SURVEY REPORT

of

2008 HEIGHT MODERNIZATION GPS SURVEY

for the

CITY OF SANTA BARBARA

by

MCGEE SURVEYING CONSULTING

Santa Barbara, California

PROJECT OVERVIEW: The City of Santa Barbara, Department of Public Works, Engineering (the City) with the assistance of Michael McGee, PLS of McGee Surveying Consulting performed a Height Modernization Survey to upgrade the Santa Barbara City Control Network (SBCN). The results of the 2008 Second Order Leveling Network Survey (see separate Report) were combined with the 2008 high accuracy GPS measurements to determine a refined geoid model and facilitate the use of GPS technology to establish accurate orthometric heights within the City.

PROJECT DATUMS & REFERENCE SYSTEMS: Positions are based on the North American Datum of 1983 (NAD 83), 1991.35 Epoch adjustment of the High Precision Geodetic Network (HPGN) as published by the National Geodetic Survey (NGS). The 1991.35 Adjustment of NAD 83 resulted from a state wide B-Order GPS Survey by the NGS which superseded the 1986 introductory adjustment of the NAD 83 Datum. NGS stations HPGN0501, HPGN0502 and HPGN0504 in the National Spatial Reference System (NSRS) were used in 1995 to establish a primary City GPS control network of 36 points. This network, known as the Santa Barbara Control Network (SBCN), is recorded in Book 147 of Records of Survey at Page 70-74, Santa Barbara County Records. In 1996, point 0006 was destroyed and reset nearby as shown in Book 149 of Records of Survey at Page 16-17. In 1997, a convention was adopted by the City to add the number 10000 to the SBCN point numbers to avoid leading zero's; therefore, 0004 is referred to as 10004 and 0031 is likewise 10031 or SBCN10031. Subsequently, additional points have been set to densify the original Network. Numbers in the range of 9001 to 9999 have been reserved for this purpose.

Orthometric heights, commonly referred to as elevations, are based on the North American Vertical Datum of 1988 (NAVD 88). The NAVD 88 Datum superseded the old NAVD 29 vertical datum in 1991. Orthometric heights established by the City in the 2008 Second Order Leveling Network Survey serve as the vertical basis for this network upgrade.

STATE PLANE COORDINATE PARAMETERS: Grid coordinates are NAD83-1991.35 California State Plane Coordinates Zone Five. The average Grid Scale Factor is 0.99993783. The Height Reduction Factor, based on the average ellipsoid heights is 0.99999479. The average Combined Grid Factor is 0.99993262. Multiply the Combined Factor times ground distances to obtain grid distances. Grid bearings should be rotated by a Convergence Angle to obtain geodetic bearings. The convergence angle varies across the City between-0°56' on the east and -1°00' on the west and averages -0°58.

FIELD SURVEYS/NETWORK: The GPS field campaign took place between June 18 and June 25 with additional observations collected on July 3, August 23 and September 19, 2008. The procedure was for one unit to be operated as a reference base station while one to two units occupied assigned points for 30 minutes. On a different hour of the day and/or on a different day the process was repeated with the reference base receiver occupying a different point. Descriptions and details of the points used in this survey are available at the City Department of Public Works, Engineering. See the Appendix for a map showing the locations of points. Nearby continuously operated GPS stations known as CGPS in California were included in the processing. A CGPS station is similar to a CORS (Continuously Operated Reference Station) except the term CORS is reserved for those published nationally by the NGS.

PROJECT ADJUSTMENTS: A separate transformation and adjustment was computed as described below.

TRANSFORMATION: A transformation was processed to validate the record 1995 horizontal coordinates of the SBCN points included in this survey, and to determine the rotations to apply to Geoid03 to best fit the local geoid.

A transformation, with no scale change, was computed using least squares to best fit the measurements of 21 SBCN points to the 1995 record horizontal positions. The differences from the record positions to the computed positions in feet are listed below under dN and dE. The north and east differences at 9027=K1215, COPR and UCSB represent the shifts from NAD 83, 2007.0 Epoch (derived from the national re-adjustment of the NSRS in February 2008) to the NAD 83, 1991.35 Epoch established for the City.

