NAVD88 Orthometric Height Determination Utilizing the California Real Time GPS Network

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BIOGRAPHY

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David E. Morgan is a Land Surveyor In Training (LSIT) and an Engineer In Training (EIT). He is employed by Psomas as a survey analyst responsible for field survey data analysis and production of survey maps. He is a graduate from New Mexico State University with a Bachelor's degree in both Surveying Engineering and Civil Engineering.

ABSTRACT

The California Spatial Reference Center (CSRC), in collaboration with the Scripps Orbit and Permanent Array Center (SOPAC) at University of California, San Diego, has completed numerous height modernization projects following the standards and specifications defined for the National Height Modernization Program, by the National Geodetic Survey. The continued demand for height modernization survey data, combined with advances in GPS processing and wireless data communication, led to the subject project utilizing the capability of the California Real-time Network (CRTN). This continuous GPS (CGPS) network utilizes real-time 1Hz data streams flowing through the SOPAC archive from more than 80-stations in southern California.

The purposes of this project included testing the application of modern real-time GNSS surveying methods to high-precision geodesy, and to obtain critical data needed to analyze a proposed accuracy model for the national geoid. These purposes were accomplished by collecting data for establishing GPS-derived North American Vertical Datum of 1988 (NAVD88) orthometric heights on about 46 passive stations (National Geodetic Survey (NGS) first order bench marks) in Southern California. This work is part of CSRC's goal to

establish NAVD88 elevations on CGPS stations. Ultimately, this network of CGPS sites, with NAVD88 elevations, will become the foundation of a sustainable geodetic reference network for the California Spatial Reference System (CSRS). Such CGPS sites are critical to maintaining the vertical component of the CSRS, as they provide the ability to efficiently maintain the network (and other) orthometric heights using GNSS survey methods in combination with a high-precision national geoid model and corrector surfaces. This observation campaign was also part of a demonstration to test the viability for National Height Modernization surveys using the Pocket GPS Manager (PGM) software, developed by CSRC for NGS, and the functionality of CRTN.

The GPS observations were collected in 2 five-hour sessions while connected to the CRTN server through a PDA cellular phone with the Geodetics RTD Rover software. Observations and 1 Hz positions were computed instantaneously (once per second) and stored at the server using Inverse Instantaneous Network RTK™ procedure, and streamed to the PDA. Single-epoch position statistics were computed at the server and running statistics were computed on the PDA. The accumulated PDA statistics were compared to positions computed by two on-line services, OPUS and SCOUT, as well as comparison to two post-processing procedures. The final GPS geodetic positions were converted to orthometric heights using the NGS Geoid '03 model and compared to published NAVD88 elevations. The differences in GPS-derived orthometric heights to NGS first order elevations were examined to determine an accuracy estimate of the Geoid '03 model in the project area.

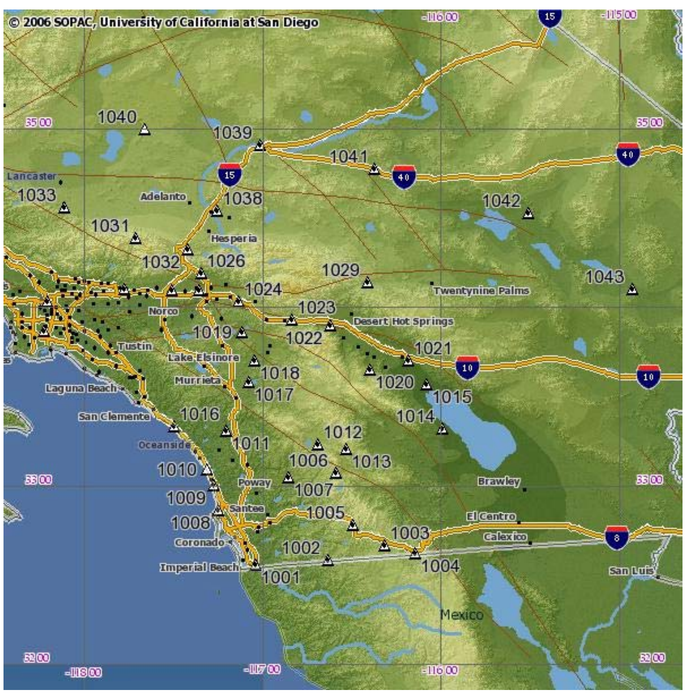

Figure No. 1. Height modernization sites in S. California.

