EarthScope Consortium

EarthScope Campaign GPS/GNSS Handbook

January 2010 (minor editing October 2023)

INTRODUCTION

This handbook is designed to introduce users to campaign GPS/GNSS surveying with high-precision GPS/GNSS equipment and to the related services offered by EarthScope. The document outlines execution of a GPS/GNSS campaign from survey planning to general surveying methods to documentation, data processing, and data archiving.

This document is intended as an introduction to be used prior to training by an EarthScope field engineer, as an outline to be used during the EarthScope training, as a reference guide after completing the EarthScope training, and as a refresher for those with previous GPS/GNSS surveying experience. It also serves as a general primer for scientists who are considering using GPS/GNSS in their research.

Note that this handbook is not tailored to a specific application or to specific equipment; application- and equipment-specific training is offered on demand, typically over the course of three days and with one or two students per instructor. Equipment-specific resources can also be found on the EarthScope GAGE Knowledgebase at https://kb.unavco.org/.

To request training or for questions not addressed here, e-mail support@earthscope.org.

These are the questions to ask while preparing for a campaign survey:

1) What are the survey goals? This will determine the survey style and, to a lesser extent, the monumentation and mounts used. This will also determine your data processing needs.

2) What is the survey geography and geometry? How large an area will the survey cover, and what is the terrain like? Is there good sky view? Are survey points visible to the base station, if there is one (for RTK surveys only)?

3) What resources are available to you? Is there already a GPS/GNSS site running in the region? Will you be traveling by car, helicopter, or other—are weight and space an issue? What are your power options in the field (and, what is the climate? Batteries drain much more quickly in the cold).

Keep these questions in mind as you move through the rest of this handbook.

BACKGROUND

1. Scientific applications

The geodetic community has long recognized the scientific applications of GPS/GNSS. High-precision GPS has been used since the mid-1980s for measuring relative tectonic plate motions (Figure 1a), isostatic adjustment (Figure 1b), motions along and across faults (Figure 1c), and volcanic motions. From these measurements, researchers have calculated strain rates, mantle viscosity, locking depths of faults, and more. GPS/GNSS can also be used to map and to navigate back to sample locations, to measure glacier velocities (Figure 1d), and to monitor landslides. As technology advances and prices come down, high-precision GPS/GNSS instruments for scientific applications are becoming more affordable, lighter, more power-efficient, and with memory better suited for long-term applications. Because of this, the scientific GPS/GNSS user community is expanding, and the demand for longer, larger campaigns is increasing.

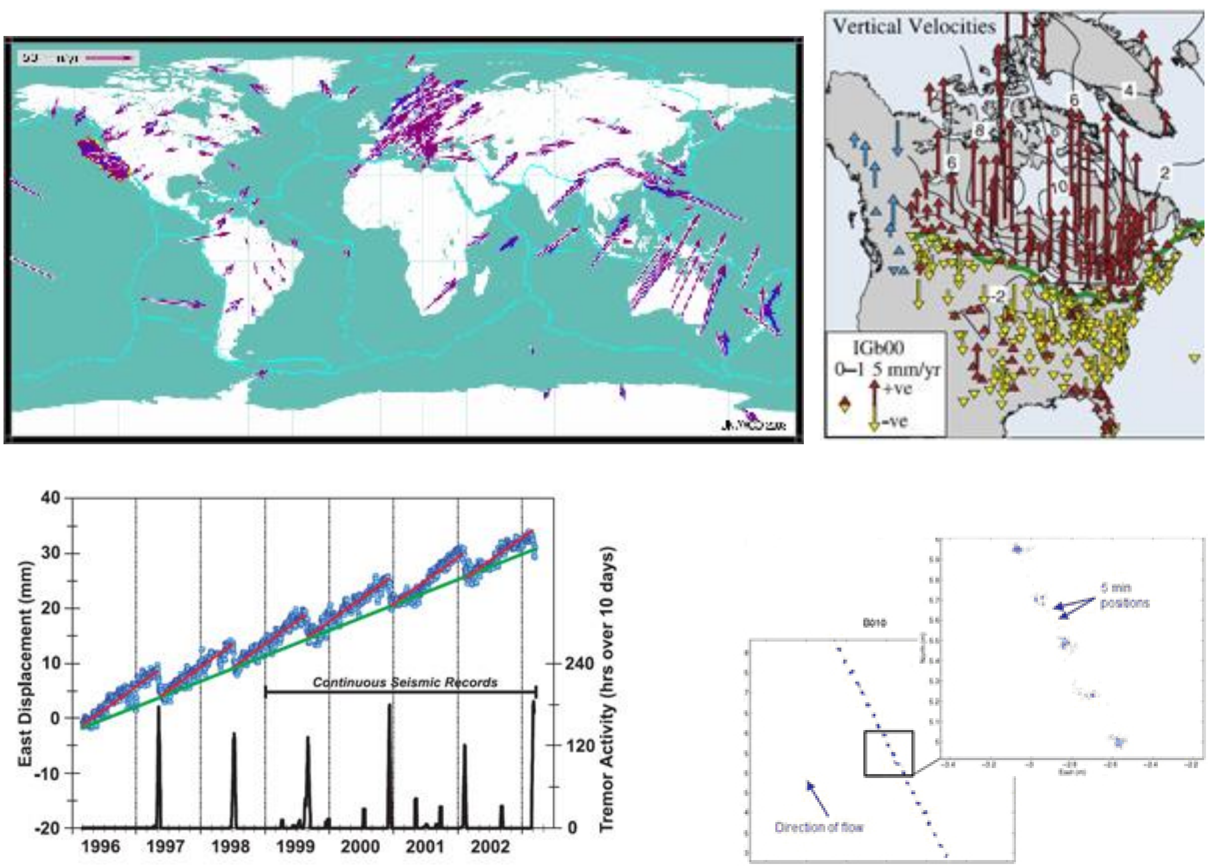


Figure 1: Examples of scientific applications of GPS/GNSS. (a) Global tectonics: composite GPS/GNSS Velocity Map showing global tectonic motions. Generated in EarthScope's interactive Voyager map tool. (b) Glacial isostatic adjustment: vertical GPS site motions in North America; note large uplift rates around Hudson Bay, where the crust is thought to be rebounding from the effect of glacial loading. (c) Earthquake and fault dynamics: plot of the change in longitudinal position of a GPS site in the Pacific Northwest as it responds to episodic tremor and slip along the Cascadia subduction zone. (d) Glacier flow: Horizontal positions at 5-minute intervals on Whillans Ice Stream, Antarctica; upper inset shows enlargement of five slip events. For more info on these data sources and other science applications of GPS/GNSS, see https://www.earthscope.org/.