The transformation also computed a best fit to the new orthometric heights established by the 2008 Second Order Leveling Network Survey on 27 points including 18 of the SBCN points. These Orthometric heights represent the local geoid. Ellipsoid height differences measured with GPS were combined with the NGS Geoid03 Model and rotations were solved to compute a best fit surface through the 27 points listed below under dZ. The differences from the leveled orthometric heights to the computed best fit orthometric heights based on GPS measurements are shown in feet. The rotations that were applied to obtain this best fit solution are listed below.

Rotation Around North Axis: -0.5536 Seconds (Solved)
Rotation Around East Axis : 0.7101 Seconds (Solved)
Rotation Around Vert Axis : -0.3366 Seconds (Solved)

Station	dN(ft)	dE(ft)	dZ(ft)	Comments
9002	n/a	n/a	-0.002	
9027	-1.650	1.697	-0.002	= K1215 HARN Station (NAD 83, 2007)
9031	n/a	n/a	0.018	
9034	n/a	n/a	0.028	= Tidal-3
9035	n/a	n/a	0.014	
9036	n/a	n/a	0.001	
9037	n/a	n/a	-0.006	
9038	n/a	n/a	0.016	
9039	n/a	n/a	~~0.038~~	(not used in vertical solution) (used 9002 nearby)
10002	-0.006	-0.042	-0.019	
10003	0.016	-0.027	0.030	
10005	-0.010	-0.021	-0.014	
10006R	0.015	-0.009	-~~0.041~~	(not used in vertical solution)(poor vertical GPS)
10007	0.018	0.004	-0.021	
10009	0.017	-0.015	0.007	
10011	0.014	-0.012	~~0.067~~	(not used in vertical solution)(no good elevation)
10012	0.002	-0.013	-0.010	
10015	-0.039	-0.011	0.019	
10020	0.009	0.008	-~~0.076~~	(not used in vertical solution) (poor vertical GPS)
10021	0.001	0.001	-0.021	
10022	0.011	-0.014	-0.031	
10023	0.000	0.017	0.024	
10026	-0.020	0.025	-0.026	
10027	-0.015	0.014	0.018	
10029	0.000	-0.006	~~0.080~~	(not used in vertical solution, anomaly in Geoid03)
10030	0.014	0.005	0.017	
10031	0.000	0.021	0.010	
10033	-0.015	0.010	-0.025	
10034	0.010	0.027	-0.008	
10035	-0.020	0.039	-0.027	
COPR	1.768	1.581	~~0.012~~	= CGPS (not used in vertical solution)
UCSB	-1.740	1.608		= CGPS (no good elevation)
W1042_BOLT	n/a	n/a	0.007	

ANALYSIS and COMMENTS:

Analysis of the above north and east differences (dN and dE) between the record and the computed positions at the 21 SBCN points follow (does not include 9027, COPR and UCSB):

Ranges are between -0.039 to +0.018 feet in the north, and -0.042 to +0.039 feet in the east component
Averages of the absolute values are 0.012 feet in the north and 0.016 feet in the east component
Standard Deviations are 0.015 feet in north and of 0.020 feet in the east

The computed positions are based on precision 2008 GPS measurements and represent a higher relative accuracy for these SBCN points; however, the differences are deemed insignificant and acceptable at the accuracy levels required for the City. The record values were accepted, rather than cast uncertainty on the considerable number of prior surveys based on the record position of the SBCN.

Analysis of the height differences (dZ), between the new leveled orthometric heights and those computed based on a best fit transformation follow (except those noted above as "not used in vertical solution"):

Ranges are between -0.031 to +0.030 feet
Average of the absolute values of the differences is 0.016 feet
Standard Deviation of 0.018 feet

The results of this analysis indicates that orthometric heights accurate to 0.03 feet can be determined using GPS technology within the City (see APPLICATION below for information).

ADJUSTMENT: A minimally constrained adjustment was processed to develop ellipsoid heights. Point 9027=K1215 (NGS B-Order Station) was fixed at its NAD 83, 2007 Epoch position to establish NAD 83, 2007 latitude, longitude and ellipsoid heights on the points included in this survey. Closures on the NAD 83, 2007 record positions of the CGPS stations COPR and UCSB are shown below as a matter of information. Units are feet.

