Central Coast
Height Modernization Project 2007-2008

FINAL REPORT

March 16, 2009

Prepared by

California Spatial Reference Center
Scripps Institution of Oceanography
Institute of Geophysics and Planetary Physics
9500 Gilman Drive
La Jolla, CA 92093-0225

And

TOWILL | Surveying, Mapping and GIS Services

88 Inverness Circle East, Suite A-207
Englewood, CO 80112
Tel: 303.974.7270
Fax: 303.974.7271

Towill Project Number
12110-101-132

EXECUTIVE SUMMARY

We report on California's Central Coast Height Modernization Project 2007-2008 (CENCHM2007) carried out by the California Spatial Reference Center (CSRC) and Towill, Inc. The project consists of the GPS survey of 150 survey monuments with respect to 49 continuous GPS (CGPS) stations using CSRC's PGM client and server software, and geodetic and orthometric adjustments of the data. It is being submitted to NGS as a standard Order B GPS network that qualifies as a 2-cm Height Modernization project. The CENCH2007 project was performed in accordance with the provisions of NOAA Technical Memorandum NOS NGS-58: Guidelines for Establishing GPS-derived Ellipsoid Heights version 4.3 (Zilkoski et al., 1997). The various elements of the project can be viewed at http://csrc.ucsd.edu/projects/pgm/cenchm2007.html.

CENCHM2007 is part of the California Spatial Reference System (CSRS) developed and maintained by the CSRC in partnership with NGS. The CSRS now consists of a statewide spatial reference frame based on over 650 CGPS stations and thousands of GPS monuments, metadata records, data processing infrastructure, geodetic models and formulas, a data portal including a GIS, SOPAC's Oracle database and web services, and guidelines and specifications. It is guided by "A Master Plan for a Modern California Geodetic Control Network" published in 2002 by CSRC and approved by the NGS in 2003 (http://csrc.ucsd.edu/general/csrcMasterPlan.html).

This report describes the CENCHM2007 field and office procedures, processing methods, results, analysis, least-squares adjustments of the GPS data, and archiving of the data and data products at the CSRC. Deliverables include the NGS fomatted files for 'blue-booking' submission, i.e., B-, G-, D-, and R-files and SERFIL, which have been verified through the ADJUST procedure.

Final geodetic coordinates are presented on two datums; ITRF2005 (GRS80 ellipsoid), epoch of 2008.0 (Appendix A); NAD83(NSRS 2007), epoch of 2007.0 (Appendix B). All coordinates refer to the geodetic reference mark, not the antenna reference point (ARP). The network comprises one hundred and ninety-nine (199) stations and seven hundred and fifty (750) baseline vectors. All the observations passed the τ-max test at the α = 0.05 level of significance. Examination of the 95% station confidence ellipses and intervals reveals that very good results were achieved. Only two passive stations have major semi-axes that exceed 10 mm in the horizontal (maximum value of 13.6 mm). Only four passive stations have vertical confidence intervals that exceed ±20 mm (maximum value of 23.0 mm).

Final orthometric heights (elevations) for 150 passive and 49 active monuments that are herein published (found in Appendix C) are referenced to the North American Vertical Datum of 1988 (NAVD88); the least squares adjustment utilized the GEOID03 model. Vertical constraints were provided by 54 geodetic control monuments with NGS-published NAVD88 elevations, 35 of which have First Order vertical accuracy. New orthometric heights were determined for 49 CGPS stations, 36 survey monuments constructed for this project or not previously in the NGS database, 42 existing NGS survey monuments, and 19 survey monuments that had previously NGS-published NAVD88 elevations. Determining new heights for the latter group is an indication of local vertical crustal motion or deficiences in GEOID03 or both.

This project also represents the completion of CSRC's development of the PGM client and server software suite, under contract to NGS. PGM has proven to be a valuable tool both in the field and in the office, most notably for maintaining the integrity of the CENCHM2007 data and derived files and products, and for delineating a workflow, which enforced discipline. Further enhancements were made to PGM during this project which facilitated the production of NGS Blue Book files. It is now a 'field-to-finish' solution for projects of this kind.

Trevor Greening, M.ScE.
Vice President

Pete DeKrom, M.ScE.
Geodetic Engineer

John F. Bloodgood, PLS, CP
Vice President

LICENSED LAND SURVEYOR
JOHN F. BLOODGOOD
No. L005734
STATE OF CALIFORNIA

February 3 , 2009

Dr. Yehuda Bock
Director, CSRC, SOPAC

March 16, 2009

Table of Contents

LIST OF FIGURES

LIST OF TABLES

APPENDICES

1. Introduction

This report descibes the Central Coast Height Modernization Project 2007-2008 (CENCHM2007) which is part of CSRC's "A Master Plan for a Modern California Geodetic Control Network" (http://csrc.ucsd.edu/input/csrc/csrcMasterPlan.pdf/). This project is being submitted to the National Geodetic Survey (NGS) as a standard Order B GPS network that qualifies as a 2-cm Height Modernization project according to the NOS NGS 58 guidelines. CENCHM2007 is part of a larger program implemented by the CSRC to establish an up-to-date unified geodetic control network throughout California, the California Spatial Reference Network (CSRN) consisting of continuous GPS stations (active) and existing or newly established control monuments (passive). The geodetic control network provides the survey community with a seamless, state-wide geodetic control network for all spatial referencing purposes including deformation monitoring, civil works, GIS and other critical projects.

The report documents the following:

- An overview of the project;
- Descriptions of the initial and final network designs;
- A description of the field operations; including scheduling, the use of Pocket GPS Manager (PGM) in the field, field procedures and the equipment used during the survey;
- An overview of the post processing of the GPS data performed in the field and a summation of the associated metadata;
- A description of the final GPS session processing through PGM including the creation of the files required for blue-booking;
- A description of the final network adjustments including the geodetic and orthometric height adjustments and a discussion of the datum issues relating to the project; and
- Appendices containing complete records of the planned and observed sessions, least squares adjustments, network diagrams and digital copies of all required Blue Book files and output files from Blue Book integrity checking programs.

1.1 Project Area

The CENCHM2007 control network is separated into two geographic regions – the northern region (Figure 1) and southern region (Figure 2). PBS denotes primary base stations (both CGPS and survey monuments) and LNS denotes local network stations (survey monuments).

Northern Region

- Extends approximately 93 miles southbound along Highway 1, just within the Mendocino County line to Sausalito and the Golden Gate.
- Extends westward approximately 15 miles from Highway 1 to Point Reyes.

- Extends approximately 15 miles along Bodega Highway between Highway 12 and Highway 101.
- Extends approximately 5.7 miles along Highway 128 just within the Mendocino County line.
- Extends approximately 80 miles along Highway 101 from just within the Mendocino County line southward to the southern tip of Marin County.
- Extends approximately 25 miles from Santa Rosa to Sonoma along Highway 12.
- Extends over 48 miles from Lake County, through Napa Valley along Highway 29.
- Extends approximately 22 miles along Highway 37 from US 101 and Interstate 80.
- Extends approximately 8 miles along Interstate 80 between Highway 37 and Highway 12.
- Extends approximately 23 miles along River Road (located northwest of Santa Rosa) between Highway 101 and Highway 1.

Southern Region

- Extends approximately 60 miles along Highway 1 northward from south of Big Sur to Castroville.
- Extends approximately 105 miles along Highway 101 from San Ardo northward to Gilroy.
- Extends approximately 114 miles along Highway 1 from Moss Landing northward through San Francisco to the Golden Gate.
- Extends approximately 14 miles through San Francisco along Highway 101.
- Extends approximately 20 miles along Highways 129 and 152 from Salinas to San Felipe.

1.2 Duration/Time Period

The field work commenced on November 27th, 2007 with observations of the Primary Base Stations. In the northern region, the PBS, consisting of five passive control points as well as nearby CGPS stations, was surveyed over three days in five-hour observation sessions. This was immediately followed by the survey of the northern portion of the local network, commencing on November 30th, 2007 and ending on December 12th, 2007. Additional observations were required for the northern region due to equipment problems, as explained further in Section 1.3.

The CENCHM2007 survey of the southern region commenced on January 8th, 2008 with the primary network consisting of two PBS passive points (and nearby CGPS stations) observed over three consecutive days in five-hour sessions. The local network observations started on January 10th, 2008 and were completed on January 22nd, 2008.

1.3 Problems Encountered During Surveys

The only significant problem encountered was a single GPS unit which failed to operate, resulting in two lost days of data during the northern survey. The northern schedule had to be revised for five (5) GPS receivers instead of six (6).

There were no additional problems encountered during the surveys.

1.4 Pocket GPS Manager (PGM)

The CENCHM2007 project used the Pocket GPS Manager (PGM) developed by the CSRC (http://csrc.ucsd.edu/projects/pgm.html). PGM is a client-server software designed to facilitate the configuration of a GPS campaign, from a campaign manager's perspective, combined with a paperless solution for collecting, assimilating and storing field occupation log information during a campaign, along with an automated, centralized workflow for managing the session information and data files.

PGM consists of two components:

- PGM Client – the installed software application with a graphical interface for the user (manager mode and technician mode); and
- PGM Server – essentially the database where the the data are stored, converted and processed.

The PGM Client (technician mode) was installed on Personal Digital Assitant's (PDA's) and laptop computers for field deployment. The PGM Client (manager mode) was installed on the field manager's computer to allow scheduling, data file management and uploading of metadata and GPS data. Further processing of PGM is discussed in Sections 3 and 5.

1.5 Points of Contact

Questions regarding the technical aspects of this report should be addressed to:

Towill, Inc.
88 Inverness Circle East, Suite A-207
Englewood, CO 80112

Trevor Greening, M.ScE.
Vice President – Director of International and Specialty Projects

Telephone: .... 303.974.7270 ext 405
FAX: 303.974.7271
Mobile:................... 303.961.2639
email: trevor.greening@towill.com

CSRC
Scripps Institution of Oceanography
Institute of Geophysics and Planetary Physics
University of California San Diego
La Jolla, CA 92093

Yehuda Bock, PhD.
Director

Telephone:................. 858.245.9518
FAX:........................... 858.534.9873
e-mail: ybock@ucsd.edu

