NOAA CO-OPS Continuous Global Navigation Satellite Systems at NWLON Stations

System Level Method Description

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1. Introduction

NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) is modernizing techniques for monitoring and measuring sea level sensor elevation by establishing continuous Global Navigation Satellite Systems (cGNSS) directly at National Water Level Observing Network (NWLON) stations. From June 2018 to July 2019, CO-OPS established long-term cGNSS stations at six different NWLON sites: Virginia Key, FL; Galveston, TX; Dahlgren, VA; Newport, RI; San Juan, Puerto Rico; Pensacola, FL. The purpose of this document is to describe the level methods to vertically tie the cGNSS system to the tidal bench mark network at each of the six stations. [1, 2].

At the time writing, the six cGNSS field stations that have been installed by CO-OPS consist of Trimble brand components. This first version of CO-OPS' cGNSS system level method document will focus solely on Trimble based systems. This is intended to be an evolving document that will be revised and reissued following CO-OPS' implementation of new cGNSS station components.

NOAA/CPO's main objective of installing cGNSS systems at NWLON observatories is to support NOAA's collaborative sea level research efforts with the UNESCO Intergovernmental Oceanographic Commission (IOC) Global Sea Level Observing System group (GLOSS). An additional objective of CO-OPS is to assess the use of GNSS observations for monitoring long-term vertical stability of the primary water level sensor at the stations.

A critical step to make GNSS observations usable for past, present and future applications is to vertically tie the GNSS antenna reference point (ARP) to the tidal bench mark network. Once the GNSS antenna's vertical position relative to the tidal bench mark network has been determined, cGNSS measurements can then be referenced to the primary water level sensor's elevation, as well as the station's water level datums.

The CO-OPS Engineering Division (ED) and Field Operations Division (FOD) collaborated to develop a GNSS level survey method for CO-OPS-installed GNSS stations that is adaptable to site specific details. The purpose of this document is to provide an overview of this developed survey level method, including techniques performed to establish an elevation on the GNSS ARP using Second Order, Class 1, differential leveling standards.

2. System Design

The schematic in figure 1 provides a high level overview of cGNSS system design for all CO-OPS installations to date. A detailed description of the GNSS System designed can be found in reference [3]. The system's primary components can be classified into 3 categories:

1. GNSS Measurement System: receiver, antenna
2. Communications: Wireless gateway modem, antenna
3. Power: Solar panel, batteries, charge regulator

Field level survey procedures require focus on only one system component, the GNSS system antenna.