Point	Latitude	Longitude	E.H.	Description
9027	34-24-41.84597	119-41-56.07706	-85.702	K1215, NAD83(2007) Fixed Position

Station	dN	dE	dZ	
9027	0.000	0.000	0.000	Fixed
COPR	-0.029	-0.113	-0.041	
UCSB	-0.019	-0.087	-0.051	

Ellipsoid heights were not published on the 1995 Record of Survey but are necessary for collecting and processing GPS measurements. The 2007 ellipsoid heights are backward compatible with the horizontal NAD83, 1991.35 Epoch positions used for the City in 1995. See the attached 2008 Height Modernization Survey Coordinate List for the results of this adjustment. Positions are published on the 2007 Epoch and the 1991.35 Epoch (1995 record horizontal combined with 2007 ellipsoid heights). The positions on the CGPS stations COPR, UCSB and RCA2 are the results of this minimally constrained adjustment relative to 9027=K1215. Note, the NAD83, 2007 Epoch positions on the City control points are provided for information to relate the City control to the 2007 national re-adjustment and are not intended to supersede the 1991.35 Epoch used for the City.

LOCAL GEOID HEIGHTS: Listed below are the following: NAD 83 ellipsoid heights (Ellipsoid Ht.) determined in the above Adjustment, the NAVD 88 Orthometric Heights determined by the 2008 Leveling, and their differences known as the Local Geoid Height (Local GH). The Local Geoid Height is the measured geoid height and is compared with the estimated geoid height computed with the Geoid03 Model. The differences between the Local GH (LGH) and the Geoid03 are listed as a matter of information in column six. Units are feet.

Point	Ellipsoid Ht.	Orthometric Ht.	Local GH	Geoid03 GH	LGH-Gd03
9002	-48.772	68.816	-117.588	-117.449	-0.140
9027	-85.702	31.343	-117.045	-116.933	-0.112
9031	556.101	671.838	-115.738	-115.693	-0.044
9035	52.047	168.824	-116.777	-116.670	-0.107
9036	-94.720	21.905	-116.625	-116.543	-0.081
9037	33.581	150.413	-116.833	-116.706	-0.126
9038	112.855	229.168	-116.313	-116.228	-0.085
10002	521.985	637.646	-115.661	-115.569	-0.093
10003	198.288	314.265	-115.977	-115.922	-0.055
10005	480.293	595.990	-115.697	-115.626	-0.070
10007	73.532	190.025	-116.493	-116.359	-0.135
10009	196.437	312.658	-116.222	-116.142	-0.080
10012	40.720	157.267	-116.547	-116.439	-0.108
10015	-36.889	79.495	-116.384	-116.332	-0.052
10021	-68.050	48.681	-116.731	-116.613	-0.118
10022	112.795	229.398	-116.603	-116.462	-0.140
10023	55.144	172.251	-117.107	-117.008	-0.099
10026	-102.029	14.695	-116.724	-116.619	-0.105
10027	-98.760	17.701	-116.461	-116.413	-0.047
10030	63.539	181.017	-117.478	-117.350	-0.127
10031	345.077	462.413	-117.336	-117.213	-0.123
10033	-105.655	11.329	-116.984	-116.859	-0.126
10034	19.769	137.407	-117.639	-117.484	-0.155
10035	-107.325	9.965	-117.290	-117.145	-0.145
W1042_BOLT	9.775	126.456	-116.681	-116.560	-0.121

APPLICATION: The results of this survey can be applied in several ways to obtain reliable orthometric heights in the City with GPS measured ellipsoid heights. Methods, procedures and site requirements to obtain accurate ellipsoid height differences between points are addressed in the Appendix. To establish orthometric heights, include the nearest two or more (minimum of two for a check) SBCN or 9000 numbered points listed above in a GPS survey and apply one of the following three procedures.

1- Single EH Difference: Using GPS measured ellipsoid height differences between two points, apply the Local GH from column four in the above table using the formula: $H_u = H_k + N_k + (h_u - h_k) - N_u$
In this formula "k" refers to the point with the known orthometric height, "u" refers to the point with the unknown orthometric height, H= Orthometric Height, N=Local Geoid Height, and h=Ellipsoid Height. The Local Geoid Heights should be interpolated as necessary.

2- Local Transformation: Use GPS measured ellipsoid height differences combined with a geoid model and include four or more of the nearest points (minimum of three required) with leveled orthometric heights to solve for a local transformation as was done in the Transformation described on Page 2. Note, the geometry of the points is important.

