CHAPTER 10

Post-Processing Differential GPS Observational Data

10-1. General. GPS baseline solutions are usually generated through an iterative process. From approximate values of the positions occupied and observation data, theoretical values for the observation period are developed. Observed values are compared to computed values, and an improved set of positions occupied is obtained using least-squares minimization procedures and equations modeling potential error sources. Observed baseline data are also evaluated over a loop or network of baselines to ascertain the reliability of the individual baselines. A generalized flow of the processes used in reducing GPS baselines is outlined below. This chapter will cover the steps outlined in this process.

Create New Project File Area
Download/Import Baseline Data from Receivers or Survey Data Collectors
Download Precise Ephemeris Data if Required
Make Changes and Edits to Raw Baseline Data
Process all Baselines
Review, Inspect, and Evaluate Adequacy of Baseline Reduction Results
Make Changes and Rejects
Reprocess Baselines and Reevaluate Results
Note/Designate Independent and Trivial Baselines
[Review Loop Closures and Adjust Baseline Network--Chapter 11]

a. The ability to determine positions using GPS is dependent on the effectiveness of the user to determine the range or distance of the satellite from the receiver located on the earth. There are two general techniques currently operational to determine this range: differential code pseudoranging and differential carrier phase measurement. This chapter will discuss general post-processing issues for differential carrier phase reductions that provide centimeter-level accuracy suitable for controlling project monuments. Post-processed differential code phase reductions, with accuracies ranging from 0.2 to 5 meters, are only briefly covered since these techniques are not intended for precise control surveys.

b. Baseline processing time is dependent on the required accuracy, processing software, computer hardware speeds, data quality, and amount of data collected. The user must take special care when processing baselines with observations from different GPS receiver manufacturers. It is important to ensure that observables being used for the formulation of the baseline are of a common format (i.e. RINEX) unless the baseline processing software being used can read the manufacturer's proprietary format.

10-2. General Differential Reduction Techniques. Differential reduction techniques basically involve the analysis of the Doppler frequency shifts that occur between the moving satellites and ground-based receivers, one of which may be in motion (e.g., RTK rover). Integration of the Doppler frequency offsets, along with interferometric processing and differencing techniques, provides for a resultant baseline vector between the two ground-based points, or velocity measurements on a moving receiver. Differencing and interferometric analysis techniques may be performed on both carrier frequencies (L1 & L2), the frequency difference (wide-laning), and on the code-phase observations. "Floating" and "Fixed" baseline solutions are computed from these interferometric differencing techniques. A variety of algorithms and methods are used to perform the reductions. Although these processes are relatively simple for static GPS observations, they become complicated when real-time (on-the-fly) integer ambiguity resolution is required. A variety of GPS data reduction software can be obtained from government agencies or commercial vendors. The detailed theory and derivations of these reductions are beyond the scope of this manual. The material presented in the following sections should be considered as only an overview. Examples of baseline reduction software will be limited to those software packages commonly used by Corps commands. Full discussions on carrier phase reductions can be found in the references listed in Appendix A. Kaplan 1996 (Chapter 8--Differential GPS) is recommended along with Leick 1995, and Remondi 1985.

10-3. Carrier Phase Observables. The carrier "beat" phase observable is the phase of the signal remaining after the internal oscillated frequency generated in the receiver is differenced from the incoming carrier signal of the satellite. The carrier phase observable can be calculated from the incoming signal or from observations recorded during a GPS survey. By differencing the signal over a period or epoch of time, one can count the number of wavelengths that cycle through the receiver during any given specific duration of time. The unknown number of cycles between the satellite and receiver antenna is known as the "integer cycle ambiguity." There is one integer ambiguity value per each satellite/receiver pair as long as the receiver maintains continuous phase lock during the observation period. The value found by measuring the number of cycles going through a receiver during a specific time, when given the definition of the transmitted signal in terms of cycles per second, can be used to develop a time measurement for transmission of the signal. Once again, the time of transmission of the signal can be multiplied by the speed of light to yield an approximation of the range between the satellite and receiver. The biases for carrier phase measurement are the same as for pseudoranges, although a higher accuracy can be obtained using the carrier phase. A more exact range between the satellite and receiver can be formulated when the biases are taken into account during derivation of the approximate range between the satellite and receiver.

10-4. Baseline Solution by Linear Combination. The accuracy achievable by pseudoranging and carrier phase measurement in both absolute and relative positioning surveys can be improved through processing that incorporates differencing of the mathematical models of the observables. Processing by differencing takes advantage of correlation of error (e.g., GPS signal, satellite ephemeris, receiver clock, and atmospheric propagation errors) between receivers, satellites, and epochs, or combinations thereof, in order to improve GPS processing. Through differencing, the effects of the errors that are common to the observations being processed are eliminated or at least greatly reduced. Basically, there are three broad processing techniques that incorporate differencing: single differencing, double differencing, and triple differencing. Differenced solutions generally proceed in the following order: differencing between receivers takes place first, between satellites second, and between epochs third (Figure 10-1).

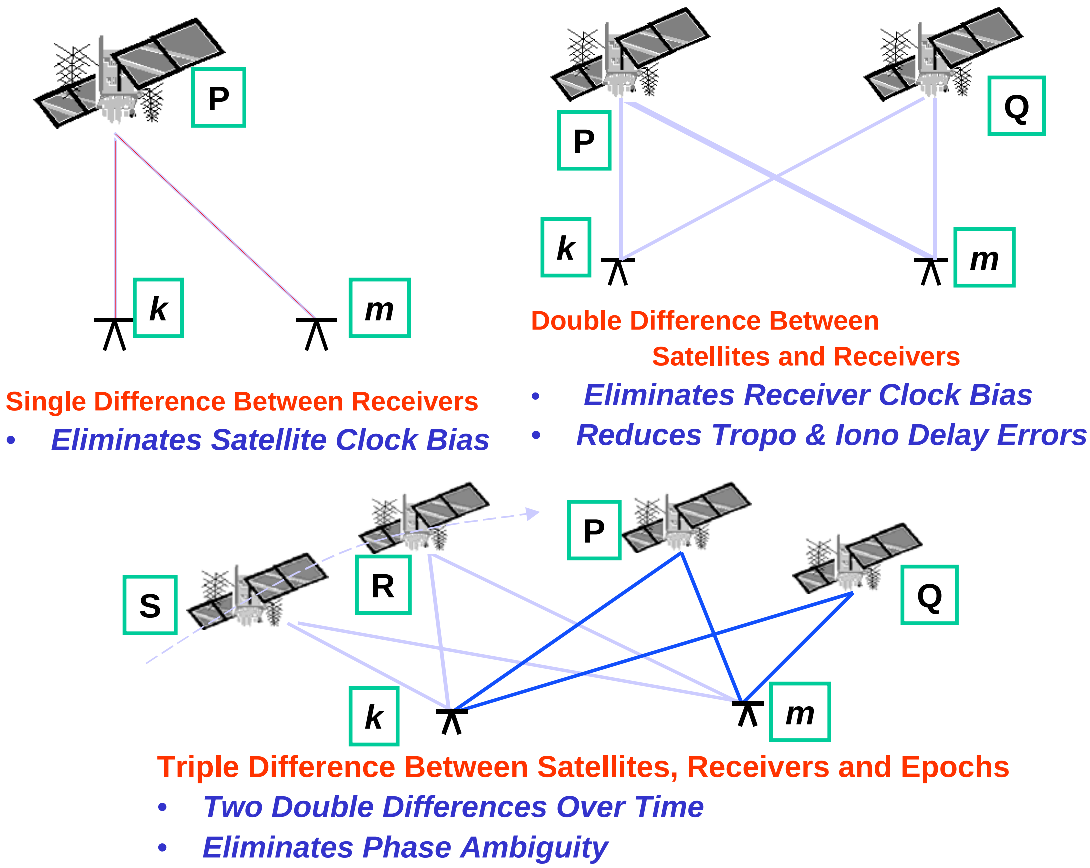


Figure 10-1. Carrier phase differencing techniques

a. Single differencing. There are three general single differencing processing techniques: between receivers, between satellites, and between epochs.

(1) Between receivers. Single differencing the mathematical models for a pseudorange (P- or C/A-code) or carrier phase observable measurements between receivers will eliminate or greatly reduce satellite clock errors and a large amount of satellite orbit and atmospheric delays. This is illustrated in upper left portion of Figure 10-1 where single differences are computed between the two receivers (*k* and *m*) and the satellite "P."

(2) Between satellites. Single differencing the mathematical models for pseudorange code or carrier phase observable measurements between satellites eliminates receiver clock errors. Single differencing between satellites can be done at each individual receiver during observations as a precursor to double differencing and in order to eliminate receiver clock errors.

(3) Between epochs. Single differencing the mathematical models between epochs takes advantage of the Doppler shift or apparent change in the frequency of the satellite signal by the relative motion of the transmitter and receiver. Single differencing between epochs is generally

done in an effort to eliminate cycle ambiguities. There are three forms of single differencing techniques between epochs: Intermittently Integrated Doppler (IID), Consecutive Doppler Counts (CDC), and Continuously Integrated Doppler (CID). IID uses a technique whereby Doppler count is recorded for a small portion of the observation period, the Doppler count is reset to zero, and then at a later time the Doppler count is restarted during the observation period. CDC uses a technique whereby Doppler count is recorded for a small portion of the observation period, reset to zero, and then restarted immediately and continued throughout the observation period.

b. Double differencing. Double differencing is actually a differencing of two single differences (as detailed above). There are two general double differencing processing techniques: receiver-time and receiver-satellite. Double difference processing techniques eliminate clock errors.

(1) Receiver-time double differencing. This technique uses a change from one epoch to the next, in the between-receiver single differences for the same satellite. Using this technique eliminates satellite-dependent integer cycle ambiguities and simplifies editing of cycle slips.

(2) Receiver-satellite double differencing. There are two different techniques that can be used to compute a receiver-satellite double difference. One technique involves using two between-receiver single differences, as shown in the upper right of Figure 10-1. This technique also uses a pair of receivers, recording different satellite observations during a survey session and then differencing the observations between two satellites. The second technique involves using two between-satellite single differences. This technique also uses a pair of satellites, but different receivers, and then differences the satellite observations between the two receivers.

c. Triple differencing. There is only one triple differencing processing technique: receiver-satellite-time (epoch). All errors eliminated during single- and double-differencing processing are also eliminated during triple differencing. When used in conjunction with carrier beat phase measurements, triple differencing eliminates initial cycle ambiguity. During triple differencing, the data is also automatically edited by the software to delete any data that cannot be solved, so that the unresolved data are ignored during the triple difference solution. This feature is advantageous to the user because of the reduction in the editing of data required; however, degradation of the solution may occur if too much of the data is eliminated during triple differencing.

d. Differencing equations. The expressions for single differences between receivers and satellites can be formed from the general carrier phase observable given back in Chapter 5 as Equation 5-2 (Kaplan 1996), which is repeated below. Refer also to Figure 10-1.

$$\phi_k^P(t) = \phi_k^P(t) - \phi^P(t) + N_k^P + S_k + f\tau_P + f\tau_k - \beta_{iono} + \delta_{tropo} \qquad \text{(Eq 10-1)}$$

where

$\phi_k^P(t)$ = length of propagation path between satellite "P" and receiver "k" ... in cycles
$\phi_k^P(t)$ = received phase of satellite "P" at receiver "k" at time "t"
$\phi^P(t)$ = transmitted phase of satellite "P"

N_k^P = integer ambiguity
S_k = measurement noise (multipath, GPS receiver, etc.)
f = carrier frequency (Hz)
τ_P = satellite clock bias
τ_k = receiver clock bias
β_{iono} = ionospheric advance (cycles)
δ_{tropo} = tropospheric delay (cycles)

For a second receiver "m" another equation can be written for the propagation path between satellite "P" and the second receiver "m":

$$\phi_m^P(t) = \phi_m^P(t) - \phi^P(t) + N_m^P + S_m + f\tau_P + f\tau_m - \beta_{\mathrm{iono}} + \delta_{\mathrm{tropo}} \quad \text{(Eq 10-2)}$$

Differencing the propagation path lengths between the two receivers "k" and "m" to the satellite "P" (Equations 10-1 and 10-2) results in a "single difference between receivers."

$$\mathrm{SD}_{km}^{P} = \phi_{km}^{P} + N_{km}^{P} + S^{P}_{km} + f\tau_{km} \quad \text{(Eq 10-3)}$$

When a second satellite "Q" is added, a "single difference between receivers" can be formed for the second satellite "Q":

$$\mathrm{SD}_{km}^{Q} = \phi_{km}^{Q} + N_{km}^{Q} + S^{Q}_{km} + f\tau_{km} \quad \text{(Eq 10-4)}$$

The "single difference" equations 10-3 and 10-4 can be differenced between themselves, thus creating a "double difference" involving two separate receivers (*k* and *m*) and two separate satellites (*P* and *Q*).

$$\mathrm{DD}_{km}^{PQ} = \phi_{km}^{PQ} + N_{km}^{PQ} + S^{PQ}_{km} \quad \text{(Eq 10-5)}$$

It is seen in the above "double difference" equation that most of the original unknown terms have been eliminated by these differencing techniques, with only the integer ambiguity (*N*) and noise (*S*) remaining to be determined. Additional "double difference" equations can be written for the two receivers between other combinations of epochs of satellites in view, and these multiple double difference equations can be again differenced (i.e. Triple Differenced) to remove the integer ambiguity term N_{km}^{PQ}.

$$\mathrm{TD}_{km}^{PQ} = \mathrm{DD}_{km}^{PQ}(t+1) - \mathrm{DD}_{km}^{PQ}(t) \quad \text{(Eq 10-6)}$$

where t and $t + 1$ are successive epochs.

