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Very Long Baseline Interferometry for Global Geodetic Reference Frames








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Abstract

Geodetic Very Long Baseline Interferometry (VLBI) is the only technique for the determination of the full set of Earth orientation parameters and for the realization of the International Celestial Reference Frame (ICRF) at radio wavelengths. Furthermore, it is making essential contributions to the determination of the scale of the International Terrestrial Reference Frame (ITRF). Based on a Memorandum of Understanding between TU Wien and the Federal Office of Metrology and Surveying (BEV), a Vienna Analysis Center (VIE) of the International VLBI Service for Geodesy and Astrometry (IVS) is jointly run by both organizations. The main focus of these activities is on the routine determination of Earth orientation parameters as well as the estimation of global reference frames.

Keywords: Very Long Baseline Interferometry (VLBI), Global Geodetic Reference Frames (GGRF), Earth Orientation Parameters (EOP)

Kurzfassung

Die geodätische Very Long Baseline Interferometry (VLBI) ist das einzige Verfahren zur Bestimmung aller Erdorientierungsparameter und für die Realisierung des International Celestial Reference Frame (ICRF) im Radiowellenbereich. Weiters liefert die VLBI essentielle Beiträge für die Bestimmung des Maßstabs des International Terrestrial Reference Frame (ITRF). Basierend auf einem Memorandum of Understanding zwischen dem Bundesamt für Eich- und Vermessungswesen (BEV) und der TU Wien wird nun ein gemeinsames Wiener Analysezentrum (VIE) des International VLBI Service for Geodesy and Astrometry (IVS) betrieben. Der Fokus liegt dabei auf der operationellen Bestimmung von Erdorientierungsparametern und der Bestimmung von Globalen Referenzrahmen.

Schlüsselwörter: Very Long Baseline Interferometry, globale geodätische Referenzrahmen, Erdorientierungsparameter

1. Introduction

Global Geodetic Reference Frames (GGRF) are fundamental for monitoring changes to the Earth, including the continents, oceans, polar ice caps, or the atmosphere. Furthermore, they are fundamental for mapping, positioning, and navigation on Earth and in space, as well as for timing applications. The importance of GGRF has been recognized by the United Nations General Assembly in February 2015 by adopting the Resolution „A Global Geodetic Reference Frame for Sustainable Development“[1].

Very Long Baseline Interferometry (VLBI) plays a key role for the realization of terrestrial and celestial reference systems (TRF, CRF) as well as for the determination of Earth orientation parameters (EOP). The measurement principle is rather simple, observing the difference in arrival time of the signals from extragalactic radio sources

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[1] https://www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/69/266

(mostly quasars) at two sites equipped with radio telescopes and very accurate clocks (see Figure 1). Since this delay τ can be represented as the scalar product of the baseline vector $\underline{b}$ with the unit vector to the source $\underline{s}_0$ (divided by the velocity of light), VLBI observations can be used to determine baseline vectors and directions to extragalactic radio sources and thus make essential contributions to the TRF and CRF. The EOP constitute the transformation between these frames and are, therefore, another result of VLBI. For more information on geodetic VLBI, see e.g., [8] Schuh and Böhm (2013).

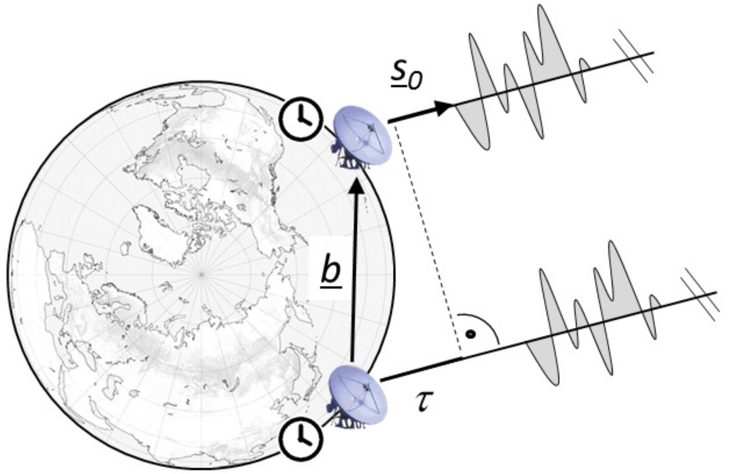

Fig. 1: *Measurement principle of VLBI: The primary observable is the difference in arrival time t of the signal from the quasar at two radio telescopes. The observable τ can also be written as the scalar product of the baseline vector $\underline{b}$ with the unit vector to the source $\underline{s}_0$.*