2. Basic positioning

GPS/GNSS positioning is based on trilateration from GPS/GNSS satellites in precisely defined orbits. Each of the 24 to 27 active GPS satellites transmits a unique code modulated onto a carrier frequency (Figure 2). The receiver generates the same codes at the same time as the satellites; by measuring the offset between the code generated and the code received, the receiver can determine the time the signal took to travel and therefore calculate the rough distance to each satellite (distance = velocity x time, where velocity for a radio wave is the speed of light). [Note that the velocity of the radio wave may vary as it travels through different media, such as the Earth's atmosphere, thus introducing error into the measurements.] By receiving data from multiple satellites, a single GPS/GNSS receiver can pinpoint its position to within a few meters (Figure 3). Four satellites are the minimum required for the receiver to solve for the four unknowns: x, y, z, and time (receiver clock error).

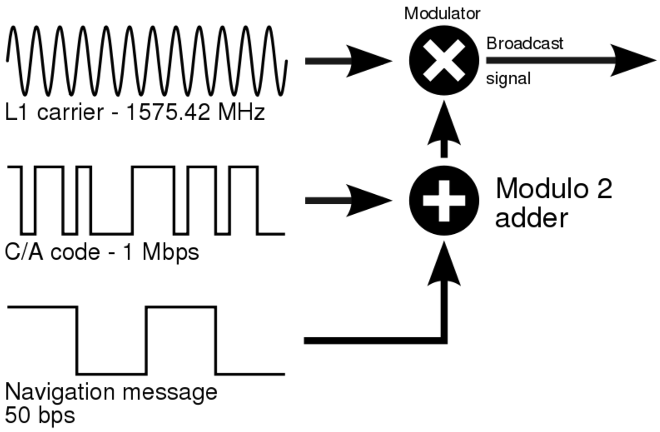


Figure 2: Visualization of the carrier frequency (sine wave) and the codes modulated onto it. (PS/GNSS)

Figure 3: By calculating the intersection points of spheres of a given radius (the distance from each satellite to our antenna) around satellites 1, 2, and 3, we can determine our location. Note that using three satellites we end up with two points of intersection; one can be eliminated by using the Earth as a third sphere. However, a fourth satellite is still needed to calculate receiver clock errors.

High-precision results (< several cm) require equipment and data processing methods not available in handheld GPS units. Equipment (receiver, antenna), survey design (using two or more systems simultaneously), and processing all contribute to high-precision GPS/GNSS. The receivers track multiple satellite frequencies (rather than just the L1 frequency) and use not the codes but the carrier frequency (Figure 2), which has a shorter wavelength, to measure the distance to satellites. This adds the complication of estimating the number of sine waves between the receiver and the satellites, called the *ambiguity,* but yields better measurements. The antennas are designed to minimize signal noise such as *multi-path*, signals bounced off reflectors rather than direct arrivals. By comparing simultaneously collected data from two or more GPS/GNSS instruments, satellite clock errors are solved for and eliminated. In surveys where survey points are close together (< 10 km), many error sources are shared and can be greatly minimized or eliminated from each solution (Figure 4). This method is called "differential GPS/GNSS." And, by processing the data after collection, precise orbital information (satellite ephemeris) are applied, the signal-delaying effects of the troposphere are modeled and those of the ionosphere are eliminated with the use of two or more satellite frequencies.

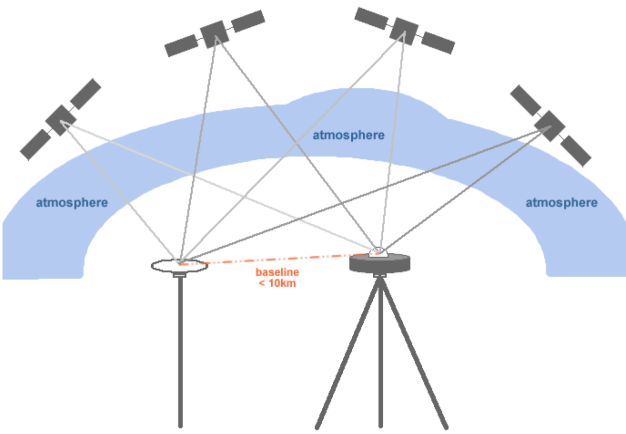


Figure 4: Diagram of differential GPS/GNSS. The base station, on the right, is set up over a known point. Because the base station and the rover (on the left) are close together, they share many error sources. For example, the signals from each satellite travel through essentially the same atmosphere to get to each GPS/GNSS antenna. This results in a *precisely* determined baseline between the two antennas. If the base coordinates are known within a chosen coordinate system, the rover coordinates can be determined with *accuracy* as well.

Note the difference between accuracy (correctness) and precision (repeatability), and relative versus absolute. GPS/GNSS measurements yield high-precision—that is, highly repeatable—baselines (the distance and azimuth between points). For measurements to be accurate, base location coordinates must be accurate (correct) within a particular reference frame; then the rover coordinates will be accurate within that reference frame as well. Think of it this way: GPS/GNSS provides very good relative measurements (one GPS/GNSS measurement relative to another, so long as there is at lease one instrument recording continuously throughout the survey) but not necessarily good absolute measurements—for this, post-processing is needed. So, baseline *precision* does not imply coordinate *accuracy* unless the initial starting coordinates are of a known high quality. Often, we are more interested in how sites are moving relative to each other (for which high precision is sufficient) than we are in exactly where the sites are. For example, how are the sites on the Pacific plate moving relative to the sites on the North American plate? We choose sites on either side of the San Andreas fault to answer this question. We don't care exactly where the sites are; we care how they are moving relative to each other. This is a strength of GPS/GNSS and the reason we always look at where GPS/GNSS measurements are relative to other GPS/GNSS measurements.

If you are new to GPS/GNSS and want to know more, check out Trimble's online tutorial at http://www.trimble.com/gps_tutorial/. For a more detailed description of how GPS works and its high-precision applications, see, for example, T. H. Dixon, An introduction to the Global Positioning System and some geological applications, *Rev. Geophys.*, *29*, 249-276, 1991.

3. Survey styles

Various methods are used to collect high-precision GPS/GNSS data. The particular method used depends on several factors, including survey objectives, desired precision, available equipment, and field logistics. Higher precision typically requires a more rigorous field methodology and longer occupation times. The following table shows the features of the most common GPS/GNSS survey methods:

	Survey style	Typical accuracy	Occupation time	Typical applications
	Continuous	< 0.5 cm	Months or more	Crustal deformation, geophysics, reference stations
	Static	0.5 cm – 2.5 cm	Hours to days	Crustal deformation, geodetic control, very long baseline surveys, geophysics
	Rapid Static	1 cm – 3 cm	Minutes	Short baseline surveys, glaciology
	Kinematic (post-processing and real-time)	1 cm – 5 cm	Seconds	Short baselines, closely spaced points, vehicle positioning, feature surveys, GIS, mapping, and navigation (RTK only)

Continuous stations are continuously operating long-term or permanent GNSS station installations involving immobile monumentation and sustainable power, and often involving data telemetry. They can be used as preexisting base stations in campaign surveys (static, rapid static, and kinematic).

