Real-time kinematic positioning with NASA's Internet-based Global Differential GPS (IGDG).

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Abstract

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The Global Differential GPS (GDGPS) system developed by JPL aims at seamless global real-time positioning at the dm accuracy level for dual-frequency receivers either static or mobile, anywhere and at any time. The GDGPS system relies on GPS data transmitted in real-time to a central processing center at JPL from a global network of permanently operating GPS dual-frequency receivers. At the processing center, the Internet-based Global Differential GPS (IGDG) system, the heart of JPL's GDGPS, generates and disseminates over the open Internet special 1-second global differential corrections (IGDG corrections) to the GPS broadcast ephemerides. The IGDG corrections enhance the accuracy of GPS broadcast orbits and clocks down to the dm level and are the key-factor in high-precise real-time positioning of a stand-alone receiver. An independent experimental verification of the dm positional accuracy of IGDG system was carried out, by means of both a static and a kinematic test in the Netherlands.

In the static test, the means of the position coordinates, taken over individual days of data, agree with the known reference at the 1-2 cm level confirming that the IGDG position solutions are free of systematic biases. The standard deviation of individual real-time position solutions turned out to be 10 cm for the horizontal components and 20 cm for the vertical component.

In the kinematic test, carried out with a small boat, the means of coordinate differences with an accurate ground-truth trajectory, are at 1-2 dm level over the almost 3 hour period; the standard deviations of individual positions were similar to values found in the static test, 10 cm for the horizontal components, and 20 cm for the vertical component. More than 99% of the IGDG-corrections were received in the field with the nominal interval of 1 second, using a GPRS cellular phone. The latency of the corrections was generally 7 to 8 seconds.

Introduction

The Jet Propulsion Laboratory (JPL) of the National Aeronautics Space Administration (NASA) set out to develop a new Global Differential GPS (GDGPS) in Spring 2001. Compared with traditional Differential GPS (DGPS) services, the position accuracy improves by almost one order of magnitude. An accuracy of 10 cm horizontal and 20 cm vertical is claimed for kinematic applications, anywhere on the globe, and at any time. This level of position accuracy is very promising for precise navigation of vehicles on land, vessels and aircraft, and for Geographic Information System (GIS) data collection, for instance with construction works and maintenance of infrastructure.

Differential GPS (DGPS) originated from the idea of positioning a second receiver (rover) with respect to a reference station. Initially, a DGPS system consisted of one reference station and one or more mobile receivers in a local area. Later, the service area of DGPS was extended from local to regional or national, and even to the continental scale with Wide-Area Differential GPS (WADGPS) systems such as the Wide-Area Augmentation

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System developed by U.S. Federal Aviation Administration, and the European Geostationary Navigation Overlay Service (EGNOS). GDGPS is regarded to be the further extension of Differential GPS to the global scale, capable of seamless positioning all over the world with dm positional accuracy. The most important feature of the GDGPS is a state-space approach, providing corrections to the GPS satellite orbits and clocks, but not to measurements, as in the traditional DGPS, see [1]. This guarantees global and uniform validity of the corrections.

The Internet-based Global Differential GPS (IGDG) system produces and subsequently disseminates corrections to the broadcast ephemerides. IGDG can be considered as a realization of the concept of Precise Point Positioning (PPP), see [2]. Instead of positioning relative to a reference station or using a network, the idea was to take advantage of precise GPS satellite orbit and clock solutions for single receiver positioning. These products are the key to stand-alone precise positioning with eventually centimeter-precision.

An independent experimental verification of JPL’s IGDG has been carried out at the Delft University of Technology in the Netherlands, in cooperation with the Ministry of Transport, Public Works and Water Management, Geo-Information and ICT Department. The verification consisted of extensive stationary tests at a well-surveyed reference marker in Delft, and of a kinematic test using a small boat on a Dutch canal. The purpose of these tests was to verify, under practical circumstances, the real-time positioning accuracy of IGDG, as well as the availability and latency of the corrective information.

After a description of the experimental set up, we will present in this paper positioning results and statistical analyses of both the static and kinematic test. Finally, we will demonstrate the results of a qualitative analysis of the IGDG differential corrections. The purpose was to ascertain the capability of the IGDG corrective information to improve the accuracy of the broadcast GPS orbits and clocks down to the decimeter level.