3- Do Nothing: Use GPS measured ellipsoid height differences and use Geoid03. The loss of accuracy may be acceptable and can be estimated by comparing the Local Geoid Heights and the Geoid03 Heights. Given that the spacing between SBCN points is about 4000 feet on average, then most surveys will be within 2000 feet of a point with a known height.

ACCURACY: After removing 22 GPS vectors with excessive residuals, the two dimensional residuals range between 0.00 and 0.08 feet and average 0.02 feet with a standard deviation of 0.014 feet. The vertical residuals range between -0.05 and +0.04 feet and average 0.015 feet with a standard deviation of 0.019 feet. Points were re-observed as necessary to obtain vertical residuals in agreement within 0.05 feet. The horizontal coordinates are estimated to have a standard deviation of 0.02 feet in north and east as discussed following the Transformation results on page 2.

NAVD 88 orthometric heights are derived from the GPS measured ellipsoid heights combined with the Geoid 03 model and constrained to points with known orthometric heights. An accuracy of better than 0.05 feet in the ellipsoid heights is obtainable when measured at unobstructed sites with repeat observations. The relative accuracy of the heights modeled from GPS measurements and a refined geoid are expected to be better than 0.05 feet. The results of the Transformation discussed on page 2, column dZ demonstrates this survey attained accuracies better than 0.03 feet.

EQUIPMENT, DATA COLLECTION & POST PROCESSING OF DATA: Geodetic grade dual frequency P-code receivers were utilized to collect satellite signal data as follows: one Leica System 300 (SR399 with internal antenna) and two Leica System 530 (with AT502 antennas). The receivers were operated by the City survey crews. Phase measurements were collected for the carrier on the L1 & L2 frequencies, C/A Code on L1 and the P-Code on L1 & L2 every 10 seconds. The criteria for data collection was to observe 6 or more satellites above 15° with an average GDOP of 5 or less. The length of the observation times was 30 minutes and points were occupied multiple times as necessary to obtain vertical residuals less than 0.05 feet. The vectors were processed with Leica Geo Office v6.0 at a cutoff angle of 15° above the horizon using a rapid ephemeris. GPS vectors are measured in the military World Geodetic System of 1984 (WGS 84) and constrained to NAD 83 geodetic positions and ellipsoid heights with "Starnet-Pro" v6.0 GPS network adjustment software.

Attachments: 2008 Height Modernization Coordinate List

SURVEYOR'S STATEMENT: This report on the criteria and procedures used on this GPS Survey was prepared by me on November 27, 2008 at the request of the City of Santa Barbara.