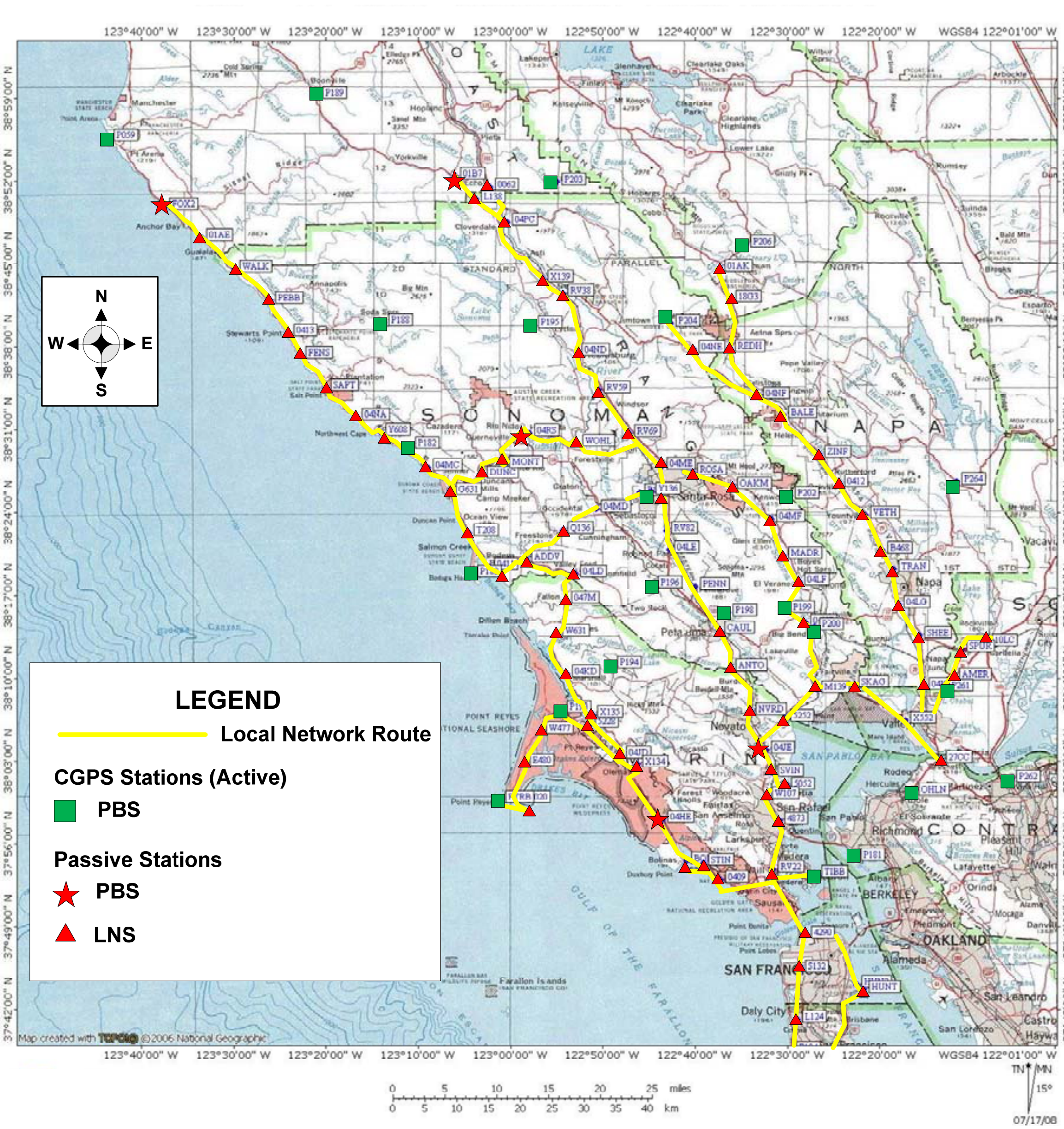


Figure 1. Northern Region of CENCHM2007

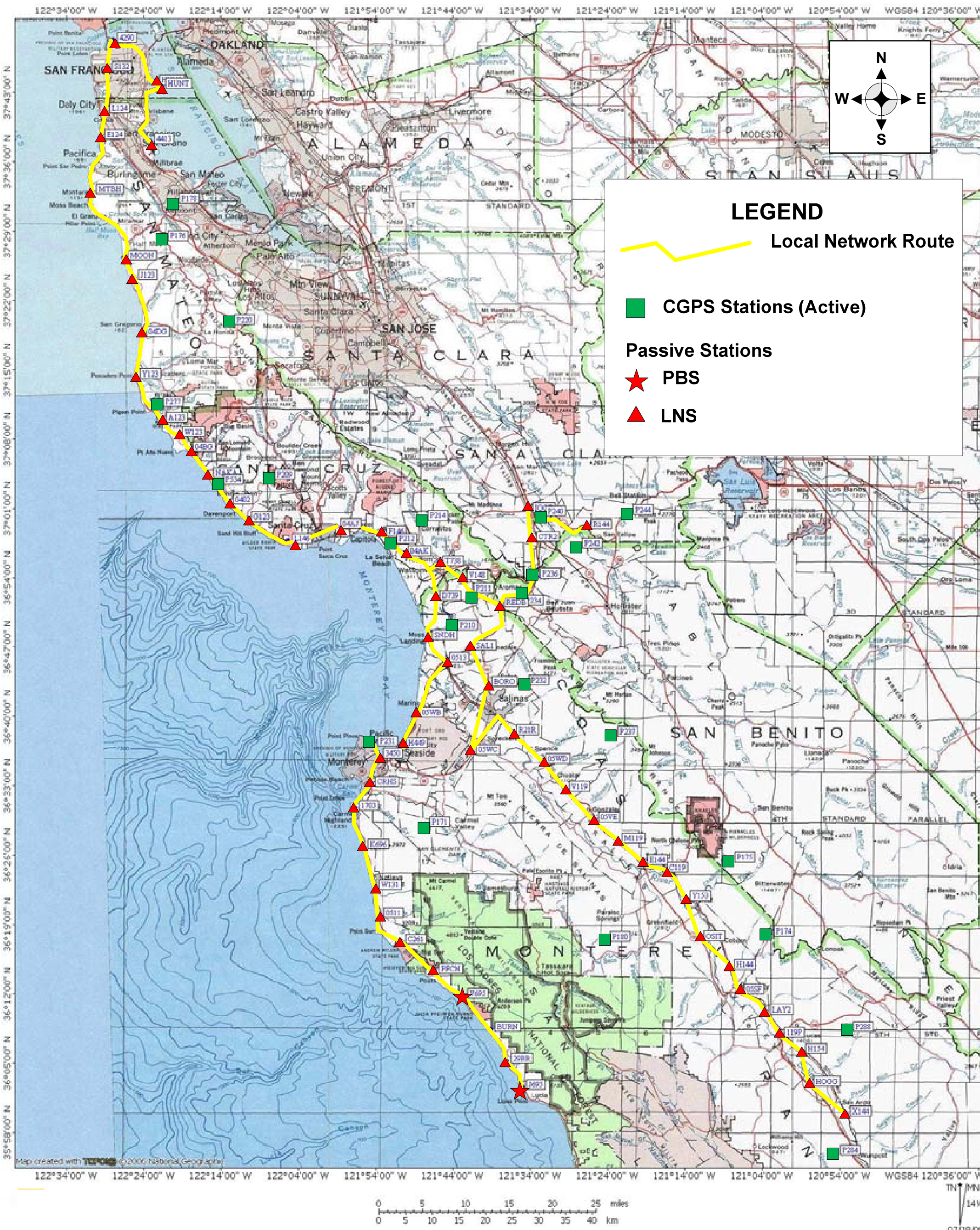


Figure 2. Southern Region of CENCHM2007

2. Reconnaissance, Monumentation, and the Design of the GPS Network

2.1 Reconnaissance and Monumentation

Reconnaissance was initially performed in December 2006 and January 2007 by Marti Ikehara, the NGS State Advisor for California, serving as CSRC Project Manager for this project. A thorough search of the NGS database (the National Spatial Reference System – NSRS) was performed, focusing on existing high order vertical control, in the vicinity of the project area. A field reconnaissance was then performed involving visits to each of the existing and proposed monument locations. The physical condition of each existing monument was assessed, as was its suitability for GPS observations. The 'drive-to' description for each station location was updated, as required, as were the station descriptions and ties to existing features. Additional information was recorded to allow for easier accessibility by Towill field crews and for future users. If spacing between primary base stations and/or local network stations did not satisfy the requirements of the NOS NGS 58 guidelines, then locations for new monuments were established.

Further reconnaissance was performed by Towill, Inc. between November 2007 and January 2008 to ensure the monuments had not been disturbed between the initial site visits and the start of the survey. This also allowed Towill personnel to familiarize themselves with the locations of the existing control as well as to establish the final locations of the new monuments prior to obtaining utility clearances.

Once the necessary utility clearances and California Department of Transportation right-of-way permits had been acquired, Towill survey crews began the installation of new monuments. New monuments mainly consisted of disks grouted into stable structures that included rock outcrops and bridge abutments. If stable structures were not available in the vicinity, then permanent deep monuments were established according to the procedures referenced in "Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques Version 5.0: Annex H. – Specifications and Setting Procedures for Three-Dimensional Monumentation" published by the Federal Geodetic Control Committee May 11, 1988, reprinted with corrections: August 1, 1989.

During the CENCHM2007 project, a total of twelve (12) three-dimensional monuments were constructed and fourteen (14) disks were set with epoxy to stable structures. In addition, three (3) additional existing monuments not in the NGS database were included in the survey.

2.2 GPS Network Design

Generally, the GPS network design complied with the 2 cm standard defined by "NOAA Technical Memorandum NOS NGS-58; Guidelines for Establishing GPS-derived Ellipsoidal Heights (Standards: 2cm and 5cm) (Zilkoski et. al 1997)". It should be noted that this project is unique in the abundance of continuous GPS (CGPS) stations in the project area and we took advantage of them in the network design. The CGPS stations provided the bulk of the ties to the CSRS/NSRS.

The guidelines for design of the GPS network for the CENCHM2007 are summarized below:

- Primary base stations are no farther than 40 km apart from each other;
- Local network stations are no farther than 10 km apart from one another;
- Primary base stations are traceable back to a minimum of two different control stations due to the abundance of CGPS stations;
- All local network stations are traceable back to two primary base stations; and
- All local network stations are connected to at least its two nearest neighbors.

2.3 Point Numbering

Each control point designation was allocated a four-character alphanumeric code. If a control point was used in a previous Height Modernization project then its designation was carried over to CENCHM2007. The list of four character codes and their designations are shown in Appendix A and at http://csrc.ucsd.edu/projects/pgm/cenchm2007.html. CGPS points were designated with their four character abbreviations as shown on the SOPAC website (http://sopac.ucsd.edu).

3. Field Operations

3.1 Scheduling

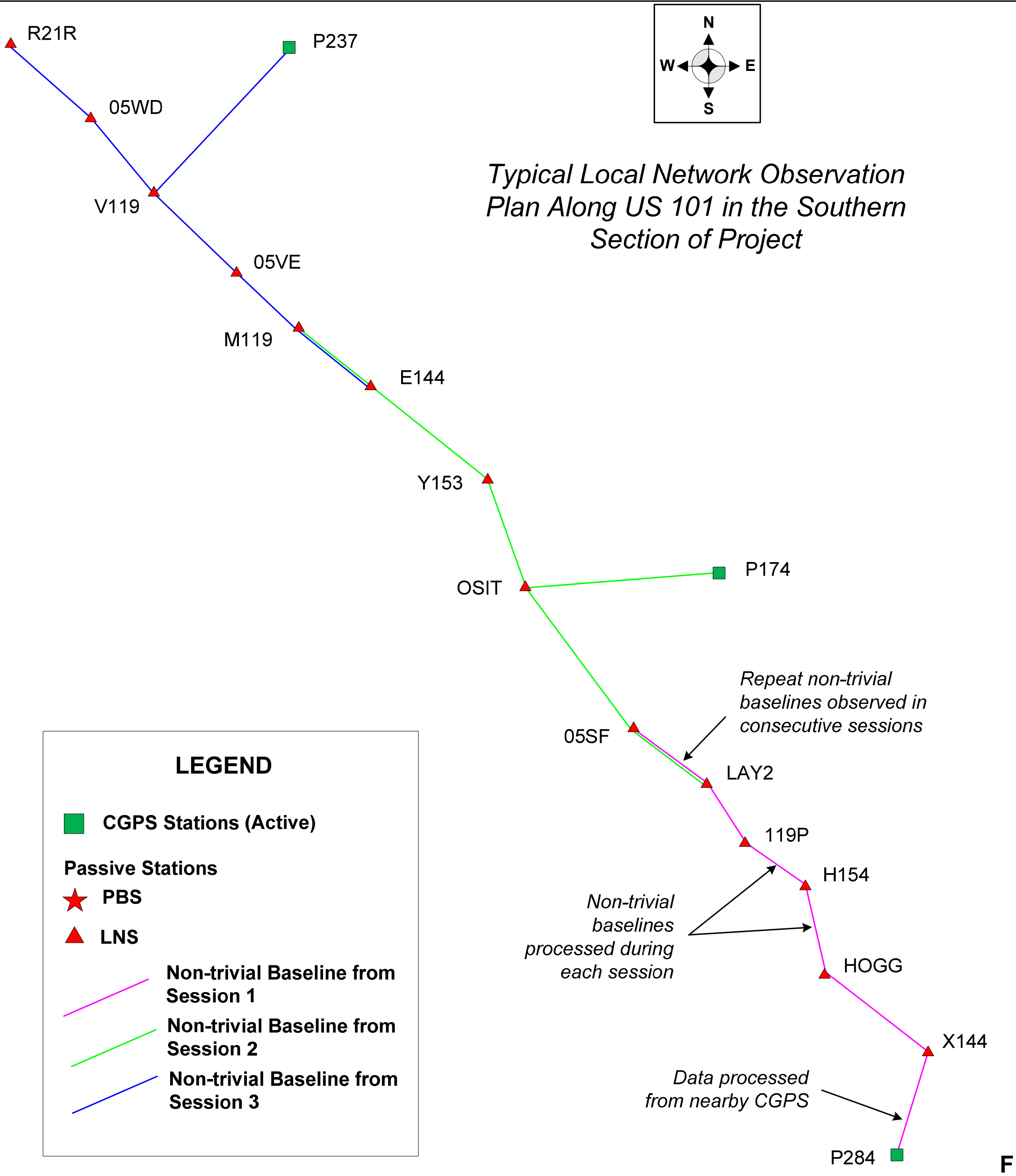
Scheduling was performed to ensure that all field procedures for Height Modernization Projects for 2 cm accuracy were followed in accordance with NOAA Technical Memorandum NOS NGS-58: Guidelines for Establishing GPS-derived Ellipsoid Heights version 4.3 (Standards: 2 cm and 5 cm), (Zilkoski et al., 1997). The procedure for scheduling is detailed below.

The majority of the passive primary base stations were occupied simultaneously for at least five (5) hours of common data. The time scheduled for each consecutive day was staggered to ensure that the satellite geometry and meteorological conditions were substantially different (>3 hours) during the three repetitions yielding a significant level of statistical independence among the sessions. The scheduled and actual observation date and times for passive primary base stations (for both the northern and southern regions of the project) are shown in Appendix D and at http://csrc.ucsd.edu/projects/pgm.html.

Local network stations were occupied simultaneously for at least 45 minutes over two (2) consecutive days, with the schedules staggered by 3.5 hours. If logistics did not allow for the observations to be repeated over two consecutive days, then Towill ensured that the daily Sidereal Time shift (~3 minutes 56 seconds a day) was taken into consideration when finally scheduling the repeat session. In addition to the NOS-58 procedures, scheduling also ensured that one repeat vector baseline was re-observed between consecutive sessions. Typical scheduling for the local network observations is shown in Figure 3.

The final configurations for the northern, central, and southern segments of the network are shown in Figures 4-6, respectively.

Daily scheduled sessions consisted of five (5) to six (6) field personnel operating one GPS receiver each per session. Five or six planned sessions were observed daily for the local network.



