the theoretical factor corresponds with a normal distribution, whereas the proposed method in this research points to a t-distribution.

The standard-used outlier detection algorithm in the VieVS software starts with an initial least-squares adjustment. Afterwards, all observations are eliminated from the data whose residuals exceed their respective standard deviations (sigma) by a factor of 3 or 5. The final parameters are estimated after the elimination of outliers in the second step. The standard outlier observation detection method is rather fast but too simple, since it might tend to wrongly eliminate correct observations.

In our work, we applied the so-called k-sigma Criteria Method as the standard outlier detection method with the standardized standard deviation and student t-test which depends on an alternative way for the calculation of standard deviation points to a t-distribution. We focus here on Earth Orientation Parameters (EOP). We compare student t-test [11, 12] with the standard approach. With the student t-test method of the outlier detection, the formal (standard) error, $s_{v_i}$ of the $i^{th}$ observational residual ($v_i$) is calculated as follows

$$s_{0i} = \sqrt{\frac{1}{f-1}([pvv] - \frac{v_i^2}{q_{v_i v_i}})} \qquad (1)$$
$$s_{v_i} = s_{0i}\sqrt{q_{v_i v_i}}$$

where

$$q_{vv} = diag(Q_{ll} - AQ_{xx}A^T) \qquad (2)$$

In Equations (1) and (2), $f$ denotes the degrees of freedom of the adjustment, $[pvv]$ is the weighted square sum of the observational residuals, $v_i$ the residual to the $i^{th}$ observation, $q_{vv}$ are the diagonal elements of the cofactor matrix of the observational residuals, $Q_{ll}$ the inverse of the weight matrix of observations, and $A$ the coefficient matrix of the linearized observation equations.

For the study, fifteen CONT17 VLBI sessions were used. The VLBI data were processed at the GFZ using the software GFZ Version of VieVS software [6]. In this research, we inserted the student t-test outlier detection method in vie-lsm module. For this purpose, special VLBI campaigns like CONT17, scheduled and observed from 28 November 0 UT to 12 December 2017 24 UT, were used to perform research work. k-sigma Outlier Elimination Criteria both by factor were evaluated for achieving the proposed student t-test outlier detection method in LSM for single-session analysis in VieVS.

Several investigations were performed to compare the accuracy of various parameters estimated by the standard outlier detection method with those estimated by student t-test outlier detection. MATLAB codes in vie-lsm have been modified properly. The impact of applying different outlier detection methods, for standard outlier detection and t-test and analysis procedures, were assessed by investigating formal errors of the dUT1 estimation results from the fifteen CONT17 XE sessions (see Figure 2).

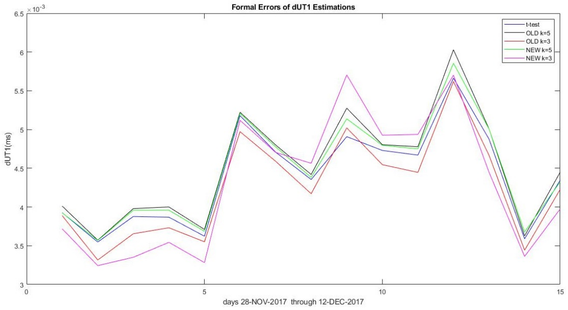

**Fig. 2** UT1 formal errors with different outlier detection methods.

In a second study, we aim to determine and interpret crustal movements at velocities determined from data obtained from different space-geodetic techniques, i.e., VLBI and GNSS. The VLBI co-located IGS network which consists of the stations CRAO in Ukraine, MADR in Spain, MATE in Italy, MEDI in Italy, METS in Finland, NOT1 in Italy, ONS1 in Sweden, SVTL in Russia, TIT2 in Germany, WTZR in Germany, YEBE in Spain, and ZECK in Russia was considered for the study. For the period from January 2017 until January 2020, the coordinates are estimated through analyzing the daily data, with Bernese *v*5.2 [13]. The coordinates of the VLBI stations, i.e., CRIMEA in Ukraine; MATERA, NOTO, MEDICINA in Italy; WETTZELL in Germany; ONSALA60 in Sweden; SVETLOE, ZELENCHK in Russia; METSHAHOV in Finland; and YEBES in Spain (see Figure 3) are estimated from the analysis of the IVS daily sessions between January 2017 and January 2020 using VieVS. The linear global velocities of the GNSS and VLBI stations will be estimated in the next step of this study.

**Fig. 3** VLBI stations considered for the study.

The Alp-Himalayan Earthquake Zone: starting from Indonesia, it reaches the Atlantic Ocean through the Himalayas and the Mediterranean. It is the second most seismically active region in the world, after the circum-Pacific belt (the Ring of Fire), with 17% of the world's largest earthquakes. Main ranges: Cantabrian Mountains (incl. the Basque Mountains), Sistema Central, Sistema Ibérico, Pyrenees, Alps, Carpathians, Balkan Mountains (Balkanides), Rila-Rhodope massifs, Thracian Sea islands, and the Crimean Mountains—entirely in Europe. Taking into consideration, two separate networks (more IGS stations relative to VLBI) will be created and analyzed as well as the position changes of the stations will be interpreted. It is aimed to determine the velocity field of the region, examine the results of different space-geodetic techniques, i.e., the horizontal and vertical deformations detected at the geodetic stations, and finally evaluate the crustal movements of the region from a geophysical point of view.

In a third study, the amplitudes and Greenwich phase-lags for each coordinate component, i.e., radial, west, and south of the principal lunar semidiurnal tide, $M_2$ of the ocean tide loading displacements were estimated at the VLBI sites of the 15-day long Continuous VLBI campaign 2014, IVS-CONT14. In the estimation of the amplitudes and Greenwich phase-lags of the $M_2$ tidal constituent, hourly VLBI station coordinate time series were used as observations derived through analyzing one-hour VLBI sessions of the

CONT14 campaign. In the analysis of hourly sessions of the CONT14 campaign, using VieVS [14] to derive accurate hourly station coordinates, troposphere delays estimated from daily sessions were reduced from the observations a priori to the analysis. For further details, readers are referred to [15].

## 4 Future Plans

In 2021 and 2022, our group will be working on estimating station velocities of the European IGS and VLBI sites in the scope of the Ph.D. thesis of Özge Karaaslan. Besides, the principal semi-diurnal and diurnal tidal constituents of the high-frequency Earth rotation variations due to the ocean tides from the recent models will be compared with those observed by VLBI and GNSS.

## Acknowledgements

We are thankful to the governing board of the IVS [1, 2]. We are grateful to Karadeniz Technical University, Hacettepe University, Deutsche GeoForschungsZentrum-Potsdam, and Technische Universität Wien for their financial, technical and/or scientific support of the KTU-GEOD IVS AC research activities.

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