The results of the Triple Difference baseline solution can then be input back into the Double Difference equations in order to resolve, or "fix," the integers in the Double Difference solution. Fixing the integers in a Double Difference solution constrains the integer ambiguity *N* to a whole number of cycles, and is the preferred baseline solution--see Leick 1995.

10-5. Baseline Solution by Cycle Ambiguity Recovery. The resultant solution (baseline vector) produced when differenced carrier phase observations resolve the cycle ambiguity is called a "fixed" solution. The exact cycle ambiguity does not need to be known to produce a solution; if a range of cycle ambiguities is known, then a "float" solution can be formulated from the range of cycle ambiguities. A floating baseline solution is a least-squares fit that may be accurate to only a few integer wavelengths. It is always desirable to formulate a fixed solution. Differences between floating and fixed solutions can be calculated over all the epochs observed. The fixed solution may be unable to determine the correct set of integers (i.e. "fix the integers") required for a solution.

10-6. Field/Office Baseline Processing. It is strongly recommended that baselines should be processed daily in the field. This allows the user to identify any problems that may exist. Once baselines are processed, the field surveyor should review each baseline output file. Certain computational items within the baseline output are common among software vendors, and may be used to evaluate the adequacy of the baseline observations in the field. Baseline outputs may include triple difference, float double difference, and fixed double difference distance vectors, variance and covariance statistics, and RMS accuracy estimates. The procedures used in baseline processing are software dependent; however, the output statistics and analysis of reliability are somewhat similar among different vendors. Discussion and examples in the following sections are largely taken from Trimble Geomatics Office software user guide manuals that are referenced in Appendix A.

Figure 10-2. Baseline processing (Huntsville, AL PROSPECT GPS Course--2002)

a. Baseline processing. Baseline processing software is now fairly automatic and user-friendly. Most software automatically performs all the interferometric differencing operations needed to solve for integer ambiguities, and displays the resultant baseline vectors along with adjustment and accuracy statistics that can be used to evaluate the results. The following procedures are taken from Trimble Navigation's "Weighted Ambiguity Vector Estimator" (WAVE) software (Trimble 2001d) and are believed to be representative of most packages. Trimble's WAVE baseline processor involves performing the following steps, in order:

(1) Load raw GPS observation DAT files

(2) Select the display options

(3) Edit occupations (station names, antenna heights, etc.)

(4) Set the processing style & baseline flow sequence Import a coordinate seed (approximate point positions)

(5) Choose baselines for processing (identify independent baselines)

(6) Process the baselines

(7) Review the results

Where multiple baselines are observed in a network, the software will process the baselines sequentially. Independent baselines should be identified during this phase. If a precise ephemeris is available, then it should be downloaded and input into the baseline reduction program. Complete details on performing each of these baseline processing steps is found in the *Trimble Geomatics Office--WAVE Baseline Processing Software User Guide* (Trimble 2001d).

b. Downloading GPS data. The first step in baseline processing is transferring the observation data from the GPS data collector device to a personal computer for processing and archiving. Various types of file formats may be involved, depending on the GPS receiver--e.g., Trimble Receiver *.DAT files, Trimble Survey Controller *.DC files, or RINEX ASCII files. Data adjustment software packages have standard downloading options for transferring GPS data files, or routines to convert proprietary GPS files to RINEX format. Trimble *.DAT files contain information on receiver type, antenna measurement method, antenna type, raw carrier phase observations, antenna height, satellite ephemeris, and station designation/name. RINEX files are also obtained for remote IGS tracking network stations or CORS base stations.

c. Preprocessing. Once observation data have been downloaded, preprocessing of data can be completed. Preprocessing procedures depend on the type of GPS data collected, e.g., static, RTK, Fast static, etc., and the type of initialization performed (static, known point, OTF, etc.). Preprocessing consists of smoothing/editing the data and ephemeris determination. Smoothing and editing are done to ensure data quantity and quality. Activities done during smoothing and editing include determination and elimination of cycle slips, editing gaps in information, and checking station names and antenna heights. In addition, elevation mask angles should be set during this phase along with options to select tropospheric and ionospheric models.

d. Ephemeris data. Retrieval of post-processed ephemerides may be required depending on the solution and type of survey being conducted. Code receivers do not require post-processed ephemerides since they automatically record the broadcast ephemerides during the survey. Most baseline reduction software provides an option to select either a broadcast or precise ephemeris.

e. Baseline solutions. Carrier phase baseline processing is fairly automatic on commercial software packages. Groups of baselines are processed in a defined or selected order. After an initial code solution is performed, a triple difference, then double-difference, solution is performed. If the integer ambiguities are successfully resolved, then a fixed solution can result. Solution types may include L1 Fixed, Ionospheric-Free Fixed, and Float. If all observed baselines are processed, any dependent baselines should be removed so they will not be used in subsequent network adjustments. Commercial baseline reduction software may have a variety of options that are automatically (or manually) set to determine the most "optimum" solution. Most software packages attempt to perform the most accurate fixed solution for short lines (e.g., less than 15 km for single-frequency and less than 30 km for dual-frequency receivers). The ability to derive an accurate fixed solution (i.e. 5 to 10 mm) will also depend on the length of time of noise-free data, good DOP, multipath, etc. For baselines longer than 30 to 50 km, if the fixed solution is not deemed to be reliable (based on various quality indicators discussed below), then the default float solution may be used. Although not as accurate as the fixed solution, if the session time is long enough (e.g., 1 to 2 hours) the float solution will be fairly accurate--e.g., 20 to 50 mm for lines less than 75 km. Most processing software provides numerous statistical and graphical displays of baseline solution results, allowing users to assess the reliability of a particular solution, and force an alternate solution if necessary--see Figure 10-3 for a typical example.

10-7. Resultant Baseline Output and Quality Criteria. Baseline post-processing software outputs vary with the software package. Baseline output data are used to evaluate the quality of the solution, and may be input into subsequent network adjustment criteria. Typically, the following types of information may be selected for text output or graphical screen display:

number of processed baselines (in network)

number of accepted and rejected baselines

session time (date, time)

data logging time (start, stop)

station information: location (latitude, longitude, height), receiver serial number used, antenna serial number used, ID numbers, antenna height

epoch intervals

number of epochs

meteorological data (pressure, temperature, humidity)

ephemeris file used for the solution formulation

listing of the filenames

elevation mask

minimum number of satellites used

type of satellite selection (manual or automatic)

triple difference solution

double difference fixed solution

double difference float solution

L1 only solution

Ionospheric-free solution (L1 & L2)

baseline vector length in meters

RMS of solution

Post-fit RMS by satellite vs. baseline

RMS--L1 phase

RMS-L1 Doppler

RMS--P-code

Cycle slips

reference variance

ratio of solution variances of integer ambiguity

phase ambiguities & drifts

phase residual plots--L1 & C/A

satellite availability and tracks during the survey for each station occupied

DOP, PDOP, VDOP, HDOP

solution files: Δx-Δy-Δz between stations, slope distance between stations, Δlatitude and Δlongitude between stations, horizontal distance between stations, and Δheight

covariance matrix

For most Corps applications, only a few of the above parameters need be output in order to assess the results and quality of a baseline solution. These parameters can best be assessed from graphical summary plots, as shown in Figure 10-3 below. Some more sophisticated reduction software, such as Waypoint Consulting's "GrafNav" and the NGS's "PAGES," provide considerably more statistical information than most other baseline processing packages; however, this level of GPS accuracy assessment is usually not applicable to most Corps engineering and construction control survey work. These detailed statistics may have application in assessing the quality of airborne GPS (ABGPS) applications. For more information on these high-level baseline reduction methods, see NGS 2000 (*PAGE-NT User's Manual*) and Waypoint 2001 (*GrafNav/GrafNet, GrafNav Lite, GrafMov Operating Manual*).

a. Variance Ratio--floating and fixed solutions. A fixed solution indicates that the integer ambiguities have been successfully resolved. A floating solution may not have accurately resolved the integers; however, this may still be the best solution for that particular baseline observation. Trimble's WAVE solution computes the variances of each integer ambiguity solution and compares the solution with the lowest variance with the next higher variance solution. This comparison "ratio" of the solutions should exceed 1.5 in order to accept the lowest variance as the fixed solution. If a variance ratio is less than 1.5 the processor defaults to the floating solution since there is no statistical basis for assuming a fixed solution has merit.

b. Reference variance. The reference variance indicates how well the computed errors in the solution compare with the estimated (*a priori*) errors for a typical baseline. A value of 1.0 indicates a good solution. Variances over 1.0 indicate the observed data were worse than the norm. Baselines with high reference variances and low variance ratios need to be checked for problems.

c. RMS. The RMS is a quality factor that helps the user determine which vector solution (triple, float, or fixed) to use in an adjustment. The RMS is dependent on the baseline length and the length of time the baseline was observed. RMS is a measurement (in units of cycles or meters) of the quality of the observation data collected during a point in time. RMS is dependent on line length, observation strength, ionosphere, troposphere, and multipath. In general, the longer the line and the more signal interference by other electronic gear, ionosphere, troposphere, and multipath, the higher the RMS will be. A good RMS factor (one that is low, e.g., between 0.01 and 0.2 cycles or less than 15 mm) may not always indicate good results, but is one indication to be taken into account. RMS can generally be used to judge the quality of the data used in the post-processing and the quality of the post-processed baseline vector.

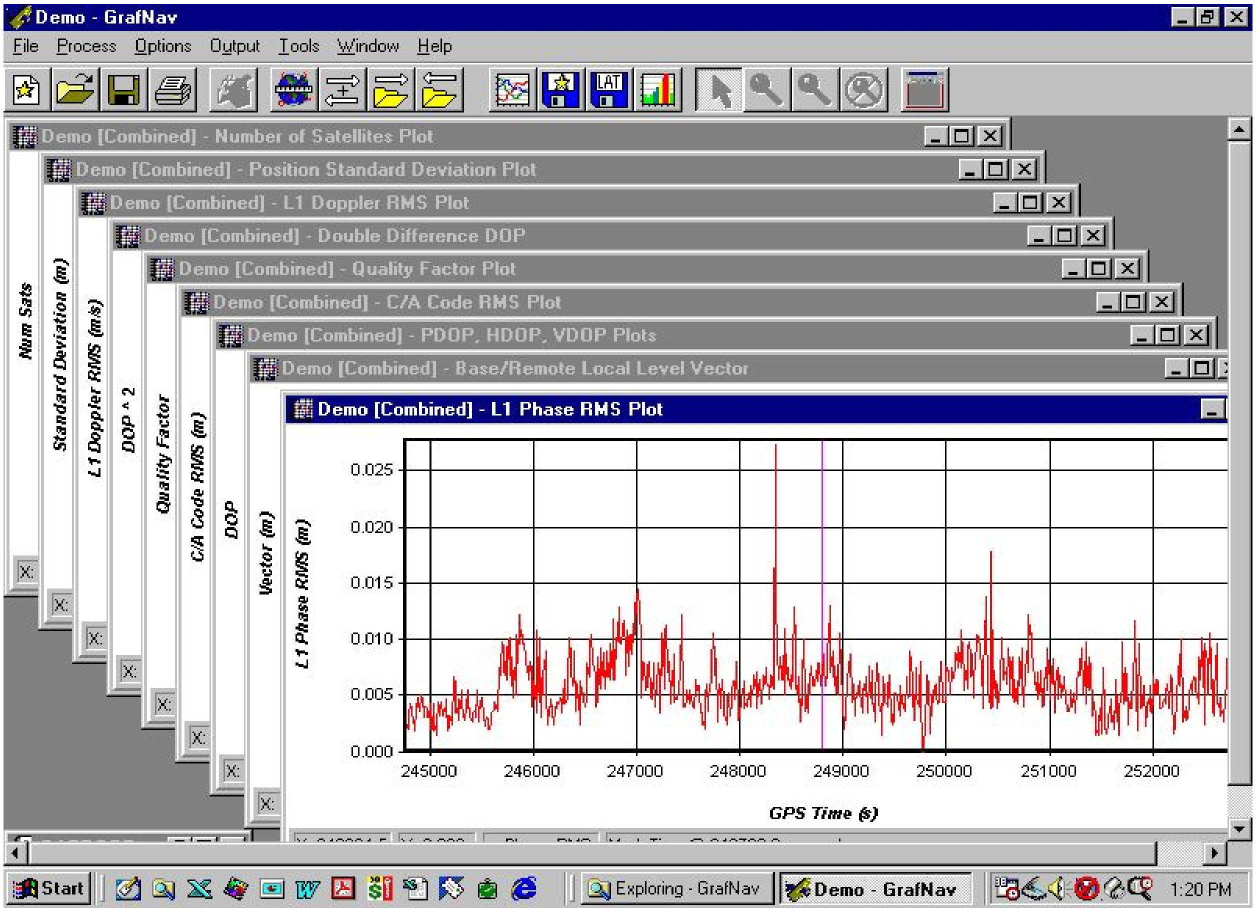


Figure 10-3. GrafNet baseline reduction output plots--some of the 28 selectable assessment options that may be plotted (Waypoint Consulting, Inc.)

d. Repeatability. Redundant lines should agree to the level of accuracy to which GPS is capable of measuring. For example, if GPS can measure a 10 km baseline to 1 cm + 1 ppm, the expected ratio of misclosure would be

$$(0.01 \text{ m} + 0.01\text{m}) / 10{,}000 \quad = \quad 1{:}500{,}000 \ \text{(1 part in 500,000)}$$

Repeated baselines should be near the corresponding ratio: (1 cm + 1 ppm) / baseline. Table 10-1 shows an example computation of the agreement between two redundant GPS baselines. Table 10-2 provides additional guidelines for determining the baseline quality if the fixed versus float solution is not readily assessed or available in the baseline processing software (i.e. Trimble variance ratio technique). If the fixed solution meets the criteria in this table, the fixed vector should be used in the adjustment. In some cases the vector passes the RMS test but after adjustment the vector does not fit into the network. If this occurs, the surveyor should try using the float vector in the adjustments or check to make sure stations were occupied correctly.

