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Report on the Analysis of the Asia Pacific Regional Geodetic Project (APRGP) GPS Campaign 2017

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Executive Summary

The annual Asia Pacific Regional Geodetic Project (APRGP) GPS campaign is an activity of the Geodetic Reference Frame Working Group (WG) of the Regional Committee of United Nations Global Geospatial Information Management for Asia and the Pacific (UN-GGIM-AP). This document overviews the data analysis of the APRGP GPS campaign undertaken in 2017. GPS data were processed using version 5.2 of the Bernese GNSS Software in a regional network together with selected IGS (International GNSS Service) sites. The GPS solution was constrained to the ITRF2014 reference frame by adopting IGS14 coordinates on selected IGS reference sites and using the final IGS earth orientation parameters and satellite ephemerides products.

Introduction

The annual Asia Pacific Regional Geodetic Project (APRGP) GPS campaign is an activity of the Geodetic Reference Frame Working Group (WG) of the Regional Committee of United Nations Global Geospatial Information Management for Asia and the Pacific (UN-GGIM-AP). The WG is continuing the annual GPS campaign activity as some member countries are at this time unable to participate in the Asia Pacific Reference Frame (APREF) project but have an ongoing requirement for geodetic positioning relative to the regional/global network. The roles of the WG include the creating and maintenance of a densely realised and accurate geodetic framework, coordinate regional cooperation in geodesy amongst national agencies, and to build and improve the regional geodetic infrastructure. The APRGP is where UN-GGIM-AP member agencies contribute GPS data to the WG. GPS data from the APRGP are available for all participant member countries for local and global scientific research and local applications. The composite GPS data set is subsequently analysed by the WG so as to provide estimates of station coordinates in the International Terrestrial Reference Frame (ITRF). The results of the APRGP are also supplied by the WG to the official ITRF product centre to densify the ITRF in the Asia Pacific region. This document overviews the data analysis of APRGP GPS campaign undertaken in 2017.

The document is organised as follows. The data set of the campaign is described first. The data processing scheme is detailed after, followed by the results of processing including the repeatability RMS (root mean square) of the station coordinates, and the final computed station coordinates.

GPS Data Set

The 2017 GPS campaign was undertaken from 17 to 23 September 2017 inclusive (day of year 260 to 266). Data were contributed by seven countries and regions, including Bangladesh, Brunei, Hong Kong (China), Indonesia, Japan, Philippines and Vietnam. Note that Hong Kong (China), and Philippines are also contributing CGPS data to the APREF project. Figure 1 shows the distribution of the APRGP 2017 campaign stations.

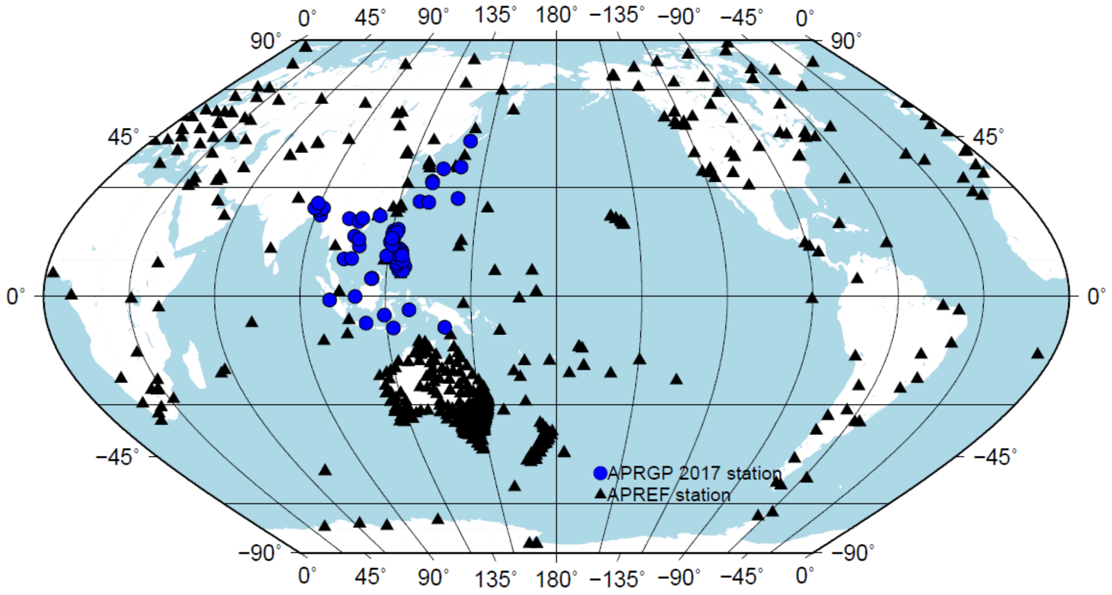

Figure 1 APRGP stations in the APRGP 2017 GPS campaign analysis along with the APREF stations and IGS stations.

