The TU Graz contribution to the International Terrestrial Reference Frame (ITRF 2020): Processing of 27 years of GNSS data

Der Beitrag der TU Graz zum Internationalen Terrestrischen Referenzrahmen (ITRF 2020): Prozessierung von 27 Jahren GNSS-Daten

  

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Abstract

A global geodetic reference frame (GGRF), such as the International Terrestrial Reference Frame (ITRF), is fundamental for quantifying geophysical changes in the Earth system. Global navigation satellite systems (GNSS) are one of the four space-geodetic techniques contributing to the construction of the ITRF. In support of the ITRF2020 release, the International GNSS Service (IGS) conducted its third reprocessing campaign (repro3), covering the years 1994 to 2020. Graz University of Technology (TUG) participated for the first time as an analysis centre in such a reprocessing campaign and TUG has been acknowledged globally for its high quality GNSS products. In this article we want to present the approach of TUG for the repro3 campaign as well as present research and analysis showing the high quality of the TUG products.

Keywords: global navigation satellite systems (GNSS), International Terrestrial Reference Frame 2020 (ITRF2020), raw observation approach

Kurzfassung

Ein globaler geodätischer Bezugsrahmen (GGRF), wie der Internationale Referenzrahmen (ITRF), ist von grundlegender Bedeutung für die Quantifizierung geophysikalischer Veränderungen im Erdsystem. Globale Satellitennavigationssysteme (GNSS) sind eine der vier weltraumgeodätischen Techniken, die zum Aufbau des ITRF beitragen. Zur Unterstützung des ITRF2020 führte der Internationale GNSS-Dienst (IGS) seine dritte Reprocessing-Kampagne (repro3) durch, die die Jahre 1994 bis 2020 abdeckt. Die Technische Universität Graz (TUG) nahm zum ersten Mal als Analysezentrum an einer solchen Reprocessing-Kampagne teil und die TUG ist weltweit für ihre qualitativ hochwertigen GNSS-Produkte anerkannt worden. In diesem Artikel möchten wir den Ansatz der TUG für die repro3-Kampagne vorstellen sowie Untersuchungen und Analysen präsentieren, die die hohe Qualität der TUG-Produkte belegen.

Schlüsselwörter: globale Satellitennavigationssysteme (GNSS), Internationaler Terrestrischer Referenzrahmen 2020 (ITRF2020), Ansatz der rohen Beobachtung

1. Introduction

An accurate and stable global geodetic reference frame (GGRF), such as the International Reference Frame (ITRF), is fundamental for quantifying geophysical changes in the earth system. Such GGRF has been deemed important enough to be recognized by the United Nations General Assembly in 2015 passing the Resolution "A Global Geodetic Reference Frame for Sustainable Development". Global navigation satellite systems (GNSS) are one of the four space-geodetic techniques contributing to the construction of the ITRF. For the newly released ITRF2020, the international GNSS service (IGS) conducted its third reprocessing campaign (repro3), ranging from the years 1994 till 2020. Graz University of Technology (TUG) participated for the first time as a GNSS analysis centre (AC) in such a reprocessing campaign. The goal of repro3 is to create high quality GNSS products with the newest models and up to date processing strategies. The individual AC solutions are combined to one IGS solution which in term

