

Local tie survey of the SLR and GNSS stations at the Shimosato Hydrographic Observatory

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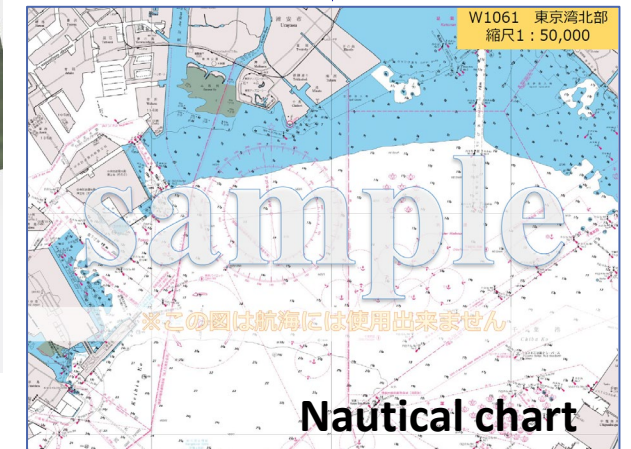
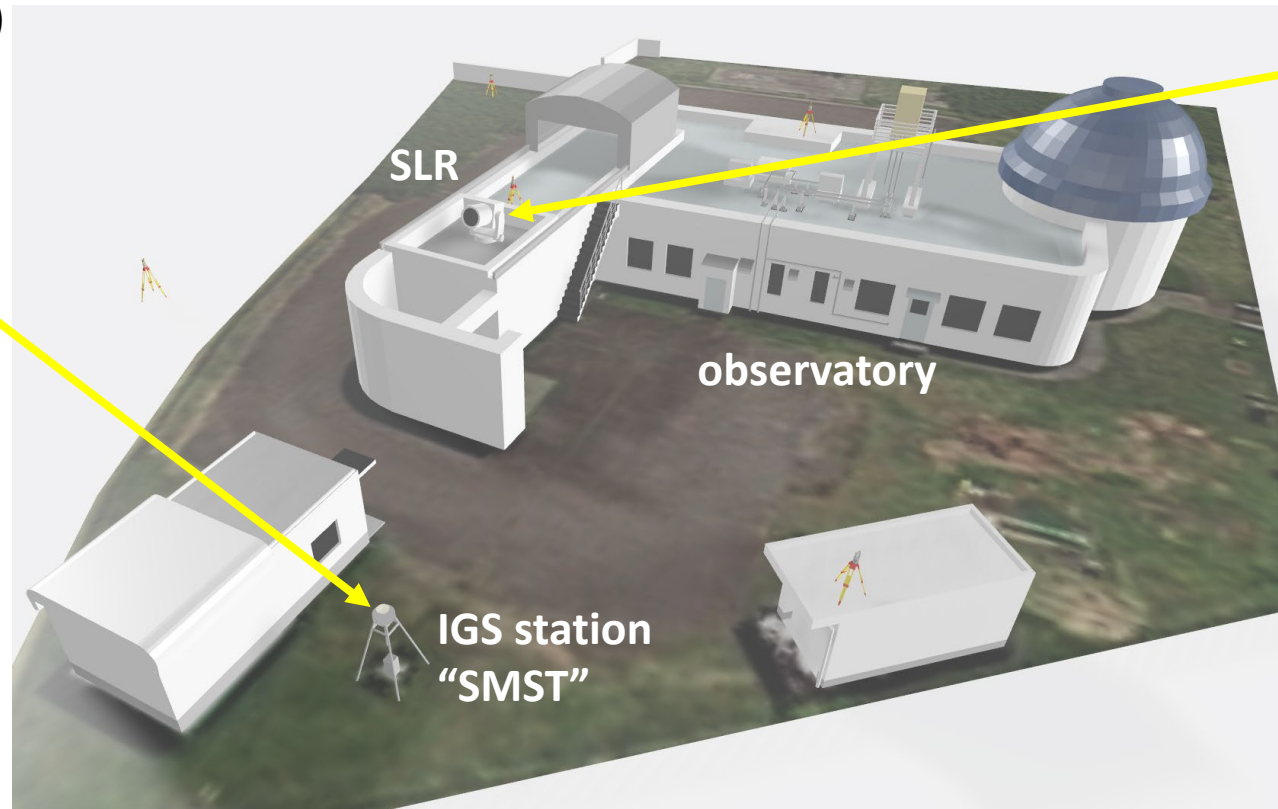
Introduction

The Japan Coast Guard (JCG) operates satellite laser ranging (SLR) at the Shimosato Hydrographic Observatory (SHO). Why? ⇒ To link JHOD's **nautical charts** to the **global geodetic reference frame**.

GNSS station
(north of the observatory)



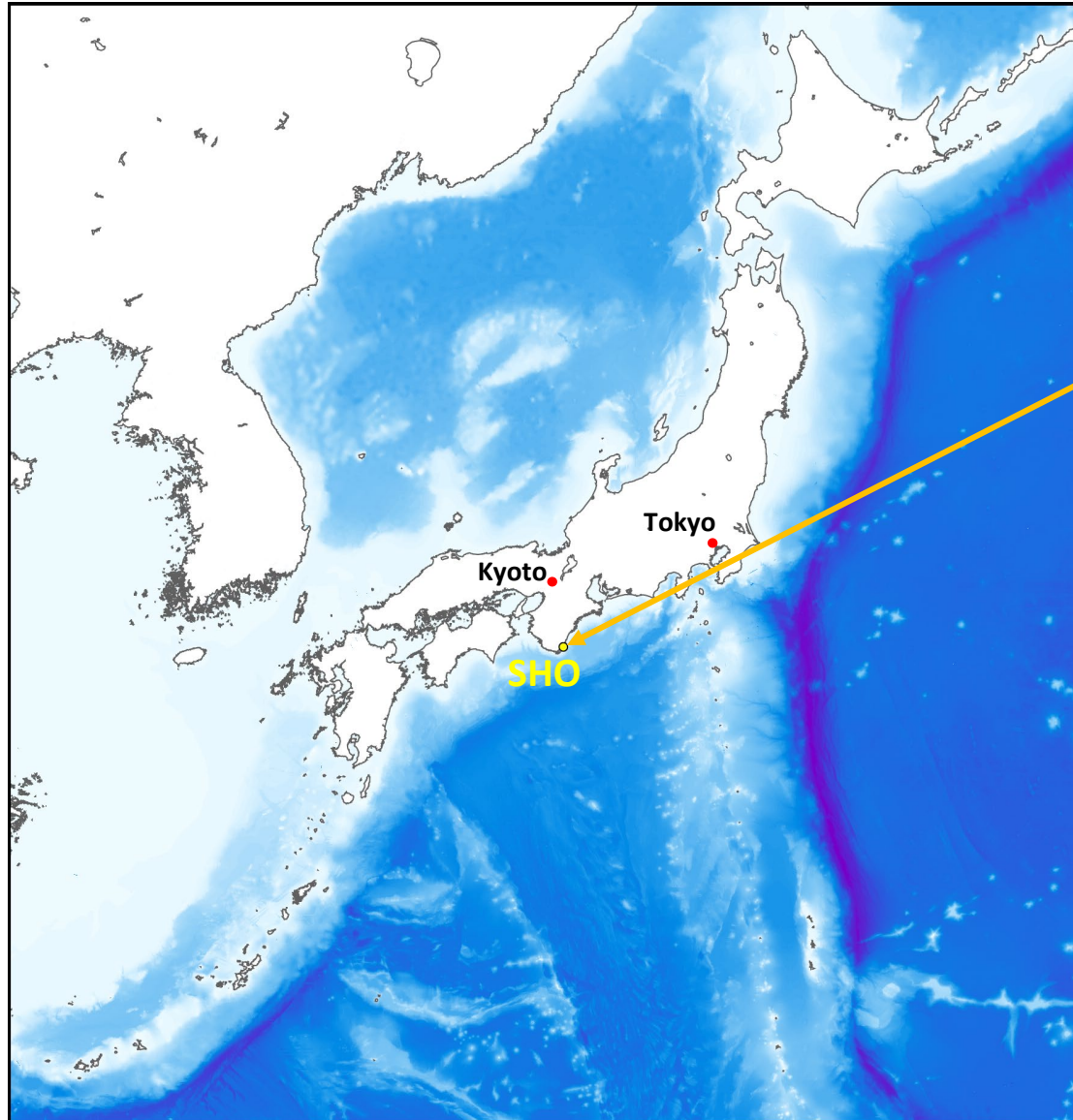
Monument
origin of nautical charts
produced by JCG



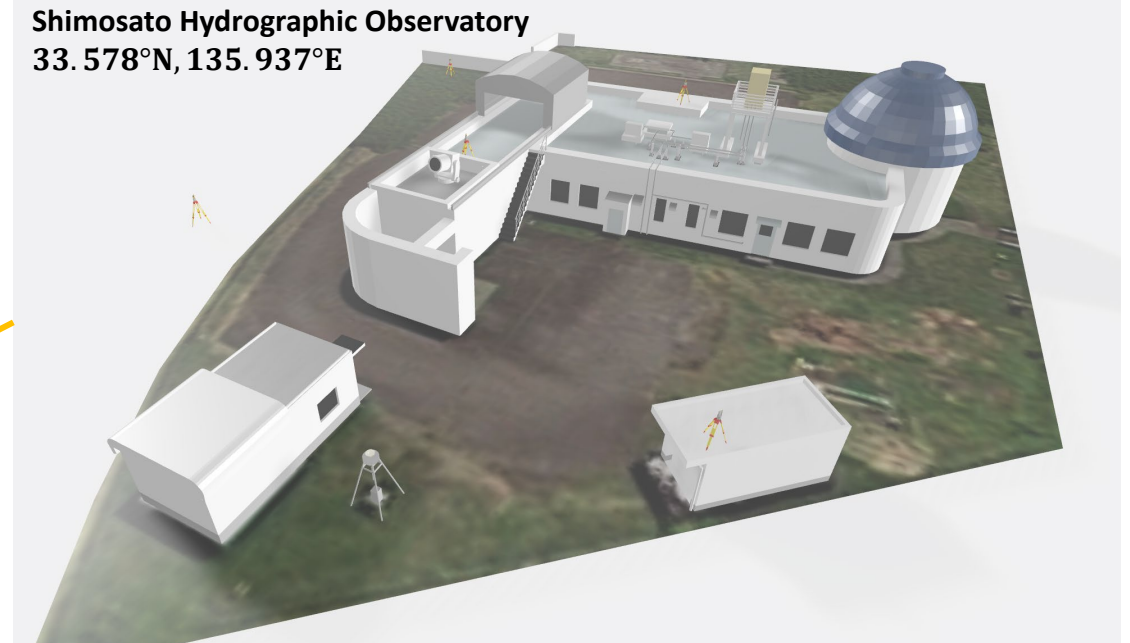
JCG is continuing SLR observation at the SHO to monitor the position of the origin with respect to the global geodetic reference frame.