F
igure 3. Typical Local Network Observation Plan

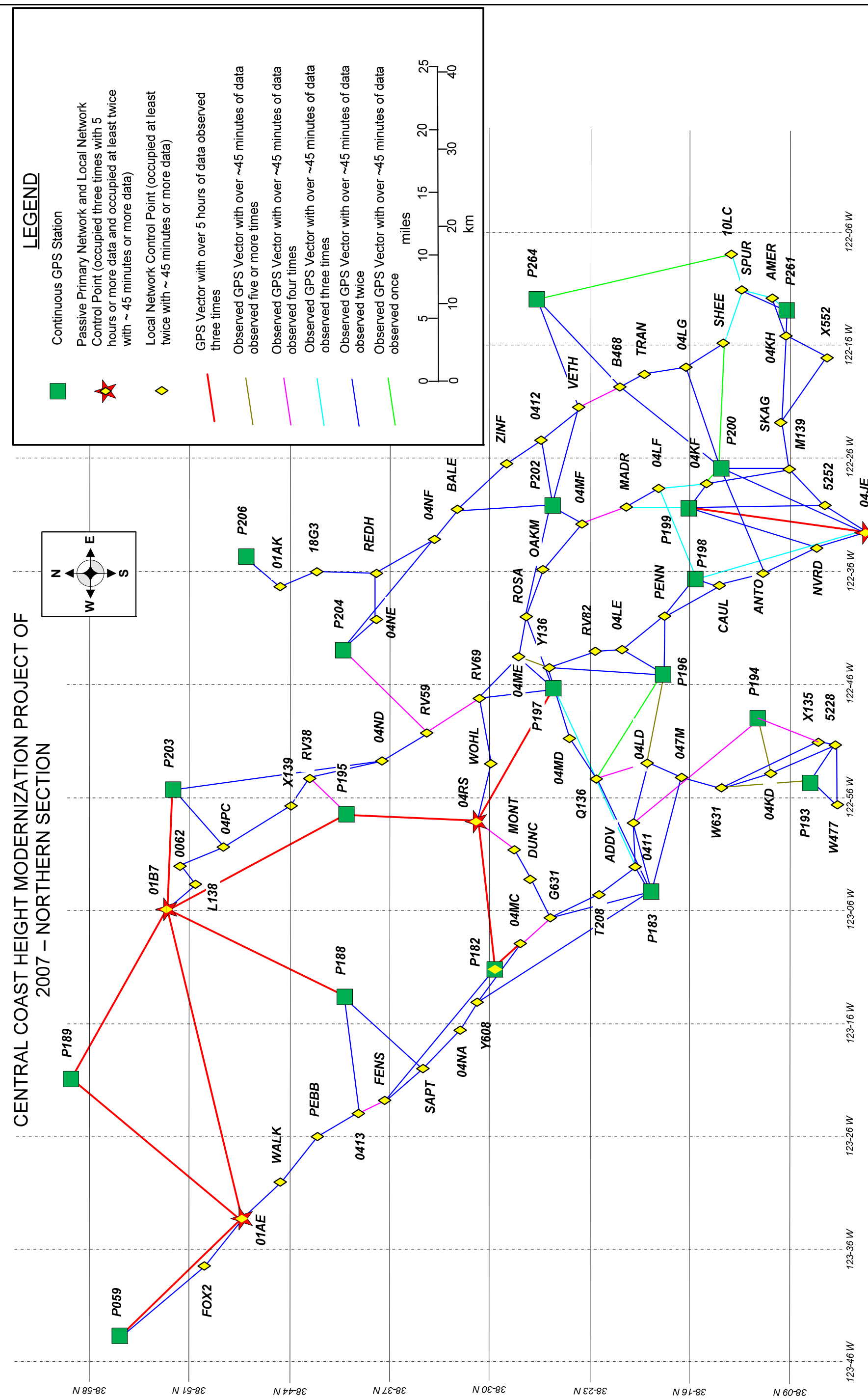


Figure 4. Final Network Configuration – North

CENTRAL COAST HEIGHT MODERNIZATION PROJECT OF 2007 – CENTRAL SECTION

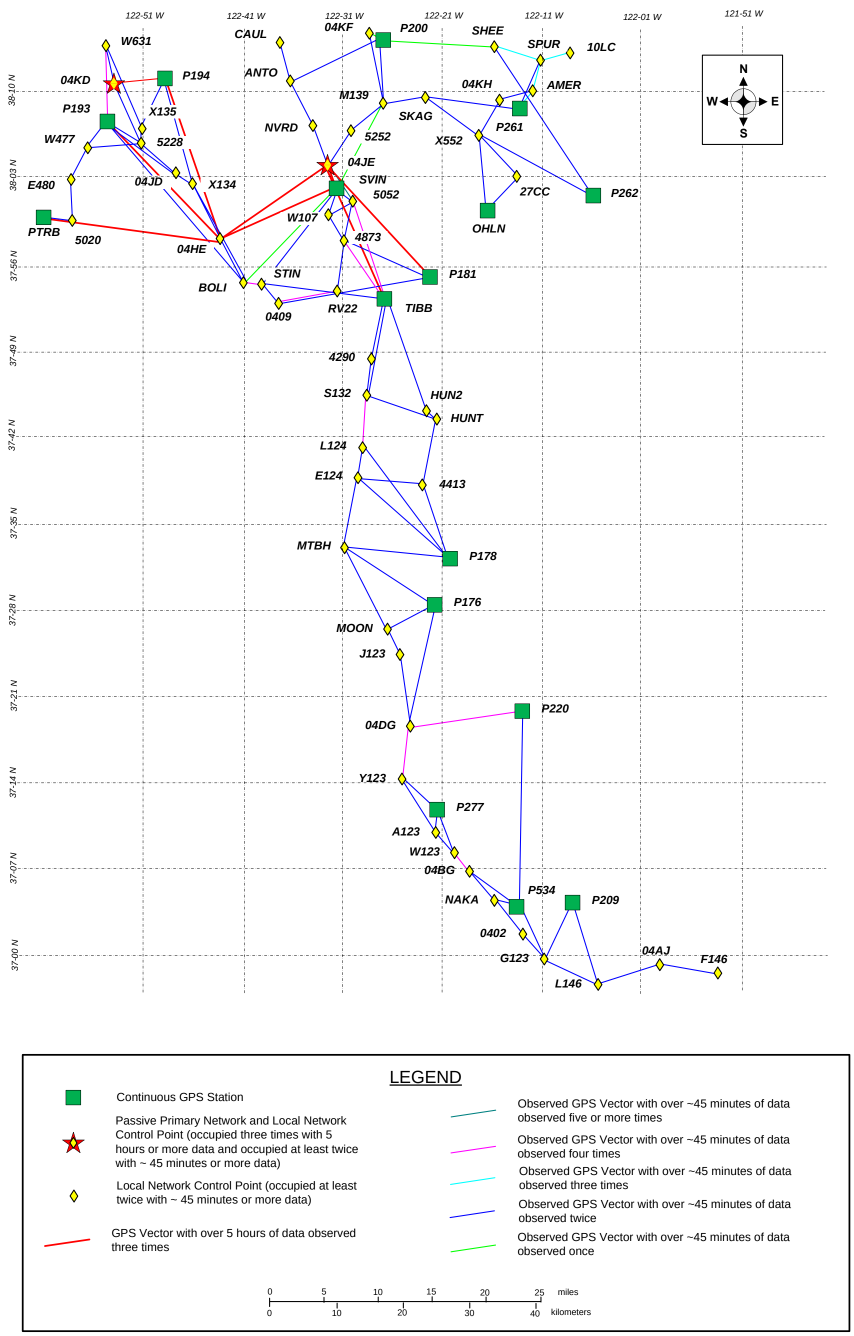


Figure 5. Final Network Configuration – Central

CENTRAL COAST HEIGHT MODERNIZATION PROJECT OF 2007 – SOUTHERN SECTION

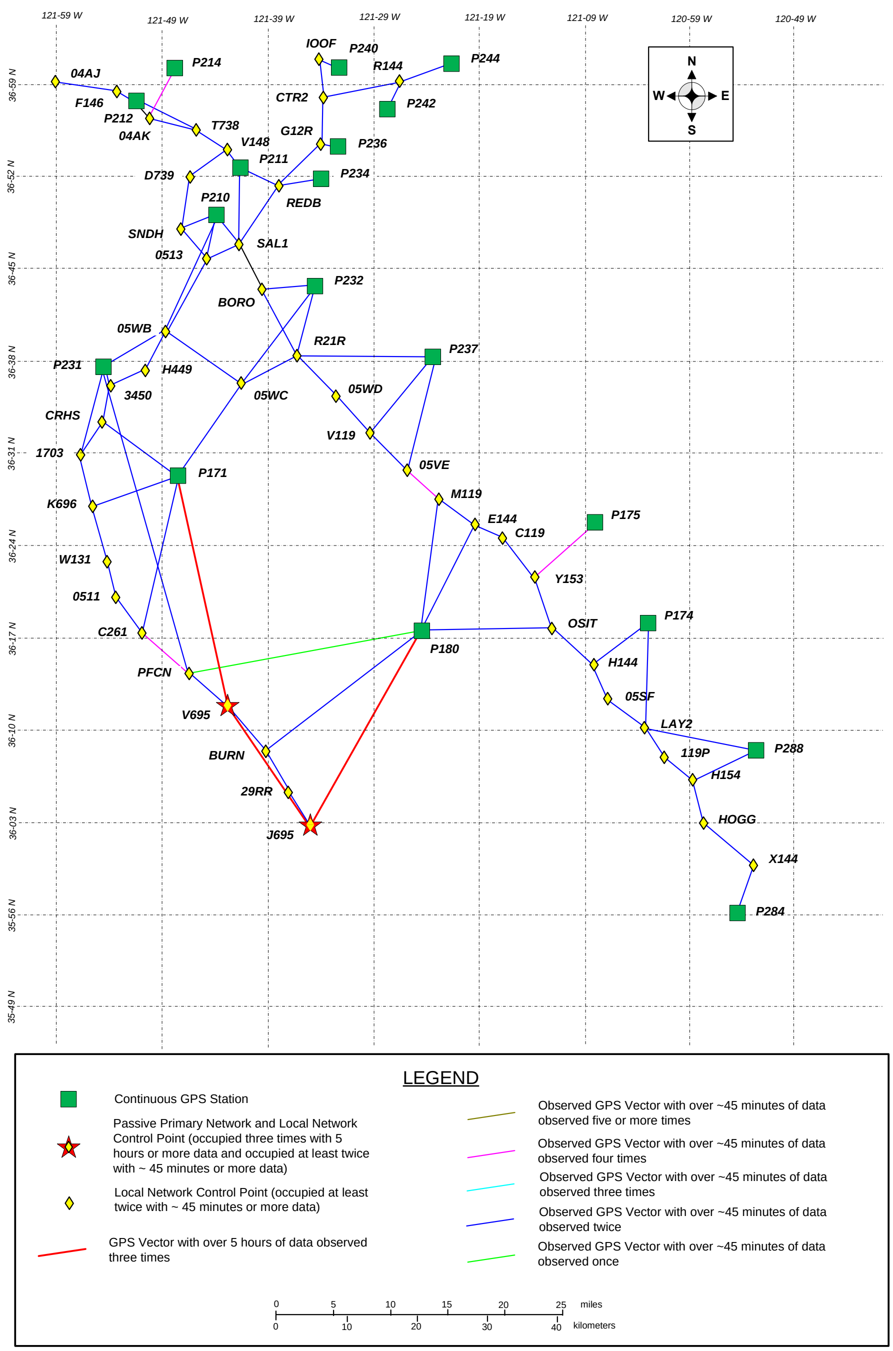


Figure 6. Final Network Configuration – South

Once the daily schedules were determined, whether they applied to the passive primary base stations or the local network stations, the schedules were uploaded to the PGM server using the PGM client (manager mode). The scheduled sessions were then downloaded to each field Personal Digital Assitant (PDA) prior to field mobilization. Further details regarding the use of the PGM by field personnel are described in Section 4. Towill's technical managers received a full day of PGM training at CSRC's facility at UCSD on September 27, 2007. Towill's Technical Field Manager subsequently provided PGM Client technician-mode training to the field crew members. Prior to the start of the north region observations, a focused PGM problem-solving session was conducted by CSRC staff on January 7, 2008 in La Jolla with Pete DeKrom and Marti Ikehara.

3.2 Field Procedures

Towill ensured that all field operations followed NOAA Technical Memorandum NOS NGS-58 guidelines. Prior to each day's surveys, crew members ensured that they had the following:

- Personal Digital Assistant (PDA) with the PGM Client software (technician mode), and including the daily schedule;
- Trimble Navigation's 4700 Geodetic Receiver and L1/L2 micro-centered geodetic antenna with ground plane;
- Fixed-height tripod (2 m in height);
- Charged batteries and antenna cables with backup supplies;
- NGS descriptions (or datasheets, if available) for each station that was scheduled for the day and, where applicable, updated descriptions from the reconnaissance;
- Assorted maps, hand-held GPS unit, and a point coordinate list ensuring safe and efficient navigation to the point;
- Digital camera;
- 100 foot fiberglass tape for measuring ties to update the NGS description (D) file.

