CHAPTER 9

Conducting GPS Field Surveys

9-1. General. This chapter presents guidance to field personnel performing GPS surveys for typical USACE military construction and civil works projects. The primary emphasis in this chapter is on performing static and kinematic carrier phase differential GPS measurements. Absolute/autonomous and differential code phase GPS positioning and mapping techniques are also covered. Detailed field instructions for specific GPS receivers are typically contained in the operating or reference manuals provided by the manufacturer. Given the wide variety of GPS receivers, coupled with the different types of data collection, logging, processing, and adjustment techniques that can be performed in the field, this chapter can only provide a brief overview of some representative systems; and highlight observing criteria which is common to all types of GPS equipment.

9-2. General GPS Field Survey Procedures. The following are some general GPS field survey procedures that should be performed at each occupied point on a GPS survey. These general procedures apply to either static or kinematic observation methods, and to either real-time or post-processed data collection.

a. Receiver set up. GPS receivers shall be set up in accordance with manufacturer's specifications prior to beginning any observations. Base station antennas are typically mounted on a fixed-height tripod and kinematic rover receivers and antenna are mounted on fixed-height range poles, continuous profile vehicles, backpacks, etc. If real-time kinematic observations are being collected, then radio or satellite communication links will need to be set up. Newer GPS systems contain a separate data controller to record, coordinate, and process all GPS data collection. Figure 9-1 depicts typical data collectors.

Figure 9-1. Typical GPS data collector used for static and real-time kinematic surveys
(Trimble, Leica, and Topcon Data Collector)

b. Antenna setup. GPS antennas are typically mounted directly to 2-meter fixed-height tripods or range poles. A reference line marked on the antenna should always be pointed or aligned in the same direction (e.g., north), using a magnetic compass. Fixed height tripods are preferred over slip-leg tripods, as they reduce the potential for antenna height measurement errors. All tripods and range poles should be in proper adjustment prior to the start of each project and periodically calibrated/adjusted as necessary throughout. At each fixed setup, plumbing bubbles must be shaded for at least 3 minutes before use to minimize convective currents in the bubble fluid. On tripods with rotating center poles, the bubble must be rotated and checked for level throughout a 180-degree arc. If a spacer or any other intermediate device must be placed between the mounting point of a fixed-height tripod and the antenna reference point (the ARP - being almost always the center of the bottom-most, permanently attached surface of the antenna), this fact, along with the dimensions of the spacer must be recorded, so that the total height of the ARP may be correctly determined. The most common error/blunder is the antenna height measurement, which should be checked using both feet and meters.

c. Height of instrument measurements. Errors in the reported HI are on of the most common blunders in vertical control surveys. Height of instrument (HI) in the context of GPS surveys refers to the vertical height of the antenna reference point (ARP) above the monument over which it has been placed. When performing vertical control extension surveys via GPS, two-meter fixed-height tripods are required for all static observations, unless extenuating circumstance prevent their use (e.g., the height of a monument with respect to the immediate surrounding terrain is such that the supporting legs, when fully extended, do not reach the ground or cannot be set in a manner that would result in a secure and stable set up). If a slip-leg tripod is necessary, the reason for its use shall be described in detail. All antenna height measurements in such cases should be carefully made and documented so that the vertical height of the ARP above the monument may be confidently derived. If the actual physical measurements must be made to some fixed point on the antenna other than the ARP (e.g., slant measurement to the antenna ground plane), great care should be taken to properly document those measurements and reduce them to a vertical distance from the monument to the ARP. For kinematic applications, it is preferable that the rover antenna be attached to a two-meter fixed-height range pole (the height of which should be confirmed by direct measurement prior to its use). The use of adjustable range poles, although discouraged, may nonetheless be unavoidable in the conduct of certain surveys. If necessary, *extreme* care should be taken to ensure that any change in rod height is noted in the hard-copy field notes and in the survey data controller. It is recommended that, after each change in rod height, the actual length from tip/shoe to ARP be measured directly and recorded. In performing static or kinematic GPS surveys, consistent field use/measurement of the ARP height reduces the risk of subsequent processing blunders. This is due to the fact that NGS has determined the phase center offsets and phase center variation for all commercially available survey-grade antennas with respect to each antenna model's ARP (see NGS Relative Antenna Calibration Report at http://www.ngs.noaa.gov/ANTCAL/). The final computation of antenna phase center heights are then simply a matter of straightforward application of the NGS relative calibration data to the ARP height.

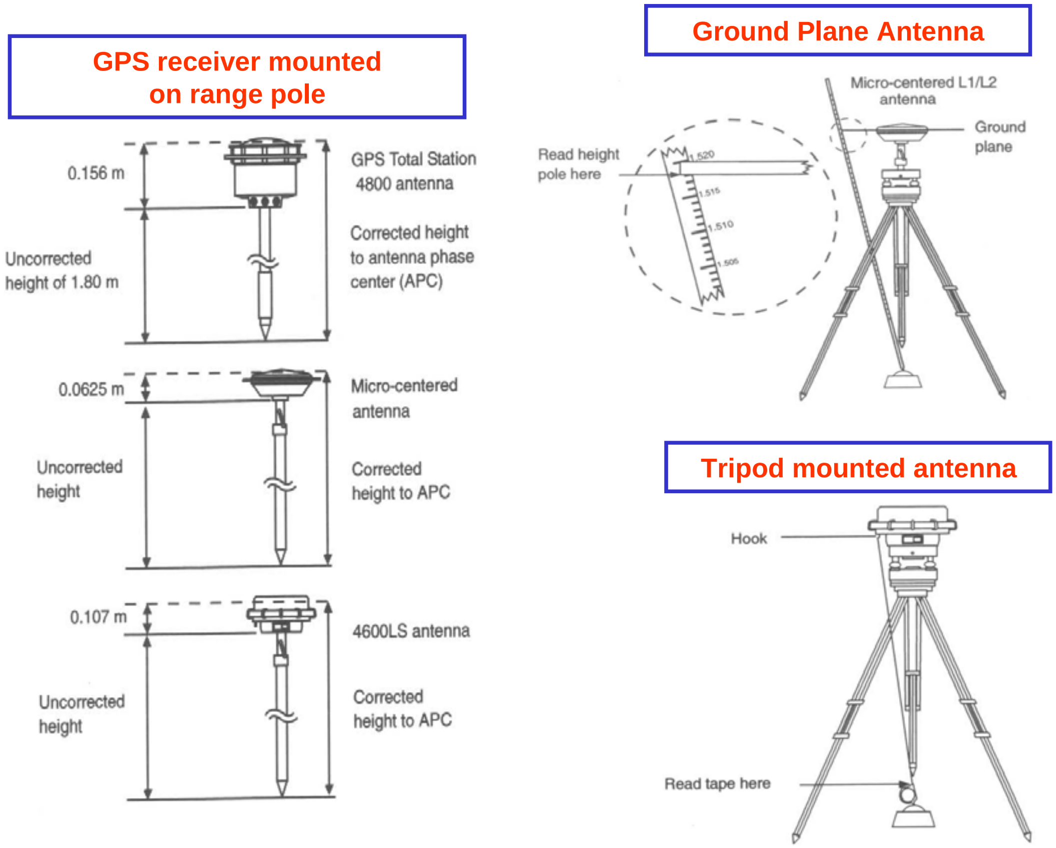

Figure 9-2 Antenna height measurements for various types of mounts
and antenna types (Trimble Navigation LTD)

d. Field GPS observation recording procedures. Field recording books, log sheets, log forms, or full-text input data collectors will be completed for each station and/or session. Any acceptable recording media may be used. For archiving purposes, standard bound field survey books are preferred; however, USACE commands may specify written or automated logging media to be used in lieu of a survey book. The amount of record keeping detail will be project dependent; low-order topographic mapping points need not have as much descriptive information as would permanently marked primary control points. The following typical data may be included on these field logging records:

(1) Project, construction contract, observer(s) name(s), and/or A-E or construction contractor firm and contract/task order number

(2) Station designation

(3) Station file number

(4) Date, weather conditions, etc.

(5) Time start/stop session (local and UTC)

(6) Receiver, antenna, data recording unit, and tribrach make, model, and serial numbers

(7) Antenna height: vertical or diagonal measures in inches (or feet) and meters (or centimeters)

(8) Sketch of station location

(9) Approximate geodetic location and elevation

(10) Problems encountered

USACE commands may require that additional data be recorded. These will be contained in individual project instructions or contract task order scopes. Samples of typical GPS recording forms are shown later in this section.

e. Field calibrations and initializations. When kinematic surveys are performed, it may be necessary to calibrate the base station to a known local coordinate point and reference datum. Calibration is especially important when using a Real Time Network (RTN). An initialization process may also be required for some types of kinematic surveys. Check with manufacturer's recommendations on specific techniques for calibrating RTK surveys to a local datum. These calibrations should be clearly noted on log records for the survey.

f. Field processing and verification. It is strongly recommended that GPS data processing and verification be performed in the field where applicable. This is to identify any problems that can be corrected before returning from the field. Survey processing and verification are covered in Chapters 10 and 11.

g. Session designations. A survey session in GPS terminology refers to a single period of observations. Sessions and station designations are usually denoted and input into the data collector using alphanumeric characters, following format restrictions allowed by the receiver vendor. The station and session designations should be clearly correlated with entries on the log forms so that there are no questions during subsequent baseline processing. The date of each survey session should be recorded during the survey as calendar dates and Julian days and used in the station/session designation. Some GPS software programs will require Julian dates for correct software operation. In addition to determination of station/session designations before the survey begins, the crew chief may need to consider or review some of the following factors:

Persons designated to occupy each station.

Satellite visibility for each station.

Site reconnaissance data for stations to be occupied. Remember the same person who performed the initial site reconnaissance may not be the individual performing the survey; therefore, previous site reconnaissance data may require clarification before survey commencement.

Project sketch.

Explicit instructions on when each session is to begin and end, and follow-up sessions.

Providing observers with data logging sheets for each occupied station.

h. GPS Station Log forms. The following figures contain samples of station logs used by various USACE districts. Note that all control, including site recon sketches and station visibility diagrams, should ordinarily be documented/archived using the new standardized Corps of Engineers U-SMART form. The form and user guide can be accessed at the following site: http://www.agc.army.mil/ndsp/index.html.

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

****

PROJECT NAME Coyote Dam LOCALITY Ukiah, Ca
OBSERVER Larry Lamb AGENCY/FIRM COE, Sacramento Dist.
RECEIVER Trimble 4000 SL S/N 2820A00223
ANTENNA Trimble Micro SL S/N 2816A00224
DATA RECORDING UNIT Receiver S/N 2820A00223
TRIBRACH Wild GDF22 S/N N/A LAST CALIBRATED: 4/24/89

****

	SESSION 1	SESSION 2	SESSION 3
STATION NAME	Pier 2	Pier 2	Pier 2
STATION NUMBER	2002	2002	2002
DAY OF YEAR	115	115	115
DATE MM DD YY	04/25/89	04/25/89	04/25/89
UTC TIME OF OBSERVATION	START 04:56 STOP 05:55	START 06:10 STOP 07:38	START 07:55 STOP 09:20

****

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	0.120 0.120 0.119 4 13/16 IN = 0.121 M MN = 0.120 M	0.116 0.116 0.116 4 9/16 IN = 0.116 M MN = 0.116 M	0.123 0.124 0.124 4 14/16 IN = 0.124 M MN = 0.1238 M
SLOPE @ END	4 11/16 4 13/16 4 11/16 0.120 M = 4 13/16 IN MN = 0.120 M	4 9/16 4 9/16 4 9/16 0.116 M = 4 9/16 IN MN = 0.116 M	4 13/16 4 14/16 4 14/16 0.123 M = 4 14/16 IN MN = 0.1230 M
MN ADJ TO VERT	0.120 M	0.116 M	0.1234 M

****

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30	39-12-22.64	39-12-30	39-12-22.48	39-12-30	39-12-22.81
LONG	123-10-30	123-10-33.42	123-10-30	123-10-33.20	123-10-30	123-10-33.62
HT	244.0	210.6	244.0	199.8	244.0	222.8
PDOP	3.6		4.8		4.0	
SVS TO TRACK	02, 03, 06, 09, 11, 12, 13, 14		02, 03, 06, 09, 11, 12, 13, 14		03, 06, 09, 11, 12, 13, 14, 16	

LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55	21:56	23:38	23:10	01:20	00:55
STOP	22:55	22:55	00:38	00:38	02:20	02:20

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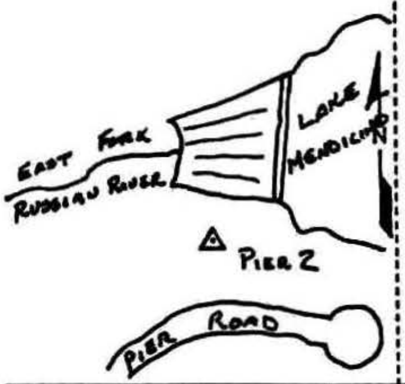
PAGE 1

Figure 9-3. Sample USACE GPS data logging sheet

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	100 ft	100 ft	35 ft
POWER SUPPLY	12v DC	12v DC	12v DC
WEATHER CONDITIONS	CLEAR, COOL 45°	CLEAR, COOL 40°	CLEAR, BREEZY 40°
MONUMENT TYPE	'C' (SET IN PIER)	← SAME	SAME
EXACT STAMPING	PIER 2 1953	← "	"
AGENCY CAST IN DISK	COE	← "	"

SKETCH OF SITE

SESSION 1	SESSION 2	SESSION 3
	SAME ← N	SAME ← N

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

THE ANTENNA WAS MOUNTED DIRECTLY OVER PIER 2 WITH NO TRIPOD USED.