Table 10-1. Sample Computation of GPS Baseline Repeatability

Baseline Observation Date	X	Y	Z	Distance
Day 203	5000.214	4000.000	7680.500	9999.611
Day 205	5000.215	4000.005	7680.491	9999.607
Difference	0.001	0.005	0.009	

Ratio = $(0.001^2 + 0.005^2 + 0.009^2)^{½}$ / 9999.6 = 0.010 / 9999.6 = 1:967,000 [acceptable]

Table 10-2. Fixed Solution Acceptance Criteria

Distance Between Receivers (km)	RMS Criteria Formulation d = distance between receivers	Formulated RMS Range (cycles)	Formulated RMS Range (meters)
0 - 10	≤ (0.02+(0.004*d))	0.02 - 0.06	0.004 - 0.012
10 - 20	≤ (0.03+(0.003*d))	0.06 - 0.09	0.012 - 0.018
20 - 30	≤ (0.04+(0.0025*d))	0.09 - 0.115	0.018 - 0.023
30 - 40	≤ (0.04+(0.0025*d))	0.115 - 0.14	0.023 - 0.027
40 - 60	≤ (0.08+(0.0015*d))	0.14 - 0.17	0.027 - 0.032
60 - 100	≤ 0.17	0.17	0.032
> 100	≤ 0.20	0.20	0.04

Note:
1. These are only general post-processing criteria that may be superseded by GPS receiver/software manufacturer guidelines; consult those guidelines when appropriate.
2. For lines longer than 20 km, dual-frequency GPS receivers are recommended to meet these criteria.

e. Residual plots. Residual plots depict the data quality of the individual satellite signals. Typically the L1 phase residual error is plotted for all the satellites in view, or for as many that will fit on a computer screen. The plot is developed relative to the satellite chosen for double differencing. Variations about the x-axis are an indicator of noise for a particular satellite. If the satellite is used for double differencing, then no residual error will be shown for that period. Residual plots typically vary around ± 5 mm from the mean. Residual deviations exceeding ± 15 mm are suspect--see Table 10-3. A sample residual plot from a baseline solution is shown in

Figure 10-4. A bias in the residuals might be due to the presence of multipath on that particular satellite measurement.

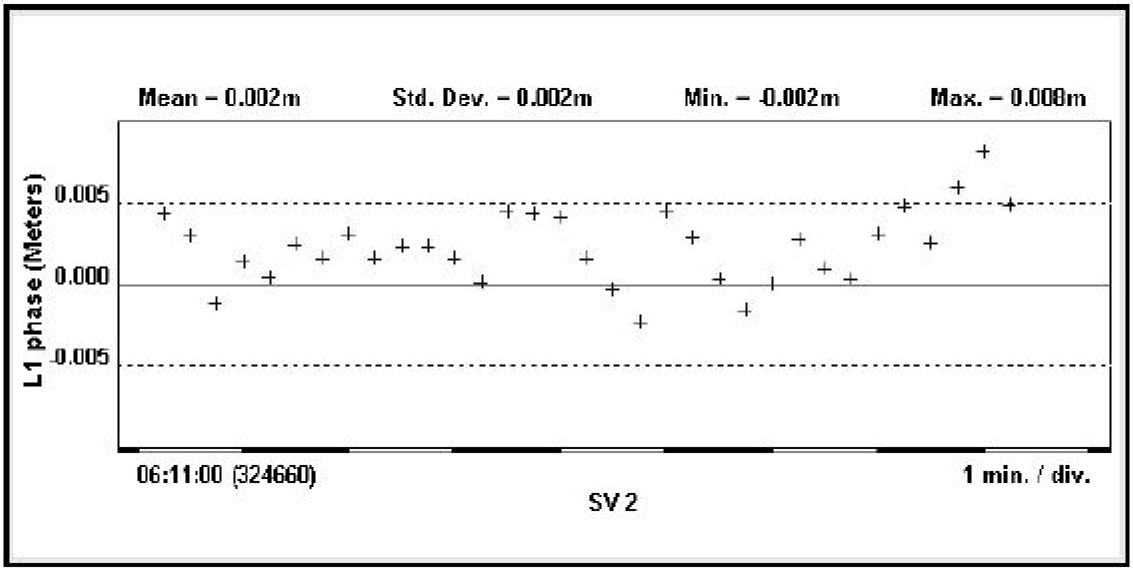


Figure 10-4. Sample residual plot (Trimble Navigation LTD WAVE baseline processing software)

f. Resolving poor baseline data. When baseline statistical data (e.g., reference variance and ratios, RMS, residual plots, etc.) does not meet the various quality checks outlined above, then a number of options are available. These include removing some or all baselines in a session (if possible), changing the elevation mask, removing one or more satellites from the solution, or, if necessary, reobserving the baseline. Eliminating multipath problems is not as easy. It may show up on the residual plot as a sinusoidal wave over time. Multipath is best minimized by good site selection, choke ring antennas, and long session times.

g. Baseline acceptance criteria (Trimble). Trimble Geomatics Office software has three levels of acceptance to assist in evaluating the quality of a processed baseline. These acceptance levels are "Pass" (passes all criteria), "Flag" (one or more quality indicators are marginal but within acceptable tolerances), and "Fail" (one or more quality indicators do not meet acceptable criteria). The "quality indicators" used are: RMS, Reference Variance, and Variance Ratio. The quality indicator Pass/Flag/Fail levels may be modified from the default levels recommended by Trimble.

h. Table 10-3 below summarizes the quality control criteria discussed above that should be used in assessing the adequacy of a baseline reduction.

Table 10-3. Summary of Baseline Processing Quality Control Criteria

Parameter	Allowable Limit
Solution:	
L1 Fixed	preferred for baselines < 10 km
Iono-free fixed	baselines 10 km to 75 km
Iono-free float	acceptable for baselines > 75 km
Reference Variance:	
Nominal value	1.0 to 10.0
Maximum NTE (L1 only)	10.0 (reject if > 20.0)
Maximum NTE (L1 & L2 iono free)	5.0 (reject if > 10.0)
RMS:	
< 5 km baseline	10 mm
< 20 km baseline	15 mm
20-50 km baseline	30 mm
NTE (with precise ephemeris)	50 mm
Variance Ratio for Integer solution	> 1.5 (fixed solution) < 1.5 (float solution) > 1.5 but < 3.0 (flag warning/suspect)
Satellite Residual Plot Deviation NTE	± 15 mm
Repeat baseline agreement	per FGCS standards

10-8. Examples of Baseline Reduction Software Output. The following pages contain example outputs from two processed baselines--one being a medium-length (26 km) ionospheric-free fixed solution and the second being a long (107 km) float solution. These baselines were observed using Ashtech receivers and were processed using Trimble WAVE Version 2.35 software. Explanatory annotations have been added to the first solution, and are similar on the 107 km solution.

IONOSPHERIC FREE FIXED DOUBLE DIFFERENCE BASELINE SOLUTION
MEDIUM LENGTH 26 KM BASELINE LENGTH (San Juan, PR--Puerto Nuevo Flood Control Project--Jacksonville District) (Trimble Navigation LTD--WAVE 2.35)

```
Project Name:     [PUERTO NUEVO FLOOD CONTROL]        02097base
Processed:                                            Thursday, July 11, 2002  12:59
                                                      WAVE 2.35
Solution Output File (SSF):                           00038752.SSF


From Station:                                         COMERIO
Data file:                                            ____1732.RNX
Antenna Height (meters):                              2.122  True Vertical
Position Quality:                                     Point Positioning

WGS 84 Position:      18° 14' 08.746057" N      X     2444052.950
                      66° 12' 52.306905" W      Y    -5545217.951
                      150.797                   Z     1983232.476
```

FROM Station
RINEX file
Antenna hgt to L1 phase ctr

Lat
Lon
ellip hgt

```
To Station:                                           DRYDOCK
Data file:                                            DRYD1732.RNX
Antenna Height (meters):                              1.683  True Vertical

WGS 84 Position:      18° 26' 47.880251" N      X     2452927.215
                      66° 05' 28.532019" W      Y    -5533065.770
                      -41.244                   Z     2005326.605
```

TO Station
RINEX file
Antenna hgt to L1 phase ctr

Lat
Lon
ellip hgt

Observed 5 hr 45 min @ 15-sec intervals

```
Start Time:             6/22/02 12:05:30.00 GPS       (1171 561930.00)
Stop Time:              6/22/02 17:51:15.00 GPS       (1171 582675.00)
Occupation Time       Meas. Interval (seconds):       05:45:45.00          15.00


Solution Type:             Iono free fixed double difference
Solution Acceptability:    Passed ratio test

Ephemeris:                 Broadcast
Met Data:                  Standard
```

Solution Type
Passed Variance Ratio Test

Broadcast ephemeris used

Slope distance and standard error

```
Baseline Slope Distance       Std. Dev. (meters):       26731.603      ±0.000921

                              Forward                    Backward
Normal Section Azimuth:   29° 09' 11.458111"        209° 11' 31.087237"
Vertical Angle:           -0° 31' 55.911654"          0° 17' 27.744089"
```

Forward & back azimuths & vertical angles

```
Baseline Components (meters): dx   8874.265    dy   12152.181    dz  22094.129
Standard Deviations (meters):      ±0.003151        ±0.006977         ±0.002847
                              dn   23344.248   de   13021.638    du  -248.296
                                   ±0.000927        ±0.000838         ±0.008072
                              dh  -192.041          ±0.008073
```

Geocentric (x-y-z) and N-E-Up coordinates and standard errors

Covariance Matrix

$$\begin{vmatrix} \sigma_X^2 & \sigma_{XY} & \sigma_{XZ} \\ \sigma_{YX} & \sigma_Y^2 & \sigma_{YZ} \\ \sigma_{ZX} & \sigma_{ZY} & \sigma_Z^2 \end{vmatrix}$$

```
Aposteriori Covariance Matrix:
9.931756E-006
-2.104302E-005        4.868030E-005
8.247290E-006        -1.865503E-005         8.107185E-006
```

Covariance Matrix: variances & correlations in x-y-z coords

```
Variance Ratio / Cutoff:     17.2        1.5
Reference Variance:           4.845
```

Variance Ratio >>> than 3.0 ... good
Reference Variance < 5.0 ... OK

IONOSPHERIC FREE FIXED DOUBLE DIFFERENCE BASELINE SOLUTION
MEDIUM LENGTH 26 KM BASELINE LENGTH (Continued)

```
Observable      Count/Rejected      RMS:       Iono free phase
                  6904/10           0.024
```

RMS = 24 mm ... < 30 mm ...OK

```
Processor Controls:

[General]
Process start time:            6/22/02 00:02:00 GPS         (1171 518520)
Process stop time:             6/23/02 00:01:30 GPS         (1172 90)
Elevation mask:                                       15 degrees
Maximum iterations:                                   10
Maximum fixable cycle slip:                           600 seconds
Ephemeris:                                            Broadcast
Residuals:                                            Disabled
Antenna phase correction:                             Enabled

[Observables]
L1 phase                                              Enabled
L2 phase                                              Enabled
Squared L2 phase                                      Enabled
L2 P code                                             Enabled
L1 C/A code                                           Enabled
L2 code (encrypted)                                   Enabled

[Static Network]
Baseline generation:                                  All baselines
Min baseline observation time                         120 seconds

[Quality]
Observation editing:               Edit multiplier              3.5
Ratio test:                        Cutoff                       1.5
Reference variance test:           Disabled

[Tropo Correction]
Model:                                                Hopfield
Estimated zenith delay interval:                      2 hours
Use observed mets:                                    Enabled

[Iono Correction]               Ambiguity Pass               Final Pass
Correction:                     Iono free                    Iono free
Applied to:                     Static, Kinematic            Static, Kinematic
Application threshold:          10 kilometers                5 kilometers

[Final Solution]
Final solution type:            L1 Fixed

[Satellites]
Disabled:
```