Each field crew member, upon arriving at their designated station, followed this procedure:

- Recovered the monument and verified the exact stamping;
- Set the antenna on the fixed height tripod, connected all associated cables to the receiver and properly plumbed the fixed height tripod over the point;
- Powered on the receiver and ensured that the receiver was logging data after a maximum of 2 minutes;
- Powered up the PDA and opened PGM in client mode;
- Entered the following data into PGM:

1. SITE: The site or monument was selected from the list of four character abbrevations. The *NAME, NEAREST CITY, MONUMENT TYPE, LATITUDE, LONGITUDE* and *NGS PID* was verified;
2. SESSION SELECTION: The scheduled session was selected from the list.
3. LOG INFO: The following metadata was entered into PGM: Actual start and end times of the session, observer name, model code and serial number of the GPS receiver used, model code and serial number of antenna used, weather codes, quality checks (i.e., obstructions present, antenna plumb confirmation prior to starting session and end of session, and additional observer's comments).

At the end of each day, the closed field log was uploaded from the PDA to the PGM database. In addition, the GPS data file was uploaded and associated with the correct closed session (i.e., metadata). Digital photographs taken by the field personnel were uploaded and associated with the site (monument).

3.3 Field Equipment

Towill employed five (5) to six (6) Trimble Navigation 4700 receivers with L1/L2 micro-centered geodetic antennas with ground planes for each observed session. In addition, a small portion of the project area referred to as the River Road Observations (i.e., Local Network Stations RV69, WOHL, 04RS, MONT, DUNC, and G631) were not observed by Towill personnel but rather by a third party (Steve Sarsfield and colleagues). These data were integrated into the CENCHM2007 project by CSRC staff. The equipment and associated serial numbers applied in these and all observations are listed in Table **1**, and at http://csrc.ucsd.edu/projects/pgm/cenchm2007.html.

Table 1. Equipment List

	Model Code	Serial Number
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220144485
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220155196*
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220155324**
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220177322
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220177715**
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220177948
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220189758
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220202920
Trimble Navigation 4700 Geodetic Receiver	TRIMBLE 4700	220203897

* unit failed during survey
** was not used in survey

	Model Code	Serial Number
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220144947
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220162093
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220174494
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220180108
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220180249
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220201224
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220202663
Trimble Navigation L1/L2 Micro-centered	TRM33429.00+GP	220210805

	Model Code	Serial Number
Leica Systems 530	LEICA SR530	36022
Leica Systems 530	LEICA SR530	36023
Topcon Hyper-Lite+	TPS GB-1000	295-2620
Trimble Navigation 5800 Geodetic Receiver	TRIMBLE 5800	4251116701
Trimble Navigation 5700 Geodetic Receiver	TRIMBLE 5700	220312558

	Model Code	Serial Number
Leica Systems 530	LEIAT502	6714
Leica Systems 530	LEIAT502	6835
Topcon Hyper-Lite+	TPSHIPER_LITE	295-2620
Trimble Navigation Zephyr Geodeitc	TRM39105.00	12541997
Trimble Navigation 5800 Geodetic Receiver	TRM_R8_GNSS	4251116701

4. Field GPS Post Processing

4.1 Preliminary Processing of GPS Vectors

The Towill field manager performed preliminary GPS vector processing on a daily basis using Trimble Geomatics Office (TGO) version 1.63. TGO accomodates the NGS antenna models, precise orbits and allows for GPS baselines to be processed with different tropospheric models. GPS data were processed on the day after the observations to allow the use of IGS ultra-rapid orbits. All vectors were processed to ensure that integer-cycle ambiguity resolution was achieved.

4.2 Preliminary Ellipsoidal Height Difference Comparisons

Upon completing the preliminary processing, Towill checked that the repeat GPS baselines agreed to within 2 cm. In the few cases that the agreement ($|\Delta(\Delta h)|$)[1] between the repeat baseline observations was larger than 2 cm, the Project Manager was consulted as to the need to re-observe baselines. No field re-observations were deemed necessary for this project. This was the result of following proper field procedures and the relatively long observation times. The majority of the local network stations had more than 45 minutes of data in common with neighboring stations.

5. Final GPS Processing at CSRC

The data entry and processing methodology used for this project are shown in Figure 7.

5.1 Final Session Processing of GPS Vectors

CSRC staff analyzed all GPS data for the project using session-mode GPS post-processing with the Geodetics, Inc. RTD software version 3.5 provided for the use of this project by UCSD. This included 150 monuments and 49 CGPS stations from PBO and BARD[2]. A complete list of monuments and CGPS can be found at: http://csrc.ucsd.edu/projects/pgm/cenchm2007.html

The processing was performed on a PC workstation using a Winbatch[3] processing script called batchRTD, which is controlled by a jobOrder file (for this project "jobOrderCENCHM2007.txt"). The first step was to define the project's processing sessions and insert them into the jobOrder file. A "processing session" is defined as data from a group of receivers that have been scheduled to simultaneously observe a group of survey monuments, and data from the CGPS stations in their vicinity[4]. The number of survey monuments can be greater or equal to one. The sessions were determined through a web link on the project status page, for this project:

http://sopac.ucsd.edu/cgi-bin/pgmGetRTD_SessFile.cgi?campaign_code='CENCHM2007'

[1] $|\Delta(\Delta h)|$ is the absolute difference between separate determinations of the differential ellipsoidal height (Δh) between two survey monuments.

[2] PBO – Plate Boundary Observatory (http://pboweb.unavco.org/) operated by UNAVCO; BARD – Bay Area Regional Deformation Array (http://www.ncedc.org/bard/) operated by UC Berkeley.

[3] Winbatch is a Microsoft Windows scripting language.

[4] We calculate the closest two CGPS stations to each survey monument to form the list of CGPS stations for a session.

Once the sessions were inserted in the jobOrder file and the appropriate project-specific parameters set, batchRTD was executed and the following steps were peformed. A cgi call was invoked to retrieve the required metadata (receiver type, antenna type, antenna height, etc.) from the PGM server in the form of an XML file. Likewise, another cgi call was invoked to retrieve from the SOPAC archive the same information for the CGPS stations, also in the form of an XML file. The corresponding RINEX files were downloaded from the SOPAC archive for the CGPS stations and from the PGM server for the survey monuments. Then the RTD analysis was launched. The sessions were processed automatically one-by-one. There were a total of 101 processing sessions for this project.

RTD uses the method of instantaneous positioning[5]. Each epoch of the observation session[6] is analyzed independently with integer-cycle GPS phase ambiguities resolved at each epoch. This is actually a two-step process; first a "biases-free" solution (ambiguities estimated at their real-number values) followed by a "biases-fixed" solution (ambiguities resolved to integer values). The single-epoch estimated parameters (for biases-fixed solutions) are station coordinates and troposphere zenith delays. The coordinate solutions are accumulated into a combined weighted least-squares solution with single-epoch outliers excluded. For this project, we used SECTOR-based CGPS coordinates in ITRF2005 at epoch 2008.0, constrained to 1 cm in each component in both biases-free and biases-fixed solutions. We applied the NOAATrop model (http://gpsmet.noaa.gov/jsp/index.jsp) to correct for tropospheric refraction and improve the precision and accuracy of ellipsoidal heights. We constrained the troposphere zenith delay parameters predicted by NOAATrop to 2.5 cm and used IGS final orbits as fixed. The survey monument coordinates were iterated, and constrained in the final iteration to 20 cm in the horizontal components and 50 cm in the vertical components in the biases-free solution. The output for each session was a SINEX file with full coordinate covariance information[7]. The session definitions and their corresponding SINEX files for this project can be found at:

http://pgm-server01.ucsd.edu/cgi-bin/pgmShowSinexData.cgi?campaign_code=CENCHM2007.

The SINEX files were converted to an NGS Blue Book G-file by propagating each SINEX file into a non-trivial set of independent baselines[8]. The NGS Blue Book B-file and SERFIL were also created from PGM entries loaded into the CSRC database. This is the first Height Modernization project for which CSRC has created Blue Book files directly from the CSRC database.

[5] Bock, Y., R. Nikolaidis, P. J. de Jonge, and M. Bevis (2000), Instantaneous geodetic positioning at medium distances with the Global Positioning System, *J. Geophys. Res.*, *105*, 28,223-28,254.

[6] Data were collected at a 5 s sample rate for the field survey, but the CGPS stations only collected data at a 15 s. Therefore, the RTD session analysis was performed at a 15 s rate.

[7] Note that the covariance matrices in the SINEX files were not scaled by their a posteriori variances of unit weight.

[8] The strategy implemented for computing an independent, non-trivial set of baselines from a processing session is as follows. *Continuous station to survey monument*: (a) for each continuous station, calculate distance to each monument, (b) sort list of pairs by distance, (c) select first (closest) monument in list that has not already been paired with a continuous station, (d) if there are more continuous stations than monuments, just use the closest monument. *Monument to monument*: (a) calculate distance between all possible pairs of monuments, (b) sort list by distance, (c) For each pair of sites, starting with the closest, (1) if both are new, create a 'branch' containing the two sites, (2) if one site in the pair is new, add to the branch that contains the other, (3) if one is in one branch and one in another, combine the two branches into a single branch, (4) if both are already in one branch discard as redundant, (5) continue until all sites have been included and there is only one branch.

5.2 Final Network Design and Delta Ellipsoidal Height Comparisons

The initial G-file, obtained from the CSRC, was formatted by Towill into a Trimble Navigation Exchange Format file and imported into Trimble Geomatics Office, analyzed visually, and delta ellipsoidal repeatabilities were computed for all repeat baselines. An iterative process occurred between Towill and CSRC to arrive at the final G-file for the project. Several CGPS stations were added to individual sessions to improve the overall network geometry, and a handful of sessions were re-processed with RTD to eliminate problematic data from individual station occupations.

The final network design resulted in 2-8 measurements of each repeat baseline. Therefore, in Appendix E we document the deviations of the ellipsoidal height differences from their mean values for the GPS processing performed by the CSRC, rather than the $|\Delta(\Delta h)|$ values for pairs of repeated baselines computed in the initial field processing as decribed in section 4.2. Overall, this process achieved the criteria for 2 cm NOS NGS 58 specifications and standards and resulted in a robust network geometry.

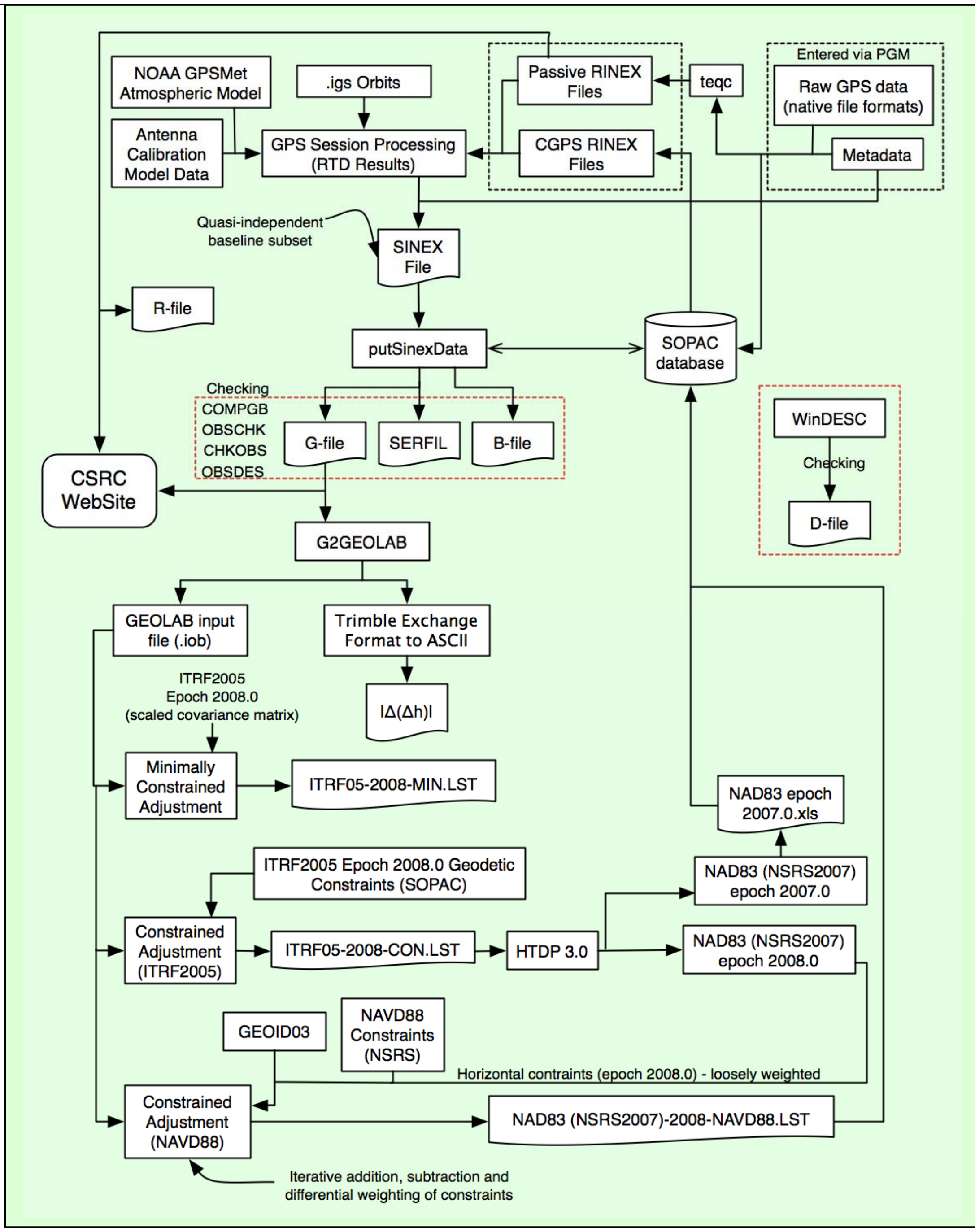


Figure 7. The Processing and Adjustment Workflow

6. LEAST SQUARES ADJUSTMENTS

6.1 Introduction

The least squares adjustments were performed using Microsearch Geolab software (version 2001.9.20.0), used successfully by Towill on a variety of geodetic projects including those requiring NGS Blue Book reporting.

