EC023: GNSS Monument (Base GPS) Siting Standards

Summary

This document seeks to clarify and standardize tradeoffs in setting up base GNSS stations (also known as GNSS monuments) for airborne survey, given the current state of the art in differential and PPP processing.

A GNSS monument is a fixed base station whose fixed position is used as a constraint to reduce errors in position solutions for a rover. Some of the desired attributes for a GNSS monument:

- Location with acceptable operator access, security from damage or theft.
- Low RF interference at GPS, Glonass frequencies
- Good sky view
- Fixed position – movement and vibration of the monument antenna transfers as an error in the rover position solution
- Proximity to aircraft parking position
- Proximity to survey area
- Good multipath rejection – Multipath (reflected) signals contribute to satellite range errors. An antenna's susceptibility to multipath from a given direction can be estimated by the difference in its antenna gain pattern to a right hand circular polarized (RHCP) signal versus a left hand circular polarized signal (LHCP)[1]
- Small size – Small antennas are less moved by wind loads, affected by snow accumulation, and operationally easier to carry and mount. Less equipment is more portable.

Science Requirements

The 2015 field season's science requirements can be summarized as:

- All requirements assume a 90 m/s aircraft at up to 500 km from the base location.
- Laser: 15 cm RMS vertical repeatability (accuracy) at a 100m horizontal scale
- Radar: 62 cm RMS horizontal and vertical repeatability
- GRV:

Base Station Operator's Site Selection/Installation Guide

Below are a list of different approaches to give your GNSS monument the desired attributes to provide high quality data for differential processing.

1. Select a site with acceptable maintenance access, power, and safety from damage.
2. Minimize RF interference in GPS/Glonass bands (1164-1591 MHz).

1 This description is valid in the ideal case of a single reflection. In some situations such as urban canyons, double reflections are common.

a) Avoid siting near permanent radio installations such as active control towers, radar/radio antennas, Iridium antennas.

b) Avoid using Iridium devices or handheld radios within 10m of a GNSS antenna during survey operations.

3. Select a stable fixed position.

a) Mount the antenna on a sturdy platform or building. For our purposes, vertical stability is more important than horizontal stability.

b) Secure tripod legs to platform.

c) Consider the level of building movement/vibration due tide, drift, to wind or equipment vibration, on timescales of the observation epoch.

4. Minimize long term position drift (tide, ice flow) unless experiment-specific requirements exist.

5. Good Sky View

a) Site GNSS antenna with minimal obstructions above 10 degrees from horizontal.

6. Reduce Multipath Signal Influence

a) Use receivers and antennas with good multipath rejection (best: choke ring, good: ground plane, aircraft antenna)

b) Minimize reflectors at all elevations, especially within 1.5m (5 ft) of antenna.

7. Site Near Aircraft Parking Location

a) Base station antenna should be close enough to sample the same atmospheric weather conditions during stationary time. Within 1km horizontal is definitely safe, within 10km horizontal is probably safe.

b) The impact of sampling different air columns may cause difficulties to the integer ambiguity resolution procedure. The true effect is unknown. In an abundance of caution, siting within 2000m elevation is recommended.[2]

8. Point the antenna reference mark to the North

a) This allows phase center variation (PCV) corrections to be applied, which may improve accuracy on the sub-centimeter scale. We do not perform PCV corrections in any existing processing flows, and likely will not in the future. PCV calibration data for aircraft antennas does not yet exist.

Decision Guide

The guide below prioritizes site selection criteria in order of typical importance. Actual importance may vary according to site and experiment details.