Static surveys are regional, sub-cm precision GNSS surveys with portable equipment and are the standard campaign data collection method for crustal deformation surveys. They typically involve occupying each point for several days to get the highest possible accuracy. Collect at least 6 hours of simultaneous data per day for processing and repeat benchmark occupations if possible.

Rapid static surveys are static surveys with just enough survey time at each point to be able to resolve the carrier phase integer ambiguity. A rule of thumb is to collect data for a minimum of 10 minutes per point, and add one minute of occupation time per kilometer of baseline length over 10 kilometers. For example, on an eight-kilometer baseline collect at least 10 minutes of data, and on a 28-kilometer baseline collect at least 28 minutes of data.

Kinematic surveys are local surveys (<10 km) using mobile GNSS equipment for the purpose of mapping features or of measuring point locations where several cm of precision is sufficient. At least two receiver set-ups are required: a base (stationary) unit and one or more rover (mobile) units. Kinematic surveys rely on continuous tracking to resolve the integer ambiguity; while the rover receiver/antenna may be moving during the surveys, continuous lock on the satellite signals must be maintained. Since the data-processing software is able to both resolve the ambiguity and track the antenna motion, fixed-integer solutions are obtained nearly instantaneously.

> *Post-processing kinematic (PPK)* refers to surveys without communication between the base and rover receivers. Processing the data after data collection is required. There are no navigational capabilities in PPK surveys.
>
> *Real-time kinematic (RTK)* refers to surveys in which the base and rover receivers communicate corrections in real time via a radio link. This requires additional hardware (base and rover radios) and additional power, and generally limits the survey to an area of several km, but eliminates the need for data processing and enables navigational capabilities.

Additional Survey Styles may be used in some situations.

> *Code differential* surveys rely only on the code data to determine a differential solution. Simultaneous data collection between the base and rover receiver is still required, but there is no requirement to maintain continuous lock on the carrier phase since the phase data is not used. As a result, this method is extremely robust but relatively coarse. For sub-meter accuracy, a rule of thumb is to collect data for five minutes per point, and add one minute of occupation time per five kilometers of baseline length over 10 kilometers. For example, on an eight-kilometer baseline collect at least 5 minutes of data, and on a 108-kilometer baseline collect at least 25 minutes of data.
>
> *Point positioning* uses only data from a single receiver to determine its coordinates. The collected data are averaged, and longer occupations significantly increase the accuracy. This method is very coarse, but sometimes it is the only way to determine base station coordinates while in the field. Although these coordinates may be off by about a meter, it is close enough to allow the computation of precise baselines while at a remote field location. When better network accuracy is desired, the base coordinates must be recomputed when back from the field.

4. Reference frames

GPS/GNSS positions are calculated in an Earth-centered, Earth-fixed Cartesian coordinate system, where the *x* and *y* axes are perpendicular and in the plane of the equator, and the *z* axis is drawn between the north and south poles. Positions are then converted into a more user-friendly reference frame. Most commonly, positions are converted to latitude, longitude, and height referenced to a precisely defined ellipsoid, such as WGS-84. These ellipsoids are mathematical models *approximating* the shape of the Earth, and do not reflect the constant-gravity defined geoid (mean sea-level) surface of the Earth. As a result, the ellipsoidal elevations are usually significantly different from the corresponding geoid, or sea-level elevations. If the user is ultimately interested in geoid elevations (elevations relative to mean sea level), a geoid model such as EGM96 must be applied.

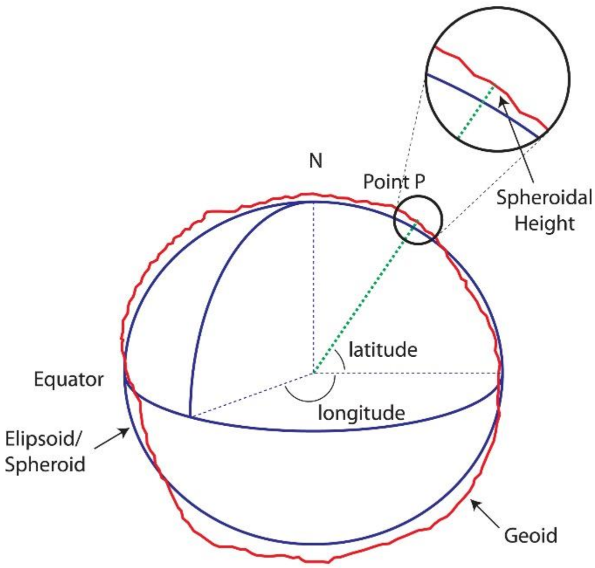


Figure 5: Schematic diagram demonstrating how the ellipsoid used in GPS/GNSS coordinates does not exactly align with a consistent gravitational surface (geoid) on the Earth. Note that sea level is dependent on the Earth's gravity, which is not constant around the globe. (From Intergovernmental Committee on Surveying & Mapping (ICSM), Australia)

Horizontal positions can also be converted to northings and eastings based on a map projection. Coordinate conversions can be done in most processing software, including Trimble Geomatics Office and Topcon TOOLS.

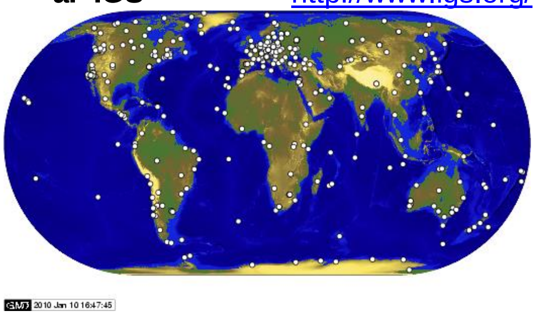
Geodetic surveys are commonly referenced to the International Terrestrial Reference Frame (ITRF), related to the International Terrestrial Reference System (ITRS). The ITRF is a reference frame defined by a set of points with their 3-dimensional Cartesian coordinates. The International Terrestrial Reference System (ITRS) is a world spatial reference system co-rotating with the Earth in its diurnal motion in space. The IERS, in charge of providing global references to the astronomical, geodetic, and geophysical communities, promotes the realization of the ITRS. Realizations of the ITRS are produced by the IERS ITRS Product Center (ITRS-PC) under the name International Terrestrial Reference Frames (ITRF). That's a lot of acronyms. For more information, see http://itrf.ensg.ign.fr/.