IONO FREE FLOAT DOUBLE DIFFERENCE BASELINE SOLUTION
LONG 107 KM BASELINE LENGTH (San Juan, PR--Puerto Nuevo Flood Control Project-Jacksonville District)
(Trimble Navigation LTD--WAVE 2.35)

```
Project Name:                                  02097base
Processed:                                     Thursday, July 11, 2002  12:20
                                               WAVE 2.35
Solution Output File (SSF):                    00038632.SSF

From Station:                                  PUR 3
Data file:                                     PUR3177L.RNX
Antenna Height (meters):                       0.000  True Vertical
Position Quality:                              Point Positioning

WGS 84 Position:      18° 27' 46.670415" N                       X      2358177.597
                      67° 04' 01.076161" W                       Y     -5573621.134
                      90.397                                     Z      2007082.890

To Station:                                    PN 007
Data file:                                     00071771.RNX
Antenna Height (meters):                       2.143  True Vertical

WGS 84 Position:      18° 24' 00.838038" N                       X      2456974.099
                      66° 03' 22.369643" W                       Y     -5533057.526
                      -30.064                                    Z      2000457.530

Start Time:           6/26/02 15:06:40.00 GPS        (1172 313600.00)
Stop Time:            6/26/02 19:01:30.00 GPS        (1172 327690.00)
Occupation Time      Meas. Interval (seconds):        03:54:50.00            30.00

Solution Type:                             Iono free float double difference
Solution Acceptability:                    Acceptable

Ephemeris:                                Broadcast
Met Data:                                 Standard
Baseline Slope Distance      Std. Dev. (meters):    107004.909      0.005491

                          Forward                        Backward
Normal Section Azimuth:   93° 33' 38.001101"             273° 52' 48.487830"
Vertical Angle:           -0° 32' 41.904306"              -0° 24' 57.517184"

Baseline Components (meters): dx   98796.502    dy   40563.608     dz       -6625.360
Standard Deviations (meters):       0.008147         0.011887                0.005161
                               dn   -6645.072    de  106793.528     du       -1017.770
                                    0.001934         0.005522                0.014145
                               dh    -120.461        0.014166

Aposteriori Covariance Matrix:   6.636701E-005
                                -6.583171E-005     1.413108E-004
                                 2.961492E-005    -5.613399E-005      2.663405E-005

Reference Variance:                                  5.359

Observable      Count/Rejected      RMS:     Iono free phase    2391/0     0.026

Ambiguity Summary (cycles):               SV       Ambiguity                 Error
Iono free                                 04       -39932607.484             ± 0.251
                                          04       -41411233.741             ± 0.284
                                          05       -19296720.802             ± 0.357
                                          06       -31002785.279             ± 0.187
```

IONO FREE FLOAT DOUBLE DIFFERENCE BASELINE SOLUTION
LONG 107 KM BASELINE LENGTH (Continued)

	09	-34051430.580	± 0.109
	10	25.791	± 0.105
	10	-31703542.767	± 0.157
	15	-20292127.579	± 0.224
	17	-28200241.402	± 0.178
	18	-27143528.717	± 0.333
	23	-25788558.784	± 0.112
	24	-9579372.631	± 0.139
	26	-297437.123	± 0.069

Processor Controls:		
[General]		
Process start time:	6/26/02 11:02:00 GPS	(1172 298920)
Process stop time:	6/26/02 20:59:10 GPS	(1172 334750)
Elevation mask:	15 degrees	
Maximum iterations:	10	
Maximum fixable cycle slip:	600 seconds	
Ephemeris:	Broadcast	
Residuals:	Disabled	
Antenna phase correction:	Enabled	
[Observables]		
L1 phase	Enabled	
L2 phase	Enabled	
Squared L2 phase	Enabled	
L2 P code	Enabled	
L1 C/A code	Enabled	
L2 code (encrypted)	Enabled	
[Static Network]		
Baseline generation:	All baselines	
Min baseline observation time	120 seconds	
[Quality]		
Observation editing:	Edit multiplier	3.5
Ratio test:	Cutoff	1.5
Reference variance test:	Disabled	
[Tropo Correction]		
Model:	Hopfield	
Estimated zenith delay interval:	2 hours	
Use observed mets:	Enabled	
[Iono Correction]	Ambiguity Pass	Final Pass
Correction:	Iono free	Iono free
Applied to:	Static, Kinematic	Static,
Kinematic		
Application threshold:	10 kilometers	5 kilometers
[Final Solution]		
Final solution type:	L1 Fixed	
[Satellites]		
Disabled:		

10-9. <u>Baseline Reduction Summaries</u>. The following list is a typical report of baseline reductions performed over a network. For each baseline, the report lists the solution type, slope distance, reference variance, and ratio (for fixed solutions). Such a report is of value in assessing the overall quality of baselines in a network prior to performing rigorous adjustments. Most of the baselines less than 5 km have fixed solutions. Iono free fixed solutions were obtained in baselines up to and exceeding 100 km, most likely because observation times typically exceeded 6 hours over these lines and the integers were reliably fixed, albeit with smaller ratios. Lines not fixed had float solutions.

Sample Baseline Reduction Project Summary Report (Trimble Navigation LTD)
Puerto Nuevo, San Juan Puerto Rico--July 2002 (RLDA Inc.--Jacksonville District)

Station (From)	(To)	Solution Type	Slope Dist (m)	Ratio	Reference Variance	Entered Ant Hgt (From)	(To)
A 1001	MESAS	Iono free fixed	20841.965	6.6	3.814	1.674	1.559
A 1001	SJH 44	L1 fixed	4426.843	13.3	11.994	2.125	1.714
COMERIO	A 1001	Iono free float	28604.039		3.059	2.122	2.125
COMERIO	DRYDOCK	Iono free fixed	26731.603	17.2	4.845	2.122	1.683
COMERIO	MESAS	Iono free fixed	17436.970	20.4	3.522	2.122	1.504
COMERIO	MP 1	Iono free fixed	26466.871	15.9	3.535	2.122	1.651
COMERIO	SJH 44	Iono free fixed	26791.206	8.0	3.748	2.122	1.714
DRYDOCK	A 1001	L1 fixed	2099.928	3.5	23.933	1.683	2.125
DRYDOCK	SJH 44	L1 fixed	2986.722	4.1	19.858	1.683	1.714
MESAS	A 1001	Iono free fixed	20841.967	1.5	3.761	1.504	2.125
MESAS	DRYDOCK	Iono free fixed	19984.666	16.6	5.558	1.504	1.683
MESAS	SJH 44	Iono free fixed	21973.981	9.3	2.783	1.504	1.714
MP 1	A 1001	L1 fixed	2160.311	4.0	21.693	1.651	2.125
MP 1	PN 007	Iono free fixed	5114.381	19.0	4.801	1.775	2.143
MP 1	PN 030	L1 fixed	4609.931	8.5	27.470	1.775	1.656
MP 1	PUR 3	Iono free fixed	104015.014	2.3	9.541	2.125	0.000
MP 1	RRS 1	L1 fixed	3154.302	50.0	23.107	1.775	0.000
MP 3	TATI	L1 fixed	2605.904	15.4	37.889	1.717	0.000
PN 007	A 1001	Iono free fixed	6568.337	4.3	3.786	2.143	1.674
PN 030	MESAS	Iono free fixed	14465.715	11.5	5.609	1.715	1.559
PN 030	MP 3	L1 fixed	4721.907	30.6	44.769	1.656	1.717
PN 030	PN 007	L1 fixed	2845.129	21.9	34.393	1.656	2.143
PN 030	RRS 1	Iono free fixed	6624.379	14.0	3.073	1.656	0.000
PUR 3	A 1001	Iono free float	104825.284		2.262	0.000	1.674
PUR 3	A 1001	Iono free float	104825.202		2.859	0.000	2.125
PUR 3	COMERIO	Iono free fixed	93542.150	4.3	13.202	0.000	2.122
PUR 3	DRYDOCK	Iono free fixed	103078.898	2.4	19.846	0.000	1.683
PUR 3	MESAS	Iono free fixed	109219.386	3.3	15.726	0.000	1.504
PUR 3	MP 1	Iono free fixed	104015.205	5.4	22.988	0.000	1.651
PUR 3	MP 3	Iono free fixed	105251.631	4.0	10.456	0.000	1.717
PUR 3	PN 007	Iono free float	107004.909		5.359	0.000	2.143
PUR 3	PN 030	Iono free fixed	104207.465	22.5	6.769	0.000	1.715
PUR 3	RRS 1	Iono free fixed	106835.866	7.8	5.010	0.000	0.000
PUR 3	SJH 44	Iono free fixed	100402.386	3.8	10.331	0.000	1.621
PUR 3	SJH 44	Iono free float	100402.461		2.740	0.000	1.714
PUR 3	SJH 44	Iono free fixed	100402.341	3.7	8.679	0.000	1.666
PUR 3	SJHL11RM	Iono free float	101479.646		3.355	0.000	2.125
PUR 3	TATI	Iono free fixed	104537.036	3.8	8.956	0.000	0.000
RRS 1	PN 007	Iono free fixed	5639.477	9.6	4.974	0.000	2.143
SJH 44	A 1001	L1 fixed	4426.901	4.8	12.273	1.621	1.674
SJH 44	MESAS	Iono free fixed	21973.970	8.4	5.657	1.621	1.559
SJH 44	MP 1	L1 fixed	4201.519	2.9	21.210	1.611	2.125

Sample Baseline Reduction Project Summary Report (Trimble Navigation LTD)--Continued
Puerto Nuevo, San Juan Puerto Rico--July 2002 (RLDA Inc.--Jacksonville District)

Station (From)	(To)	Solution Type	Slope Dist (m)	Ratio	Reference Variance	Entered Ant Hgt (From)	(To)
SJH 44	MP 1	L1 fixed	4201.586	38.9	25.690	1.666	1.775
SJH 44	MP 3	Iono free fixed	5319.058	27.9	5.499	1.666	1.717
SJH 44	PN 007	Iono free fixed	9092.812	1.7	5.592	1.621	2.143
SJH 44	PN 030	Iono free fixed	7680.376	20.4	6.122	1.666	1.656
SJH 44	PUR 3	Iono free fixed	100402.358	8.0	6.727	1.611	0.000
SJH 44	RRS 1	Iono free fixed	6481.387	61.2	4.617	1.666	0.000
SJH 44	SJHL11RM	L1 fixed	3556.239	2.1	11.339	1.621	2.125
SJH 44	TATI	Iono free fixed	6204.031	8.0	5.361	1.666	0.000
SJHL11RM	A 1001	L1 fixed	4682.576	10.0	7.149	2.125	1.674
SJHL11RM	MESAS	Iono free float	18419.372		5.138	2.125	1.559
SJHL11RM	PN 007	Iono free fixed	6188.465	1.8	4.479	2.125	2.143
SJHL11RM	PN 030	L1 fixed	4247.108	1.6	31.691	2.125	1.715
TATI	PN 007	L1 fixed	2943.738	15.0	29.619	0.000	2.143
TATI	RRS 1	L1 fixed	4586.193	17.5	36.664	0.000	0.000

**** End of Report *****

Other useful baseline reduction summaries include satellite tracking summaries depicting signal losses, cycle slips, or residual plots for each satellite observed. These plots may be used to decide whether poor satellites should be removed from the reduction. In addition, graphical summary plots are much easier to review than pages of statistical text. A unique type of graphical baseline quality plot is shown in the following figure (Figure 10-5) from Waypoint Consulting, Inc. In this plot, a quality number (from one to six) is computed using seven different baseline reduction statistics. A "good" quality value of "1" would represent a fixed integer solution, while values of 5-6 indicate worse DGPS accuracies. Each epoch is plotted with a certain color depending on its quality number, which allows for a quick visual inspection. Waypoint GrafNAV baseline reduction software contains options for 26 different types of graphical plots for use in assessing baseline quality. These include plots such as DOPs, L1 phase RMS, C/A-code RMS, forward/reverse separation, quality number, standard deviation, L1 Doppler RMS, ambiguity drift (i.e. solution stability), forward/reverse weighting, and satellite elevation and loss of lock plots for each satellite being tracked. Other commercial baseline reduction software provides options for similar graphical assessment features.

10-10. <u>Baseline Reduction in Mapping Grade GPS Receivers</u>. Small hand-held, mapping grade GPS receivers are easy and efficient to operate, with minimal training. Some are capable of achieving decimeter-level accuracy when paired and post-processed with a nearby CORS base station receiver. The software for performing the baseline reduction and position computation is fairly simple to operate. The following listing is an example of GPS positions logged by a hand-held Trimble GeoExplorer on points that potentially impact maintenance dredging limits. The resultant accuracy of the points is about 2 feet (95% RMS), which is more than adequate for defining dredging limits. The baseline reduction was performed using a nearby CORS reference station in Miami, FL.