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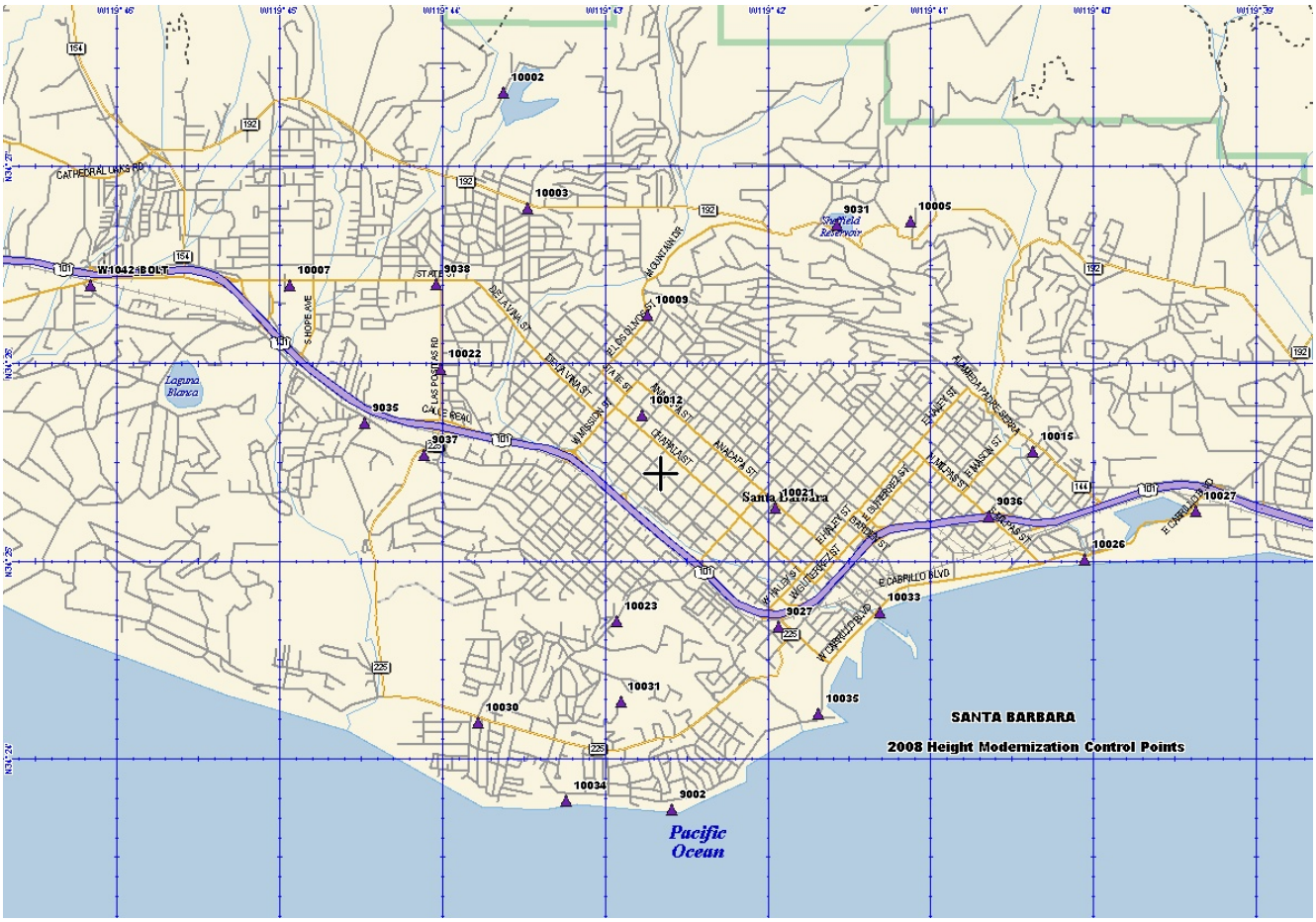
Michael R. McGee, PLS 3945

APPENDIX

Methods and procedures to obtain accurate ellipsoid heights: Trees and plants will block or attenuate satellite signals passing through the foliage degrading accuracies. To obtain the best possible accuracies, available satellite obstruction diagrams should be used to estimate the best time for observing points. Upon arriving at a point to be observed, a dual frequency receiver is set up and the location of each satellite in the sky is estimated with a compass and abney/clinometer. Satellites obstructed by foliage and trees are turned off. If 5 or more un-obstructed satellites with a PDOP of 4 or less or a GDOP of 5 or less are available then the measurement is taken for 15-30 minutes of data collection. The observation of the point is repeated at a time of the day differing by at least 2 hours and preferably on a different day. To be acceptable, the difference of the two observations should approach the desired vertical accuracy for the survey.