INTRODUCTION

One of the goals of the California Spatial Reference Center (CSRC) is to improve the availability and sustainability of an accurate spatial reference frame throughout the seismically active areas of California (CSRC, 2003). As part of this goal, and as a constituent partner of the National Height Modernization Program, the Center has been concentrating on height modernization statewide. (Over 400 continuous GPS (CGPS) sites reporting daily, together with extensive research and velocity models currently provide accurate predictions past and future for horizontal motion.) Height Modernization projects have been completed in the subsidence areas of the San Joaquin Valley, in the counties around southern San Francisco Bay, in the subsidence areas of Glenn County, in mountainous Tuolumne County and in the seismically active ten southern counties (CSRC, 2007a). Current projects are in the northernmost counties, the central coast and this project in southern California. The goal with all these projects is to provide current, accurate values, but also to determine ways to maintain these values for the future. By determining accurate ellipsoidal heights on monuments that have a NAVD88 elevation, the Center expects to determine accurate observed geoid heights. These geoid heights can then be analyzed to compute a local corrector surface for the national geoid height model. A locally accurate geoid model will allow for quick height recovery utilizing CGPS and campaign GPS after seismic events. The process can also be used to compute and distribute corrector surfaces for alternate datum such as Mean Lower Low Water (MLLW) needed for tidal boundaries and precise navigation.

This current project is located in the ten southern counties of California (below the 36th parallel). Forty-six (46) locations were chosen to fill in areas that had known height inaccuracy or were deemed to have questionable accuracy.

Additional goals of this project were to test the functionality of the newly operational California Real-time Network (CRTN) (CRTN, 2007) and also the Pocket GPS manager (PGM) software (CSRC, 2007e), which was developed for NGS to be used for handling the metadata associated with height modernization projects.

FIELD METHODS

The forty-six (46) target locations were determined by examining existing GPS-derived orthometric heights in the NGS database and looking for unexplained anomalies. With the target locations identified, the first stage of the project was to research the "best candidate" of all of the nearby NGS 1st Order benchmarks at each location. Benchmarks were chosen based on stability of mark (most likely to have held elevation well) and the GPS suitability of the mark. During this initial stage of the project, it was immediately apparent that the historical vertical component (passive benchmarks) of the California spatial reference network is in decline. In the office research of the NGS database, five or six suitable benchmarks were identified as possible sites. Then during the field

Figure No. 2. Field equipment setup.

reconnaissance, it was found that a much larger proportion of marks than expected were destroyed, disturbed, subject to settlement or unsuitable for GPS due to changed conditions at the site. We estimate that overall about 1 in 6 of the marks deemed useable from database research is actually still in original to good condition in the field. This early observation amplified the need to pursue this type of height modernization utilizing CGPS and the benefit of having NAVD88 heights on the CGPS themselves, versus just on passive marks.

The field observation of the selected marks used certain field methods designed by NGS for 2 – 5 cm ellipsoid heights per NOS NGS-58 (Zilkowski, 1997), modified to utilize the capability of modern real-time GNSS survey methods. The field data collection was scheduled to collect continuously for two 5-hour occupations. The sessions were scheduled on two (vs. 3) different days and for different times of the day. Remote logistics and travel considerations necessitated, collecting the 2 sessions on the same day (morning and afternoon) for some stations.

The field GPS equipment utilized were Trimble 5800 dual frequency receivers, with Zephyr Geodetic antennas. These were mounted on two-meter fixed height tripods. The "data collectors" were Verizon 6700 cell phones and Hewlett-Packard iPAQs that were connected by Bluetooth to the 5800 receiver (see Figure No. 2).

The data collectors had two specialized programs loaded for this project. The first program, called Pocket GPS Manager (PGM) (CSRC, 2007e), was used to set up the project ahead of the field campaign, with all the site information and equipment metadata. This project information was then uploaded to the data collectors. Once in the field, the observer used the PGM program to select the correct site and equipment, enter other pertinent information and then start the survey. The outstanding benefit of this program is the immediate capture of all pertinent field data, while still at the site, in a digital format. Large GPS campaigns can be a nightmare when it comes to metadata organization and this program provided excellent quality control in that aspect.