Location

Shimosato Hydrographic Observatory (SHO) is located in southern Honshu, near the Kumano Kodo.



Shimosato Hydrographic Observatory
33.578°N, 135.937°E



Kumano Hongu Taisha (left) and Kumano Kodo (right)

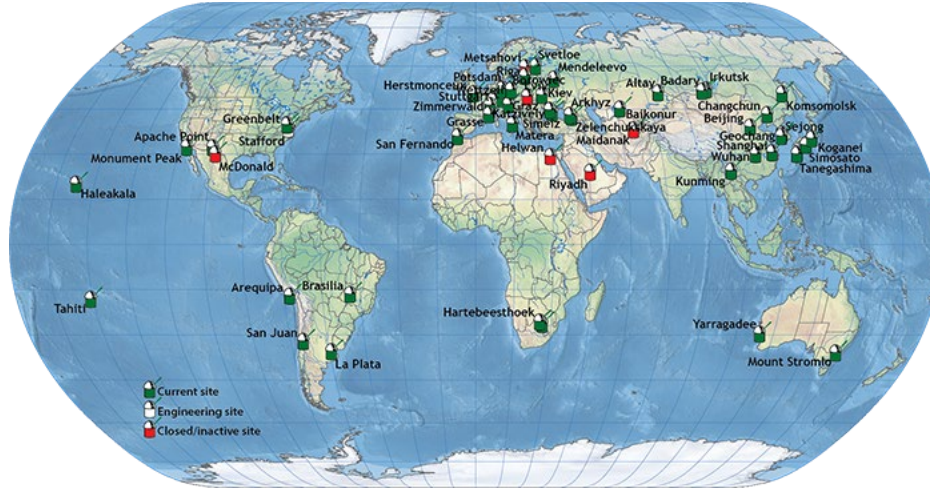
Photos from Kumano Hongu Tourist Association official website

<https://www.hongu.jp/en/kumano-kodo/>

Introduction

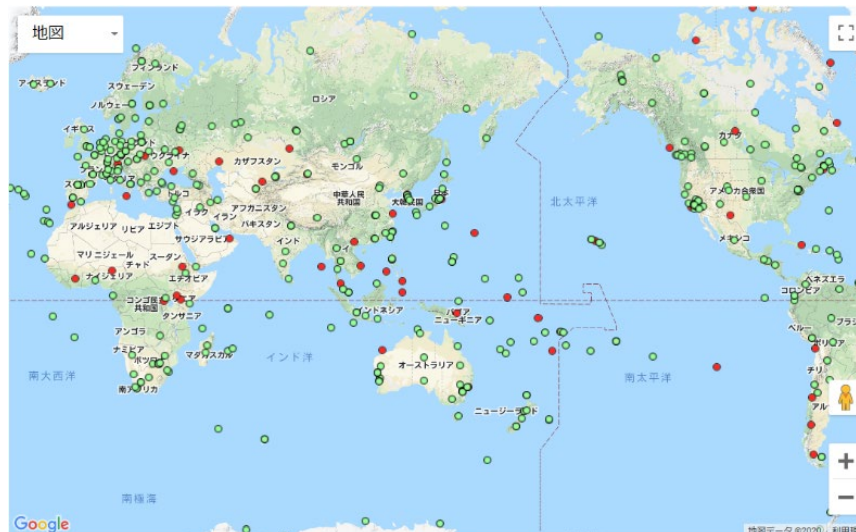
SHO is a co-location site, operating two types of space geodetic techniques (SLR and GNSS).

SLR



ILRS: International Laser Ranging Service

GNSS



IGS: International GNSS Service

Advantages of SLR

- Determination of the Earth's centroid and scale
 - Determination of satellite orbits
 - Determination of low-degree gravity terms
- Supports the base of GNSS

Disadvantages of SLR

- Expensive!
 - Observation is limited by weather
 - Operation is necessary
- low observation frequency, sparse network (especially in the southern hemisphere)

The SHO, operating both SLR and GNSS, is a **co-location site**.

Co-location site: A site that operates multiple space geodetic techniques (GNSS, SLR, VLBI, DORIS)

SLR and GNSS at SHO: analysis methods

SLR data used in the analysis

Ranging data of LAGEOS-1 and LAGEOS-2

Analysis software

- C5++ (Otsubo et al. 2016, EPS)
- Only the velocity of ITRF2014 is used.

Estimated parameters

- Orbital elements of LAGEOS-1 and LAGEOS-2
- Position of the Earth's centroid
- Monthly solution of the position of SISL
- Range bias (measurement system bias) of SISL



GNSS data

- GPS data (30 sec. interval) of the IGS station "SMST" (since 2004/4/1)
- Antenna: Trimble Zephyr Geodetic 2 (TRM57971.00)
- Receiver: Trimble NetR9

Analysis methods

- RTKLIB v2.4.2 (Takasu, 2013)
- Final ephemeris/clock of IGS were used in the analysis.
- Daily analysis using static mode PPP (Precise Point Positioning)
- Offsets due to replacement of equipment (such as the antenna) were corrected by subtracting the difference of 15-day average before and after the replacement.

**After the analysis, the displacements are converted to local East-North-Up (ENU) coordinates.
Only the linear trend of ITRF2014 is corrected. Displacements due to earthquakes are not corrected.**



SLR and GNSS observation results

Sep. 5, 2004
Southeast-Off Kii Peninsula Earthquake

Mar. 11, 2011
Tohoku-oki Earthquake

SLR time series

Black dots

Error bars indicate 1σ .

Red broken line: updates of SLR telescope

Purple broken line: updates of calibration target

GNSS time series

Yellow dots

Yellow broken line: replacement of GNSS antenna and/or radome

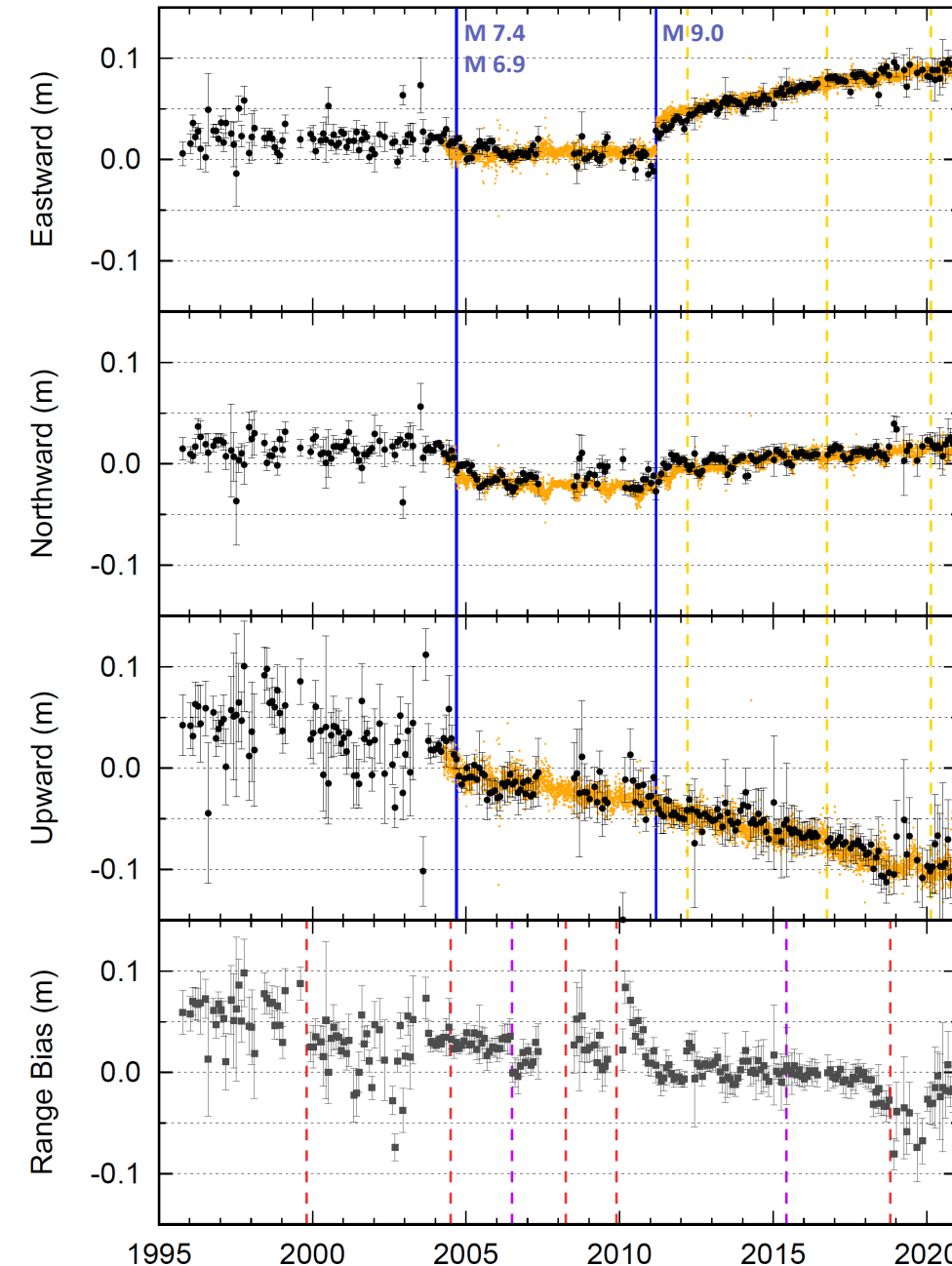
- Overall, the GNSS and SLR time series seem to be consistent.
- Co- and postseismic displacements after major earthquakes can be seen.
- Subsidence of approximately 6 mm/yr: offset from ITRF2014?

SLR observation results

- The solution is unstable since the laser update in the end of 2018.
 - Observation frequency was low due to maintenance of the instruments.
- Subsidence is observed before the laser update (since beginning of 2018)
 - The displacement is coherent with the range bias.
 - May be due to the update of the photomultiplier (PMT)?
- The negative range bias began to decrease around the end of 2019.

Annual variability

- Annual variability can be seen in the north-south and up-down components.
- Annual variability can be seen in both SLR and GNSS, implying that this variability is not caused by instrumental biases.



Co-location survey at the SHO (Nov. 9-17, 2020)

Systems determined by different space geodetic techniques can be linked together at co-location sites, where multiple space geodetic techniques are operated.

GNSS



SLR



At SHO, SLR and GNSS can be linked together.