1. Internet-based Global Differential GPS

Precise satellite orbits and clocks at the global level are provided by the International GPS Service [3]. The IGS clocks and orbits are combinations of the individual solutions obtained by the different analysis centers and are very robust. IGS final orbit and clock solutions have a latency of 2 weeks, IGS rapid products of about 1 day, and ultra-rapid orbits are available twice each day. At present, the process of determination and dissemination of these products is moving towards near real-time execution. The availability of satellite orbit and clock solutions at decimeter accuracy, in real-time, enables Global Differential GPS.

A subset of some 40 reference stations of NASA's Global GPS Network (GGN) allows for real-time streaming of data to a processing center, that determines and subsequently disseminates over the open Internet, in real-time, precise satellite orbits and clocks errors, as global differential corrections to the GPS broadcast ephemerides (as contained in the GPS navigation message). An introduction to IGDG can be found in [1] and [4]. Technical details are given in [5] and [6].

Internet-based users can simply download the low-bandwidth correction data stream into a computer, where it will be combined with raw data from the user's GPS receiver. The final, but critical element in providing an end-to-end positioning and orbit determination capability is the user's navigation software. In order to deliver 10 cm real-time positioning accuracy the software must employ most accurate models for the user's dynamics and the GPS measurements. For terrestrial applications these models include corrections for Earth tides, periodic relativity effect, and phase wind-up, see the review in [7]. The end-user version of the Real-Time Gipsy (RTG) software employs, in addition to these models, powerful estimation techniques for optimal positioning or orbit determination, including stochastic modelling, estimation of tropospheric delay, continuous phase smoothing and reduced dynamics estimation with stochastic attributes for every parameter.

Results of static post-processing precise point positioning are shown in, for instance, the articles [7] and [8]. Similarly, [9] evaluates JPL’s automated GPS data analysis service. Furthermore, kinematic post-processing point positioning results can be found e.g. in [10]. All the above examples, and also the results in the present contribution, rely on geodetic grade *dual-frequency* receivers.

2. Data processing

In this paper we used GIPSY-OASIS II software, but not Real-Time Gipsy for the processing. Though the data of the tests were processed after data collection (post-processing), *real-time* operation was emulated. Epochs of data were processed sequentially and intermediate results (epoch after epoch) were used for the analysis.

The GIPSY-OASIS II software, which stands for GPS Inferred Positioning System and Orbital Analysis and Simulation System [11], has been used for processing the data of both the static and kinematic experiment. Ionospheric-free combinations of dual-frequency GPS pseudorange code and carrier phase measurements were taken as basic observables. The whole set of parameters being determined with GIPSY consisted of the coordinates of the receiver's antenna, phase ambiguities, receiver clock errors, wet zenith delays and troposphere gradients. The gradient parameters were included by default into the list of unknowns. However, as can be expected, for this kind of application it turned out not to be necessary to estimate gradients. The coordinates as well as the clock errors are modelled as white noise processes, phase ambiguities are considered as constant float numbers, and troposphere parameters are modelled as random walk with a random walk sigma of $10.2\mathrm{mm}/\sqrt{\mathrm{h}}$ for the wet zenith delays and of $0.3\mathrm{mm}/\sqrt{\mathrm{h}}$ for the troposphere gradients (the GIPSY default values). The process noise for the coordinates of the receiver's antenna was 1m in the static test, and 100 m in the kinematic test. The value of 100 m in the kinematic test was chosen in order to accommodate for dynamics of the boat and avoid possible divergence problems. By default a 15 degrees satellite elevation cut-off angle was used for data processing in the static test, and 10 degrees in the kinematic test.

3. Static test

During Autumn 2002, a geodetic dual-frequency receiver, an Ashtech Z-XII3 with a choke-ring antenna, was installed on a reference marker with accurately known position coordinates, see figure 1.

Figure 1: The Ashtech choke-ring antenna, with conical radome, installed on the observation platform of the (formerly) TU Delft building for Geodesy, for the static test. This site, about 30 meters above ground level, offers unobstructed visibility of the sky, down to the horizon. The satellite elevation cut-off angle was maintained at 10 degrees during the measurements (elevation cut-off angle for the data processing was 15 degrees).