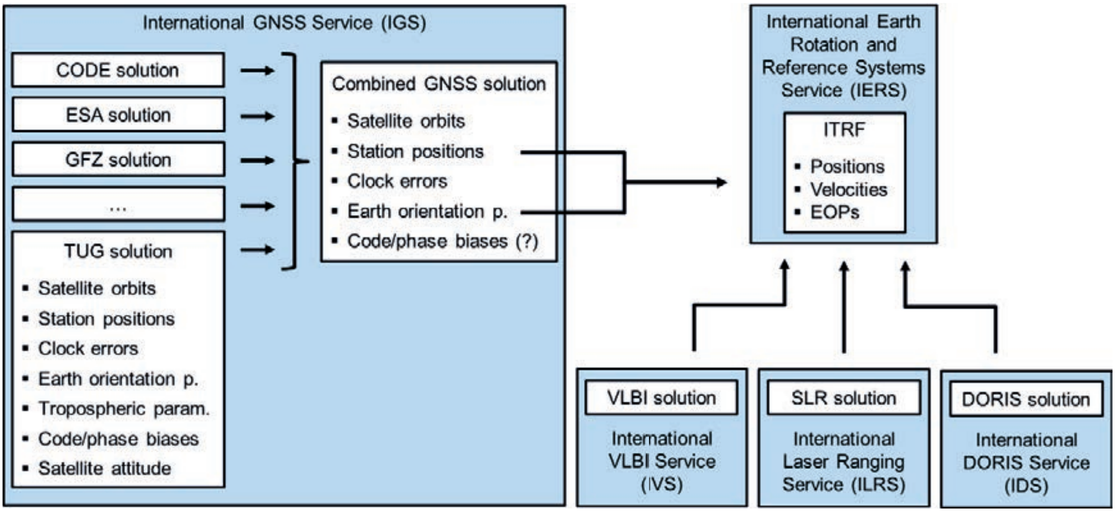


Fig. 1: Combination of the space geodetic techniques and their respective services which are used in creating the ITRF

is combined in the ITRF with the other space-geodetic techniques as shown in Figure 1. In the following sections we want to elaborate the processing strategy and the impact of the TUG contribution to the repro3 and ITRF2020.

2. Processing Strategy

TUG adapted the raw observation approach for GNSS and developed it further to be feasible for global GNSS station network processing (Strasser et al. 2019 [1]). The raw observation approach uses all measurements as observed by the receivers without explicitly creating any linear combinations or differences. This approach allows for the full exploitation of the information contained within each individual observation type while also preserving the original measurement accuracy. This requires the observation equation to take every effect into account by a priori models or by adding more unknown parameters. The raw observation approach only gained popularity with increasing computational powers.

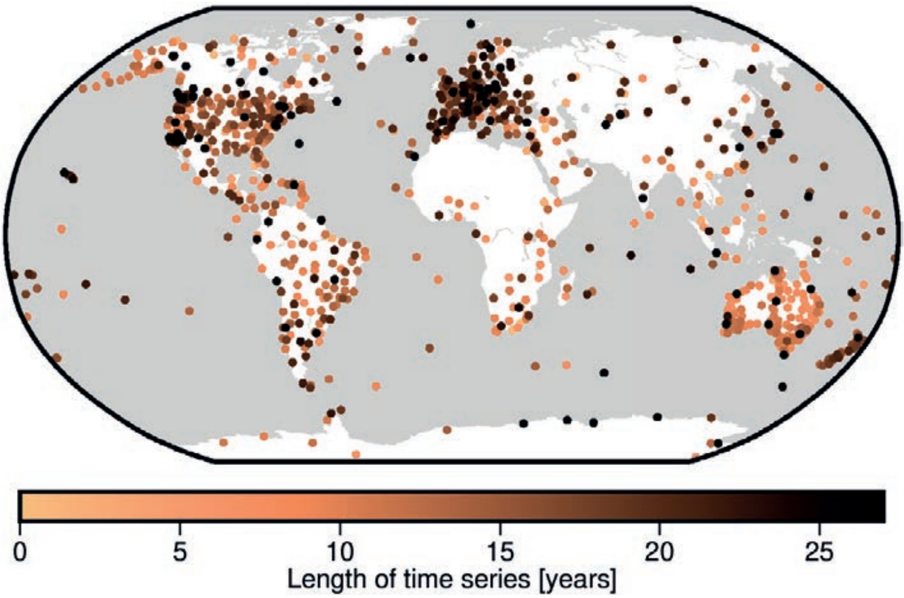


Fig. 2: Stations used in the reprocessing and their time series lengths (adapted from Rebischung, 2021)

