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EFFECT OF USING DIFFERENT SATELLITE EPHEMERIDES ON GPS PPP AND POST PROCESSING TECHNIQUES

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Abstract. The orbital error is one of the errors in GPS which affect the accuracy of GPS positioning. In this research GPS broadcast, ultra-rapid, rapid and precise satellite ephemerides are used for processing different baseline lengths among some CORS stations by using the Trimble Business Center software (TBC) and different satellite ephemerides (NRCan ultra-rapid, NRCan rapid and IGS final) are tested in CSRS-PPP online application at the same CORS stations.
In this research, when using TBC software for processing the different baseline lengths by using the different satellite ephemerides and compared the coordinates of CORS stations which obtained from the different satellite ephemerides with each other. The results showed that the best satellite ephemerides closest to rapid and final satellite ephemerides are the ultra-rapid (00 UTC) and ultra-rapid (06 UTC). When processing the same CORS stations which used at TBC on CSRS-PPP online application by using the different satellite ephemerides it is found also that the NRCan ultra-rapid closest to final satellite ephemerides.

Keywords: Trimble Business Center software (TBC), Continuously Operating Reference Stations (CORS), Differential Global Positioning System (DGPS), Precise Point Positioning (PPP), Coordinated Universal Time (UTC).

Introduction

The accuracies to compute the positioning are various depending on the employed GPS error mitigation methods. The DGPS can provide mm to cm level accuracy because most errors can be removed from the differential process between receivers. However, when using the single receiver, PPP has to separately consider all GPS errors, in order to obtain comparable positioning accuracy as DGPS (Shi, 2012).

There are three forms of IGS orbit combination solutions are ultra-rapid, rapid, and final (precise). For real-time and near real-time applications the ultra-rapid product is useful and available at regular intervals four times per day. The ultra-rapid solution comprises both observed and predicted satellite orbits (National Aeronautics and Space Administration [NASA], n.d.-a). In April 2000, IGS began to give sub daily IGU–GPS combined orbit products to the world at 00:00 and 12:00 UTC each day. Since GPS week 1267, IGS shortened the update cycle to 6 hours by adding 06:00 and 18:00 UTC. Each IGU orbit file contains the observed orbits for the first 24 hours and the predicted orbits for the next 24 hours (Geng et al., 2018).

The IGS Rapid products have a quality nearly comparable to that of the final (precise) products. They are available on a daily basis with a delay of about 17 h after the end of the previous observation day, i.e., IGS Rapid products are released daily at about 17:00 UTC. The IGS final (precise) products have the highest quality and internal consistency of all IGS products, they are available on a weekly basis, by each Friday, with a delay up to 13 (for the last day of the week) to 20 (from the first day of the week) days (International GNSS Service, n.d.).

The Natural Resources Canada (NRCan) is the one of the seven International GPS Service for Geodynamics (IGS) Analysis Centers providing independent computation of GPS satellite orbits, clocks and Earth Orientation Parameters (EOP). The precise satellite orbits and clocks have been generated at NRCan using the Jet Propulsion Laboratory (JPL) GIPSY-OASIS II software since August 1992 (Huot et al., 1997).

1. Study area and data sources

The CORS stations which are used in the study area are (BSHM, RAMO, DRAG, NIZN, NICO. DYNG, ISTA,

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IZMI and TUBI), see Figure 1. The observation data are obtained on 13 August 2020.

The observation files of the nine used CORS stations are downloaded from SOPAC (n.d.-a).

The fixed coordinates of the NICO CORS station, which is used in TBC software is obtained from SOPAC (n.d.-b).

The different satellite ephemerides which are used for processing the different baseline lengths at TBC software are obtained from NASA (n.d.-b).

The CSRS-PPP online application for processing the CORS stations is used from Government of Canada (n.d.-b).

