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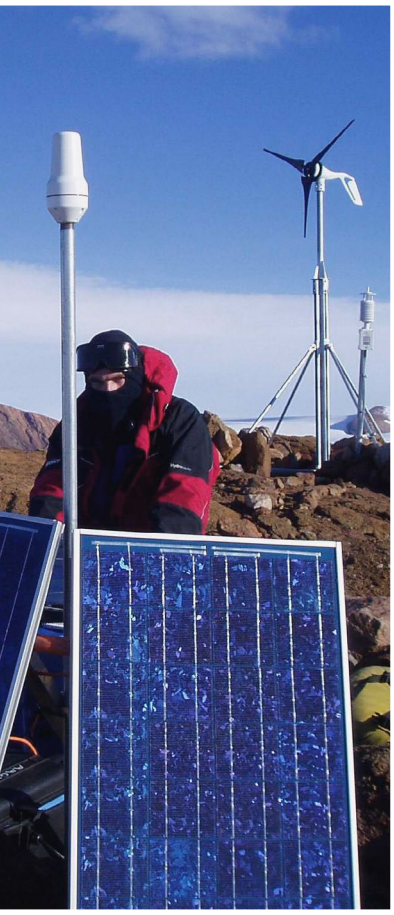

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Report on the Analysis of the Asia Pacific Regional Geodetic Project (APRGP) GPS Campaign 2019

G. Hu

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Geoscience Australia acknowledges the traditional custodians of the country where this work was undertaken. We also acknowledge the support provided by individuals and communities to access the country, especially in remote and rural Australia.

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Contents

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 describes the data analysis of the APRGP GPS campaign undertaken between the 15th and 21nd of September 2019. Campaign GPS data collected at 101 sites in ten countries across the Asia Pacific region 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. The average of the root mean square repeatability of the station coordinates for the campaign was 1.8 mm, 1.6 mm and 5.4 mm in north, east and up components of station position respectively.

Introduction

The annual Asia Pacific Regional Geodetic Project (APRGP) GPS campaign is an activity of the Geodetic Reference Frame for Sustainable Development Working Group (WG) of the Regional Committee of United Nations Global Geospatial Information Management for Asia and the Pacific (UN-GGIM-AP). The WG continues to undertake an annual GPS campaign activity as some member countries are unable to participate in the Asia Pacific Reference Frame (APREF) project but have an ongoing requirement for geodetic positioning relative to a stable global/regional reference network. One of the roles of the WG is to create and maintain 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 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 2019.

The document is organised as follows. The data set of the campaign is described first. The data processing scheme is detailed thereafter, 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 2019 GPS campaign was undertaken from 15 to 21 September 2019 inclusive (day of year 258 to 264). Data were contributed by sixteen countries across the region, including Bangladesh, Brunei, Hong Kong (China), Indonesia, Japan, Laos, Mongolia, Myanmar, Philippines, Singapore, Tonga and Vietnam. Note that Hong Kong (China) and Philippines are also contributing Continuous GPS (CGPS) data to the APREF project. Figure 1 APRGP stations in the APRGP 2019 GPS campaign analysis along with the APREF stations and IGS stations, blue circles are APRGP campaign sites, and black triangles are APREF stations. shows the distribution of the APRGP 2019 campaign stations.