Continuous GPS measurements are carried out, on a neighbouring marker at this site, and these data are being used on a weekly basis as a part of the EUREF Permanent Network (EPN) [12]. The position of this marker is well known in ITRF2000. The local tie to the marker used for the static test is accurately known from earlier surveys and were independently verified for this test. Thereby, accurate reference coordinates in ITRF2000, at the epoch of observation, were available for the static test.

Data were collected for five consecutive days at a 1 second interval. All 5 × 24 hours were processed in batches of 3 hours (the filter was restarted each 3 hours with the next data file) using JPL's GIPSY software, in kinematic mode, though the receiver was actually stationary. For the static test computations, the wet troposphere was estimated as a constant parameter over a 3-hour time span (one parameter per each batch); the troposphere gradients were estimated stochastically with a (small) random walk sigma of $0.3\text{mm}/\sqrt{\text{h}}$. At the same time, as additional experiments showed, exclusion of the troposphere gradients from the list of unknown (stochastic) parameters did not change significantly the results of the Ashtech antenna kinematic positioning.

Accuracy

Table 1 demonstrates the mean and standard deviation of the position differences with the known reference at 1 second interval, on all five days. The means of the position coordinates taken over each time one day of data do agree with the known reference at the 1-2 cm level in ITRF2000. The IGDG position solutions appeared to be really free of systematic biases. The standard deviations of individual real-time position solutions turned out to be 10 cm for the horizontal components and 20 cm for the vertical component. This agrees with earlier claims on IGDG position accuracy.

day	North		East		Height	
	mean	stdev	mean	stdev	mean	stdev
1	1.7	10.1	-1.7	10.4	-0.5	21.4
2	-0.4	8.8	0.7	8.1	-5.5	16.2
3	-2.0	9.5	1.1	7.0	-0.8	19.1
4	2.9	12.9	-1.3	11.0	-0.8	22.7
5	0.9	8.7	0.4	6.7	0.7	18.6

Table 1: Mean and standard deviation of position differences, in centimeter, in static test.

During the day, the number of satellites above the 15 degrees elevation cut-off angle was usually in the range from 5 through 8; there were a few periods with only the minimum of 4 satellites. Over the day, two periods occurred with only 4 satellites for which the PDOP exceeded the value of 10. In these cases the standard deviation values rose up to 40-50 cm, in particular for the vertical. Also, it was found that frequent changes in the satellite configuration (satellites disappearing, new satellites showing up) may lead to deteriorated positioning performance.

Because we started the filtering process for every 3-hour data batch with the same position uncertainty and initial receiver position, the Kalman filter required some time to 'stabilize' the position estimates. This circumstance was used to evaluate the filter convergence time in the static test. Analyses of the positioning results showed that almost complete convergence was reached in the first few seconds after the initial epochs, even if deviations of the position estimates were large in magnitude (the deviations exceeded the 1-m level at maximum).

Final orbit and clock products

Though only *real-time* satellite orbit and clock products are relevant to navigation applications, comparison of the positioning results with those obtained on the basis of *final* orbit and clock products, gives a first impression of the quality of the real-time products. The data of day 4 and 5 of the static test were used, and a 5 minutes sampling interval was taken, in order to basically avoid interpolation effects (with the orbits and clocks). Table 2 gives the standard deviations of the coordinate differences, in North, East and Height. Avoiding interpolation effects (columns real-time) causes a factor of 2 reduction in the standard deviation (cf. table 1), and using the final products (three columns at right) yields again a factor 2 of improvement.

	real-time			final		
day	North	East	Height	North	East	Height
4	5.4	5.2	9.0	3.0	2.9	4.8
5	4.6	4.6	8.7	2.6	2.9	4.2

Table 2: Standard deviation of position differences at 5 minutes interval, in centimeter, in static test, using real-time orbits and clocks at left, and using final orbits and clocks at right.

4. Kinematic test

The kinematic test was carried out during Spring 2003. With a small boat, see figure 2, a 2 km stretch on the Schie-canal was sailed repeatedly. A dual-frequency Ashtech Z-XII3 receiver, connected to an Ashtech choke-ring antenna, was used on the boat for the kinematic test. A trajectory of almost 3 hours was observed, again at a

1 second interval. There were 8 to 10 satellites above the 10 degrees elevation cut-off angle and these were consequently used in the position solution (apart from two short periods with 7 satellites).

