NAVD88 ORTHOMETRIC HEIGHT DETERMINATION UTILIZING THE CALIFORNIA REAL TIME GPS NETWORK AND VARIED OCCUPATION TIME INTERVALS

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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 precursor to 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 to establish GPS-derived North American Vertical Datum of 1988 (NAVD88) orthometric heights on about 46 passive stations (National Geodetic Survey (NGS) first order benchmarks) in Southern California. This observation campaign was also part of a demonstration to test the viability of using the CRTN for National Height Modernization surveys. 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.

From this prior campaign, we found that using the CRTN to collect and adjust the 3D solutions (but specifically the height component), the final result was actually determined in much shorter time intervals than the specified 5 hours. This second project was designed to determine whether we could define new specifications (specifically shorter occupation times) for achieving orthometric heights in a more economical process. A timelier and economically feasible method is needed for quick and accurate height recovery after seismic events in southern California. This paper discusses our findings.

1. INTRODUCTION

This paper is further analysis of data collected from a prior CSRC height modernization survey project. The prior project methods and results are fully detailed in Whitaker, et.al. (2007), but will be briefly reviewed here. The purposes of the prior 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 NAVD88 orthometric heights on about 46 passive stations (NGS first order bench marks) in southern California. 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 (CSRC, 2008e), developed by CSRC for NGS, and the functionality of CRTN (CRTN, 2008).

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 (Geodetics, 2008) software. Observations and 1 Hz positions were computed instantaneously (once per second) and stored at the server using Inverse Instantaneous Network RTK™ procedure (Bock, 2004), 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 (NGSa, 2008) and SCOUT (CSRCb, 2008), as well as comparison to two post-processing procedures. The final GPS geodetic positions were converted to orthometric heights using the NGS Geoid03 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 Geoid03 model in the project area.

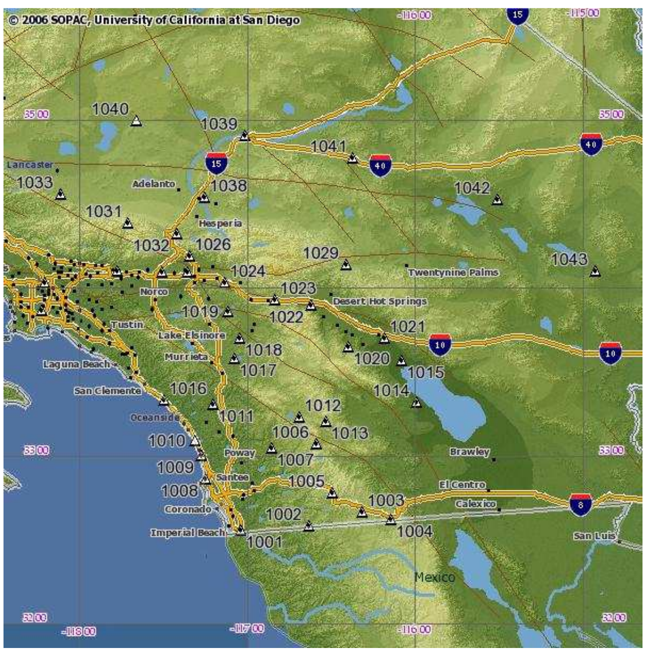

Figure N.º 1. Prior height modernization project sites in southern California.

1.1. Prior project results

From this project there were 36 of the 46 sites that met the NGS specifications for 2 -5 cm ellipsoid height determination per NOS NGS-58 (Zilkoski, et. al., 1997). The orthometric heights were then determined using Geoid03, per NOS NGS-59 (Zilkoski, et. al., 2005). Of these 36, 11 sites matched the NGS elevation within 2 cm and 16 sites didn't match the NGS elevation, but did consistently agree with each other (all processing methods came up with the same result). Most of these sites fell in localized regions of southern California, highlighting a possible bias in the Geoid03 model in those areas or possible regional subsidence.

