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# Report on the Analysis of the Asia Pacific Regional Geodetic Project (APRGP) GPS Campaign 2018

G. Hu



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G. Hu

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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 describes the data analysis of the APRGP GPS campaign undertaken between the 16<sup>th</sup> and 22<sup>nd</sup> of September 2018. 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.

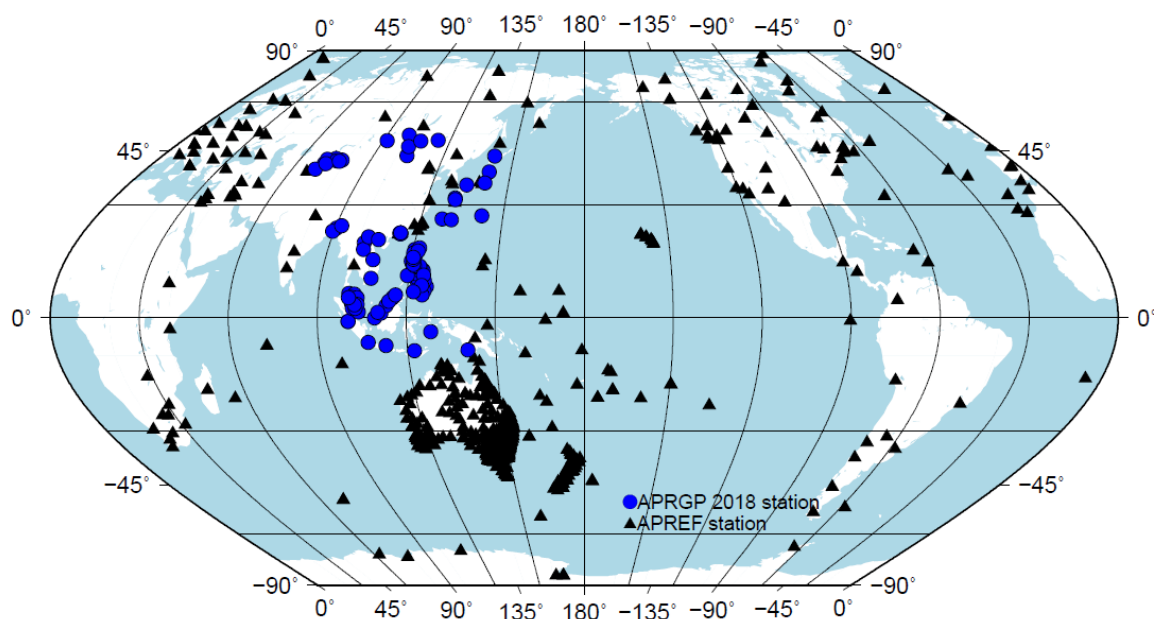
# Introduction

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 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 2018.

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 2018 GPS campaign was undertaken from 16 to 22 September 2018 inclusive (day of year 259 to 265). Data were contributed by ten countries across the region, including Bangladesh, Hong Kong (China), Indonesia, Japan, Kyrgyzstan, Laos, Malaysia, Mongolia, Philippines and Vietnam. Note that Hong Kong (China), Malaysia and Philippines are also contributing CGPS data to the APREF project. Figure 1 shows the distribution of the APRGP 2018 campaign stations.



*Figure 1 APRGP stations in the APRGP 2018 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 were 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-Wübbena 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 1.8 mm, 1.6 mm and 5.4 mm in north, east and up components, respectively.

*Table 1 Daily repeatability RMS for the APRGP 2018 GPS campaign stations.*

| Station | Country           | North (mm) | East (mm) | Up (mm) |
|---------|-------------------|------------|-----------|---------|
| CHIT    | Bangladesh        | 1.9        | 1.6       | 8.8     |
| DHAK    | Bangladesh        | 1.1        | 1.0       | 7.9     |
| KHUL    | Bangladesh        | 1.5        | 2.2       | 8.9     |
| MAUL    | Bangladesh        | 1.6        | 1.0       | 9.2     |
| HKKT    | Hong Kong (China) | 1.1        | 1.5       | 6.4     |
| HKLT    | Hong Kong (China) | 0.6        | 1.9       | 6.4     |
| HKQT    | Hong Kong (China) | 1.7        | 1.8       | 12.1    |
| HKSC    | Hong Kong (China) | 1.0        | 1.2       | 7.1     |
| HKSL    | Hong Kong (China) | 1.7        | 1.4       | 11.7    |
| HKST    | Hong Kong (China) | 1.3        | 0.8       | 6.1     |
| KYC1    | Hong Kong (China) | 0.9        | 2.6       | 6.6     |
| T430    | Hong Kong (China) | 1.3        | 1.5       | 1.2     |
| BAKO    | Indonesia         | 1.8        | 2.0       | 8.4     |
| CAMB    | Indonesia         | 1.9        | 2.4       | 8.5     |
| CMRE    | Indonesia         | 1.8        | 3.3       | 14.0    |
| CPDG    | Indonesia         | 2.3        | 2.5       | 6.3     |
| CPON    | Indonesia         | 2.3        | 2.3       | 11.3    |
| CSBY    | Indonesia         | 2.2        | 1.6       | 6.5     |
| CUKE    | Indonesia         | 2.7        | 2.7       | 3.7     |
| 0029    | Japan             | 1.1        | 2.2       | 8.7     |
| 0745    | Japan             | 0.8        | 1.3       | 6.7     |
| 0746    | Japan             | 1.1        | 3.4       | 6.4     |
| 0837    | Japan             | 1.8        | 3.3       | 9.2     |
| 1135    | Japan             | 1.1        | 1.2       | 9.3     |
| 2004    | Japan             | 1.0        | 4.9       | 15.3    |
| 2005    | Japan             | 2.4        | 3.0       | 7.9     |
| 2007    | Japan             | 2.1        | 3.2       | 5.8     |