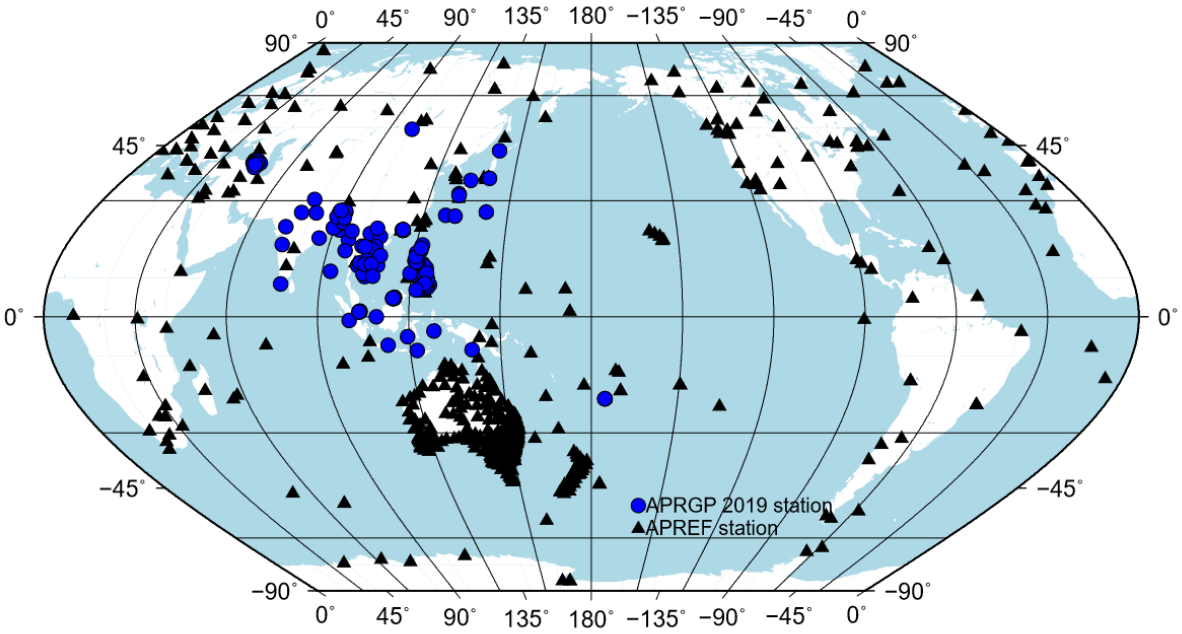

Figure 1 APRGP stations in the APRGP 2019 GPS campaign analysis along with the APREF stations and IGS stations, blue circles are APRGP campaign sites, and black triangles are APREF stations.

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 based on 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 daily 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 daily repeatability (RMS) of the station coordinates. The average of the repeatability (i.e. RMS) of the station coordinates for the campaign was 1.6 mm, 1.8 mm and 5.8 mm in north, east and up components, respectively.

Table 1 Daily repeatability RMS for the APRGP 2019 GPS campaign stations.

Station	Country	North (mm)	East (mm)	Up (mm)
AKHU	Armenia	0.9	0.9	2.0
APAR	Armenia	2.6	3.0	3.3
ARMV	Armenia	0.7	0.9	3.6
ARTA	Armenia	1.2	0.9	3.1
GVAR	Armenia	1.6	1.4	6.0
IJVN	Armenia	2.0	1.0	3.5
KHND	Armenia	1.1	1.2	5.4
MART	Armenia	1.5	1.4	3.6
MGHR	Armenia	1.3	2.5	4.1
VARD	Armenia	1.5	1.4	3.8
YGGD	Armenia	1.5	0.8	2.4
CHIT	Bangladesh	1.2	1.9	7.1
DHAK	Bangladesh	1.2	1.7	9.3
KHUL	Bangladesh	1.6	1.4	9.0
MAUL	Bangladesh	1.6	1.8	8.8
RANG	Bangladesh	1.4	1.4	8.0
AERO	Bhutan	1.9	1.6	4.5
BUMT	Bhutan	1.4	1.7	7.0
DEOT	Bhutan	1.1	1.6	8.6
GELE	Bhutan	3.5	2.3	9.1
KAMJ	Bhutan	2.6	2.4	10.1
KANG	Bhutan	1.2	1.6	7.0
PARO	Bhutan	1.0	1.9	6.5
PHUN	Bhutan	4.1	2.0	12.2
THIM	Bhutan	1.1	1.9	8.6
LIAN	Brunei	1.7	0.4	8.4
MURA	Brunei	2.0	2.7	10.0

Station	Country	North (mm)	East (mm)	Up (mm)
TEMB	Brunei	0.5	2.5	0.5
TUTO	Brunei	1.0	2.4	16.2
CBOR	Cambodia	3.7	3.5	11.3
KK01	Cambodia	2.0	2.8	7.7
SAKE	Cambodia	3.4	2.9	8.3
SISA	Cambodia	1.6	1.6	10.0
STEM	Cambodia	2.5	1.7	7.7
STUE	Cambodia	2.5	3.0	8.1
HKKT	Hong Kong (China)	2.1	2.7	4.8
HKLT	Hong Kong (China)	1.5	1.3	5.7
HKQT	Hong Kong (China)	1.0	3.0	7.8
HKSC	Hong Kong (China)	2.6	1.4	6.2
HKSL	Hong Kong (China)	1.0	2.0	6.6
HKST	Hong Kong (China)	2.2	2.5	7.8
KYC1	Hong Kong (China)	1.7	1.7	8.3
T430	Hong Kong (China)	1.7	2.6	5.6
BBSR	India	1.3	1.0	9.5
CHAN	India	1.8	0.9	2.7
DEHR	India	2.2	2.2	8.0
GJRT	India	1.5	1.5	10.4
LUCK	India	1.5	2.0	5.2
PTBL	India	2.5	1.8	7.0
PUNE	India	2.3	3.2	7.6
RGDC	India	2.8	4.2	10.0
SHIL	India	2.2	1.3	8.3
TRIV	India	1.8	1.9	8.2
BAKO	Indonesia	1.5	2.0	6.9
CAMB	Indonesia	2.7	1.9	5.5
CMAK	Indonesia	1.3	2.3	6.6
CMRE	Indonesia	1.8	3.8	5.7
CPDG	Indonesia	1.2	2.3	10.7
CPON	Indonesia	1.3	2.2	6.2
CSBY	Indonesia	1.4	1.5	7.6
CUKE	Indonesia	2.2	1.3	5.6
0029	Japan	2.3	1.3	8.0
0745	Japan	1.7	1.8	2.8