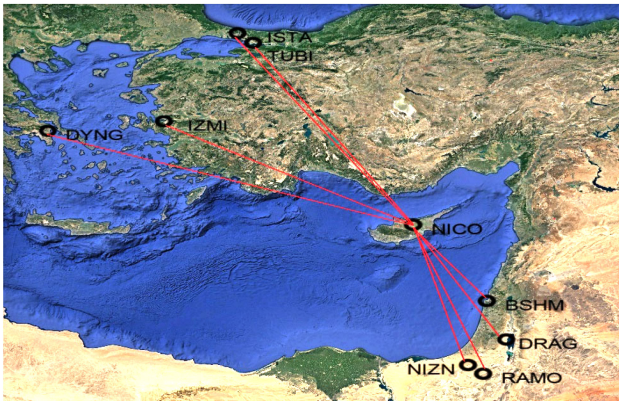

Figure 1. Shows the used CORS stations

2. PPP technique versus relative positioning

In surveying applications which needed high accuracy, the GNSS users prefer relative positioning method. The methods of GNSS depending on relative positioning principle require simultaneous observations occupied at least one reference station whose coordinates are well known. Therefore, minimum two receivers should be used in surveys: one receiver occupied the reference station and the other occupied the point whose coordinates will be determined. The baseline length between two receivers and the observation duration are the primary factors for point positioning accuracy (Ocalan et al., 2016).

The PPP technique is an absolute positioning technique, which gives cm or dm level point accuracy in static or kinematic mode depending on observation duration with a dual-frequency receiver. The PPP uses undifferenced ionospheric-free both carrier-phase (Φ) and code pseudorange (P) observations collected by a dual-frequency receiver for data processing. The PPP technique introduces precise positioning by using precise ephemerides and clock products provided by IGS and other organizations and by considering other corrections such as satellite effects (satellite antenna offsets and phase wind-up), site displacement effect (solid earth tides, polar tides, ocean loading, earth rotation parameters) and compatibility considerations (products formats, reference frames, receiver antenna phase centre offsets, modelling/observation conventions) (Ocalan et al., 2013).

3. GPS error sources

The contributing sources that degrade the performance of accurate GPS position solution include: Earth's atmosphere, satellite clock and orbit errors, geometry of the constellation, radio frequency interference, multipath signals, and receiver clock error (Barchesky, 2011).

4. Satellite ephemerides

The ephemerides products which needed for the real-time applications are broadcast ephemerides and the IGS ultra-rapid (predicted-half), while the IGS rapid and final (precise) products aim for post-processing applications. According to the IGS official website, the nominal accuracies of broadcast orbits are reported as ~1 m. The two types of ultra-rapid products are generated by IGS, one of which is observed-half with 3~9 hours latency and the other is predicted-half without latency. The nominal accuracy of ultra-rapid observed-half and predicted-half orbits are reported as 3 cm and ~5 cm, respectively. The nominal accuracies of final (precise) and rapid orbits are reported as ~2.5 cm (Ogutcu, 2020).

5. CSRS-PPP web-based service

The CSRS-PPP is an online application for GNSS data post-processing allowing users to compute higher accuracy positions from their raw observation data. The CSRS-PPP computes the coordinates on reference frame NAD83 or ITRF 2014 (Government of Canada, n.d.-a). Canadian Spatial Reference System (CSRS) PPP service is presented by Natural Resources Canada's Canadian Geodetic Survey. The NRCAN CSRS-PPP service uses single or dual-frequency GPS and GLONASS data for solution computation and supports both Static and Kinematic modes, depending on the accuracy level and time that is required to get the solution. The NRCAN CSRS-PPP service can calculate the data in the following modes: Final (precise): The accuracy approximately 2 cm, available 13–15 days after the end of the week, Rapid: The accuracy approximately 5 cm, available the next day and Ultra-rapid: The accuracy approximately 15 cm, available every 90 minutes (Emlid, n.d.).

6. Methodology

Firstly, using the TBC software to determine the coordinates for all CORS stations for all different baseline lengths by fixing the NICO IGS station and determine the coordinates for the remaining CORS stations on ITRF2008. The following are the approximate lengths of baselines NICO-BSHM is 302.034 km, NICO-DRAG is 435.008 km, NICO-NIZN is 481.633 km, NICO-RAMO is 519.734 km, NICO-IZMI is 668.950 km, NICO-TUBI is 715.626 km, NICO-ISTA is 764.456 km and NICO-DYNG is 906.015 km.

Determine the difference in coordinates (dX, dY, dZ) between the coordinates obtained by using Broadcast, Ultra-Rapid, Rapid and Precise GPS satellite ephemerides.

Secondly, using the CSRS-PPP online application to compute the positions for all CORS stations in the study area on ITRF2014 by using NRCan Ultra-rapid, NRCan rapid and IGS final satellite ephemerides. Determine the difference in coordinates (dX, dY, dZ) between the coordinates obtained by using NRCan Ultra-rapid, NRCan rapid and IGS final satellite ephemerides for each station.