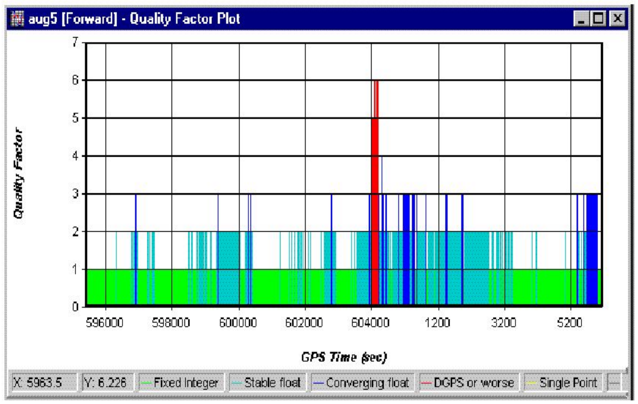


Figure 10-5. Typical quality factor plot for a baseline
(Waypoint Consulting, Inc. GrafNAV)

LOCATIONS OF DOCKS AND BULKHEADS ALONG THE MIAMI RIVER
Sample results from post-processed differential carrier observations using nearest CORS station in Miami, FL.
GeoExplorer carrier phase differential data--5-sec update rate. All Float solutions

Point	Ref No.	Point Description	FL SP Coordinate X	FL SP Coordinate Y	Obs	95% Precision * Y	95% Precision * X	95% Precision * X-Y	95% Precision * Z
38-1	38	Concrete Bulkhead, in line with East edge of Building	920,742.89	522,331.98	720	0.6 ft	0.6 ft	0.8 ft	0.9 ft
38-2	38	Concrete Bulkhead, in line with West edge of Building	920,696.28	522,324.20	120	1.0 ft	1.0 ft	1.3 ft	1.6 ft
94-3	94	Northeast corner of concrete pier @ La Coloma Marina	918,350.11	525,035.11	723	0.5 ft	0.5 ft	0.7 ft	0.8 ft
94-4	94	Northwest corner of concrete pier @ La Coloma Marina	918,343.00	525,039.66	101	1.2 ft	1.2 ft	1.6 ft	2.7 ft
110-5	110	Point on corrugated steel bulkhead	917,156.88	525,821.07	676	0.9 ft	0.9 ft	1.1 ft	1.6 ft
116-6	116	Northeast corner of wooden pier @ Langer-Krell Marine Electronics	916,946.64	525,963.01	724	0.5 ft	0.5 ft	0.6 ft	0.7 ft
46-7	46	Northeast corner of wooden pier	919,868.69	522,728.61	794	0.5 ft	0.5 ft	0.7 ft	1.4 ft
46-8	46	Point on concrete bulkhead	919,736.36	522,881.29	200	1.8 ft	1.8 ft	2.3 ft	6.8 ft **
177-9	177	Southwest corner of finger pier @ Hurricane Cove Marina	910,470.96	528,929.65	724	0.6 ft	0.6 ft	0.8 ft	0.8 ft
177-10	177	Southwest corner of finger pier @ Hurricane Cove Marina	910,574.96	528,899.27	181	0.9 ft	0.9 ft	1.2 ft	2.7 ft
177-11	177	Southwest corner of finger pier @ Hurricane Cove Marina	910,692.35	528,851.62	168	1.2 ft	1.2 ft	1.5 ft	3.8 ft

* computed by Trimble Pathfinder Office software
** apparent multipath problem at this point

10-11. Field/Office Loop Closure Checks. Post-processing criteria are aimed at an evaluation of a single baseline. In order to verify the adequacy of a group of connected baselines, one must perform a loop closure computation on the formulated baselines. When GPS baseline traverses or loops are formed, their linear (internal) closure should be determined in the field. If job requirements are less than Third-Order (1:10,000 or 1:5,000), and the internal loop/traverse closures are very small, a formal (external) adjustment may not be warranted.

a. Loop closure software packages. The internal closure determines the consistency of the GPS measurements. Internal closures are applicable for loop traverses and GPS networks. It is required that one baseline in the loop be independent. An independent baseline is observed during a different session or different day. Today, most post-processing software packages come with a loop closure program, such as the example in Figures 10-6 through 10-9. These loop closure routines allow for a graphical selection of baselines in a network from which a loop closure is automatically computed in real-time. Refer to the individual manufacturer post-processing user manuals for a discussion on the particulars of the loop closure program included with the user hardware.

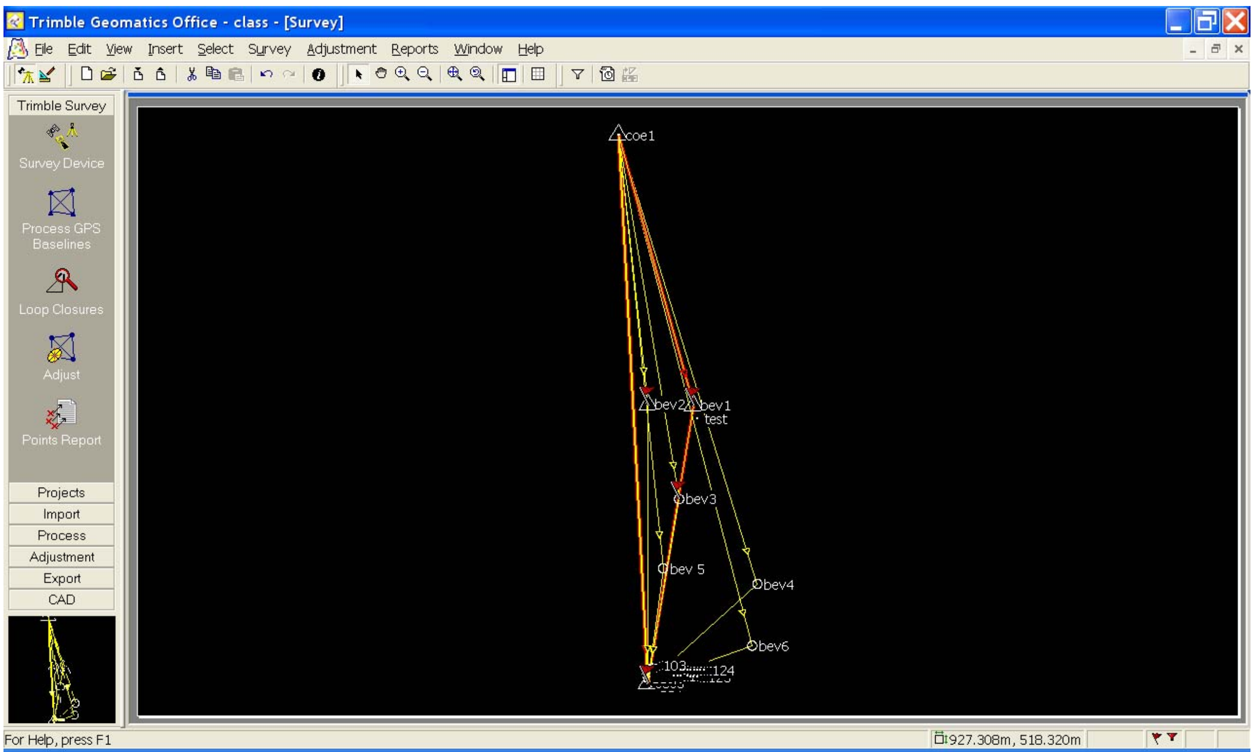


Figure 10-6. Selected baselines for Loop Closure Report (Trimble Geomatics Office)

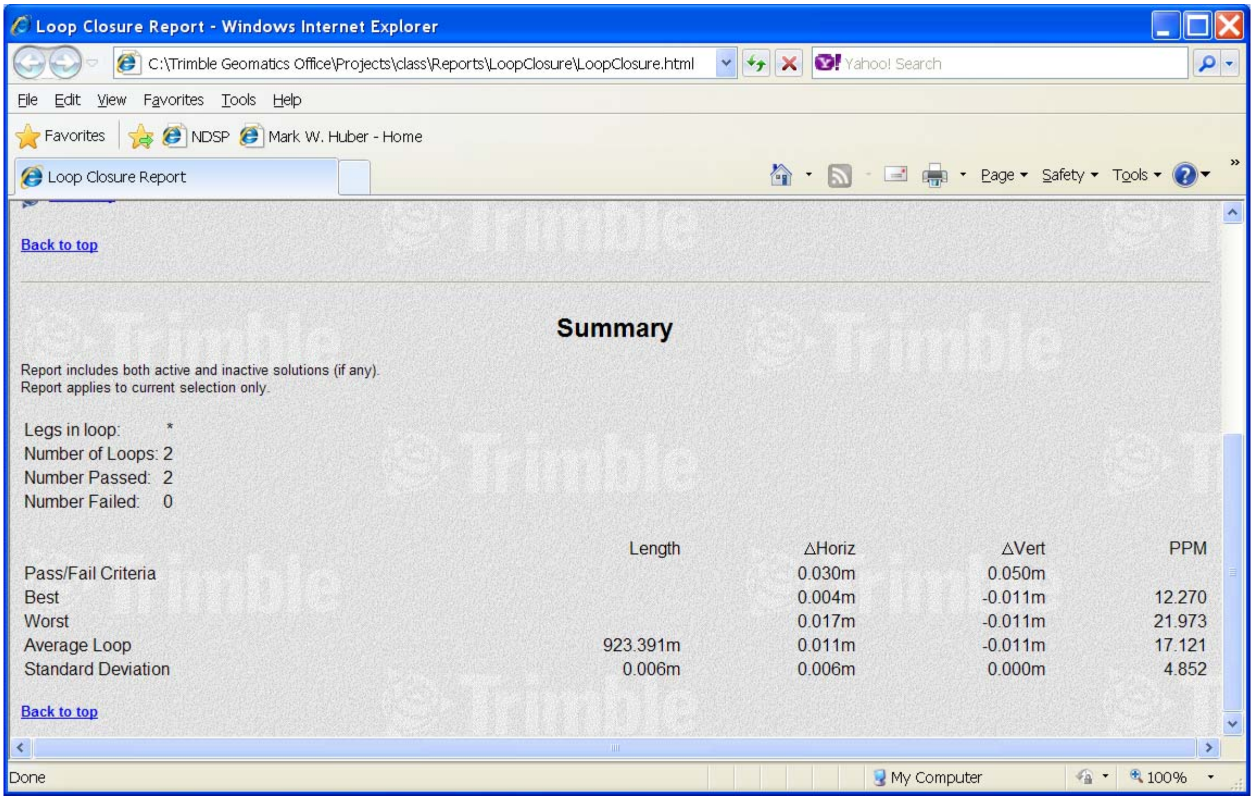


Figure 10-7. Loop closure report on selected baselines (Trimble Geomatics Office)

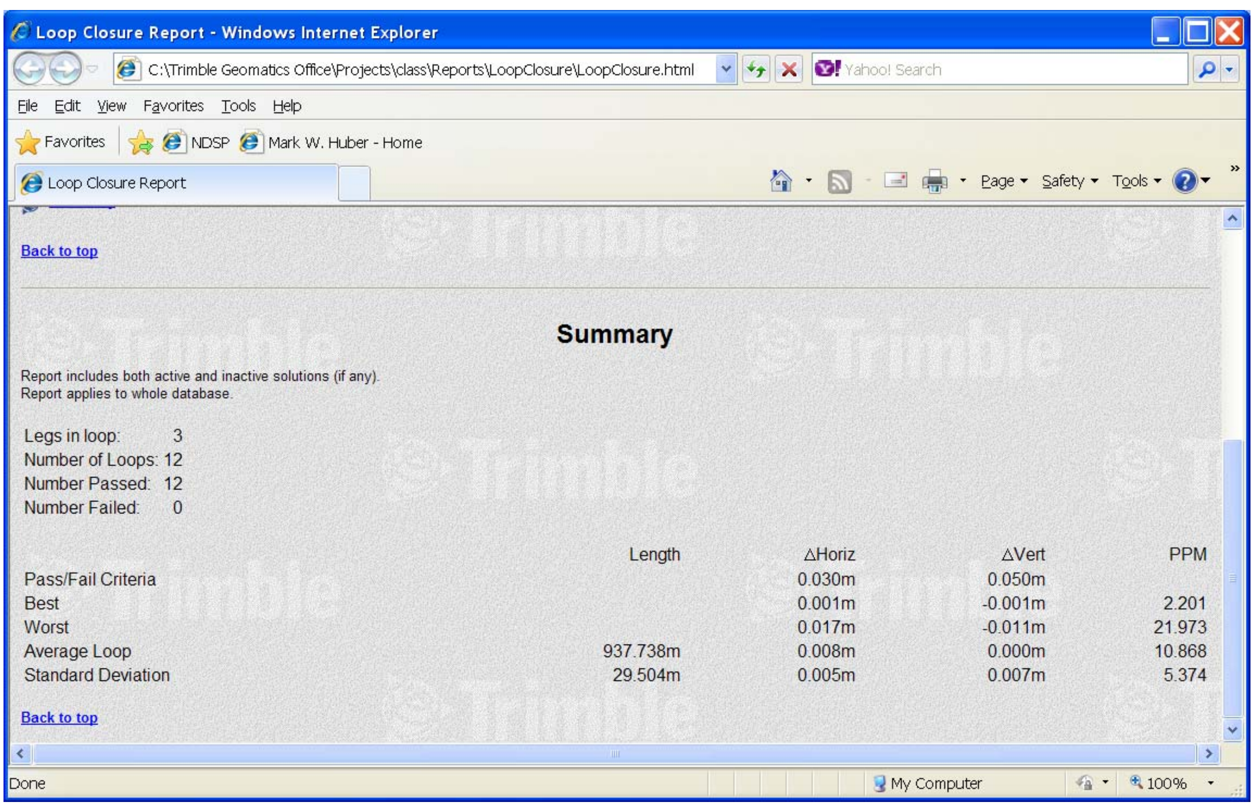


Figure 10-8. Loop closure report on all possible loops (Trimble Geomatics Office)