SURVEY RESOURCES

1. Reference stations

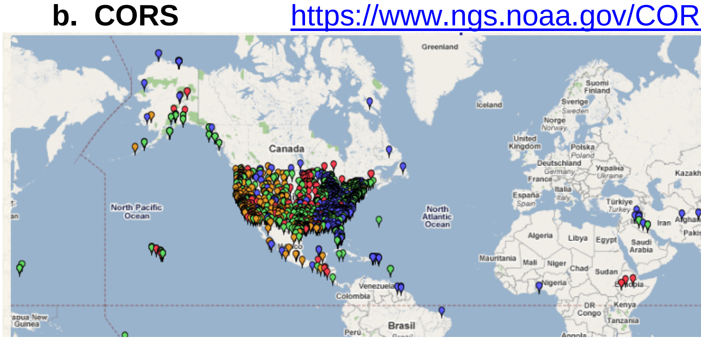
Global, regional, and local networks of GPS/GNSS reference stations log data continuously and, in many cases, make those data freely available to the public. These data can be used as base station data for users who don't want to, or can't, set up their own base station, and/or can be used to tie surveys into known networks. Several large-scale networks to note are listed below. Local reference stations may also be found by contacting, for example, the county surveyor's office.

a. IGS http://www.igs.org/



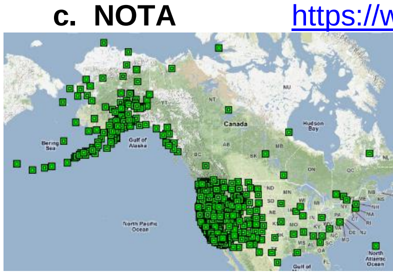
The International GNSS Service (IGS) is a voluntary federation of more than 200 worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. Currently the IGS includes two GNSS (Global Navigation Satellite Systems), GPS and the Russian GLONASS, and intends to incorporate future GNSS. You can think of the IGS as the highest-precision international civilian GNSS community.

b. CORS https://www.ngs.noaa.gov/CORS/



The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service, coordinates two networks of continuously operating reference stations (CORS), the National CORS network and the Cooperative CORS network. Together, the networks span the United States and its territories. The CORS system enables positioning accuracies that approach a few centimeters relative to the National Spatial Reference System, both horizontally and vertically.

c. NOTA https://www.unavco.org/instrumentation/networks/status/nota

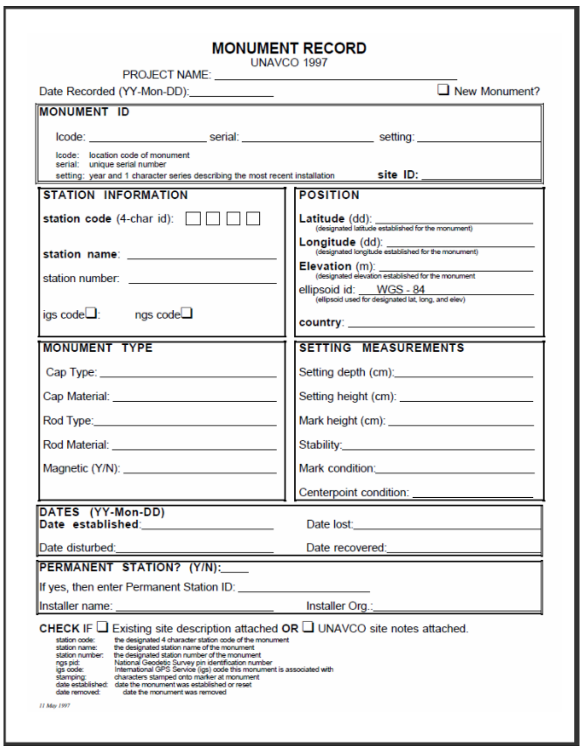


Network of the Americas (NOTA), part of the EarthScope project that is funded by the National Science Foundation, studies the three-dimensional strain field resulting from active plate boundary deformation across the Western United States. The project includes installation of more than 800 continuous GPS stations throughout the Western United States, from the Pacific to the Rocky Mountains, including Alaska.

Data from many of the sites available globally and all of the sites in the Network of the Americas can be accessed through the EarthScope GPS/GNSS Data Archive at http://www.unavco.org/data/gps-gnss/data-access-methods/data-access-methods.html.

2. Log sheets and field notes

Field notes provide information about each survey point that is required to process and archive the GPS/GNSS data once collected. Information on site access, monument description, sky visibility, and nearby resources should be documented when a monument is established and updated as needed. This information can be recorded on the *Monument Record* form. Critical survey information such as antenna height above the survey mark, GPS/GNSS receiver and antenna model and serial number, benchmark identification and location, and survey start and end times are recorded on the *Monument Visit Log sheet*. The log sheet is required for each monument visit that is archived by EarthScope. The ability to revisit and meaningfully remeasure a mark, to troubleshoot data while processing, and for other groups to use the data depends strongly on the quality and accuracy of the information recorded during the survey.



MONUMENT RECORD
UNAVCO 1997

PROJECT NAME: ____
Date Recorded (YY-Mon-DD): ____ ❑ New Monument?

MONUMENT ID
lcode: ____ serial: ____ setting: ____
lcode: location code of monument
serial: unique serial number
setting: year and 1 character series describing the most recent installation
site ID: ____

STATION INFORMATION
station code (4-char id): ☐☐☐☐
station name: ____
station number: ____
igs code❑: ngs code❑

POSITION
Latitude (dd): ____ (designated latitude established for the monument)
Longitude (dd): ____ (designated longitude established for the monument)
Elevation (m): ____ (designated elevation established for the monument
ellipsoid id: WGS - 84 (ellipsoid used for designated lat, long, and elev)
country: ____

MONUMENT TYPE
Cap Type: ____
Cap Material: ____
Rod Type: ____
Rod Material: ____
Magnetic (Y/N): ____

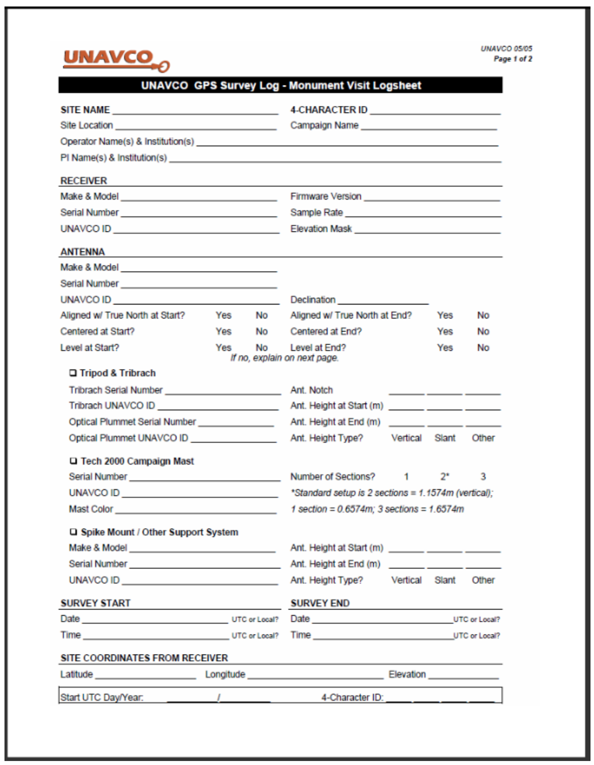
SETTING MEASUREMENTS
Setting depth (cm): ____
Setting height (cm): ____
Mark height (cm): ____
Stability: ____
Mark condition: ____
Centerpoint condition: ____