Station	Country	North (mm)	East (mm)	Up (mm)
0746	Japan	1.6	1.4	5.4
0837	Japan	2.0	2.4	6.2
1135	Japan	1.6	1.4	7.4
2004	Japan	1.3	3.4	9.0
2005	Japan	1.7	2.2	5.7
2007	Japan	3.5	1.8	9.7
3009	Japan	2.2	1.2	8.4
HUV1	Mongolia	2.9	1.9	7.6
1233	Myanmar	2.0	1.7	9.6
NGYA	Myanmar	2.7	2.5	10.5
POL1	Myanmar	1.3	3.4	10.3
PBAY	Philippines	1.3	1.7	5.0
PBIS	Philippines	0.9	1.8	8.3
PCAT	Philippines	0.6	1.2	5.6
PCB2	Philippines	1.1	1.8	7.6
PCEB	Philippines	1.1	1.8	6.4
PCLP	Philippines	0.9	2.7	7.8
PCOT	Philippines	1.3	1.6	5.9
PDDN	Philippines	0.6	1.3	3.9
PDUM	Philippines	1.8	1.8	9.5
PGEN	Philippines	1.2	2.0	2.9
PKAL	Philippines	1.5	3.8	7.1
PLEG	Philippines	1.2	3.0	6.7
PMAS	Philippines	2.5	2.2	6.4
PMOG	Philippines	1.2	2.5	6.3
PMRV	Philippines	1.8	2.8	6.5
PNAG	Philippines	1.4	2.4	8.0
PNDO	Philippines	2.1	3.1	13.7
PSRF	Philippines	0.7	1.9	5.0
PSTN	Philippines	1.1	2.0	7.4
PSUR	Philippines	0.8	1.5	7.8
PTAC	Philippines	1.7	1.4	6.2
PTAG	Philippines	1.7	2.2	9.7
PTGO	Philippines	0.9	2.4	4.2
PTGY	Philippines	1.6	1.9	4.6
PTLC	Philippines	1.8	1.9	5.6

Station	Country	North (mm)	East (mm)	Up (mm)
PTUG	Philippines	0.8	2.7	5.1
PZAM	Philippines	1.6	2.9	7.0
SLYG	Singapore	1.2	1.5	4.1
SNUS	Singapore	1.3	1.4	2.3
SNYU	Singapore	1.1	2.7	3.9
SRPT	Singapore	0.8	2.1	0.8
T007	Tonga	1.3	1.7	3.7
TGPU	Tonga	1.2	2.2	3.2
DIEB	Vietnam	2.2	2.3	6.3
DSON	Vietnam	2.3	2.5	7.0
EAHL	Vietnam	1.3	2.5	2.5
HGIA	Vietnam	2.4	4.1	13.0
HTIE	Vietnam	1.9	1.7	9.9
KANH	Vietnam	1.6	1.3	7.4
QNAM	Vietnam	2.2	2.8	10.2
VUNT	Vietnam	1.4	2.2	4.6

The final computed Cartesian and geodetic coordinates (ITRF2014, GRS80 ellipsoid) are listed in Table 2 The final computed Cartesian coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2019. 715 (in decimal year). and Table 3 The final computed Geodetic coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2019. 715 (in decimal year)., respectively, along with their formal error estimates. These estimates provide an indication of the quality of the measurements; they only characterise the internal precision of positioning performance and should not be taken as realistic estimates of position accuracy. More realistic estimates of station positioning uncertainty are provided by the RMS statistics given in Table 1. 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 stations because of data quality issues: RAJS (Bangladesh), KBEL, LAMU and UKUR (Brunei), PBAT, PDAV, PFLO, and PILC (Philippines), SNPT (Singapore), and T001 (Tonga).The solutions in Solution Independent Exchange (SINEX) format can be found in the ftp link: ftp://ftp.ga.gov.au/geodesy-outgoing/apref/APRGP/.

Table 2 The final computed Cartesian coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2019. 715 (in decimal year).