7. Results

In processing the baselines by using Trimble Business Centre software (TBC), using the broadcast satellite ephemerides, the baselines which are less than 500 km got a fixed solution while the baselines that have more than 500 km length got float solutions. Additionally, all different baselines obtained fixed solutions when using all remaining satellite ephemerides.

When processing the different baseline lengths by using TBC software, all coordinates which obtained by using final (precise) satellite ephemerides have the same coordinates by using rapid satellite ephemerides, see Table 1.

In the case that baseline lengths of less than 300 km, the maximum difference in coordinates between using broadcast and using (ultra-rapid, rapid and final (precise)) satellite ephemerides is 20 mm, see Tables 2–6.

In the case that baseline lengths range from 300 to 500 km, the maximum difference in coordinates between using broadcast and using (ultra-rapid, rapid and final (precise)) satellite ephemerides is 38 mm, see Tables 2–6.

In the case that baseline lengths larger than 500 km the maximum difference in coordinates between using broadcast and using (ultra-rapid, rapid and final (precise)) satellite ephemerides is 1450 mm see Tables 2–6.

Table 1. The difference in coordinates between using Rapid and using Final (Precise) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	0	0	0
DRAG	0	0	0
NIZN	0	0	0
RAMO	0	0	0
IZMI	0	0	0
TUBI	0	0	0
ISTA	1	0	0
DYNG	0	0	0

Table 2. The difference in coordinates between using Broadcast and using Ultra-Rapid (00 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	15	18	9
DRAG	32	31	16
NIZN	32	20	4
RAMO	– 312	228	310
IZMI	0	39	–6
TUBI	–1448	346	–1056
ISTA	–701	551	301
DYNG	31	98	–92

Table 3. The difference in coordinates between using Broadcast and using Ultra-Rapid (06 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	18	20	11
DRAG	33	32	15
NIZN	31	20	3
RAMO	–310	228	310
IZMI	3	42	–2
TUBI	–1447	348	–1053
ISTA	–703	552	303
DYNG	28	98	–93

Table 4. The difference in coordinates between using Broadcast and using Ultra-Rapid (12 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	15	17	10
DRAG	38	33	17
NIZN	36	22	7
RAMO	–314	225	306
IZMI	5	42	–3
TUBI	–1438	351	–1046
ISTA	–695	556	308
DYNG	32	101	–88

Table 5. The difference in coordinates between using Broadcast and using Ultra-Rapid (18 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	16	17	8
DRAG	37	33	19
NIZN	37	24	7
RAMO	–312	226	309
IZMI	1	40	–5
TUBI	–1442	350	–1049
ISTA	–702	552	303
DYNG	34	98	–87

Table 6. The difference in coordinates between using Broadcast and using Rapid and Final (Precise) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	15	18	7
DRAG	31	33	12
NIZN	26	18	–2
RAMO	–311	228	306
IZMI	–1	40	–7
TUBI	–1450	346	–1057
ISTA	–703	552	298
DYNG	25	99	–97

In the baseline lengths less than 300 km it was the maximum difference in coordinates between using ultra-rapid (00 UTC) and using ((remaining ultra-rapid), rapid and final (precise)) satellite ephemerides is 3 mm see Tables 7–10.

In the baseline lengths that ranges from 300 km to 500 km it was the maximum difference in coordinates between using ultra-rapid (00 UTC) and using ((remaining ultra-rapid), rapid and final (precise)) satellite ephemerides is 6 mm see Tables 7–10.

In the baseline lengths larger than 500 km it was the maximum difference in coordinates between using ultra-rapid (00 UTC) and using ((remaining ultra-rapid), rapid and final (precise)) satellite ephemerides is 10 mm see Tables 7–10.