The results from this first project showed potential that GPS height modernization surveys utilizing the CRTN methodology could provide ellipsoid heights, that when combined with Geoid03, would provide a NAVD88 elevation matching the NGS published value in the 2 – 5 cm range.

1.2. Further analysis of project needed

One issue that has plagued surveyors trying to perform height mod surveys to NGS specifications is the long, 5-hour time intervals required for the observation sessions. In seismically active areas, it is necessary to have a method that will quickly and accurately recover elevations after an event.

This is especially important for the MWD to be able to verify critical pipeline and water distribution elevations as soon as possible after an earthquake. Although differential levelling was used to determine the elevations initially, it is too time consuming to use when an immediate answer is needed. It was decided to look at the actual real-time 1 Hz data file to find out exactly when the real-time session had determined the same final result that the post processing had determined.

2. ANALYSIS OF REAL-TIME 1HZ OBSERVATIONS

Ten sites were chosen to analyze. Five sites were selected from the 11 sites that matched NGS elevations (1017, 1024, 1032, 1038, 1043) and 5 sites from the 16 sites that consistently differed from NGS elevations (1011, 1016, 1021, 1025, 1027) (Whitaker et. al., 2007). The raw data files for these sites were brought into a spreadsheet program to be able to look at each 1 Hz epoch individually. Ideally, it was expected that there would be 18,000 consecutive epochs of data (60 sec x 60 min x 5 hr). Immediately it was discovered that this was not the case. Although field technicians reported few problems with phone connectivity during data collection, it became obvious from looking at the data files that several, to many, times throughout the 5-hr observation session the phone had dropped connection to the CRTN server. When the connection reestablished with the server, data collection started again. Each time that the connection restarted, the server reset the epoch count, as if a new session had started. So on close examination of the raw data, we had many shorter time intervals, not one continuous 5-hr solution as we had planned. Site 1027 is shown as an example in Table No.1. (The reason for so many dropped phone/server connections needs to be looked into further.)

2.1. Analysis of 15 minute data sets

From Table No. 1 it is apparent that instead of two complete 5 hr. sessions, we actually had four or five partial sessions. This observation pattern was repeated at all sites we reviewed. The longest uninterrupted session was a 4-hour session, but the general pattern was 2 – 3 hours long. We decided to mean the 15 minute results (5 independent sessions, in the case of Site 1027 per Table No. 1) and compare those values to the values attained by the longer interval sessions. These values were plotted against the mean of the longer time intervals (which amounted to one 1-hr session, one 2-hr and one almost 3-hr, in the case of Site 1027). As a surveyor accustomed to performing 30-minute observation sessions for most static GPS

13:22:47	316.074	(0.00% outliers in 1 solns.)	start 1st sess
13:37:51	316.084	(0.00% outliers in 900 solns.)	15 min
13:52:51	316.081	(0.00% outliers in 1800 solns.)	30 min
14:23:13	316.080	(0.00% outliers in 3600 solns.)	1 hr
15:50:28	316.080	(0.00% outliers in 7200 solns.)	2 hr
15:59:11	316.082	(0.00% outliers in 7664 solns.)	2:07 hr
17:08:13	316.076	(0.00% outliers in 1 solns.)	reset
17:23:12	316.113	(0.00% outliers in 900 solns.)	15 min
17:38:12	316.114	(0.00% outliers in 1800 solns.)	30 min
18:08:51	316.115	(0.00% outliers in 3600 solns.)	1 hr
18:21:19	316.111	(0.00% outliers in 4348 solns.)	1:12 hr
18:23:25	316.102	(0.00% outliers in 1 solns.)	reset
18:37:18	316.095	(0.00% outliers in 813 solns.)	13 min
18:39:59	316.126	(0.00% outliers in 1 solns.)	start 2nd sess
18:58:27	316.086	(0.00% outliers in 900 solns.)	15 min
19:13:27	316.091	(0.00% outliers in 1800 solns.)	30 min
20:01:03	316.090	(0.00% outliers in 3600 solns.)	1 hr
21:11:21	316.093	(0.01% outliers in 7200 solns.)	2 hr
22:32:23	316.091	(0.01% outliers in 10260 solns.)	2:51 hr
22:32:24	316.041	(0.00% outliers in 1 solns.)	reset
22:48:21	316.048	(0.00% outliers in 900 solns.)	15 min
23:03:21	316.082	(0.00% outliers in 1800 solns.)	30 min
23:04:57	316.084	(0.00% outliers in 1896 solns.)	