Data Processing Scheme

Analysis of the GPS observations was undertaken using the Bernese GNSS software V5.2. The Bernese GNSS software conforms to the IERS2010 conventions (Gérard and Brian, 2010). In order to tie the APRGP network to the ITRF2014 reference frame (Altamimi et al., 2016), the campaign data was processed along with the available data from IGS sites located around the Asia-Pacific region and APREF stations. For the details of APREF project, see http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/asia-pacific-reference-frame.

An overview of the processing strategy is as follows:

- IGS final precise GPS satellite ephemeris and Earth rotation parameters were used for the daily data processing to generate daily normal equations.
- Site displacement due to ocean tidal loading for all stations were corrected by using the FES2004 model (Lyard et al., 2006).
- Antenna phase centre variations were taken into consideration using consistent, absolute IGS models of both receiver and satellite antenna phase centres (Schmid et al., 2007).
- Dual frequency carrier phase and code data were used with an elevation cut off angle of 7° and elevation-dependent weighting. Code measurements were only used for receiver clock synchronisation. Pre-processing used a sampling rate of 30 seconds, a sampling rate of three minutes was used for other processing.
- Carrier phase pre-processing was conducted on a baseline by baseline mode using triple differences. The observations with small pieces and the observations suspected to be corrupted by a cycle slip were marked. Subsequent processing did not use the marked observations. Different linear combinations of L1 and L2 cycle slips were fixed if possible. New ambiguity parameters were introduced if cycle slips could not be fixed reliably or if significant gaps in the observations where present. In addition, a data screening step in a baseline by baseline mode was performed on the basis of weighted post-fit residuals and outliers were marked and removed from further processing.
- A priori dry tropospheric delay computed from a standard atmosphere was mapped with the Dry Global Mapping Function (GMF) (Böhm et al., 2006). For the wet component, continuous piecewise linear troposphere parameters were estimated in 1-hour intervals without any a priori model using the wet Vienna Mapping Function (VMF) and the ionosphere-free combination observations.
- After the pre-processing, ionosphere maps were estimated using the geometry-free linear combination. The vertical electron content was modelled with a single-layer model in a solar geomagnetic reference frame. The height of the single layer was 450 km above the Earth's surface. The previously estimated ionosphere maps were introduced as a priori ionosphere information and, in addition, stochastic ionosphere parameters were set up to support the Quasi Ionospheric Free (QIF) ambiguity resolution strategy (Dach et al., 2015).
- Ambiguity resolution was attempted on all baselines within the network in a baseline by baseline model using Melbourne-Wüebbena strategy for baselines up to 6000 km; the QIF approach was used for baselines up to 2000 km; and the phase-based wide-lane/narrow-lane method for baselines up to 200 km; and direct L1/L2 method for baselines up to 20 km. The QIF strategy is based on the ionospheric free linear combination, but also incorporates the estimation of an ionospheric parameter for each epoch to account for the residual ionospheric biases, details can be found in Dach et al. (2015).

- The daily normal equations were generated and combined into a campaign solution. As part of this process the daily solutions were compared with the combined solution and the resulting differences were analysed for the presence of outliers and the daily repeatability.

Results

The repeatability root mean square (RMS) of the station coordinates, an estimate of the day-to-day scatter of coordinate components about a weighted epoch mean, was used to assess the quality of the final epoch solution and as a measure of internal precision. Table 1 lists the repeatabilities (RMS) of the station coordinates. The average of the repeatabilities (i.e. RMS) of the station coordinates for the campaign was 1.4 mm, 1.5 mm and 4.9 mm in north, east and up components, respectively.

Table 1 The repeatability RMS for the APRGP 2017 GPS campaign stations.