The second program was the RTDRover software program (Geodetics, 2007a). This program facilitated the collection and handling of observation data. RTDRover collects the raw observation data into a file that resides in the data collector (in the case of Trimble), the data flowing from the receiver to the collector wirelessly by Bluetooth. RTDRover also facilitates the connection to the CRTN server (phone service/Verizon 6700; wireless aircard/HP iPAQ). A Radio Shack device accomplished the Bluetooth connection between the data collector and the Trimble 5800 (see arrow on Figure No. 2).

RTDRover was set to collect 1 Hz data while simultaneously sending this data to the SOPAC server that hosts the CRTN. Through a process called Inverse Instantaneous Positioning TM (Bock, 2004), the NMEA observables would be processed against the three closest CGPS in the CRTN network and the 1-Hz network-adjusted position (corrected for troposphere and ionosphere) would be sent back to the field data collector site every second (possible latency of 1-2 seconds).

OFFICE METHODS

The CRTN server, which is located at Scripps in La Jolla, CA. provides real-time data streams from over 80 CGPS sites via a suite of programs known as RTDPro (Geodetics, 2007b). The RTD-Server component is a multi-baseline processor utilizing instantaneous inverse positioning techniques to process the project site as if it was a site in the CRTN network (facilitated by the RTDRover data collection program) in real-time with troposphere and ionosphere models. The server picks the three closest CGPS sites in the network and processes the field site against those three sites to provide an Epoch-by-Epoch™ network-adjusted position. This adjusted position is then transmitted back to the field user.

The original plan was to process 1-Hz observation data from each site (for each 5-hour observation session) as collected. At the time that the field campaign was ready to begin, the troposphere model that was to be utilized on the CRTN server was not. We decided that we would proceed with the fieldwork, collecting the data in real-time without the troposphere model. We would then post-process the data after field collection utilizing the model. (This post-processing involved downloading the CGPS 1-Hz data files (CRTN, 2007a) and the precise ephemeris (CSRC, 2007d), and then running them through RTDPro Ver. 3.5 (Geodetics, 2007b), along with the project data, basically the same process as if they had been processed in real-time.)

The collected data was also to be post-processed using Trimble Geomatics Office© software (Trimble, 2007) (Ver. 1.63; single baseline post-processor with Saastamoinen troposphere model and 2-hour zenith delay). This was to provide a comparison between the software methods generally available to the average user and the more advanced scientific capabilities. Each data set would also be run through two readily available on-line post-processing services – OPUS (NGS, 2007a), on the NGS web site and SCOUT (CSRC, 2007b), on the CSRC (SOPAC) web site. All methods would utilize the final precise ephemeris and some method of atmospheric modeling. By processing the data in these various methods, we hoped to be able to draw comparisons from the results.

The following outlines the five methods of data processing and analysis that each 5-hour observation session was run through:

1. Processed and least squares adjusted using RTD-Pro multi-baseline processor, *without* a tropospheric model (but with troposphere estimation), utilizing the IGS final ephemeris, in epoch of data observation
2. Processed and least squares adjusted using RTD-Pro multi-baseline processor, *with* the NOAA tropospheric model, utilizing the IGS final ephemeris, in epoch of data observation
3. Processed using Trimble Geomatics Office™ single-baseline processor, with the Saastamoinen tropospheric model, utilizing the IGS final ephemeris, in epoch of data observation, with a 2-hour zenith delay. Least squares adjusted using StarNet-Pro (StarNet, 2007)
4. Processed and least squares adjusted using SCOUT on-line coordinate generator, with some tropospheric modeling utilizing the IGS final ephemeris, in epoch of data observation
5. Processed and least squares adjusted using OPUS on-line coordinate generator, with some tropospheric modeling, utilizing the IGS final ephemeris, in epoch of data observation

Figure No. 3. Bluetooth adaptor device.