Three adjustments were performed (refer to Figure 7):

1. Minimally constrained adjustment. The geodetic coordinates of a single CGPS station were held fixed. This adjustment (Appendix F) was used to quantify the overall network precision and to estimate an appropriate variance factor[9] that was used to scale the covariances for all subsequent adjustments.
2. Constrained geodetic adjustment. Completed on ITRF2005, and at approximately the midpoint of observations (2008.0), this adjustment yielded final geodetic coordinates (ϕ, λ, h) for all 199 survey monuments. The GRS80 ellipsoid was used. Constraints were applied to the coordinates of 49 CGPS stations obtained from SOPAC, thus tying the adjusted coordinates to the CSRS/NSRS. The adjustment output listing is included in Appendix F. We used HTDP 3.0 to convert geodetic coordinates from Epoch 2008.0 to Epoch 2007.0 (last epoch date published by CSRC) (Appendix G).
3. Orthometric height adjustment. This adjustment was completed on NAD83 (NSRS 2007), epoch of 2008.0. For existing benchmarks, NAVD88 elevations from the NSRS database were used as vertical constraints. GEOID03 was used. The output listing is presented in Appendix H.

Coordinates refer to the geodetic reference mark (GRM), not the antenna reference point (ARP).

6.2 Minimally Constrained Least Squares Adjustment

A utility program written by Towill was used to extract the baseline vector components and their associated variance-covariance elements from the CSRC-produced G-file and to reformat the data into a Geolab compatible input file (ITRF05-MIN.iob, included in digital form with this report). All data were processed in a single network adjustment. The network was constrained to the ITRF2005 (epoch of 2008.0) geodetic coordinates of CGPS station P059 obtained from SOPAC's SECTOR utility[10] (see Table 2).

The minimally constrained adjustment resulted in an *a posteriori* variance factor ($\hat{\sigma}_o^2$) of 2.1. This is quite reasonable considering that the coordinate variance-covariance matrices in the CSRC SINEX files (and subsequently propagated to individual baseline covariances in the CSRC G-file)

[9] The variance factor is also known as the variance of unit weight.

[10] See http://sopac.ucsd.edu/cgi-bin/sector.cgi

were not scaled by the *a posteriori* variance of unit weight in the RTD session processing. The variance-covariance data were scaled accordingly and the minimally constrained network adjustment was re-run. No residuals were flagged under the τ-max test and the final *a posteriori* variance factor (1.05) passed the χ^2-test. Both tests were performed at the α = 0.05 level of significance. The results of the final minimally constrained adjustment are documented in the Geolab output file CENCHM2007-ITRF05-MIN.lst, included in digital form with this report.

6.3 Constrained Least Squares Adjustment – International Terrestrial Reference Frame 2005, Epoch of 2008.0

This least squares adjustment was referenced to ITRF2005, epoch of 2008.0, and to the GRS80 ellipsoid. All of the CGPS stations were used as constraints. Their (X, Y, Z) Cartesian, Earth Centered Earth Fixed (ECEF) coordinates and their associated precision (standard deviations) were obtained via the Internet from SOPAC's SECTOR utility. These constraint data, including residuals, are presented in Table 2.

The network comprises one hundred and ninety-nine (199) stations and seven hundred and fifty (750) baseline vectors. As with the minimally constrained adjustment, *a priori* weights for the observations were based on the scaled variance-covariance data obtained from the minimal constraint adjustment described in section 6.2 above. The Geolab input file CENCHM2007-ITRF05-CON.iob is included in digital format with this report.

In the resulting adjustment, the (estimated) *a posteriori* variance factor ($\hat{\sigma}_o^2$= 0.99) passed the χ^2–test suggesting that the *a priori* GPS baseline variances-covariances and the CGPS coordinate constraints were realistic. None of the observations was flagged for possible rejection under the τ-max test at the α = 0.05 level of significance. The results of the adjustment are presented in Appendix F and in the Geolab output file CENCHM2007-ITRF05_CON.lst attached in digital format with this report.

Examination of the 95% station confidence ellipses (horizontal) and intervals (vertical) reveals that very good results were achieved. In summary:

- Only two passive stations have major semi-axes that exceed 10 mm:
    - 04NA 13.6 mm
    - TRAN 10.6 mm
- Only four passive stations have (95%) vertical confidence intervals that exceed 20 mm:
    - 04NA 23.0 mm
    - C119 20.7 mm
    - 0511 20.4 mm
    - W131 20.1 mm

The adjusted ITRF2005 geodetic coordinates at epoch 2008.0 and their 1-σ uncertainties (standard deviations) are provided in an Excel worksheet (Appendix A). These results are 'relative' to the underlying datum (ITRF2005, epoch 2008.0), as realized by the CGPS station coordinates generated by SOPAC.

6.4 Transformation of Coordinates between ITRF2005, Epoch of 2008.0 and NAD83 (NSRS2007), Epoch of 2007.0

The project specifications required that the final deliverable coordinates also be referenced to the North American Datum of 1983, National Spatial Reference System of 2007 [NAD83 (NSRS2007)], epoch of 2007.0.

The transformation was performed in one-step using the Horizontal Time-Dependent Positioning (HTDP) utility version 3.0 (http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.html). Underlying this operation are three reference frame transformations as well as a point velocity correction to transform point locations from 2008.0 (approximate mid-point of survey) to 2007.0 (last epoch date published by CSRC). The first transformation from ITRF2005 to ITRF2000 (epoch of 2008.0) uses the 14-parameter transformation (3 translations, 3 rotations, a uniform scale factor, and their rates) listed in Table 3. The transformation data shown are published by The International Earth Rotation and Reference Systems Service (IERS) (http://www.iers.org/). The second transformation from ITRF2000 to NAD83 (CORS96) is based on a 14-parameter transformation presented in Table 4 and published by the NGS. The third transformation is from NAD83 (CORS96) to NAD83 (NSRS2007). Since the NAD83 (NSRS2007) reference frame realization is based on a subset of NAD83 (CORS96) station constraints, they are considered congruent. As stated by the NGS:

> *"Derived NAD83(NSRS2007) positional coordinates should be consistent with corresponding NAD83(CORS) positional coordinates to within the accuracy of the GPS data used in the adjustment and the accuracy of the corrections applied to the data…"*

Reference: NGS(http://www.ngs.noaa.gov/NationalReadjustment/adjustment_faq.html#5)

The results of the HTDP 3.0 transformation between the two epochs are listed in Appendix G.

The final NAD83(NSRS2007) geodetic coordinates at epoch 2007.0 are provided in an Excel worksheet in Appendix B. We decided not to introduce an uncertainty for the transformation of coordinates from epoch 2008.0 to 2007.0, although this step is not without error and depends on the accuracy of the underlying geophysical model of HTDP. Therefore, we carried over the 1-σ uncertainties (standard deviations) from Appendix A to Appendix B.

6.5 Orthometric Height Adjustment – North American Datum of 1983 (NSRS2007), Epoch of 2008.0 and North American Vertical Datum of 1988

Final orthometric heights (elevations) for 150 passive and 49 active monuments that are herein published (found in Appendix C) are referenced to the North American Vertical Datum of 1988 (NAVD88). The orthometric height adjustment (Appendix H) was performed in NAD83 (NSRS2007), at the 2008.0 epoch[11], with GEOID03 providing the link between the ellipsoidal and

[11] The choice of reference epoch for the orthometric adjustment is arbitrary, and is most conveniently performed at epoch 2008.0, (the approximate midpoint of the observations). The results would be the same at any epoch since HTDP 3.0 assumes zero vertical velocity (see Appendix G).

orthometric height differences. Vertical constraints were provided by 54 geodetic control monuments with NGS-published NAVD88 heights, 35 of which have First Order vertical accuracy. New orthometric heights were determined for 49 CGPS stations, 36 survey monuments constructed for this project or not previously in the NGS database, 42 existing NGS survey monuments, and 19 survey monuments that had previous NGS-published NAVD88 heights. Determining new heights for the latter group is an indication of local vertical crustal motion or deficiencies in GEOID03 or both.

The orthometric adjustment was constrained 'loosely' to the NAD83 (NSRS2007) geodetic latitudes and longitudes of the CGPS points, by assigning them standard deviations of 5 cm. The ellipsoidal heights were not constrained, since, in general, GEOID03 does not adequately model the direct relationships between ellipsoidal heights and localized realizations of NAVD88. The 'loose' weighting of horizontal coordinates accommodates any strain that might be induced in the network owing to the divergence of the ellipsoidal normals among the CGPS stations and has no influence on the resulting adjusted elevations.

The orthometric adjustment was constrained to a subset of the published NGS vertical control points occupied during the survey. The subset of vertical constraints was determined via an iterative process and based on discussions among NGS, CSRC and Towill personnel. The discussions and repeated re-adjustments resulted in the selection of a subset of existing benchmarks that provided the 'best fit' of the network to the constraints subject to a variety of factors, most notably the well-founded suspicion that GEOID03 is deficient in the project area and would lead to residual and discrepancy trends across the network. Other factors that influenced the selection of constraints were the physical locations of the monuments (e.g., the proximity to fault lines, substrate conditions, etc.), NSRS accuracy classifications (e.g., first order class I, third order, etc.), stability criteria, and the history or 'provenance' of the benchmark elevations. For example, it is known that the elevations of some geodetic control stations (generally California Dept of Transportation (Caltrans) High Precision Geodetic Network (HPGN) monuments) designated as 'leveled' were actually based on leveling from benchmarks with VERTCON[12]-derived NAVD88 elevations. Visual inspection of the mapped locations of 'leveled' marks provided insight as to whether they might be based on VERTCON transformations or on direct ties from an NAVD88 leveling line. However, published elevations that were determined via 'leveling' were used as constraints if they were not rejected in the adjustment.

An initial set of seventy-six (76) NGS benchmarks (with NAVD88 elevations) was selected throughout the project area to provide constraints for the orthometric adjustment. The constraints consisted of First Order, Second Order and Third Order benchmarks. Each was assigned an appropriate weight based on the following standard deviations:

- First order class I; first order class II ----------------------- 7 mm
- Second order class I -- 10 mm

[12] VERTCON is a PC software application which computes the modeled difference in orthometric height between the North American Vertical Datum of 1988 (NAVD88) and the National Geodetic Vertical Datum of 1929 (NGVD29) for a given location specified by latitude and longitude. This conversion is sufficient for many mapping purposes, but is generally not reliable for height modernization purposes (http://www.ngs.noaa.gov/PC_PROD/VERTCON/).

- Second order class II; Height Modernization points --- 20 mm
- Third order--- 30 mm

After the iterative process described above, the final constraint subset consisted of 54 NGS benchmarks.

Table 5 shows the constraints with their associated residuals. The discrepancies from the published elevations for 18 withheld benchmarks are also shown. Figure 8 and Figure 9 show the locations of the vertical constraints as well as the discrepancies at the withheld benchmarks, for the northern and southern regions, respectively. The residuals and discrepancies are all reported in the sense of 'adjusted minus published'.

The final NAVD88 orthometric heights are provided in an Excel worksheet in Appendix C. They are divided into passive and active (CGPS) stations. The results of the orthometric adjustment are shown in the Excel worksheet under the column labeled "Adjusted", with the corresponding 1-σ uncertainties (standard deviations) in the adjacent column. The column labeled "Final" includes the NGS-published orthometric heights for 54 of these benchmarks, and the adjusted orthometric heights for all other survey monuments. The monuments highlighted in green are the 54 benchmarks that were used as constraints in the orthometric adjustment. The 19 monuments highlighted in blue are monument 04JD[13] and 18 benchmarks that were not used as constraints in the orthometric adjustment, and which received new elevation values. Note that standard deviations were not provided in the last column for the 54 constrained benchmarks (in green) since we used the published NGS elevations.

None of the active stations has previously published NGS NAVD88 values so the "Adjusted" and "Final" columns are identical.

[13] Monument 04JD was constrained to 30 mm in the adjustment but its discrepancy compared to the NGS-published value was 54 mm. We decided, therefore, to publish a new elevation for this monument.

