Impact of terrestrial datum on the estimation of Earth Orientation Parameters by geodetic VLBI

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Abstract The selection of terrestrial datum stations has a significant impact on the geodetic parameters. Continuous observation with precise a priori information is required in defining geodetic datum to avoid error propagation in the estimation of Earth orientation parameters (EOP) through VLBI. When estimating EOP, stable positions of the stations and sources are included in the respective datum. This study assesses the influence of station removal from the terrestrial datum on EOP. We removed three different stations- Wettzell, Sejong, and Kokee, individually. The study has utilized data from 2001 to 2022, derived from geodetic VLBI sessions, and analyzed them with VieVS. To understand the statistics, the EOP solutions, obtained after removing the stations from the datum are compared against standard Vienna, IERS 20 C04, and IGS finals solutions. The results reveal that celestial pole offsets (CPO) remain unaffected, regardless of the station's removal, while UT1-UTC and PM are influenced by station location and the presence of neighboring stations.

Keywords EOP, Datum, VLBI, ITRF

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1 Introduction

Group delays in VLBI sessions, observed from baselines forming a polyhedron, are associated with a ”free” network where the datum is defined by selecting a subset of points. According to Heinkelmann et al. (2007), the selection of points is contingent upon various criteria, including the objectives of the network or session, the type, quantity, and precision of measurements, as well as the attributes of the sources (such as structure and stability) or stations (encompassing ground properties, monumentation, episodic motions, etc.). These designated datum points substantially impact the Terrestrial Reference Frame (TRF) defined by geodetic Very Long Baseline Interferometry (VLBI).

United Nations highlighted the significance of the Global Geodetic Reference Frame (GGRF) for the benefit of society and the scientific community. As per Plag et al. (2009), GGRF is realized as the International Terrestrial Reference Frame (ITRF) with the intention to achieve mm-level accuracy to the geodetic products. To fulfill this goal, continuous observations with precise a priori information regarding station positions and velocities are required to avoid significant noise in the definition of geodetic datum that subsequently propagates in the determination of various geodetic parameters such as Celestial Reference Frame (CRF) and Earth Orientation Parameters (EOP) (Raposo-Pulido et al., 2016). Geodetic VLBI utilizes an interferometric technique, observing a catalog of distant radio sources to establish a quasi-inertial external reference frame, commonly referred to as CRF (Karbon at al., 2019). The determination of these two reference frames, TRF and CRF, is intricately interlinked and not mutually consistent. The transition between these reference frames is facilitated through

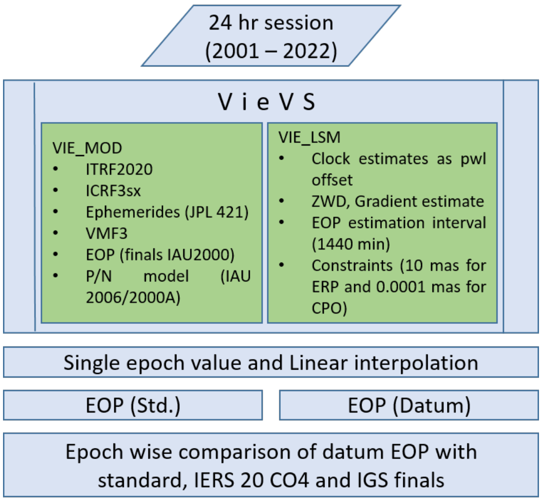

Fig. 1 Flowchart showing the models and steps involved in the estimation of EOP.

a set of five angles, collectively termed as EOP. These parameters encompass celestial pole offsets (CPO) (dX and dY), polar motion (x_p and y_p), and variations in universal time (UT1-UTC), all of together can exclusively be measured through geodetic VLBI.

In general, it can be imagined that the reliability of a terrestrial datum should improve as the number of stations used in its definition increases. However, for this to be true, the prerequisite is that all stations exhibit similar accuracy and stability. Paradoxically, in certain scenarios, both the addition and removal of stations can adversely affect the reliability of the terrestrial datum, consequently influencing other geodetic parameters such as the CRF and EOP. In the scope of this study, we quantify the impact of eliminating stations from the terrestrial datum on EOP. The central question we investigate is whether removing a single station from the terrestrial datum, regardless of its geographical location, produces a consistent impact on EOP. In anticipation of future scenarios necessitating the removal of stations from the terrestrial datum, our research aims to point out which station should be prioritized for removal to maximize the precision of EOP.