In the first three methods, the SOPAC SECTOR utility (CSRC, 2007c) was used to establish the control coordinates for the three CGPS sites to be used at each project site. These coordinates were used for coordinate seeding in the baseline processing and as fixed control values in the least squares analysis. All processing and data handling was done using the ITRF2000 coordinates (except towards the end of the project, ITRF2005 was implemented and some of the later datasets were in ITRF2005).

The CGPS sites that were selected for the first three methods were the three closest CGPS sites that are streaming 1 Hz data through the CRTN. The selection criteria was to be within a 50 km radius at a maximum, but the majority of sites had much shorter distances to the CGPS sites. A few sites that were at the 50 km range or farther were processed with nearby "static" CGPS sites (30 second data rate vs. 1 second).

After the observation data was processed and adjusted, the ITRF2000/2005 value for the ellipsoid height of each project site was compared to the second 5-hour session. The criteria set forth in NGS-58 is that these two values should compare to within 2 cm of each other. These ITRF ellipsoid heights were then converted to a NAD83 ellipsoid height using the NGS utility HTDP (NGS, 2007b). The HTDP utility transforms the ITRF coordinates into a NAD83 ellipsoid height. This NAD83 ellipsoid height was then converted to a NAVD88 elevation by subtracting the Geoid03 model height that was listed on the NGS datasheet for that particular project site. The last step was comparing the GPS derived NAVD88 height to the NGS NAVD88 adjusted elevation on the datasheet to determine the project derived difference in elevation.

Site No.	Ellipsoid Ht. Processing Method	Ave NAD83 EH (m)	Ave NAVD88 GPS OH (m)	Ave delta (proj - NGS) (m)	Std Dev mean (m)	95% confid (m)
1017	mean of all methods	384.723	417.143	-0.039	0.005	0.009
	mean RTD2&Trimble	384.726	417.146	-0.036	0.000	0.001
1024	mean of all methods	527.636	560.056	-0.002	0.007	0.015
	mean RTD2&Trimble	527.636	560.056	-0.001	0.012	0.023
1028	mean of all methods	286.001	319.411	-0.025	0.010	0.020
	mean RTD2&Trimble	285.998	319.408	-0.028	0.005	0.010
1032	mean of all methods	1119.529	1151.229	-0.007	0.008	0.016
	mean RTD2&Trimble	1119.532	1151.232	-0.004	0.002	0.005
1037	mean of all methods	1133.135	1164.575	-0.025	0.018	0.035
	mean RTD2&Trimble	1133.139	1164.579	-0.021	0.013	0.026
1038	mean of all methods	837.799	869.459	-0.050	0.013	0.026
	mean RTD2&Trimble	837.801	869.461	-0.049	0.010	0.019
1040	mean of all methods	714.255	745.945	0.007	0.014	0.028
	mean RTD2&Trimble	714.261	745.951	0.013	0.009	0.018
1042	mean of all methods	209.374	241.054	-0.056	0.014	0.028
	mean RTD2&Trimble	209.378	241.058	-0.052	0.019	0.037
1043	mean of all methods	227.271	259.241	-0.019	0.021	0.042
	mean RTD2&Trimble	227.256	259.226	-0.033	0.001	0.003
1044	mean of all methods	-16.731	19.109	-0.036	0.010	0.020
	mean RTD2&Trimble	-16.725	19.115	-0.030	0.003	0.006
1046	mean of all methods	-2.204	33.686	0.014	0.007	0.015
	mean RTD2&Trimble	-2.210	33.680	0.012	0.007	0.015

Table No. 1. Sites meeting ±5cm comparison to NGS NAVD88 elevation.