Table 7. The difference in coordinates between using Ultra-Rapid (00 UTC) and using Ultra-Rapid (06 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	3	2	2
DRAG	1	1	–1
NIZN	–1	0	–1
RAMO	2	0	0
IZMI	3	3	4
TUBI	1	2	3
ISTA	–2	1	2
DYNG	–3	0	–1

Table 8. The difference in coordinates between using Ultra-Rapid (00 UTC) and using Ultra-Rapid (12 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	0	–1	1
DRAG	6	2	1
NIZN	4	2	3
RAMO	–2	–3	–4
IZMI	5	3	3
TUBI	10	5	10
ISTA	6	5	7
DYNG	1	3	4

Table 9. The difference in coordinates between using Ultra-Rapid (00 UTC) and using Ultra-Rapid (18 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	1	–1	–1
DRAG	5	2	3
NIZN	5	4	3
RAMO	0	–2	–1
IZMI	1	1	1
TUBI	6	4	7
ISTA	–1	1	2
DYNG	3	0	5

Table 10. The difference in coordinates between using Ultra-Rapid (00 UTC) and using Rapid and Final (Precise) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	0	0	– 2
DRAG	–1	2	–4
NIZN	–6	–2	–6
RAMO	1	0	–4
IZMI	–1	1	–1
TUBI	–2	0	–1
ISTA	–2	1	–3
DYNG	–6	1	–5

In the baseline lengths less than 300 km it was the maximum difference in coordinates between using ultra-rapid (06 UTC) and using ((remaining ultra-rapid), rapid and final (precise)) satellite ephemerides is 4 mm, see Tables 11–13.

In the baseline lengths that ranges from 300 km to 500 km it was the maximum difference in coordinates between using ultra-rapid (06 UTC) and using ((remaining ultra-rapid), rapid and final (precise)) satellite ephemerides is 6 mm, see Tables 11–13.

In the baseline lengths larger than 500 km it was the maximum difference in coordinates between using ultra-rapid (06 UTC) and using ((remaining ultra-rapid), rapid and final (precise)) satellite ephemerides is 9 mm, see Tables 11–13.

In the baseline lengths less than 300 km it was the maximum difference in coordinates between using ultra-rapid (12 UTC) and using ultra-rapid (18 UTC), rapid and final (precise) satellite ephemerides is 3 mm, see Tables 14 and 15.

In the baseline lengths that ranges from 300 km to 500 km it was the maximum difference in coordinates between using ultra-rapid (12 UTC) and using ultra-rapid (18 UTC), rapid and final (precise) satellite ephemerides is 10 mm, see Tables 14 and 15.

In the baseline lengths larger than 500 km it was the maximum difference in coordinates between using ultra-rapid (12 UTC) and using ultra-rapid (18 UTC), rapid and final (precise) satellite ephemerides is 12 mm, see Tables 14 and 15.

In the baseline lengths less than 300 km it was the maximum difference in coordinates between using ultra-rapid (18 UTC) and using rapid and final (precise) satellite ephemerides is 1 mm, see Table 16.

In the baseline lengths that ranges from 300 km to 500 km it was the maximum difference in coordinates between using ultra-rapid (18 UTC) and using rapid and final (precise) satellite ephemerides is 11 mm, see Table 16.

In the baseline lengths larger than 500 km it was the maximum difference in coordinates between using ultra-rapid (18 UTC) and using rapid and final (precise) satellite ephemerides is 10 mm, see Table 16.

In the Tables 2–16 which obtained by using TBC software, the difference in coordinates (dX, dY, dZ) between using different ultra-rapid and using (rapid and final (precise)) satellite ephemerides at different baseline lengths (less than 300 km, from 300 km to 500 km and larger than 500 km) are (2, 4 and 6 mm) by using ultra-rapid (00 UTC), (4, 3 and 5 mm) by using ultra-rapid (06 UTC), (3, 7 and 12 mm) by using ultra-rapid (12 UTC) and (1, 7 and 11 mm) by using ultra-rapid (18 UTC).

Table 11. The difference in coordinates between using Ultra-Rapid (06 UTC) and using Ultra-Rapid (12 UTC) GPS satellite ephemerides by using TBC software

Stations	dX(mm)	dY (mm)	dZ (mm)
BSHM	–3	–3	–1
DRAG	5	1	2
NIZN	5	2	4
RAMO	–4	–3	–4
IZMI	2	0	–1
TUBI	9	3	7
ISTA	8	4	5
DYNG	4	3	5

Table 12. The difference in coordinates between using Ultra-Rapid (06 UTC) and using Ultra-Rapid (18 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	–2	–3	–3
DRAG	4	1	4
NIZN	6	4	4
RAMO	–2	–2	–1
IZMI	–2	–2	–3
TUBI	5	2	4
ISTA	1	0	0
DYNG	6	0	6