2 Parametrization and Analysis

In this study, we utilized VLBI 24-hour sessions observed by the International VLBI Service for Geodesy and Astrometry (IVS) from 2001 to 2022. These sessions were analyzed using VieVS (Böhm et al., 2018) to estimate the daily value of EOP. The a priori models employed in the routine analysis of IVS 24-hour sessions by the Vienna Analysis Center were implemented (Fig 1). The EOP values were estimated at 1440 min intervals with relative constraints of 10 mas for Earth Rotation Parameters (ERP) and 0.1 μas for Celestial Pole Offsets (CPO). Furthermore, piecewise linear offsets with 60 min interval and 1.3 cm relative constraint for the clocks, zenith wet delays with 30 min interval and 1.5 cm relative constraint, and troposphere gradients with 180 min and 0.5 mm constraint were also estimated. Additionally, station coordinates were also estimated and the datum was defined by applying no-net-translation (NNT) and no-net-rotation (NNR) conditions for stations with continuous observations in the ITRF2020.

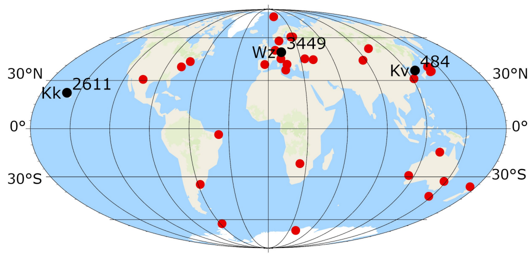

Fig. 2 Distribution of VLBI stations (red), whereas black represents the station removed one at a time from the datum. Numbers denote the participation in sessions (2001–2022).

To evaluate the impact of terrestrial datum on EOP, we removed different stations—Wettzell (Wz), Kokee (Kk), and Sejong (Kv)—one at a time from the datum (Fig 2). Four distinct EOP time series were estimated using VieVS in this study using the same a priori models and parameters: the standard EOP file (utilizing standard parameters), and three variations obtained after individually excluding Wz, Kk, and Kv. The estimated time series were not continuous, with some epochs having missing values, and in a few instances, multiple EOP values for the same epoch. To address this, we selected the EOP value with the minimum standard error when multiple values were present for the same epoch and applied linear interpolation to fill in missing values. The quality assessment of the three variations of the EOP time series (after excluding Wz, Kk, and Kv) was performed in terms of weighted mean (WM) and weighted root mean square (WRMS) value with respect to standard Vienna, IERS 20 C04 and IGS final solution. However, the comparison with respect to IGS finals was limited to a subset of EOP directly observed from GNSS, specifically, x_p and y_p. IERS 20 C04 solution served as the reference epoch, and both VieVS solutions (CPO) and IGS finals were linearly interpolated to the IERS 20 C04 epoch, which is at $00:00$ UTC.

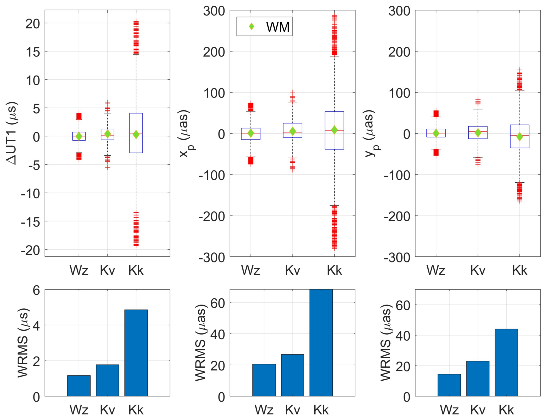

Fig. 3 Statistics showing the comparison of EOP solution, when stations are removed with respect to standard Vienna solution.

3 Results and Discussion

3.1 Comparison w.r.t. standard Vienna solution

Our initial analysis focuses on comparing three different datum time series solutions with respect to the Vienna standard solution. Looking at Fig 3, it becomes apparent that the distribution of variations in UT1-UTC and PM exhibits significant dispersion when Kokee (Kk) is removed from the terrestrial datum, whereas the dispersion is reduced when Wettzell (Wz) is excluded. Notably, the WRMS values are found to be highest when Kk is removed from the terrestrial datum. Upon the removal of Wz, 3449 epochs were compared, while with the exclusion of Kv and Kk, the epochs compared were 484 and 2611, respectively, spanning from 2001 to 2022. Specifically, when Kk is removed, the WRMS value for x_p is 60 μas, compared to 40 μas for y_p. It can be because most of the session in the time frame is best suitable for the estimation of y_p. Nilsson et al. (2014) and Raposo-Pulido et al. (2016) stated that to have a good sensitivity for x_p, N-S long baseline close to 0° or 180° longitude is needed. Consequently, the significant distribution and higher WRMS value in x_p compared to y_p may be due to an insufficient number of N-S baselines after the removal of Wz and Kk. However, since only 484 epochs were compared after the removal of Kv, the difference in WRMS values for x_p and y_p is not as pronounced.