ANALYSIS OF DATA

The first analysis was to determine which sets of 5-hour observations met the NGS-58 criteria for repeatability of 2cm. Reviewing the comparison between sessions of the same project point, showed that overall, all methods were able to repeat the ellipsoid heights within 2cm in the two observation sessions. SCOUT had the highest number of out-of-tolerance sessions with 14 (out of a total of 92 solutions) and an additional 5 sessions that would not solve at all. OPUS was the next having 6 sessions solved out-of-tolerance and 5 that would not solve. Trimble TGO methods had 5 sessions out-of-tolerance and 4 sessions (2 sites) that would not solve. RTD methods, both with and without the tropo model, had three out-of-tolerance solutions and only one session it could not solve. Regarding the "not solved" sessions, they were in most cases not the same sites that would not solve. With the exception of two sites, in all other cases one method wouldn't solve a dataset but all others did solve. This would indicate that something other than bad raw data was the problem. Considerable effort was expended to figure out this somewhat anomalous problem, but further research is needed. Since this result seems more related to on-line processors than post-processing methods, it was decided to use the criteria of being within tolerance on both post-processed methods (2&3) to determine whether a site met the 2cm NGS requirement. Out of 46 project locations, 36 sites met the NGS criteria of the ellipsoid heights comparing within 2cm in repeat sessions. The ten non-conforming sites will need further investigation, along with those that did not solve at all.

Once the datasets meeting the 2cm criteria were determined, a comparison of the GPS derived NAVD88 height to the NGS published elevation was performed. Having processed each dataset using five different methods, this was fairly complex. Upon reviewing the results for a particular project site, the results weren't as consistent as one would have hoped. A first look at averaging the five results and then comparing to the published value was done. In some cases the mean would be "skewed" due to one of the on-line results differing greatly from the post-processed values. Since the two on-line methods did not allow much user intervention, there was no ability to re-evaluate the on-line result if it was not within the range of the other methods. A second comparison was done using the mean of the values determined by the two post-processed methods (2 & 3) that utilized the tropospheric model and that gave the user greatest control in refining the result.

Of the 36 sites meeting the 2cm criteria, 11 of these sites matched the published NGS NAVD88 elevation within the NGS stated range of ± 5cm (see Table No. 1). From these same 36 sites, 16 sites exceeded the elevation criteria of ± 5cm. Most of these showed consistent

Site No.	Ellipsoid Ht. Processing Method	Ave NAD83 EH (m)	Ave NAVD88 GPS OH (m)	Ave delta (proj - NGS) (m)	Std Dev mean (m)	95% confid (m)
1003	mean of all methods	1150.455	1182.755	-0.148	0.020	0.039
	mean RTD2&Trimble	1150.464	1182.764	-0.139	0.009	0.017
1007	mean of all methods	434.181	466.561	-0.064	0.005	0.011
	mean RTD2&Trimble	434.185	466.565	-0.061	0.006	0.011
1010	mean of all methods	-18.697	15.974	-0.098	0.011	0.022
	mean RTD2&Trimble	-18.697	15.974	-0.098	0.011	0.021
1011	mean of all methods	26.822	60.182	-0.093	0.013	0.026
	mean RTD2&Trimble	26.827	60.187	-0.088	0.017	0.033
1012	mean of all methods	841.865	873.485	-0.126	0.006	0.013
	mean RTD2&Trimble	841.861	873.481	-0.130	0.006	0.012
1013	mean of all methods	1167.507	1199.157	-0.150	0.012	0.023
	mean RTD2&Trimble	1167.514	1199.164	-0.143	0.001	0.002
1014	mean of all methods	-52.928	-19.268	-0.134	0.015	0.029
	mean RTD2&Trimble	-52.928	-19.268	-0.134	0.015	0.029
1015	mean of all methods	-92.369	-58.939	-0.174	0.009	0.017
	mean RTD2&Trimble	-92.372	-58.942	-0.177	0.000	0.000
1016	mean of all methods	14.273	48.783	-0.084	0.012	0.023
	mean RTD2&Trimble	14.273	48.783	-0.084	0.017	0.033
1020	mean of all methods	696.243	728.243	-0.075	0.003	0.007
	mean RTD2&Trimble	696.244	728.244	-0.074	0.004	0.008
1021	mean of all methods	-46.361	-13.231	-0.161	0.012	0.024
	mean RTD2&Trimble	-46.362	-13.232	-0.161	0.016	0.030
1025	mean of all methods	330.879	363.699	-0.069	0.010	0.020
	mean RTD2&Trimble	330.870	363.690	-0.077	0.000	0.001
1026	mean of all methods	480.769	513.099	-0.073	0.008	0.017
	mean RTD2&Trimble	480.769	513.099	-0.074	0.013	0.026
1027	mean of all methods	314.036	346.956	-0.065	0.006	0.012
	mean RTD2&Trimble	314.030	346.950	-0.071	0.005	0.009
1036	mean of all methods	1055.979	1088.299	-0.065	0.015	0.030
	mean RTD2&Trimble	1055.981	1088.301	-0.064	0.008	0.015
1039	mean of all methods	610.588	641.958	-0.109	0.005	0.009
	mean RTD2&Trimble	610.590	641.960	-0.106	0.003	0.006