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
0029	-3862398.9822	0.0006	3105008.4012	0.0005	4001960.9556	0.0006
0745	-3512920.2231	0.0006	4524558.0723	0.0007	2795881.7836	0.0005
0746	-3786804.8163	0.0004	4311846.2123	0.0005	2774485.6144	0.0003
0837	-3530185.8846	0.0009	4118797.2251	0.0009	3344036.7314	0.0008
1135	-3591931.1928	0.0005	3758796.8449	0.0005	3682342.7699	0.0004
1233	-634106.7022	0.0003	5968827.7039	0.0009	2149806.5418	0.0005
2004	-3565271.9577	0.0005	4118973.0235	0.0005	3306292.9983	0.0004
2005	-3642161.4492	0.0004	2861487.8602	0.0003	4370351.2204	0.0004
2007	-4490605.1286	0.0006	3483895.0118	0.0005	2884928.3151	0.0004
3009	-3997616.3979	0.0004	3276761.8954	0.0003	3724230.1887	0.0004
AERO	-149352.3979	0.0003	5691043.7303	0.0009	2869052.7878	0.0004
AKHU	3486864.4159	0.0004	3353312.4280	0.0003	4145122.7371	0.0004
APAR	3468968.0915	0.0005	3392122.0000	0.0005	4129171.7349	0.0005
ARMV	3509670.0709	0.0004	3393944.4093	0.0003	4091788.2457	0.0004
ARTA	3489230.9053	0.0005	3434911.4722	0.0005	4075100.6639	0.0005
BAKO	-1836969.4651	0.0004	6065616.9441	0.0010	-716257.9259	0.0003
BBSR	439209.3072	0.0003	5969659.0386	0.0011	2195052.6191	0.0005
BUMT	-71428.8570	0.0003	5661326.4689	0.0009	2933192.7524	0.0005
CAMB	-3934881.6838	0.0007	5003056.0200	0.0008	-408361.9973	0.0003
CBOR	-1238275.8048	0.0007	6087601.0487	0.0018	1440478.8239	0.0006
CHAN	-2674427.6475	0.0004	3757143.0698	0.0004	4391521.5234	0.0005
CHIT	-185607.5154	0.0002	5896239.4262	0.0007	2416802.2581	0.0004
CMAK	-3119382.0803	0.0005	5534200.5735	0.0008	-567039.5424	0.0003
CMRE	-3362412.5970	0.0009	5335364.2357	0.0011	-950458.6347	0.0004
CPDG	-1147179.6338	0.0004	6273233.4969	0.0011	-105481.0825	0.0003
CPON	-2111129.6531	0.0005	6018657.1089	0.0012	-399.8271	0.0003
CSBY	-2443857.6897	0.0004	5835257.9742	0.0010	-808826.4631	0.0003
CUKE	-4860592.7716	0.0007	4021866.1508	0.0007	-935407.9742	0.0003
DEHR	1140604.5227	0.0002	5391406.9650	0.0006	3201808.0440	0.0004
DEOT	-145517.0645	0.0003	5692756.9181	0.0008	2864817.2717	0.0004
DHAK	-40573.4175	0.0002	5840711.2477	0.0008	2553577.2133	0.0004

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
DIEB	-1336847.2127	0.0005	5787979.2457	0.0013	2315717.0809	0.0006
DSON	-1724386.8639	0.0005	5714538.8307	0.0011	2239949.4027	0.0005
EAHL	-1940045.7827	0.0003	5900174.0150	0.0007	1448740.9556	0.0003
GELE	-42920.4004	0.0003	5691631.5866	0.0010	2869353.8955	0.0005
GJRT	1748671.1779	0.0005	5598210.6180	0.0014	2498202.5386	0.0007
GVAR	3434422.4849	0.0005	3449991.0779	0.0005	4110374.0702	0.0005
HGIA	-1518216.9808	0.0007	5682319.5107	0.0015	2459169.4171	0.0007
HKKT	-2405144.5478	0.0003	5385195.0305	0.0006	2420032.3177	0.0003
HKLT	-2399063.3816	0.0003	5389237.6246	0.0005	2417326.8352	0.0003
HKQT	-2421568.5326	0.0006	5384910.3366	0.0009	2404264.1723	0.0005
HKSC	-2414267.5638	0.0005	5386768.7622	0.0008	2407459.8080	0.0004
HKSL	-2393383.0651	0.0003	5393860.9521	0.0005	2412592.1880	0.0003
HKST	-2417143.5220	0.0005	5382345.2637	0.0009	2415036.7262	0.0004
HTIE	-1566049.4030	0.0005	6076067.8882	0.0013	1140478.4051	0.0003
HUV1	-730630.8086	0.0003	4074608.0717	0.0006	4837618.4387	0.0007
IJVN	3406090.1499	0.0005	3423480.6854	0.0006	4153586.9494	0.0006
KAMJ	54252.2224	0.0004	5693442.9284	0.0017	2867873.7692	0.0009
KANG	-150881.9562	0.0003	5671995.8494	0.0009	2907342.9814	0.0005
KANH	-1700737.4941	0.0004	5821573.0919	0.0008	1967522.4904	0.0004
KHND	3396826.8507	0.0005	3570913.6402	0.0005	4037424.1456	0.0005
KHUL	50585.7453	0.0002	5877137.8388	0.0004	2468978.4946	0.0002
KK01	-1492903.3821	0.0005	6080134.1431	0.0013	1214171.7989	0.0004
KYC1	-2408855.8997	0.0004	5391043.0039	0.0007	2403590.9063	0.0004
LIAN	-2638655.3603	0.0010	5783351.5033	0.0019	519610.0458	0.0005
LUCK	889588.3919	0.0003	5624012.2245	0.0012	2864453.4139	0.0006
MART	3337352.3050	0.0004	3557213.2128	0.0005	4096546.5819	0.0004
MAUL	-193340.6566	0.0002	5808683.2675	0.0005	2618404.5864	0.0003
MGHR	3437584.6045	0.0007	3590325.1499	0.0006	3984381.0510	0.0007
MURA	-2691871.4481	0.0008	5755365.4052	0.0016	555841.9460	0.0004
NGYA	-650955.1440	0.0003	6067217.8635	0.0010	1850052.6321	0.0005
PARO	55524.5815	0.0003	5668920.6004	0.0010	2917777.4832	0.0005
PBAY	-3164088.0475	0.0004	5236293.6660	0.0007	1797982.2218	0.0003
PBIS	-3742521.5450	0.0005	5084796.8058	0.0007	902504.3814	0.0003