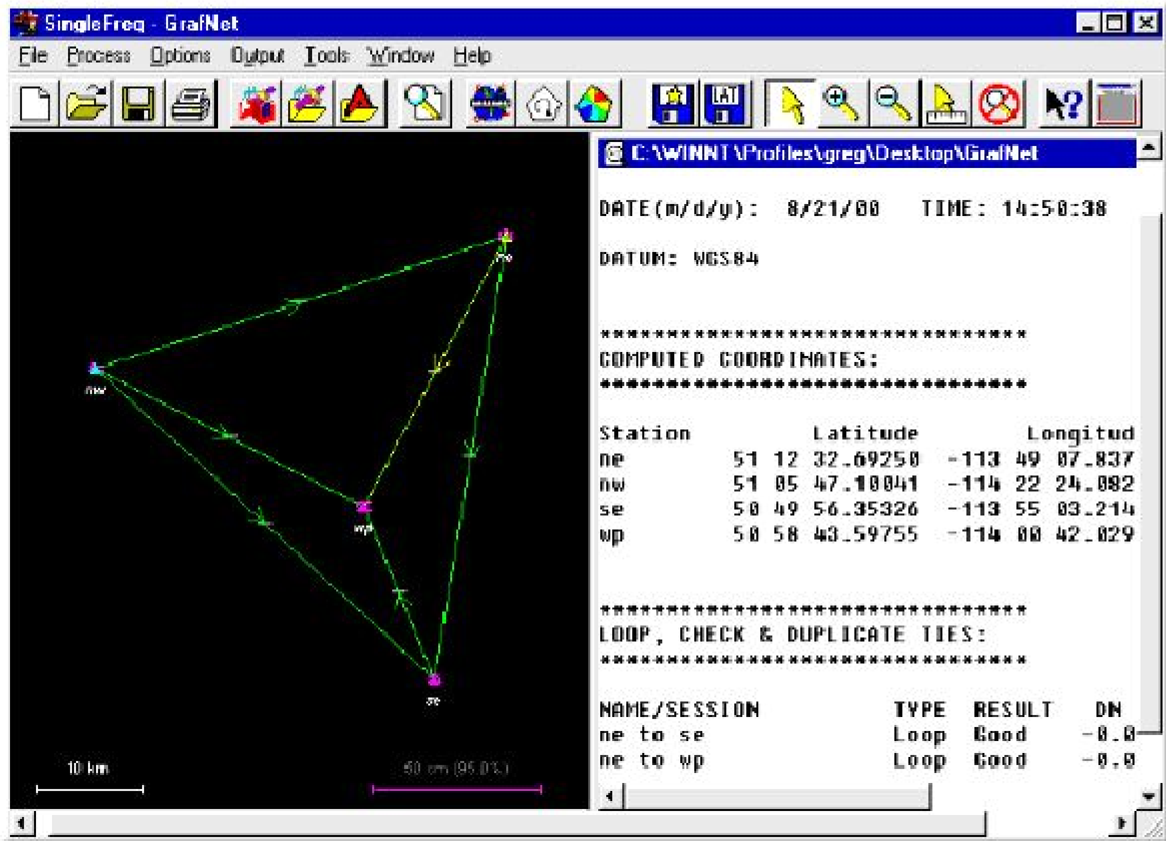


Figure 10-9. Loop closure diagram (Waypoint GrafNet)

b. General loop closure procedure. If the post-processing software package does not contain a loop closure program, the user can perform a loop closure as shown below.

(1) List the Δx-Δy-Δz differences and length of the baseline being used as shown in Table 10-4.

Table 10-4. Loop Closure Procedure

Baseline	Julian Day	Session	Δx	Δy	Δz	ΔDistance
Baseline #1	Day	#	Δx #1	Δy #1	Δz #1	Distance #1
Baseline #2	Day	#	Δx #2	Δy #2	Δz #2	Distance #2
Baseline #3	Day	#	Δx #3	Δy #3	Δz #3	Distance #3

(2) Sum the Δx -Δy- Δz differences and distance components for all baselines used in the loop closure. For instance, for the baselines in Table 10-4, the summation would be ΣΔx, ΣΔy, ΣΔz, and ΣDistances or (Δx#1 + Δx#2 + Δx#3), (Δy#1 + Δy#2 + Δy#3), (Δz#1 + Δz#2 + Δz#3), and (ΔDistance#1 + ΔDistance#2 + ΔDistance#3), respectively.

(3) Once summation of the Δx, Δy, Δz, and ΔDistance components has been completed, the square of each of the summations should be added together and the square root of this sum then taken. This resultant value is the misclosure vector for the loop. This relationship can be expressed in the following manner:

$$m = [(\Sigma \Delta x^2) + (\Sigma \Delta y^2) + (\Sigma \Delta z^2)]^{1/2} \qquad \text{(Eq 10-7)}$$

where

m = misclosure for the loop
$\Sigma \Delta x$ = sum of all Δx vectors for baselines used
$\Sigma \Delta y$ = sum of all Δy vectors for baselines used
$\Sigma \Delta z$ = sum of all Δz vectors for baselines used

(4) The loop misclosure ratio may be calculated as follows:

$$\text{Loop misclosure ratio} = m/L \qquad \text{(Eq 10-8)}$$

where
L = total loop distance (perimeter distance)

(5) The resultant value can be expressed in the following form:

1: Loop Misclosure Ratio

with all units for the expressions being in terms of the units used in the baseline formulations (e.g., m, ft, mm, etc.).

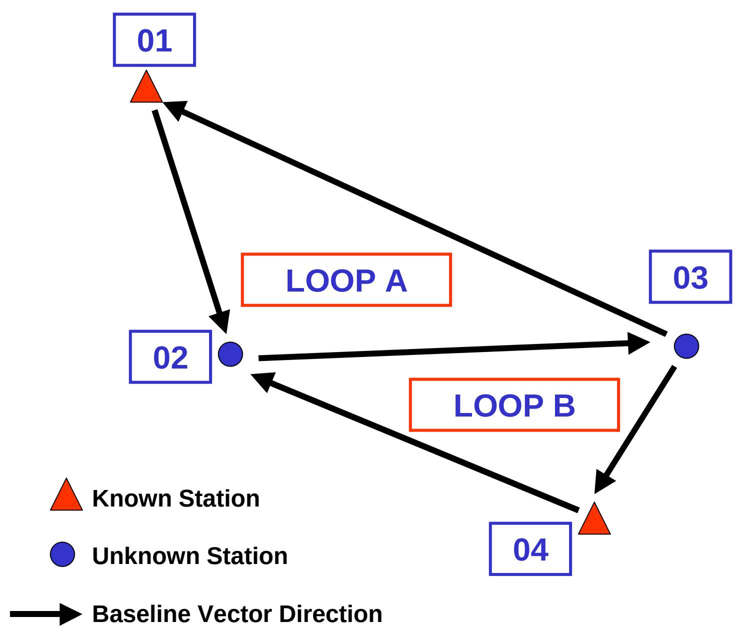


Figure 10-10. Internal loop closure scheme

c. Sample loop closure computation. Figure 10-10 shows two loops that consist of four stations. Stations 01 and 04 were known control stations. During Session A on day 065, three GPS receivers observed the baselines between Stations 01, 02, and 03 for approximately 1 hour. The receivers were then turned off and the receiver at Station 01 was moved to Station 04. The tripod heights at Stations 02 and 03 were adjusted. The baselines between Stations 02, 03, and 04 were then observed during Session B, day 065. This provided an independent baseline for both loops.

(1) The closure for loop 01-02-03 is computed with the vectors 01-02 and 01-03, day 065, session A, and the vector 02-03, day 065, session B. The vector 02-03 from session B provides an independent baseline. The loop closure is determined by arbitrarily assigning coordinate values of zero to station 01 (X=0, Y=0, Z=0). The vector from 01-02 is added to the coordinates of Station 01. The vector from 02-03, session B, is added to the derived coordinates of Station 02. The vector from 03-01 is then added to the station coordinates of 02. Since the starting coordinates of Station 01 were arbitrarily chosen as zero, the misclosure is then the computed coordinates of Station 01 (dx, dy, dz). The vector data are listed in Table 10-5.

Table 10-5. Vector Data for Stations 01, 02, and 03

Baseline	Julian Day	Session	ΔX	ΔY	ΔZ	ΔDistance
01-02	065	A	-4077.865	-2877.121	-6919.829	8531.759
02-03	065	B	7855.762	-3129.673	688.280	8484.196
03-01	065	A	-3777.910	6006.820	6231.547	9443.869

(2) To determine the relative loop closure, the square root of the sum of the squares of the loop misclosures (mx, my, mz) is divided into the perimeter length of the loop:

$$\text{Loop misclosure ratio} = [\, 1 / L \,] \cdot [\, (\Delta x^2) + (\Delta y^2) + (\Delta z^2) \,]^{½} \qquad \text{(Eq 10-9)}$$

Where the perimeter distance (L) = Distance 01-02 + Distance 02-03 + Distance 03-01, or:

$$L = 8531.759 + 8484.196 + 9443.869 = 26{,}459.82$$

And where distance 03-01 was computed from:

$$(-3777.912^2 + 6006.8202^2 + 6231.5472^2)^{1/2} = 9443.869$$

(Other distances are similarly computed)

Summing the misclosures in each coordinate:

$$\Delta x = -4077.865 + 7855.762 - 3777.910 = -0.0135$$

$\Delta y = -2877.121 - 3129.673 + 6006.820 = +\ 0.0264$
$\Delta z = -6919.829 + 688.280 + 6231.547 = -\ 0.0021$

then the loop misclosure is

$$(\Delta x^2 + \Delta y^2 + \Delta z^2)^{1/2} = 0.029$$

Loop Misclosure Ratio = 0.029/26,459.82 or (approximately) 1 part in 912,000 (1:912,000)

(3) This example is quite simplified; however, it illustrates the necessary mechanics in determining internal loop closures. The values Δx , Δy, and Δz are present in the baseline output files. The perimeter distance is computed by adding the distances between each point in the loop.

d. External closures. External closures are computed in a similar manner to internal loops. External closures provide information on how well the GPS measurements conform to the local coordinate system. Before the closure of each traverse is computed, the latitude, longitude, and ellipsoid height must be converted to geocentric coordinates (X,Y,Z). If the ellipsoid height is not known, geoid modeling software can be used with the orthometric height to get an approximate ellipsoid height. The external closure will aid the surveyor in determining the quality of the known control and how well the GPS measurements conform to the local network. If the control stations are not of equal precision, the external closures will usually reflect the lower-order station. If the internal closure meets the requirements of the job, but the external closure is poor, the surveyor should suspect that the known control is deficient and an additional known control point should be tied into the system.

10-12. On-Line Positioning User Service (OPUS). OPUS is a free on-line baseline reduction and position adjustment service provided by the National Geodetic Survey. The static OPUS solution provides an X-Y-Z baseline reduction and position adjustment relative to three nearby national CORS reference stations. OPUS is ideal for establishing accurate horizontal control relative to the NSRS. It can also be used as a quality control check on previously established control points. OPUS processes your GPS data files with the same models and tools which help manage the CORS network, resulting in coordinates which are both highly accurate and highly consistent with other users. Your computed NSRS position is sent privately via email, and, if you choose, can also be shared publicly via the NGS database.

As of June 2010, NGS was still beta testing OPUS Projects, its web-based application to plan, administer and process multi-day GPS campaign data. OPUS Projects was designed so all administrative and data processing tasks associated with a GPS campaign could be managed through a number of web pages and tools at NGS. The web pages, in turn, will be linked to a number of cgi-based programs to perform several administrative tasks such as creating new projects, adding supplementary data to a project, processing GPS data or modifying an existing project. A project manager could then oversee a number of GPS projects with a web browser, either from their office computer or from a remote location via the Internet. (Weston, Mader and Soler)

Figure 10-11. On-Line Positioning User Service (OPUS) Web input screen

a. On-line data input. OPUS is accessed at the following web page address: www.ngs.noaa.gov/OPUS. The input screen is shown in Figure 10-11 where the required information is entered/selected (i.e., e-mail address, observation data file, antenna type, and antenna height). The antenna height in meters is the vertical (not slope) distance measured between the monument/benchmark and the antenna reference point (ARP). The ARP is almost always the center of the bottom-most, permanently attached, surface of the antenna. In order for OPUS to properly compute the vertical position of a given monument/benchmark, the user must provide the correct antenna height (as described above) AND select the correct antenna type. Selection of the correct antenna type enables OPUS to properly reduce the vertical position of the antenna phase center (which is solved for directly) to the vertical position of the ARP, as the phase center offset with respect to the ARP is unique for each antenna type. The final vertical position of the monument/benchmark is computed in OPUS by deducting the antenna height (vertical distance from monument/benchmark to ARP) from the ARP vertical position.

b. Solution. The processing method used to obtain your solution is dependent upon the content and duration of your data file. For dual-frequency observation files of 2-hours or longer, static processing is performed with NGS' PAGES software. Your coordinates are averaged from three independent single-baseline solutions computed by double-differenced, carrier-phase measurements between your data file and each of 3 surrounding CORS (see Figure 10-12). Shorter dual-frequency data files, between 15-minutes and 2-hours duration, are processed rapid-statically using RSGPS software. RSGPS employs more aggressive algorithms to resolve carrier phase ambiguities but has more stringent data continuity and geometry requirements; therefore, there are many remote areas of the country in which it will not work (above text and figure excerpted from http://www.ngs.noaa.gov/OPUS/about.html)