Station	Country	North (mm)	East (mm)	Up (mm)
CHIT	Bangladesh	1.8	3.1	10.5
DHAK	Bangladesh	1.4	2.1	5.9
MAUL	Bangladesh	1.5	2.6	5.8
RAJS	Bangladesh	2.1	2.9	7.9
RANG	Bangladesh	2.0	2.2	6.0
MURA	Brunei	1.3	1.1	5.0
UKUR	Brunei	2.2	1.2	6.1
HKKT	Hong Kong (China)	2.5	3.0	7.1
HKLT	Hong Kong (China)	2.2	2.7	6.8
HKQT	Hong Kong (China)	2.3	2.7	18.9
HKSC	Hong Kong (China)	1.9	2.7	9.4
HKSL	Hong Kong (China)	1.8	1.9	8.1
HKST	Hong Kong (China)	2.1	2.6	7.1
KYC1	Hong Kong (China)	2.0	2.2	8.0
T430	Hong Kong (China)	1.0	2.5	8.2
BAKO	Indonesia	3.6	3.2	9.4
CAMB	Indonesia	4.3	2.1	15.9
CMAK	Indonesia	1.2	1.8	6.8
CMRE	Indonesia	1.8	3.4	18.0
CPDG	Indonesia	3.6	2.1	7.1
CPON	Indonesia	3.6	2.6	10.6
CSBY	Indonesia	2.0	1.5	3.9
CUKE	Indonesia	2.0	1.5	3.9
0029	Japan	2.0	1.7	9.0
0745	Japan	1.6	2.3	10.2
0746	Japan	2.3	2.4	8.8
0837	Japan	2.0	2.4	9.7

Station	Country	North (mm)	East (mm)	Up (mm)
1135	Japan	1.4	1.0	7.0
2004	Japan	1.6	2.0	18.0
2005	Japan	1.3	2.2	6.0
2007	Japan	1.4	3.4	6.4
3009	Japan	1.8	1.3	10.2
PBAT	Philippines	2.2	1.5	5.6
PBAY	Philippines	1.9	1.7	6.0
PBIS	Philippines	1.7	1.7	8.1
PCAT	Philippines	2.0	1.7	5.5
PCB2	Philippines	2.2	2.9	7.5
PCDN	Philippines	1.3	2.3	7.4
PCOT	Philippines	1.9	3.4	10.2
PDAV	Philippines	1.1	1.3	3.0
PDDN	Philippines	1.7	1.3	3.0
PDIP	Philippines	1.8	2.4	6.3
PDUM	Philippines	1.2	2.4	7.9
PFLO	Philippines	0.9	1.6	5.5
PGEN	Philippines	0.9	1.7	5.3
PILC	Philippines	1.5	1.0	5.6
PKAL	Philippines	0.8	1.6	5.5
PLEG	Philippines	1.4	2.5	7.0
PMAS	Philippines	2.9	4.1	15.5
PMOG	Philippines	1.1	1.7	7.2
PNDO	Philippines	1.7	1.5	6.7
PPPC	Philippines	2.8	1.5	7.9
PSNR	Philippines	1.7	1.4	5.2
PSRF	Philippines	2.3	0.5	5.3
PSTC	Philippines	1.7	0.9	3.8

Station	Country	North (mm)	East (mm)	Up (mm)
PSTN	Philippines	1.9	1.8	6.5
PSUR	Philippines	1.4	1.9	6.0
PTAC	Philippines	0.9	2.0	3.4
PTAG	Philippines	1.7	1.6	6.6
PTAR	Philippines	2.3	2.3	5.1
PTGO	Philippines	2.2	1.1	6.4
PTGY	Philippines	1.2	1.2	5.6
PTUG	Philippines	2.2	1.5	5.6
PURD	Philippines	1.9	1.7	6.0
BIDI	Vietnam	2.2	1.6	7.2
DIEB	Vietnam	1.3	2.0	5.5
DOSN	Vietnam	1.6	2.4	12.2
HTIE	Vietnam	0.8	1.8	8.7
KHES	Vietnam	1.5	1.8	0.9
MCAI	Vietnam	1.6	1.7	8.7
QNAM	Vietnam	2.8	2.6	15.9
VUNT	Vietnam	0.9	1.7	6.4

The final computed Cartesian and geodetic coordinates (ITRF2014, GRS80 ellipsoid) are listed in Table 2 and Table 3, respectively, along with their formal error estimates. These estimates provide an indication of the quality of the measurements; they also characterise the internal precision of positioning performance. Note that the listed coordinates are at the mean epoch of the measurements in the ITRF2014 reference frame, and only for the campaign sites, the weekly coordinates of other CGPS stations of APREF project can be found in http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/asia-pacific-reference-frame . There are no solutions for the following three stations because of poor data quality: KBEL(Brunei), PMRV and PZAM (Philippines).