| Station | Country    | North (mm) | East (mm) | Up (mm) |
|---------|------------|------------|-----------|---------|
| 3009    | Japan      | 1.1        | 2.2       | 9.7     |
| ALAB    | Kyrgyzstan | 1.5        | 2.6       | 6.8     |
| BALY    | Kyrgyzstan | 1.7        | 2.0       | 2.1     |
| FANA    | Kyrgyzstan | 1.7        | 2.4       | 5.4     |
| JTGZ    | Kyrgyzstan | 1.3        | 2.1       | 3.8     |
| KANT    | Kyrgyzstan | 2.1        | 2.5       | 7.3     |
| KBUR    | Kyrgyzstan | 1.7        | 2.4       | 4.8     |
| KOCH    | Kyrgyzstan | 1.2        | 2.3       | 4.9     |
| TASH    | Kyrgyzstan | 1.9        | 2.3       | 6.2     |
| TON_    | Kyrgyzstan | 2.0        | 2.0       | 4.2     |
| LPBG    | Laos       | 2.4        | 3.9       | 12.4    |
| VITE    | Laos       | 6.5        | 4.9       | 5.3     |
| XEKG    | Laos       | 3.5        | 3.9       | 14.4    |
| AMAN    | Malaysia   | 1.3        | 1.0       | 3.5     |
| ARAU    | Malaysia   | 2.3        | 1.7       | 2.9     |
| BEHR    | Malaysia   | 2.8        | 2.7       | 9.0     |
| BIN1    | Malaysia   | 1.8        | 3.2       | 4.1     |
| GET2    | Malaysia   | 1.4        | 1.8       | 7.7     |
| GMUS    | Malaysia   | 0.6        | 1.4       | 8.8     |
| GRIK    | Malaysia   | 1.3        | 1.6       | 3.2     |
| JHJY    | Malaysia   | 2.0        | 2.0       | 5.3     |
| KUAL    | Malaysia   | 2.5        | 2.1       | 6.9     |
| LAB1    | Malaysia   | 2.0        | 2.0       | 2.2     |
| MIRI    | Malaysia   | 1.6        | 1.8       | 3.6     |
| PDIC    | Malaysia   | 2.0        | 1.4       | 4.8     |
| PEKN    | Malaysia   | 1.8        | 1.5       | 7.2     |
| SEG1    | Malaysia   | 1.2        | 1.1       | 6.2     |
| TLOH    | Malaysia   | 1.6        | 1.9       | 6.3     |
| UMAS    | Malaysia   | 1.1        | 1.9       | 5.5     |
| UMSS    | Malaysia   | 3.1        | 3.7       | 17.8    |
| USMP    | Malaysia   | 1.6        | 1.0       | 3.9     |
| DOA1    | Mongolia   | 1.7        | 2.2       | 4.9     |
| HOA1    | Mongolia   | 1.2        | 2.0       | 5.8     |
| HUV1    | Mongolia   | 1.2        | 2.0       | 5.0     |
| OMA1    | Mongolia   | 1.8        | 2.2       | 5.4     |
| OVA1    | Mongolia   | 1.4        | 1.9       | 5.2     |

| Station | Country     | North (mm) | East (mm) | Up (mm) |
|---------|-------------|------------|-----------|---------|
| UB01    | Mongolia    | 1.5        | 2.2       | 4.1     |
| PBAT    | Philippines | 1.8        | 1.4       | 4.8     |
| PBAY    | Philippines | 1.9        | 1.2       | 5.4     |
| PBIS    | Philippines | 1.5        | 1.7       | 5.1     |
| PCAT    | Philippines | 2.5        | 1.7       | 6.5     |
| PCB2    | Philippines | 2.1        | 2.6       | 5.6     |
| PCDN    | Philippines | 1.3        | 1.8       | 5.6     |
| PCEB    | Philippines | 1.4        | 2.6       | 8.2     |
| PCLP    | Philippines | 2.4        | 1.7       | 8.7     |
| PCOT    | Philippines | 2.1        | 2.0       | 5.4     |
| PDAV    | Philippines | 2.2        | 1.0       | 6.9     |
| PDUM    | Philippines | 1.3        | 2.1       | 10.4    |
| PFLO    | Philippines | 1.8        | 2.0       | 6.9     |
| PGEN    | Philippines | 1.4        | 1.4       | 3.4     |
| PILC    | Philippines | 1.9        | 0.8       | 5.4     |
| PKAL    | Philippines | 1.8        | 1.1       | 7.6     |
| PLEG    | Philippines | 2.8        | 4.4       | 12.4    |
| PMAS    | Philippines | 1.7        | 1.0       | 9.6     |
| PMOG    | Philippines | 0.6        | 2.1       | 7.1     |
| PMRV    | Philippines | 2.0        | 1.2       | 6.2     |
| PNAG    | Philippines | 3.8        | 1.2       | 7.3     |
| PNDO    | Philippines | 1.2        | 1.1       | 4.0     |
| PSJN    | Philippines | 3.2        | 1.6       | 7.6     |
| PSNR    | Philippines | 1.5        | 3.0       | 5.0     |
| PSRF    | Philippines | 2.0        | 3.5       | 5.7     |
| PSTN    | Philippines | 1.6        | 1.9       | 6.9     |
| PSUR    | Philippines | 1.8        | 1.1       | 7.6     |
| PTAC    | Philippines | 2.6        | 1.3       | 7.6     |
| PTAG    | Philippines | 2.6        | 1.3       | 7.6     |
| PTGO    | Philippines | 3.4        | 1.0       | 5.0     |
| PTGY    | Philippines | 2.1        | 1.1       | 8.0     |
| PTLC    | Philippines | 1.7        | 1.7       | 8.7     |
| PTUG    | Philippines | 1.8        | 2.4       | 5.6     |
| PURD    | Philippines | 1.5        | 1.0       | 11.2    |
| PZAM    | Philippines | 1.5        | 1.4       | 10.7    |
| DIEB    | Vietnam     | 1.6        | 2.3       | 8.6     |

| Station | Country | North (mm) | East (mm) | Up (mm) |
|---------|---------|------------|-----------|---------|
| DOSN    | Vietnam | 2.0        | 1.0       | 3.7     |
| VUNT    | Vietnam | 3.4        | 1.2       | 10.5    |

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: CMAK (Indonesia), DOG1 (Mongolia) and QNAM (Vietnam).