2008 Height Modernization GPS Control Points



			Santa Barbara Control Network						
			2008 Height Modernization Survey Coordinate List (Feet)						
11/13/2008	NAD83, 2007 Epoch			NAD83, 1991.35 Epoch					NAVD88
Point ID	Latitude	Longitude	Ellipsoid Ht	Latitude	Longitude	Ellipsoid Ht	SPC North	SPC East	Height
9002	34-23-46.31024	119-42-35.34552	-48.77	34-23-46.29416	119-42-35.32493	-48.77	1970950.95	6045897.68	68.82
9027	34-24-41.84597	119-41-56.07706	-85.70	34-24-41.82993	119-41-56.05647	-85.70	1976508.40	6049282.64	31.34
9031	34-26-43.97486	119-41-34.67555	556.10	34-26-43.95884	119-41-34.65501	556.10	1988822.30	6051283.35	671.84
9034	34-24-36.38310	119-41-29.54948	-106.60	34-24-36.36707	119-41-29.52890	-106.60	1975918.77	6051495.54	10.43
9035	34-25-43.61570	119-44-28.53044	52.05	34-25-43.59959	119-44-28.50985	52.05	1982970.26	6036620.00	168.82
9036	34-25-15.14826	119-40-38.49679	-94.72	34-25-15.13224	119-40-38.47626	-94.72	1979765.28	6055837.64	21.91
9037	34-25-34.09553	119-44-07.01111	33.58	34-25-34.07945	119-44-06.99060	33.58	1981976.85	6038405.65	150.41
9038	34-26-25.76131	119-44-02.42392	112.86	34-26-25.74523	119-44-02.40339	112.86	1987192.29	6038879.94	229.17
9039	34-23-44.28465	119-42-33.95538	-51.33	34-23-44.26859	119-42-33.93481	-51.33	1970744.23	6046010.67	66.27
10002	34-27-24.29082	119-43-37.73179	521.98	34-27-24.27473	119-43-37.71099	521.98	1993072.52	6041049.33	637.65
10003	34-26-48.88964	119-43-28.72070	198.29	34-26-48.87334	119-43-28.70002	198.29	1989481.39	6041742.35	314.26
10005	34-26-44.85695	119-41-07.47686	480.29	34-26-44.84109	119-41-07.45625	480.29	1988873.20	6053562.33	595.99
10006R	34-26-28.37427	119-45-36.61149	57.00	34-26-28.35781	119-45-36.59098	57.00	1987593.46	6030997.37	173.60
10007	34-26-25.61337	119-44-56.13088	73.53	34-26-25.59693	119-44-56.11052	73.53	1987255.23	6034382.28	190.03
10009	34-26-16.57643	119-42-44.61042	196.44	34-26-16.56017	119-42-44.58982	196.44	1986152.20	6045380.19	312.66
10011	34-25-58.50759	119-44-47.06569	45.21	34-25-58.49120	119-44-47.04509	45.21	1984502.35	6035093.81	
10012	34-25-46.23409	119-42-46.33028	40.72	34-25-46.21798	119-42-46.30966	40.72	1983087.84	6045183.90	157.27
10015	34-25-35.19014	119-40-22.36319	-36.89	34-25-35.17462	119-40-22.34258	-36.89	1981768.54	6057222.71	79.50
10020	34-25-04.57660	119-42-28.61392	-57.53	34-25-04.56044	119-42-28.59346	-57.53	1978852.07	6046596.10	59.44
10021	34-25-17.85514	119-41-57.52969	-68.05	34-25-17.83909	119-41-57.50919	-68.05	1980150.07	6049222.49	48.68
10022	34-25-59.98587	119-44-00.75029	112.80	34-25-59.96957	119-44-00.72967	112.80	1984584.62	6038975.16	229.40
10023	34-24-43.38466	119-42-55.95484	55.14	34-24-43.36855	119-42-55.93445	55.14	1976749.12	6044269.39	172.25
10026	34-25-02.25079	119-40-03.20476	-102.03	34-25-02.23510	119-40-03.18452	-102.03	1978412.51	6058772.04	14.70
10027	34-25-17.03591	119-39-22.53093	-98.76	34-25-17.02022	119-39-22.51059	-98.76	1979850.59	6062203.67	17.70
10029	34-24-18.84908	119-44-21.65690	-88.10	34-24-18.83285	119-44-21.63620	-88.10	1974392.59	6037047.41	29.33
10030	34-24-12.51460	119-43-47.08916	63.54	34-24-12.49829	119-43-47.06857	63.54	1973702.36	6039932.28	181.02
10031	34-24-18.88868	119-42-54.32557	345.08	34-24-18.87258	119-42-54.30517	345.08	1974270.88	6044363.62	462.41
10033	34-24-46.11663	119-41-18.68528	-105.66	34-24-46.10079	119-41-18.66483	-105.66	1976887.30	6052422.15	11.33
10034	34-23-48.88775	119-43-14.29681	19.77	34-23-48.87151	119-43-14.27643	19.77	1971267.14	6042638.62	137.41
10035	34-24-15.31513	119-41-41.53329	-107.32	34-24-15.29931	119-41-41.51312	-107.32	1973806.26	6050455.70	9.96
COPR	34-24-53.65236	119-52-46.24080	-72.86	34-24-53.63606	119-52-46.22023	-72.86	1978671.21	5994842.32	
RCA2	34-29-59.91741	119-43-11.93664	3871.17	34-29-59.90148	119-43-11.91609	3871.17	2008765.41	6043478.14	
UCSB	34-24-47.88819	119-50-37.68055	-29.39	34-24-47.87194	119-50-37.65997	-29.39	1977889.15	6005600.25	
W1042_BOLT	34-26-25.42172	119-46-09.80638	9.77	34-26-25.40559	119-46-09.78583	9.77	1987343.88	6028212.44	126.46