ANTENNA HEIGHT WAS MEASURED VERTICALLY FROM GROUND PLANE TO BRASS DISK.

PAGE 2

Figure 9-3. (Concluded)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

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PROJECT NAME ______________________ LOCALITY ______________
OBSERVER __________________ AGENCY/FIRM __________________
RECEIVER __________________________ S/N __________________
ANTENNA ___________________________ S/N __________________
DATA RECORDING UNIT _______________ S/N __________________
TRIBRACH _______________ S/N _______ LAST CALIBRATED: ______

****

	SESSION 1	SESSION 2	SESSION 3
STATION: NAME	___________	___________	___________
NUMBER	___________	___________	___________
DAY OF YEAR	___________	___________	___________
DATE MM DD YY	___________	___________	___________
UTC TIME OF OBSERVATION	START STOP ___________	START STOP ___________	START STOP ___________

****

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M
SLOPE @ END	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M
MN ADJ TO VERT:	__________ M	__________ M	__________ M

****

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	______	______	______	______	______	______
LONG	______	______	______	______	______	______
HT	______	______	______	______	______	______
PDOP	______	______	______	______	______	______

SVS TO TRACK	____________ ____________	____________ ____________	____________ ____________

LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	______	______	______	______	______	______
STOP	______	______	______	______	______	______

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PAGE 1

a. Front

Figure 9-4. Worksheet 9-1, USACE GPS Data Logging Sheet

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

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	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	________	________	________
POWER SUPPLY	________	________	________
WEATHER CONDITIONS	________	________	________
MONUMENT TYPE	________	________	________
EXACT STAMPING	________	________	________
AGENCY CAST IN DISK	________	________	________

****

SKETCH OF SITE

SESSION 1	SESSSION 2	SESSION 3

****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurence and duration.

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PAGE 2

b. Back

Figure 9-4. (Concluded)

GPS SESSION FORM		**CORPS OF ENGINEERS, JACKSONVILLE DISTRICT**
Jax Survey No.	**Project Name**	**Date**
Agency/AE Project No.	**Agency/AE Firm**	**Operator Name**
Monument Name/Designation		**Exact Stamping (***include photo in survey report***)**
Monument No./PID	**Agency Cast in Disk**	**File Name (***receiver generated***)**
Receiver Manufacturer	**Receiver Model**	**Receiver Serial No.**
Data Collector Manufacturer	**Data Collector Model**	**Data Collector Serial No.**
Antenna Part No.	**Antenna Model**	**Antenna Serial No.**
Starting Antenna Height in Feet 1 2 3 AVG	**Starting Antenna Height Meters** 1 2 3 AVG	**Type of Measurement (***circle one***)** TRUE VERTICAL SLANT
Ending Antenna Height in Feet 1 2 3 AVG	**Ending Antenna Height in Meters** 1 2 3 AVG	**Type of Measurement (***circle one***)** TRUE VERTICAL SLANT
Antenna Reference Point (*include and reference a dimensioned diagram in Survey Report***)** *e.g., bottom edge of notch in ground plane, Page 5, Figure 2*		
Start Date (UTC)	**Start Time (UTC)**	**Approx. Lat. (***if available***)**
End Date (UTC)	**End Time (UTC)**	**Approx. Lon. (***if available***)**
Describe any abnormalities and/or problems encountered during the session, include time of occurrence and duration.	**Site Diagram**	

version 20020912

ALL FIELDS REQUIRED UNLESS OTHERWISE NOTED
SUBMIT DIGITAL COPY OF ORIGINAL AND TYPED VERSIONS

Figure 9-5. Jacksonville District GPS Session Recording Form

GPS STATION OBSERVATION LOG (01-Nov-2000)

Station Designation: (check applicable: FBN / CBN / PAC / SAC / BM) BALD 2 RESET		Station PID, if any: QE2736	Date (UTC): 31-Dec-98
General Location: Boiler Bay Wayside	Airport ID, if any: ---	Station 4-Character ID: BALD	Day of Year: 365
Project Name: Sample GPS, 1998	Project Number: GPS- 1234	Station Serial # (SSN):	Session ID:(A,B,C etc) A

NAD83 Latitude: 44° 49' 49.17802"	NAD83 Longitude: 124° 03' 56.23447"	NAD83 Ellipsoidal Height: -6.44 meters	Agency Full Name: Oregon DOT
Observation Session Times (UTC): Sched. Start 12:00 Stop 17:30; Actual Start 11:55 Stop 17:32	Epoch Interval= 15 Seconds; Elevation Mask = 10 Degrees	NAVD88 Orthometric Ht. 17.0 meters; GEOID99 Geoid Height -23.52 meters	Operator Full Name: John Q. Surveyor; Phone #: ( ) (301) 713-3194; e-mail address: jqs@ordot.gov

GPS Receiver:
Manufacturer & Model: Leica SR530
P/N: p/n 667122
S/N: s/n 0030354
Firmware Version: Version 3.0
✔CamCorder Battery. • 12V DC. • 110V AC. • Other

GPS Antenna:
Manufacturer & Model: Trimble Choke Ring
P/N: p/n 29659-00
S/N: s/n 02200-63591
Cable Length, meters: 30 meters
Vehicle is Parked 25 meters N (direction) from antenna.

Antenna plumb before session? ✔Y / N
Antenna plumb after session? ✔Y / N
Antenna oriented to true North? ✔Y / N
Weather observed at antenna ht ✔Y / N
Antenna ground plane used? ✔Y / N
Circle Yes or No -If no, explain

Antenna radome used? (Y / N)✔
Eccentric occupation (>0.5 mm)? (Y / N)✔
Any obstructions above 10°? (Y / N)✔
Radio interference source nearby (Y / N)✔
If yes, describe. Use Vis. form

Tripod or Ant. Mount: Check one: ✔Fixed-Height Tripod. • Slip-Leg Tripod. • Fixed Mount
Manufacturer & Model: SECO
P/N: none.
S/N: 97-G
Last Calibration date: 1998-11-01

Tribrach: Check one: ✔None. • Wild GDF 22. • Topcon. • Other (describe)
Last Calibration date:

** ANTENNA HEIGHT ** (see back of form for measurement illustration)	Before Session Begins: measure and record both Meters	Feet	After Session Ends: measure and record both Meters	Feet
A= Datum point to Top of Tripod (Tripod Height)	2.000		2.000	
B=Additional offset to ARP if any (Tribrach/Spacer)	-0.003		-0.003	
H= Antenna Height = A + B = Datum Point to Antenna Reference Point (ARP)				

Note: Meters = Feet X (0.3048)
Height Entered Into Receiver = 2.000 Meters.
Please note &/or sketch ANY unusual conditions. Be Very Explicit as to where and how Measured!

Barometer:
Manufacturer & Model:
P/N: pretel altiplus A2
none.
S/N: J.Q.S.
Last Calibration or check Date: 11-Sep-01

Psychrometer:
Manufacturer & Model: Psychrodyne
S/N: J.Q.S.

Weather DATA	Time (UTC)	Dry-Bulb Temp Fahrenheit	Dry-Bulb Temp Celsius	WetBulb Temp Fahrenheit	WetBulb Temp Celsius	Rel. % Humidity	Atm. Pressure Inches Hg	Atm. Pressure millibar	Weather Codes *
Before	12:00	74.0		68.0		74	29.4		00000
Middle	14:45	77.0		72.5		81	29.6		00001
After	17:30	82.5		78.0		82	29.7		00102
Average of Readings									* See back of form for codes

Remarks, Comments on Problems, Sketches, Pencil Rubbing, etc:

1. Winds, calm at start, gradually increased to 20 knots by end of session.

2. Semi-trailer parked 12 meters SSE of antenna from 15:17 to 15:32 UTC, possibly blocking satellites and causing multipath environment.

3. Center pole of tripod projected 3 mm into dimple of disk.
Antenna height was therefore 2 m - 3 mm = 1.997 m

Note: Entries are Required in all Unshaded areas.

Data File Name(s): BALD365A.dat
(Standard NGS Format = aaaaddds.xxx)
where aaaa=4-Character ID, ddd=Day of Year, s=Session ID, xxx=file dependent extension

Updated Station Description: ✔Attached • Submitted earlier
Visibility Obstruction Form: ✔Attached • Submitted earlier
Photographs of Station: ✔Attached • Submitted earlier
Pencil Rubbing of Mark: ✔Attached

LOG CHECKED BY: JGE

Figure 9-6. NGS Station Observation Log

Section I: Conducting Absolute or Autonomous GPS Positioning and Navigation Surveys

9-3. General. Absolute or autonomous point positioning GPS receivers acquire and process satellite range data to provide 10-30 meter horizontal accuracy positions. This real-time positional data is typically displayed on a hand-held receiver screen, either in numeric or graphic (navigation) format, depending on the application. Numerous hand-held receivers are available for real-time dynamic navigation uses. Although absolute/autonomous positional data are most often expressed in real time, some mapping-grade receivers can post-process data if station occupation was static over a period of time--e.g., 6 to 24 hours. The post-processing produces a best-fit point position and meter-level accuracy can be achieved--dual-frequency receivers using the precise ephemeris can produce even better (sub-meter) absolute positional accuracies. Absolute/autonomous positions are based on the WGS 84 ellipsoid. Therefore, observed horizontal positions need to be transformed to a local reference datum (e.g., NAD83) and ellipsoid elevations need to be corrected for geoid undulation in order to obtain approximate orthometric elevations on NAVD88.

9-4. Absolute/Autonomous Point Positioning Techniques. Absolute/autonomous point positioning techniques are employed where differential techniques are impractical and a new reference point is needed. This might occur in some OCONUS locations. Given the ready availability of automated differential techniques in CONUS (e.g., FAA WAAS, USCG radiobeacon) there is no longer any need to perform absolute/autonomous point positioning. There are two techniques used for point positioning in the absolute/autonomous mode. They are long term averaging of positions and differencing between signals.

a. In long-term averaging, a receiver is set up to store positions over a fixed period of time. The length of observation time varies based upon the accuracy required. The longer the period of data collection, the better the average position will be. This observation time can range between 1 and 24 hours. This technique can also be done in real-time (i.e. the receiver averages the positions as they are calculated). Positions can be stored at either 15, 30, or 60 second intervals, depending on storage capacity and length of observation. Typically, a 24-hour observation period is used to obtain an absolute/autonomous point position accurate to the meter-level.

b. The process of differencing between signals can only be performed in a post-processed mode. National Geospatial-Intelligence Agency (NGA) has produced software that can perform this operation. There are few USACE requirements for this technique.

9-5. Absolute/Autonomous GPS Navigation Systems. General vehicle and vessel navigation systems typically use inexpensive single-frequency GPS receivers. Various types of these receivers are sold at prices ranging from $100 to $1,000, depending largely on the display and software options. Operation of these receivers is simple and briefly explained in operating manuals provided with the device. Some receivers can log feature data for subsequent download to a GIS. Other receivers can log code and carrier phase data for post-processing adjustment to a reference station such as CORS. A typical receiver is shown in Figure 9-7. This receiver weighs only 5.3 ounces and has a high-contrast LCD display. It can save up to 500 waypoints and contains more than 100 map datums.