Table No. 1. Raw 1 Hz. data intervals showing reset of observation solutions (Site 1027, 8/30/2006).

projects, the author decided to also look at the results determined at 30-minutes of real-time data. This analysis was done for all ten sites, but due to paper space, only four charts will be shown.

3. RESULTS OF REAL TIME SOLUTIONS

The first two sites charted, Site 1017 and Site 1024, were two of the sites that matched the published NGS orthometric height within the 2 -5 cm specifications.

For Site 1017, the mean ellipsoid height of the 15-minute intervals (5 sessions) was 384.775 m with a standard deviation of 0.012 m. The 30-minute interval (6 sessions) mean was 384.779 m with a standard deviation of 0.011m. The mean height for the long interval sessions (4 – 1½ to 2-hour sessions) was 384.781 m with a standard deviation of 0.006 m. In this case, both real-time results were within the 6 mm uncertainty of the more "rigidly" determined longer interval result. (See Figure No. 2.)

The mean ellipsoid height of the 15 minute observation sessions (4 sessions) for Site 1024 was 527.683 m with a 0.017 m standard deviation. The mean value for the 30-minute sessions (4 sessions) was 527.686 m with a standard deviation of 0.012 m. The mean height for the longer interval sessions (4- 1-hour sessions) was 527.682 m with a standard deviation of 0.014 m. (Figure No. 3). Both real-time results fell within the uncertainty of the longer interval result.

The next two sites charted, Sites 1021 and 1027, were both sites that although the final GPS derived orthometric height did not match the published NGS NAVD88 elevation, all the processing methods used per Whitaker, et al (2007), consistently came up with the same result for the orthometric height.

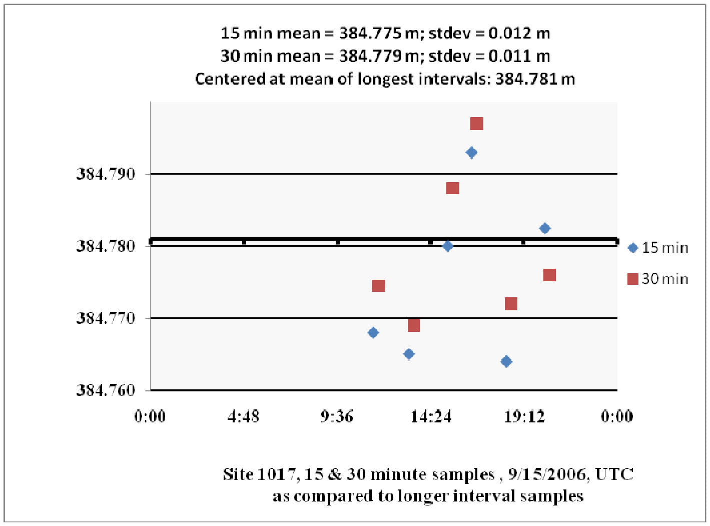

Figure No. 2. Site 1017 -15 & 30 min interval results vs. 2-3 hr results.

Figure No. 4 shows the results for Site 1027. The mean ellipsoid height of the 15-minute sessions (5 sessions) was 314.085 m with a standard deviation of 0.024 m. The 30-minute interval result (5 sessions) was 314.092 m with a standard deviation of 0.015 m. The longer interval (3 sessions as stated earlier) result was 314.095 m with a standard deviation of 0.007 m. In this case, the 15-minute interval result fell outside of the longer interval result uncertainty (by 3 mm) but the 30-minute interval was very close to the same result. As can be seen by the graph, there was a seeming outlier in one of the 15-minute sessions that caused the mean to be lower. If this outlier is removed, the mean of the 15-minute sessions would be 314.095 m, the same value as the longer interval.

