The 2023 Local Tie Surveys Conducted by GSI

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Abstract Local-tie vectors represent the positional relationship between the reference points of different space geodetic technologies: VLBI, SLR, GNSS, and DORIS, and they are essential for connecting the coordinate frames of each technique to construct a global reference frame, called the International Terrestrial Reference Frame (ITRF). The Geospatial Information Authority of Japan (GSI) conducts a local tie survey between a VLBI antenna and an IGS Continuously Operating Reference Station "ISHI" at the Ishioka Geodetic Observing Station every year. In this paper, we introduce the method, results of the survey conducted in October 2023, and discussion about the consistency with the ones of previous surveys. In addition, we report GSI's effort to cooperate on local tie surveys at other institutes which operate geodetic equipment using the multiple space geodetic techniques.

Keywords Local Tie, VLBI, GNSS, Ishioka

1 Local Tie Survey at Ishioka

1.1 Introduction

The International Terrestrial Reference Frame (ITRF) is a global reference frame which is constructed by integrating multiple space geodetic techniques: VLBI, SLR, GNSS, and DORIS. Local-tie vectors are essential to integrate several different techniques to construct an ITRF. According to Altamimi (2008) [1], a 1-mm level accuracy of local-tie vectors is needed to derive a robust ITRF.

The Ishioka Geodetic Observing Station (hereafter referred to as Ishioka) operates VLBI and GNSS and is therefore capable of contributing to the ITRF by surveying the local-tie vector on the order of sub-millimeters. The Geospatial Information Authority of Japan (GSI) conducts a local tie survey between a VLBI antenna and an IGS Continuously Operating Reference Station "ISHI" at Ishioka (Figure 1) every year, and the results of the surveys in 2018 and 2020 were submitted to the International Earth Rotation and Reference Systems Service (IERS) for ITRF2020.

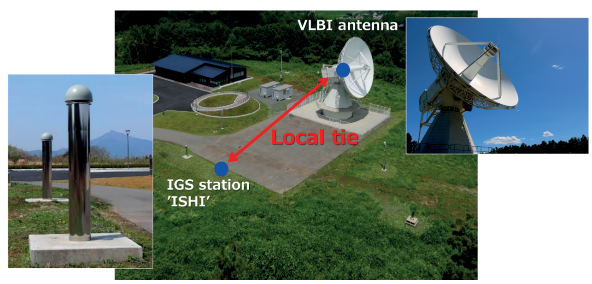

Fig. 1 Overview of the Ishioka station.

1.2 Method

Because the local-tie vector cannot be measured directly, surrounding survey pillars are used to determine the local positions of the VLBI antenna and "ISHI" to calculate the vector. The process includes multiple surveying to measure angles and distances among the pil-

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lars, VLBI and GNSS antennas using total station (TS), geodetic level, and static GNSS.

The reference point of the VLBI antenna is the antenna invariant point (IVP), generally defined as the intersection of the azimuth (AZ) and elevation (EL) axes (Figure 2). The IVP should be estimated by surveying, and we have adopted the 'inside method' (Matsumoto et al., 2022 [3]) to conduct the surveys efficiently. In this method, a target reflector is set on the inner wall of the antenna cabin and observed by the TS, installed on the pillar inside the antenna for several angles of the AZ/EL axis. This method can be applied only for the antennas that have a pillar installed close to the IVP which does not move with the rotation of the antenna.

For more details of the local tie survey at Ishioka, refer to the YouTube video:
`https://www.youtube.com/watch?v=oG4_FxtLh0E`

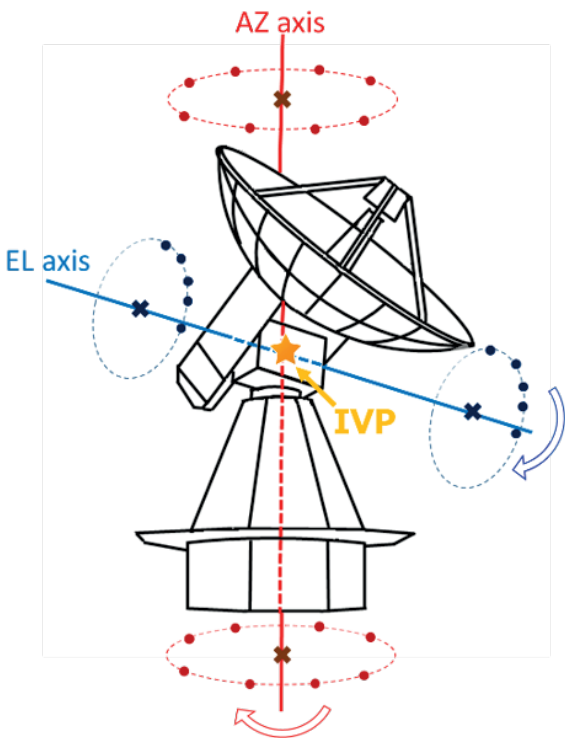

Fig. 2 Schematic image of an antenna invariant point (IVP).

1.3 Results

The latest local tie survey was conducted in October 2023, and the preliminary results are shown in Table 1. The upper row represents the local-tie vector and its standard deviation from IGS station "ISHI" to VLBI antenna "Ishioka", and the lower row shows the differences from 2022. The accuracy of the local-tie vector is less than 1 mm, as intended. On the the other hand, the difference of the east-west component between 2022 and 2023 is larger than the other results. A possible cause is that there might be an unexpected error in the orientation angle measurements. We are planning to re-measure the orientation angle in 2024 and re-calculate the result of the local-tie vector from 2023's surveying.