For the purpose of computing an accurate reference trajectory for the on-board receiver, the site and equipment of the static test served as a local reference station (about 3-5 km away). In-house software was used to compute the dual frequency carrier phase, ambiguity fixed, solution, using the data of both the stationary reference and the rover on the boat in a classical short-baseline model. The resulting trajectory in ITRF2000 at the epoch of observation, possesses cm accuracy, and is thereby one order of magnitude more accurate than the IGDG solution, consequently serving as the ground-truth.

Figure 2: The boat used for the kinematic test on the Schie-canal between Delft and Rotterdam in the Netherlands.

Position accuracy

Differences, in North, East and Height, of the filtered position estimates for the Ashtech receiver on the boat with the ground-truth trajectory are shown in figure 3. One can note a peak in the Height component, between 9:40 and 9:50. The peak is most likely caused by a deviating clock error estimate for one of the satellites in the JPL real-time ephemerides at epoch 9:45. Additional tests showed that removing GPS measurements throughout the 10-min time span between 9:40 and 9:50 for SVN15 had a major impact on the behaviour of the Height component, the deviation was reduced by approximately a factor 2.

Table 3 gives the mean and standard deviation of the position differences in the kinematic test. Both the full period is considered, as well as the period without the 'initialization', leaving out the first 40 minutes. Examination of table 3 shows that, apart from the initialization, the standard deviations (the data sample scattering around the mean) are again 10 cm for the horizontal components and 20 cm for the vertical, but the filtered position estimates in the kinematic test appeared to be slightly biased; the means over the full test period are at 1-2 dm level.

	North		East		Height	
	mean	stdev	mean	stdev	mean	stdev
full	-5.0	19.1	13.3	18.9	-17.2	59.4
w/o init	-2.2	8.0	18.9	12.3	-24.7	20.3

Table 3: Mean and standard deviation of position differences, in centimeter, in kinematic test.

Effect of weakened satellite geometry

Because of good environment in the area of the kinematic experiment (open field, no big trees and man-made constructions nearby the channel), the visibility was quite good, and up to 10 satellites were observed simultaneously in the sky above the elevation cut-off angle of 10 degrees. As a result, we have a quite stable and strong satellite-to-user geometry (PDOP was about 2). We assessed the influence of a weakened satellite geometry on the kinematic positioning results by setting the minimal elevation angle to 15 degrees instead of 10 degrees. The accuracy estimates are given in table 4.

	North		East		Height	
	mean	stdev	mean	stdev	mean	stdev
full	-0.7	28.6	17.6	15.7	-20.4	64.9
w/o init	0.0	9.8	21.2	13.3	-22.4	32.3

Table 4: Mean and standard deviation of position differences, in centimeter, in kinematic test. Satellite cut-off elevation angle is 15 degrees.

As expected, augmentation of the minimal elevation angle weakens the satellite geometry. This immediately led to some degradation of the accuracy of the boat position estimates (cf. table 3).

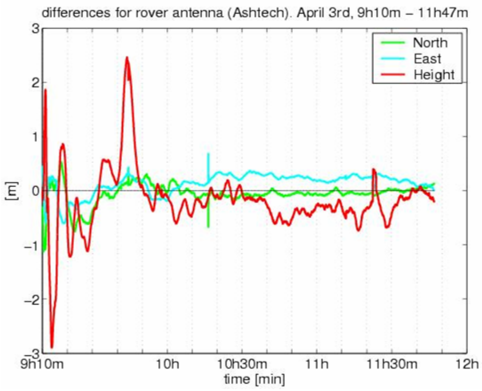

Figure 3: Coordinate time series for the receiver onboard the boat in the kinematic test corresponding to strategy B from table 5.

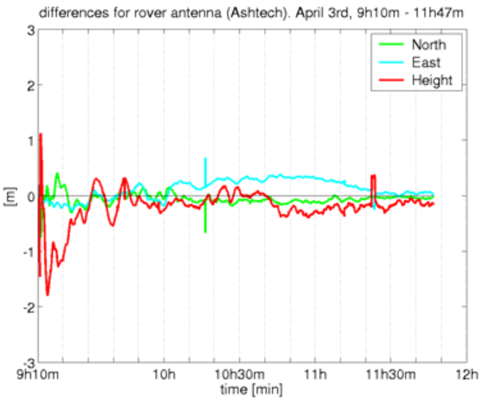

Figure 4: Coordinate time series for the receiver onboard the boat in the kinematic test corresponding to strategy A from table 5.