Table 2 The final computed Cartesian coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2017. 72.

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
0029	-3862398.8263	0.0006	3105008.4546	0.0006	4001960.9829	0.0006
0745	-3512920.1476	0.0005	4524558.0843	0.0006	2795881.8492	0.0004
0746	-3786804.8920	0.0005	4311846.1813	0.0005	2774485.5726	0.0004
0837	-3530185.8057	0.0009	4118797.2136	0.0008	3344036.7378	0.0008
1135	-3591931.1406	0.0004	3758796.8773	0.0004	3682342.7796	0.0004
2004	-3565271.8893	0.0006	4118973.0359	0.0007	3306293.0329	0.0006
2005	-3642161.4252	0.0006	2861487.8580	0.0005	4370351.2297	0.0006
2007	-4490605.1762	0.0009	3483894.9581	0.0007	2884928.2907	0.0005
3009	-3997616.3640	0.0005	3276761.8852	0.0005	3724230.2107	0.0005
BIDI	-2026751.4299	0.0004	5851345.1483	0.0010	1522891.2639	0.0004
CAMB	-3934881.6954	0.0004	5003056.0729	0.0005	-408362.0417	0.0002
CHIT	-185607.4421	0.0003	5896239.4724	0.0008	2416802.2000	0.0004
CMAK	-3119382.0360	0.0003	5534200.5997	0.0005	-567039.5235	0.0002
CMRE	-3362412.5452	0.0007	5335364.2712	0.0010	-950458.6845	0.0003
CPDG	-1147179.5796	0.0003	6273233.5031	0.0009	-105481.1120	0.0003
CPON	-2111129.5836	0.0006	6018657.0645	0.0013	-399.8106	0.0003
CSBY	-2443857.6382	0.0003	5835257.9929	0.0006	-808826.4439	0.0002

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
CUKE	-4860592.7162	0.0006	4021866.2007	0.0005	-935408.0941	0.0002
DHAK	-40573.3345	0.0003	5840711.2921	0.0009	2553577.1557	0.0005
DIEB	-1336842.5207	0.0003	5787988.4060	0.0009	2315702.1646	0.0004
DOSN	-1724757.4523	0.0005	5714523.7807	0.0010	2239791.9500	0.0005
HKQT	-2421568.4726	0.0005	5384910.3583	0.0009	2404264.1924	0.0005
HTIE	-1566049.3515	0.0004	6076067.8863	0.0010	1140478.4245	0.0003
KHES	-1760217.7816	0.0011	5854659.3243	0.0028	1813271.1551	0.0010
MAUL	-193340.5793	0.0003	5808683.2937	0.0008	2618404.5247	0.0004
MCAI	-1832589.5615	0.0005	5646288.9466	0.0011	2324879.3665	0.0005
MURA	-2691871.4012	0.0004	5755365.4345	0.0006	555841.9638	0.0002
PBAT	-3082933.6780	0.0004	5224292.1244	0.0007	1964073.7054	0.0003
PBAY	-3164088.1212	0.0004	5236293.6316	0.0006	1797982.1738	0.0003
PBIS	-3742521.5972	0.0005	5084796.7747	0.0006	902504.3396	0.0003
PCAT	-3541625.4170	0.0005	5122609.3989	0.0007	1372754.1039	0.0003
PCB2	-3161494.0201	0.0004	5274361.1756	0.0006	1687745.0737	0.0003
PCDN	-3088458.6492	0.0003	5255341.0310	0.0005	1870978.2076	0.0002
PCOT	-3561309.0636	0.0006	5231065.2364	0.0009	794050.1876	0.0003
PDAV	-3688320.2696	0.0003	5143554.6668	0.0004	786028.7223	0.0002