Table No. 2. Sites with consistent difference to published NGS NAVD88 elevation.

differences indicating possible change in height from published elevation (see Table No. 2).

Of the remaining nine sites, five sites had a high mean of all the methods, but a mean of the post-processed methods that would meet the 5cm criteria. These sites all had unsatisfactory results with one or both of the on-line processors. Efforts to QC the raw data and to pick different CGPS sites to use in the on-line processing were not enough to improve the results for these sites to an acceptable range. Further analysis will be done on this. The other four sites, while meeting the 2cm criteria for repeatability, were wide ranging in the delta from NGS and need further examination.

A final comparison of the difference between the mean being determined from all methods versus just the post-processed methods shows that in only 6 instances (yellow highlighting) does the overall mean have a better result than the post-processed result mean. This highlights a limitation of the on-line methods. With limited user input and error checking, or prior information to compare your result to, you will have a greater chance of an unverifiable result than when using a post-processed method. As always, it is a function of using the right tool for the accuracy and precision needed for your desired result.

DISCUSSION

One of the intriguing aspects of the on-line processors can be demonstrated with a short discussion of project site 1037. This site is located an average of 1 km away from CGPS sites LJRN, FZHS and P553 (approximate elevation 1165m; NW'ly most tip of Los Angeles Co., Frazier Park area). For this site, both 5-hour datasets were collected on Julian day 261 2006. Both datasets were initially run through SCOUT on Jan. 23, 2007. The first session failed with an ellipsoid height (EH) standard deviation (SD) of 8.000 meters! The second session worked fine with an EH SD of 0.023m. Further investigation of this site occurred on Mar. 28, 2007. The first session was rerun using the same three sites and having made no changes to the dataset. This output showed no change to the coordinates but significant changes to the SD of the ITRF horizontal components as well as the EH which was now 6.000m. A second try was run using CGPS sites FZHS, P553 and P554 (another nearby CGPS site). This resulted in an EH SD of 9.000m (ave. baseline length still 2km). One more attempt using LJRN, P553 and P554 netted a result of 0.021 SD, with baseline length ave. still 2km.

For this same site, OPUS returned the results of 0.024m and 0.014m, respectively for the first and second session. However, it had chosen 3 CGPS sites with an ave. baseline length of 110 km and 146 km, respectively, from the project site. Both sessions were run through OPUS on the same day, 5:35 minutes apart, and yet different sites were chosen for the second session that greatly increased baseline length and still managed to improve the SD by almost half. The second session had 13% more observations than the first session, but OPUS statistics showed both sessions had 100% fixed ambiguities and 98% of observations used.

The ellipsoid heights generated by the four "passing" runs from the on-line processing were 1132.444 and 1132.443 for SCOUT (SD=2cm for both) and 1132.441 (SD=2cm) and 1132.451 (SD=1cm) for OPUS. (The EH for the three failing runs averaged 1132.774m.)

The output files have little information to help the user decide what is actually happening. Both state the use of the precise ephemeris and OPUS gives a statement on fixed ambiguity and observations used percentages. Neither output gives users information regarding usage (or not) of any type of tropospheric or ionospheric correction, but both NGS and SOPAC will state that the program is handling it. A question to be answered is whether the on-line processors can do a QC check on the CGPS sites chosen, or do they just pick the three closest by distance? Apparently not all CGPS sites are operating equally well, so users need to be knowledgeable about alternative CGPS in their project area. At this point neither on-line processor seems consistent enough to wholly rely on the results without some other verification.