Figure 9-7. Garmin eTrex handheld differential-ready 12 parallel channel GPS receiver

9-6. Mapping Grade GPS Receivers. A variety of mapping grade GPS receivers are available to collect and process real-time absolute/autonomous and code differential positional data, post-processed carrier differential positional data, and correlate these positions with CADD/GIS map features. These georeferenced features can then be exported into a specific GIS platform. Mapping grade receiver systems, including software, range in cost between $3,000 and $10,000 and typically provide an integrated data collector for mapping, relocating, and updating GIS and spatial data bases. These systems can provide meter-level accuracy code-phase data acquired from USCG radiobeacon stations or from commercial wide area providers. They can also collect high-precision data using differential GPS carrier-phase measurements. The data collector can be used to navigate to features in an existing data base, collect new data, view system status and satellite availability, and control the GPS receiver. These systems are well suited to the collection of geographic data, using and updating existing GIS data, and navigating in the field. They can collect the feature attributes and GPS position of geographic points, lines, and areas. This information captured in the field may be stored and later transferred for postprocessing and editing. The final data sets can then be exported into a variety of CADD/GIS compatible formats. Feature data dictionaries can be created or edited in the field or in the office as necessary. Applications for mapping grade receivers include utility mapping and locating, forestry mapping, environmental and resource management, disaster assessment, and urban asset management. Additional capabilities and specifications are available from the various manufacturers.

Figure 9-8 Real-time, meter-level accuracy, feature mapping-grade GPS system. (USACE PROSPECT Course, GPS for GIS - 2009)

Section II: Conducting Differential GPS Code Phase Positioning and Mapping Surveys

9-7. General. Differential (or relative) GPS surveying is the determination of one location with respect to another location. When using this technique with the C/A or P-code it is called differential code phase positioning, as distinct from carrier phase positioning techniques covered in the next section. Differential code phase positioning has limited application to detailed engineering control surveying and topographic site plan mapping applications. However, it is widely used for general reconnaissance surveys, hydrographic survey positioning, offshore core drilling rig positioning, dredge positioning, and some operational military survey support functions. Additional applications for relative code phase positioning have been on the increase as positional accuracies have improved. Real-time, meter-level DGPS correctors can be obtained from the USCG radiobeacon navigation service or from a variety of commercial wide-area augmentation systems. This section primarily focuses on the USCG radiobeacon system; however, a number of commercial augmentation systems are also capable of providing comparable (or better) survey positioning capability. Calibration guidance in this section is applicable to all these augmentation systems.

GPS differential systems fall into one of three categories: measurement domain, position domain, and state-space domain (Abousalem, 1996). Measurement domain algorithms provide the user with corrections from a reference station or a weighted average of corrections from a network of reference stations. In the position domain approach, the user computes independent positions using corrections from separate reference stations. A weighted average of these solutions is then computed. The disadvantage of both the measurement and position domain algorithms is a degradation of accuracy with distance from the network's center. In contrast, the state-space approach models and estimates real physical parameters including satellite clocks and orbits, reference station troposphere and clocks. The ionosphere delays can additionally be modeled from dual frequency reference station data for single-frequency end users. (Ronald J. Muellerschoen, Mark Caissy, 2004*, Real-Time Data Flow and Product Generation for GNSS*).

Advantages to using the states-pace method over measurement domain and position domain are as follows: 1) the state-space approach has superior spatial decorrelation properties so that performance is independent of reference station locations, 2) fewer reference sites are required, 3) minimal bandwidth is needed to transmit the data, and 4) performance degradation is insignificant for single reference site loss and degrades gracefully for multiple reference site loss. (Penno, Whitehead, and Feller 1998). Implementations of the state-space approach include the Wide Area Augmentation System or WAAS (FAA in the US), the European Geostationary Navigation Overlay Service or EGNOS (European Triparite Group), the Multi-Functional Satellite Augmentation System or MSAS (Japanese Civil Aviation Bureau), and the NASA Jet Propulsion Laboratorie's (JPL's) Global Differential GPS or GDGPS. (Ronald J. Muellerschoen, Mark Caissy, 2004*, Real-Time Data Flow and Product Generation for GNSS*).

9-8. USCG DGPS Radiobeacon Navigation Service.

a. General. The USCG radiobeacon system is by far the most widely applied use of code phase DGPS in USACE--in fact, the Corps funds and operates some USCG radiobeacon stations at various points along the Mississippi River and tributaries. This real-time positioning system is used for many dredge positioning and hydrographic survey operations in USACE. In the past, Loran-C and Omega systems were used as the primary positioning tools for marine navigation. Today, the USCG is making use of the full coverage from GPS for a more accurate positioning tool for marine navigation. Utilizing DGPS and marine radiobeacon technology, the USCG has designed a real-time positioning system for the coastal areas and Great Lakes regions of the US. Through the Nationwide DGPS (NDGPS) program, the USCG has also partnered with USACE and other government agencies to expand this coverage to inland waterways and eventually over the entire nation. The system consists of a series of GPS reference stations with known coordinate values based on the North American Datum of 1983 (NAD83) datum. GPS C/A-code pseudorange corrections are computed based on these known coordinate values and transmitted via a marine radiobeacon. A user with a marine radiobeacon receiver and a GPS receiver with the ability to accept and apply pseudorange corrections can obtain a relative accuracy of 0.5-3 meters. This accuracy is dependent on many factors including the design and quality of the user's GPS receiver, distance from the reference station, and the satellite geometry. This service can be used for all USACE hydrographic surveys and dredge positioning requiring an accuracy of 0.5 to 3 meters. The USCG DGPS service is available for positioning and navigation. Users may experience service interruptions without advance notice. USCG DGPS broadcasts should not be used under any circumstances where a sudden system failure or inaccuracy could constitute a safety hazard. Differential corrections are based on the NAD83 position of the reference station (REFSTA) antenna. Positions obtained using USCG DGPS are referenced to NAD83 coordinate system. All sites are broadcasting RTCM Type 9-3 correction messages.

b. Site set-up and configuration. Each USCG radiobeacon site consists of two GPS L1/L2 geodetic receivers (as reference station receivers) with independent geodetic antennas to provide redundancy, and a marine radiobeacon transmitter with transmitting antenna. The site is also equipped with two combined L1 GPS / Minimum Shift Key (MSK) receivers which are used as integrity monitors. Each combined receiver utilizes an independent GPS antenna and a MSK near-field passive loop antenna.

(1) Site Location. The location of the reference station GPS antennas are tied into the North American Datum of 1983 (NAD83) and the International Terrestrial Reference Frame (ITRF). The geodetic coordinates for these positions were determined by NGS. DGPS pseudorange corrections are based on measurements made by the reference receiver relative to the NAD83 antenna coordinates. These pseudorange corrections are then transmitted via the marine radiobeacon to all users having the necessary equipment.

(2) Data Transmission (data types). The corrections are transmitted using the Type 9-3 message format designated by the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104). Other RTCM SC-104 message types transmitted to the user include Type 3 (contains the NAD83 coordinates for the broadcast site), Type 5 (provides information if a GPS satellite is deemed unhealthy), Type 7 (information on adjacent radiobeacons), and Type 16 (alerts the user of any outages). More detailed descriptions of these message types can be downloaded from the USCG Navigation Center (NAVCEN) web site.

(a) Pseudorange corrections are generated for a maximum of nine satellites tracked by the reference station GPS receiver at an elevation angle of 5 degrees or higher above the horizon.

Satellites below a 5-degree elevation mask are highly susceptible to multipath and spatial decorrelation. If there are more than nine satellites observed at the reference station above 5 degrees, then the corrections broadcast are based on the nine satellites with the highest elevation angle.

(b) The sites transmit these corrections at a 100 or 200 baud rate. Since a Type 9-3 message is 210 bits (includes header information and corrections for three satellites), the latency of the data is 2.1 seconds for a site transmitting at 100 baud. For stations transmitting at 200 baud, the latency would be half, or 1.05 seconds. The user can expect a latency of 2 to 5 seconds for all of the corrections for a group of satellites observed at the reference station to reach them. A correction can be considered valid for a period of 10 to 15 seconds from generation (the USCG limit is 30 seconds). Using corrections beyond this period of time, especially for positioning of a moving platform, may cause spikes in the positional results.

c. Availability and reliability of the system. The system was designed for and operated to maintain a broadcast availability (i.e. transmitting healthy pseudorange corrections) that exceeds 99.7% (in designed coverage areas) assuming a healthy and complete GPS constellation. The signal availability, in most areas, will be higher due to the overlap of broadcast stations. The USCG monitors each site within the entire system for problems or errors, and immediately alerts users of any problems. Each site is equipped with two integrity monitors (i.e. a GPS receiver with a MSK radiobeacon) whose antennas are mounted over known positions. The integrity monitors receive the pseudorange corrections from that site and compute a check position. The computed or corrected position is compared to the known location to determine if the corrections are within the expected tolerance. The corrected positions calculated by the integrity monitors are sent via phone lines to the control monitoring stations. For the stations east of the Mississippi River, this information is sent to USCG's NAVCEN in Alexandria, Virginia. Sites west of the Mississippi River send their corrected positions to the NAVCEN Detachment in Petaluma, California. Users are notified via the type 16 message of any problems with a radiobeacon site within 10 seconds of an out-of-tolerance condition.

d. Coverage. The system was designed to cover all harbors and harbor approach areas and other critical waterways for which USCG provides aids to navigation. Each site has a coverage area between 150 to 300 miles, depending on the transmitter power, terrain, and signal interference. Since the sites utilize an omnidirectional transmitting antenna, some areas have overlapping coverage. Currently the system covers all US coastal harbor areas, the Mississippi, the Missouri, and Ohio Rivers, and the Great Lakes Region. Additional areas within the Midwest and other non-coastal areas are being added to provide nationwide coverage, under the Nationwide DGPS program (NDGPS). Figure 9-9 and 9-10 depict existing radiobeacon coverage and site locations as of 2009. An updated map of the coverage area can be found at the NAVCEN web site under the DGPS section.
(USCG NAVCEN link at http://www.navcen.uscg.gov/dgps/coverage/Default.htm)

e. User requirements and equipment. To receive and apply the pseudorange corrections generated by the reference station, the user needs to have a MSK radiobeacon receiver with antenna and, at a minimum, a L1 C/A-code GPS receiver with antenna. The MSK receiver demodulates the signal from the reference station. Most MSK receivers will automatically select the reference station with the strongest signal strength to observe from or allow the user to select a specific reference station. A MSK receiver can be connected to most GPS receivers. The GPS receiver must be capable of accepting RTCM Type 9 messages and applying these corrections to compute a "meter-level" position. Since the reference station generates corrections only for satellites above a 7.5-degree elevation, satellites observed by the user's GPS receiver below a 7.5-degree elevation will not be corrected. Some receiver manufacturers have developed a combined MSK radiobeacon and GPS receiver with a combined MSK and GPS antenna.