1. Basic Requirements (Core Requirements for radar survey)

    1. Site with acceptable operator access, power provisions, and security.
    2. Avoid sources of 1164-1591 MHz RF interference (e.g., UHF, Iridium)

2 See General Comments, “Proximity to Aircraft Parking Location” for more analysis.

    3. No major RF occlusions above 10 degrees elevation of the antenna.
    4. Minimize long term position drift (tide, ice flow) unless experiment-specific requirements exist.[3] Select a site that will allow the antenna to be installed undisturbed for as long as possible, up to the entire survey campaign.
    5. Vertical/horizontal stability within half your error budget (if your error budget is 10 cm, make sure it is stable to 5cm between observation epochs)
    6. GNSS antenna with ground plane
    7. Site within the same weather system as aircraft parking location. (site-dependent. 10km horizontal?, 2000m vertical)
2. Level 2 Requirements
    1. GNSS antenna with choke ring
    2. No major reflectors above 0 degrees elevation of the antenna to reduce multipath
3. Level 3 Requirements
    1. Prevent unintended RF interference and select a site away from radio transmitter installations.
    2. Site within 100m of aircraft parking location.
    3. Vertical/horizontal stability within 1 order of magnitude better than your desired horizontal/vertical error budget.
    4. Antenna mark pointed to true north. Note antenna make and model for postprocessing.
4. Geodetic Requirements: Recommendations for geodetic quality precision survey
    1. Vertical/horizontal stability to within 1 mm
    2. No major reflectors above -10 degrees elevation of the antenna (10 degrees below horizon)
    3. Auxiliary ground planes and RF absorbing material

In practice, geodetic requirements will not be achieved during Antarctic field work.

Case Studies

Below are several hypothetical examples based on real-world tradeoffs.

Case 1: McMurdo Station

Pegasus Field is located is located at approximately sea level, 12km from McMurdo Station. Williams Field is located at approximately sea level 9km from McMurdo Station. All are affected by the same weather system. The Crary Lab is approximately 120m above sea level. From Crary Lab, Observation Hill has an elevation of 8.1 degrees, below the 10 degree limit. UNAVCO operates a station in the Arrival Heights area, around 225m elevation.

In 2014, the ENCALM airborne survey group and Lamont (ICEPOD) preferred the results of using

3 See Case Study 2: McMurdo Ice Shelf Survey

base stations located at Crary Lab rather than at Williams Field.

Once previously, UTIG tried to use data from a base station at Crary Lab for differential processing, and failed to get a differential solution.

Case 2: McMurdo Ice Shelf Survey

In application-specific contexts, it may be desirable to site the antenna in contradiction to these guidelines. For example, when doing a laser altimetry survey of the McMurdo Sound, siting the GNSS antenna on the targeted floating ice or ice shelf provides information about the tidal movement of the survey region.

In this case, the GNSS base monument provides more accurate results relative to the target, but less accurate relative to the earth frame of reference.

Case 3: Casey Station

The Casey skiway provides several buildings with limited heat and power on slowly flowing ice. Casey Station, located 9.4 km away, and 330m below and toward the coast, with reliable heat and power, on an earth foundation. Both provide acceptable levels of access, but the station provides easier access and more reliable provisions.

Case 4: Zhongshan Station

Zhongshan Station (ZGN) is situated on rock near sea level. The airfield for ZGN is located 5.75 km south, at 200m elevation on slowly flowing ice.

Case 5: Dumont D'Urville

Cap Prudhomme is at 30m elevation, and the D10 skiway is 4.0 km away at 225m elevation. The hill presents an occluder with at most 3.4 degrees elevation.

Case 6: Dome C (Concordia Station)

Concordia Station is about 20-30m tall. So placing an antenna more than 120m-170m from the main station would prevent the station from occluding satellites.

General Comments

Installation Guideline	**Impact of Complying with Guidelines**
Maximum horizontal deflection	Conversations with C. Petersen in the GNSS group at ARL imply that for some precision survey applications, mm stability is desired, and that for a 10 cm error budget, 1 cm of movement is probably acceptable.
Vertical movement	Vertical movements translate to errors in final position solution. Be aware that an ice shelves move with tides and contribute to errors in position solutions, when using standard processing.