SLR telescope

GNSS monument

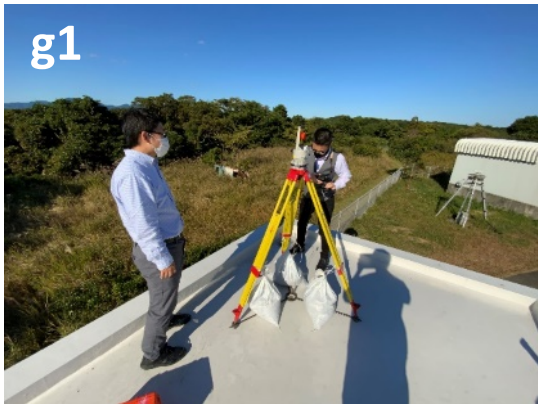
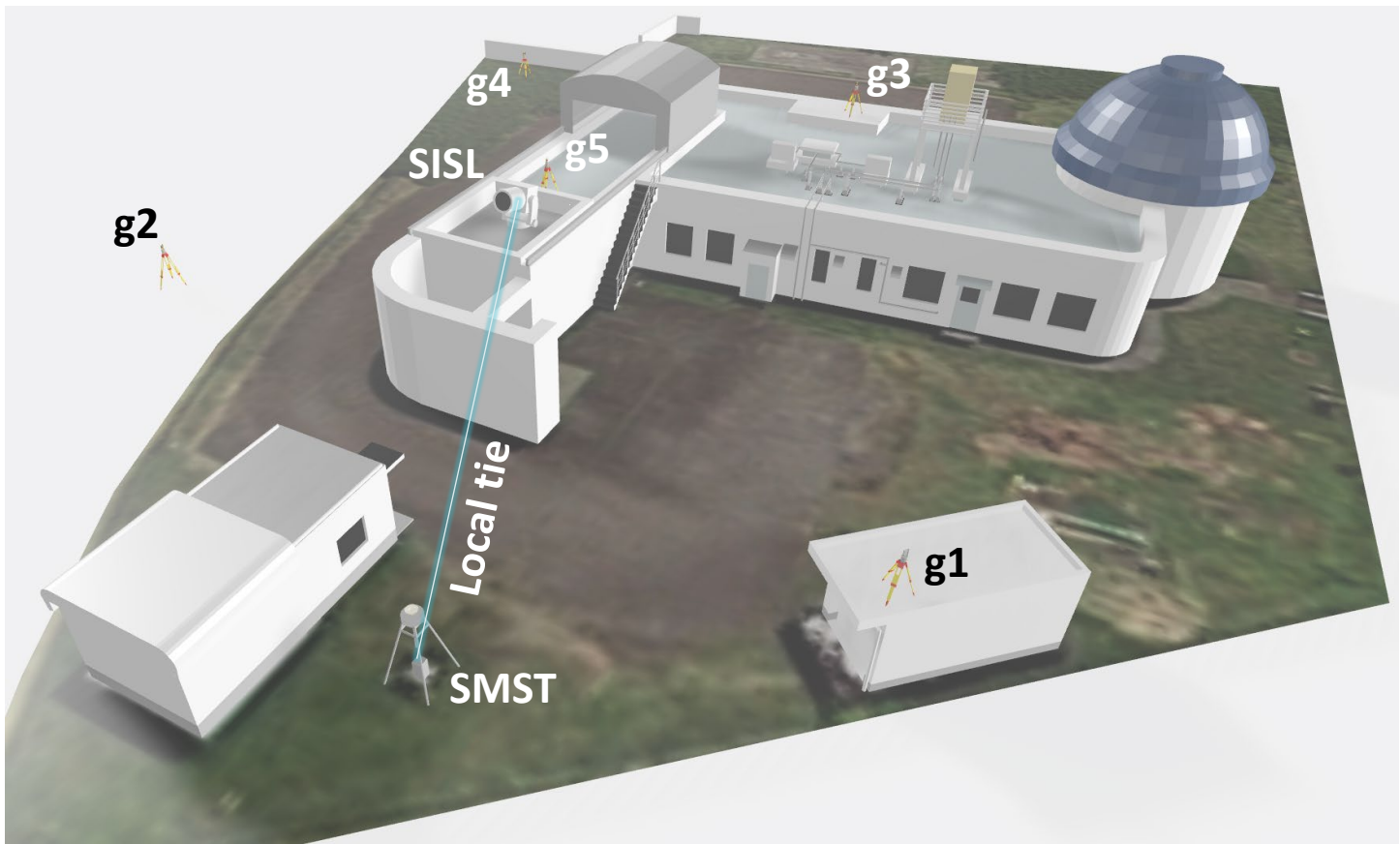
Local tie vector

How can we link the different space geodetic techniques?

➡ A **co-location survey** is necessary to precisely determine the local tie (relative position) of the space geodetic techniques (at SHO, the local tie of SLR and GNSS).

Co-location survey at the SHO (Nov. 9 -17, 2020)

JCG collaborated with the Geospatial Information Authority of Japan (GSI) and performed a co-location survey of the SLR telescope (SISL) and the GNSS monument (SMST).

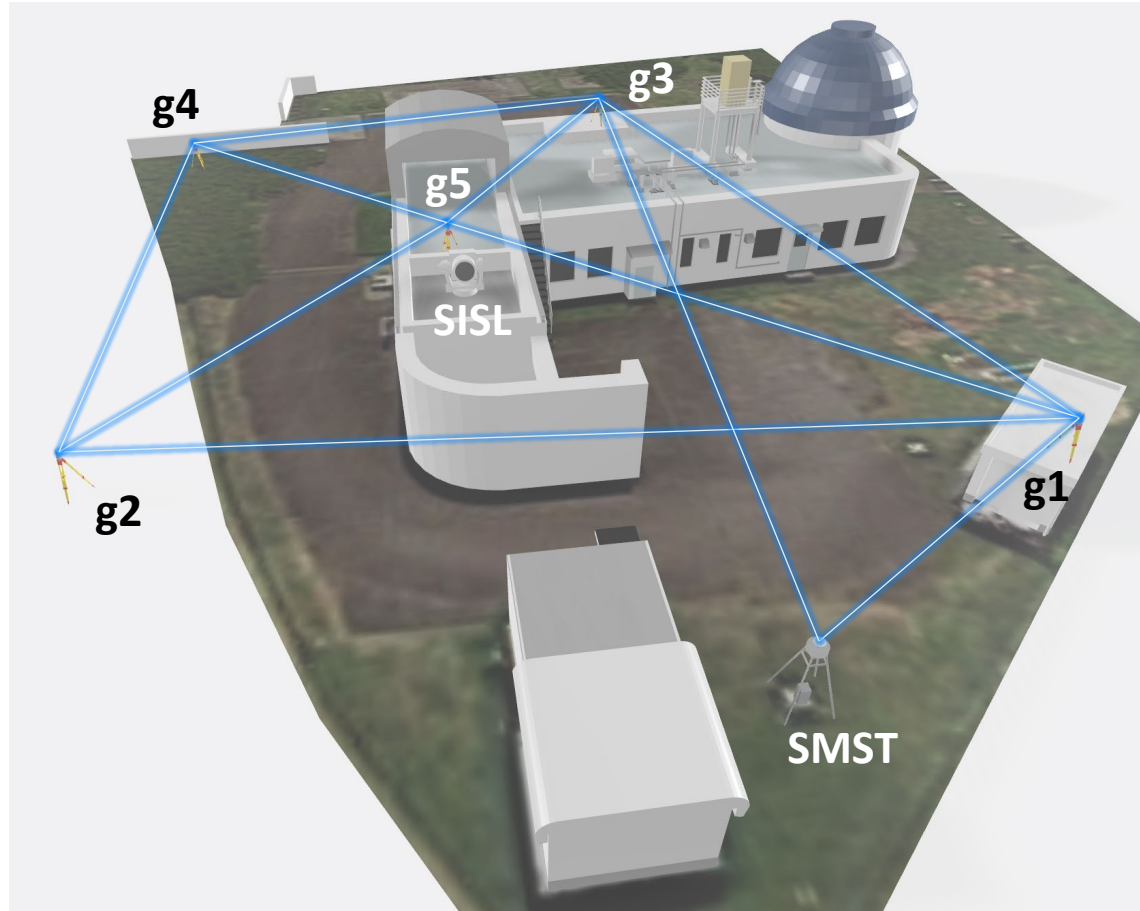


Temporary sites g1-g5 were set in the observatory for the survey network.

Triangulation of the survey network and IGS station (Nov. 10-11)

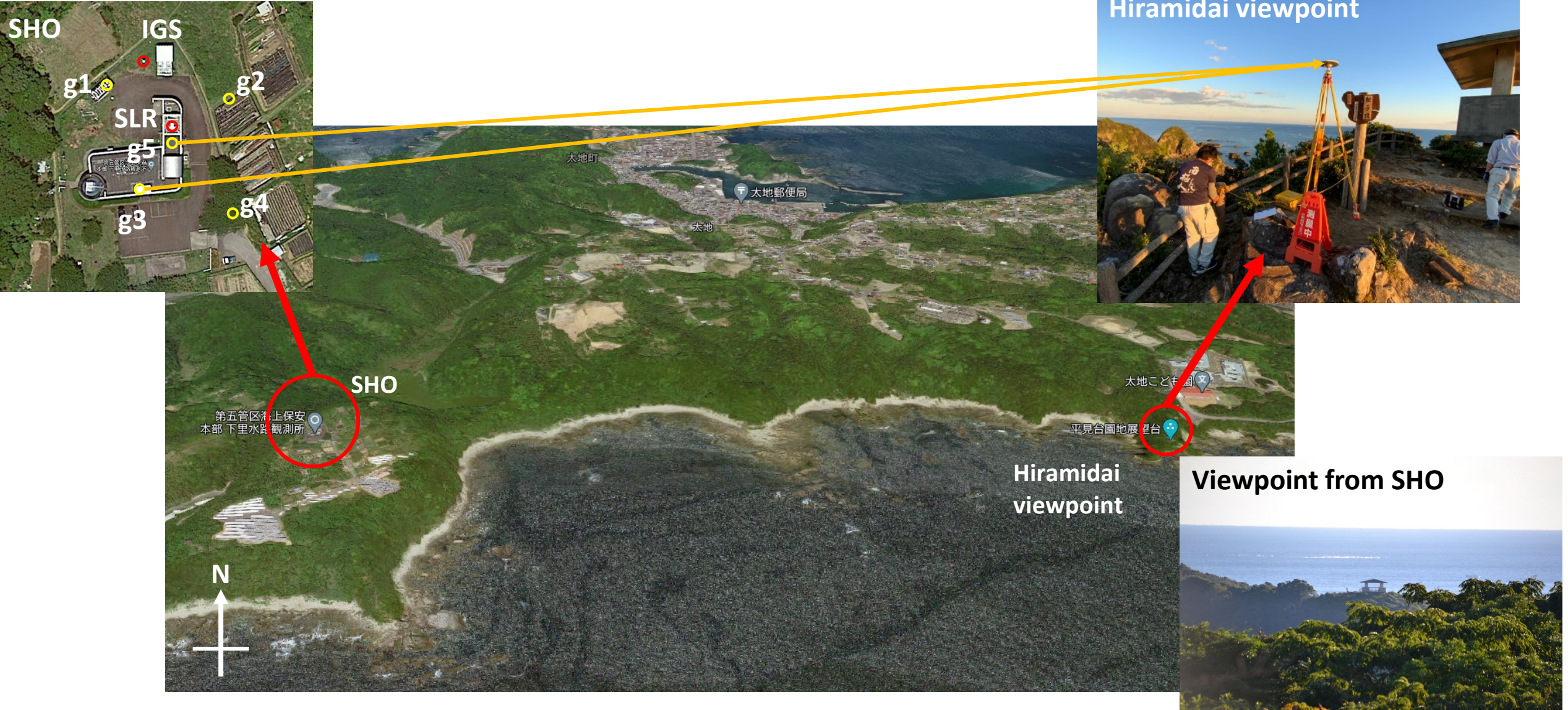
Triangulation was conducted between the temporary sites and the ARP of the IGS station “SMST”.