5. Effect of troposphere estimation on the kinematic positioning

The GIPSY-OASIS II software is able to estimate both the wet troposphere (zenith wet delays) and the troposphere gradients. These parameters are modelled as either constant (bias) parameters over a whole observation time span or stochastic parameters driven by a random process noise. Additional investigations have been made on the PPP processing strategy for kinematic data, in order to assess the impact of various strategies of troposphere estimation on filter convergence and kinematic positioning accuracy. The importance of these investigations stems from the fact that the Height component of a receiver's position, the receiver clock error and the wet zenith delay (and gradients), tend to be highly correlated. We experimented with a number of estimation strategies and selected those that demonstrated the best single receiver kinematic positioning performance. The estimation strategies we experimented with are outlined in table 5.

strategy	description
A	wet troposphere is estimated as a constant; trop. gradients are not estimated
B	both wet troposphere and trop. gradients are estimated stochastically
C	wet troposphere is estimated stochastically; trop. gradients are not estimated
D	wet troposphere is estimated as a constant; trop. gradients are estimated stochastically

Table 5: Differences between tested PPP estimation strategies.

strategy	standard deviations			convergence time
	North	East	Height	min
A	6.2	14.2	15.8	20
B	8.0	12.3	20.3	40
C	6.7	12.9	23.6	40
D	7.1	12.7	19.8	40

Table 6: Standard deviation of position differences, in centimeter (filter convergence is left out), and filter convergence time, in minutes, for the strategies described in table 5.

It is to be noted here that strategy B was used to obtain the results presented in section 4. Table 6 summarizes the kinematic positioning results obtained using these strategies. Here we confined ourselves to the standard deviations of the coordinate differences, in North, East and Height, for the period without the filter ‘initialization’. The filter convergence time (approximate value) is given in a separate column.

Examination of the results presented in table 6 shows that strategy A yielded a better Height component estimation performance and a decrease of the filter ‘initialization’ time by a factor of 2. The coordinate time series corresponding to strategy A is given in figure 4. The time series plotted in figure 3 represent strategy B.

These results suggest that the strategy used for the kinematic test data processing (strategy B) appeared to be suboptimal. Because the troposphere gradients are generally smaller than 1 cm [13], they have a minor impact on kinematic positioning results, and their estimation seems not to be necessary in case of kinematic positioning at the dm level. Besides, estimation of troposphere parameters as stochastic processes in case of single receiver precise kinematic positioning might significantly affect filter initialization and render the filtered estimates vulnerable to various error sources capable of degrading the positional accuracy (due to the large number of unknown parameters). For example, the time series corresponding to strategies B (see figure 3), C and D show peaks in the Height between 9:40 and 9:50 with a comparable magnitude of the Height component deviation. At the same time, the peak in figure 4 is also present, but the magnitude of the corresponding Height component deviation is decreased significantly.

In order to check how the convergence of the horizontal components is influenced by less accurate or erroneous initial position estimates, the initial values for the North and East position components in the kinematic experiment were artificially shifted by 10 m. This was done in order to take into account a practical situation, in which the initial horizontal position is known only approximately (e.g. obtained from a standalone GPS solution). As analysis of the results showed, the behaviour of the horizontal position component during the filter initialization demonstrated noticeable stability against the deteriorated initial position. Actually, the boat positioning results corresponding to strategy A from table 5 were almost identical to those presented in figure 4.

Despite the fact that the best kinematic positioning results were attained with a strategy without troposphere gradients estimation, according to the results demonstrated in [13], utilization of troposphere gradient models might lead to improvements in precision and accuracy for precise point positioning in a ‘true’ static case, when only one position estimate per a whole observation time span is computed.

6. IGDG corrections

Real-time precise positioning with IGDG is enabled through dissemination of corrections over the Internet. The corrections pertain to the satellite position (the rate of change of the coordinate corrections is given as well) and to the satellite clock error, and are to be applied to the information in the GPS broadcast ephemerides (navigation message). Correction messages are disseminated nominally at a 1Hz sampling rate using a 44-byte/second message and the User Datagram Protocol (UDP) as transport layer.

