GNSS-IR Station Deployment for Enhanced Sea-Level Monitoring in Lieyu, Kinmen County

**Peter T.Y. SHIH, Yunung Nina LIN, Allen C.M. LEE,
Chung-Yen KUO, Yen-Ti CHEN, Chinese Taipei**

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SUMMARY

GNSS Interferometric Reflectometry (GNSS-IR) has proven to be an effective tool for measuring changes in sea surface height. It provides measurements directly referenced to the referenced ellipsoid by combining GNSS positioning, making it ideal for sea-level rise monitoring. Additionally, the GNSS-IR structure can be positioned above the water, reducing interference from sea waves and adverse weather conditions. In Lieyu, an island in Kinmen County situated between Taiwan and China, the daily tidal range can reach up to 6 meters. Traditional tide gauges, such as those based on pressure sensors and sonic instruments, are difficult to set up and face challenges from biofouling caused by marine organisms like barnacles, necessitating frequent maintenance. To address these challenges, a GNSS-IR CORS (Continuously Operating Reference Station) has been deployed in Lieyu. This article discusses the site selection, equipment, and data analysis associated with this deployment.

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1. INTRODUCTION

GNSS Reflectometry (GNSS-R) utilizes reflected multipath signals from reflective surfaces. When the reflection is from water, the changes of water level can be monitored. The receiving antenna can be placed in space or on the ground, meaning that the GNSS-R CORS (Continuously Operating Reference Station) could serve as a tide gauge. To measure both the direct and reflected signals, the station can be implemented with dual polarization antennas, one with Right-Hand Circular Polarization (RHCP) and the other with Left-Hand Circular Polarization (LHCP). In later development, a CORS tide gauge is equipped with a single RHCP antenna, while the sea level height is retrieved from the interference pattern between the direct and reflected waves, recorded in the signal-to-noise ratio (SNR) data. This technology is termed as 'GNSS Interferometric Reflectometry' (GNSS-IR, Larson et al., 2013).

Using GNSS-R or GNSS-IR for sea level measurements can eliminate the necessity of connecting to a 'vertical datum system.' Of course, when measuring orthometric height through leveling, the uncertainty is much lower over short distances compared to obtaining 'ellipsoidal height' with GNSS. However, GNSS avoids the uncertainties associated with linking the sensor's zero point to the reference point and connecting the reference point to the Tide Gauge Benchmark (TGBM), which are common issues in traditional tide observations.

This article describes the site selection and pilot implementation of a GNSS-IR CORS in Lieyu, Kinmen, aimed at measuring sea surface heights.

2. THE SITE SELECTION

GNSS-IR aims to capture high-quality sea surface reflection signals to calculate tidal variations. Therefore, the station should be positioned at a high elevation, with a surrounding area of open water as large as possible—the wider the azimuth coverage the better. Considering these conditions, promontory or cape terrains are the most suitable, as they offer a field of view exceeding 180 degrees. Geremia-Nievinski & Hobiger (2019) provide guidelines for the setup of multi-purpose GNSS continuous tracking stations. This literature is referenced in this mission. A higher antenna installation can capture reflections from farther offshore, avoiding interference from breaking waves near the coast. However, as the distance increases, the signal strength decreases, requiring a corresponding increase in GNSS sampling frequency. Section 4 of this document suggests that 'the GNSS sampling interval should be inversely proportional to the antenna height above the surface,' meaning that the higher the antenna, the higher the required sampling frequency (related to the Nyquist frequency).

The initial site selection was conducted using Google Earth, with the 'Terrain' layer enabled. The status bar displays the latitude, longitude, and elevation. Based on the terrain analysis using Google Earth, the southern part of Lieyu is higher in elevation. Therefore, assuming all other conditions are equal, the southern sites are preferable to the northern ones. Six preliminary candidate sites were selected, marked with yellow pins in Figure 1. Among them, the first three candidate sites are located in the southern part of Lieyu and are all situated on promontory terrain.

Figure 1: The site candidates in Lieyu

Field reconnaissance was conducted from July 31 to August 5, taking various factors into account, including the surrounding vegetation and site accessibility. Ultimately, the selected site was the Nanshan Fort military area. Nanshan Fort is the southernmost coastal military base in Lieyu, consisting of two gun-emplacements, seven underground firing bunkers, and a command post. The site was opened for public visits in early 2018 (https://kinmen.travel/zh-tw/travel/attraction/1665) and is managed by the Lieyu Workstation of the Kinmen National Park Administration. Since it is located on a promontory and has existing structures near the coast, the station was installed on the rooftop of one of the buildings, providing an excellent field of view. The actual measured height of the antenna above the water surface exceeds 20 meters, which is higher than the elevation indicated in Figure 1.

3. THE LIEY STATION AND PRELIMINARY DATA ANALYSIS

The CORS for GNSS-IR tide measurements, LIEY, was established on 2024/11/04 (Figure 2) and the data collection started on 2024/11/06. The GNSS receiver at this station uses a Septentrio MOSAIC X5 chip, Serial Number 3678215, and a navXperience 3G+C antenna, Serial Number RE0617. The observation frequency is 1 Hz.

Figure 2: The LIEY station

In this preliminary test, 20 days of observation data from the LIEY station were used, as shown in Table 1. The observation period spans from November 6, 2024 (DOY 311) to November 25, 2024 (DOY 330). The first data record is timestamped 2024/11/06 at 03:03:40.00.