DATES (YY-Mon-DD)
Date established: ____ Date lost: ____
Date disturbed: ____ Date recovered: ____

PERMANENT STATION? (Y/N): ____
If yes, then enter Permanent Station ID: ____
Installer name: ____ Installer Org.: ____

CHECK IF ❑ Existing site description attached **OR** ❑ UNAVCO site notes attached.
station code: the designated 4 character station code of the monument
station name: the designated station name of the monument
station number: the designated station number of the monument
ngs pid: National Geodetic Survey pin identification number
igs code: International GPS Service (igs) code this monument is associated with
stamping: characters stamped onto marker at monument
date established: date the monument was established or reset
date removed: date the monument was removed

11 May 1997



UNAVCO

UNAVCO 05/05
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UNAVCO GPS Survey Log - Monument Visit Logsheet

SITE NAME ____ **4-CHARACTER ID** ____
Site Location ____ Campaign Name ____
Operator Name(s) & Institution(s) ____
PI Name(s) & Institution(s) ____

RECEIVER
Make & Model ____ Firmware Version ____
Serial Number ____ Sample Rate ____
UNAVCO ID ____ Elevation Mask ____

ANTENNA
Make & Model ____
Serial Number ____
UNAVCO ID ____ Declination ____
Aligned w/ True North at Start? Yes No — Aligned w/ True North at End? Yes No
Centered at Start? Yes No — Centered at End? Yes No
Level at Start? Yes No — Level at End? Yes No
If no, explain on next page.

❑ **Tripod & Tribrach**
Tribrach Serial Number ____ Ant. Notch ____ ____ ____
Tribrach UNAVCO ID ____ Ant. Height at Start (m) ____ ____ ____
Optical Plummet Serial Number ____ Ant. Height at End (m) ____ ____ ____
Optical Plummet UNAVCO ID ____ Ant. Height Type? Vertical Slant Other

❑ **Tech 2000 Campaign Mast**
Serial Number ____ Number of Sections? 1 2* 3
UNAVCO ID ____ **Standard setup is 2 sections = 1.1574m (vertical);*
Mast Color ____ *1 section = 0.6574m; 3 sections = 1.6574m*

❑ **Spike Mount / Other Support System**
Make & Model ____ Ant. Height at Start (m) ____ ____ ____
Serial Number ____ Ant. Height at End (m) ____ ____ ____
UNAVCO ID ____ Ant. Height Type? Vertical Slant Other

SURVEY START
Date ____ UTC or Local?
Time ____ UTC or Local?

SURVEY END
Date ____ UTC or Local?
Time ____ UTC or Local?

SITE COORDINATES FROM RECEIVER
Latitude ____ Longitude ____ Elevation ____

Start UTC Day/Year: ____ / ____ 4-Character ID: ____ ____ ____ ____

Figure 6: Examples of a Monument Record form (left) and Monument Visit Log sheet (right) from UNAVCO, now EarthScope Consortium. All UNAVCO references signify older EarthScope resources.

Formal log sheets are not required for surveys of nonrepeatable points, such as temporary glacier stakes or terrain features such as lakebed shorelines. But good field notes are still necessary for post-processing of the data, and should contain site identification, data file/job name, time of survey, and antenna type, height, and measurement method.

The Monument Record form (http://kb.unavco.org/assets/63/monument.pdf) and the Monument Visit Log sheet (http://kb.unavco.org/article/campaign-monument-log-sheet-62.html) can be found in the EarthScope Knowledge Base campaign support page (Figure 6).

EarthScope Consortium

SURVEYING

1. Equipment

High-precision GPS/GNSS systems consist of separate components that power the system (AC power systems, batteries, and solar panels), receive the signals (the antenna), process the signals (the receiver), and store the data (the receiver and download media). The equipment used for GPS/GNSS surveys is designed for use in most weather conditions and is fairly rugged. However, as with all electronics the equipment should be handled with care. While this becomes second nature to people who use the equipment regularly, it may not be obvious to new users.

Note: If you have a system, go through the different pieces and learn how to connect them and where to look for possible problems such as blown fuses or missing parts.

Proper GPS/GNSS equipment handling:

a. Be security conscious – theft of GPS/GNSS equipment is common.
b. Before doing anything with the equipment, verify that the contents match the enclosed manifest.
c. Check that the equipment is packed as it was received from EarthScope.
d. Use the dustcaps found on the antenna cables, receiver, and other equipment when the connectors are not in use.
e. Do not force connectors when inserting or removing.
f. Make sure all cable connectors are clean before making a connection.
g. Do not tug on cables – this may damage the internal connection.
h. Keep exposed connectors and other components away from moisture, dust, and grit.
i. Keep sharp or abrasive objects away from equipment display panels and cables.
j. Roll up cables to be free of kinks – do not loop cables around your arm.
k. Use proper transport containers and pack them so there are no loose parts inside that may cause damage.
l. Secure tripods and other antenna mounts to prevent toppling from wind gusts.
m. Attend bi-pods when set up with an antenna – these can easily be toppled, resulting in antenna damage.
n. Secure solar panels so they're not picked up by the wind.
o. Report any equipment problems to EarthScope as soon as possible.

Before the equipment leaves EarthScope, it is configured, tested, and determined to be suitable for field use. For extended projects, checking the components periodically may be desired. The following checklist highlights the most important field-check items:

- [ ] Configure receiver
- [ ] Verify receiver L1 and L2 continuous tracking
- [ ] Test antennas for L1 and L2 tracking
- [ ] Test antenna cables, receiver for loose connections
- [ ] Check cables for visible damage
- [ ] Charge batteries, check for extra fuses
- [ ] Check/calibrate tribrachs/rangepole levels
- [ ] Test solar panels

2. Monumentation

Various forms of monumentation can be used for surveying with GPS/GNSS (Figure 7). Things to consider when establishing monumentation include precision and environment. If high precision (<1 cm), repeatable results are desired, the mark itself should be 1 mm in diameter and the marker should be durable and stable in its medium. All markers should be resistant to weathering, but the type of marker used may be dictated by land use. For example, a low-profile marker may be required in sensitive areas such as national parks. You must check with authorities or landowners before installing survey markers.

When choosing the location for a benchmark, consider what will affect the motion of the substrate. The best place for a benchmark when measuring regional tectonic motion or establishing a base station is in stable bedrock; if there is no bedrock, consider installing a concrete pier. Markers for rover setups can then be established in the nearby feature of interest, e.g. glacier ice, unstable slope, or ice wedges.