Minimize multipath reflectors from below the antenna.	Standard choke ring antenna designs show strong roll-off in multipath sensitivity pattern from -90 degrees from zenith down to -100 degrees from zenith (10 degrees below the horizon) (Kerkhoff 2010, Fig 2). Once all potential reflectors are 10 degrees below the horizon, the multipath improvements are minimal.
Point antenna "North" mark toward true north	One reason to point the antenna toward true north is so that the measurements can be offset relative to the Antenna Reference Point. In our case, we do not care about precisely referencing our positions to an absolute point, so this reason is unimportant. It is still good practice in geodetic survey to point the antenna toward true north. Pointing antenna the antenna mark north allows 2D antenna calibrations to be applied, to remove the effects of Phase Center Variation (PCV). PCVs result in phase errors depending on the direction from which a GNSS signal is received. If the antenna mark is not pointed toward true north, then only 1D antenna calibrations may be applied. In practice, phase center variations are relatively symmetric in azimuth, so failing to point the antenna toward true north may have an effect of (??) on the accuracy of the positioning data. In some precision survey applications that use the same antenna for base and rover, phase center variations will cancel if both antennas are pointed in the same direction. For airborne survey, satisfying these constraints is impractical. Within +-5 degrees of true north is probably generally good enough to apply a 2D calibration, but this is obviously dependent on your error budget and antenna model.
Proximity to aircraft parking position	Base station must be close enough to aircraft parking position to sample the same atmospheric conditions. If too different, differential processing may fail. Sampling different atmospheric conditions may cause variation in estimated path length during integer ambiguity resolution. Using Rueger, 2002, we can calculate the max error contribution in path length due to trophospheric refraction. Uncalibrated delays beyond one cycle length may cause problems during integer ambiguity resolution. Assuming the maximum difference in refractivity due to

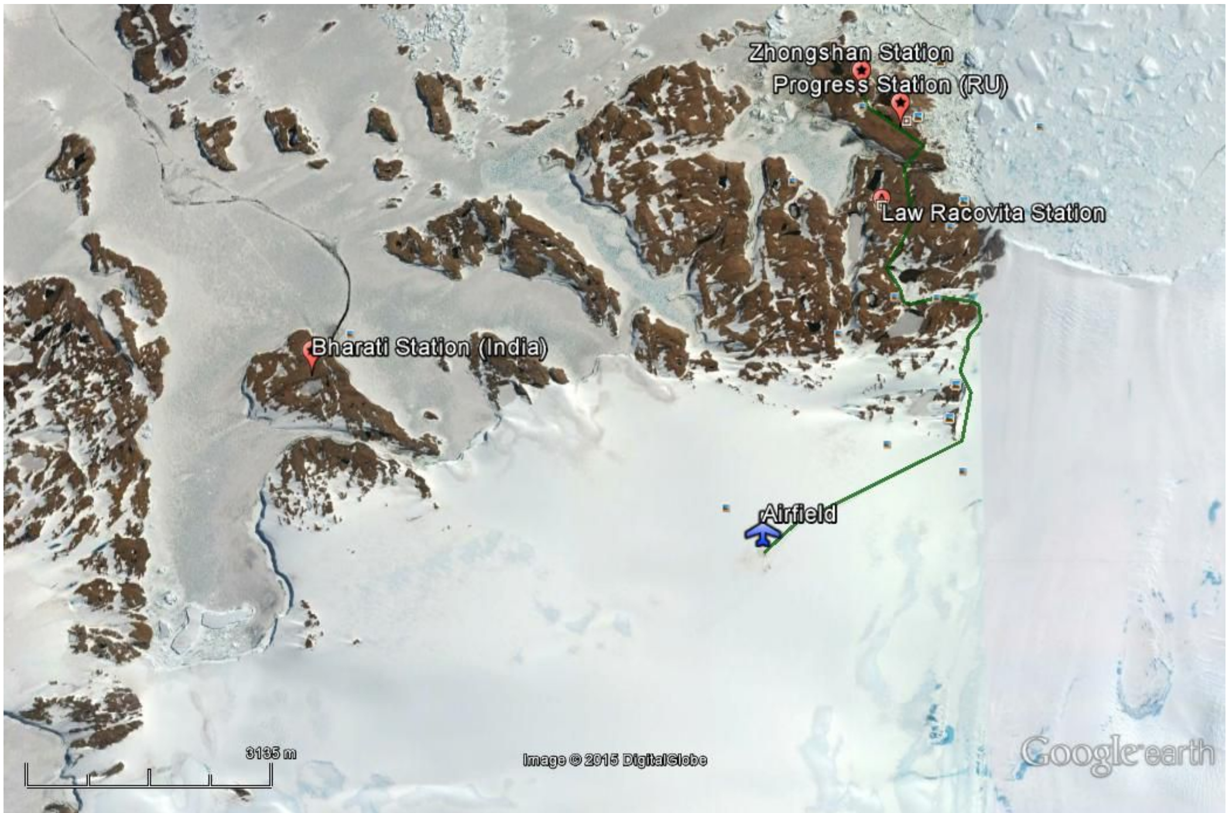
	completely dry vs completely wet air at 5 deg C, 2000m of air column will contribute 10 cm of error, or half of one integer wavelength. Lower temperatures give smaller error bounds.