Table 2. Geodetic Adjustment Constraints and Residuals

CENTRAL COAST HEIGHT MODERNIZATION PROJECT 2007 [CENCHM2007]
Geolab Adjustment Constraints and Residuals
Datum: ITRF2005; epoch 2008.0

CGPS Site	Name	Array	X	Y [meters]	Z	σX	σY [meters]	σZ	resid X	resid Y [meters]	resid Z
P059	PointArenaCN2006	PBO	-2758534.6856	-4132154.0848	3986124.8537	0.0017	0.0023	0.0023	0.0008	-0.0005	0.0004
P171	SantaLuciaCN2004	PBO	-2705141.4806	-4364218.9225	3771983.6803	0.0016	0.0021	0.0019	0.0002	0.0004	0.0000
P174	LlanoGrandCN2007	PBO	-2654559.3467	-4409051.8796	3755466.2274	0.0020	0.0029	0.0026	0.0004	-0.0001	-0.0004
P175	RosasCyn_CN2006	PBO	-2656852.6913	-4398263.0257	3766589.7111	0.0019	0.0016	0.0010	0.0001	-0.0001	0.0000
P176	MillsCreekCN2007	PBO	-2712719.3671	-4281637.9721	3859342.0320	0.0021	0.0027	0.0025	-0.0021	0.0006	0.0010
P178	SanMateoCCCN2007	PBO	-2708470.7180	-4279023.7487	3864681.4653	0.0021	0.0030	0.0027	0.0010	0.0005	-0.0001
P180	JuanFiestaCN2007	PBO	-2682088.8289	-4393408.4781	3754840.5394	0.0019	0.0027	0.0024	-0.0011	0.0017	-0.0003
P181	MillerKnoxCN2005	PBO	-2697941.0148	-4255089.4652	3898009.5854	0.0030	0.0044	0.0041	-0.0003	0.0003	0.0005
P182	MeyersGradCN2006	PBO	-2735748.3737	-4183649.9220	3948843.2408	0.0019	0.0028	0.0026	0.0005	-0.0006	-0.0005
P183	BodegaHeadCN2006	PBO	-2734197.4093	-4199233.0223	3932827.2894	0.0016	0.0022	0.0021	-0.0007	-0.0008	-0.0004
P188	BurnetRidgeCN2006	PBO	-2732637.7380	-4171209.2078	3963725.4473	0.0022	0.0030	0.0029	-0.0012	-0.0007	-0.0012
P189	Bradford_CN2005	PBO	-2729042.9813	-4146928.0926	3991345.3530	0.0016	0.0021	0.0020	-0.0002	0.0003	-0.0003
P193	PointReyesCN2007	PBO	-2729545.3158	-4217920.4327	3916228.9597	0.0016	0.0023	0.0021	0.0016	-0.0012	-0.0012
P194	WalkerCrk_CN2007	PBO	-2720516.3191	-4218785.6186	3921812.8706	0.0014	0.0019	0.0018	-0.0002	0.0019	0.0003
P195	WineCreek_CN2007	PBO	-2713026.5141	-4184197.2534	3963410.0814	0.0022	0.0030	0.0028	0.0014	-0.0006	0.0008
P196	MeachumLflCN2006	PBO	-2710854.0935	-4215684.5921	3931525.1350	0.0017	0.0025	0.0023	0.0004	-0.0006	-0.0002
P197	SantaRosa_CN2005	PBO	-2707773.0942	-4206898.5018	3942820.1376	0.0014	0.0019	0.0018	0.0003	0.0005	-0.0003
P198	PetalumaAirCN2004	PBO	-2702277.3626	-4224223.0853	3928131.5135	0.0016	0.0021	0.0020	-0.0008	0.0023	-0.0004
P199	RodgersCrkCN2005	PBO	-2694488.8953	-4228940.3090	3928501.5783	0.0018	0.0024	0.0022	0.0015	0.0001	-0.0008
P200	SonomaCrk_CN2005	PBO	-2691515.0516	-4232701.8337	3926371.6550	0.0016	0.0022	0.0020	-0.0009	-0.0018	0.0011
P202	NunnsCyn__CN2007	PBO	-2688246.9257	-4220352.5812	3942750.0246	0.0016	0.0021	0.0020	-0.0002	0.0015	0.0003
P203	Mayacmas__CN2007	PBO	-2702657.1706	-4174954.4690	3981336.5421	0.0015	0.0020	0.0020	-0.0007	0.0011	0.0007
P204	MaacamaCrkCN2007	PBO	-2694819.5252	-4195915.7860	3963650.2190	0.0017	0.0021	0.0020	-0.0007	-0.0002	-0.0001
P206	CrazyCreekCN2006	PBO	-2680785.4665	-4195731.7648	3973296.0582	0.0023	0.0033	0.0032	0.0002	0.0003	0.0000
P209	BonnyDoon_CN2007	PBO	-2709926.3661	-4315521.6411	3823876.3188	0.0017	0.0023	0.0021	0.0004	-0.0004	-0.0002
P210	ElkhrnSlghCN2005	PBO	-2688758.7702	-4348064.6879	3801079.6546	0.0015	0.0020	0.0018	0.0003	-0.0009	0.0004
P211	LewisRdLflCN2007	PBO	-2684012.7767	-4346119.9863	3806712.3254	0.0016	0.0023	0.0020	0.0006	0.0000	-0.0002
P212	LarkinVly_CN2006	PBO	-2693569.3553	-4333680.5964	3814047.2395	0.0019	0.0026	0.0024	0.0002	-0.0001	0.0001
P214	CorralitosCN2007	PBO	-2687206.2916	-4334599.6984	3817527.6126	0.0021	0.0031	0.0028	0.0000	0.0000	-0.0001
P220	RussianRdgCN2007	PBO	-2707249.7183	-4296663.6983	3846996.1466	0.0021	0.0031	0.0028	0.0000	0.0004	-0.0011

Table 2. Geodetic Adjustment Coordinate Constraints and Residuals (cont.)

CENTRAL COAST HEIGHT MODERNIZATION PROJECT 2007 [CENCHM2007]
Geolab Adjustment Constraints and Residuals
Datum: ITRF2005; Epoch 2008.0

CGPS Site	Name	Array	X	Y [meters]	Z	σX	σY [meters]	σZ	resid X	resid Y [meters]	resid Z
P231	HopkinsStnCN2006	PBO	-2708724.7988	-4350832.6662	3783764.2427	0.0024	0.0035	0.0031	-0.0008	0.0013	0.0001
P232	BengardRchCN2007	PBO	-2680400.9425	-4360502.8177	3792952.0808	0.0020	0.0030	0.0026	0.0003	0.0002	-0.0004
P234	LasAromitaCN2006	PBO	-2676639.6798	-4352309.0712	3804898.2041	0.0018	0.0026	0.0023	-0.0003	-0.0001	0.0001
P236	Lomerias__CN2005	PBO	-2672262.0458	-4351445.7802	3808872.6111	0.0014	0.0019	0.0017	0.0000	0.0000	0.0000
P237	MountOlds-CN2007	PBO	-2669014.4806	-4374808.6703	3785571.2926	0.0020	0.0029	0.0025	-0.0002	-0.0013	0.0000
P240	MillerSlghCN2005	PBO	-2667666.4409	-4346076.0473	3818100.5089	0.0020	0.0028	0.0025	0.0001	0.0000	0.0000
P242	FrazierAirCN2004	PBO	-2663555.5654	-4352803.4907	3813317.7307	0.0019	0.0026	0.0024	-0.0005	0.0001	0.0000
P244	PachecoCrkCN2005	PBO	-2653337.3159	-4354633.7760	3818387.7206	0.0015	0.0020	0.0018	0.0002	-0.0001	0.0000
P261	HunterHillCN2004	PBO	-2677432.9224	-4248806.2599	3918882.0499	0.0017	0.0021	0.0019	0.0001	0.0001	0.0000
P262	Waterbird_CN2005	PBO	-2673021.9066	-4261799.1680	3907637.9403	0.0018	0.0022	0.0021	-0.0002	0.0005	-0.0006
P264	Capell_Valley_CA	PBO	-2665156.9097	-4232962.5008	3944324.8885	0.0019	0.0026	0.0024	0.0003	0.0002	0.0005
P277	PigeonPt__CN2007	PBO	-2723379.2439	-4296846.6425	3834491.5746	0.0014	0.0018	0.0016	0.0003	-0.0002	-0.0001
P284	AvilaRanchCN2005	PBO	-2655929.9538	-4436532.8895	3722498.6577	0.0020	0.0030	0.0026	-0.0001	0.0001	-0.0001
P288	MooneyCyn_CN2006	PBO	-2646784.7653	-4426153.1535	3741001.1770	0.0014	0.0019	0.0016	-0.0002	0.0001	0.0002
P534	CookePeak_CN2007	PBO	-2718401.5161	-4310470.8155	3822941.0259	0.0016	0.0021	0.0019	-0.0012	0.0007	0.0010
OHLN	Ohlone Park	BARD	-2686856.4248	-4254625.9977	3905990.5290	0.0017	0.0023	0.0022	0.0004	-0.0007	0.0000
PTRB	Point Reyes Lighthouse	BARD	-2742441.2498	-4219970.1027	3905199.1457	0.0018	0.0024	0.0022	-0.0004	-0.0007	0.0001
SVIN	St. Vincent	BARD	-2704640.4417	-4241134.6211	3908328.4109	0.0019	0.0026	0.0024	-0.0002	-0.0019	0.0013
TIBB	Tiburon Peninsula	BARD	-2704026.8758	-4253050.0328	3895879.2583	0.0021	0.0027	0.0024	0.0005	-0.0029	-0.0004

Table 3. Parameters for the Transformation between ITRF2005 and ITRF2000

Reference: ITRF Website (http://itrf.ensg.ign.fr/ITRF_solutions/2005/tp_05-00.php)

14 transformation parameters between ITRF2005 and ITRF2000 have been estimated and using 70 stations

	T1	T2	T3	D	R1	R2	R3
	mm	mm	mm	10-9	mas	mas	mas
	0.1	-0.8	-5.8	0.40	0.000	0.000	0.000
+/-	0.3	0.3	0.3	0.05	0.012	0.012	0.012
Rates	-0.2	0.1	-1.8	0.08	0.000	0.000	0.000
+/-	0.3	0.3	0.3	0.05	0.012	0.012	0.012

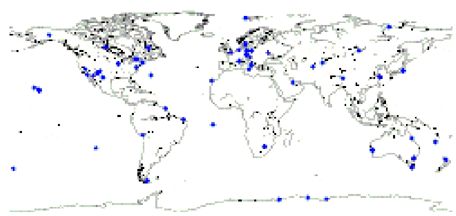


Table 4. Parameters for the Transformation between ITRF2000 and NAD83 (CORS96)

Reference: NGS Website (http://www.ngs.noaa.gov/CORS/Coords.html)

The transformation from ITRF2000 to NAD83(CORS96) is perfomed by the following formulas as determined by the National Geodetic Survey;

ITRF00 --> NAD83 (CORS96)

[12 common points]

$t_0 = 1997.0$

$T_x(t_0) = 0.9956$ m; $T_y(t_0) = -1.9013$ m; $T_z(t_0) = -0.5215$ m

$\varepsilon_x(t_0) = 25.915$ mas; $\varepsilon_y(t_0) = 9.426$ mas; $\varepsilon_z(t_0) = 11.599$ mas

$s(t_0) = 0.62 \cdot 10^{-9}$ (unitless)

$\dot{T}_x = 0.0007$ m $\cdot$ year^{-1}; $\dot{T}_y = -0.0007$ m $\cdot$ year^{-1}; $\dot{T}_z = 0.0005$ m $\cdot$ year^{-1}

$\dot{\varepsilon}_x = 0.067$ mas $\cdot$ year^{-1}; $\dot{\varepsilon}_y = -0.757$ mas $\cdot$ year^{-1}; $\dot{\varepsilon}_z = -0.051$ mas $\cdot$ year^{-1}

$\dot{s} = -0.18 \cdot 10^{-9}$ year^{-1}

Table 5. NAVD88 Published Elevations, Residuals and Constraints

CENTRAL COAST HEIGHT MODERNIZATION PROJECT 2007 [CENCHM2007]
Orthometric Adjustment [NAVD88] Constraints, Residuals and Discrepancies