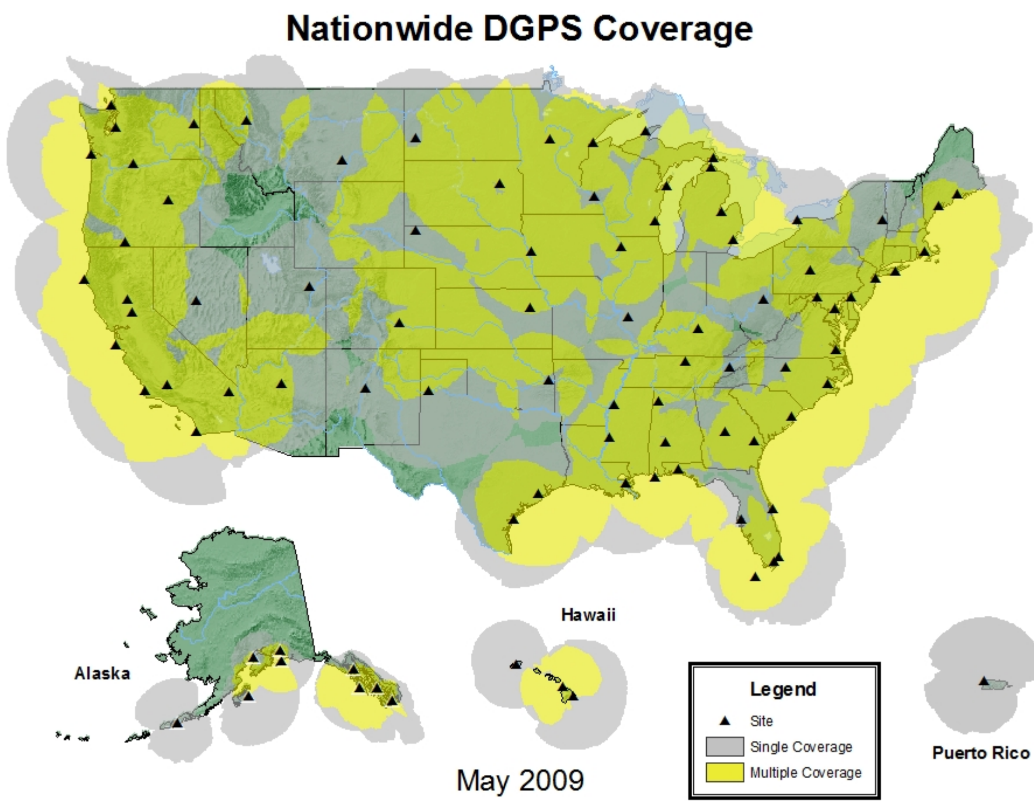

Figure 9-9. USCG DGPS Radiobeacon coverage (2009)

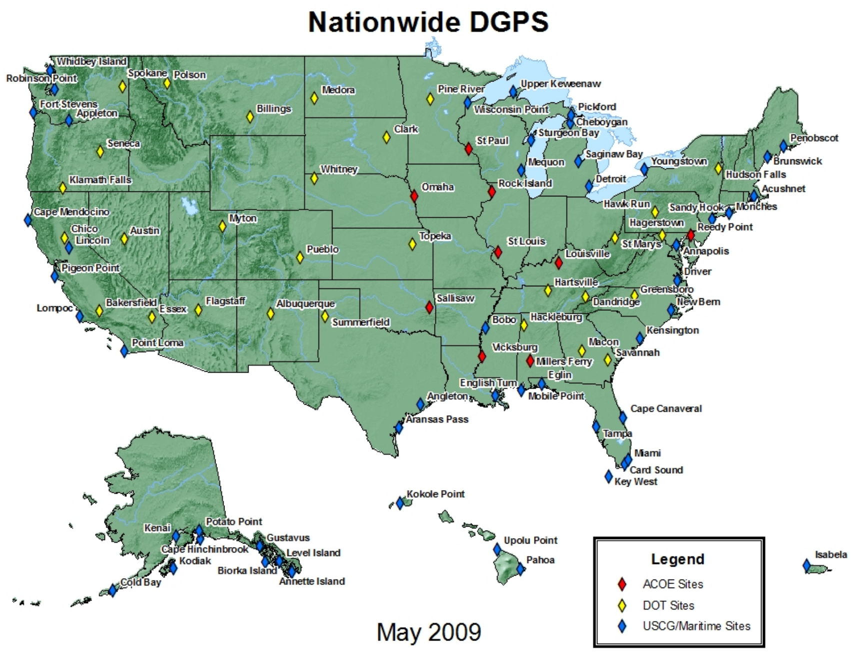

Figure 9-10. USCG DGPS Site Locations (2009)
http://www.navcen.uscg.gov/dgps/coverage/SiteLocations.htm

f. Position QC tolerance checks. Most precise DGPS augmentation systems are capable of providing sub-meter accuracies at reasonable distances from the nearest reference station. However, at increasing distances, spatial decorrelation errors (due to differing ionospheric/tropospheric conditions) can induce systematic positional biases. In general, under nominal atmospheric conditions, a 2-meter RMS (95%) positional accuracy may be achieved at distances upwards of 150 miles. To confirm a positional accuracy is within this 2-meter tolerance, it is strongly recommended that a static check position be obtained at some known survey point near the project. When operating with the USCG radiobeacon system, static positions should be observed from different radiobeacon reference stations to ascertain if positional systematic biases are present--and select the beacon with minimal biases. In practice, this would normally be the closest beacon. If no fixed survey point is available, then a static comparison of different beacon positions should be observed; however, any large biases between beacon positions may be ambiguous. When large or ambiguous positional biases occur in a project area, it may be necessary to establish a local DGPS network (code or RTK carrier) if high positional accuracy is critical to the project. Commercial wide area DGPS systems should be checked in a similar manner.

9-9. <u>FAA Wide Area Augmentation System (WAAS)</u>. The FAA's WAAS is a GPS-based navigation and landing system that will provide precision guidance to aircraft at thousands of airports and airstrips where there is currently no precision landing capability. Although still under development, this system will have potential USACE positioning, mapping, and navigation applications; either as a primary or supplemental positioning system. Many GPS receivers have been developed to acquire and process FAA WAAS signals--e.g., Garmin, Magellan, Trimble ProXR/XRS. As with most augmentation systems, WAAS is designed to improve the accuracy and ensure the integrity of information coming from GPS satellites.

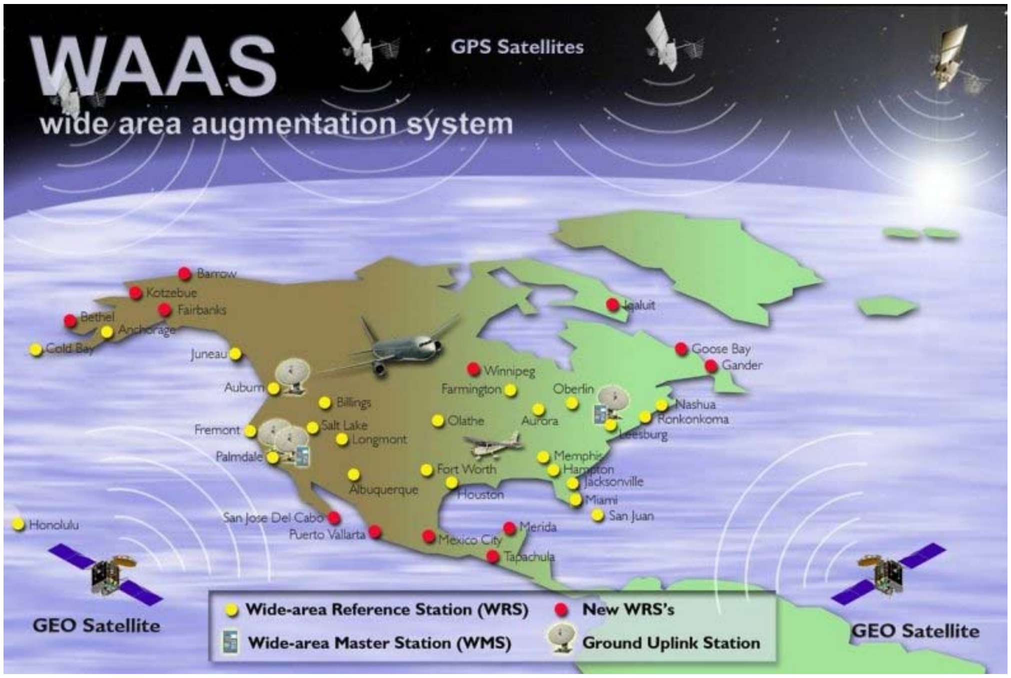

Figure 9-11. FAA WAAS coverage of North America

a. FAA WAAS is based on a network of ground reference stations that cover a very large service area--see Figure 9-11. Signals from GPS satellites are received by wide area ground reference stations (WRSs). Each of these precisely surveyed reference stations receives GPS signals and determines if any errors exist. These WRSs are linked to form the US WAAS network. Each WRS in the network relays the data to the wide area master station (WMS) where correction information is computed. The WMS calculates correction algorithms and assesses the integrity of the system. A correction message is prepared and uplinked to a geosynchronous satellite via a ground uplink system. The message is then broadcast from the satellite on the same frequency as GPS (L1--1575.42 MHz) to receivers on board aircraft (or ground-based hand-held receivers) that are within the broadcast coverage area and are capable of receiving FAA WAAS corrections. These communications satellites also act as additional navigation satellites for the aircraft, thus providing additional navigation signals for position determination. The FAA WAAS will improve basic GPS accuracy to approximately 7 meters vertically and horizontally, improve system availability through the use of geostationary communication satellites (GEOs) carrying navigation payloads, and provide important integrity information about the entire GPS constellation.

b. At present there are two geostationary satellites serving the WAAS area (Inmarsat IIIs: POR (Pacific Ocean Region) and AOR-W (Atlantic Ocean Region-West)--see Figure 9-12. The European area will eventually be served by two Inmarsats, AOR-E (Atlantic Ocean Region-East) and IOR (Indian Ocean Region) and the European Space Agency satellite, ARTEMIS. Europe's Geostationary Navigation Overlay Service (EGNOS) is Europe's first venture into satellite navigation and is Europe's first stage of the Global Navigation Satellite System (GNSS). EGNOS, like WAAS, is a spaced-based augmentation system (SBAS) that became operational in 2009. In some respects, it is a precursor to GALILEO, the full global satellite navigation system under development in Europe. On the future ARTEMIS satellite, the GPS/GLONASS augmentation is made directly from aircraft based equipment. In Asia, Japan is developing the Multi-functional Satellite Augmentation System (MSAS).

c. Garmin WAAS receiver operation. Garmin is typical of receivers that have been configured to receive FAA WAAS corrections. Garmin units can access 19 WAAS/EGNOS/MSAS unique GEO satellites. They are depicted on the GPS as Satellite IDs 33-51, which is actually a NMEA convention. Each WAAS/EGNOS/MSAS satellite will have its own unique PRN code assigned from the list of 19. These satellites do not move on the screen as do the other GPS low-earth-orbit satellites. Garmin receivers use one or two channels to track WAAS satellites and they will use the WAAS satellite in the position solution, if the WAAS system indicates it is OK to use for navigation. Sometimes the WAAS satellite is flagged as "do not use for navigation" but the corrections are still useful.