Typically, there are about three 24 hour sessions per week with six to eight radio telescopes observing a pre-defined sequence of sources. Additionally, once per day, there are so-called 1 hour Intensive sessions on a single baseline with a long east-west extension for the observation of UT1-UTC, which is the Earth orientation parameter reflecting the Earth rotation angle (see Nießner et al., this issue). UT1-UTC is a primary product of VLBI, because Global Navigation Satellite Systems (GNSS) are dependent on this information.

The complete process chain of VLBI comprises the scheduling, i.e., the preparation of the observation plans, the observations at the stations with radio telescopes, correlation and fringe-fitting to derive the group delays τ, as well as the analysis of the observations for the determination of geodetic and astrometric parameters. In July 2018, TU Wien and the Federal Office of Metrology and Surveying (BEV) signed a Memorandum of Understanding for joint work in the field of VLBI analysis. In the following sections, we describe the VLBI activities in more details.

2. Scheduling

VLBI observation plans, commonly referred to as schedules, define which antennas simultaneously observed a radio source at a particular time, i.e. which antennas of the network form a scan. Since the observation constellations defined in a schedule determine its applicability for the estimation of specific target parameters, e.g. EOPs, schedules have to be prepared carefully by applying dedicated optimization approaches.

Most of the geodetic schedules for the International VLBI Service for Geodesy and Astrometry (IVS; [6] Nothnagel et al., 2017) are prepared with the software *sked*. In Vienna, we use VieSched++ ([7] Schartner and Böhm, 2019) developed in C++, which is part of the Vienna VLBI and Satellite Software (VieVS; [2] Böhm et al., 2018). VieSched++ has already been used for the scheduling of Australian sessions, T2 sessions, INT3 sessions, OHG, sessions, or European sessions. The ability to use the Monte Carlo method in a feedback loop allows the VieSched++ software to produce schedules that are based on a rigorous simulation approach. More information about the session types can be found at: *https://ivscc.gsfc.nasa.gov/sessions/*

3. Correlation and fringe-fitting

All participating stations in a session pick up the schedule file and observe the sequence of sources with the defined observing mode. Typical data rates are 512 Mbit/sec or 1024 Mbit/sec. These streams of raw data then need to be (e-) transferred to a powerful supercomputer where the initial processing of the recorded raw observation data is conducted - the correlation. As VLBI correlation is very CPU intensive, powerful computer clusters are used in order to derive results in a reasona-

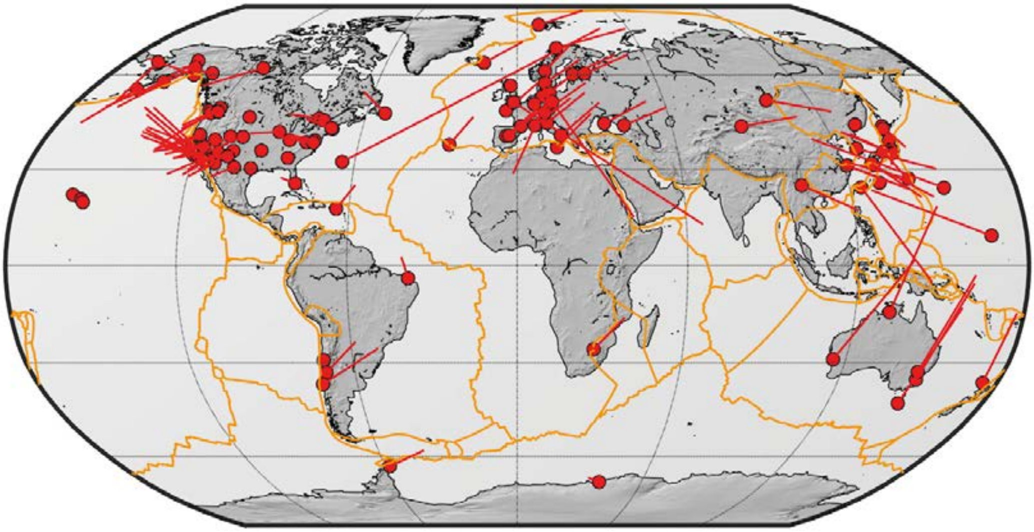

Fig. 2: Distribution of IVS radio telescopes with estimated velocities. Session-wise normal equations from all VLBI sessions until the end of 2014 as set up at TU Wien went into the combination process of ITRF2014.