*Table 2 The final computed Cartesian coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2018. 72.*

| Station | X (m)         | 1 std (m) | Y (m)        | 1 std (m) | Z (m)        | 1 std (m) |
|---------|---------------|-----------|--------------|-----------|--------------|-----------|
| 0029    | -3862398.9109 | 0.0009    | 3105008.4281 | 0.0008    | 3105008.4281 | 0.0008    |
| 0745    | -3512920.1850 | 0.0008    | 4524558.0766 | 0.0009    | 4524558.0766 | 0.0006    |
| 0746    | -3786804.8537 | 0.0006    | 4311846.1955 | 0.0007    | 4311846.1955 | 0.0004    |
| 0837    | -3530185.8566 | 0.0011    | 4118797.2302 | 0.0011    | 4118797.2302 | 0.0009    |
| 1135    | -3591931.1739 | 0.0007    | 3758796.8654 | 0.0007    | 3758796.8654 | 0.0006    |
| 2004    | -3565271.9208 | 0.0007    | 4118973.0290 | 0.0007    | 4118973.0290 | 0.0005    |
| 2005    | -3642161.4469 | 0.0010    | 2861487.8652 | 0.0008    | 2861487.8652 | 0.0008    |
| 2007    | -4490605.1550 | 0.0009    | 3483894.9950 | 0.0007    | 3483894.9950 | 0.0006    |
| 3009    | -3997616.3897 | 0.0007    | 3276761.8950 | 0.0007    | 3276761.8950 | 0.0006    |
| ALAB    | 1520847.8902  | 0.0005    | 4544154.9066 | 0.0010    | 4544154.9066 | 0.0008    |
| AMAN    | -2332691.9896 | 0.0004    | 5934768.0774 | 0.0007    | 5934768.0774 | 0.0003    |
| ARAU    | -1131051.9843 | 0.0005    | 6236311.7307 | 0.0014    | 6236311.7307 | 0.0004    |
| BAKO    | -1836969.4433 | 0.0004    | 6065616.9510 | 0.0010    | 6065616.9510 | 0.0003    |
| BALY    | 1124851.9440  | 0.0005    | 4577461.3424 | 0.0010    | 4577461.3424 | 0.0007    |
| BEHR    | -1270756.8442 | 0.0014    | 6236377.9630 | 0.0032    | 6236377.9630 | 0.0006    |
| BIN1    | -2497850.2653 | 0.0006    | 5857731.6219 | 0.0012    | 5857731.6219 | 0.0004    |
| CAMB    | -3934881.6737 | 0.0005    | 5003056.0168 | 0.0006    | 5003056.0168 | 0.0003    |

| Station | X (m)         | 1 std (m) | Y (m)        | 1 std (m) | Z (m)        | 1 std (m) |
|---------|---------------|-----------|--------------|-----------|--------------|-----------|
| CHIT    | -185607.4816  | 0.0005    | 5896239.4554 | 0.0011    | 5896239.4554 | 0.0006    |
| CMRE    | -3362412.5757 | 0.0010    | 5335364.2474 | 0.0012    | 5335364.2474 | 0.0004    |
| CPDG    | -1147179.6072 | 0.0005    | 6273233.4913 | 0.0013    | 6273233.4913 | 0.0004    |
| CPON    | -2111129.6111 | 0.0005    | 6018657.0502 | 0.0013    | 6018657.0502 | 0.0004    |
| CSBY    | -2443857.6679 | 0.0005    | 5835257.9854 | 0.0011    | 5835257.9854 | 0.0003    |
| CUKE    | -4860592.7522 | 0.0010    | 4021866.1773 | 0.0010    | 4021866.1773 | 0.0004    |
| DHAK    | -40573.3760   | 0.0005    | 5840711.2735 | 0.0012    | 5840711.2735 | 0.0006    |
| DIEB    | -1336842.5563 | 0.0007    | 5787988.4053 | 0.0014    | 5787988.4053 | 0.0007    |
| DOA1    | -1772383.0107 | 0.0005    | 3884842.2784 | 0.0009    | 3884842.2784 | 0.0008    |
| DOSN    | -1724757.4802 | 0.0013    | 5714523.7773 | 0.0035    | 5714523.7773 | 0.0013    |
| FANA    | 1715883.5398  | 0.0006    | 4595337.3247 | 0.0011    | 4595337.3247 | 0.0009    |
| GET2    | -1329700.5080 | 0.0004    | 6199778.6650 | 0.0009    | 6199778.6650 | 0.0004    |
| GMUS    | -1317445.3216 | 0.0005    | 6217407.6264 | 0.0013    | 6217407.6264 | 0.0004    |
| GRIK    | -1225760.8339 | 0.0005    | 6230325.9190 | 0.0012    | 6230325.9190 | 0.0004    |
| HKKT    | -2405144.5149 | 0.0005    | 5385195.0340 | 0.0010    | 5385195.0340 | 0.0005    |
| HKLT    | -2399063.3476 | 0.0005    | 5389237.6257 | 0.0009    | 5389237.6257 | 0.0005    |
| HKQT    | -2421568.5033 | 0.0008    | 5384910.3468 | 0.0012    | 5384910.3468 | 0.0006    |
| HKSC    | -2414267.5312 | 0.0007    | 5386768.7635 | 0.0011    | 5386768.7635 | 0.0005    |