Wettzell (Wz) is located in the European region, surrounded by a cluster of nearby VLBI stations. Conversely, Sejong (Kv) is located in the eastern part with only a few neighboring VLBI stations, and Kokee (Kk) stands as the sole VLBI station in the western part. From Fig 2, it becomes evident that if we eliminate Wz from the datum, there are ten other neighboring stations that can effectively maintain the network geometry. However, removing Kk leaves no other station available to uphold the network geometry. Consequently, the sequential removal of Wz, followed by Kv and Kk, leads to progressively higher WRMS values (Fig 3). Moreover, it is observed that the removal of any station from the terrestrial datum does not have an impact on CPO.

3.2 Comparison w.r.t. IERS 20 C04 and IGS finals solution

In this section, we compare the EOP solutions derived from the removed datum with reference to the IERS 20 C04 and IGS finals solutions. Nilsson et al. (2014) mentioned that WRMS values are independent of the datum. Consequently, we focus our comparison on the WM values in this section.

The WM value for UT1-UTC is found to be highest when Kv is removed. However, it is noteworthy that WM values exhibit similarity regardless of which station is removed from the terrestrial datum. This uniformity in behavior may be attributed to the sensitivity of UT1-UTC, which relies on a long East-West (E-W) baseline, as indicated by Schartner et al. (2021). Consequently, the removal of any of the stations appears to impact the E-W baseline in a comparable manner. A similar pattern is observed for CPO, particularly in the case of dX, but the reason may be different. However, for PM, the WM values concerning the IGS fi-

Table 1 EOP solutions obtained after removing the stations from the datum are compared against IERS 20 C04/IGS finals solution in terms of WM. All units are in μas except for UT1-UTC (μs).

	Wz	Kv	Kk
$UT1-UTC$	−2.24	−2.09	−2.59
dX	1.32	1.3	1.33
dY	−0.83	−0.84	−0.96
x_p	−31.31	−31.3	−30.23
x_p (IGS)	−21.8	−21.38	−16.76
y_p	4.97	5.12	8.41
y_p (IGS)	8.99	9.02	13.67

nals are higher. This outcome aligns with expectations since Global Navigation Satellite Systems (GNSS) offer the most precise PM estimates. This is primarily attributed to the extensive and globally distributed IGS GNSS network, which encompasses hundreds of stations and operates continuously. In contrast, the ITRF data is derived from the combination of various space geodetic techniques. Notably, the removal of Kokee (Kk) has a more substantial impact on PM in comparison to Wettzell (Wz) and Sejong (Kv). This difference may be attributed to the unique geographical position of Kokee as the sole station in the western part.

4 Conclusions and Outlook

Our comparative analysis has examined the effects of removing three distinct stations, individually, from the terrestrial datum on EOP. Within the EOP, CPO exhibit no noticeable impact, regardless of which station is excluded from the datum. Conversely, the influence on UT1-UTC is relatively minor and seems to be contingent on the specific location of the station being removed. Significantly, we have observed a substantial impact on PM, which appears to depend not only on the station's geographical location but also on the density of neighbouring stations. This study highlights the importance of recognizing that the removal of a station from the terrestrial datum can have a significant impact on ERP, particularly when no other nearby stations are available to uphold the network geometry. The study also reveals that the precision of EOP doesn't depend on the number of sessions. It is emphasized that, for datum stability, stations should be strategically removed, only when alternative stations are available in the vicinity to maintain the integrity of the network geometry.

The effect of removing any station from the southern hemisphere has not been addressed in this study. Additionally, separate analyses for stations situated at different longitudes and that affect the E-W baseline, would contribute to a more comprehensive understanding of how station removal influences ERP. A separate analysis can be implemented on the intensive sessions to understand the effect on UT1-UTC.

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