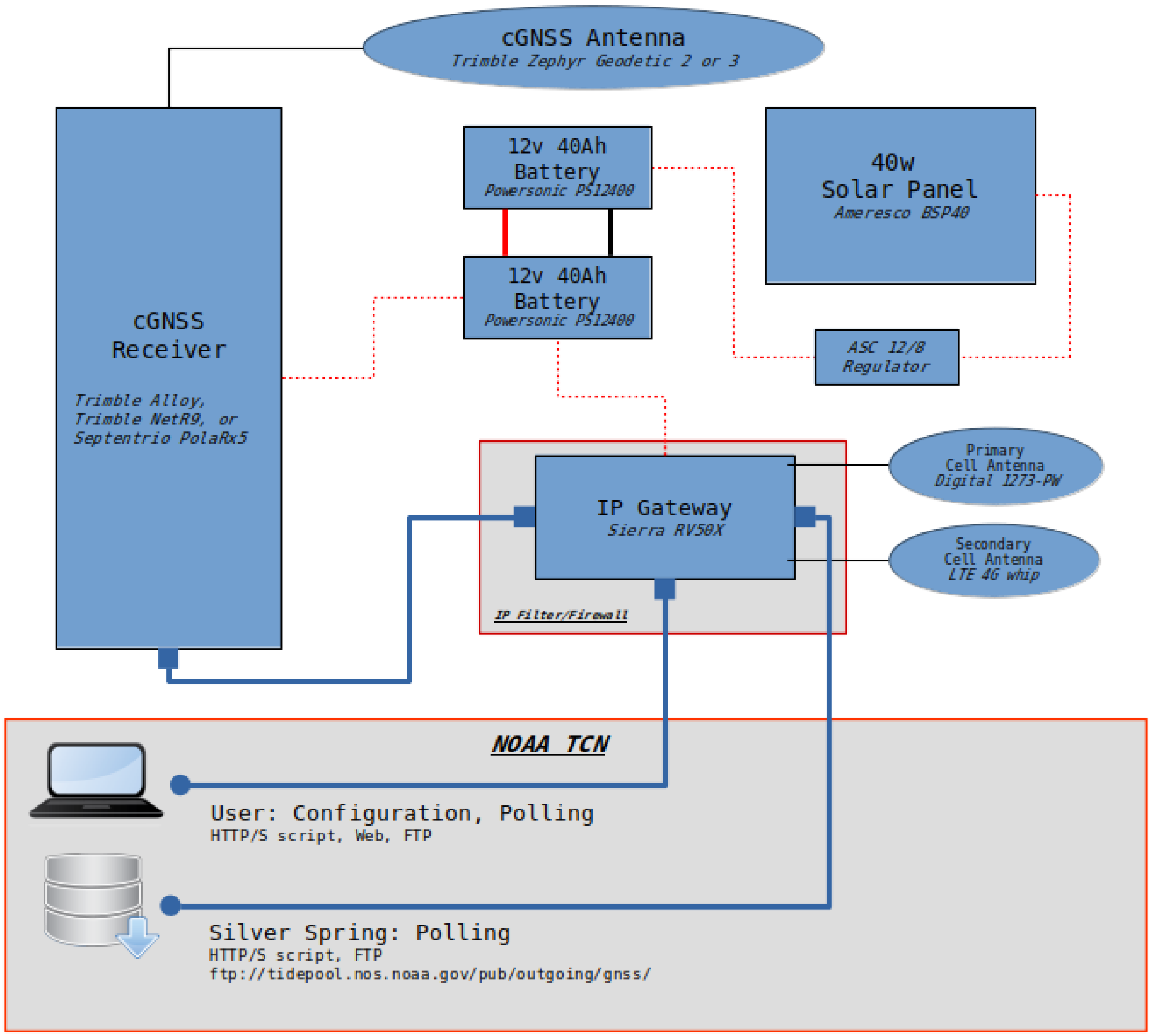


Figure 1. cGNSS system design schematic.

Trimble Zephyr Geodetic Antennas

CO-OPS cGNSS field installations have included both Zephyr Geodetic (ZG) II and III model antennas. The ZG III is an improved version of the ZG II. The external components and appearance of both models are nearly identical (Appendix A). Figure 2 shows photos of the top and bottom of a Zephyr Geodetic II antenna, with key components labeled. Major features are similar on the ZG model III.