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
PCAT	-3541625.3812	0.0006	5122609.4211	0.0008	1372754.1649	0.0003
PCB2	-3161493.9517	0.0004	5274361.1525	0.0007	1687745.0689	0.0003
PCEB	-3499371.4736	0.0005	5209600.2286	0.0007	1134904.7417	0.0003
PCLP	-3213834.0696	0.0005	5307813.9908	0.0007	1471474.6008	0.0003
PCOT	-3561309.0497	0.0005	5231065.2536	0.0008	794050.1710	0.0003
PDDN	-3698127.2736	0.0006	5130740.6207	0.0008	822545.2704	0.0003
PDUM	-3455857.4471	0.0005	5261024.5532	0.0006	1026318.8241	0.0002
PGEN	-3650007.4560	0.0006	5187339.6815	0.0008	669409.3994	0.0003
PHUN	60145.8837	0.0005	5694448.5373	0.0022	2863591.1354	0.0010
PKAL	-3343823.0911	0.0003	5276062.3383	0.0004	1285509.1069	0.0002
PLEG	-3449311.3242	0.0005	5166215.7231	0.0009	1442826.2385	0.0003
PMAS	-3450751.8194	0.0005	5188374.9844	0.0007	1357308.7816	0.0003
PMOG	-3274635.9531	0.0006	5269089.7905	0.0008	1476547.3564	0.0003
PMRV	-3134714.2860	0.0005	5323767.3133	0.0007	1579758.3138	0.0003
PNAG	-3394665.4509	0.0004	5187871.0946	0.0005	1492904.4931	0.0002
PNDO	-3073489.5353	0.0005	5450701.8752	0.0008	1230702.5470	0.0003
POL1	-666918.0737	0.0003	5878675.9653	0.0010	2377399.8489	0.0005
PSRF	-3167387.7726	0.0004	5286532.2003	0.0007	1638185.0415	0.0003
PSTN	-3219843.4020	0.0005	5124936.7005	0.0008	2005414.0916	0.0004
PSUR	-3649683.0293	0.0006	5117857.9031	0.0008	1077577.7319	0.0003
PTAC	-3588936.6474	0.0004	5124727.4142	0.0005	1236144.3832	0.0002
PTAG	-3184318.6167	0.0005	5291065.5587	0.0008	1590418.2742	0.0003
PTBL	-298530.5724	0.0003	6240614.9691	0.0009	1278761.7779	0.0004
PTGO	-3596112.0257	0.0005	5182802.6307	0.0007	939355.0875	0.0003
PTGY	-3181285.0529	0.0005	5307488.4824	0.0007	1543919.2122	0.0003
PTLC	-3128650.4836	0.0003	5292970.9238	0.0004	1690799.4344	0.0002
PTUG	-3199386.2209	0.0003	5169557.8406	0.0005	1922601.3662	0.0003
PUNE	1679352.4631	0.0004	5811229.8860	0.0009	2017151.5857	0.0004
PZAM	-3361516.1652	0.0006	5365985.9652	0.0011	764311.8973	0.0004
QNAM	-1939181.9235	0.0004	5824574.9165	0.0008	1724681.8876	0.0004
RANG	78085.8865	0.0002	5747205.3444	0.0007	2755540.6471	0.0004
RGDC	1396817.0035	0.0004	5514751.2056	0.0010	2875200.8112	0.0005
SAKE	-1293025.5631	0.0006	6057824.9533	0.0015	1515302.1262	0.0005

Station	X (m)	1 std (m)	Y (m)	1 std (m)	Z (m)	1 std (m)
SHIL	-189399.2318	0.0003	5755481.2085	0.0008	2736393.5130	0.0004
SISA	-1513343.8856	0.0005	5983860.8952	0.0012	1602575.5598	0.0004
SLYG	-1539524.7834	0.0003	6187725.8935	0.0007	151763.8657	0.0002
SNUS	-1518383.2814	0.0003	6193172.5887	0.0006	142897.1464	0.0002
SNYU	-1508025.8765	0.0003	6195576.1176	0.0008	148798.2036	0.0002
SRPT	-1519249.6060	0.0010	6192544.7185	0.0028	159624.0098	0.0007
STEM	-1481813.9536	0.0005	6025851.5383	0.0012	1469486.4476	0.0005
STUE	-1706562.7898	0.0005	5962886.3832	0.0011	1482541.0080	0.0004
T007	-5930470.7760	0.0009	-500209.2266	0.0003	-2285916.9304	0.0004
T430	-2411015.8745	0.0004	5380265.4992	0.0009	2425132.4777	0.0004
TEMB	-2693843.1316	0.0049	5757787.7997	0.0120	520314.5286	0.0032
TGPU	-5930280.9738	0.0009	-486624.2995	0.0003	-2289338.2688	0.0004
THIM	36547.7605	0.0003	5664531.3705	0.0009	2926613.4415	0.0005
TRIV	1422705.0838	0.0002	6147290.9564	0.0006	928074.5581	0.0002
TUTO	-2651866.3698	0.0009	5776287.8223	0.0017	530901.0258	0.0005
VARD	3406685.2730	0.0004	3495946.9700	0.0004	4094603.0762	0.0004
VUNT	-1849587.1318	0.0003	5995310.0572	0.0007	1143318.5930	0.0003
YGGD	3452123.4186	0.0005	3492321.0463	0.0005	4058630.3717	0.0005