4CHAR Code	Designation	PID	Class/Order	Published Elevation [meters]		Residual or Discrepancy [meters]	Constraint [meters]
0402	HPGN CA 04 02	HT3666	First Class II	27.192	Adjusted	0.012	0.007
0511	HPGN CA 05 11	GU4261	Third	39.68	Leveling	-0.005	0.030
0513	HPGN CA 05 13	GU4263	Third	8.03	Leveling	-0.062	Witheld
3450	941 3450 M TIDAL	GU4116	First Class II	3.565	Adjusted	-0.038	Witheld
4290	941 4290 N TIDAL	AE5209	Second Class I	3.669	Adjusted	0.010	0.020
4413	SEAPLANE	DG6888	Ht Mod	3.00	Published	-0.005	0.020
4873	941 4873 TIDAL 17	HT1754	First Class II	2.908	Adjusted	0.005	0.007
5020	941 5020 Q TIDAL	HT3505	First Class II	19.812	Adjusted	-0.119	Witheld
5052	941 5052 C	AE7862	Ht Mod	2.11	Published	0.021	0.020
5228	941 5228 TIDAL 3	JT0913	First Class II	3.059	Adjusted	-0.106	Witheld
5252	941 5252 E TIDAL	JT9547	Ht Mod	1.77	Published	0.000	0.020
01B7	HPGN D CA 01 B7	JT9639	First Class II	387.356	Adjusted	-0.007	0.007
047M	47 M	JT0652	First Class II	8.460	Adjusted	-0.146	Witheld
04AK	HPGN D CA 04 AK	AB7670	Third	125.04	Leveling	-0.020	0.030
04BG	HPGN D CA 04 BG	AB7674	Third	33.21	Leveling	0.017	0.020
04JD	HPGN D CA 04 JD	JT9611	Third	8.78	Leveling	-0.054	0.030
04JE	HPGN D CA 04 JE	JT9612	Ht Mod	11.19	Published	0.016	0.020
04PC	HPGN D CA 04 PC	JT9632	Third	94.10	Leveling	0.023	0.030
05VE	HPGN D CA 05 VE	GU4317	Third	44.73	Leveling	-0.023	Witheld
05WB	HPGN D CA 05 WB	GU4318	Third	25.29	Leveling	-0.048	Witheld
10LC	HPGN D CA 10 LC	AC9890	Ht Mod	8.04	Published	0.004	0.020
119P	P 1190	GU2433	First Class II	120.253	Adjusted	0.000	0.007
27CC	27 CC CO	JT0530	Ht Mod	18.55	Published	0.006	0.020
A123	A 1239	HT1536	First Class II	7.582	Adjusted	-0.002	0.007
AMER	AMERICAN GPS	AE7863	Ht Mod	140.19	Published	0.024	0.020
C119	C 1191	GU2533	First Class I	65.392	Adjusted	0.006	0.007
C261	C 261	GU2795	First Class I	28.875	Adjusted	0.050	Witheld
E124	E 1241	HT0469	First Class I	15.863	Adjusted	0.002	0.007
E144	E 1441	GU4126	First Class II	60.085	Adjusted	-0.008	0.007
F146	F 1460	GU4227	First Class II	47.312	Adjusted	0.000	0.007
G123	G 1238	GU1979	First Class I	22.437	Adjusted	0.005	0.007
G12R	G 1236 RESET	GU4314	Third	54.91	Reset	0.010	0.020
H144	H 1441	GU4129	First Class II	92.628	Adjusted	0.001	0.007
H154	H 154	GU2317	First Class I	124.299	Adjusted	0.009	0.010

Table 5. NAVD88 Published Elevations, Residuals and Constraints (cont.)

CENTRAL COAST HEIGHT MODERNIZATION PROJECT 2007 [CENCHM2007]
Orthometric Adjustment [NAVD88] Constraints, Residuals and Discrepancies

4CHAR Code	Designation	PID	Class/Order	Published Elevation		Residual or Discrepancy	Constraint
				[meters]		[meters]	
H449	H 1449	GU4111	First Class II	13.05	Adjusted	-0.018	0.010
HOGG	HOG	GU3516	Ht Mod	179.33	Published	0.005	0.020
HUNT	HUNTER WEST 1	HT0613	Ht Mod	3.35	Published	-0.001	0.020
J123	J 1239	HT1461	First Class I	48.883	Adjusted	-0.012	0.010
J695	J 695 RESET 1963	GU2755	First Class I/Ht Mod	49.508	Adjusted	0.003	0.007
K696	K 696	GU2779	First Class I	40.107	Adjusted	-0.072	Witheld
L124	L 1241	HT0481	First Class I	123.18	Adjusted	0.001	0.007
L138	L 1398	JT9416	First Class II	254.887	Adjusted	0.009	0.007
L146	L 1462	GU4239	First Class II	18.417	Adjusted	-0.001	0.007
LAY2	LAYOUS 2	GU2441	First Class I	111.643	Adjusted	0.014	0.010
M119	M 1191	GU2511	First Class I	51.491	Adjusted	-0.006	0.007
M139	M 1393	JT9545	First Class II	4.262	Adjusted	-0.001	0.007
MOON	MOON 2	HT1455	Second Class II	22.251	Adjusted	-0.028	0.020
Q136	Q 1396	JT9464	First Class II	98.285	Adjusted	-0.141	Witheld
R144	R 1447	GU4095	First Class II	52.153	Adjusted	0.003	0.007
R21R	R 21 RESET	GU2214	First Class I	19.268	Adjusted	-0.037	Witheld
RV22	RV 223	HT1789	First Class II	2.335	Adjusted	0.000	0.007
RV38	RV 138	JT1067	First Class II	64.148	Adjusted	-0.009	0.007
RV59	RV 159	JT1100	First Class II	34.77	Adjusted	-0.073	Witheld
RV69	RV 169	JT1113	First Class II	37.157	Adjusted	-0.118	Witheld
S132	S 1320	HT2268	First Class I	102.431	Adjusted	-0.002	0.007
T738	T 738 RESET	GU2250	First Class II	28.338	Adjusted	0.002	0.007
V119	W 1191	GU2710	First Class I	33.13	Adjusted	0.004	0.007
V148	V 1448	GU4098	First Class II	14.856	Adjusted	-0.005	0.007
V695	V695 RESET 1954	GU2814	First Class I	167.438	Adjusted	0.065	Witheld
W107	W 107 RESET	JT0826	First Class II	2.693	Adjusted	0.023	0.010
W123	W 1238	HT1540	First Class II	32.827	Adjusted	-0.008	0.007
W131	W 1317	GU3240	First Class I	45.213	Adjusted	0.002	0.007
W477	W 477	JT0959	First Class II	33.746	Adjusted	-0.127	Witheld
W631	W 631	JT0656	First Class II	3.991	Adjusted	-0.161	Witheld
X134	X 1394	JT9509	First Class II	110.534	Adjusted	-0.022	0.010
X135	X 1395	JT9483	First Class II	6.416	Adjusted	-0.092	Witheld
X139	X 1397	JT9429	First Class II	81.24	Adjusted	-0.001	0.007
X144	X 1449	FV1942	Ht Mod	134.56	Published	-0.004	0.007
X552	X 552	JT0321	First Class II	3.98	Published	0.005	0.007
Y123	Y 1239	HT1514	First Class I	13.997	Adjusted	-0.016	0.010
Y136	Y 1396	JT9455	First Class II	37.481	Adjusted	-0.098	Witheld
Y153	Y 153	GU2508	First Class I	67.831	Adjusted	-0.001	0.007

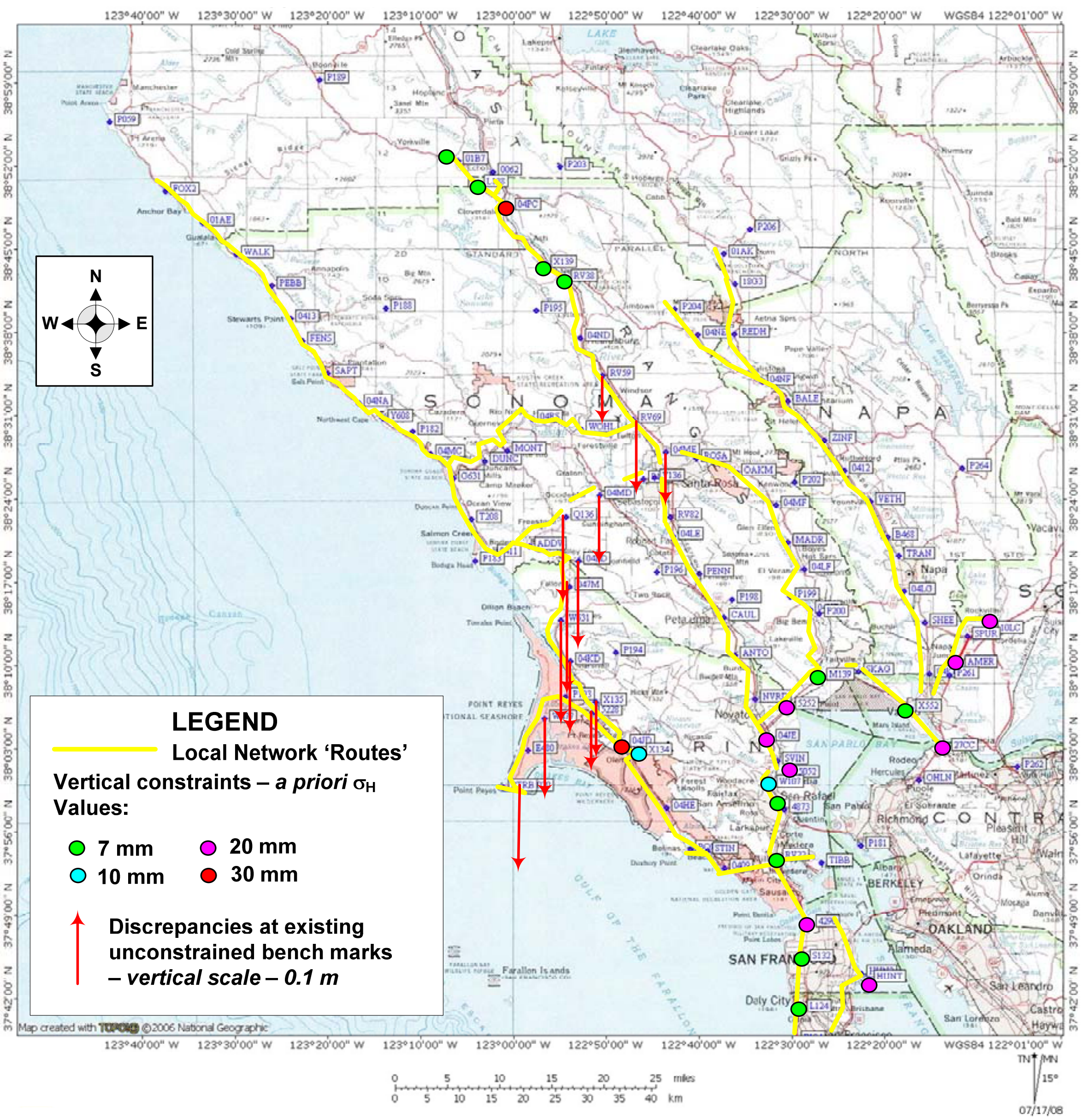


Figure 8. Vertical Constraints and Discrepancies: Northern Region

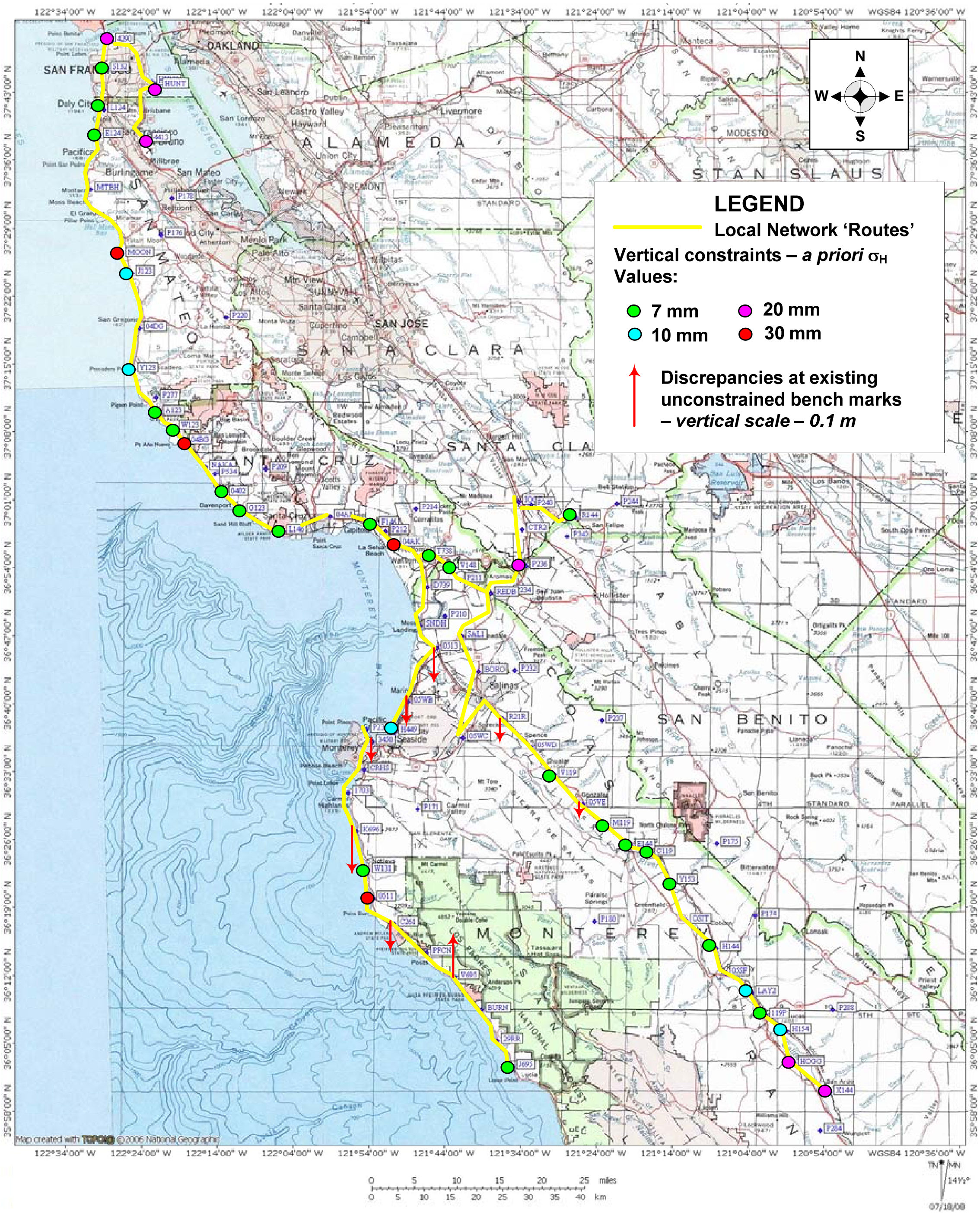


Figure 9. Vertical Constraints and Discrepancies: Southern Region

7. NGS Blue Book File Generation

7.1 Project Blue Book Files

We insured that the requirements for generating Blue Book files were met by following the provisions of the NGS's "Input Formats and Specifications of the National Geodetic Survey Data Base" (http://www.ngs.noaa.gov/FGCS/BlueBook/). The following annexes were consulted in the Blue Book preparation process and during its integration into PGM:

- Annex K: Project Report Instructions
- Annex L: Guidelines for Submitting GPS Relative Positioning Data
- Annex M: NGS GPS Antenna Codes
- Annex N: Global Positioning System Data Transfer Format (G-file); and
- Annex P: Geodetic Control Descriptive Data (D-File).