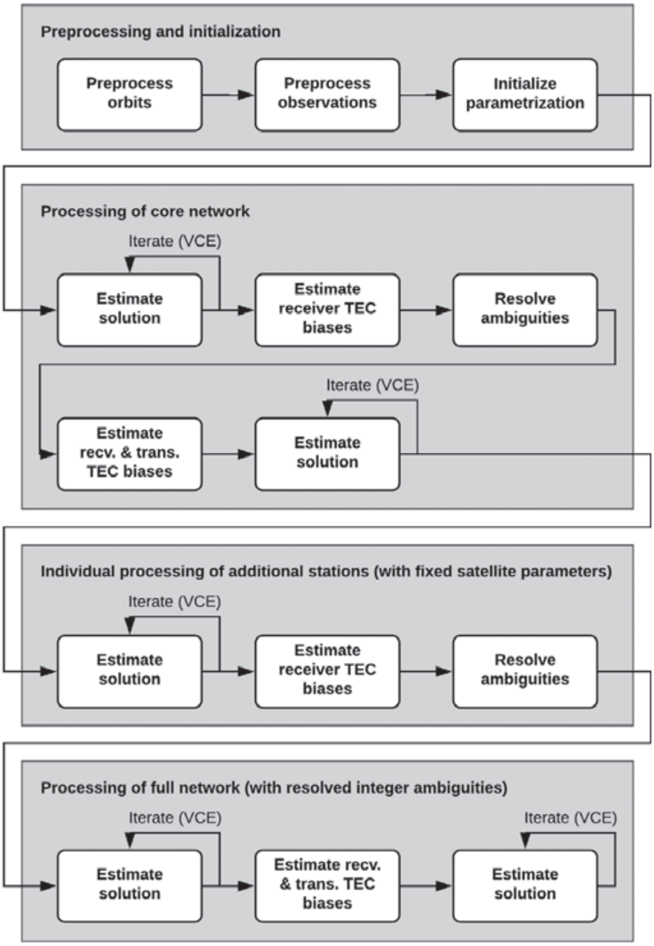


Fig. 3: Processing strategy at Graz University of Technology

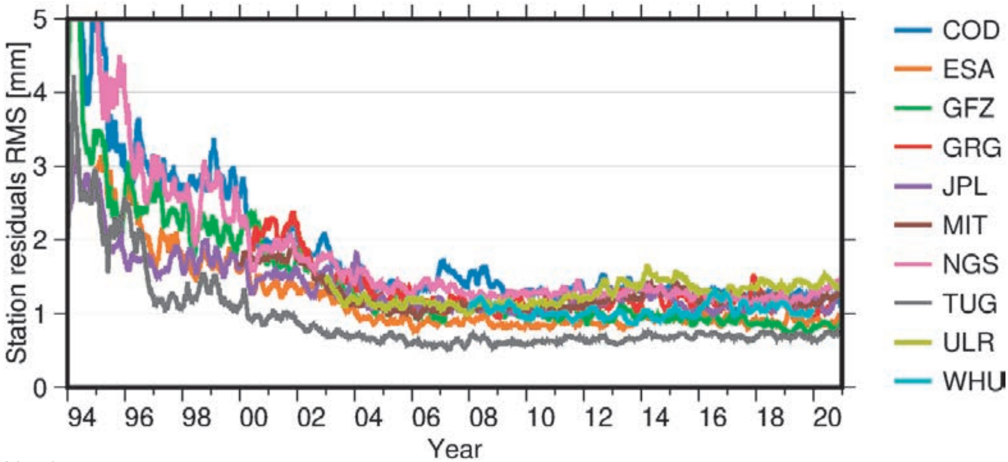
The reprocessing campaign consisted of the GPS, GLONASS and Galileo GNSS as well as a total of 1182 ground stations as seen in Figure 2. In the latter timeframe of the campaign over 800 stations have been processed together with a sampling rate of 30 seconds leading to equation systems consisting of hundreds of millions of observations and millions of parameters each individually evaluated daily. Since the full computation of the stations and satellites is not feasible to be computed at once, the estimation is split into several processing steps to accommodate the huge set of observations and parameters. TUG approaches this problem for the raw observation approach in four overarching processing levels as shown in the flowchart Figure 3.