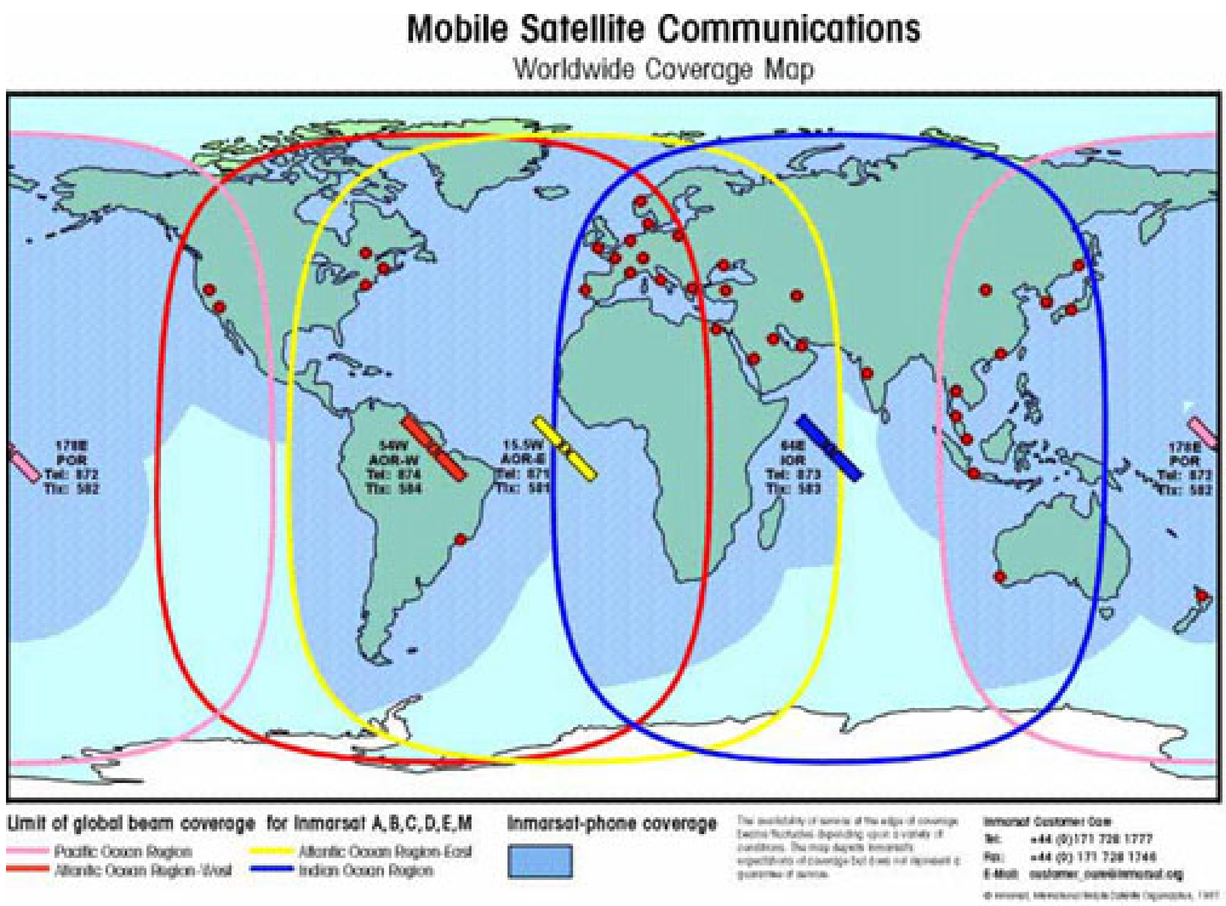

Figure 9-12. Inmarsat global coverage

9-10. FAA Local Area Augmentation System (LAAS). The FAA is also developing a Local Area Augmentation System (LAAS) for high accuracy aircraft landing. This LAAS will include a ground facility that has four Reference Receivers (RR), RR antenna pairs, redundant Very High Frequency Data Broadcast (VDB) equipment feeding a single VDB antenna, and equipment racks. These sets of equipment are installed on the airport property where LAAS is intended to provide service. The ground facility receives, decodes, and monitors GPS satellite information and produces correction messages. To compute corrections, the ground facility calculates position based on GPS, and then compares this position to their known location. Once the corrections are computed, a check is performed on the generated correction messages to help ensure that the messages will not produce misleading information for the users. This correction message, along with suitable integrity parameters and approach path information, is then sent to the airborne LAAS user(s) using the VDB from the ground-based transmitter. Airborne LAAS users receive this data broadcast from the ground facility and use the information to assess the accuracy and integrity of the messages, and then compute accurate Position, Velocity, and Time (PVT) information using the same data. This PVT is utilized for the area navigation guidance and for generating Instrument Landing System (ILS)-look-alike guidance to aid the aircraft on an approach. Although these FAA LAAS systems will not have any direct USACE application, the technology developed by the FAA may have use on unique Corps projects where high-accuracy real-time positioning is required, such as in obstructed areas.

9-11. Global Differential GPS and Global Satellite-Based Augmentation Systems. There are a growing number of commercial or "fee-for service" global satellite-based augmentation systems (GSBAS) or Global Differential GPS (GDGPS) services capable of providing sub-meter or even decimeter accuracy in real time. These systems typically offer different levels of service that may employ either a standard wide-area DGPS approach and/or some variation of the state-space approach to modeling and correcting satellite clock and orbit errors. In the state-space approach, GPS satellite orbit and clock corrections are calculated from a global tracking network of dual frequency receivers and the corrections are then transmitted via satellite link directly to remote receivers in real time. Ionospheric delay is accounted for at the remote receiver either through dual-frequency observations (or through receipt of advanced modeling parameters computed from the network of globally distributed control stations for single-frequency users). Tropospheric delays are calculated from a multi-state time and position model. Many of the state-space solution are based on licensing of NASA JPL's (Jet Propulsion Laboratory's) GIPSY (GPS Inferred Positioning SYstem) software. Users should be aware that, despite the high level of reliability, accuracy, and repeatability offered by these GSBAS/GDGPS solutions, the coordinate data output is ordinarily with respect to the ITRF (and would therefore require conversion to the NSRS for use in Corps applications).

a. NASA Global Differential GPS System (refer to http://www.gdgps.net/). The NASA Global Differential GPS (GDGPS) System is a complete, highly accurate, and extremely robust real-time GPS monitoring and augmentation system. Employing a large ground network of real-time reference receivers, innovative network architecture, and real-time data processing software, the GDGPS System provides decimeter (10 cm) positioning accuracy and sub-nanosecond time transfer accuracy anywhere in the world, on the ground, in the air, and in space, independent of local infrastructure. A complete array of real-time GPS state information, environmental data, and ancillary products are available in support of the most demanding GPS

Augmentation operations, Assisted GPS (A-GPS) services, situational assessment, and environmental monitoring - globally, uniformly, accurately, and reliably.

(1) System Overview. Employing the largest global real-time tracking network, the Global Differential GPS (GDGPS) System tracks the GPS civil signals on the L1 and L2 frequencies. Highly redundant satellite coverage (25 fold, on average) ensures seamless and robust global coverage. The raw measurements are streamed via redundant communication paths to multiple GDGPS Operation Centers (GOC) (3 centers as of October 2006). At the GOC the data is processed by the Real Time GIPSY (RTG) software to derive the real-time differential corrections to the GPS orbit and clock states, as well as many by-products and services. The state-space approach to orbit determination ensures that all the products are globally and uniformly valid. The fundamental latency of the system is ~5 seconds from reception of the navigation signal by the tracking receiver to the production and dissemination of the differential corrections and the other real-time by-products. Lower latency for certain products, such as integrity monitoring, is supported. The data products are disseminated to customers through a variety of channels. Customers are encouraged to access multiple GOCs and use multiple communications channels to ensure end-to-end redundancy for mission-critical products and services. Supported channels include: internet, VPN over internet, T1, Frame Relay, modems, and satellite broadcast. Extremely high reliability has been accomplished through an extremely high level of end-to-end redundancy, without any single point of failure. Innovative software ensures automatic fault detection and seamless failover between various redundant components of the system, resulting in uninterrupted service to customers.

(2) Global Virtual Reference Network. NASA GDGPS can translate the globally-uniform GPS orbit and clock corrections as well as a real-time global ionospheric map into RTCM 104 formatted corrections from a virtual reference site anywhere in the world. In other words, if your augmentation or A-GPS service is based on local differential corrections GDGPS can mimic these types of corrections. Local corrections of tropshperic delay using near-real-time weather fields that take into account the local topography may also be folded in. The resulting differential corrections enable single-frequency users anywhere in the world to derive positioning nearly as accurately as dual-frequency users.

(3) Automatic Precise Positioning Service (APPS). NASA JPL also provides a free precise point positioning service that is similar in some respects to OPUS. APPS accepts GPS measurement files (in RINEX format) and applies NASA JPL GIPSY processing technology to estimate the position of your GPS receivers, whether they are static, in motion, on the ground, or in the air Data files may be uploaded via e-mail or ftp transfer. Static and kinematic processing modes are available with two latency options: near real time and "most accurate" which takes about a week to ensure that the most accurate JPL orbit and clock parameters are used. All coordinate output will be for the location of the antenna phase center and with respect to ITRF2005. Therefore, further processing is required to reduce the coordinate data to the monument or feature of interest and with respect to the NSRS. (refer to http://apps.gdgps.net/)

b. NavCom's StarFire Network. (refer to http://www.navcomtech.com/StarFire/). StarFire is one of the first of the commercial global satellite-based augmentation systems (GSBAS). It provides decimeter positioning accuracy on a worldwide basis (with respect to ITRF2005), completely independent of geographical boundaries, allowing users to roam freely while maintaining the most precise positioning information. NavCom provides both GSBAS signal service based on licensing of the NASA JPL GIPSY software engine and high-precision GPS products of its own design.

c. OmniSTAR Wide-Area Differential Positioning Service (refer to http://www.omnistar.com/). OmniSTAR is a commercial "fee-for-service" wide-area differential GPS system, using satellite broadcast techniques to deliver accurate GPS correctors. Data from many widely spaced reference stations is used in a proprietary multi-site solution to achieve sub-meter positioning over most land areas worldwide. OmniSTAR is proprietary system operated by the Fugro group. Corps applications include all mapping and navigation solutions where the USCG or FAA WAAS systems are not available or are blocked. OmniSTAR's "Virtual Base Station" technology generates corrections optimized for the user's location. OmniSTAR receivers output both high quality RTCM SC-104 Version 2 corrections and differentially corrected Lat/Long in NMEA format.

d. C&C Technologies' C-Nav (refer to http://www.cctechnol.com/site47.php). C-Nav is a dynamic GPS Precise Point Positioning system, providing worldwide accuracy of <0.1 meter horizontally and 0.2 meter vertically (at one sigma within adequate INMARSAT and GPS satellite visibility). C-Nav's superior solution is based on Real Time GYPSY technology developed by NASA's Jet Propulsion Laboratory to provide centimeter-level accuracy for navigation in space and for a range of complex spacecraft maneuvers. A technological leap from DGPS, C-Nav does not suffer from the effects of spatial decorrelation found in traditional DGPS systems, nor does it require seeing common GPS satellites. It solves the problem by solving the cause of the problem at its source. C-Nav's positioning is just as accurate in both marine and land environments. A single RTG subscription service, combined with C-Nav hardware, will provide worldwide positioning capability of 0.1 meter or better. C-Nav operates in a variety of redundant modes, incorporating redundancy through system and software diversity. In the unlikely event that the RTG signal subscription service fails, C-Nav will continue to deliver its inherent accuracy for some 20 minutes before reverting to fail-safe wide area augmentation solutions (e.g. WAAS or EGNOS) providing 1-2 meter accuracy.

9-12. Other Code and Carrier Phase Wide Area Augmentation Services. A number of commercial subscription augmentation systems are now available that are designed to achieve decimeter or even centimeter accuracy over wide areas by processing carrier phase observables. These systems have application in Corps navigation projects where real-time, decimeter-level vertical accuracy is required--e.g., water surface elevation measurement. These systems operate like the wide-area code systems described above, but are functionally similar to RTK systems. They involve multiple reference stations surrounding a project area, and adjust correctors at a central server to best model the remote receiver's location. The main difference is that more accurate phase measurements are observed at the reference stations and remote receiver, resulting in a more accurate real-time position. These systems use a cellular phone network to communicate between reference receivers and roving receivers. Code and carrier phase data from a network of fixed reference stations are processed in a central server where quality checks are performed, cycle slips are detected, and double difference solutions are computed. The central server communicates with the remote user in order to model the location of the rover.

Final corrector data are then transmitted by cellular modem to the rover. Accuracies at the centimeter-level for local topographic applications are attainable. A primary advantage of all these systems is redundancy achieved from using multiple reference stations to model the user's position, as opposed to having only a single reference station. Another advantage is the clear satellite or cellular communication link, as opposed to less reliable RF methods. These wide-area carrier-phase systems are described in more detail in Section 9-20 below.

Section III: Conducting Differential GPS Carrier Phase Surveys

9-13. General. Differential (or relative) GPS carrier phase surveying is used to obtain the highest precision from GPS and has direct application to most USACE military construction and civil works engineering, topographic, photogrammetric, and construction surveying support functions.

a. Differential survey techniques. There are a variety of differential GPS surveying techniques used in the past or today. Some of the more common methods include:

Static
Kinematic
Post-Processed Kinematic
Pseudo-Kinematic
Pseudo-Static
Intermittent Static
Stop and Go Kinematic
Rapid Static Kinematic
Fast Static Kinematic
Continuous kinematic
Real-Time Kinematic (RTK)
Post Process Infill (PPRTK)
Kinematic Ambiguity Resolution
"On-the-Fly" Initialized Real-Time Kinematic
RTN

Some of the above methods are identical or performed similarly, with minor differences depending on the GPS receiver manufacturer. Procedurally, all these methods are similar in that each measures a 3-D baseline vector between a receiver at one point (usually of known local project coordinates) and a second receiver at another point, resulting in a vector difference between the two points occupied. The major distinction between static and kinematic baseline measurements involves the method by which the carrier wave integer cycle ambiguities are resolved; otherwise they are functionally the same process. General procedures for performing some of these methods are described in this section. However, manufacturer's recommended survey methods should be followed for conducting any GPS field survey.

b. Carrier phase data reduction. Most carrier phase surveying techniques, except OTF real-time kinematic (RTK) techniques, require post-processing of the observed data to determine the relative baseline vector differences. Post-processing of observed satellite data involves the differencing of signal phase measurements recorded by the receiver. The differencing process reduces biases in the receiver and satellite oscillators. It is also strongly recommended that all baseline reductions be performed in the field, if possible, in order to allow an on-site assessment of the survey adequacy.