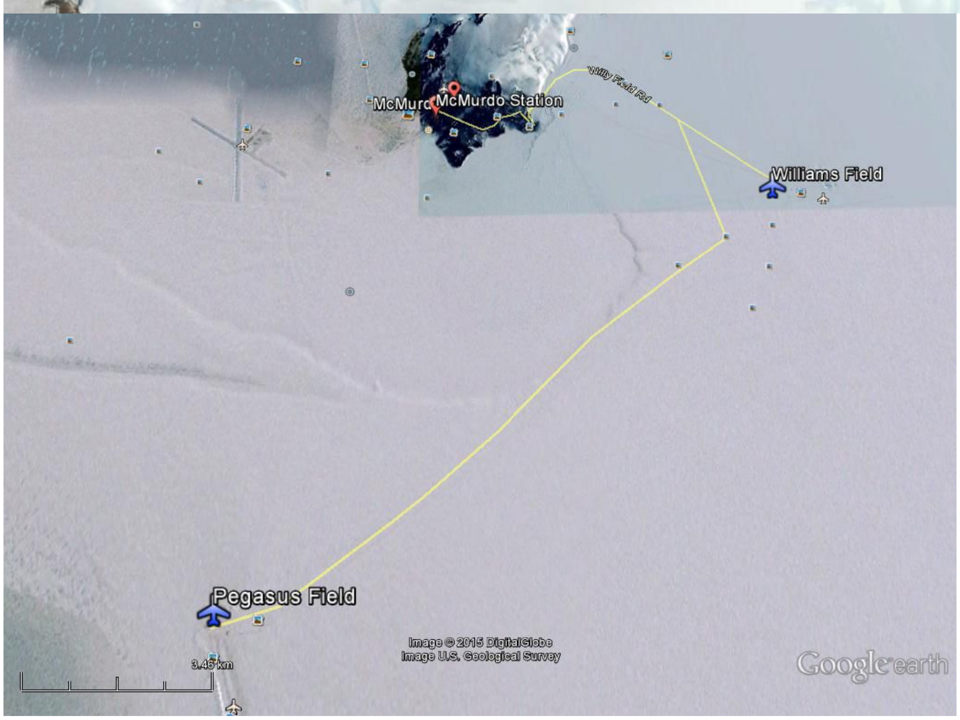
Recommendations for Geodetic Monuments

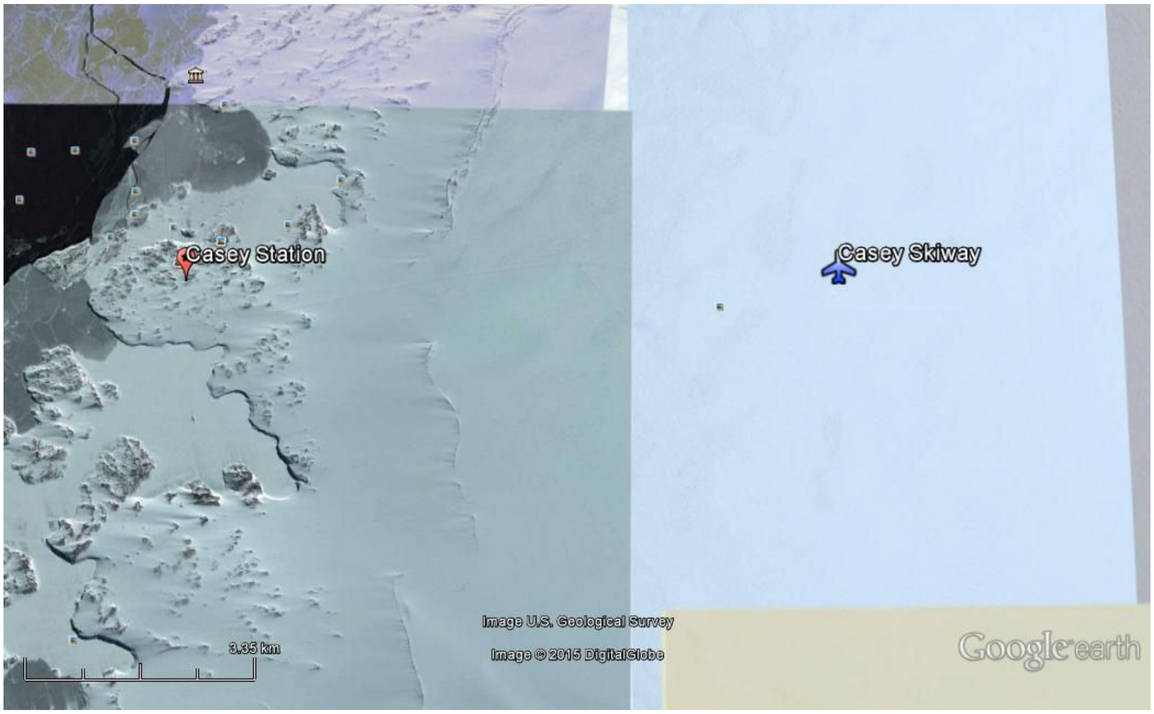
Below are summarized recommendations for GNSS monument installations from operators of geodetic GNSS monuments. In general, these recommendations are in priority order, meaning that a subsequent recommendation should not override a prior recommendation.

1. Mount the antenna so that potential reflectors are below 0 deg elevation relative to the base of the antenna. If possible, position the antenna so that they are 10 degrees below the base of the antenna, but not at the expense of any of the other key recommendations.
2. Mount the antenna on a mast or tripod with horizontal/vertical stability at least one order of magnitude better than your desired horizontal/vertical error budget. (If your error budget is 10 cm, be sure it is stable to 1 cm between observation epochs)
3. When practical, point the North reference mark toward true north to allow PCV corrections. If following this procedure, note the antenna make and model.

Appendix A: Site Maps






Casey Station
Casey Skiway
3.35 km
Image U.S. Geological Survey
Image © 2015 DigitalGlobe
Google earth

Appendix B: Topcon Net-G3A Reference Station Recommendations

The following sections are excerpted from the Topcon Net-G3A operator's manual.

Consider the Net-G3A Reference Station Application

Several decisions about the reference station application need to be determined before considering both the physical location and the receiver setup. These decisions affect virtually all the associated project planning, site inspection, hardware/software setup, and data gathering activities. Among the questions to consider are the following:

- who the end-user will be and how many there will be (those accessing the data, those analyzing the data, etc.)
- what kinds of communication links will be used
- what kind of data are required and data formats
- where the receiver needs to be placed (based on available sites and intended application)
- how the receiver will be used: as a single reference station or as part of a network
- how long the project will last: a short-term or a long-term project

All project team members should have a clear understanding of the project's purpose, goals, and application. Once the goals of the application have been identified, preliminary sites can be chosen, and then narrowed down to the most appropriate site.