| Station | X (m)         | 1 std (m) | Y (m)        | 1 std (m) | Z (m)        | 1 std (m) |
|---------|---------------|-----------|--------------|-----------|--------------|-----------|
| HKSL    | -2393383.0323 | 0.0005    | 5393860.9556 | 0.0008    | 5393860.9556 | 0.0004    |
| HKST    | -2417143.4909 | 0.0007    | 5382345.2691 | 0.0011    | 5382345.2691 | 0.0005    |
| HOA1    | -124480.5836  | 0.0005    | 4274103.0092 | 0.0010    | 4274103.0092 | 0.0008    |
| HUV1    | -730630.7825  | 0.0005    | 4074608.1099 | 0.0009    | 4074608.1099 | 0.0008    |
| JHJY    | -1520490.3236 | 0.0005    | 6191944.3926 | 0.0013    | 6191944.3926 | 0.0004    |
| JTGZ    | 981309.5655   | 0.0004    | 4619535.1746 | 0.0008    | 4619535.1746 | 0.0006    |
| KANT    | 1223702.3949  | 0.0005    | 4517393.3165 | 0.0011    | 4517393.3165 | 0.0009    |
| KBUR    | 1484973.9429  | 0.0005    | 4460760.0461 | 0.0010    | 4460760.0461 | 0.0008    |
| KHUL    | 50585.7864    | 0.0004    | 5877137.8573 | 0.0009    | 5877137.8573 | 0.0005    |
| KOCH    | 1164522.1785  | 0.0005    | 4586942.4779 | 0.0009    | 4586942.4779 | 0.0007    |
| KUAL    | -1443668.5671 | 0.0005    | 6184650.0693 | 0.0011    | 6184650.0693 | 0.0004    |
| KYC1    | -2408855.8673 | 0.0006    | 5391043.0077 | 0.0011    | 5391043.0077 | 0.0006    |
| LAB1    | -2708735.5812 | 0.0005    | 5744698.4318 | 0.0008    | 5744698.4318 | 0.0003    |
| LPBG    | -1262964.3930 | 0.0013    | 5865655.0322 | 0.0030    | 5865655.0322 | 0.0014    |
| MAUL    | -193340.6195  | 0.0004    | 5808683.2884 | 0.0010    | 5808683.2884 | 0.0005    |
| MIRI    | -2586925.5111 | 0.0004    | 5809853.2832 | 0.0008    | 5809853.2832 | 0.0003    |
| OMA1    | -1148361.6791 | 0.0005    | 4482078.4864 | 0.0009    | 4482078.4864 | 0.0007    |
| OVA1    | -977156.7540  | 0.0004    | 4308800.7225 | 0.0007    | 4308800.7225 | 0.0005    |

| Station | X (m)         | 1 std (m) | Y (m)        | 1 std (m) | Z (m)        | 1 std (m) |
|---------|---------------|-----------|--------------|-----------|--------------|-----------|
| PBAT    | -3082933.6348 | 0.0006    | 5224292.1376 | 0.0009    | 5224292.1376 | 0.0004    |
| PBAY    | -3164088.0834 | 0.0006    | 5236293.6434 | 0.0009    | 5236293.6434 | 0.0004    |
| PBIS    | -3742521.5664 | 0.0007    | 5084796.7854 | 0.0009    | 5084796.7854 | 0.0004    |
| PCAT    | -3541625.4001 | 0.0008    | 5122609.4081 | 0.0011    | 5122609.4081 | 0.0004    |
| PCB2    | -3161493.9852 | 0.0006    | 5274361.1589 | 0.0009    | 5274361.1589 | 0.0004    |
| PCDN    | -3088458.6160 | 0.0005    | 5255341.0483 | 0.0007    | 5255341.0483 | 0.0004    |
| PCEB    | -3499371.4735 | 0.0008    | 5209600.2277 | 0.0011    | 5209600.2277 | 0.0004    |
| PCLP    | -3213834.0698 | 0.0006    | 5307813.9846 | 0.0009    | 5307813.9846 | 0.0004    |
| PCOT    | -3561309.0534 | 0.0008    | 5231065.2383 | 0.0011    | 5231065.2383 | 0.0005    |
| PDAV    | -3688320.2511 | 0.0005    | 5143554.6805 | 0.0006    | 5143554.6805 | 0.0003    |
| PDIC    | -1304198.0421 | 0.0004    | 6237114.2937 | 0.0008    | 6237114.2937 | 0.0003    |
| PDUM    | -3455857.4489 | 0.0006    | 5261024.5430 | 0.0008    | 5261024.5430 | 0.0003    |
| PEKN    | -1474284.8740 | 0.0005    | 6193341.5190 | 0.0013    | 6193341.5190 | 0.0004    |
| PFLO    | -3127780.1069 | 0.0006    | 5310053.4153 | 0.0009    | 5310053.4153 | 0.0004    |
| PGEN    | -3650007.4632 | 0.0008    | 5187339.6723 | 0.0011    | 5187339.6723 | 0.0004    |
| PILC    | -3372132.9166 | 0.0006    | 5282112.8197 | 0.0009    | 5282112.8197 | 0.0004    |
| PKAL    | -3343823.0880 | 0.0004    | 5276062.3424 | 0.0006    | 5276062.3424 | 0.0003    |
| PLEG    | -3449311.3406 | 0.0006    | 5166215.7258 | 0.0010    | 5166215.7258 | 0.0004    |