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
PDIP	-3466870.3769	0.0003	5268924.8739	0.0005	946017.0169	0.0002
PDUM	-3455857.4500	0.0005	5261024.5427	0.0007	1026318.8122	0.0002
PFLO	-3127780.1235	0.0004	5310053.4022	0.0007	1638299.4665	0.0003
PILC	-3372134.9612	0.0004	5282116.0456	0.0006	1183263.5639	0.0002
PKAL	-3343823.0904	0.0002	5276062.3603	0.0003	1285509.1015	0.0002
PLEG	-3449311.3697	0.0004	5166215.7357	0.0006	1442826.1773	0.0003
PMAS	-3450751.8125	0.0004	5188374.9860	0.0007	1357308.7771	0.0003
PMOG	-3274635.9613	0.0006	5269089.7863	0.0009	1476547.3338	0.0004
PNDO	-3073489.4863	0.0004	5450701.8911	0.0007	1230702.5678	0.0003
PSNR	-3088261.3021	0.0003	5332018.5815	0.0005	1641796.7883	0.0002
PSRF	-3167387.8285	0.0004	5286532.1789	0.0006	1638185.0310	0.0003
PSTC	-3222393.2846	0.0004	5276123.2704	0.0006	1563214.3327	0.0003
PSTN	-3219843.4926	0.0003	5124936.6593	0.0004	2005414.0310	0.0002
PSUR	-3649683.0714	0.0005	5117857.8924	0.0006	1077577.6650	0.0003
PTAC	-3588936.6817	0.0003	5124727.4051	0.0004	1236144.3284	0.0002
PTAR	-3128650.5307	0.0002	5292970.9080	0.0004	1690799.4275	0.0002
PTGY	-3181285.0816	0.0004	5307488.4487	0.0006	1543919.1926	0.0003
PTUG	-3199386.3051	0.0003	5169557.8030	0.0005	1922601.3115	0.0003

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
PURD	-3119483.9623	0.0004	5279887.1232	0.0005	1747196.5112	0.0003
QNAM	-1939077.2145	0.0005	5824547.8048	0.0013	1724921.3081	0.0005
RAJS	142155.8960	0.0003	5810553.3972	0.0009	2617535.2070	0.0005
RANG	78085.9691	0.0002	5747205.3795	0.0007	2755540.5865	0.0004
UKUR	-2678449.2195	0.0004	5762777.5638	0.0007	543962.3828	0.0002
VUNT	-1849617.1178	0.0003	5995299.8076	0.0006	1143372.6574	0.0003

Table 3 The final computed Geodetic coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2017. 72.

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
0029	141	12	14.27017	0.0003	39	6	38.18694	0.0003	172.2333	0.0010
0745	127	49	34.26707	0.0002	26	10	6.97799	0.0002	97.1345	0.0008
0746	131	17	26.39399	0.0002	25	57	13.43218	0.0002	72.5824	0.0008
0837	130	35	58.54594	0.0003	31	49	26.61377	0.0003	314.6339	0.0014
1135	133	41	58.47479	0.0002	35	29	25.43677	0.0002	72.4503	0.0006
2004	130	52	42.88715	0.0003	31	25	31.10726	0.0003	134.5430	0.0010
2005	141	50	41.35196	0.0003	43	31	43.11359	0.0003	118.5811	0.0009
2007	142	11	42.09108	0.0003	27	4	3.11745	0.0003	104.2002	0.0011
3009	140	39	33.29640	0.0002	35	57	19.62691	0.0003	65.7893	0.0008
BIDI	109	6	17.04414	0.0003	13	54	21.58820	0.0003	12.3711	0.0010

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
CAMB	128	11	5.62385	0.0002	-3	-41	-44.02021	0.0002	87.4742	0.0006
CHIT	91	48	10.85662	0.0003	22	24	48.77011	0.0003	-19.0974	0.0009
CMAK	119	24	28.85999	0.0002	-5	-8	-5.28997	0.0002	77.5883	0.0005
CMRE	122	13	10.69467	0.0003	-8	-37	-38.98633	0.0003	59.4500	0.0012
CPDG	100	21	47.20794	0.0003	0	-57	-14.33373	0.0003	3.8595	0.0009
CPON	109	19	44.56304	0.0004	0	0	-13.01668	0.0003	36.8092	0.0013
CSBY	112	43	27.71930	0.0002	-7	-20	-3.60646	0.0002	51.2349	0.0007
CUKE	140	23	38.98484	0.0002	-8	-29	-23.47550	0.0002	80.1880	0.0008
DHAK	90	23	52.82487	0.0003	23	45	22.20553	0.0003	-29.3103	0.0010
DIEB	103	0	19.62655	0.0003	21	25	39.41261	0.0003	465.6656	0.0010
DOSN	106	47	41.50814	0.0003	20	41	40.00782	0.0003	32.6381	0.0012
HKQT	114	12	47.59905	0.0003	22	17	27.71961	0.0003	5.1494	0.0011
HTIE	104	27	10.41207	0.0003	10	22	10.35913	0.0003	-4.9399	0.0011
KHES	106	44	0.72624	0.0007	16	37	31.85190	0.0006	382.6190	0.0030
MAUL	91	54	22.93912	0.0003	24	23	49.88966	0.0003	-15.7382	0.0009
MCAI	107	58	53.87718	0.0003	21	31	6.17229	0.0003	-13.8490	0.0013
MURA	115	3	58.32913	0.0002	5	1	59.36059	0.0002	63.7988	0.0007
PBAT	120	32	43.78759	0.0002	18	3	14.05207	0.0002	51.7521	0.0008