Figure 7: Examples of benchmarks. (a) A circular marker at the bedrock surface, with a pin which extends and anchors it into the rock. This mark requires a tripod, bipod, or spike mount setup (see below). Another common design is a stainless steel pin epoxied into bedrock, flush with the rock surface. (b) A threaded, stainless steel pin epoxied into bedrock. Often a tripod, bipod, or spike mount setup can be used, although a leveling mount can be screwed directly onto the pin for a low-profile, stable option suitable for both short- and long-term deployments. (c) Bamboo frozen into glacier ice, shown here with the antenna mounted on a PVC sleeve which slides over the bamboo. (d) A metal rod pushed into compact snow on an ice stream, suitable for long-term deployments.

In ice, markers must extend deep enough to remain stable through ablation and be tall enough to keep the antenna higher than rising snow levels, if the instrument is to be left for a long time period.

For monumentation options available from EarthScope, see http://kb.unavco.org/article/unavco-resources-gnss-station-monumentation-104.html.

3. Antenna mounts

There are a variety of antenna mounting options available for stabilizing the antenna over the survey monument (Figure 8). Proper antenna setup is one of the single most critical components of a campaign survey, determining measurement accuracy and repeatability. To avoid setup error, it is important that the GPS/GNSS antenna is precisely centered and leveled over the survey mark. The antenna height must be carefully measured and documented. Generally, the antenna is also aligned to true north. In choosing a mount option, consider that the antenna must be set up above any local obstructions, such as rocks or foliage, that would block or degrade the incoming satellite signals. Otherwise, mounting the antenna close to the ground will increase stability and decrease visibility (helpful if security is a concern). Also consider logistical constraints; for example, a spike mount (see below) is much easier to carry in to a remote site than is a tripod.

Figure 8: Examples of antenna mounts. (a) Standard tripods are bulky but are ideal for sites where the antenna must be elevated. (b) Fixed-height spike mounts are lightweight and highly portable; good for remote, open areas. (c) Fixed-height leveling mounts screw directly onto a threaded pin monument; highly portable and highly stable. (d) Bipods can be used for fast-static occupations or, by removing the legs, for kinematic surveys. Ideal for surveys with many survey marks within a small area.

For more detailed information, see http://kb.unavco.org/article/unavco-resources-gnss-antenna-mounts-394.html. The antenna height above the survey monument in all cases must be recorded accurately for data archiving and processing. Antenna height is usually measured as either:

1. **Vertical –** the vertical distance from the survey mark to the Antenna Reference Point, or ARP, which is typically the bottom surface of the antenna housing.
2. **Slant –** the distance from the survey mark to the *bottom edge* of the antenna choke ring or ground plane (tripods only) (Figure 9).

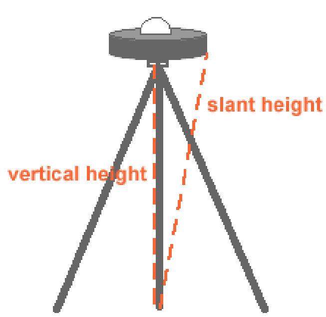

Figure 9: Measuring height on a choke ring antenna.

Since a GPS/GNSS antenna's physical center and electronic center (phase center) may be different depending on variable factors such as satellite geometry, all antennas in a survey network should be oriented in the same direction to ensure that the measurements reflect the actual distance between monuments. Antennas are typically aligned to true (not magnetic) north. Many antennas are labeled with a north arrow; when they are not, the antenna cable connector is usually meant to be aligned to north. Multiple magnetic declination calculators can be found online, such as this one from NOAA:
https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml.
Or, use an accurate map to determine true north and align the antennas with a compass accounting for the appropriate magnetic declination.

For antenna mount options available from EarthScope, see
http://kb.unavco.org/article/unavco-resources-gnss-antenna-mounts-394.html.

4. Receiver configuration

Receivers can be configured with either a computer, a survey controller (recommended for fast-static and kinematic surveys only), or, for some receiver models, through a LED screen.

Consider the following for your survey:

File length – do you want the receiver to bin the data into files of a fixed time window?
Sample rate – how often do you want the receiver to collect data? The base station (fast static and kinematic surveys) must collect data at least as often as the rover(s).
Elevation cutoff angle – data coming from low-elevation satellites is often noisy because of the atmosphere; from below what elevation do you want the receiver to discard, rather than store, the data? Note that these data can also be discarded during processing.

Typical file lengths, sample rates, and elevation cutoffs:

Survey style	File length	Sample rate	Elevation cutoff angle
Continuous	24 hr (UTC 0:00)	30 seconds	0 or 5 degrees
Static	24 hr (UTC 0:00)	30 seconds	5 degrees
Rapid Static	none	15 seconds	13 degrees
Kinematic	none	1–15 seconds	13 degrees

There must be enough free memory in the receiver for the desired survey. Whereas memory is an issue with older receivers, the later generation receivers have large amounts of data storage. At a 15 sec sample rate and 5 deg elevation mask, the Trimble 5700 and R7 receivers can log data for approximately 3 months onto a 128 MB compact flash card. Larger flashcards are also available. The Trimble NetRS logs the same file type to internal memory, which is commonly 1 GB of storage, yielding space for around 2 years of data collection. The Topcon GB-1000 file format is significantly larger than that of Trimble, producing an ~7 MB file for a 24-hr session collected at a 30 sec sample rate. Both internal and external memory (a compact flashcard) of typically 1 GB each are available.

For information (specifications, how-tos, dealer information) on receivers available from EarthScope, see http://kb.unavco.org/category/gnss-and-related-equipment/gnss-receivers/84/

5. Power

Several options exist for powering a GPS/GNSS receiver in the field. AC (outlet) power may be used when available, with battery back-up in case of a power outage. Remote sites usually require battery power, and solar panels can be added to extend battery life or provide continuous power. The battery capacity and solar panels required depend on several factors, including survey period, receiver power consumption, charging options, weight limitations getting to the site, and amount of sunlight available. During field campaigns, charging batteries between sites is critical and must be factored in when planning field logistics, unless the batteries are able to maintain sufficient charge from solar panels. AC battery chargers and solar panels are available from EarthScope. *Always double-check battery capacity before leaving an unattended site.*

EarthScope provides rechargeable 12 Ah and 18 Ah batteries for field use. These batteries weigh 10 lbs and 15 lbs each, respectively. Battery capacity will vary depending on the condition of the individual battery, and will decrease at low temperatures and with battery age. EarthScope also provides power cables that can be used with larger deep-cycle batteries to extend the receiver run time. Power draw on the receivers available for campaign use from EarthScope is as follows, under ideal conditions:

Receiver	**Power draw (approximate)**	**Time lasts on a 12 V, 18 Ah battery**
Trimble NetRS	3.5 W	2.25 days
Trimble 5700 or R7	3–4 W	2–2.5 days
Topcon GB1000	4 W	1.9 days

For information on power options available from and testing performed by EarthScope, see http://kb.unavco.org/category/gnss-and-related-equipment/power/93/.