| Station | X (m)         | 1 std (m) | Y (m)        | 1 std (m) | Z (m)        | 1 std (m) |
|---------|---------------|-----------|--------------|-----------|--------------|-----------|
| PMAS    | -3450751.8145 | 0.0007    | 5188374.9764 | 0.0010    | 5188374.9764 | 0.0004    |
| PMOG    | -3274635.9575 | 0.0008    | 5269089.7830 | 0.0011    | 5269089.7830 | 0.0005    |
| PMRV    | -3134714.3065 | 0.0006    | 5323767.2957 | 0.0009    | 5323767.2957 | 0.0004    |
| PNAG    | -3394665.4713 | 0.0005    | 5187871.0774 | 0.0008    | 5187871.0774 | 0.0003    |
| PNDO    | -3073489.5139 | 0.0006    | 5450701.8822 | 0.0010    | 5450701.8822 | 0.0004    |
| PSJN    | -3228520.3529 | 0.0006    | 5287794.8408 | 0.0009    | 5287794.8408 | 0.0004    |
| PSNR    | -3088261.2831 | 0.0006    | 5332018.5931 | 0.0010    | 5332018.5931 | 0.0004    |
| PSRF    | -3167387.8002 | 0.0006    | 5286532.1829 | 0.0009    | 5286532.1829 | 0.0004    |
| PSTN    | -3219843.4500 | 0.0005    | 5124936.6819 | 0.0007    | 5124936.6819 | 0.0004    |
| PSUR    | -3649683.0476 | 0.0007    | 5117857.8955 | 0.0010    | 5117857.8955 | 0.0004    |
| PTAC    | -3588936.6670 | 0.0005    | 5124727.4096 | 0.0007    | 5124727.4096 | 0.0003    |
| PTAG    | -3184318.6437 | 0.0008    | 5291065.5411 | 0.0011    | 5291065.5411 | 0.0004    |
| PTGO    | -3596112.0306 | 0.0008    | 5182802.6183 | 0.0012    | 5182802.6183 | 0.0005    |
| PTGY    | -3181285.0630 | 0.0006    | 5307488.4529 | 0.0009    | 5307488.4529 | 0.0004    |
| PTLC    | -3128650.5082 | 0.0004    | 5292970.9161 | 0.0006    | 5292970.9161 | 0.0003    |
| PTUG    | -3199386.2646 | 0.0005    | 5169557.8216 | 0.0008    | 5169557.8216 | 0.0004    |
| PURD    | -3119483.9324 | 0.0007    | 5279887.1302 | 0.0010    | 5279887.1302 | 0.0004    |
| PZAM    | -3361516.1480 | 0.0009    | 5365985.9643 | 0.0015    | 5365985.9643 | 0.0005    |

| Station | X (m)         | 1 std (m) | Y (m)        | 1 std (m) | Z (m)        | 1 std (m) |
|---------|---------------|-----------|--------------|-----------|--------------|-----------|
| SEG1    | -1404378.3549 | 0.0004    | 6215518.6408 | 0.0008    | 6215518.6408 | 0.0003    |
| T430    | -2411015.8371 | 0.0007    | 5380265.4924 | 0.0013    | 5380265.4924 | 0.0007    |
| TASH    | 1464166.0479  | 0.0005    | 4566611.7669 | 0.0011    | 4566611.7669 | 0.0009    |
| TLOH    | -1369260.6795 | 0.0005    | 6217732.1039 | 0.0013    | 6217732.1039 | 0.0004    |
| TON_    | 1066604.1251  | 0.0005    | 4617945.7295 | 0.0010    | 4617945.7295 | 0.0007    |
| UB01    | -1245727.4102 | 0.0005    | 4097908.0060 | 0.0009    | 4097908.0060 | 0.0007    |
| UMAS    | -2225109.3107 | 0.0006    | 5975252.5501 | 0.0012    | 5975252.5501 | 0.0004    |
| UMSS    | -2791752.3247 | 0.0014    | 5695647.4564 | 0.0021    | 5695647.4564 | 0.0006    |
| USMP    | -1135919.7228 | 0.0005    | 6248058.4487 | 0.0014    | 6248058.4487 | 0.0004    |
| VITE    | -1314798.1897 | 0.0028    | 5923043.4339 | 0.0076    | 5923043.4339 | 0.0029    |
| VUNT    | -1849617.1447 | 0.0006    | 5995299.8019 | 0.0012    | 5995299.8019 | 0.0004    |
| XEKG    | -1770022.4209 | 0.0012    | 5892282.9282 | 0.0031    | 5892282.9282 | 0.0009    |

*Table 3 The final computed Geodetic coordinates in ITRF2014 at the mean epoch of the measurements, i.e. @2018. 72.*

| Station | LONGITUDE (DMS) |    |          | 1 std (m) | LATITUDE (DMS) |    |          | 1 std (m) | ELLIPSOID HEIGHT (m) | 1 std (m) |
|---------|-----------------|----|----------|-----------|----------------|----|----------|-----------|----------------------|-----------|
| 0029    | 141             | 12 | 14.27324 | 0.0004    | 39             | 6  | 38.18548 | 0.0006    | 172.2603             | 0.0013    |
| 0745    | 127             | 49 | 34.2683  | 0.0004    | 26             | 10 | 6.97667  | 0.0004    | 97.1333              | 0.0012    |
| 0746    | 131             | 17 | 26.39261 | 0.0003    | 25             | 57 | 13.43286 | 0.0004    | 72.5764              | 0.0009    |
| 0837    | 130             | 35 | 58.547   | 0.0005    | 31             | 49 | 26.6131  | 0.0005    | 314.6748             | 0.0017    |