The first level consists of the pre-processing of the available data, quality checks and validations to eliminate rough outliers and errors in the data. In the second processing level a smaller station network consisting of 40-50 stations from the 1182 available stations are selected to fix the satellite parameters as well as resolving the integer ambiguities of the reduced station network receivers. The third processing level consists of the integer ambiguity resolving of the individual stations not yet processed. For this the transmitter dependent parameters estimated in the second level are held fixed throughout the third level to solve the individual station receiver parameters as well as ambiguities. With all integer ambiguities resolved the last step consists of a full network processing with all receiver and transmitter parameters. The last processing level requires the most computational time and memory and overshadows the previous levels in terms of required processing power. The result of all four levels are high quality products such as station position time series, satellite orbits, receiver/transmitter clocks, code/phase biases, earth orientation parameters and many more. A more thorough detailed explanation of the processing strategy and raw observation approach can be found in Strasser (2022) [2].

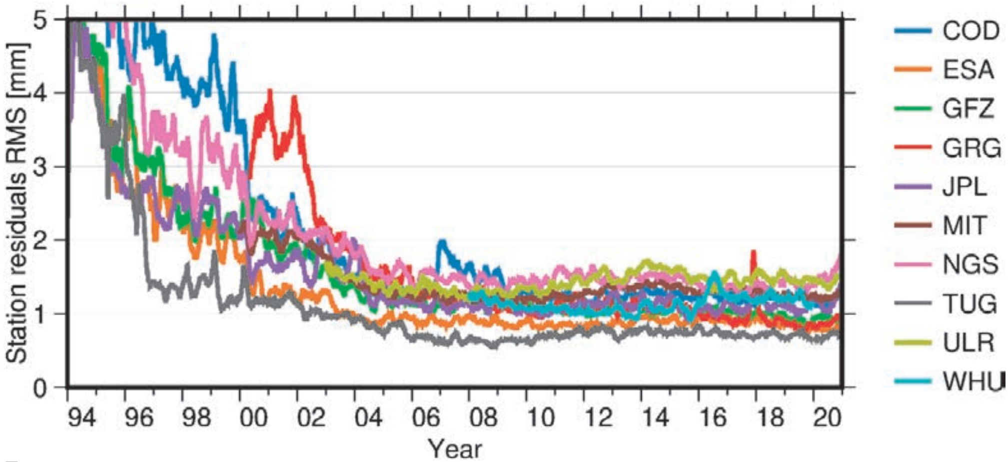
3. TUG product validation

The most important product of the reprocessing campaign is the station position time series. The evaluation between the AC is based on the residuals and formal errors from the IGS combined process and an in-depth analysis can be found in Rebischung (2021) [3]. The conclusion from the analysis is that TUG products (Strasser et al 2021 [4]) are of high quality and is a front runner among all AC contributions. An example of this validation is seen in Figure 4 which shows the time series of 91-day median filtered station position residuals.