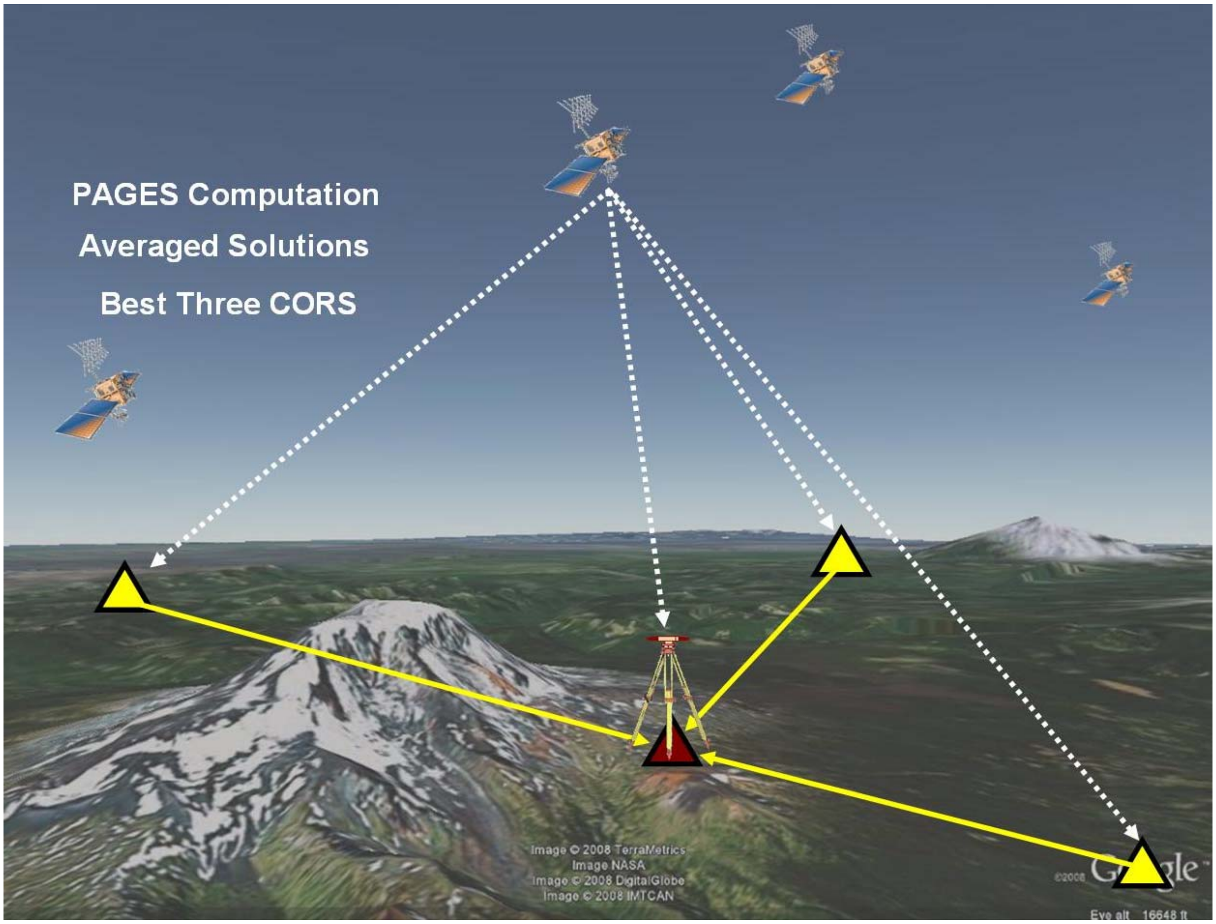


Figure 10-12. On-Line Positioning User Service (OPUS) Solution

c. Accuracy. Under ideal conditions, OPUS can easily resolve most positions to within centimeter accuracy. Estimating the accuracy for a specific data file is difficult, however, as formal error propagation is notoriously optimistic for GPS reductions. Instead, the peak-to-peak error, or error range, is provided for each coordinate component (XYZ, Φλh and H). The peak-to-peak error is the difference between the maximum and the minimum value of a coordinate obtained from the 3 baseline solutions, as shown in Figure 10-13. Please note that peak-to-peak accuracy estimates depend upon freedom from systematic error. Any misidentification of the antenna type or height, local multipath or adverse atmospheric conditions will not be averaged away by the 3 "independent" CORS solutions. The advantage of the peak-to-peak error measure is that the error range also reflects any error in the CORS reference coordinates. On the average, one should obtain larger peak-to-peak errors in the NAD 83 coordinates, when compared to the ITRF coordinates. This is due to the procedures used to derive the CORS coordinates. To serve NGS users, the NAD 83 coordinates of the National CORS are updated less frequently than ITRF coordinates. However, this also results in the NAD 83 coordinates being somewhat less accurate. For rapid static: Absent any warning messages, the best estimates of coordinate accuracies are the standard deviations reported by single baseline analysis. Typically, the actual error is less than these estimated accuracies more than 95 percent of the time, RSGPS statistics (above text and figure excerpted from http://www.ngs.noaa.gov/OPUS/about.html).

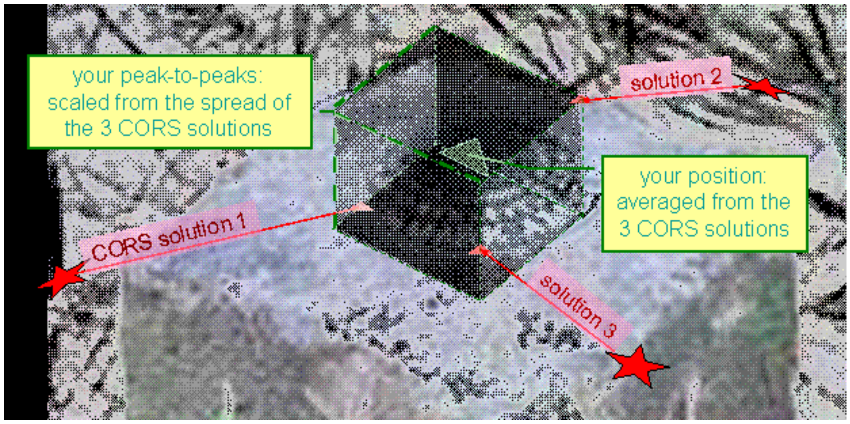


Figure 10-13. On-Line Positioning User Service (OPUS) Peak-to-Peak Error

d. OPUS DB. Through the NGS Online Positioning User Service (OPUS), user may register and publish as part of the NSRS the results of their own OPUS solutions. In making this service available to the professional surveying community, NGS expects that users will share only quality data from marks of permanent public interest. Users are advised that, although OPUS will enforce some quality limits, it will not identify all errors. Professional discretion is necessary to maintain the integrity of this archive. Users should ensure quality by using trained personnel, geodetic-grade instrumentation, and field procedures which minimize blunders. Monumentation must be stable, permanent, unique, and recoverable. The basic requirements for publishing are as follows:

High-Quality OPUS Solution:
- > 4 hour duration, < 48hrs (can't cross GMT midnight more than once)
- > 70% observations used
- > 70% ambiguities fixed
- < 0.04m horizontal peak-to-peak
- < 0.08m vertical peak-to-peak
- < 0.03m RMS
- IGS precise or rapid orbits (available next day)
- see using OPUS (http://www.ngs.noaa.gov/OPUS/about.html#input)

Descriptive Metadata:
- quality survey mark (http://www.ngs.noaa.gov/marks/descriptors.shtml#setting)
- photos of mark & equipment
- mark details (name, type, stability)
- description to aid mark recovery
- preview mark description form: (http://www.ngs.noaa.gov/OPUS/newMark.jsp?seq=000350999?rnxf=junk365o.060)
- help file for form elements: (http://www.ngs.noaa.gov/marks/descriptors.shtml)

Field Procedures:

fixed height tripod recommended
brace tripod with sandbags or chain
verify antenna height and plumb
calibrate your tripod or tribrach height & plumb
antenna type properly identified
(http://www.ngs.noaa.gov/OPUS/about.html#antennatype)
antenna height > 0.1 m
(http://www.ngs.noaa.gov/OPUS/about.html#antennaheight)
more suggestions at HARN guidelines:
(http://www.ngs.noaa.gov/PROJECTS/GPSmanual/observations.htm#procedures)

e. Recommendation for best static results. The single best way to get a more accurate result is to submit a longer time span of data. While NGS currently accepts a minimum of 2 hours of data, they recommend at least 4 hours of data. As an example, their height modernization surveys, which routinely achieve 1 cm, one sigma, ellipsoidal height accuracy, require three or more sessions, each at least 5.5 hours long, on two or more days, where two of the observation time spans are offset to sample different satellite geometries. While good results can be obtained with 2 hour solutions, they have found that longer time spans are consistently more reliable (above text excerpted from http://www.ngs.noaa.gov/OPUS/about.html).

f. Sample Solutions. The following examples were performed to locate aerial photo control targets to be used in aerotriangulation. In the first solution below, 3.5 hours of dual-frequency data were recorded in October 2009 and processed in OPUS Static against three optimally selected CORS points. In the second solution, 30 minutes of dual-frequency data were recorded and processed in OPUS Rapid-Static against nine nearby and surrounding CORS points.

OPUS Solution: Photo Control Point in Southwest Louisiana

```
 FILE: BBD01109.292 000132273

                              NGS OPUS SOLUTION REPORT
                              ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: www.ngs.noaa.gov/OPUS/Using_OPUS.html#accuracy

      USER: sgi_rmf@bellsouth.net                    DATE: October 20, 2009
RINEX FILE: bd01292n.09o                             TIME: 21:51:26 UTC


  SOFTWARE: page5  0909.08 master29.pl 081023      START: 2009/10/19  13:41:00
EPHEMERIS: igr15541.eph [rapid]                     STOP: 2009/10/19  17:14:00
  NAV FILE: brdc2920.09n                         OBS USED:  8043 /  8417   :  96%
  ANT NAME: AERAT2775_42    NONE              # FIXED AMB:    35 /    36   :  97%
ARP HEIGHT: 1.582                            OVERALL RMS: 0.011(m)

REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)             ITRF00 (EPOCH:2009.7990)

         X:      -322455.235(m)   0.016(m)          -322455.942(m)   0.016(m)
         Y:     -5470015.148(m)   0.019(m)         -5470013.682(m)   0.019(m)
         Z:      3253416.032(m)   0.029(m)          3253415.838(m)   0.029(m)
```

```
       LAT:   30 52  6.95239      0.015(m)        30 52  6.97068      0.015(m)
     E LON:  266 37 34.82642      0.015(m)       266 37 34.79660      0.015(m)
     W LON:   93 22 25.17358      0.015(m)        93 22 25.20340      0.015(m)
    EL HGT:           36.267(m)   0.031(m)                34.947(m)   0.031(m)
ORTHO HGT:           63.350(m)   0.077(m) [NAVD88 (Computed using GEOID03)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 15)         SPC (1702 LA S)
Northing (Y) [meters]     3415099.189           264292.723
Easting (X)  [meters]      464279.275           804875.954
Convergence  [degrees]    -0.19171576          -1.02018889
Point Scale                0.99961574           1.00004020
Combined Factor            0.99961005           1.00003451

US NATIONAL GRID DESIGNATOR: 15RVQ6427915099(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF7069 1ULM U OF LA AT MONROE CORS ARP     N323144.501 W0920433.234  221418.1
DF3567 CSAL MONTICELLO COOP CORS ARP       N333531.136 W0914853.230  335796.0
DF7054 SIHS SICILY ISLAND CORS ARP         N315036.158 W0913919.561  195969.0

                 NEAREST NGS PUBLISHED CONTROL POINT
BK3069      CARTER                         N305105.640 W0932113.280    2690.0

This position and the above vector components were computed without any
knowledge by the National Geodetic Survey regarding the equipment or
field operating procedures used.
```