| Station | LONGITUDE (DMS) |    |          | 1 std (m) | LATITUDE (DMS) |     |          | 1 std (m) | ELLIPSOID HEIGHT (m) | 1 std (m) |
|---------|-----------------|----|----------|-----------|----------------|-----|----------|-----------|----------------------|-----------|
| 1135    | 133             | 41 | 58.47607 | 0.0003    | 35             | 29  | 25.43638 | 0.0005    | 72.4596              | 0.0010    |
| 2004    | 130             | 52 | 42.88822 | 0.0004    | 31             | 25  | 31.10639 | 0.0005    | 134.5445             | 0.0010    |
| 2005    | 141             | 50 | 41.3523  | 0.0004    | 43             | 31  | 43.11305 | 0.0006    | 118.5952             | 0.0013    |
| 2007    | 142             | 11 | 42.08955 | 0.0004    | 27             | 4   | 3.11756  | 0.0005    | 104.2084             | 0.0011    |
| 3009    | 140             | 39 | 33.29675 | 0.0003    | 35             | 57  | 19.62603 | 0.0005    | 65.8018              | 0.0010    |
| ALAB    | 71              | 29 | 43.87903 | 0.0006    | 41             | 24  | 17.09743 | 0.0005    | 1227.266             | 0.0011    |
| AMAN    | 111             | 27 | 27.25474 | 0.0003    | 1              | 13  | 18.69233 | 0.0003    | 52.2667              | 0.0007    |
| ARAU    | 100             | 16 | 47.06173 | 0.0004    | 6              | 27  | 0.56445  | 0.0004    | 18.0531              | 0.0015    |
| BAKO    | 106             | 50 | 56.08899 | 0.0003    | -6             | -29 | -27.7998 | 0.0003    | 158.1165             | 0.0011    |
| BALY    | 76              | 11 | 37.91909 | 0.0006    | 42             | 27  | 45.72202 | 0.0005    | 1612.849             | 0.0011    |
| BEHR    | 101             | 31 | 1.97257  | 0.0010    | 3              | 45  | 55.32906 | 0.0006    | 68.7702              | 0.0034    |
| BIN1    | 113             | 5  | 39.62109 | 0.0004    | 3              | 14  | 25.13997 | 0.0004    | 58.9914              | 0.0013    |
| CAMB    | 128             | 11 | 5.62442  | 0.0003    | -3             | -41 | -44.0198 | 0.0003    | 87.4156              | 0.0008    |
| CHIT    | 91              | 48 | 10.85802 | 0.0005    | 22             | 24  | 48.77116 | 0.0004    | -19.1011             | 0.0012    |
| CMRE    | 122             | 13 | 10.69592 | 0.0004    | -8             | -37 | -38.9857 | 0.0004    | 59.4432              | 0.0015    |
| CPDG    | 100             | 21 | 47.20889 | 0.0004    | 0              | -57 | -14.3334 | 0.0004    | 3.8526               | 0.0013    |
| CPON    | 109             | 19 | 44.56403 | 0.0004    | 0              | 0   | -13.0169 | 0.0004    | 36.8048              | 0.0014    |
| CSBY    | 112             | 43 | 27.72029 | 0.0003    | -7             | -20 | -3.60699 | 0.0003    | 51.2416              | 0.0011    |

| Station | LONGITUDE (DMS) |    |          | 1 std (m) | LATITUDE (DMS) |     |          | 1 std (m) | ELLIPSOID HEIGHT (m) | 1 std (m) |
|---------|-----------------|----|----------|-----------|----------------|-----|----------|-----------|----------------------|-----------|
| CUKE    | 140             | 23 | 38.98618 | 0.0004    | -8             | -29 | -23.4737 | 0.0004    | 80.1926              | 0.0014    |
| DHAK    | 90              | 23 | 52.82633 | 0.0005    | 23             | 45  | 22.20662 | 0.0005    | -29.3154             | 0.0013    |
| DIEB    | 103             | 0  | 19.62776 | 0.0005    | 21             | 25  | 39.41229 | 0.0005    | 465.6696             | 0.0016    |
| DOA1    | 114             | 31 | 26.08216 | 0.0004    | 48             | 4   | 28.00401 | 0.0006    | 731.787              | 0.0011    |
| DOSN    | 106             | 47 | 41.50909 | 0.0008    | 20             | 41  | 40.00755 | 0.0008    | 32.6401              | 0.0038    |
| FANA    | 69              | 31 | 28.33247 | 0.0006    | 39             | 50  | 15.89681 | 0.0005    | 1266.116             | 0.0014    |
| GET2    | 102             | 6  | 18.54768 | 0.0004    | 6              | 13  | 33.49491 | 0.0003    | 1.807                | 0.0010    |
| GMUS    | 101             | 57 | 49.66973 | 0.0004    | 4              | 51  | 46.70416 | 0.0004    | 125.9414             | 0.0013    |
| GRIK    | 101             | 7  | 49.00017 | 0.0004    | 5              | 26  | 20.44052 | 0.0004    | 149.1663             | 0.0012    |
| HKKT    | 114             | 3  | 59.65716 | 0.0004    | 22             | 26  | 41.65464 | 0.0004    | 34.5378              | 0.0011    |
| HKLT    | 113             | 59 | 47.86709 | 0.0004    | 22             | 25  | 5.27571  | 0.0004    | 125.8857             | 0.0010    |
| HKQT    | 114             | 12 | 47.60019 | 0.0004    | 22             | 17  | 27.71916 | 0.0004    | 5.1461               | 0.0015    |
| HKSC    | 114             | 8  | 28.29936 | 0.0004    | 22             | 19  | 19.81227 | 0.0004    | 20.1974              | 0.0013    |
| HKSL    | 113             | 55 | 40.75581 | 0.0004    | 22             | 22  | 19.2101  | 0.0004    | 95.2598              | 0.0009    |
| HKST    | 114             | 11 | 3.29297  | 0.0004    | 22             | 23  | 42.9672  | 0.0004    | 258.6852             | 0.0013    |
| HOA1    | 91              | 40 | 5.63613  | 0.0005    | 48             | 0   | 31.57608 | 0.0006    | 1378.657             | 0.0012    |
| HUV1    | 100             | 9  | 57.06055 | 0.0004    | 49             | 38  | 9.81303  | 0.0006    | 1243.509             | 0.0011    |
| JHJY    | 103             | 47 | 47.52461 | 0.0004    | 1              | 32  | 12.51351 | 0.0004    | 39.1552              | 0.0013    |