- Site g5 (can observe all of the surrounding sites g1-g4) was set at the south of the SLR telescope, to reinforce the survey network.



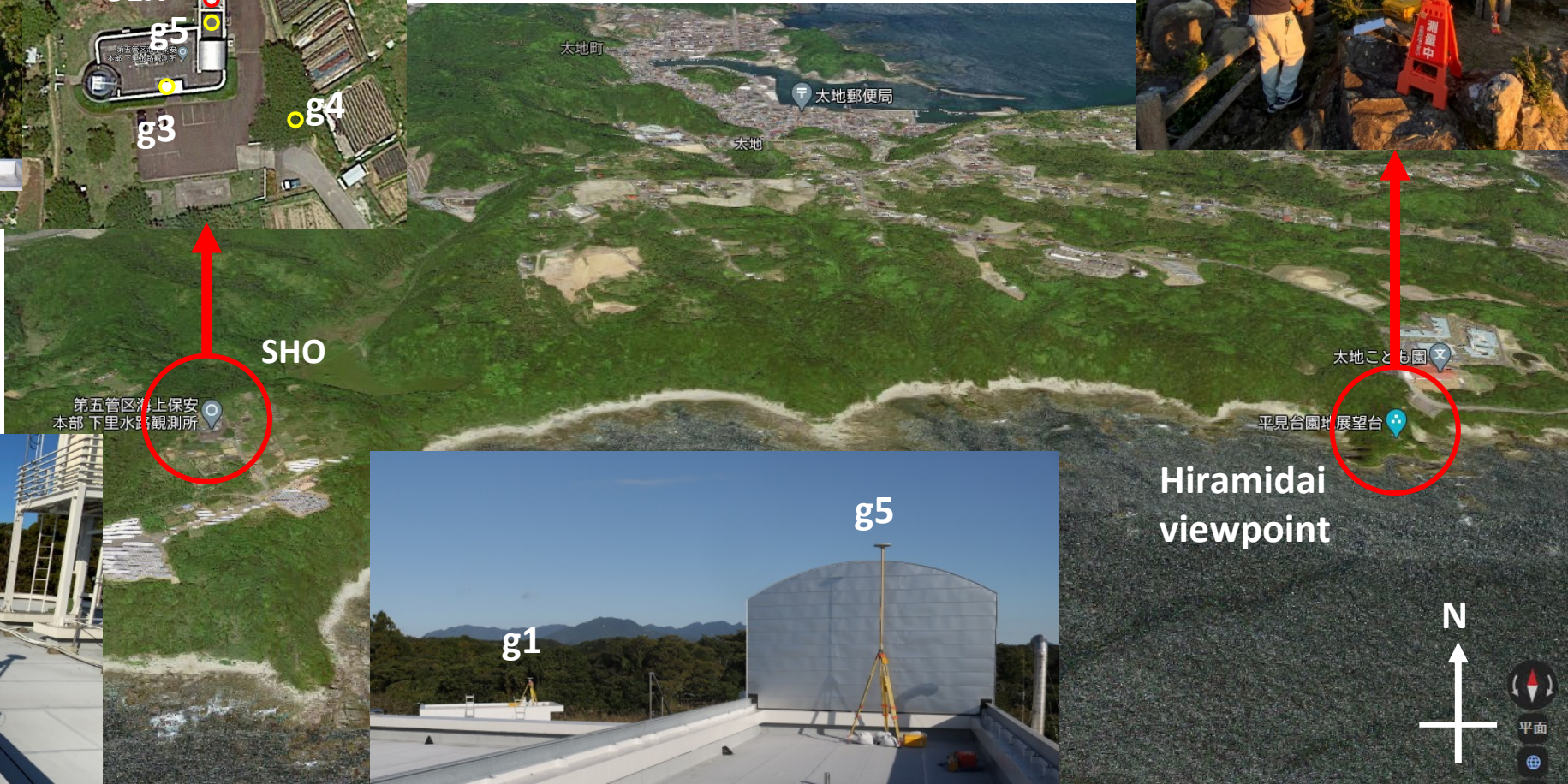
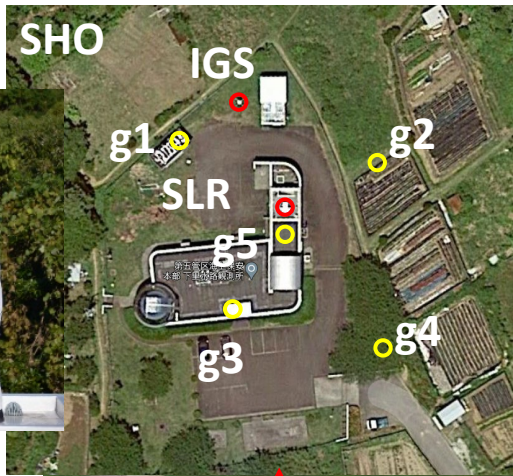
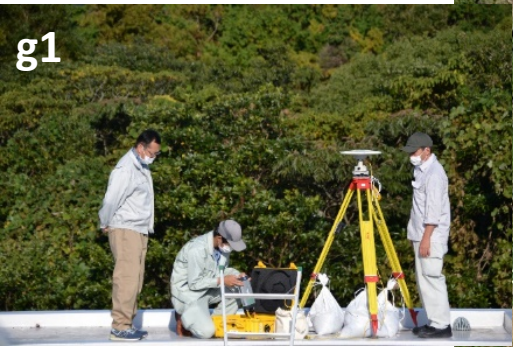
Azimuth marker observation (Nov. 10)

We observed the azimuth marker set at the Hiramidai viewpoint (approximately 1.3 km east of SHO) from temporary sites g3 and g5.



GNSS observation (Nov. 10-11)

We conducted GNSS observations to determine the true north.