Table 3 The final computed Geodetic coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2019. 715 (in decimal year).

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
0029	141	12	14.27596	0.0002	39	6	38.18445	0.0003	172.2844	0.0009
0745	127	49	34.26948	0.0003	26	10	6.97555	0.0003	97.1386	0.0010
0746	131	17	26.39120	0.0002	25	57	13.43378	0.0002	72.5767	0.0007
0837	130	35	58.54793	0.0004	31	49	26.61257	0.0004	314.6815	0.0015
1135	133	41	58.47718	0.0002	35	29	25.43627	0.0003	72.4549	0.0007
1233	96	3	50.94468	0.0003	19	49	40.13584	0.0003	92.4486	0.0010
2004	130	52	42.88941	0.0002	31	25	31.10571	0.0003	134.5551	0.0007
2005	141	50	41.35254	0.0002	43	31	43.11291	0.0003	118.5894	0.0005
2007	142	11	42.08848	0.0002	27	4	3.11823	0.0003	104.2071	0.0008
3009	140	39	33.29694	0.0002	35	57	19.62572	0.0002	65.8028	0.0006
AERO	91	30	11.84984	0.0003	26	54	4.59458	0.0003	1299.7563	0.0009

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
AKHU	43	52	53.26562	0.0002	40	46	53.96669	0.0002	1576.1393	0.0006
APAR	44	21	29.87417	0.0002	40	35	22.56074	0.0003	1922.9117	0.0008
ARMV	44	2	22.69575	0.0002	40	9	20.08030	0.0002	906.4360	0.0006
ARTA	44	33	1.89961	0.0003	39	57	34.36005	0.0003	867.4934	0.0008
BAKO	106	50	56.08973	0.0003	-6	-29	-27.79988	0.0003	158.1164	0.0010
BBSR	85	47	31.64932	0.0003	20	15	47.61807	0.0003	-13.2522	0.0011
BUMT	90	43	22.30137	0.0003	27	32	40.95085	0.0003	2873.6550	0.0010
CAMB	128	11	5.62461	0.0003	-3	-41	-44.01887	0.0003	87.4226	0.0010
CBOR	101	29	51.52018	0.0004	13	8	23.22415	0.0004	42.7529	0.0019
CHAN	125	26	39.13637	0.0002	43	47	26.46591	0.0003	273.2472	0.0006
CHIT	91	48	10.85923	0.0002	22	24	48.77240	0.0002	-19.1158	0.0008
CMAK	119	24	28.86166	0.0002	-5	-8	-5.29059	0.0003	77.5890	0.0009
CMRE	122	13	10.69672	0.0004	-8	-37	-38.98474	0.0003	59.4402	0.0014
CPDG	100	21	47.20970	0.0003	0	-57	-14.33277	0.0003	3.8626	0.0011
CPON	109	19	44.56469	0.0004	0	0	-13.01721	0.0003	36.8741	0.0013
CSBY	112	43	27.72108	0.0003	-7	-20	-3.60707	0.0003	51.2400	0.0010
CUKE	140	23	38.98725	0.0003	-8	-29	-23.47159	0.0003	80.1811	0.0010
DEHR	78	3	16.76600	0.0002	30	19	28.38141	0.0002	648.6113	0.0006
DEOT	91	27	51.35003	0.0003	26	51	38.17483	0.0003	823.6996	0.0009
DHAK	90	23	52.82781	0.0002	23	45	22.20781	0.0002	-29.3271	0.0008
DIEB	103	0	19.85687	0.0004	21	25	39.95751	0.0003	463.7894	0.0014
DSON	106	47	29.09814	0.0003	20	41	45.86204	0.0003	1.5994	0.0013
EAHL	108	12	5.27712	0.0002	13	12	54.76488	0.0002	642.2848	0.0007
GELE	90	25	55.40641	0.0003	26	54	31.10116	0.0003	357.2187	0.0011
GJRT	72	39	11.34666	0.0004	23	12	38.97647	0.0004	20.2659	0.0015
GVAR	45	7	46.45184	0.0002	40	21	58.31483	0.0003	2043.2116	0.0008
HGIA	104	57	32.44551	0.0004	22	49	39.13921	0.0003	107.9430	0.0017
HKKT	114	3	59.65827	0.0002	22	26	41.65436	0.0002	34.5451	0.0007
HKLT	113	59	47.86820	0.0002	22	25	5.27543	0.0002	125.8960	0.0006
HKQT	114	12	47.60127	0.0003	22	17	27.71894	0.0003	5.1463	0.0011
HKSC	114	8	28.30041	0.0003	22	19	19.81206	0.0003	20.2078	0.0010
HKSL	113	55	40.75691	0.0002	22	22	19.20989	0.0002	95.2680	0.0005