For Site 1021, the mean ellipsoid height of the 15-minute sessions (5 sessions) was -46.289 m with a standard deviation of 0.016 m. The 30-minute interval result (5 sessions) was -46.292 m with a standard deviation of 0.019 m. The longer interval (5 – 1½ - 3 hour sessions) had a mean of -46.291 m with a standard deviation of 0.023 m. This site showed good agreement among all results, but had one of the highest uncertainty levels of the various sites.

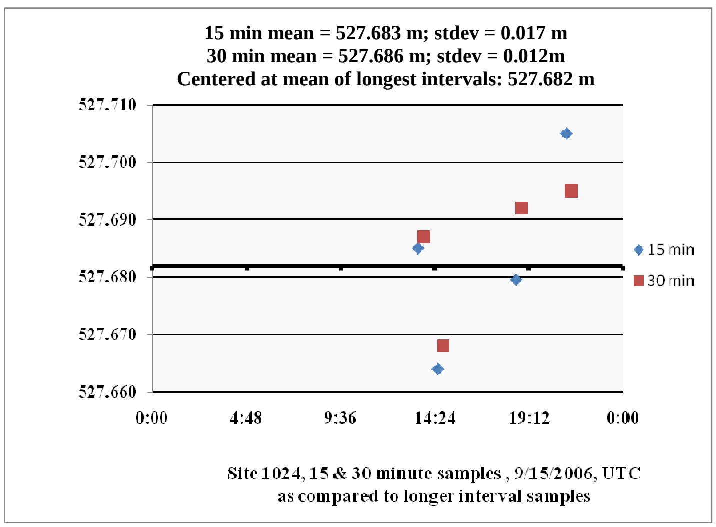

Figure No. 3. Site 1024-15 & 30 min interval results vs. 2-3 hr results

4. DISCUSSION

Comparison of the real-time results at different time intervals shows very promising results. The next step of course was to compare these resultant values to the post-processed results. At this step, we realized we had a bit of an "apples and oranges" comparison.

The post-processed values had been calculated in a true-of-survey-date epoch. The field surveys were performed in late 2006 and very early 2007. At this time, the epoch that was being broadcast from the CRTN was still the 2004.0 epoch, which was the approved reference. So in most cases, there was an approximate 2 year difference in the true-of-date epoch and the epoch of the real-time results. The resultant comparison (Table No. 2) of the two sets of values showed an approximate 5 -7 cm difference in the post-processed value as compared to the real-time result. This is approximately the amount of crustal motion that would have occurred in the 2 year time frame on the Pacific Plate in southern California.