1.4 Discussion

The local-tie vectors' components obtained by the yearly local tie survey were compared with the ones calculated from positions and velocities based on ITRF2020 (Figure 3). The measured value appears to be almost constant. On the other hand, the calculated value takes on the appearance of a linear displacement which is not consistent with reality.

In ITRF2020, the estimated velocities of Ishioka's VLBI and GNSS antennas are slightly different (Figure 4; Altamimi et al. 2022 [2]), and this should be the cause for the linear trend we can see in the calculated local-tie values. As shown in Figure 4, the model of GNSS contains several discontinuities, whereas the model of VLBI consists of only one line. This difference can cause the difference of estimated velocities. Also, a linear fitting might be not accurate enough to estimate the velocity of the VLBI and GNSS antennas in Ishioka because Ishioka is affected by large post-seismic deformation caused by the 2011 Tohoku earthquake off the Pacific Coast. A post-seismic deformation model might reduce the unexpected linear displacement seen in the calculated local-tie vector.

Table 1 Preliminary result of calculated local-tie vectors in 2023. E, N, and U represent the east-west, north-south, and up-down components, respectively.

	E (m)	N (m)	U (m)	Baseline (m)
ISHI $\rightarrow$ ISHIOKA	0.1923 ± 0.0008	$39.8201 \pm .0006$	8.4070 ± 0.0009	40.6984
$\Delta(2023-2022)$	-0.0049	-0.0009	0.0008	-0.0007

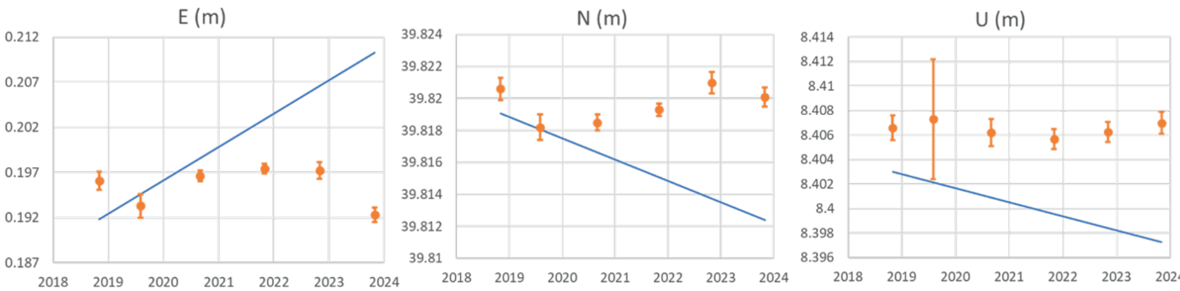

Fig. 3 Results for local tie surveys (orange circle) and the calculated values based on ITRF2020 (blue line). The left, middle, and right panels represent the east-west, north-south, and up-down components, respectively.

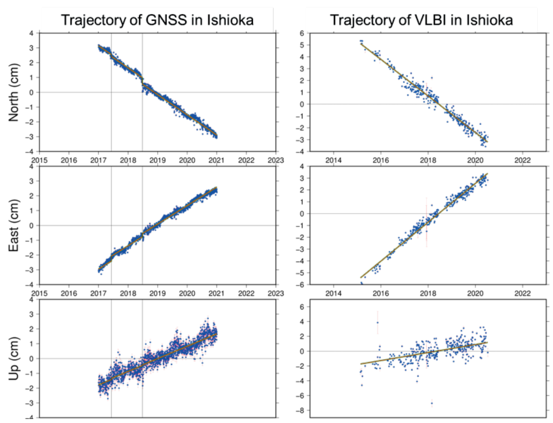

Fig. 4 Trajectory of GNSS and VLBI in Ishioka. Blue dots are the raw data, green lines are the linear fit, and the red lines are the PSD model (not applied here). The vertical gray lines represent discontinuities. These graphs were outputted by a tool on the ITRF website to a plot station time series (`https://itrf.ign.fr/en/timeseries`).

2 Local Tie Surveys in Japan and GSI's Contribution

There are six GGOS sites, which operate geodetic equipment using multiple space geodetic techniques for the Global Geodetic Observing System, including Ishioka in Japan. In FY2023, local tie surveys were conducted at three of them as well as Ishioka. The summary is shown in Table 2. GSI carried out the surveying work at Tsukuba Space Center, the Japan Aerospace Exploration Agency (hereafter referred to as JAXA), and Syowa Station, Antarctica (hereafter referred to as Syowa) and supported the survey at Shimosato Hydrographic Observatory, JCG (Japan Coast Guard, hereafter referred to as Shimosato). At JAXA and Shimosato, a local-tie vector between SLR and GNSS was measured, and at Syowa, local-tie vectors between VLBI, GNSS, and DORIS were measured. Because the VLBI antenna at Syowa does not have a pillar inside the antenna that does not move with the antenna's rotation, the survey to estimate the IVP was done from the outside of the antenna by rotating on AZ/EL several angles. The IVP of the SLR telescope was determined in the same way as that of the VLBI antenna.

Table 2 Local-tie survey conducted in FY2023.

Site	Period	Target equipment
JAXA	July 2023	SLR, GNSS
Shimosato	November–December, 2023	SLR, GNSS
Syowa	December 2023–January 2024	VLBI, GNSS, DORIS

3 Summary and Future Prospects

GSI conducted local tie surveys at Ishioka regularly and cooperated to perform the surveys at other GGOS sites in Japan technically to contribute to ITRF construction. We will continue to measure the local-tie vector yearly at Ishioka.

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