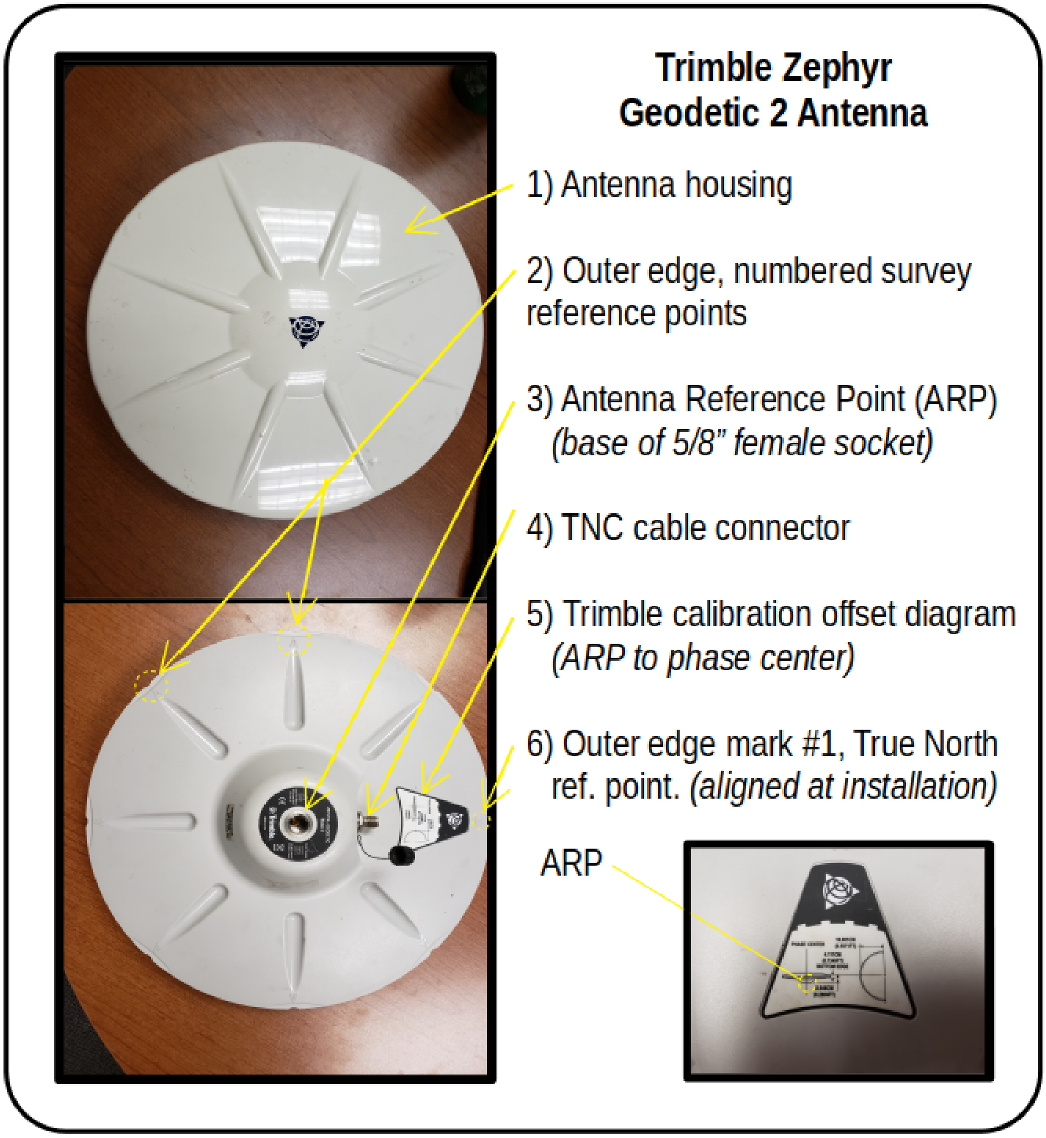


Figure 2. Top and bottom of Zephyr Geodetic 2 antenna.

At all six CO-OPS GNSS stations, a SECO brand Adjustable Tilt Monument Adapter (SA) was used to mount the ZG antennas. Figure 3 shows a picture of the SA and an example field installation. SA features include:

1. A removable brass 5/8 -11 male stud (threads to antenna base) that is adjustable in azimuth
2. The 5/8 x 11 male stud is held in place by two set screws
3. The adapter is leveled by three adjusting screws with a tilt range of +/- 7 degrees
4. The adapter has a female base that is threaded to match the male pipe used.(available in 1.5", 2", 3" MPT, or 5/8 x 11 thread)

Figure 3. SECO adapter.

3. GNSS Antenna Leveling

For comprehensive details on the leveling methods and procedures used by FOD refer to FOD standard operating procedures and the Second Order, Class 1 Leveling Techniques as described in *User's Guide to Vertical Control and Geodetic Leveling for CO-OPS Observing Systems to bench marks* as required in the Project Instructions (Appendix B).

Once the antenna is installed it should not be removed again unless absolutely necessary. For this reason, upon initial installation of the GNSS system at the NWLON station, the GNSS antenna height will be measured at two pre-selected points: 1) the GNSS Antenna Reference Point (ARP) and 2) one of the GNSS antenna's outer edge numbered and marked survey points (Fig 2). The outer edge point chosen must be recorded, as all subsequent leveling to the GNSS antenna will use only that point.