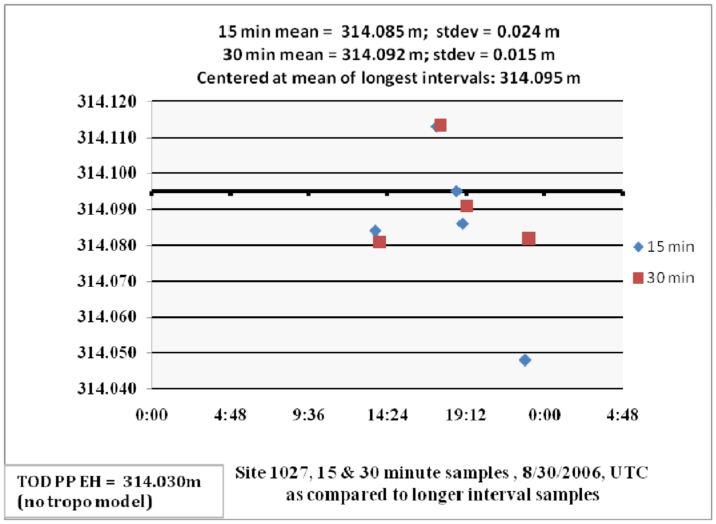

Figure No. 4. Site 1027-15 & 30 min interval results vs. 2-3 hr results

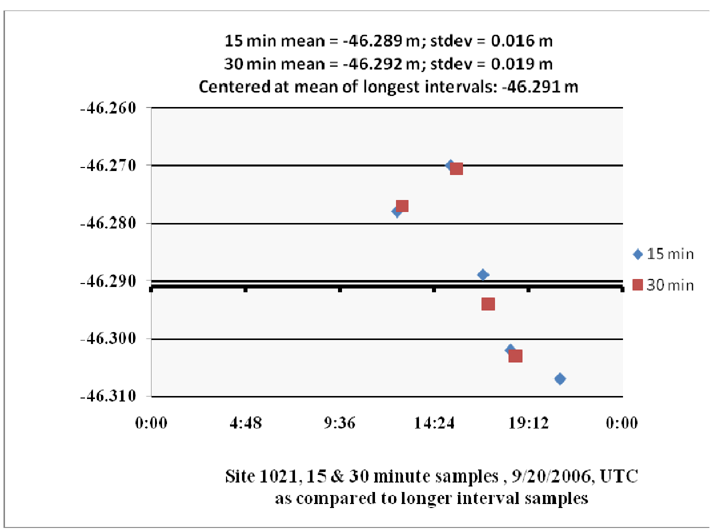

Figure No. 5. Site 1021-15 & 30 min interval results vs. 2-3 hr results

At the time of writing, it is planned to perform a new real-time new survey on these ten sites, using a special 2004.0 epoch broadcast from the CRTN, to be able to determine repeatability, while eliminating the epoch difference problem. (California has since moved to a new 2007.0 epoch (since the National Readjustment) and the CRTN is now broadcasting that epoch.) Another difference between the two processes was different handling of the troposphere and ionosphere modelling in the post-processing scenarios than in the real-time data. The analysis and removal of these biases were unable to be accomplished by time of writing and will be the subject of future research.

5. CONCLUSIONS

Analysis of the real-time 1 Hz data for various time intervals has shown promise that the ellipsoid height (and ultimately, the orthometric height), could be determined in shorter time intervals than the recommended 5 hour observation time. While the real-time data results showed good consistency between the 15-minute, 30-minute and longer interval sessions, it is not yet determined whether we were able to get an accurate orthometric height in 15 or 30 minutes. We now have the NOAA troposphere available when logged into the CRTN for a survey. This was not available at the time of the original survey, so this introduced a slight bias when comparing the real-time result to the post-processed result. We are also close to

Site ID	15 min Mean	Std Dev	Long Interval Mean	Post-processed	Long Int. minus 15 min	PP minus 15 min	PP minus long int
1017	384.775	0.012	384.781	384.726	-0.006	-0.049	-0.055
1024	527.683	0.017	527.682	527.636	0.001	-0.047	-0.046
1032	1119.550	0.024	1119.571	1119.532	-0.021	-0.018	-0.039
1038	837.835	0.009	837.820	837.801	0.015	-0.034	-0.019
1043	227.326	0.011	227.318	227.256	0.008	-0.070	-0.062
1011	26.888	0.013	26.890	26.827	-0.002	-0.061	-0.063
1016	14.335	0.009	14.333	14.273	0.002	-0.062	-0.060
1021	-46.289	0.016	-46.291	-46.362	0.002	-0.073	-0.071
1025	330.921	0.018	330.922	330.870	-0.001	-0.051	-0.052
1027	314.085	0.024	314.088	314.030	-0.003	-0.055	-0.058

Table No. 2. Result comparison – real-time and post processed.

having a velocity model available to the user of the CRTN. The user will be able to request his real-time result to be in the epoch of his choice. This would eliminate the problem we currently have, of the real-time data being in a different epoch that the actual survey date.

With the future resurvey, we hope to show that the orthometric height can be derived in the field in 30 minutes or less, accurately taking into account epoch date issues and proper troposphere and ionosphere modeling. Although it was shown that outliers are possible that skew the 15-minute result, depending on the accuracy needed, the result may still be within useful limits

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