Table 1: The data used for preliminary analysis

File Name	File Size	File Name	File Size
LIEY3110.24O	571369768	LIEY3210.24O	672406859
LIEY3120.24O	658202649	LIEY3220.24O	659499233
LIEY3130.24O	670891459	LIEY3230.24O	665123136
LIEY3140.24O	664561066	LIEY3240.24O	658152119
LIEY3150.24O	653216819	LIEY3250.24O	653920412
LIEY3160.24O	666972104	LIEY3260.24O	663756487
LIEY3170.24O	669633677	LIEY3270.24O	671075513
LIEY3180.24O	658016653	LIEY3280.24O	665948349
LIEY3190.24O	662991387	LIEY3290.24O	657812834
LIEY3200.24O	669453839	LIEY3300.24O	672882928

Data analysis is performed with gnssrefl software (Larson, 2024; 2024a). The preliminary results are shown in Figure 3, clearly capturing the tidal range in Lieyu, which is approximately 6 meters. This demonstrates the successful deployment of the GNSS-IR station. The technique, along with the collected observations, provides valuable supplementary data for sea level monitoring. Additionally, the continuous measurements from GNSS-IR can enhance the understanding of tidal variations and contribute to the integration of multiple observation methods for more comprehensive coastal monitoring.

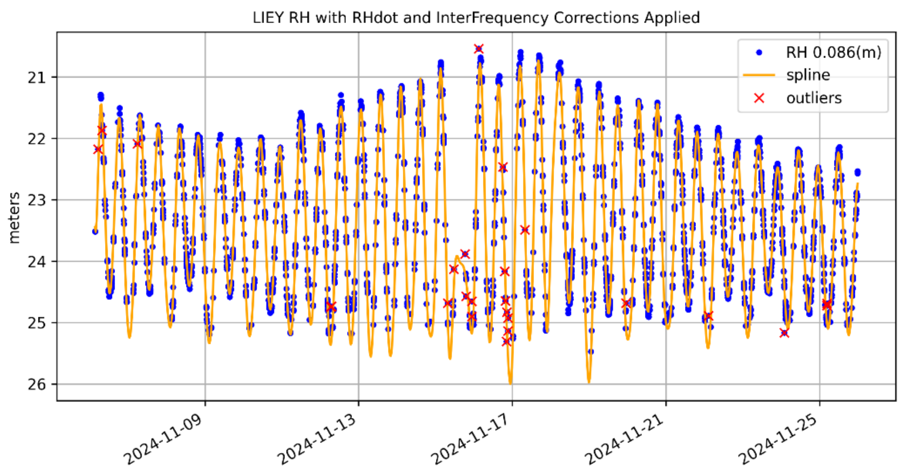

Figure 3: Spline fitting of antenna heights above water after corrections (peak2noise=3.0; Azimuth=135°-270°)

4. CONCLUDING REMARKS

A 'GNSS-IR tide gauge station' not only prevents the damage from seawater and marine organisms by keeping the station structure out of direct contact with the water but also features an integrated reference frame, allowing observations to be directly referenced to the WGS84 or GRS80 ellipsoid. This capability contributes to the establishment of the International Height Reference System (IHRS).

However, the 'GNSS-IR tide gauge station' also has limitations, such as uneven sampling intervals for sea level measurements and challenges in real-time processing. These limitations must be taken into account during the setup.

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REFERENCES

Geremia-Nievinski, F., & Hobiger, T., 2019. Site guidelines for multi-purpose GNSS reflectometry stations, Zenodo, https://doi.org/10.5281/zenodo.5335890. Last accessed on 2024/12/04.

Larson, K.M., Lofgren, J., & Haas, R., 2013. Coastal sea level measurements using a single geodetic GPS receiver, Adv. Space Res., 51(8):1301-1310, doi:10.1016/j.asr.2012.04.017.

Larson, K.M., 2024. Gnssrefl: an open source software package in python for GNSS interferometric reflectometry applications, GPS Solutions, 28:165, https://doi.org/10.1007/s10291-024-01694-8. Last accessed on 2025/01/20.

Larson, K.M., 2024a. Kristine M. Larson and GNSS-IR community, https://gnssrefl.readthedocs.io/_/downloads/en/1.3.21/pdf/, Last accessed on 2024/12/05.

BIOGRAPHICAL NOTES

Peter T.Y. Shih is a Professor Emeritus at the Department of Civil Engineering of the National Yang Ming Chiao Tung University, Taiwan. He received his PhD degree from the Department of Surveying Engineering, University of New Brunswick, Canada in 1989. His main research and teaching interests are in the fields of photogrammetry, terrain mapping, satellite positioning and navigation, and hydrography.

Yunung Nina Lin is an Associate Research Fellow at Institute of Earth Sciences, Academia Sinica. She received PhD in 2013, from California Institute of Technology, U.S.A. Her Research Fields include Interferometric Synthetic Aperture Radar (InSAR) Processing, Time-series Analysis, Reflection Seismology, Velocity Model Building.

Allen C.M. Lee is currently a PhD Candidate in the Department of Geomatics, National Cheng Kung University (NCKU). He received Master degree in 2016 from NCKU and has been focusing on GNSS-IR technology since 2015.

Chung-Yen Kuo became a full Professor in the Department of Geomatics, NCKU in 2015. He received PhD degree from Ohio State University in 2005. His research interests include, Geodesy, Sea level, Climate Change, Gravity, GNSS-R, Hydrographic survey and Unmanned Surface Vehicle.

Yen-Ti Chen received Master degree from the Department of Geomatics, NCKU in 2007. He is a senior officer in the Department of Land Administration, Ministry of the Interior. His work includes to serve as a leader in the Taiwan ENC Center.

CONTACTS

Prof. Peter T.Y. Shih
Department of Civil Engineering
National Yang Ming Chiao Tung University
1001 Ta-Hsueh Road
Hsinchu
300093, TAIWAN
Tel. +886 3 5712121 #54957
Fax +886 3 5716257
Email: tyshih@nycu.edu.tw
Web site: https://ce.nycu.edu.tw/en/member/educators/4