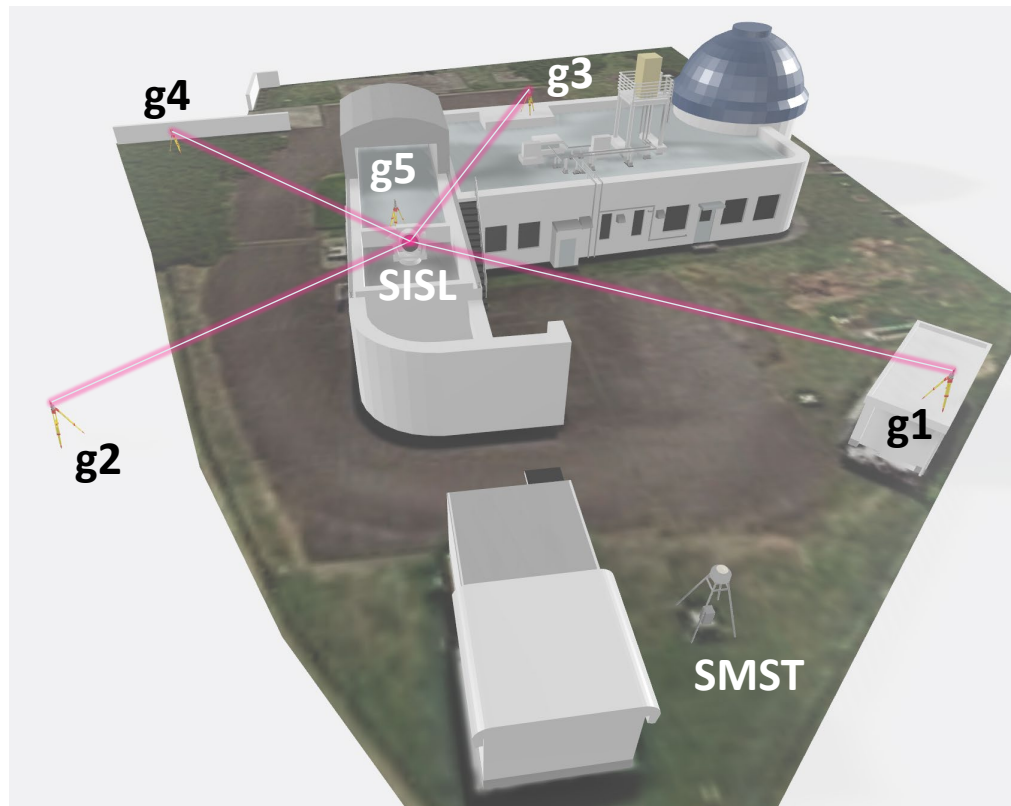


Hiramidai viewpoint

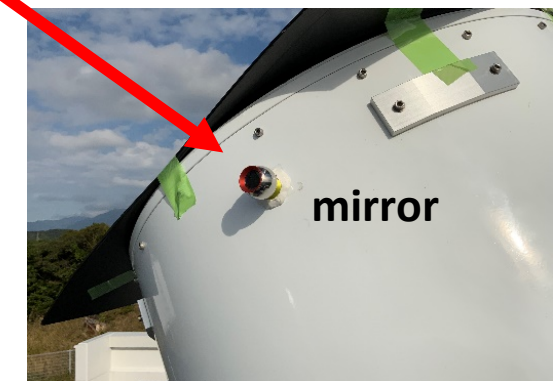
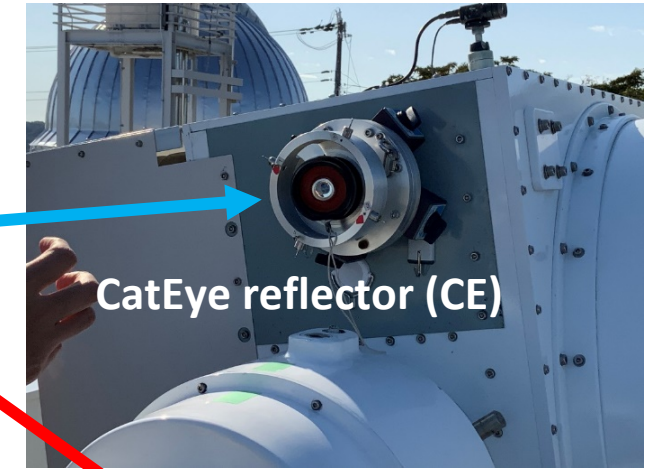
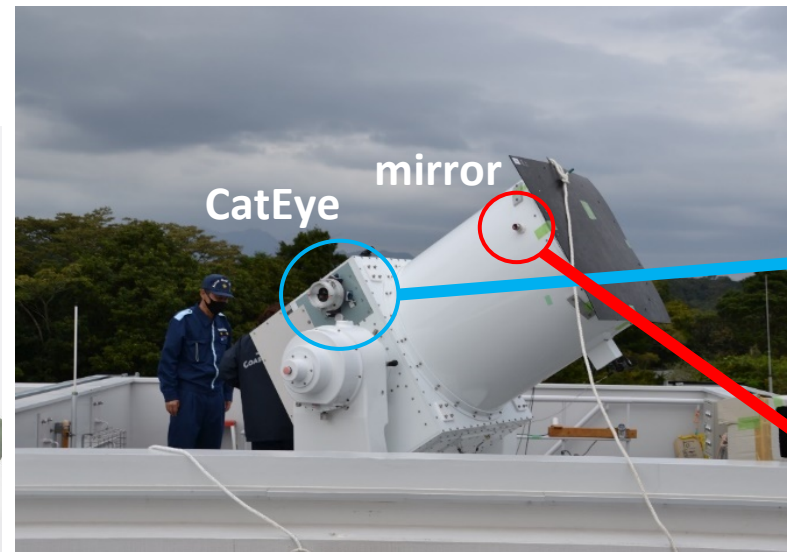


Target observation (Nov. 11-14)

We observed targets (CatEye, mirrors) mounted on the telescope from temporary sites g1, g2, g3, and g4.



Temporary site g5 was used only for reinforcing the observation network, and was not used for the target observation.

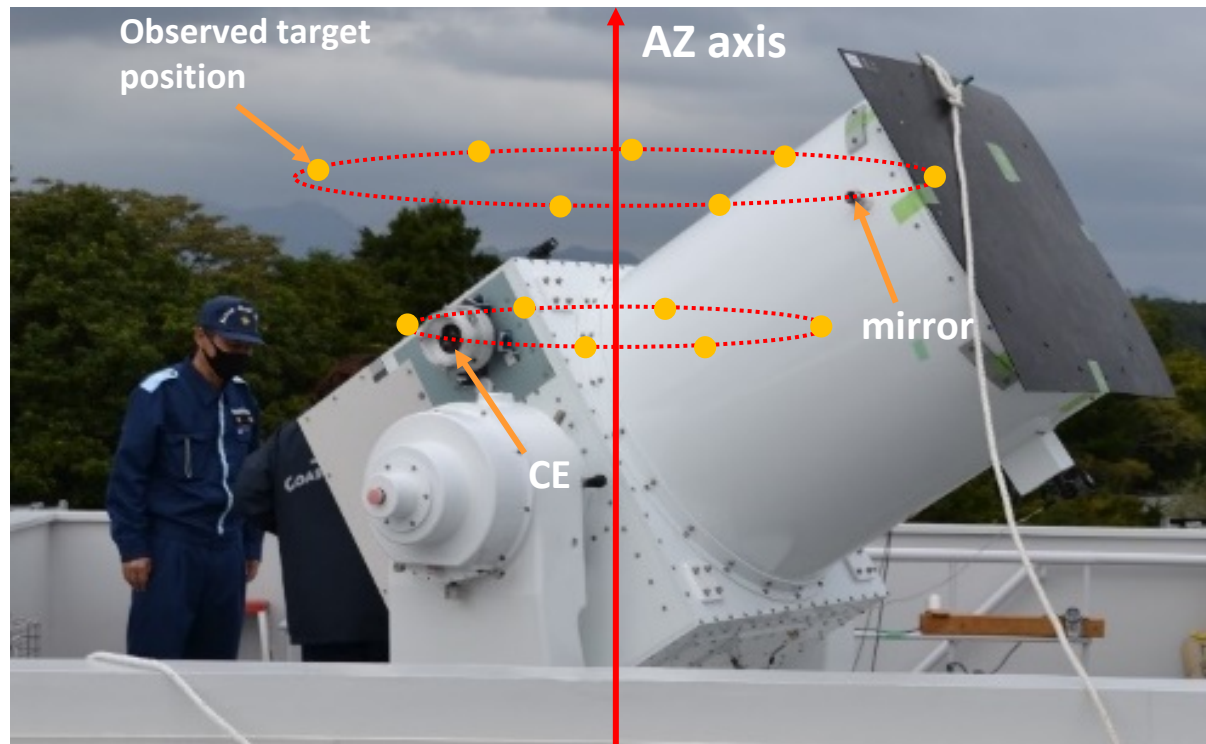


- 1 CatEye reflector
- 3 mirrors were mounted on the telescope.

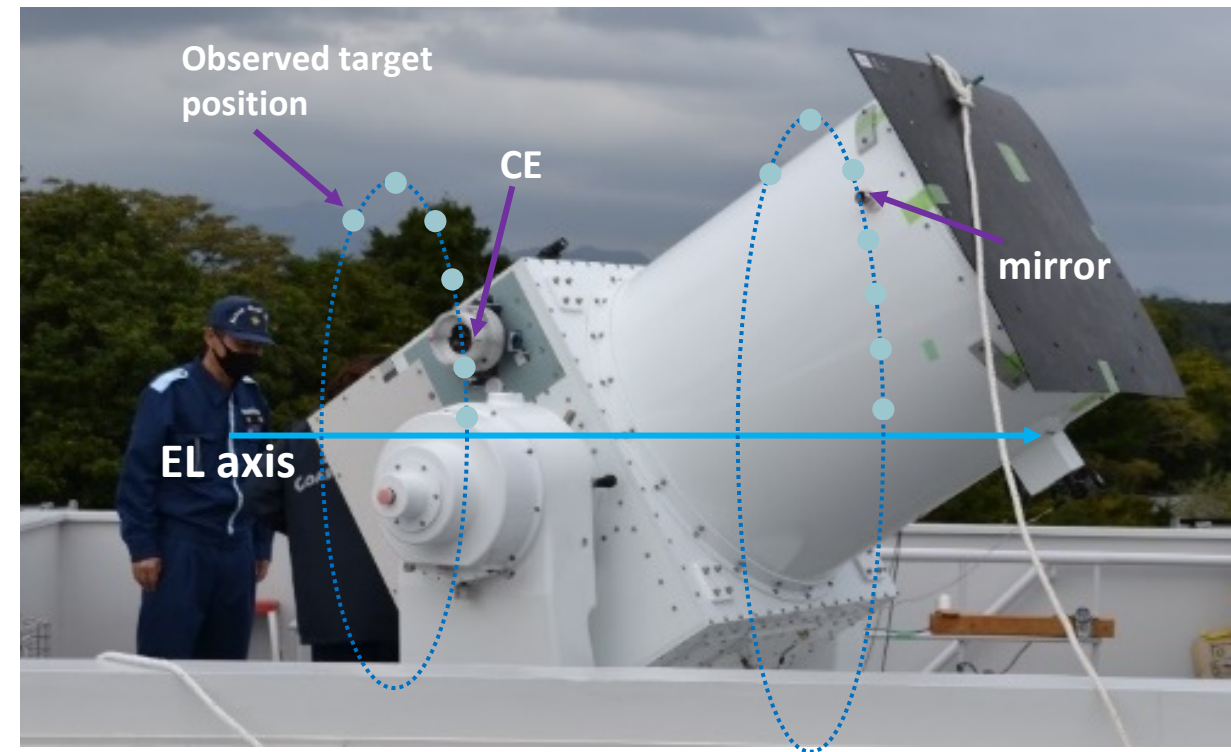
Target observation (Nov. 11-14)

To determine the AZ-EL intersect of the SLR telescope, the telescope was rotated around the azimuth (AZ) and elevation (EL) axes during the target observation.

- The targets observed at different AZ/EL angles form arcs around the axes.



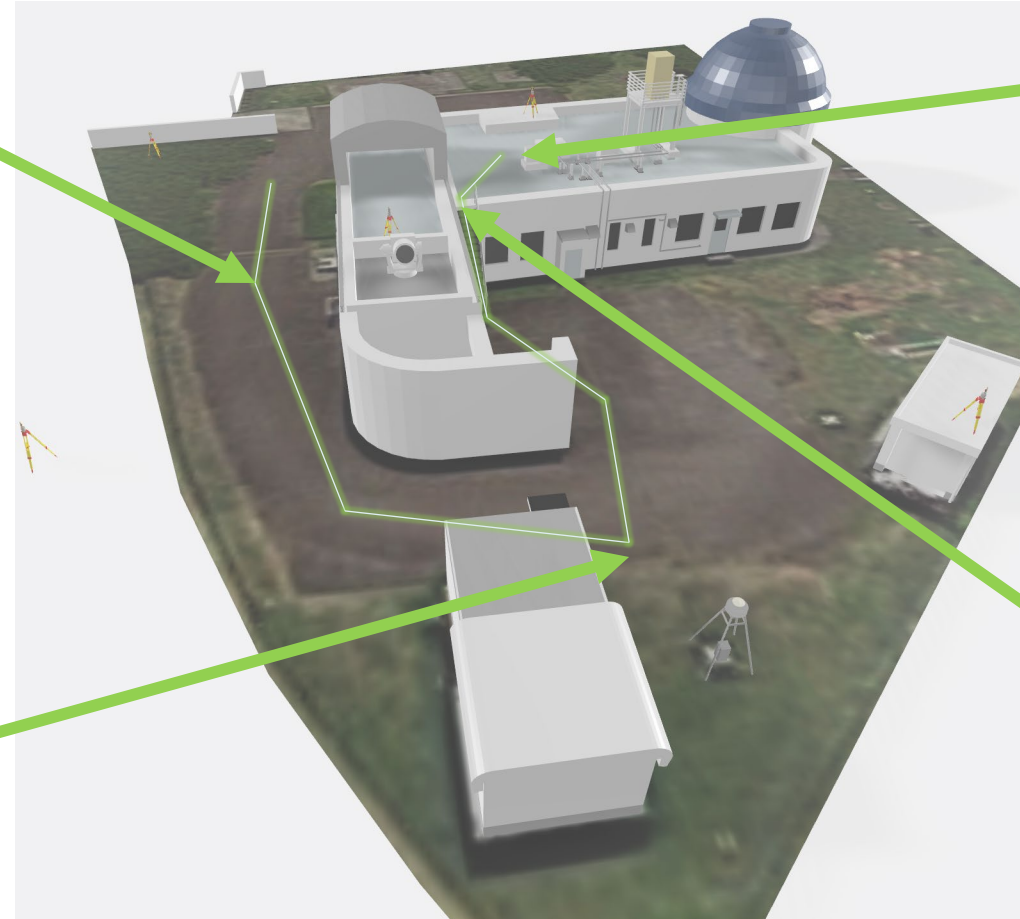
Schematic diagram of the target arcs formed around the AZ axis.