An example of the IGDG (position) corrections is given in figure 5. The small discontinuities in the position corrections correspond to changes in the broadcast ephemerides (GPS navigation message) that are used as a reference, and as reflected by the Issue Of Data Ephemeris (IODE). The changes (renewals) take place nominally in 2-h intervals.

Availability and latency of IGDG corrections

During the kinematic test IGDG corrections were logged in the office over the university’s network and in the field using mobile data communication by a General Packet Radio Service (GPRS) cellular phone (Nokia 6310i). A wireless Bluetooth link was established between the cellular phone and the laptop in the boat’s cabin. The laptop on the boat was equipped with Windows 98SE as an operating system. In the office a stand-alone Linux PC was used. In both cases a Perl-script was used to log the IGDG-corrections.

Availability refers to the number of (1 second epoch) correction messages received (irrespective of latency) as percentage of the number of epochs in the time span. Latency is defined here as the difference between the time of reception by the user, and the epoch of the (clock) corrections. The PC and laptop were synchronized to UTC using a secondary Network Time Protocol (NTP) timeserver. The 13 seconds difference between UTC and GPS system were accounted for.

In the field 99.05% of the messages were received with the expected interval of 1 second, only a few interruptions occurred with a maximum of 18 missing messages. In total 106 messages, out of 13008 (logged over a more than three and a half hour period), went missing. Using the Linux PC in the office, with a direct Internet access, availability reached up to 99.97%.

The latency of the corrections on the PC in the office was generally between 6 and 7 seconds. In the field, using the mobile data communication, the latency was 1 second larger, and generally between 7 and 8 seconds. Only incidentally, the latency reached up to 11 seconds in the field, see figure 6. These latencies are considered to be insignificant, because the satellite position corrections are transmitted at a one satellite per one second message rate, in cycles of 28 seconds. Therefore, the IGDG corrections performance is promising for real-time kinematic applications. It is to be noted here that the use of the corrections in real-time requires GPS clock extrapolation to an epoch of interest. According to [6], clock extrapolation error for latencies of less than 6 seconds is under 1 cm.

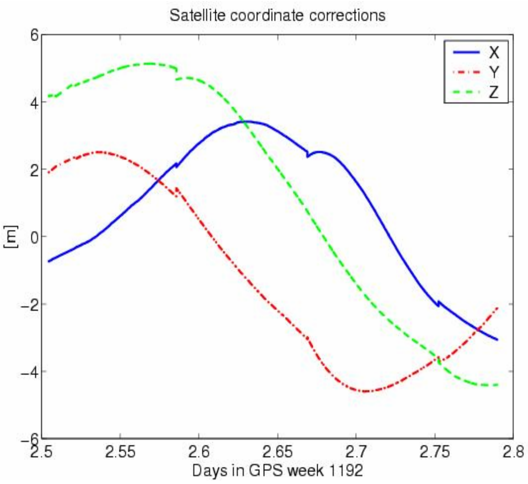

Figure 5: Position coordinate corrections for SVN32, in meters, over the first 6 hours of the static test period. The horizontal axis gives the day since the start of GPS week 1192.

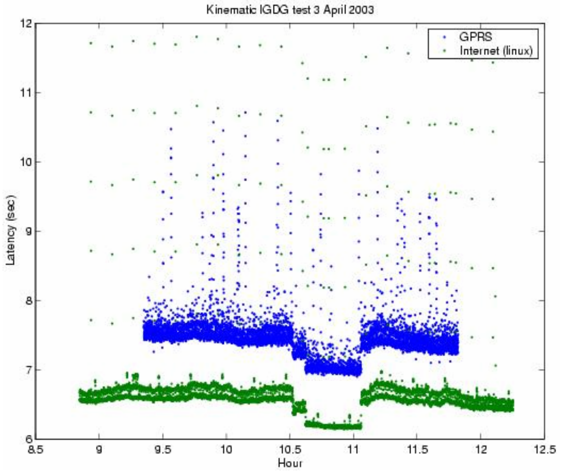

Figure 6: The latency (in seconds) as a function of time for the corrections logged both in office (green) and in the field (blue) during the kinematic test.