9-14. <u>Ambiguity Resolution</u>. Cycle ambiguity is the unknown number of whole carrier wavelengths between the satellite and receiver, as was described in Chapter 5. Successful ambiguity resolution is required for baseline formulations. Generally, in static surveying, ambiguity resolution can be achieved through long-term averaging and simple geometrical calibration principles, resulting in solutions to a linear equation that produces a resultant position. Thus, 30 minutes or more of observations may be required to resolve the ambiguities in static surveys. A variety of physical and mathematical techniques have been developed to rapidly resolve the carrier phase ambiguities. The physical methods involve observations over known length baselines or equivalent known points. The most reliable method is to set the base and remote receivers up over known WGS84 points, and collect data for at least 30 seconds. Initialization can also be accomplished over extremely short baselines, such as those shown in Figure 9-13. Another method that was more commonly used in the past was a reference-rover antenna swapping process. Most GPS systems today can automatically resolve ambiguities mathematically "on-the-fly" (OTF)--the technique used for many real-time kinematic (RTK) applications.

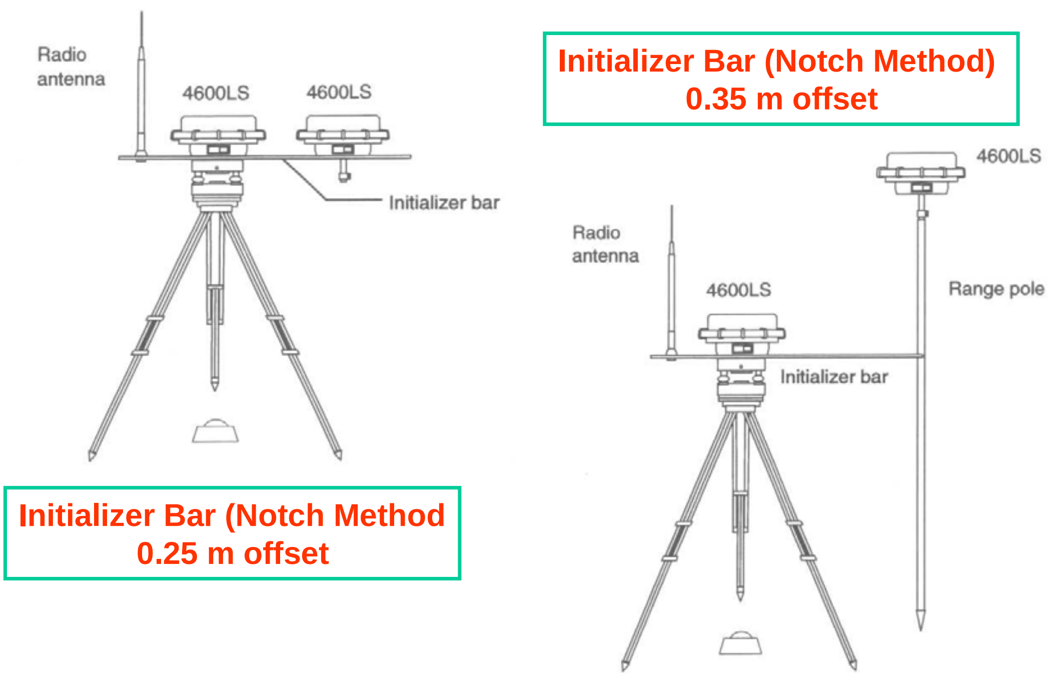

Figure 9-13. Ambiguity resolution of a Trimble 4600LS receiver using an Initializer Bar (Trimble Navigation, LTD)

9-15. <u>Static Carrier Phase Field Survey Techniques</u>. Static GPS surveying is perhaps the most common method of densifying project network control. Two GPS receivers are used to measure a GPS baseline vector. The line between a pair of GPS receivers from which simultaneous GPS data have been collected and processed is a vector referred to as a baseline. The station coordinate differences are calculated in terms of a 3-D, earth-centered coordinate system that utilizes X-, Y-, and Z-values based on the WGS84 geocentric ellipsoid model. These coordinate differences are then subsequently shifted to fit the local project coordinate system.

a. General. GPS receiver pairs are set up over stations of either known or unknown location. Typically, one of the receivers is positioned over a point whose coordinates are known (or have been carried forward as on a traverse), and the second is positioned over another point whose coordinates are unknown, but are desired. Both GPS receivers must receive signals from the same four (or more) satellites for a period of time that can range from a few minutes to several hours, depending on the conditions of observation and precision required. Guidance for planning static occupation times for horizontal and vertical control surveys is covered in Chapter 8.

b. Satellite visibility requirements. The stations that are selected for GPS survey observations should have an unobstructed view of the sky of at least 15 degrees or greater above the horizon during the "observation window." An observation window is the period of time when observable satellites are in the sky and the survey can be successfully conducted.

c. Common satellite observations. It is critical for a static survey baseline reduction/solution that the receivers simultaneously observe the same satellites during the same time interval. For instance, if receiver No. 1 observes a satellite set during the time interval 1000 to 1200 and another receiver, receiver No. 2, observes that same satellite set during the time interval 1100 to 1300, only the period of common observation, 1100 to 1200, can be processed to formulate a correct vector difference between these receivers.

d. Data post-processing. After the observation session has been completed, the received GPS signals from both receivers are then processed (i.e. "post-processed") in a computer to calculate the 3-D baseline vector components between the two observed points. From these vector distances, local or geodetic coordinates may be computed and/or adjusted. This baseline reduction process is explained in Chapter 10.

e. Survey configuration. Static baselines may be extended from existing control using any of the control densification methods described in Chapter 8. These include networking, traverse, spur techniques, or combinations thereof. Specific requirements are normally contained in project instructions (or scopes of work) provided by the District office.

f. Receiver operation and data reduction. Specific receiver operation and baseline data post-processing requirements are very manufacturer dependent. The user is strongly advised to consult and study manufacturer's operations manuals thoroughly along with the baseline data reduction examples shown in this manual.

9-16. Rapid/Fast Static Field Surveying Procedures. Rapid or Fast Static surveying is a form of static surveying techniques. The rover or remote receiver spends only a short time on each unknown point, loss of lock is allowed while the rover traverses between points, and accuracies are similar to those of static survey methods. Observed rapid static data are post-processed. Rapid static surveys are normally performed over small project areas. The rapid static technique does require the use of dual-frequency (L1/L2) GPS receivers with either cross correlation or squaring (or other techniques) to compensate for A/S.

a. Survey procedure. Rapid static surveying requires that one receiver be placed over a known control point. A rover or remote receiver occupies each unknown station for 5-30 minutes, depending on the number of satellites and their geometry. Because most receiver operations are manufacturer specific, following the manufacturer's guidelines and procedures for this type of survey is important.

b. Rapid static data processing. Data collected in the rapid static mode should be post-processed in accordance with the manufacturer's specifications and software procedures.

c. Accuracy of rapid static surveys. Accuracies of rapid static surveys are similar to static surveys of a centimeter or less. This method can be used for medium to high accuracy surveys up to 1/100,000.

9-17. Kinematic GPS Field Survey Techniques. Kinematic surveying using differential carrier phase tracking is similar to static carrier phase methods because it also requires two receivers recording observations simultaneously. The reference receiver remains fixed on a known control point while the roving receiver collects data on a constantly moving platform (vehicle, vessel, aircraft, manpack, etc.), as illustrated in Figure 9-14. The observation data is later post-processed to calculate relative vector/coordinate differences to the roving receiver. A kinematic survey requires, at minimum, two GPS receivers. One receiver is set over a known point (reference station) and the other is used as a rover (i.e. moved from point to point or along a path). Before the rover receiver can collect positional data at an unknown point, a period of static initialization may be required. (Alternatively, an OTF initialization technique may be used, as described below). This period of initialization is dependent on the number of visible satellites. Once initialization is completed, the rover receiver can move from point to point as long as satellite lock is maintained. If loss of satellite lock occurs, a new period of static initialization may be required. Some of the field techniques for the more common types of kinematic GPS surveying are described below. More detailed field procedures are found in operator's manuals provided by the GPS receiver manufacturer.

9-18. Real-Time Kinematic (RTK) Field Surveying Techniques. Unlike the static and kinematic methods previously covered, RTK methods provide real-time positioning results. Real-time surveys are most useful for construction stakeout, setting project control, and topographic mapping. To obtain real-time coordinates, a communication link (radio or satellite) is required between the reference base station and the roving receiver. RTK surveying is similar to other kinematic GPS survey methods in that it requires two receivers simultaneously recording observations. Unlike other GPS methods, the rover receiver can be continuously moving. RTK surveys require dual-frequency (L1/L2) GPS observations. Periodic losses of satellite lock can also be tolerated. Since RTK uses the L2 frequency, the GPS receiver must be capable of tracking the L2 frequency during A/S. There are several techniques used to obtain L2 during A/S. These include squaring and cross correlation methods.

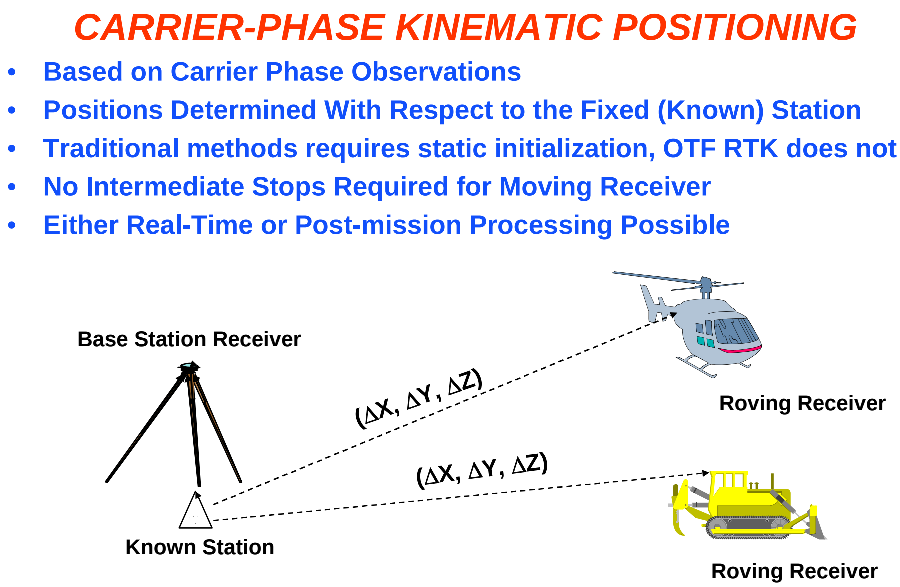

Figure 9-14. Kinematic survey techniques

Figure 9-15. Real-Time kinematic survey at the Bevill Center, Huntsville, AL
(PROSPECT GPS Training Course - 2010)

a. Ambiguity resolution. As previously explained, carrier phase integer ambiguity resolution is required for successful baseline formulations. RTK surveys can be initialized using the methods previously described--e.g., at a known point. However, if the receiver is equipped with "on-the-fly" (OTF) initialization technology, then the remote can initialize and resolve integers without a period of static initialization. With OTF capability, if loss of satellite lock occurs, initialization can occur while in motion. OTF integers can usually be resolved at the rover within 10-30 seconds, depending on the distance from the reference station. This initialization is automatically performed by the survey controller device. OTF makes use of the L2 frequency in resolving the integer ambiguity. At least 5 satellites are required for OTF initialization, and after initialization, at least 4 satellites must be tracked. After the integers are resolved, typically only the L1 C/A is used compute the positions. If no OTF capability is available, then initialization should be made at a known point and 4 satellites must be kept in view at all times--loss of lock requires reinitialization.

b. Survey procedure. RTK/OTF surveying requires dual-frequency L1/L2 GPS receivers. One of the GPS receivers is set over a known point and the other is placed on a moving or roving platform. The survey controller will determine the amount of time required to lock in over each remote point. If the survey is performed in real-time, a data link and a processor (external or internal) are needed. The data link is used to transfer the raw data from the reference station to the remote. If the radio link is lost, then post-processing techniques are available to compute the survey--e.g., Trimble's "Infill" option.

c. Accuracy of RTK surveys. RTK surveys are accurate to within 3-10 cm (in 3-D) when the distance from the reference to the rover does not exceed 10 k.