Schematic diagram of the target arcs formed around the EL axis.

Levelling (Nov. 16)

Finally, we conducted levelling of the survey network (temporary sites and the IGS ARP).



3. Going up the stairs



Calculation of the local tie vector

We used the open source software “pyaxis” provided by the Land Information New Zealand (LINZ) to calculate the local tie vector between the GNSS monument “SMST” and the fixed point of the SLR telescope “SISL”.

- The observed targets form arcs around the axes (Figure 1), from which the AZ/EL axes were determined.
- The fixed point of the SLR telescope was determined by calculating the intersection of the axes (Figure 2).

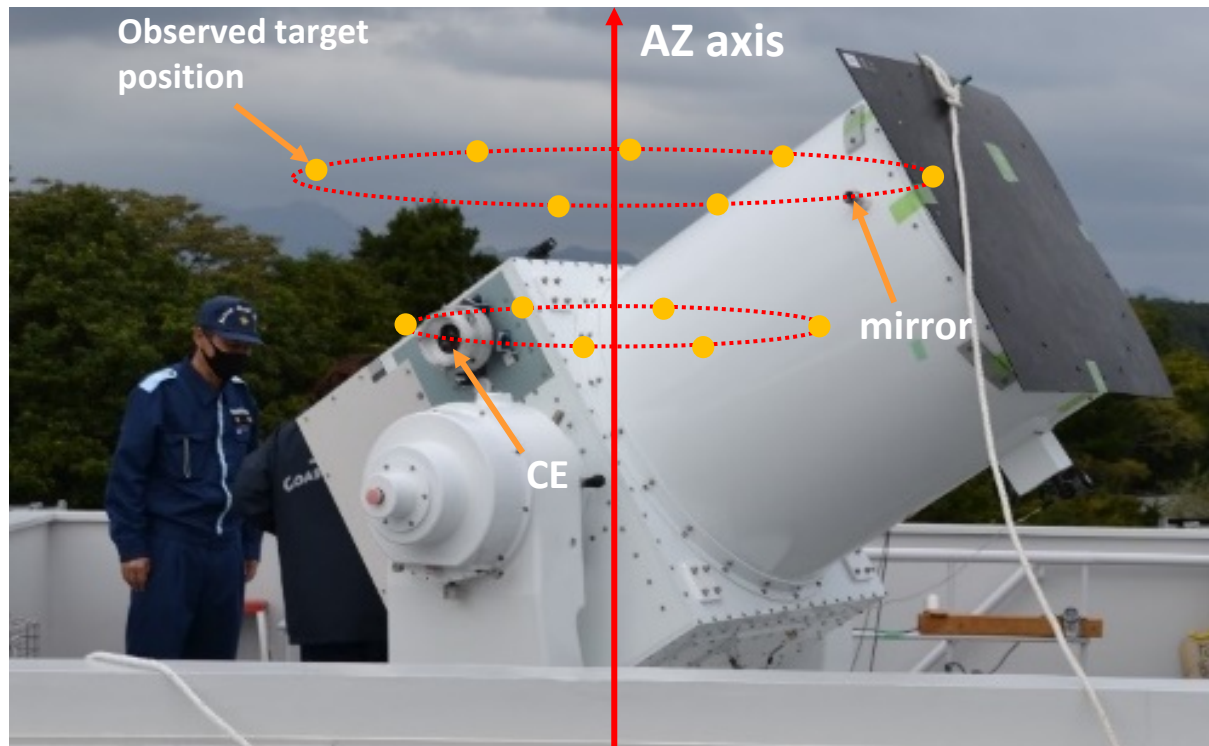


Figure 1: Schematic diagram of the target arcs formed around the AZ axis.

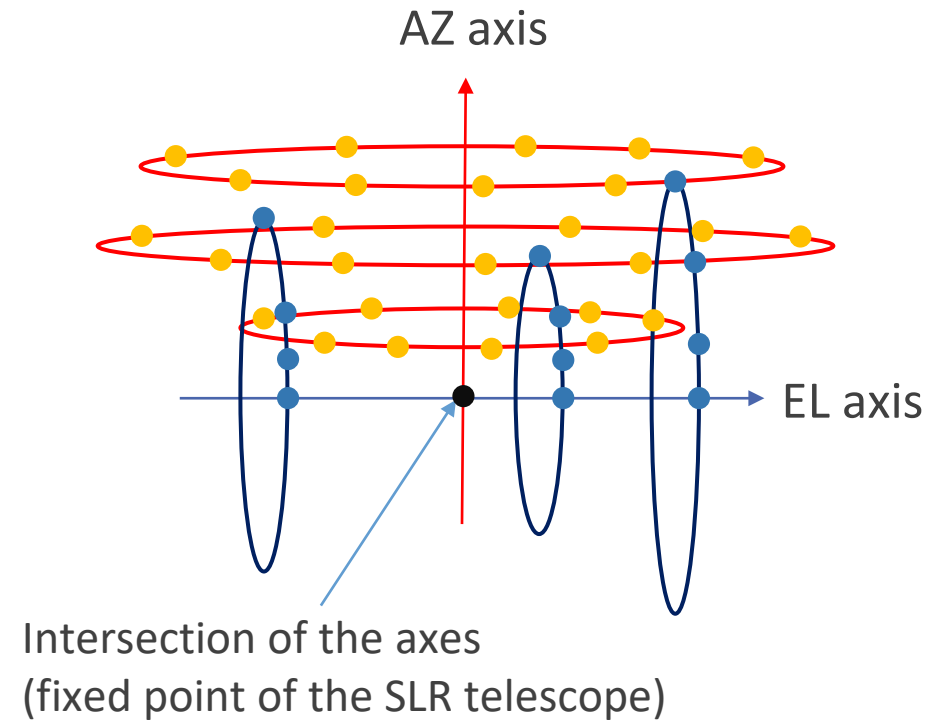
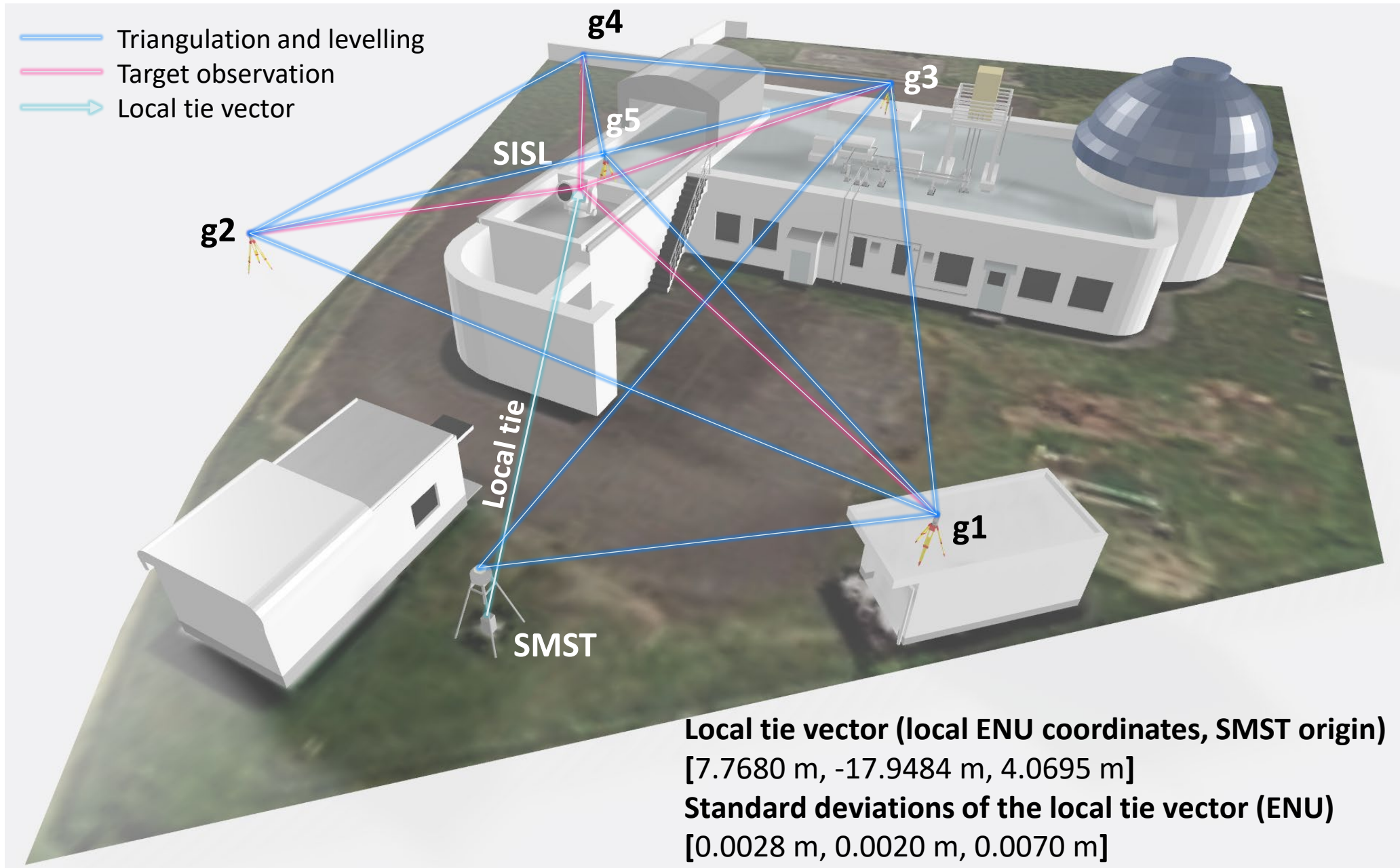


Figure 2: Schematic diagram of determining the fixed point from the target arcs.