Level to ARP

As shown in figure 2 the ZG antenna ARP is located at the bottom center of the antenna. When the antenna is screwed down onto the brass fitting of the SECO brand Adjustable Tilt Monument Adapter (SA) it will be tight and flush with the SA top surface and hence not accessible for placement of a survey rod or tape. As such, it is ideal to conduct the initial level survey at the time of the GNSS installation, before the cGNSS data record is intended to begin. Since the ARP is not accessible once the antenna is mounted, a custom ZG ARP leveling bar was designed and developed to create an ARP survey level point for a rod or tape to be set during the survey.

As shown in figure 4, the ARP leveling bar has a threaded hole where the SA brass fitting can attach. Once screwed down tight and temporarily installed in the SA, the bottom surface of the leveling bar will be at the same elevation as the ARP. The bar's bottom surface provides plenty of room to set a survey rod or to attach a tape, and the orientation can be rotated 360 degrees in the horizontal to provide an optimal location depending on site specifics.

Prior to installing the GNSS level bar onto the fixed SECO mount, a bubble level will be inserted into the center of the SA to verify that the mount is level (Fig 4). If not the SA will be leveled using the three leveling screws. Once the SA is level, the antenna leveling bar is secured to the SA and a spirit level is placed on the bar to ensure that it is level (Fig 4). The survey team will then level to the survey bar bottom surface using the predetermined method and tool (rod or tape) developed by the level team, which will depend on height and location of the antenna. Figure 5 shows two examples of this, one using a tape down method, the other a leveling rod.

Level to Antenna Survey Point

After leveling to the ARP is complete, the GNSS level survey bar is removed and the GNSS antenna installed. The level team using a predetermined method to precisely measure the antenna height will then select which antenna survey point to level to. Accessibility to the antenna survey point is the key criteria for this. Any of the antenna's eight available survey points can be used; however, the number of the particular point selected must be recorded to ensure that all subsequent surveys use the same point.

Special care must be taken to ensure that the survey rod is properly set on the appropriate slot of the outer edge reference point and that undue upward force ***is not*** exerted on the antenna. Differences between the ARP and the outer edge survey point elevations measured via field level survey are compared to values in the manufacturer provided offset diagram (on the back of the antenna, shown in figure 2) as an initial check of the quality and accuracy of the level survey.

Figure 4. The left photo shows the level bar used to measure to the ARP, the center photo is the bubble level to ensure the SA is level, and the photo on the right shows the ZG survey points.

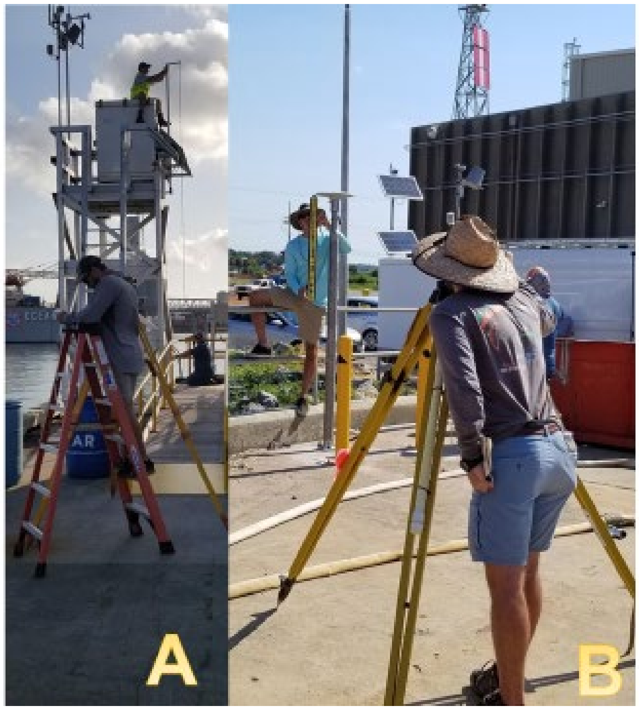


Figure 5. Photo A uses a tape down method and photo B uses a leveling rod.

4. Summary

The purpose of the level survey is to produce a vertical tie of the GNSS system (antenna) to the tidal bench mark network, so that all GNSS observations can be referenced to the station datum, and all associated tidal datums. Inversely, sea level observations can be referenced to the GNSS vertical position observations to obtain geocentric referenced sea level. Another derived product is a very accurate vertical offset between the GNSS ARP and the primary water level sensor's survey point. The resulting measurements will meet CPO & GLOSS requirements for global sea level research applications.