Another aspect of the project that provided some interesting results was the use of the cellular phones for data collectors. Cell coverage is very dense in S. California, especially Verizon. Although we had excellent results overall, we had occasional unexplainable "outages" in areas we knew had coverage. We could only guess that cell coverage must have been down at that time for some reason. This lack of control and reliance on a third party system being fully operational, is one aspect that surveyors must take into account in the planning stages of a project. Lack of phone service simply turns a real-time data collection into a post-processed type of survey.

Similarly, a Plan A and a backup plan for use of the CGPS sites is a good idea. We had great success with the availability of CGPS sites, both with real-time data streaming and archived data. However, we did find that some CGPS sites had issues with a particular day's data and so we used a nearby site instead. This was mostly a problem with the on-line processors, but the large numbers of available CGPS sites and the solid reliability of the CRTN server makes this third party system easier for field surveyors to recover from surprises in the field.

The Pocket GPS Manager is an excellent tool for the orderly collection and archiving of metadata that accompanies a field survey project. Having the site data and equipment choices loaded into the data collector, limited field mistakes and assured all necessary information was collected. Further refinements are planned for this product and it will be utilized on future height modernization projects by both the CSRC and NGS.

FUTURE ANALYSIS OF DATA

The final GPS-derived orthometric heights for those observations considered "passing" are being assembled into the CSRC database together with heights from previous conventional height modernization campaigns. This subset of the CSRC database will become the basis for a geo-referenced accuracy model of the national geoid height model. Software is being developed to analyze height differences in a collocated least squares adjustment considering the observed geoid height residual, estimated observation errors, and the correlation distances between observation data points. This accuracy model will be a valuable tool for GNSS surveying throughout the region in that surveyors will be able to determine the ability to establish orthometric heights meeting a specific level of accuracy in a given area using the most efficient methods. Developing software linked to the database will allow CSRC to run similar analysis using additional data sets and updated national geoid models.

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REFERENCES

Bock, Yehuda (2004). "Instantaneous Network RTK Positioning in Areas of Active Deformation." Geodetics, Inc., La Jolla, CA. http://www.geodetics.com/WebSite/papers/YBock_ION2004.pdf

California Spatial Reference Center (CSRC) (2003). "A Master Plan for a Modern California Geodetic Control Network". http://csrc.ucsd.edu/input/csrc/csrcMasterPlan.pdf .

Starplus Software (2007). Star*Net-Pro, Version 6. Oakland, CA. starplus@earthlink.net

Zilkoski, D., D'Onofrio, J. and Frakes, S., NOAA Technical Memorandum NOS NGS-58: Guidelines For Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm), Version 4.3 , 1997. http://www.ngs.noaa.gov/PUBS_LIB/NGS-58.html

WEB SITE REFERENCES

CSRC Web Site: http://csrc.ucsd.edu (2007)
a. CSRC height modernization projects http://csrc.ucsd.edu/projects
b. SCOUT utility: http://csrc.ucsd.edu/cgi-bin/SCOUT.cgi
c. SECTOR utility: http://csrc.ucsd.edu/cgi-bin/sector.cgi
d. Precise Ephemeris: http://csrc.ucsd.edu/cgi-bin/csrcDataPortal.cgi?main_option=viewPortalResources#PRECISE_ORBITS
e. PGM program: http://csrc.ucsd.edu/projects/pgm.html

CRTN Web Site: http://sopac.ucsd.edu/projects/realtime/ (2007)
a. 1 Hz data archive: http://garner.ucsd.edu/pub/highrate/cache/raw/
b. 1 Hz data access: http://sopac.ucsd.edu/input/realtime/IPPorts.rtf

Geodetics, Inc.: http://www.geodetics.com (2007)
a. RTDRover software: http://www.geodetics.com/WebSite/products/RTDFamily/RTDRoverSpecs.html
b. RTDPro software: http://www.geodetics.com/WebSite/products/RTDFamily/RTDClient.html

NGS Web Site: http://www.ngs.noaa.gov (2007)
a. OPUS: http://www.ngs.noaa.gov/OPUS/
b. HTDP: http://www.ngs.noaa.gov/cgi-bin/HTDP/htdp.prl?f1=4&f2=1

Trimble Web Site: http://www.trimble.com (2007)
TGO: http://www.trimble.com/geomaticsoffice.shtml