Quality assessment of IGDG corrections

We compared JPL's 15-min Real-Time orbits/clocks solutions, which are available from a JPL's ftp server [14], with the GPS broadcast orbits and clocks improved with IGDG corrections. The purpose was to assess the capability of IGDG corrective information to improve the accuracy of the broadcast orbits and clocks to the decimeter level. We used GPS data as well as the IGDG corrections logged during the static test and the JPL Real-Time orbits and clocks. Because the GPS broadcast elements provide the coordinates of the satellite's antenna phase center and in order to simplify the comparison procedure we used the antenna phase center as a reference point. The sampling interval was 5 min (the sampling interval of JPL Real-Time orbits/clocks solutions). ITRF2000 was used as a reference frame for comparison.

Figures 7 and 8 show typical results of the comparison for GPS satellites of Block IIA/IIR types. The IGDG corrections appeared to be able to improve the GPS broadcast satellite orbits and clocks to a decimeter accuracy level. The improved GPS broadcast ephemerides behave smoothly and are not subject to significant variations and trends.

The differences between the broadcast GPS ephemerides improved with IGDG corrections and JPL Real-Time orbits/clocks solutions were typically about 5-10 cm for orbits and about 15-25 cm for clocks. The corresponding empirical standard deviations were at the cm level. Although the IGDG corrections are being formed at JPL as differences between real-time dynamic orbits and clocks, and GPS broadcast ephemerides, the differences with JPL's real-time orbits/clocks solutions not equal to zero, as one might expect. This is due to the fact that the IGDG corrections that were used and the JPL real-time products came from two different processes. The accuracy of JPL real-time orbits is about 20 cm [15] what is in a good agreement with our results.

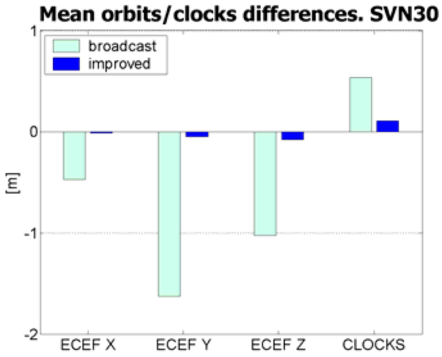

Figure 7: Mean of the differences between the improved broadcast GPS orbits/clock and JPL Real-Time GPS orbits/clocks solutions for SVN30 (Block IIA) over a 2-hour time span.

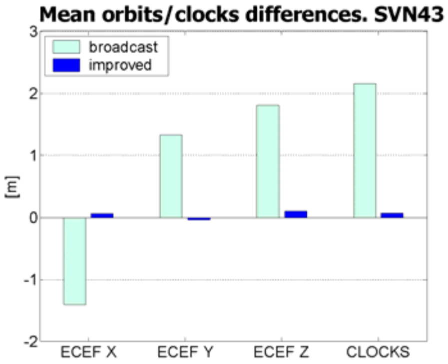

Figure 8: Mean of the differences between the improved broadcast GPS orbits/clock and JPL Real-Time GPS orbits/clocks solutions for SVN43 (Block IIR) over a 2-hour time span.

Conclusions

We can confirm the dm-accuracy of IGDG stand-alone fixed/mobile receiver positioning claimed by JPL. The standard deviation for static positioning is about 10 cm in each horizontal component and about 20 cm in the vertical component. The standard deviation for the kinematic positioning case is about 20 cm in each horizontal component and about 60 cm in the vertical component (including a 40-min period for the filter convergence), or about 12 cm in each horizontal component and about 20 cm in the vertical component excluding the filter convergence period.

Additional analyses were performed to assess the impact of various approaches for troposphere estimation implemented in GIPSY on filter convergence and kinematic positioning estimates. A strategy with wet troposphere estimation as a constant parameter over a whole observation time span resulted in faster filter convergence (about 20 min) and a better precision of the Height component estimates as compared to other strategies considered. Estimation of tropospheric zenith delays and gradients (as stochastic processes) weakened single receiver kinematic positioning performance rendering the filtered estimates vulnerable to various error sources capable of degrading the positional accuracy. Generally it took 20-40 minutes for the filter algorithm implemented in GIPSY to achieve dm-accuracy. The horizontal components tend to converge quite quickly, whereas the Height component demonstrates noticeable variations during the ‘initialization’ period.

The availability of the IGDG corrections logged during the kinematic test was very good (more than 99% of the messages were received with the expected interval of 1 second), and a latency of only 7 to 8 seconds.

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