5. References

1. CO-OPS GNSS Installation Reports: https://sites.google.com/a/noaa.gov/co-ops-ostep/home/currentprojects/gnss
2. CO-OPS GNSS Level Reports: https://sites.google.com/a/noaa.gov/co-ops-ostep/home/currentprojects/gnss
3. NOAA CO-OPS Continuous Global Navigation Satellite Systems at NWLON Stations, System Design Description. Authors: Bob Heitsenrether, Kevin Harrison & Eric Breuer, 2020

6. APPENDIX A - ZEPHYR GEODETIC ANTENNA SPECIFICATIONS SHEET

DATASHEET

Trimble Zephyr 3 Base Antenna

PRECISION BASE ANTENNA WITH MILLIMETER ACCURACY

Integrated with Trimble Stealth™ ground plane to minimize multipath and protected by weather resisting materials, the top of the range Zephyr 3 Base antenna is the ideal antenna for control work.

COMPREHENSIVE GNSS SUPPORT

The Trimble Zephyr 3 Base antenna offers full support for current and near-future GNSS signals including GPS, GLONASS, Galileo, BeiDou, QZSS, IRNSS, OmniSTAR, Trimble RTX and SBAS.

TRIMBLE ZEPHYR 3 BASE

In addition to fixed base stations, the Zephyr 3 Base antenna is also suitable as a rover antenna for use in high multi-path environments. The Zephyr 3 Base antenna's quality performance and extreme accuracy are achieved through millimeter phase center repeatability, robust low-elevation tracking and reduced ground-based multipath interference.

Key Features:

- Additional Iridium filtering above 1616MHz allows antenna to be used as close as 20m of Iridium transmitter
- Additional filtering below 1510MHz allows for antenna placement closer to Japanese LTE cell tower
- Trimble Stealth Ground Plane – integrated lightweight stealth technology with enhanced right hand circular polarization to reduce multipath interference
- Advanced LNA (low noise amplifier) to reduce interference by high power out-of-band transmitters
- 50 dB signal gain for reliable tracking in challenging environments and long cable runs

Key Features

- Comprehensive GNSS support, including GPS Modernization signals, GLONASS, BeiDou and Galileo
- Robust low-elevation satellite tracking
- Large Trimble Stealth™ ground plane for multipath rejection
- Millimeter phase center repeatability
- Ideal for fixed reference stations and GNSS infrastructure networks
- Additional Iridium and Japanese LTE filtering
- High signal gain (50dB) for reliable tracking
- Low cross-sectional profile to reduce wind loading

DATASHEET

Trimble Zephyr 3 Base Antenna

TECHNICAL SPECIFICATIONS

- Comprehensive GNSS Tracking:
  - GPS: L1, L2, L5
  - GLONASS: L1, L2, L3
  - BeiDou: B1, B2, B3
  - Galileo: E1, E5a, E5b, E6
  - QZSS: L1, L2, L5, LEX
  - IRNSS: L5
  - SBAS: WAAS, EGNOS, GAGAN, and MSAS
  - MSS: OmniSTAR, Trimble RTX
- Quality signal tracking, even at low elevations
- Four point antenna feed for phase center stability and enhanced polarization
- Powered by GNSS receiver via coaxial cable
- Optional transparent protection radome (available if desired)

ENVIRONMENTAL QUALIFICATIONS

Operating Temperature . . −40 °C to +85 °C (−40 °F to +185 °F)
Humidity. . . . . 100% humidity proof, fully sealed, IP67
Shock and Vibration
Tested and meets the following environmental standards:
Shock: MIL-STD-810-F to survive a 2 m (6.56 ft) drop onto concrete
Vibration: . . . . MIL-STD-810-F on each axis
Compliance . . . . CE compliant including ISO 13766:2006, 2014/45/EU (RED), EN 60950, E-Mark and RoHS, FCC, IC and RCM compliant