| Station | LONGITUDE (DMS) |    |          | 1 std (m) | LATITUDE (DMS) |    |          | 1 std (m) | ELLIPSOID HEIGHT (m) | 1 std (m) |
|---------|-----------------|----|----------|-----------|----------------|----|----------|-----------|----------------------|-----------|
| JTGZ    | 78              | 0  | 25.75887 | 0.0005    | 42             | 20 | 38.74057 | 0.0005    | 1723.602             | 0.0008    |
| KANT    | 74              | 50 | 35.07307 | 0.0006    | 42             | 53 | 52.18883 | 0.0006    | 703.2467             | 0.0014    |
| KBUR    | 71              | 35 | 15.1823  | 0.0006    | 42             | 37 | 5.3979   | 0.0005    | 897.531              | 0.0011    |
| KHUL    | 89              | 30 | 24.6784  | 0.0004    | 22             | 55 | 27.12403 | 0.0004    | -30.2157             | 0.0009    |
| KOCH    | 75              | 45 | 17.43865 | 0.0006    | 42             | 12 | 46.52464 | 0.0005    | 1777.322             | 0.0010    |
| KUAL    | 103             | 8  | 20.93709 | 0.0004    | 5              | 19 | 7.99767  | 0.0003    | 54.9779              | 0.0011    |
| KYC1    | 114             | 4  | 34.72695 | 0.0004    | 22             | 17 | 2.58248  | 0.0004    | 116.3356             | 0.0012    |
| LAB1    | 115             | 14 | 41.19839 | 0.0003    | 5              | 16 | 57.50569 | 0.0003    | 57.293               | 0.0008    |
| LPBG    | 102             | 9  | 4.09687  | 0.0009    | 19             | 53 | 38.44148 | 0.0008    | 258.5517             | 0.0033    |
| MAUL    | 91              | 54 | 22.94055 | 0.0004    | 24             | 23 | 49.89071 | 0.0004    | -15.7279             | 0.0010    |
| MIRI    | 114             | 0  | 6.28641  | 0.0003    | 4              | 22 | 19.55816 | 0.0003    | 62.3715              | 0.0008    |
| OMA1    | 104             | 22 | 14.62158 | 0.0004    | 43             | 36 | 19.30099 | 0.0006    | 1416.437             | 0.0010    |
| OVA1    | 102             | 46 | 39.02236 | 0.0004    | 46             | 15 | 59.73745 | 0.0005    | 1816.935             | 0.0008    |
| PBAT    | 120             | 32 | 43.7861  | 0.0004    | 18             | 3  | 14.05227 | 0.0004    | 51.7429              | 0.0011    |
| PBAY    | 121             | 8  | 34.55613 | 0.0004    | 16             | 28 | 53.59151 | 0.0004    | 322.8772             | 0.0010    |
| PBIS    | 126             | 21 | 13.96993 | 0.0004    | 8              | 11 | 21.02033 | 0.0004    | 78.2267              | 0.0011    |
| PCAT    | 124             | 39 | 31.93709 | 0.0004    | 12             | 30 | 42.86983 | 0.0004    | 59.5847              | 0.0013    |
| PCB2    | 120             | 56 | 19.70591 | 0.0004    | 15             | 26 | 45.80125 | 0.0004    | 76.7287              | 0.0010    |

| Station | LONGITUDE (DMS) |    |          | 1 std (m) | LATITUDE (DMS) |    |          | 1 std (m) | ELLIPSOID HEIGHT (m) | 1 std (m) |
|---------|-----------------|----|----------|-----------|----------------|----|----------|-----------|----------------------|-----------|
| PCDN    | 120             | 26 | 30.84139 | 0.0003    | 17             | 10 | 16.93004 | 0.0003    | 55.3328              | 0.0008    |
| PCEB    | 123             | 53 | 23.5924  | 0.0004    | 10             | 19 | 5.18737  | 0.0004    | 124.8605             | 0.0013    |
| PCLP    | 121             | 11 | 40.31404 | 0.0004    | 13             | 25 | 39.38424 | 0.0004    | 64.0521              | 0.0011    |
| PCOT    | 124             | 14 | 49.3177  | 0.0004    | 7              | 11 | 58.57348 | 0.0004    | 86.1598              | 0.0013    |
| PDAV    | 125             | 38 | 36.25347 | 0.0003    | 7              | 7  | 35.36372 | 0.0003    | 96.7714              | 0.0007    |
| PDIC    | 101             | 48 | 37.92792 | 0.0003    | 2              | 31 | 34.23118 | 0.0003    | 31.1739              | 0.0008    |
| PDUM    | 123             | 18 | 0.28101  | 0.0003    | 9              | 19 | 18.62506 | 0.0003    | 88.3859              | 0.0010    |
| PEKN    | 103             | 23 | 22.89831 | 0.0004    | 3              | 29 | 33.34753 | 0.0004    | 25.9824              | 0.0013    |
| PFLO    | 120             | 29 | 57.68156 | 0.0004    | 14             | 58 | 58.55955 | 0.0004    | 90.7731              | 0.0011    |
| PGEN    | 125             | 7  | 53.98163 | 0.0004    | 6              | 3  | 53.68345 | 0.0004    | 121.091              | 0.0013    |
| PILC    | 122             | 33 | 15.86952 | 0.0004    | 10             | 45 | 46.38381 | 0.0003    | 71.4569              | 0.0010    |
| PKAL    | 122             | 21 | 55.43205 | 0.0003    | 11             | 42 | 18.92053 | 0.0003    | 80.4178              | 0.0007    |
| PLEG    | 123             | 43 | 47.01202 | 0.0004    | 13             | 9  | 40.39268 | 0.0004    | 210.0087             | 0.0011    |
| PMAS    | 123             | 37 | 39.36052 | 0.0004    | 12             | 22 | 8.03357  | 0.0004    | 77.9561              | 0.0012    |
| PMOG    | 121             | 51 | 36.50607 | 0.0004    | 13             | 28 | 29.11299 | 0.0004    | 62.8316              | 0.0014    |
| PMRV    | 120             | 29 | 24.78125 | 0.0004    | 14             | 26 | 9.59592  | 0.0004    | 59.2569              | 0.0011    |
| PNAG    | 123             | 11 | 54.92681 | 0.0003    | 13             | 37 | 36.52973 | 0.0003    | 71.547               | 0.0009    |
| PNDO    | 119             | 25 | 2.5138   | 0.0004    | 11             | 11 | 59.22431 | 0.0004    | 54.3835              | 0.0012    |