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
HKST	114	11	3.29403	0.0003	22	23	42.96696	0.0003	258.6905	0.0010
HTIE	104	27	10.41370	0.0003	10	22	10.35843	0.0003	-4.9289	0.0013
HUV1	100	9	57.06216	0.0003	49	38	9.81293	0.0003	1243.4542	0.0009
IJVN	45	8	45.22300	0.0003	40	53	19.67768	0.0003	751.0381	0.0009
KAMJ	89	27	14.58371	0.0004	26	53	20.17812	0.0005	1389.1446	0.0019
KANG	91	31	25.59988	0.0003	27	17	12.92899	0.0003	1823.4755	0.0009
KANH	106	17	7.45827	0.0003	18	5	12.74192	0.0002	-13.7915	0.0009
KHND	46	25	52.38894	0.0003	39	30	47.51484	0.0003	1556.0021	0.0008
KHUL	89	30	24.67984	0.0002	22	55	27.12524	0.0002	-30.2205	0.0005
KK01	103	47	43.33705	0.0004	11	2	51.12428	0.0003	24.1990	0.0014
KYC1	114	4	34.72804	0.0003	22	17	2.58217	0.0003	116.3423	0.0009
LIAN	114	31	29.47090	0.0005	4	42	15.56598	0.0005	65.7978	0.0021
LUCK	81	0	41.77730	0.0004	26	51	37.65111	0.0003	50.2135	0.0013
MART	46	49	35.35339	0.0002	40	12	54.27765	0.0002	457.8415	0.0007
MAUL	91	54	22.94189	0.0002	24	23	49.89181	0.0002	-15.7342	0.0005
MGHR	46	14	42.13497	0.0003	38	54	10.47668	0.0003	710.4232	0.0011
MURA	115	3	58.33091	0.0004	5	1	59.36003	0.0004	63.7906	0.0017
NGYA	96	7	25.93055	0.0003	16	58	25.41215	0.0003	0.4384	0.0011
PARO	89	26	19.79163	0.0003	27	23	25.70644	0.0003	2342.9345	0.0011
PBAY	121	8	34.55470	0.0002	16	28	53.59249	0.0002	322.8870	0.0008
PBIS	126	21	13.96897	0.0003	8	11	21.02123	0.0003	78.2345	0.0009
PCAT	124	39	31.93633	0.0003	12	30	42.87096	0.0003	59.5924	0.0010
PCB2	120	56	19.70506	0.0002	15	26	45.80157	0.0002	76.7079	0.0008
PCEB	123	53	23.59238	0.0003	10	19	5.18756	0.0002	124.8624	0.0008
PCLP	121	11	40.31393	0.0003	13	25	39.38449	0.0002	64.0593	0.0009
PCOT	124	14	49.31732	0.0003	7	11	58.57343	0.0003	86.1702	0.0009
PDDN	125	46	59.70252	0.0003	7	27	33.75699	0.0003	90.4276	0.0010
PDUM	123	18	0.28078	0.0003	9	19	18.62536	0.0002	88.3950	0.0008
PGEN	125	7	53.98126	0.0003	6	3	53.68335	0.0003	121.0941	0.0009
PHUN	89	23	41.47162	0.0005	26	51	0.43972	0.0006	403.3705	0.0024
PKAL	122	21	55.43221	0.0002	11	42	18.92083	0.0002	80.4179	0.0005
PLEG	123	43	47.01161	0.0003	13	9	40.39392	0.0003	210.0060	0.0010