Result



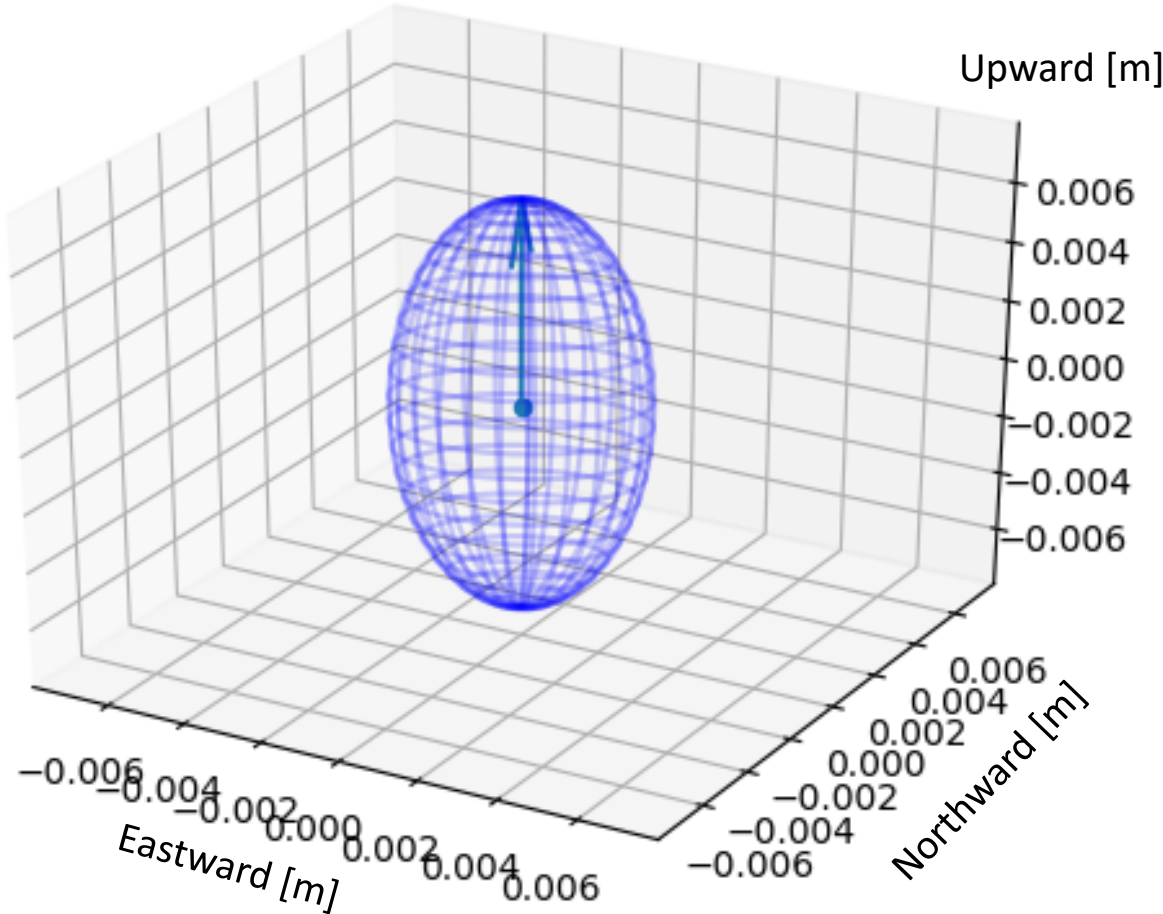
Result

Local tie vector (local ENU coordinates, SMST origin)
[7.7680 m, -17.9484 m, 4.0695 m] →

Standard deviation (SD) of the local tie vector (ENU)
[0.0028 m, 0.0020 m, 0.0070 m]



Error ellipsoid of the local tie vector

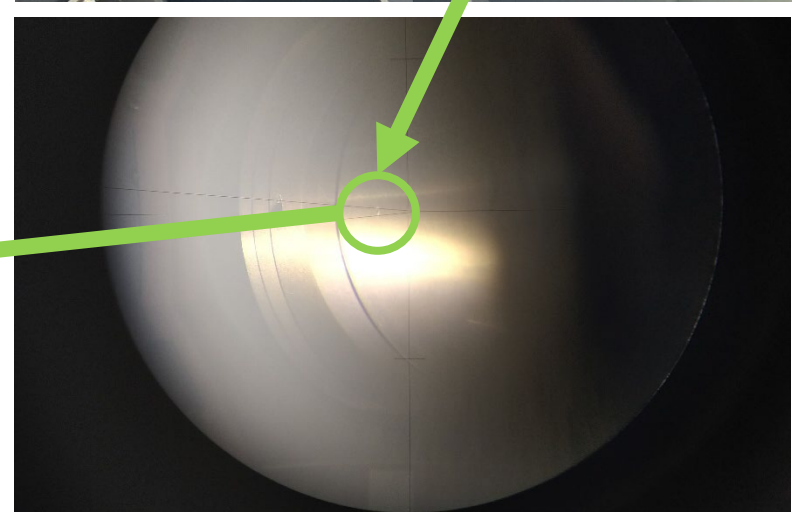
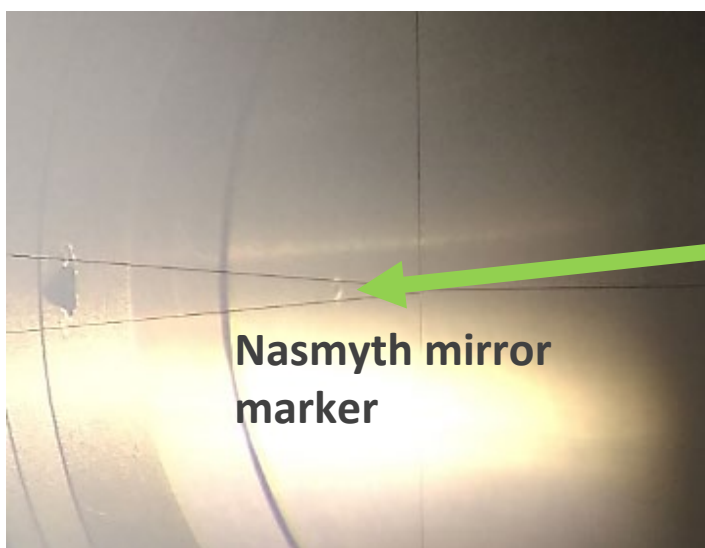
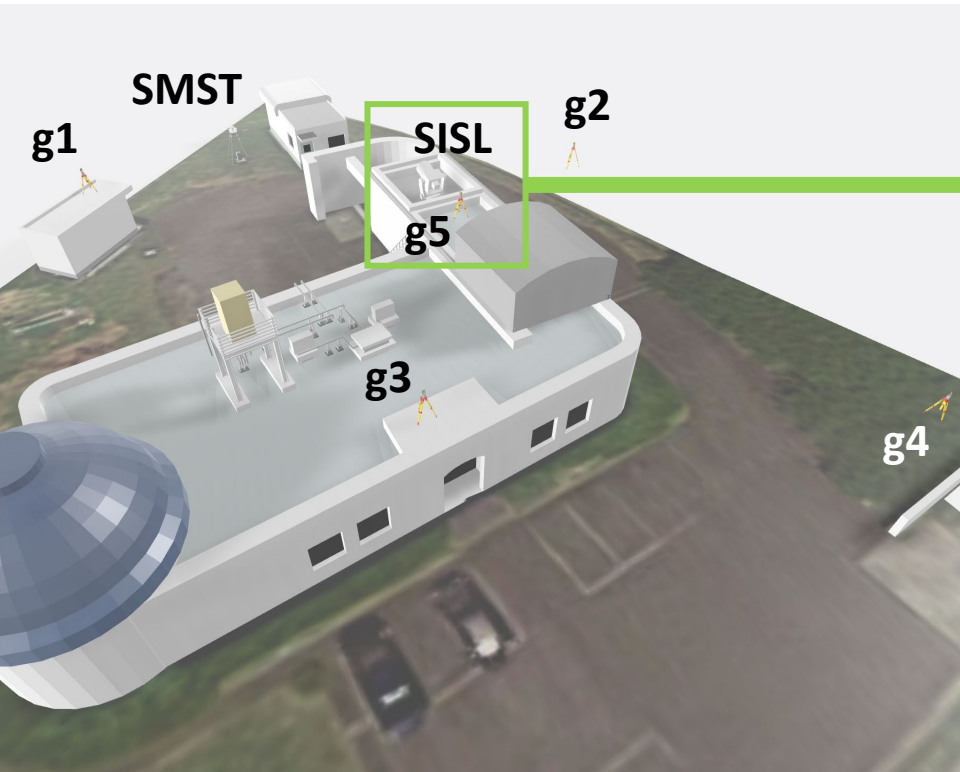


Major axis of the error ellipsoid →
Length of the major axis: 0.0070 m
Unit vector of the major axis (ENU)
[−0.00334, 0.00318, 0.99995]

Discussion: verification of the local tie up-down component

We conducted levelling of the SLR telescope by observing the fixed point marker on the nasmyth mirror (which is assumed to be the designed AZ-EL intersect of the telescope), to verify the calculated up-down component of the local tie.

5. Nasmyth mirror observation



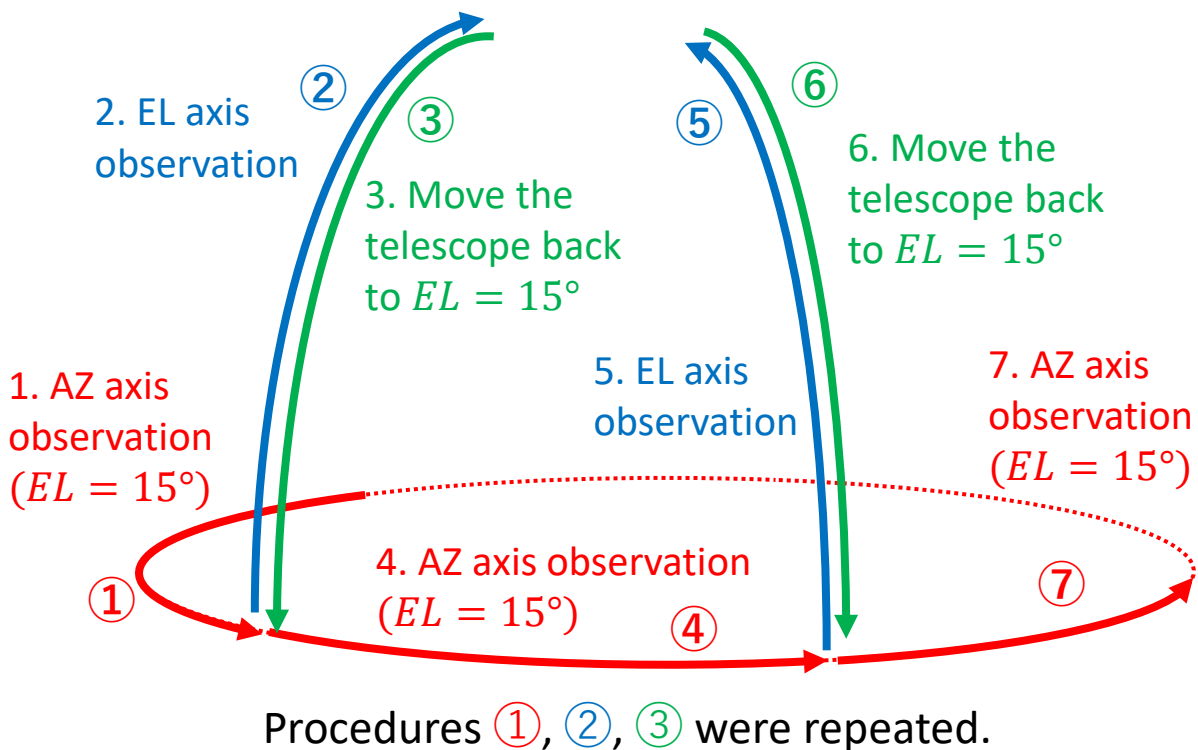
Up-down component of the local tie vector:
4.0695 m
Relative height of SMST and the marker:
4.0779 m