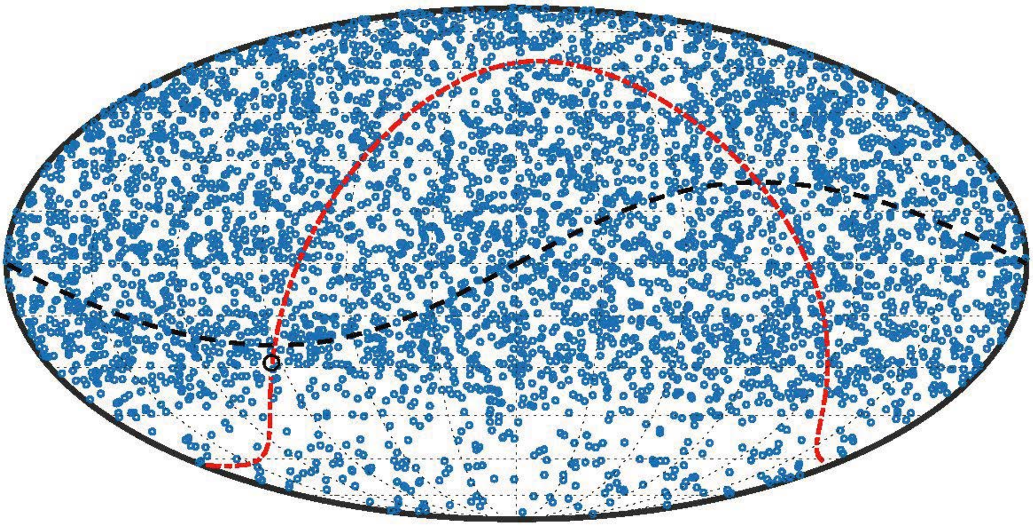

Fig. 3: Source distribution of the Vienna prototype solution for the ICRF3 ([5] Mayer, 2019). The ecliptic is depicted as a black dashed line, the galactic plane is illustrated as a red dashed line and a black circle in the bottom left part of the figure marks the Galactic center.

ble time. In Vienna, we use the Vienna Scientific Cluster 3 (VSC-3), which provides in total 2020 processing nodes. In 2019, we will move our correlation activities to the VSC-4, where we will have 10 private nodes and about 1 PByte storage capacity. Currently, we are correlating Australian sessions, European Intensives and K-band sessions for astrometry. Correlation and fringe-fitting, which is needed to determine the group delays that are then used in the VLBI analysis, are carried out with the software packages DiFX ([4] Deller et al., 2011) and HOPS/Fourfit[2], respectively.

4. LBI Analysis

Since July 2018, BEV and TU Wien form a Special IVS Analysis Center. We plan to become an Operational Analysis Center of the IVS, which means that we will operationally analyze all 24 hour R1- and R4-Sessions on Mondays and Thurs-

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[2] https://www.haystack.mit.edu/tech/vlbi/hops.html

days, respectively. The results (normal equations) are submitted to the IVS Combination Center at BKG in Frankfurt/Main with a short latency. This submission contains the Earth orientation parameters, which will then go into the products of the International Earth Rotation and Reference Systems Service (IERS).

For VLBI analysis, we use the VLBI module of the Vienna VLBI and Satellite Software (VieVS). VieVS is developed in Matlab and is publicly available at https://github.com/TUW-VieVS. We want to highlight that a Vienna solution with VieVS went into the combination for the ITRF2014 ([1] Altamimi et al., 2016) (see Figure 2) and we provided solutions for the International Celestial Reference Frame 3 (ICRF3; [3] Charlot et al., 2019) (see Figure 3), which was officially approved by the International Astronomical Union (IAU) in August 2018.

5. Summary and Outlook

The joint IVS Analysis Center VIE (TU Wien/BEV) is contributing to a variety of tasks in the field of Very Long Baseline Interferometry, comprising scheduling, correlation, and the analysis of VLBI observations. By doing so, BEV and TU Wien are also making an important Austrian contribution to the realization of Global Geodetic Reference Frames as requested by the UN General Assembly Resolution.

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