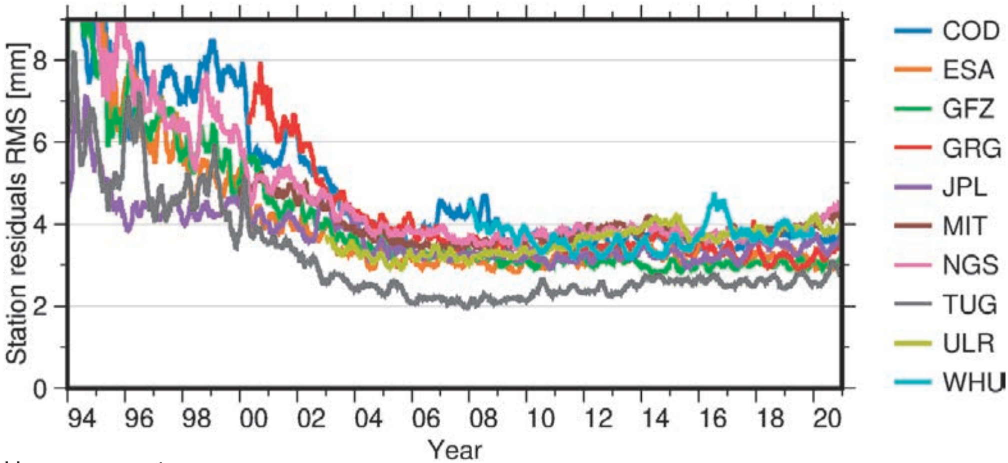
TUG provided the only solution in the sub millimetre RMS value in the horizontal and an up-component RMS below 3 mm. Table 1 shows the formal errors of the analysis centres contribution and TUGs solution are significantly smaller than those of other analysis centres which implies that it got the highest weight on average in the combined IGS solution.



North component



East component



Up component

Fig. 4: *Smoothed (i.e., 91-day median filtered) station position residuals RMS of individual analysis center solutions with respect to the IGS combination. Note the different y-axis scale for the up component.*

Analysis centre	Median residuals RMS [mm]			Median formal errors [mm]		
	North	East	Up	North	East	Up
COD	1.5	1.5	4.1	1.3	1.2	4.2
ESA	1.0	1.0	3.3	1.0	0.9	3.3
GFZ	1.1	1.2	3.4	1.0	1.0	3.6
GRG	1.2	1.2	3.6	1.1	0.9	3.3
JPL	1.2	1.3	3.5	1.2	1.1	3.6
MIT	1.2	1.3	3.8	1.2	1.2	3.7
NGS	1.4	1.6	4.1	1.3	1.1	3.9
TUG	0.7	0.8	2.7	0.7	0.7	2.5
ULR	1.3	1.4	3.6	1.2	1.2	3.6
WHU	1.0	1.1	3.6	1.0	1.0	3.3

Tab. 1: Median values of daily station position residuals RMS for individual analysis centre solutions with respect to the IGS combination and their median formal errors after optimal weighting

Also, Sakic et al (2022) [5] investigated the combination of the IGS repro3 orbit products by variance component estimation (VCE) and within his analysis it is shown that TUG accomplished the most stable and best RMS GPS orbit solutions with RMS around 6 mm. The TUG GLONASS solutions were on par with the other AC solutions and on the European Galileo constellation the TUG solution showed the same level of agreement to other prominent ACs with a similar RMS around 5 mm.

4. Summary and outlook

TUG contributed to the ITRF2020 as GNSS AC with high quality products on par with other more established AC. TUG even managed to surpass expectations and has been internationally recognized for the impact it had on the ITRF2020 contribution with its high-quality GNSS results. TUG is further developing its approach for global network processing with the raw observation approach. Current research focuses on a more sophisticated stochastic modelling (Dumitraschkewitz et al 2022 [6]) of the observations and receiver/transmitter clocks. Furthermore, another aspect that is currently in investigation is the improvement of the quality checks in the form of a more robust cycle slip detection (Dumitraschkewitz et al 2023 [7]) especially in low elevation based observations and much more. The software used in the repro3 campaign also known as "Gravity Recovery Object Oriented programming System" (GROOPS) has been made publicly available as open source on https://github.com/groops-devs/groops (Mayer-Gürr et al. 2021 [8]). Other key features of the software besides GNSS processing include gravity field recovery from satellite and terrestrial data.

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