OPUS-RS Solution: Photo Control Point in Southwest Louisiana

```
FILE: BBD02209.292 001018324

                              NGS OPUS-RS SOLUTION REPORT
                              ========================

      USER: sgi_rmf@bellsouth.net                     DATE: October 20, 2009
RINEX FILE: bd02292s.09o                              TIME: 21:48:04 UTC


  SOFTWARE: rsgps  1.32 RS12.prl 1.54               START: 2009/10/19 18:34:35
EPHEMERIS: igr15541.eph [rapid]                      STOP: 2009/10/19 19:06:20
  NAV FILE: brdc2920.09n                         OBS USED:  1782 /  2205   :  81%
  ANT NAME: AERAT2775_42                      QUALITY IND.  11.37/  9.54
ARP HEIGHT: 1.958                          NORMALIZED RMS:        0.313


REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2009.79941)

         X:      -322422.570(m)   0.008(m)          -322423.277(m)   0.008(m)
         Y:     -5469846.990(m)   0.034(m)         -5469845.524(m)   0.034(m)
         Z:      3253701.305(m)   0.018(m)          3253701.111(m)   0.018(m)

       LAT:   30 52 17.73204      0.008(m)        30 52 17.75032      0.008(m)
     E LON:  266 37 35.68142      0.007(m)       266 37 35.65160      0.007(m)
     W LON:   93 22 24.31858      0.007(m)        93 22 24.34840      0.007(m)
    EL HGT:           36.904(m)   0.038(m)                35.584(m)   0.038(m)
ORTHO HGT:           63.984(m)   0.080(m) [NAVD88 (Computed using GEOID03)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 15)         SPC (1702 LA S)
Northing (Y) [meters]     3415430.959           264624.255
Easting (X)  [meters]      464303.089           804904.575
Convergence  [degrees]    -0.19161065          -1.02007014
Point Scale                0.99961572           1.00004099
Combined Factor            0.99960993           1.00003520
```

```
US NATIONAL GRID DESIGNATOR: 15RVQ6430315430(NAD 83)



                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DF7048 LESV LEESVILLE CORS ARP             N310832.877 W0931608.243   31645.6
DG5390 OAKH OAKDALE HS CORS ARP            N304855.806 W0923925.103   68816.7
DF7992 LSUA LSU-ALEXANDRIA CORS ARP        N311043.577 W0922444.335   97880.5
DG5396 1NSU NORTHWESTERN S.U. CORS ARP     N314502.861 W0930551.343  100955.0
DH3610 TXLF LUFKIN CORS ARP                N312122.843 W0944305.912  139089.6
DH3612 TXLI LIBERTY CORS ARP               N300321.180 W0944615.679  161832.7
DG7396 SHRV SHREVEPORT CORS ARP            N322539.651 W0934216.664  175372.0
DF7054 SIHS SICILY ISLAND CORS ARP         N315036.158 W0913919.561  195765.1
AF9521 LKHU LAKE HOUSTON CORS ARP          N295448.440 W0950844.689  200720.8

                 NEAREST NGS PUBLISHED CONTROL POINT
BK3069      CARTER                         N305105.640 W0932113.280    2919.8

This position and the above vector components were computed without any
knowledge by the National Geodetic Survey regarding the equipment or
field operating procedures used.
```

As is indicated by the results above, OPUS solutions are typically more stable and accurate horizontally. Even when the ellipsoid height uncertainty is small, careful consideration should be given to potential difference between orthometric heights derived through the NGS "active" control network (i.e., the CORS network stations together with the particular hybrid geoid model on which the computed orthometric heights depend) and orthometric heights of nearby control points that are part of the NGS "passive" control network (i.e., conventionally published vertical control in the Survey Mark Datasheets) Following is an example OPUS-DB datasheet (Figure 10-14) of a point observed and published as a result of a successful dual-frequency GPS observation and OPUS Static processing run. Below that is the standard Survey Mark Datasheet for the same monument. Note the different orthometric height values (14.19 meters versus 14.32 meters respectively or about a 0.4' difference).

SURVEY DATASHEET (Version 1.0) Page 1 of 1

SURVEY DATASHEET (Version 1.0)

PID: BW0055
Designation: G 208 RESET 1976
Stamping: G208 RESET 1976
Stability: Monument will probably hold position well
Setting: Copper-clad steel rod without sleeve (10FT+ or 3.048M+)
Mark Condition: G
Description:
Observed: 2009-12-03T18:15:00Z See Also 2002-11-06
Source: OPUS - page5 0909.08

Close-up View

REF_FRAME: NAD_83 (CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

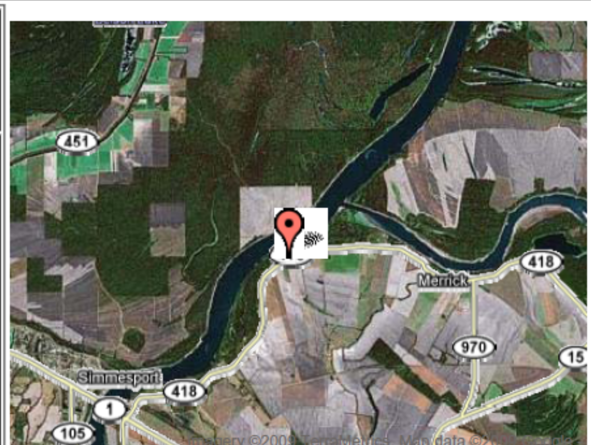
LAT:	31° 0' 29.21285"	± 0.029	m
LON:	-91° 45' 35.37678"	± 0.029	m
ELL HT:	-12.794	± 0.046	m
X:	-168029.975	± 0.029	m
Y:	-5468936.070	± 0.053	m
Z:	3266658.061	± 0.014	m
ORTHO HT:	14.189	± 0.116	m

	UTM 15	SPC 1702(LA S)
NORTHING:	3431161.367m	278100.249m
EASTING:	618388.786m	959268.332m
CONVERGENCE:	0.63896132°	-0.21325219°
POINT SCALE:	0.99977289	1.00008004
COMBINED FACTOR:	0.99977490	1.00008205

CONTRIBUTED BY

Joshua.T.Hardy
US Army Corps of Engineers

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

Figure 10-14. OPUS-DB Datasheet for Station G 208 RESET 1976 derived from OPUS Static

Standard Survey Mark Datasheet for Station G 208 RESET 1976 as Currently Published

```
1        National Geodetic Survey,   Retrieval Date = DECEMBER 15, 2009
 BW0055 ***********************************************************************
 BW0055  HT_MOD      -  This is a Height Modernization Survey Station.
 BW0055  DESIGNATION -  G 208 RESET 1976
 BW0055  PID         -  BW0055
 BW0055  STATE/COUNTY-  LA/POINTE COUPEE
 BW0055  USGS QUAD   -  BIG BEND (1982)
 BW0055
 BW0055                         *CURRENT SURVEY CONTROL
 BW0055  ___________________________________________________________________
 BW0055* NAD 83(2007)-  31 00 29.21267(N)    091 45 35.37736(W)     ADJUSTED
 BW0055* NAVD 88     -        14.32   (meters)      47.0    (feet)  GPS OBS
 BW0055  ___________________________________________________________________
 BW0055  EPOCH DATE  -        2002.00
 BW0055  X           -    -168,029.990 (meters)                     COMP
 BW0055  Y           -  -5,468,936.055 (meters)                     COMP
 BW0055  Z           -   3,266,658.046 (meters)                     COMP
 BW0055  LAPLACE CORR-          -0.02  (seconds)                    USDV2009
 BW0055  ELLIP HEIGHT-         -12.815 (meters)          (02/10/07) ADJUSTED
 BW0055  GEOID HEIGHT-         -26.98  (meters)                     GEOID09
 BW0055
 BW0055  ------- Accuracy Estimates (at 95% Confidence Level in cm) --------
 BW0055  Type    PID    Designation                      North   East  Ellip
 BW0055  -------------------------------------------------------------------
 BW0055  NETWORK BW0055 G 208 RESET 1976                  0.39   0.39   0.90
 BW0055  -------------------------------------------------------------------
 BW0055
 BW0055.The horizontal coordinates were established by GPS observations
 BW0055.and adjusted by the National Geodetic Survey in February 2007.
 BW0055
 BW0055.The datum tag of NAD 83(2007) is equivalent to NAD 83(NSRS2007).
 BW0055.See National Readjustment for more information.
 BW0055.The horizontal coordinates are valid at the epoch date displayed above.
 BW0055.The epoch date for horizontal control is a decimal equivalence
 BW0055.of Year/Month/Day.
 BW0055
 BW0055.The orthometric height was determined by GPS observations and a
 BW0055.high-resolution geoid model using precise GPS observation and
 BW0055.processing techniques. It supersedes the leveled height previously
 BW0055.determined for this station.
 BW0055
 BW0055.Photographs are available for this station.
 BW0055
 BW0055.The X, Y, and Z were computed from the position and the ellipsoidal ht.
 BW0055
 BW0055.The Laplace correction was computed from DEFLEC99 derived deflections.
 BW0055
 BW0055.The ellipsoidal height was determined by GPS observations
 BW0055.and is referenced to NAD 83.
 BW0055
 BW0055.The geoid height was determined by GEOID09.
 BW0055
 BW0055;                    North         East     Units Scale Factor Converg.
 BW0055;SPC LA S     -   278,100.244   959,268.316   MT  1.00008004   -0 12 47.7
 BW0055;SPC LA S     -   912,400.55  3,147,199.47   sFT  1.00008004   -0 12 47.7
 BW0055;UTM  15      - 3,431,161.361   618,388.771   MT  0.99977289   +0 38 20.3
 BW0055
 BW0055!             -  Elev Factor  x  Scale Factor =   Combined Factor
 BW0055!SPC LA S     -   1.00000201  x   1.00008004  =   1.00008205
 BW0055!UTM  15      -   1.00000201  x   0.99977289  =   0.99977490
 BW0055
 BW0055                          SUPERSEDED SURVEY CONTROL
 BW0055
 BW0055  NAD 83(1992)-  31 00 29.21261(N)    091 45 35.37714(W) AD(       ) B
 BW0055  ELLIP H (12/29/04)  -12.815  (m)                       GP(       ) 4 1
 BW0055  NAVD 88 (02/14/94)   14.165  (m)           46.47   (f) ADJUSTED    1 1
 BW0055  NAVD 88 (06/15/91)   14.191  (m)           46.56   (f) UNKNOWN     1 1
 BW0055  NGVD 29 (??/??/??)   14.140  (m)           46.39   (f) ADJUSTED    1 1
```

```
BW0055
BW0055.Superseded values are not recommended for survey control.
BW0055.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
BW0055.See file dsdata.txt to determine how the superseded data were derived.
BW0055
BW0055_U.S. NATIONAL GRID SPATIAL ADDRESS: 15RXQ1838831161(NAD 83)
BW0055_MARKER: DB = BENCH MARK DISK
BW0055_SETTING: 46 = COPPER-CLAD STEEL ROD W/O SLEEVE (10 FT.+)
BW0055_SP_SET: COPPER-CLAD STEEL ROD
BW0055_STAMPING: G208 RESET 1976
BW0055_PROJECTION: FLUSH
BW0055_MAGNETIC: I = MARKER IS A STEEL ROD
BW0055_STABILITY: B = PROBABLY HOLD POSITION/ELEVATION WELL
BW0055_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
BW0055+SATELLITE: SATELLITE OBSERVATIONS - October 31, 2006
BW0055_ROD/PIPE-DEPTH:  3.0 meters
BW0055
BW0055  HISTORY     - Date     Condition        Report By
BW0055  HISTORY     - 1976     MONUMENTED       NGS
BW0055  HISTORY     - 20021106 GOOD             3001
BW0055  HISTORY     - 20061031 GOOD             JCLS
BW0055
BW0055                          STATION DESCRIPTION
BW0055
BW0055'DESCRIBED BY NATIONAL GEODETIC SURVEY 1976
BW0055'3.4 MI NE FROM SIMMESPORT.
BW0055'3.4 MILES NORTHEAST ALONG STATE HIGHWAY 418 FROM THE JUNCTION OF
BW0055'STATE HIGHWAY 417, 0.1 MILE NORTH OF A LARGE WHITE FARMHOUSE, 34 FT
BW0055'NORTHWEST OF THE CENTER LINE OF THE HIGHWAY, 33 FT NORTHEAST OF THE
BW0055'CENTER OF A WIRE GATE, 1.5 FT NORTHWEST OF A FENCE LINE
BW0055
BW0055                          STATION RECOVERY (2002)
BW0055
BW0055'RECOVERY NOTE BY 3001, INC 2002 (KC)
BW0055'THE STATION IS LOCATED 3.2 MILES NORTHEAST OF SIMMSPORT, 4.9 MILES
BW0055'NORTHWEST OF  LETTSWORTH, 5 MILES WEST OF A BRIDGE OVER OLD RIVER
BW0055'LOCKS.
BW0055'
BW0055'OWNERSHIP- COE
BW0055'
BW0055'TO REACH THE STATION FROM THE INTERSECTION OF HWY 1 AND HWY 418 ON THE
BW0055'SOUTHERN END  OF THE SIMMSPORT BRIDGE OVER ATCHAFALAYA RIVER, GO
BW0055'NORTHEAST ON HWY 418 ALONG LEVEE  FOR 3.6 MILES TO A MARK ON THE LEFT
BW0055'NEAR THE TOE OF THE LEVEE JUST PAST A WHITE HOUSE 16403.
BW0055'
BW0055'THE STATION IS 34' NORTHWEST OF THE CENTERLINE OF HWY 418, 41'
BW0055'NORTHEAST OF A LONER 6IN  ROUND FENCE POST WITH A WITNESS SIGN NAILED
BW0055'TO IT. STATION IS A BENCH MARK DISK SET ON  TOP OF A COPPER CLAD STEEL
BW0055'ROD WHICH IS DRIVEN 10 FT INTO THE GROUND, STAMPED G208  RESET 1976.
BW0055
BW0055                          STATION RECOVERY (2006)
BW0055
BW0055'RECOVERY NOTE BY JOHN CHANCE LAND SURVEYS INC 2006 (MRY)
BW0055'RECOVERED IN GOOD CONDITION.
```

10-13. <u>Baseline Data Management and Archival</u>. The raw data are defined as data recorded during the observation period. Raw data shall be stored on an appropriate medium (CD-ROM, portable hard drive, magnetic tape, etc.). The raw data and the hard copy of the baseline reduction (resultant baseline formulations) shall be stored at the discretion of each USACE Command. See also data archiving requirements covered in Chapter 11.