Discussion: error source

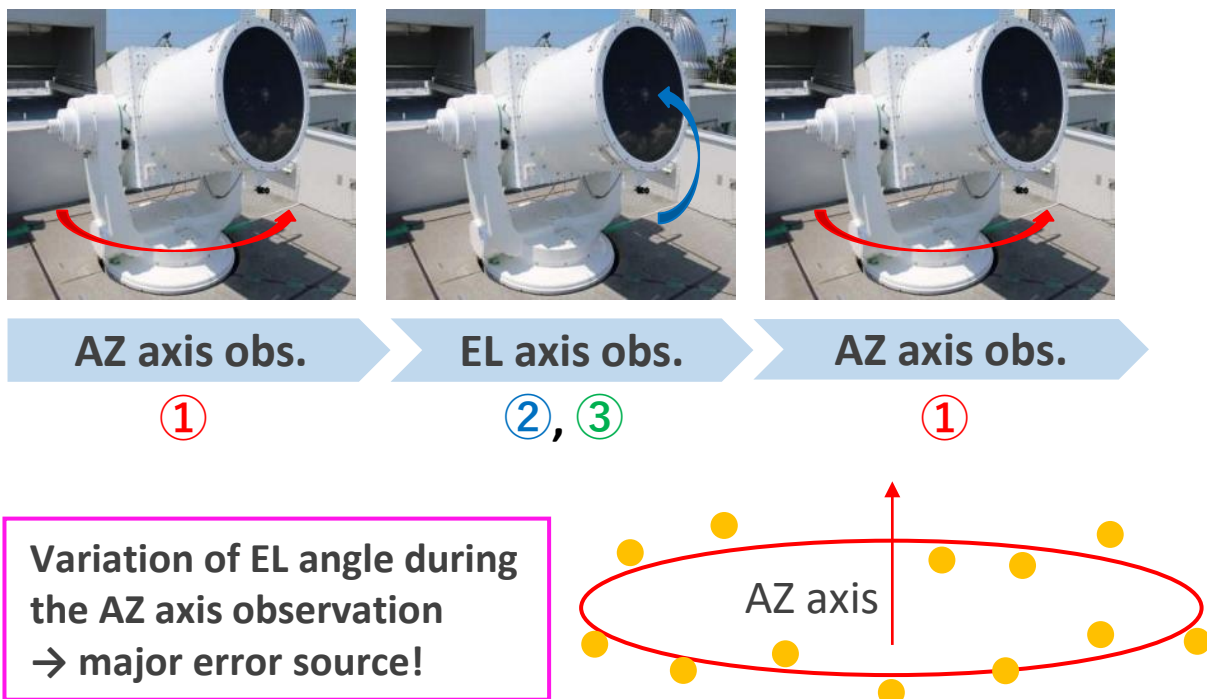
SD of the local tie vector(in local ENU coordinates): [0.0065 m, 0.0073 m, 0.0083 m]

Recommended local tie vector SD: < 1 mm; we were unable to meet the recommendation. **Why?**

- To increase the observation efficiency, we conducted EL axis observations between the AZ axis observation, like procedures ①, ②, ③... in the bottom figure.
- It is impossible to perfectly restore the EL angle in procedure ③, resulting in variation of the EL angle during the AZ axis observation.



Target observation of this survey



Discussion: error source

To reduce the error, it is necessary to completely separate the AZ/EL observations (bottom figure).

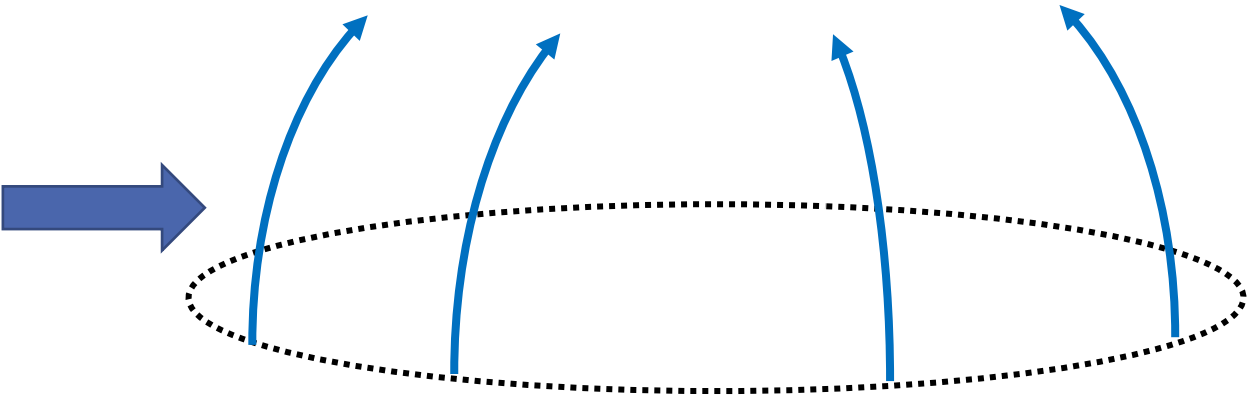
By separating the AZ/EL observations, we can observe the AZ axis at a constant elevation, which would significantly reduce the local tie vector SD.

1. AZ axis observation



AZ axis observed at a constant EL angle.

2. EL axis observation

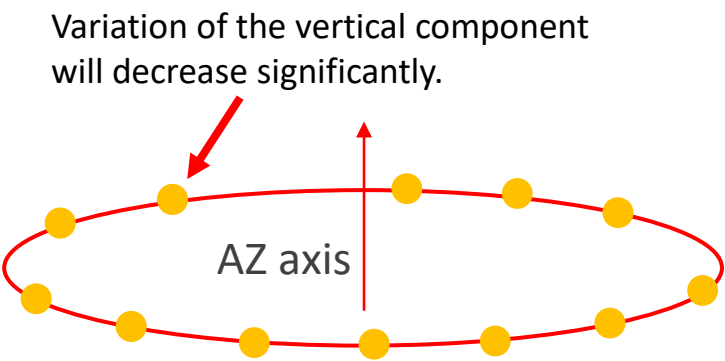


①AZ axis obs.



②EL axis obs.

Separation of the AZ/EL observations will significantly reduce EL angle error.

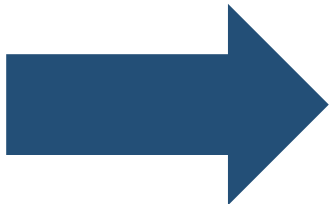


Target observation in the future

Submission of the SINEX file

```
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+FILE/REFERENCE
DESCRIPTION      Simosato 2020 local tie survey
OUTPUT           SMST GNSS reference and SISL SLR AZ-EL intersect
CONTACT          eisei@jodc.go.jp
SOFTWARE         pyaxis software: Land Information New Zealand
HARDWARE         N/A
INPUT            N/A
-FILE/REFERENCE
+SITE/ID
7838 A 21726S001 C SLR AZ-EL intersect 135 56 13.3 33 34 39.7 101.6
SMSA A 21726S002 C GNSS ARP          135 56 13.0 33 34 40.3 99.5
...
TIE5 A 21726M006 C Temporary marker 5 135 56 13.4 33 34 39.6 100.5
-SITE/ID
+SOLUTION/EPOCHS
7838 A 0001 C 20:318:00000 20:318:00000 20:318:00000
SMSA A 0001 C 20:318:00000 20:318:00000 20:318:00000
...
-SOLUTION/EPOCHS
+SOLUTION/STATISTICS
VARIANCE FACTOR      1.816027750768252e+00
SUM OF SQUARED RESIDUALS 2.088431913383490e+02
NUMBER OF OBSERVATIONS      283
NUMBER OF UNKNOWNNS        168
-SOLUTION/STATISTICS
+SOLUTION/ESTIMATE
1 STAX 7838 A 0001 20:318:00000 m 2 -3.82238829365310e+06 1.81162e-02
...
-SOLUTION/ESTIMATE
+SOLUTION/MATRIX_ESTIMATE L COVA
1 1 3.28196159259120e-04
2 1 -2.01291777293728e-04 3.53960230799003e-04
3 1 -2.06569712639277e-04 2.29273998093150e-04 3.87847166040208e-04
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%ENDSNX
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The co-location SINEX file was submitted to the ITRS Center and the IERS Central Bureau.



Contribution to the global geodetic community
The submitted local tie will be used for constructing the upcoming ITRF2020.

Summary

- The Japan Coast Guard conducts satellite laser ranging (SLR) and GNSS observations at the Shimosato Hydrographic Observatory (SHO).
 - The SLR and GNSS time series are consistent, and show co- and postseismic movements after major earthquakes.
 - Annual variability is present in both the SLR and GNSS time series.
- The Japan Coast Guard collaborated with the Geospatial Information Authority of Japan to conduct a co-location survey of the SLR telescope and the GNSS station at the SHO.
 - A precise survey was conducted to determine the local tie vector between AZ-EL intersect of the SLR telescope and the GNSS monument.
 - The standard deviations of the local tie vector between the SLR and the GNSS were approximately 2-3 mm for the horizontal components, and 7 mm for the vertical component.
 - We prepared and submitted the local tie SINEX file to IERS and ITRS for the upcoming ITRF2020.

Future works

- Work on reducing the local tie vector error in the next survey. It is necessary to completely separate the observations of the azimuth and elevation axes of the SLR telescope.
- Technical training, maintenance of survey equipment: so that JCG can conduct this survey individually in the future.