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
PBAY	121	8	34.55743	0.0002	16	28	53.59092	0.0002	322.8817	0.0007
PBIS	126	21	13.97094	0.0002	8	11	21.01986	0.0002	78.2343	0.0008
PCAT	124	39	31.93772	0.0002	12	30	42.86901	0.0002	59.5812	0.0008
PCB2	120	56	19.70663	0.0002	15	26	45.80124	0.0002	76.7621	0.0007
PCDN	120	26	30.84265	0.0002	17	10	16.92985	0.0002	55.3330	0.0006
PCOT	124	14	49.31801	0.0003	7	11	58.57399	0.0003	86.1660	0.0010
PDAV	125	38	36.25422	0.0002	7	7	35.36394	0.0002	96.7719	0.0005
PDIP	123	20	39.45367	0.0002	8	35	12.63014	0.0002	86.8242	0.0006
PDUM	123	18	0.28104	0.0002	9	19	18.62501	0.0002	88.3860	0.0008
PFLO	120	29	57.68227	0.0002	14	58	58.55964	0.0002	90.7708	0.0008
PILC	122	33	15.86911	0.0002	10	45	46.38392	0.0002	75.3452	0.0007
PKAL	122	21	55.43180	0.0002	11	42	18.92054	0.0002	80.4347	0.0004
PLEG	123	43	47.01264	0.0002	13	9	40.39171	0.0002	210.0269	0.0008
PMAS	123	37	39.36029	0.0002	12	22	8.03361	0.0002	77.9634	0.0008
PMOG	121	51	36.50612	0.0003	13	28	29.11278	0.0003	62.8350	0.0011
PNDO	119	25	2.51286	0.0002	11	11	59.22480	0.0002	54.3805	0.0008
PSNR	120	4	44.65109	0.0002	15	0	56.59549	0.0002	63.5947	0.0006
PSRF	120	55	39.47077	0.0002	14	58	54.89992	0.0002	68.4362	0.0008

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
PSTC	121	24	52.22447	0.0002	14	16	53.93859	0.0002	60.4754	0.0007
PSTN	122	8	23.67712	0.0002	18	26	49.98323	0.0002	41.2097	0.0005
PSUR	125	29	37.30662	0.0002	9	47	30.52053	0.0002	80.2415	0.0008
PTAC	125	0	15.22928	0.0002	11	14	59.61477	0.0002	79.7147	0.0005
PTAR	120	35	13.69128	0.0002	15	28	28.58099	0.0002	112.3233	0.0004
PTGY	120	56	17.82852	0.0002	14	6	1.00954	0.0002	715.3976	0.0007
PTUG	121	45	10.58442	0.0002	17	39	36.49266	0.0002	84.3764	0.0006
PURD	120	34	32.20541	0.0002	16	0	15.10585	0.0002	80.4034	0.0006
QNAM	108	24	48.07980	0.0003	15	47	42.24505	0.0003	11.9040	0.0014
RAJS	88	35	54.71286	0.0003	24	23	18.89551	0.0003	-17.7342	0.0010
RANG	89	13	17.69953	0.0002	25	45	50.44368	0.0002	0.9755	0.0007
UKUR	114	55	41.77517	0.0002	4	55	31.13098	0.0002	74.7169	0.0007
VUNT	107	8	44.08846	0.0002	10	23	46.00974	0.0002	14.3646	0.0006

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