POST-SURVEY

1. Data downloading and backup

Data collected with geodetic GPS/GNSS receivers must be downloaded as soon after data collection as possible to free up receiver memory (if needed) and to back up the data. As a field precaution, a duplicate copy of the data should be made as soon as it is downloaded from the receiver. Data are typically downloaded to a laptop computer; to download a receiver, manufacturer-specific download software and procedures are usually required.

Downloading instructions depend on the equipment (receiver and/or survey controller) being used; see http://kb.unavco.org/category/gnss-and-related-equipment/2/.

Considerable expense goes into collecting geodetic quality GPS/GNSS data, and the data should always be backed up as soon as possible to safeguard against loss, destruction, or corrupted media. While the particular data backup strategy may vary with logistics and personal preferences, there should always be three independent copies of all GPS/GNSS data until it is confirmed that the data have been safeguarded in a data archive such as EarthScope's. Options for data storage prior to final archiving include CDs, PC memory cards, computer hard drives, and the GPS/GNSS receiver memory. Before deleting any files from a GPS/GNSS receiver, make sure they are adequately backed up elsewhere! A good practice is to keep copies of the data in separate locations and with different people.

2. Data formats

GPS/GNSS receivers generally collect and store the raw GPS/GNSS data in a proprietary format, which may need to be translated into a different format for data processing or data sharing. Later generation Trimble GPS receivers (5700, R7, NetRS) collect data in .T01 files, a format that must be translated to be read into Trimble's processing software, Trimble Geomatics Office (TGO). These data are automatically translated to .DAT files, a Trimble format that can be read by TGO, when downloaded via the Trimble Data Transfer Utility. The Topcon GB-1000 collects data in a .tps file.

RINEX (Receiver Independent Exchange Format) is the ubiquitously accepted data format for raw GPS/GNSS data. Reference site data (see section on Reference stations) are generally provided in RINEX. RINEX is read by most processing software, including Trimble Geomatics Office and Topcon Tools, and also more sophisticated processing software like Bernese, GAMIT, and GIPSY. Almost any raw high-precision GPS/GNSS data can be converted to RINEX using teqc. **Teqc** (pronouced "tek") is a simple yet powerful and unified approach to solving many pre-processing problems with GPS, GLONASS, and SBAS data. The three main functions from which teqc gets its name—**t**ranslation, **e**diting, and **q**uality **c**heck—can be performed altogether, in pairs, or separately. You can download teqc for free at https://www.unavco.org/software/data-processing/teqc/teqc.html.

While most raw data are stored as binary files, RINEX is in an ascii format and can therefore be viewed in a text editor. An example of a RINEX file is given below (Figure 10), and illustrates the information contained in raw GPS/GNSS data files.

```
     2.10           OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
teqc  2004Oct27     UNAVCO Archive Ops  20041028 19:19:00UTCPGM / RUN BY / DATE
Solaris 2.7|Ultra 2|cc SC5.0|=+|*Sparc                     COMMENT
BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION       COMMENT
P020                                                        MARKER NAME
                                                            MARKER NUMBER
Mike Jackson        UNAVCO                                  OBSERVER / AGENCY
4413233095          TRIMBLE NETRS       0.7-0               REC # / TYPE / VERS
0220330167          TRM29659.00     SCIT                    ANT # / TYPE
 -2083774.1380 -3827351.0369  4642283.4316                  APPROX POSITION XYZ
        0.0083        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
     6    L1    L2    C1    P2    S1    S2                  # / TYPES OF OBSERV
    15.0000                                                 INTERVAL
RINEX file created by UNAVCO GPS Archive.                   COMMENT
For more information contact archive@unavco.org             COMMENT
Monument ID: 00000000-18321-2004a                           COMMENT
UNAVCO 4-char name:   P020                                  COMMENT
4-char name from Log or data file: P020                     COMMENT
Monument location: 47.002209 -118.565769 480.1383           COMMENT
Visit ID: 76927                                             COMMENT
                                                            COMMENT
WSU_Dryland_Research_Station_Lind_WA_2004_CGPS              COMMENT
                                                            COMMENT
End of DB comments                                          COMMENT
 SNR is mapped to RINEX snr flag value [0-9]                COMMENT
  L1 & L2:  2-19 dBHz = 1, 20-27 dBHz = 2, 28-31 dBHz = 3   COMMENT
           32-35 dBHz = 4, 36-38 dBHz = 5, 39-41 dBHz = 6   COMMENT
           42-44 dBHz = 7, 45-48 dBHz = 8, >= 49 dBHz = 9   COMMENT
  2004     6    17     0     0   15.0000000     GPS         TIME OF FIRST OBS
                                                            END OF HEADER
 04  6 17  0  0 15.0000000  0  8G 1G 4G25G11G13G16G30G20
  -3009032.38359  -2334639.62958  20726832.8364   20726820.9734
        53.7504         46.0004
  -3692368.30957  -2871796.35252  23958733.3914   23958722.8164
        43.0004         22.2504
   8468383.67659   6575277.72356  22094150.9694   22094139.1054
        51.0004         40.0004
  11821613.29356   9184820.42652  24814845.6094   24814834.4494
        39.7504         21.2504
  -6586713.07057  -5464689.84452  23734383.6954   23734372.0084
        43.5004         25.2504
  -7043354.68058  -5468882.80555  22454713.5394   22454701.2664
        48.5004         36.7504
   9647017.67655   7491528.96151  25227887.4304   25227876.7384
        37.0004         14.7504
    265471.93859    207372.30558  20246338.1564   20246325.4734
        52.7504         48.0004
 04  6 17  0  0 30.0000000  0  8G 1G 4G25G11G13G16G30G20
  -3017172.37149  -2340982.47348  20725283.8594   20725271.8794
        53.7504         46.0004
  -3697743.72746  -2875984.98442  23957710.2814   23957700.3524
        41.0004         23.5004
   8517694.52749   6613701.75046  22103534.3524   22103522.6054
        51.0004         39.7504
  11881161.02046   9231221.22742  24826176.9454   24826165.9614
        39.5004         21.2504
  -6619885.39547  -5490538.40242  23728071.8204   23728059.6054
        43.5004         27.2504
  -7070702.28149  -5490192.60545  22449509.7424   22449497.2344
        49.2504         37.2504
   9704628.90245   7536420.81341  25238849.7894   25238839.7424
        38.0004         17.7504
    280861.96149    219364.52348  20249266.8444   20249253.9264
```

Figure 10: Sample RINEX file.

3. Data processing

GPS/GNSS data collected for high-precision applications (excluding data collected using RTK methods) must be post-processed to provide millimeter- to meter-level precision. Typically, the post-processing involves differential processing relative to a fixed base location. For certain survey types, such as stop-and-go kinematic, it is essential to process the data while still in the field as a data quality check. This allows for a re-survey if there are problems with the data. For more robust data collection methods such as static surveys, data processing in the field is not required. For many high-accuracy applications final data processing in the field is not possible. Advanced data processing methods typically require internet access to continuous station data, precise satellite orbits, and on-line data processing services. A common process is to field process data as a quick quality check, then spend more time back in the office to rigorously develop the final results.