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
PMAS	123	37	39.36051	0.0003	12	22	8.03374	0.0003	77.9667	0.0009
PMOG	121	51	36.50581	0.0003	13	28	29.11350	0.0003	62.8395	0.0010
PMRV	120	29	24.78036	0.0003	14	26	9.59605	0.0002	59.2628	0.0008
PNAG	123	11	54.92593	0.0002	13	37	36.53087	0.0002	71.5588	0.0006
PNDO	119	25	2.51453	0.0003	11	11	59.22407	0.0003	54.3865	0.0010
POL1	96	28	20.50065	0.0003	22	1	31.24680	0.0003	1026.4665	0.0011
PSRF	120	55	39.46880	0.0002	14	58	54.90034	0.0002	68.4289	0.0008
PSTN	122	8	23.67376	0.0003	18	26	49.98524	0.0003	41.2163	0.0009
PSUR	125	29	37.30529	0.0003	9	47	30.52276	0.0003	80.2374	0.0009
PTAC	125	0	15.22819	0.0002	11	14	59.61660	0.0002	79.7135	0.0006
PTAG	121	2	26.75055	0.0003	14	32	7.59138	0.0003	86.6509	0.0009
PTBL	92	44	19.51640	0.0003	11	38	35.23159	0.0003	1.2876	0.0009
PTGO	124	45	18.10525	0.0003	8	31	33.32312	0.0002	91.5593	0.0008
PTGY	120	56	17.82712	0.0003	14	6	1.01005	0.0002	715.4161	0.0008
PTLC	120	35	13.68965	0.0002	15	28	28.58129	0.0002	112.3151	0.0004
PTUG	121	45	10.58132	0.0002	17	39	36.49448	0.0002	84.3813	0.0006
PUNE	73	52	53.58770	0.0003	18	33	27.59951	0.0003	494.3740	0.0010
PZAM	122	3	54.15249	0.0003	6	55	43.13806	0.0003	84.2224	0.0013
QNAM	108	24	51.13012	0.0003	15	47	34.22939	0.0002	3.3177	0.0009
RANG	89	13	17.70248	0.0002	25	45	50.44596	0.0002	0.9692	0.0008
RGDC	75	47	11.83033	0.0003	26	58	3.03762	0.0003	426.1999	0.0011
SAKE	102	2	55.72742	0.0004	13	50	7.24213	0.0004	11.1333	0.0016
SHIL	91	53	5.23685	0.0003	25	33	56.85067	0.0003	1497.6199	0.0009
SISA	104	11	33.89781	0.0003	14	38	55.91275	0.0003	135.3121	0.0012
SLYG	103	58	18.03617	0.0002	1	22	21.44567	0.0002	50.5002	0.0008
SNUS	103	46	31.85980	0.0002	1	17	32.68600	0.0002	62.7235	0.0006
SNYU	103	40	47.94365	0.0003	1	20	44.84668	0.0002	75.5706	0.0008
SRPT	103	47	3.91510	0.0007	1	26	37.41771	0.0007	58.7480	0.0029
STEM	103	48	55.61417	0.0003	13	24	33.38999	0.0003	-2.2425	0.0013
STUE	105	58	15.54897	0.0003	13	31	49.88346	0.0003	37.6021	0.0012
T007	-175	-10	-43.54851	0.0003	-21	-8	-25.32890	0.0003	54.3958	0.0009
T430	114	8	17.54074	0.0003	22	29	40.98820	0.0003	41.3017	0.0010

Station	LONGITUDE (DMS)			1 std (m)	LATITUDE (DMS)			1 std (m)	ELLIPSOID HEIGHT (m)	1 std (m)
TEMB	115	4	22.98171	0.0044	4	42	38.57956	0.0028	65.1698	0.0123
TGPU	-175	-18	-32.25272	0.0003	-21	-10	-24.51167	0.0003	62.3674	0.0009
THIM	89	37	49.19051	0.0003	27	28	48.36940	0.0003	2381.8012	0.0010
TRIV	76	58	8.80060	0.0002	8	25	22.61935	0.0002	-17.9090	0.0006
TUTO	114	39	34.67178	0.0005	4	48	24.37164	0.0004	79.9681	0.0019
VARD	45	44	27.17389	0.0002	40	10	50.13024	0.0002	1979.1226	0.0006
VUNT	107	8	43.04714	0.0002	10	23	44.27341	0.0002	5.5475	0.0008
YGGD	45	19	53.94191	0.0002	39	45	47.66262	0.0003	1278.0778	0.0008

References

Altamimi, Z., P. Rebischung, L. Métivier, and X. Collilieux (2016), ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, J. Geophys. Res. Solid Earth , 121 , 6109–6131, doi:10.1002/2016JB013098.

Böhm, J., A. Niell, P. Tregoning and H. Schuh, 2006. Global Mapping Function (GMF): A new empirical mapping function based on numerical weather model data, Geophysical Research Letters, Vol. 33, L07304, doi:10.1029/2005GL025546.

Dach R., S. Lutz, P. Walser, and P. Fridez, editors. Bernese GNSS Software, Version5.2. Astronomical Institute, University of Bern, Bern, Switzerland, November 2015. ISBN 978-3-906813-05-9. doi: 10.7892/boris.72297. URL ftp://ftp.unibe.ch/aiub/BERN52/DOCU/DOCU52.pdf. User manual.

Gérard Petit and Brian Luzum (eds.). IERS Conventions (2010). (IERS Technical Note ; 36) Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2010. 179 pp., ISBN 3-89888-989-6

Lyard, L., Lefevre, L., Letellier, T., Francis, O, 2006. Modelling the global ocean tides: insights from FES2004.Ocean Dynamics, 56, 394-415.

Niell, A.E., 1996. Global mapping functions for the atmosphere delay at radio wavelengths. J. Geophys. Res., 101(B2): 3227 - 3246.

Schmid, R., P. Steigenberger, G. Gendt, M. Ge, and M. Rothacher, 2007. Generation of a consistent absolute phase center correction model for GPS receiver and satellite antennas. J Geod., 81: 781 - 798, doi: 10.1007/s00190-007-0148-y.