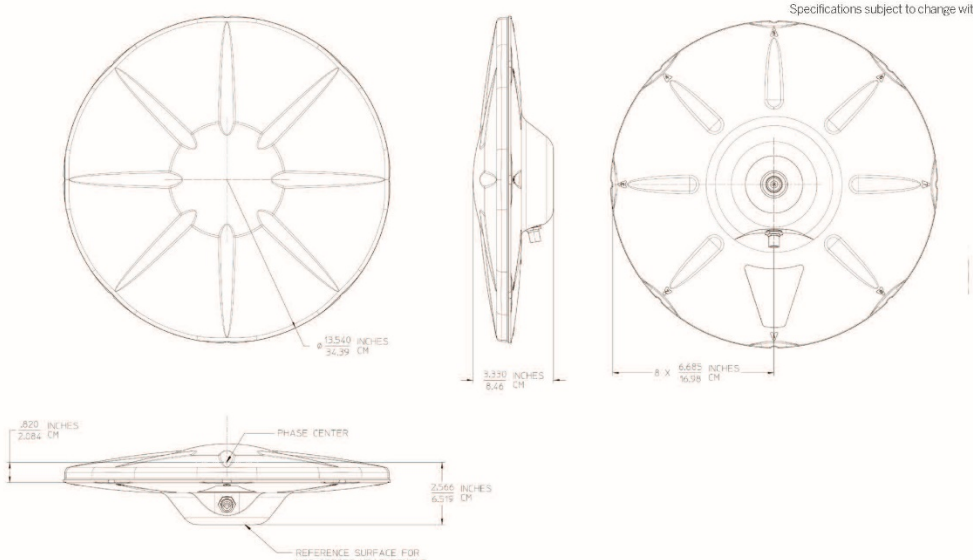
PHYSICAL AND ELECTRICAL SPECIFICATIONS

Dimensions . . . . 34.3 cm diameter x 7.9 cm height (13.5 in diameter x 3.1 in height)
Weight . . . . 1.36 kg (3 lb)
Input Voltage. . . . . 3.5 V DC to 20 V DC
MSS Narrow Band Mode (1555 to 1559 MHz): >6.4 V DC to 9 V DC
MSS Wide Band Mode (1525 to 1559 MHz): 3.5 V DC to 6.0 V DC and 9.4 V DC to 20 V DC
Input Current. . . . . 125 mA
Signal Gain . . . . 50 dB
Signal Connector . . . . TNC Female
Mounting . . . . 5/8" - 11 Female Thread

PART NUMBERS

115000-50-INT . . . . Zephyr Model 3 Base Antenna

Specifications subject to change without notice



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7. APPENDIX B - Second Order, Class 1, Differential Leveling Procedures

1. Perform Second Order, Class 1 Leveling techniques as described in *User's Guide to Vertical Control and Geodetic Leveling for CO-OPS Observing Systems*, to bench marks as required in the Project Instructions
2. Perform a level section from bench mark or Water Level sensor to ARP (Leveling Fixture)
    a. Run Forward Section
        i. From a Bench Mark or WLS
        ii. Take Backsight on Rod / Invar Staff Level instrument
        iii. Turn instrument to take Foresight
        iv. Before taking foresight changed Instrument settings to take inverted shot
        v. Rod is turned upside down or inverted place rod foot on the ARP (Leveling Fixture), plum Rod using Rod Level Bubble
        vi. Take Foresight, record all metadata
        vii. Section is closed, record difference
    b. Run Backward Section
        i. From the ARP (Leveling Fixture)
        ii. With Instrument still set to take inverted shot
        iii. Place inverted Rod on ARP (Leveling Fixture), plum Rod using Rod Level Bubble, take Backsight on inverted Rod
        iv. Changed instrument settings back to take non- inverted shot
        v. Turn instrument to take Foresight
        vi. Take Foresight with Rod or Invar Staff on Bench Mark or WLS, record all metadata
        vii. Section is closed, record difference
    c. Apply ARP Offset by manually input ARP offset (Noted on the bottom of GNSS antenna)
        i. Manual add a Forward and Backward section applying the ARP in record file
3. Processing leveling data using WinDesc and Translev programs to ensure all tolerance are maintained