Figure 9-16. Rover GPS receiver setup for RTK surveys--Trimble R8 GNSS and Trimble 4000 series base station. (Trimble Navigation LTD)

9-19. RTK Survey Field Procedures and Calibrations. The USFS and BLM *Standards and Guidelines for Cadastral Surveys* (USFS/BLM 2001) contains guidance for performing RTK surveys that is directly applicable to USACE RTK topographic mapping and construction control surveys. Some of the more significant field procedures recommended by the USFS/BLM are outlined below. These generally reduce down to (1) system checks, (2) measurement procedures, (3) and calibrations. Additional and more up-to-date guidance may be found in the *User Guidelines for Classical Real Time GNSS Positioning* recently published by NGS. (http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v1.1.pdf)

a. RTK system check. A RTK system check shall be made prior to any measurements. RTK system checks may also be made at any time during the course of each RTK survey session or at any time the base receiver(s) and rover receiver(s) are set up and initialized per the manufacturer's recommended procedures. This check is a measurement from the RTK base setup to another known project control monument. The resulting observed position is then compared by inverse to the previously observed position for the known point. This inverse should be within the manufacturer's recommended values for duplicate point tolerance measurements--typically within ± 2.5 cm in position and within ± 5 cm in elevation. This RTK system check is designed to check the following system parameters:

The correct reference base station is occupied.
The GPS antenna height is correctly measured and entered at the base and rover.
The receiver antennas are plumb over station at base and rover.
The base coordinates are in the correct datum and plane projections are correct.
The reference base stations or the remote stations have not been disturbed.
The radio-communication link is working.
The RTK system is initialized correctly.
RMS values are within manufacturer's limits.

b. RTK measurements. RTK topographic observations are usually made using one or more base stations and one or more rover receivers. RTK measurements shall be made after the system setup check procedures have been completed. Use manufacturer's recommended observation times for the highest level of accuracy when setting mapping or construction control points, for example, 180 seconds of time or when the horizontal (e.g., 2 cm) and vertical (e.g., 5 cm) precision has been met for a kinematic control point. Under optimal conditions a deviation from the manufacturer's suggested time is appropriate; for example, a point may be observed using 30 seconds of time and 20 epochs of measurement data. However, observation times should be set to account for field conditions, measurement methods (i.e. Trimble "topo point" or "kinematic control point") and the type of measurement checks being performed.

c. Recommended methods for setting control points using RTK. One method is to observe the unknown point two or more times with the same point name (e.g., 100700) and use a duplicate point tolerance measurement criteria of 2.5 cm. When observing these measurements, the antenna shall be inverted and the receiver reinitialized between observations. Another method is to observe two separate baselines (M1 and M2) to the unknown point. The baseline data are stored to the data collector or receiver for a specified number of seconds or epochs to meet a specified level of precision recommended by the manufacturer for a kinematic control point. Observation time may be increased due to the constraints of on-the-fly (OTF) post-processing kinematic (i.e. 200+ sec) if the field data is post-processed as a check. Between the M1 and M2 baseline measurements the antenna should be inverted to force a loss of satellite lock, which forces the system to reinitialize. The point values resulting from the first baseline measurement are stored and labeled (e.g., 100700M1), and the point values resulting from the second baseline measurement are stored and labeled (e.g., 100700M2). A field check of the level of accuracy between the measurements may be done by an inverse between M1 and M2. The resulting inverse distances should agree within 2.5 cm.

Figure 9-17. RTK feature collection at Huntsville, AL Tom Bevill Center (PROSPECT GPS Training Course - 2010)

9-20. Real Time Network (RTN). One significant drawback of the single base RTK approach described above is that the maximum distance between reference and rover receiver must not exceed 10 to 20 kilometers in order to be able to rapidly and reliably resolve the carrier phase ambiguities. This limitation is caused by distance-dependent biases such as orbit error, and ionospheric and tropospheric signal refraction. These errors, however, can be accurately modeled using the measurements of an array of GNSS reference stations surrounding the rover site. Thus, RTK positioning is extended from a single base to a Real Time Network technique (Lambert Wanninger, 2008, *Introduction to Network RTK*).

a. RTN Overview. One technique proven in production systems for RTN is the Virtual Reference Station (VRS) paradigm, simulating a local reference station for the user. Ideally, this provides a data quality equivalent to a very close reference station. The Virtual Reference Station technique uses the complex filter state model for the complete network to compute a virtual reference station dataset at a location near the rover. Today, more than 95% of the network RTK installations are using the VRS technique to transport the correction stream in standardized formats (RTCM 2.3, RTCM 3.0 or CMR) from the server to the field user. All major geodetic receiver manufacturers support these formats. In addition to the compatibility with all modern geodetic rover receiver types, the VRS technique has an advantage in that the server, using the latest model for all error sources, can continuously optimize the correction stream for each rover position. Since these error models are updated every second on a continuous 24/7 basis, every rover connecting into the system benefits from the optimal model immediately after a connection with the server is established. The VRS method requires bidirectional communication, which is available via GSM, GPRS and other cellphone-based data transmission methods. Today, more than 99% of the worldwide network RTK installations are using bidirectional communication technologies. (Ulrich Vollath, Herbert Landau, Xiaoming Chen, Ken Doucet, Christian Pagels, 2002, *Network RTK Versus Single Base RTK -Understanding the Error Characteristics)*

b. RTN Benefits. Benefits to the user of an RTN over classical RTK positioning include:

(1) No user base station is necessary. Therefore, there are no security issues with the base, no control recovery is necessary to establish its position, and the user needs only half the equipment to produce RT work. Additionally, there is no lost time setting up and breaking down the base station equipment and radio.

(2) The first order ppm error is eliminated (or drastically reduced) because ionospheric, tropospheric and orbital errors are interpolated to the site of the rover.

(3) The network can be positioned to be aligned with the NSRS with high accuracy. The users will then be collecting positional data that will fit together seamlessly. This is important to all users of geospatial data, such as GIS professionals who may deal with such regional issues as emergency management and security issues.

(4) Datum readjustments or changes can be done transparently to the user with no post campaign work. New datum adjustments to NAD83 or even transformations to another geodetic datum such as the International Terrestrial Reference Frame (ITRF) are done at the network level and are broadcast to the users.

(5) With some business models, the user can share in the network profits by installing a network reference station and getting a share of the subscription fees imposed upon other network users.

(6) Different formats and accuracies are readily available. GIS data, environmental resource data, mapping grade data, etc. can be collected with one or two foot accuracy while surveyors and engineers can access the network with centimeter level accuracy. RTCM, CMR+ and other binary formats can be user selected.

(7) The RTN can be quality checked and monitored in relation to the NSRS using NGS programs such as OPUS and TEQC from UNAVCO. (http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v3.1.1.pdf)

c. RTN Drawbacks. Drawbacks to the user of an RTN compared to classical RTK positioning include:

(1) Network subscription fees. These may be prohibitive for small companies.

(2) Limited wireless data access.

(3) Interpolation issues. Network spacing, communication and error modeling must be handled optimally.

(4) Work outside the network envelope (extrapolation of corrections) degrades accuracy.

(5) The network solution may not fit to local control. Calibration may be necessary.

(6) Coordinate metadata. Is the network datum the user's required datum?

(7) It is usually necessary for the user to perform site calibration or localization at the project's designated control points. (http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v3.1.1.pdf)

d. VRS Processing, In general, when a receiver is started in the field, a coarse estimate of the receiver position is sent to the VRS network computing center via e.g. cell phone. The center generates virtual reference station data for that position and transmits it in a standard format like RTCM enabling centimeter-level RTK operation for the user. The computation of VRS data is generally carried out as follows: (Ulrich Vollath, Herbert Landau, Xiaoming Chen, Ken Doucet, Christian Pagels, 2002, *Network RTK Versus Single Base RTK -Understanding the Error Characteristics)*

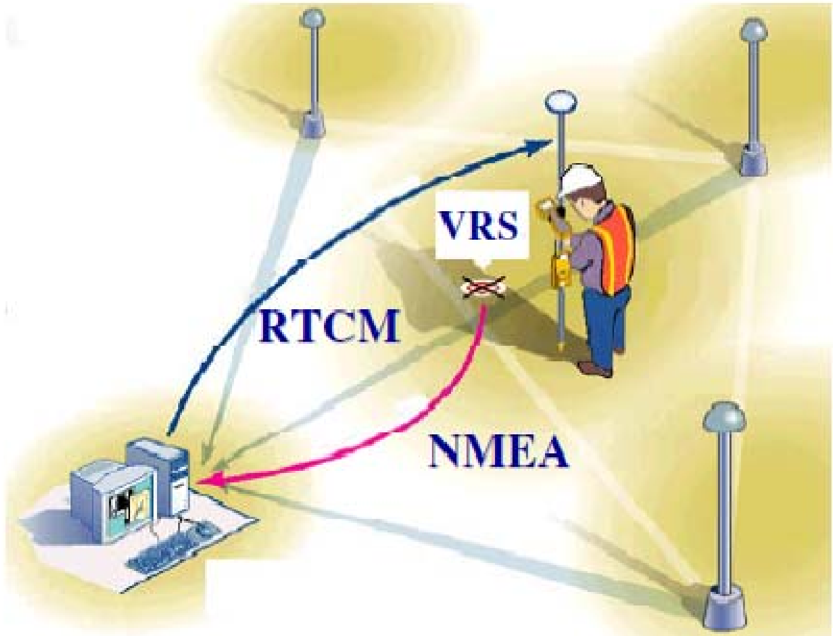

Figure 1: VRS field set-up procedure.

Figure 9-18. VRS Setup Procedure

(1) In the first processing step ambiguity fixing is performed in the reference station network. Only observations with fixed ambiguities can be used for the precise modeling of the distance-dependent biases. The relatively long distances between the reference stations and the requirement to fix the ambiguities in real-time makes this processing step the main challenge of Network RTK.

(2) In the second processing step correction model coefficients are estimated. Ionospheric and orbit biases must be modeled individually for each satellite. Tropospheric corrections, however, may be estimated station by station. It is advantageous to separate the dispersive (ionospheric) biases from the non-dispersive biases (orbit and troposphere, sometimes referred to as "geometric"), since ionospheric errors show much larger temporal variations as compared to the other distance-dependent biases. Thus, ionospheric corrections must be updated (transmitted to the user) more often, in practice e.g. every 10 seconds as compared to every 60 seconds for orbit and tropospheric corrections.

(3) In the third processing step, an optimum set of reference observations is computed from the observations of a selected master reference station, e.g. the one closest to the rover receiver, and the precise correction models for distance-dependent biases. Based on the correction models and horizontal coordinate differences between master reference position and approximate rover position, the reference observations are virtually shifted to the rover site. This

results in Virtual Reference Station (VRS) observations which are used by the rover receiver to determine his position from the processing of the short baseline to the VRS.

e. Site Calibrations or Localization. Localization to passive (and validated) NSRS control is recommended for most projects. Often, the VRS network is in sufficient harmony with the NSRS horizontal reference system that horizontal localization is unnecessary. However, due to inherent difference in active and passive control systems, localization to available NSRS vertical control is usually required. Field localization to any control not included in the NSRS (e.g., legacy Corps baseline monumentation) should ordinarily be discouraged. This is because, despite apparent conformance with the recommended calibration adjustment statistics, field calibrations may be inadvertently carried out without due regard for the internal consistency/conformality of the selected control. This, together with the use of affine/non-orthogonal calibration functions (available in most receiver/controllers), may introduce significant undesired distortion into the resultant coordinates. Furthermore, field localization to control monuments not included in the NSRS could (if the control monuments are subsequently disturbed or destroyed) result in a survey data set that cannot be reproduced or confidently integrated with other properly acquired data sets. The need to localize to control that is not part of the NSRS should be addressed on a case by case basis. It would be preferable to log/document un-calibrated positions at the subject monumentation and develop localization parameters in the office after careful evaluation and analysis.

f. RTN General Guidance (adapted from *An examination of commercial network RTK GPS services in Great Britain,* School of Civil Engineering and Geosciences, Newcastle University Newcastle upon Tyne ,NE1 7RU, Dr Stuart Edwards, Prof. Peter Clarke, Dr Sibylle Goebell, Dr Nigel Penna).

(1) Basic guidance for classical RTK should be incorporated into RTN field procedures where appropriate (http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v3.1.1.pdf):

Set rover elevation mask between 12° & 15°
The more satellites the better
The lower the PDOP the better
The more redundancy the better
Beware multipath
Beware long initialization times
Beware antenna height blunders
Survey with “fixed” solutions only
Always check known points before, during and after new location sessions
Keep equipment adjusted for highest accuracy
Communication should be continuous while locating a point
Precision displayed in the data collector is usually at the 68 percent level (or1σ), which is only about half the error spread to get 95 percent confidence
Have back up batteries & cables
RT doesn’t like tree canopy or tall buildings

(2) You need to use the correct equipment and have it suitably configured. For example, the correct antenna files or other offsets must be loaded on the rover device in order to avoid additional height errors. You also need to be aware that it is best practice to make connection to the network correction service where there is a clear view of the sky. Be aware that, in some instances, the coordinate system that the corrections are delivered in may not be the end coordinate system that you require.