| Station | LONGITUDE (DMS) |    |          | 1 std (m) | LATITUDE (DMS) |    |          | 1 std (m) | ELLIPSOID HEIGHT (m) | 1 std (m) |
|---------|-----------------|----|----------|-----------|----------------|----|----------|-----------|----------------------|-----------|
| PSJN    | 121             | 24 | 23.7736  | 0.0004    | 13             | 47 | 30.03961 | 0.0004    | 66.6305              | 0.0011    |
| PSNR    | 120             | 4  | 44.65034 | 0.0004    | 15             | 0  | 56.59538 | 0.0004    | 63.5943              | 0.0011    |
| PSRF    | 120             | 55 | 39.46989 | 0.0004    | 14             | 58 | 54.89998 | 0.0004    | 68.4252              | 0.0010    |
| PSTN    | 122             | 8  | 23.67548 | 0.0003    | 18             | 26 | 49.98409 | 0.0003    | 41.2147              | 0.0008    |
| PSUR    | 125             | 29 | 37.30593 | 0.0004    | 9              | 47 | 30.52159 | 0.0004    | 80.2356              | 0.0012    |
| PTAC    | 125             | 0  | 15.2288  | 0.0003    | 11             | 14 | 59.61555 | 0.0003    | 79.7146              | 0.0009    |
| PTAG    | 121             | 2  | 26.75162 | 0.0004    | 14             | 32 | 7.59092  | 0.0004    | 86.6459              | 0.0013    |
| PTGO    | 124             | 45 | 18.10562 | 0.0004    | 8              | 31 | 33.32296 | 0.0004    | 91.5511              | 0.0015    |
| PTGY    | 120             | 56 | 17.82791 | 0.0004    | 14             | 6  | 1.00952  | 0.0004    | 715.3913             | 0.0011    |
| PTLC    | 120             | 35 | 13.69049 | 0.0003    | 15             | 28 | 28.58092 | 0.0003    | 112.3181             | 0.0007    |
| PTUG    | 121             | 45 | 10.58292 | 0.0003    | 17             | 39 | 36.49337 | 0.0004    | 84.3775              | 0.0009    |
| PURD    | 120             | 34 | 32.20442 | 0.0004    | 16             | 0  | 15.10586 | 0.0004    | 80.394               | 0.0011    |
| PZAM    | 122             | 3  | 54.15203 | 0.0004    | 6              | 55 | 43.13815 | 0.0004    | 84.2128              | 0.0017    |
| SEG1    | 102             | 43 | 55.28119 | 0.0003    | 2              | 29 | 10.6738  | 0.0003    | 28.5014              | 0.0009    |
| T430    | 114             | 8  | 17.53964 | 0.0005    | 22             | 29 | 40.98851 | 0.0005    | 41.2824              | 0.0015    |
| TASH    | 72              | 13 | 22.42029 | 0.0006    | 41             | 20 | 51.84369 | 0.0005    | 569.5916             | 0.0013    |
| TLOH    | 102             | 25 | 9.72593  | 0.0004    | 3              | 26 | 58.01765 | 0.0004    | 56.9913              | 0.0013    |
| TON_    | 76              | 59 | 40.18223 | 0.0006    | 42             | 7  | 5.38175  | 0.0005    | 1772.893             | 0.0011    |

| Station | LONGITUDE (DMS) |    |          | 1 std (m) | LATITUDE (DMS) |    |          | 1 std (m) | ELLIPSOID HEIGHT (m) | 1 std (m) |
|---------|-----------------|----|----------|-----------|----------------|----|----------|-----------|----------------------|-----------|
| UB01    | 106             | 54 | 31.69105 | 0.0004    | 47             | 55 | 16.82565 | 0.0006    | 1277.877             | 0.0011    |
| UMAS    | 110             | 25 | 28.92486 | 0.0004    | 1              | 28 | 5.91123  | 0.0004    | 51.3572              | 0.0013    |
| UMSS    | 116             | 6  | 43.31945 | 0.0007    | 6              | 2  | 21.23399 | 0.0005    | 76.3196              | 0.0025    |
| USMP    | 100             | 18 | 14.54232 | 0.0004    | 5              | 21 | 28.03093 | 0.0004    | 19.8442              | 0.0014    |
| VITE    | 102             | 30 | 56.128   | 0.0017    | 18             | 1  | 31.84579 | 0.0018    | 192.3817             | 0.0082    |
| VUNT    | 107             | 8  | 44.08936 | 0.0004    | 10             | 23 | 46.00941 | 0.0004    | 14.3653              | 0.0013    |
| XEKG    | 106             | 43 | 12.34245 | 0.0008    | 15             | 20 | 32.97388 | 0.0008    | 129.4008             | 0.0033    |

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