Table 13. The difference in coordinates between using Ultra-Rapid (06 UTC) and using Rapid and Final (Precise) GPS satellite ephemerides by using TBC software

Stations	dX(mm)	dY (mm)	dZ (mm)
BSHM	–3	–2	–4
DRAG	–2	1	–3
NIZN	–5	–2	–5
RAMO	–1	0	–4
IZMI	–4	–2	–5
TUBI	–3	–2	–4
ISTA	0	0	–5
DYNG	–3	1	–4

Table 14. The difference in coordinates between using Ultra-Rapid (12 UTC) and using Ultra-Rapid (18 UTC) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	1	0	–2
DRAG	–1	0	2
NIZN	1	2	0
RAMO	2	1	3
IZMI	–4	–2	–2
TUBI	–4	–1	–3
ISTA	–7	–4	–5
DYNG	2	–3	1

Table 15. The difference in coordinates between using Ultra-Rapid (12 UTC) and using Rapid and Final (Precise) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	0	1	–3
DRAG	–7	0	–5
NIZN	–10	–4	–9
RAMO	3	3	0
IZMI	–6	–2	–4
TUBI	–12	–5	–11
ISTA	–8	–4	–10
DYNG	–7	–2	–9

Table 16. The difference in coordinates between using Ultra-Rapid (18 UTC) and using Rapid and Final (Precise) GPS satellite ephemerides by using TBC software

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	–1	1	–1
DRAG	–6	0	–7
NIZN	–11	–6	–9
RAMO	1	2	–3
IZMI	–2	0	–2
TUBI	–8	–4	–8
ISTA	–1	0	–5
DYNG	–9	1	–10

By using the CSRS-PPP online application for processing the CORS stations using the different satellite ephemerides. The following results obtained:

- The maximum difference in coordinates (dX, dY, dZ) for all CORS stations between using NRCan ultra-rapid and using NRCan rapid satellite ephemerides is 8 mm, see Table 17.
- The maximum difference in coordinates (dX, dY, dZ) for all CORS stations between using NRCan ultra-rapid and using final (precise) satellite ephemerides is 3 mm, see Table 18.
- The maximum difference in coordinates (dX, dY, dZ) for all CORS stations between using NRCan rapid and using final (precise) satellite ephemerides is 8 mm, see Table 19.

Table 17. The difference in coordinates between using NRCan Ultra-rapid and using NRCan rapid satellite ephemerides by using CSRS-PPP online application

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	5	5	4
DRAG	5	5	5
NIZN	5	5	5
RAMO	5	5	4
IZMI	5	3	4
TUBI	8	5	7
ISTA	4	3	4
DYNG	5	3	4

Table 18. The difference in coordinates between using NRCan Ultra-rapid and using Final (Precise) satellite ephemerides by using CSRS-PPP online application

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	1	2	0
DRAG	2	3	1
NIZN	1	3	1
RAMO	1	2	0
IZMI	2	2	0
TUBI	0	1	–1
ISTA	1	1	0
DYNG	2	2	1

Table 19. The difference in coordinates between using NRCan rapid and using Final (Precise) satellite ephemerides by using CSRS-PPP online application

Stations	dX (mm)	dY (mm)	dZ (mm)
BSHM	–4	–3	–4
DRAG	–3	–2	–4
NIZN	–4	–2	–4
RAMO	–4	–3	–4
IZMI	–3	–1	–4
TUBI	–8	–4	–8
ISTA	–3	–2	–4
DYNG	–3	–1	–3

Conclusions

The results obtained from all CORS stations in this research by using IGS rapid and final orbit has the same values, these results are identical to the International GNSS Service (IGS) website, since the accuracies of rapid and final orbit are equal.

It is possible to use other satellite ephemeris in the post processing instead using IGS rapid and final satellite ephemerides. This is clear from the results, whereas by using the ultra-rapid (00 UTC) or ultra-rapid (06 UTC) satellite ephemeris for processing the different baseline lengths the results obtained from uses these orbits are close to the results obtained by using rapid and final (precise) satellite ephemerides.

In CSRS-PPP online application the coordinates which obtained by using NRCan ultra-rapid are closest to the coordinates obtained by using the final (precise) satellite ephemerides compared to the coordinates obtained by using NRCan rapid satellite ephemerides. So, it is possible to obtain coordinates by using NRCan ultra-rapid satellite ephemerides instead of waiting for using final (precise) satellite ephemerides.

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