Post-processing the data accomplishes several things. First, there are numerous error sources in GPS/GNSS positioning, the most significant of which are: receiver and satellite clock errors, delay of the GPS/GNSS signal through the Earth's atmosphere (most significantly, the ionosphere and the troposphere), use of imprecise satellite orbits, and multi-path (multiple signal arrivals resulting from the signal bouncing off nearby objects or the ground). Many of these errors can be greatly minimized or eliminated in post-processing by using data from at least two receivers with at least four satellites in common.

Different processing programs can serve different surveying needs. The following summarizes some of the options:

To obtain a position to within several cm of a static point where a very accurate position is not needed, several online services are available.

a. **CSRS-PPP** https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/tools-outils/ppp.
Canadian Spatial Reference System–Precise Point Positioning (CSRS-PPP) is a flexible service that offers both static and kinematic data processing. Access to the database is free but requires a username and password. Data files may be uploaded directly to the site.

b. **OPUS** http://www.ngs.noaa.gov/OPUS/
A data file of at least two hours is recommended. Data files may be uploaded directly to the site.

c. **AusPos** http://www.ga.gov.au/geodesy/sgc/wwwgps/
Data files may be uploaded directly to the site.

d. **APPS** https://pppx.gdgps.net//
A JPL service that replaces AutoGIPSY. Data files may be uploaded directly to the site.

For cm-level static or kinematic surveys with short (ideally < 10 km) baselines, commercially available software (e.g. Trimble Geomatics Office [TGO], Topcon Tools) is often adequate. See http://kb.unavco.org/article/trimble-geomatics-office-how-to-process-fast-static-and-post-processing-kinematic-surveys-using-tgo-613.html for a how-to on TGO.

For highest precision (sub-cm) surveys and most surveys including long baselines (> 50 km), a more sophisticated software package is required. Several software packages to process precise GPS/GNSS data for research applications have been developed by different international research groups. The availability of executable code, documentation, and user support varies with the individual development group.

a. **GAMIT/GLOBK** http://www-gpsg.mit.edu/~simon/gtgk/index.htm

GAMIT and GLOBK are a comprehensive suite of programs for analyzing GPS/GNSS measurements primarily to study crustal deformation. The software has been developed by MIT, Scripps Institution of Oceanography, and Harvard University, with support from the National Science Foundation. GAMIT/GLOBK may be obtained without written agreement or royalty fee by individuals, universities, and government agencies for any noncommercial purposes.

b. **Bernese** http://www.bernese.unibe.ch/

Bernese software was developed at the Astronomisches Institut der Universität Bern in Bern, Switzerland. A license is needed to use the software.

c. **GIPSY-OASIS** https://gipsy-oasis.jpl.nasa.gov/

GIPSY-OASIS (GOA II) software was developed and is supported by NASA's Jet Propulsion Laboratory (JPL). The software is available with a no-fee license to members of the international research community.

Additional helpful processing resources include the following:

Several organizations provide precise satellite orbital information, which is calculated daily and available with a two-week delay. The application of this information (rather than the orbital information broadcast by the satellites) can improve precision of ground coordinate solutions. Examples of places to find precise orbital information, generally available in files appended .SP3, are:

SOPAC http://sopac.ucsd.edu/

IGS http://www.igs.org/

NIMA EGM96 Geoid Calculator, to calculate the geoid-ellipsoid separation at any given point: http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/intpt.html

NGS Reference Frame Transformation, to translate coordinates from one reference frame to another: https://www.ngs.noaa.gov/NCAT/

Also, see the section on Reference Stations for links to data from continuous GPS/GNSS sites.

4. Data archiving and data access

As a service to the geodetic community, EarthScope manages, stores, and provides access to high-precision GPS/GNSS geodetic data. The archive will also accept non-geodetic GPS data projects (e.g. mapping). The data stored are primarily collected on research projects sponsored by the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA). Please contribute to the EarthScope GPS/GNSS Data Archive immediately after campaign completion to best preserve time-sensitive information. Most data must be archived within six months of data collection. See the EarthScope GPS/GNSS Data Policy for more information: http://www.unavco.org/community/policies_forms/DataPolicy.html.

To archive project data, fill out a project Request Support form if you have not already done so for your project: https://www.unavco.org/data/data-help/submission/submission.html.

Prepare legible copies of site descriptions and log sheets (e.g. Monument Record forms and Site Visit Log sheets) and any other pertinent material (photos etc.) to accompany data. At the very least, the archive needs the site name, antenna height, antenna height measurement method (e.g. slant), antenna mount type, and antenna and receiver models and serial numbers; this is the minimum information needed to meaningfully process the GPS/GNSS data.

Data should be submitted in raw format if possible. Data may additionally be submitted in a translated format.

Coordinate submissions with the EarthScope Data Management and Archiving Group: archive@earthscope.org. Submissions may be mailed/shipped or dropped off via ftp (preferred) for the archive. For more details, look up Submissions on the EarthScope Data page: https://www.unavco.org/data/data-help/submission/submission.html.

If submitting data and metadata (accompanying information) via ftp, a directory will be assigned to you.

To access both campaign and permanent station data, check out our interactive Data Archive Interface, the DAI2 (Figure 11): http://www.unavco.org/community/policies_forms/DataPolicy.html. Search for data by station name, marker name, campaign name, or geographical region. For a brief tutorial, see the Help feature at the top of the page (you may have to widen your browser window to see the Help option).

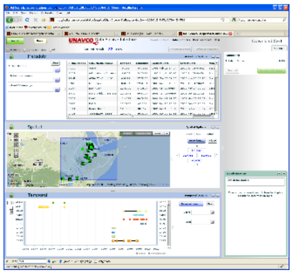

Figure 11: Screenshot of the DAI2, EarthScope's Data Archive Interface. Search for data by four-character code, site/marker name, network or campaign, or by geographical region. View metadata, operational history, and station health and time series where available.

WORKING WITH EARTHSCOPE

EarthScope is a nonprofit, membership-governed consortium funded through the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA). EarthScope's mission is to support and promote high-precision measurement techniques for the advancement of Earth sciences. Member organizations are primarily research universities who study deformation of the Earth's crust, addressing mechanisms for large- and small-scale tectonic features and processes, such as earthquakes, volcanoes, plate motion, faulting and folding, and mountain building.

EarthScope provides a variety of support options, including equipment loans, field support, budgeting, consultation, training, and data archiving. Request support through the On-line Request Support Form at:
https://bsportal.unavco.org/newproject/supportform.aspx

Useful Links

EarthScope website: http://www.earthscope.org

About EarthScope: https://www.earthscope.org/about/earthscope/

EarthScope Resources: Campaign and Kinematic GPS/GNSS:
http://kb.unavco.org/article/unavco-resources-campaign-and-kinematic-gps-gnss-390.html