(3) GPS correction services only remove the baseline dependent errors so quality checks are still essential. At the rover, errors from the working environment, multipath (GPS signal reflections) and satellite constellation geometry will still affect the quality of the work.

(4) It is all well and good having optimum GPS satellite coverage, but the corrections also have to make their way to you. This is generally done using a data enabled SIM card in a mobile phone or directly in the instrument, but radio and the Internet are other options. RTK GPS corrections provided over a mobile phone network need to be at a bandwidth which corresponds at least to that available from GSM. GPRS and 3G networks where available are likely to prove better and more economical methods of connecting to the network.

(5) When using networked GPS the other elements of best survey practice still apply. It is even more essential to ensure points forming a control framework are installed and appropriately measured external to the area of detail. It is best practice to periodically measure control points during a survey. The control framework will also allow subsequent checking and confirmation of the survey data and any subsequent work.

(6) Do you have a mobile telephone network into which you can connect? In marginal areas of telephone coverage there could be a high likelihood of losing the connection at a critical moment during the work. For critical surveys, raw observation data should also be logged along with the corrected positions – as with a traditional RTK survey.

(7) The use of a single averaged window solution (user definable in the manufacturer's equipment) can significantly improve the levels of accuracy compared with a single epoch network RTK solution. RMS errors can be reduced by around 5 mm, particularly in the Up coordinate component, through the adoption of the mean of two 3-minute averaged windows separated by 20 minutes.

(8) Due to the nature of receiver locations comprising RTK Network, the user may find themselves at an altitude significantly above or below the surrounding Network sites. This geographical offset has implications for the systems' ability to effectively model/estimate and ultimately remove residual atmospheric effects and in particular tropospheric bias. Network RTK is able to mitigate residual tropospheric errors to a large degree. However, where height differences between the user and the nearest Net base stations exceed 250 m surveyors should consider the adoption of windowing techniques.

g. Network RTK Recommended Best Practice (adapted from *An examination of commercial network RTK GPS services in Great Britain,* School of Civil Engineering and

Geosciences, Newcastle University Newcastle upon Tyne ,NE1 7RU, Dr Stuart Edwards, Prof. Peter Clarke, Dr Sibylle Goebell, Dr Nigel Penna).

(1) Accuracy. Accuracy is a measure of the difference between a particular measured coordinate and its true value, often quoted as the root mean square error (rms). If the measurement is unbiased and has normally distributed errors, then for each coordinate component roughly 68% of individual solutions will have errors smaller than the rms, and 95% will have errors smaller than twice the rms. However, systematic errors (biases) will reduce these percentages. Typically, commercial Network RTK solutions provide instantaneous results (i.e. single epoch coordinate solutions) that achieve rms accuracies around 10 - 20 mm in plan and 15 - 30 mm in height, with relatively small biases.

(2) Equipment configuration. Users of commercial network RTK should ensure that their rover firmware is configured according to manufacturer guidelines. Significant variations from recommended settings may lead to unacceptable variations in determined coordinates. Geometric Dilution of Precision (GDOP) is a measure of the worsening of a GNSS solution caused by the geometric arrangement of visible satellites. Often a maximum GDOP of 5 is imposed. Reducing the GDOP limit to 3 will increase the robustness of determined coordinates under challenging conditions (e.g. urban canyons) but does not reduce productivity in open/benign environments where GDOP values between 2 and 3 predominate. The imposition of such a filter on average provides the user with over 95% of possible coordinate solutions.

(3) Quality indicators. Users of network RTK should ensure their rover unit is set to display all available coordinate quality indicators for their position fix and pay close attention to them. In most situations these indicators reflect well the actual performance of your system. Coordinate solutions where the reported quality is worse than 10 cm generally result from problems with satellite lock or ambiguity resolution, and should always be discarded. In the most challenging environments (e.g. restricted satellite visibility, large distances or height differences to surrounding RTK Net active stations, or high multipath), reported coordinate quality may be over-optimistic by a factor of 3 – 5 especially in the height component. This can be mitigated as below.

(4) Improving solution robustness. For topographic survey, the use of a 5 second window average will reduce the effect of individual coordinate solution variations. For precise work, especially where the height component is important e.g. control station establishment, the process of double window averaging should be undertaken. Users should observe an averaged window of around 3 minutes followed by another averaged window of the same length separated from the first by a suitable time period e.g. 20 minutes. On average, a time separation of 20 minutes will yield a 10 – 20% improvement in coordinate accuracy and a 45 minute separation will yield improved accuracies at the 15 – 30% level compared to a single epoch solution. Window separations of greater than 45 minutes do not typically provide appreciable further improvement to the determined coordinates, except for the mitigation of ocean tide loading effects.

(5) Additional satellite constellations. When surveying in challenging satellite visibility environments (e.g. urban canyons), the use of satellites from other global navigation satellite

system constellations (e.g. GLONASS) can improve overall satellite visibility and hence allow surveying to proceed with less downtime, but may not necessarily lead to an improvement in accuracy. Where satellite availability is significantly diminished (e.g. under a tree or close to an overhang), it is recommended that surveyors/engineers adopt standard terrestrial survey techniques to radiate from a nearby unobstructed point and should not attempt to use network RTK.

(6) Surveying at the limits of the network. Network RTK performance at the network extents shows greater frequency of coordinate excursion from the expected norm. System users should examine the mean distance to the nearest four active network stations. Users of network RTK who work frequently in areas where this mean distance is large (> 50 km), or where they are outside the polygon formed by the nearest active network stations, should consider making greater use of single window averaging for normal topographic survey and double window averaging for control station establishment.

(7) Height Effects. Errors caused by the tropospheric effects and height variations between active network stations and your rover position are generally well modelled by network RTK providers. However, where these height differences increase (> 250 m), it is recommended that the procedures as for surveying at the limits of the network be adopted to reduce heighting error. To aid planning, height difference from the nearest four active network stations should be taken into account.

9-21. <u>Other Techniques Superseded By Newer Technology</u>.

a. Pseudo-Kinematic Field Survey Techniques. Pseudo-kinematic GPS surveying is similar to stop-and-go kinematic techniques except that loss of satellite lock is tolerated when the receiver is transported between occupation sites (in fact, the roving receiver can be turned off during movement between occupation sites, although this is not recommended). This feature provides the surveyor with a more favorable positioning technique since obstructions such as bridge overpasses, tall buildings, and overhanging vegetation are common. Loss of lock that may result due to these obstructions is more tolerable when pseudo-kinematic techniques are employed.

(1) General. The pseudo-kinematic technique requires that one receiver be placed over a known control station. A rover receiver occupies each unknown point or monument for 5-10 minutes. Approximately 1 hour (but not longer than 4 hours) after the initial occupation, the same rover receiver must reoccupy each unknown point.

(2) Common satellite requirements. The pseudo-kinematic technique requires that at least four of the same satellites be observed between initial unknown point occupations and the requisite reoccupations. For example, the rover receiver occupies Station A for the first 5 minutes and tracks satellites 6, 9, 11, 12, 13; then 1 hour later, during the second occupation of Station A, the rover receiver tracks satellites 2, 6, 8, 9, 19. In this example, only satellites 6 and 9 are common to the two sets, so the data cannot be processed because four common satellites were not tracked for the initial station occupation and the requisite reoccupation.

(3) Planning. Prior mission planning is essential in conducting a successful pseudo-kinematic survey. Especially critical is the determination of whether or not common satellite coverage will be present for the desired period of the survey. Also, during the period of observation, one receiver, the base receiver, must continuously occupy a known control station.

(4) Pseudo-kinematic data processing. Pseudo-kinematic survey satellite data records and resultant baseline processing methods are similar to those performed for static GPS surveys. Since the pseudo-kinematic technique requires each station to be occupied for 5 minutes and then reoccupied for 5 minutes approximately an hour later, this technique is not suitable when control stations are widely spaced and transportation between stations within the allotted time is impractical.

(5) Accuracy of pseudo-kinematic surveys. Pseudo-kinematic survey accuracies are at the centimeter level.

b. Stop-and-Go Kinematic Field Survey Techniques. Differential GPS surveying known as "stop-and-go" is typically used for setting accurate topographic mapping or construction control points. It is similar to static surveying methods in that each method requires at least two receivers simultaneously recording observations. Unlike static methods, an initial calibration process is required prior to conducting the survey. A major difference between static and stop-and-go surveying is the amount of time required for a roving receiver to stay fixed over a point of unknown position. In stop-and-go surveying, the first receiver--the base station or reference receiver--remains fixed on a known control point. The second receiver--the "rover" receiver--collects observations statically on a point of unknown position for a period of time (usually a few minutes), and then moves to subsequent unknown points to collect data for a short period of time. During the survey, at least four common satellites (preferably five) need to be continuously tracked by both receivers. Once the rover receiver has occupied all required points, the observations are then post-processed to calculate baseline vector/coordinate differences between the known control point and points occupied by the rover receiver during the survey session. The main advantage of this form of GPS surveying over static surveying is the reduced occupation time required over the unknown points. Stop-and-go kinematic surveying requires less occupation time over unknown points than static methods. Therefore, time and cost for the conduct of a survey are significantly reduced. Achievable accuracies typically equal or exceed 10 mm.

(1) Survey procedure. Stop-and-go surveying is performed similarly to a conventional electronic total station radial survey. The system is initially calibrated by performing either an antenna swap with one known point and one unknown point, by performing a static measurement over a known baseline, or by observing static data at another known point on the network. This calibration process is performed to resolve carrier phase cycle ambiguities. A known baseline may be part of the existing network or can be established using static GPS survey procedures described above. The roving receiver then traverses between unknown points as if performing a radial topographic survey. Typically, the points are double-connected, or double-run, as in a level line. Optionally, two fixed receivers may be used to provide redundancy on the remote points. With only a few minutes of data collection at a point, topographic X-Y-Z coordinate production is high.

(2) Satellite lock. During a stop-and-go survey, the rover receiver must maintain lock on at least 4 satellites during the period of survey. The reference station must also be observing at least the same 4 satellites. Loss of lock occurs when the receiver is unable to continuously record satellite signals or the transmitted satellite signal is disrupted and the receiver is not able to record it. If satellite lock is lost, the roving receiver must reobserve the last fixed point surveyed before loss of lock. The operator must closely monitor the GPS receiver when performing the stop-and-go survey to ensure loss of lock does not occur. Some manufacturers have now incorporated an alarm into their receiver that warns the user when loss of lock occurs, thus making the operator's job of monitoring the receiver easier.

(3) Site constraints. Survey site selection and the route between points to be surveyed are critical. All observing points must have a clear view of satellites having a vertical angle of 15 degrees or greater. The routes between rover occupation points must be clear of obstructions so that the satellite signal is not interrupted. Each unknown station to be occupied should be observed for a minimum of at least 90 seconds. Remote points should be occupied two or three times to provide redundancy between observations.

(4) Antenna swap calibration procedure. The antenna swap initialization procedure requires that two nearby points be occupied and that both points maintain an unobstructed view of the horizon. A minimum of four satellites and constant lock are required; however, more than four satellites are preferred. To perform an antenna swap, one receiver/antenna is placed over a point of known control and the second, a distance of 10 to 100 m away from the other receiver. The receivers at each station collect data for approximately 2 to 4 minutes. The receivers/antennae sets then swap locations: the receiver/antenna at the known station is moved to the unknown site while the other receiver/antenna at the unknown site is moved to the known site. Satellite data are again collected for 2 to 4 minutes. The receivers are then swapped back to their original locations. This completes one antenna swap calibration. If satellite lock is lost during the process, the calibration procedure must be repeated. The baseline data are processed to determine and eliminate the carrier integer ambiguity. Although an antenna swap procedure is used to initialize a stop-and-go survey, the same technique can also be used to determine a precise baseline and azimuth between two points.

(5) Accuracy of stop-and-go surveys. Accuracy of stop-and-go baseline measurements will well exceed 1 part in 5,000; thus, supplemental project/mapping horizontal control can be established using this technique. For many USACE projects, this order of horizontal accuracy will be more than adequate; however, field procedures should be designed to provide adequate redundancy for what are basically "open-ended" or "spur" points. Good satellite geometry and minimum multipath are also essential in performing acceptable stop-and-go surveys.