The Blue Book files include:

- G-File – the differential GPS solutions (i.e., vector/baseline data and their associated variance/covariance information);
- B-File – the GPS project and station metadata (includes project title, location, start/stop times and project dates);
- D-File – the descriptions for all the control and survey points used in the GPS network ;
- SERFIL – a file that associates the four-character code with a station serial number;
- R-File – an archive of all CGPS and passive occupation RINEX files.

The B-file, G-file, R-file and SERFIL for this project were generated from the PGM server. The final files were generated by CSRC staff through the password-protected link at http://pgm-server01.ucsd.edu/cgi-bin/pgmPutSinexData.cgi. The D-file was generated by the Project Manager, Marti Ikehara, using the WinDESC program. All the Blue Book files can be viewed and downloaded at:

http://pgm-server01.ucsd.edu/cgi-bin/pgmShowSinexData.cgi?campaign_code=CENCHM2007.

7.2 Integrity Checks for Blue Book Files

From the Adjust and Utilities software available at: http://www.ngs.noaa.gov/PC_PROD/ADJUST/:

OBSCHK checks the integrity of the B-file and G-file. OBSCHK produced short (obschkshort.out) and long (obschklong.out) version output files with no error messages. The two output files are provided in Appendix J.

CHKOBS checks an observation dataset for correct structure and syntax. CHKOBS returned no errors. Its output file, chkobs_final.out, is provided in Appendix J.

COMPVECS is used to find differences among redundant vectors in a G-file. Its output file (compVecs.out) is provided in Appendix J. COMPVECS returned no errors.

COMPGB is available at: http://www.ngs.noaa.gov/PC_PROD/COMPGB/. COMPGB tests the consistency and compatibility of the B-file and the G-file for a GPS project. Its output file (compgb_multiBaseline_final.out) is provided in Appendix J. COMPGB could not be run in the single baseline mode because the program has a limitation of 90 baselines per day. In multibaseline mode, the 'star' formation of sites is assumed, in which the vectors all originate at one site for that session, but this project used an optimizing criterion that calculated the set of vectors that were independent and shortest in length. These vectors are listed in the G-file as though they were independent sessions, but with a single session code for each SINEX file because the session code may only be one alphanumeric character and this project has as many as 58 independent vectors per day. Consequently, COMPGB, using the multi-baseline check, flagged a number of pairs with statements similar to this:

1J6951P171 omitted from gfile baseline vectors for day 8

OBSDES compares a horizontal Blue Book Description data set with its respective Blue Book Observation data set. This description file or D-file, CENCHM_COMB.dsc, was prepared by the Program Manager, Marti Ikehara. The OBSDES output check file ,obsdes_final.out, shows no errors.

Running the D-file checking program, WinDESC, generated the output error file, windesc_final.out. This program detected 49 errors, which refer to urls which, by definition, contain an invalid character, not anticipated when the D-file format was first developed by NGS.

8. Discussion of Results

8.1 Horizontal Results

The adjusted geodetic coordinates of the CENCHM2007 project are presented in Appendices A and B. It should be noted that a large number of the passive points have since been re-adjusted by the NGS and now have published NAD83 (NSRS2007) values. The average magnitude of the differences between the published coordinates and the values determined from this project appear to be approximately 15 mm. This is within the accuracy of the re-adjusted NGS values and the current survey. However, because the CENCHM2007 survey meets the Federal Geodetic Control Subcommittee (FGCS) accuracy order B standard, it is recommended that the coordinate values determined in this project supersede the NGS computed values.

However, the decision to update the geodetic coordinates of the existing horizontal control will depend on whether the NGS considers the specifications and procedures employed as adequate for an order B classification.

8.2 Orthometric Heights

Analysis of the results of the orthometric adjustment has revealed geoidal trends that are most likely caused by a paucity of gravity and leveling/GPS data in the area. However, this will continue to be a problem until a revised geoid model is produced from additional data. These higher order geoidal trends are evident in Figure 8 and in Figure 9. The residuals and discrepancies are all reported in the sense 'adjusted minus published'.

The northwestern region of the project area reveals the most significant discrepancy trends, particularly in a band extending from Point Reyes in western Marin County, and extending northwards towards Sonoma County. These residuals are all negative, with magnitudes around 0.1 m. In general, such trends may be examined in the light of a localized geoidal modeling deficiency, geotectonic processes (vertical crustal motion), geomorphological processes (benchmark instability), or the existence of a severe systematic error in the geodetic leveling associated with the published elevations. The possibility of the occurrence of such large systematic errors in the current GPS survey is very unlikely given the stringent provisions of NOS NGS 58, many of which are explicitly designed to detect blunders and to mitigate systematic errors, and the large number of accurate CGPS stations used in the geodetic adjustment. After weighing the possibilities, it is the authors' contention that the trend can most likely be ascribed to localized GEOID03 modeling errors. Ancillary to this observation is a concern that the new height modernization points located along the coastline between Point Reyes and Point Arena will also be burdened by similar systematic errors.

The central region of the project area does not exhibit the modeling trends evident in the northwest, with the fit at existing benchmarks appearing to be quite reasonable given the accumulative sources of possible error (residual geoidal modeling errors combined with GPS and geodetic leveling errors).

To the south, near Monterey, there is a patch of discrepancies which exhibit a possible trend, albeit about half the magnitude of the trend in the northwestern region. South of Monterey towards Big Sur, the results are mixed.

Considering the overall network data, and taking into account the proximity to the coast, the outcome is not unexpected. It is suggested that the results of this survey should ultimately be used to refine future geoidal models. In the meantime, the survey does provide useful NAVD88 elevation data at locations not previously served by NSRS benchmarks. In summary, as Zilkoski (2008, personal commun.) has pointed out, most end-users are interested primarily in high accuracy in a localized relative sense, so errors over larger regions are of lower importance.

8.3 The Use of PGM

PGM proved to be a valuable tool both in the field and in the office, most notably for maintaining the integrity of the CENCHM2007 data and derived files and products, and for delineating a workflow which streamlined the process of getting data into a centralized database quickly, enhancing project management. Further revisions and enhancements were made to PGM during this project which facilitated the production of Blue Book files. It is now very close to becoming a 'field-to-finish' post-processing solution for projects of this kind.

8.4 The Blue Book Process and ADJUST

It is understood that the NGS will supplement the final processing with Geolab described in this report with processing through ADJUST and may submit the data to the NSRS database based on the ADJUST analysis.

9. DELIVERABLES

The final deliverables presented with this report include the following:

1. This hard copy of the report;
2. Digital copy of the report in attached CD;
3. Appendices in attached CD (see following Appendix listing in this report). The primary deliverables are:
    a. Final Geodetic Coordinates (Appendix A and Appendix B)
    b. Final Orthometric Coordinates (Appendix C)
    c. Final Blue Book Files (Appendix I)

The other materials in the appendices provide supporting documentation. All material are available at the CSRC website at http://csrc.ucsd.edu/projects/pgm/cenchm2007.html.

APPENDIX A

Final Geodetic Coordinates
International Terrestrial Reference Frame 2005,
Epoch 2008.0,
GRS80 ellipsoid

**See attached Excel spreadsheet:
AppendixA_CENCHM2007_ITRF2005_2008.xls**

The values were derived from the constrained Geolab geodetic adjustment (see Appendix F).

APPENDIX B

Final Geodetic Coordinates
North American Datum 1983 (National Spatial Reference System 2007), Epoch 2007.0

See attached Excel spreadsheet: AppendixB_CENCHM2007_NAD83_2007.xls

The values were derived from HTDP version 3.0 (see Appendix G). It should be noted that we decided not to introduce an uncertainty for the transformation of coordinates from epoch 2008.0 to 2007.0, although this step is not without error and depends on the accuracy of the underlying geophysical model of HTDP.

APPENDIX C
Final Elevations
North American Vertical Datum of 1988, NAD83(NSRS2007), Epoch 2008.0

See attached Excel spreadsheet: AppendixC_CENCHM2007_NAVD88_OrthometricHeights.xls

The elevation values (column labeled "Adjusted") were derived from the Geolab NAVD88 orthometric adjustment (see Appendix H). The highlighted marks (green) indicate those 54 leveled NAVD88 benchmarks whose elevations were held as constraints in the orthometric adjustment. The highlighted marks (blue) indicate 19 leveled NAVD88 NGS-published benchmarks for which new elevations were estimated. The adjusted values were transcribed to the column labeled "Final" except for 53 NAVD88 benchmarks, which were held fixed to their NGS-published NAVD88 values (Note: Monument 04JD was constrained to 30 mm in the adjustment but its discrepancy compared to the NGS-published value was 54 mm. We decided, therefore, to publish a new elevation for this monument)

APPENDIX D
Scheduled Observations and Actual Observations Dates/Times

See attached file AppendixD.pdf

APPENDIX E
Repeat Ellipsoidal Height Differences

See attached file AppendixE.pdf
In this appendix we document the deviations of the ellipsoidal height differences from their mean values for the GPS processing performed by the CSRC. The final network design resulted in 2-8 measurements of each repeat baseline.

APPENDIX F
Constrained Least Squares Adjustments ITRF2005, Epoch 2008.0, GRS80 ellipsoid

See attached files:

(1) CENCHM2007-ITRF2005-MIN.iob (Geolab input file, minimally constrained adjustment)
(2) CENCHM2007-ITRF2005-MIN.lst (Geolab output file, minimally constrained adjustment)
(3) CENCHM2007-ITRF2005-MIN.pdf (Geolab output file, minimally constrained adjustment, pdf format)
(4) CENCHM2007-ITRF2005-CON.iob (Geolab input file, constrained adjustment)
(5) *CENCHM2007-ITRF2005-CON.lst (Geolab output file, constrained adjustment)
(6) *CENCHM2007-ITRF2005-CON.pdf (Geolab output file, constrained adjustment, pdf format)
(7) default.gpj (Geolab options file)

*This adjustment was the basis for the final CSRC-published coordinates given in Appendix A.

APPENDIX G

HTDP Output of Transformation from ITRF2005, Epoch 2008.0 to NAD83(NSRS2007), Epoch 2007.0

See attached file AppendixG.pdf

APPENDIX H
Orthometric Height Adjustment
NAD83(NSRS2007), Epoch 2008.0, NAVD88, GEOID03

See attached files:

(1) CENCHM2007-NAD83(NSRS2007)-2008-NAVD88.iob
(Geolab input file, orthometric adjustment)
(2) CENCHM2007-NAD83(NSRS2007)-2008-NAVD88.lst
(Geolab output file, orthometric adjustment)
(3) CENCHM2007-NAD83(NSRS2007)-2008-NAVD88.pdf
(Geolab output file, orthometric adjustment, pdf format)
(4) default.gpj (Geolab options file)
(5) g2003u05pc.gsp (GEOID2003 geoid undulations)
(6) g2003u05pc.bin (Geolab GEOID03 input file)

APPENDIX I
NGS Blue Book Files

See attached files:

(1) B-File (BFIL)
(2) G-File (GFIL)
(3) D-file (DFILE.zip)
(4) SERFIL
(5) R-files (RINEX files)

APPENDIX J
Integrity Checks for NGS Blue Book Files

See attached files:

(1) OBSCHK output (obschklong_final.out, obschkshort_final.out)
(2) OBSDES output (obsdes_final.out)
(3) CHKOBS output (chkobs_final.out)
(4) COMPVECS output (compvecs_final.out)
(5) COMPGB output (compgb_multiBaseline_final.out)
(6) WinDesc output (windesc_final.out)