Perform a Site Inspection for the Net-G3A Reference Station

When determining the location in which to place the Net-G3A, consider the relative safety of the physical location for both the receiver and personnel. Successful installation and operation of the reference station should meet the following guidelines:

- Location of the site and the receiver
    - The building site should have a clear view of the sky with no reflective objects or surfaces in the vicinity.
    - The location of the receiver: Receiver should be indoors, placed on a flat surface (such as a table or stable shelf), provide free access to the receiver's front and rear panels, and be easy to reach and handle for maintenance activities.
- • Equipment connectivity and antenna cabling system
    - The site should provide appropriate routings for connecting the various equipment. Cables should be unobtrusive, but easy to maintain.

For proper equipment connectivity and functionality, use only original and dedicated cables. Consider the following recommendations when connecting your devices:

- Label each cable: On all cable ends, securely attach a sticker with a cable identifier.

- Do not exceed standard cable lengths: The cable length should not exceed the maximum distance specified in appropriate standards for the cable being used.
- Keep all cable connectors free of dust, dirt, and contaminants.

– If you make your own cables, make sure that the cables are properly crimped.

– Verify that you have connected each cable to its mating connector, and it is firmly seated.

Building an antenna cabling system is one of the key components to successful operation of the Reference Station—especially when using an antenna cable longer than 30 meters or connecting multiple antennas to the same receiver. For guidelines on building a cabling system, see "Building an Antenna Cabling System" on page 3-20.

• Power accessibility

The site should provide and meet power specifications for the receiver and other installed equipment. The receiver should have direct access to a grounded outlet.

The Net-G3A is designed to accept two external power inputs and automatically switch during power fluctuations to keep the receiver operational.

– PWR 1 can be connected to the main power using the Universal Power Supply included with the Net-G3A.

– PWR 2 can be connected to any alternative power source capable of supplying 6 to 28 V DC (including an Uninterrupted Power Supply).

If the main power fails, then the unit automatically switches from PWR 1 to PWR 2. When power is restored on PWR 1, the Net-G3A reverts to PWR 1, maintaining continuous operation throughout the power interruption.

If both power inputs fail to deliver power to the receiver, then the intelligent Battery-based Energy STorage (iBEST) system will maintain continuous emergency operation. This system provides you with ample time (up to 25 hours) to save valuable data, isolate the problem, and restore the normal operation without an interruption in the service. When the normal operation is restored, the iBEST systemautomatically transfers the load to an external power source and maintains the backup batteries in a charged condition.

• Temperature and humidity control

The Net-G3A is designed to withstand harsh field environments and can be used as a temporary or semipermanent Reference Station,as needed. For permanent installations, install the Net-G3A in a more protected and controlled environment.

• Protection against lightning and other power surges

To protect against sudden surges in electricity, installing lightning finials, surge protectors, etc. will help shield electronic equipment from direct or indirect lightning strikes.

Consult a certified electrician for recommendations and installation.

References

1. "Antenna Calibration FAQ." http://www.ngs.noaa.gov/ANTCAL/FAQ.jsp, Retrieved 2015-01-07

2. https://www.ll.mit.edu/mission/aviation/publications/publication-files/atc-reports/Dinius_1995_ATC-238_WW-15318.pdf[4]
3. Rueger, J.M. “Refractive Index Formulae for Radio Waves.”, 2002. https://www.fig.net/resources/proceedings/fig_proceedings/fig_2002/Js28/JS28_rueger.pdf
4. Calais, E., “GPS Signal Propagation.”, http://web.ics.purdue.edu/~ecalais/teaching/geodesy/GPS_signal_propagation.pdf
5. Topcon Net-G3A Operating Manual
6. http://facility.unavco.org/
7. http://www.ngs.noaa.gov/CORS/Establish_Operate_CORS.html
8. Trimble NetR9 Reference Receiver User Guide.

4 Plots comparing choke ring performance vs ground plane performance.

Base GNSS Installation Information

Site Name	
Date and Time (UTC)	
Estimated Position (LLH)	
Model of Antenna	
GNSS Receiver Model Number	
GNSS Receiver Serial Number	
Mast/Tripod Type	
Description of Installation	

Site Name	
Date and Time (UTC)	
Estimated Position (LLH)	
Model of Antenna	
GNSS Receiver Model Number	
GNSS Receiver Serial Number	
Mast/Tripod Type	
Description of Installation	