Influence of Global Ionosphere Model in Static GPS Surveying using Commercial GPS Processing Software

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Key words: Static GPS, ionosphere model

SUMMARY

Static GPS is still commonly used for establishing and maintaining geodetic reference networks. It is general knowledge that the accuracy of long baselines improves when precise orbits are used. Atmosphere is one of the biggest error sources in GPS measurements and it is divided into two parts: troposphere and ionosphere. The influence of the troposphere is mostly taken into account with a model and ionospheric effects are expected to vanish by using dual frequency receivers. However, some commercial GPS software packages allow users to include an ionosphere model into their processing.

We studied the influence of a global ionosphere model in practical static GPS surveying for baselines shorter than 33 km. We used different observing times (10 min…6 hours) and ephemerides (precise and broadcast) with CODE global ionosphere model. The model contains measured information of vertical total electron content (VTEC) in the ionosphere.

The use of ionosphere model improves accuracy drastically, especially if observing time is short compared to baseline length. For example, improvement was over 90% with 10 minutes observing time if ionosphere model was used. Also the success rate for solving baselines increases. Influence of orbits was negligible compared to that of ionosphere model.

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1. INTRODUCTION

This study is a part of Finnish Geodetic Institutes project to study the accuracy and the quality of geodetic GPS. In this study we focus our interests on the use of global ionosphere model in static geodetic GPS surveying. The goal was to find out the influence of global ionosphere model on GPS solution for baselines shorter than 33 kilometers and session durations 10 min…6 hours. We computed nearly 8,000 baselines with different baseline lengths and observation times.

2. GLOBAL IONOSPHERE MODEL

Ionosphere is one of the biggest error sources in GPS processing. Ionosphere is dispersive medium with respect to the GPS frequencies. Traditionally the ionospheric effects have been eliminated using dual frequency receivers and ionosphere-free linear combination in processing. (Hoffman-Wellenhof et al., 2001)

The ionosphere is from about 50 km up to 1,000 km above ground. Influence of ionosphere depends on the electron density and it has time-dependent variation. Solar activity has 11-year cycle with great influence for number of electrons. There is also significant seasonal and diurnal variation. Measure of electrons is defined as TEC that is the total electron content along the signal path between the satellite and receiver (Hoffman-Wellenhof et al., 2001). VTEC (vertical total electron content) is also widely used especially in ionosphere models. (Schaer, 2002)

There is possibility to use global ionosphere maps (GIM) that has been generated from world-wide GPS observations. We used CODE final ionosphere model in our processing. CODE IONEX (IONosphere map EXhange) files contain VTEC information with two hour interval. CODE products are maintained by Astronomical Institute, University of Berne, Switzerland. (Schaer, 2002; CODE, 2008)

3. TEST METHODS

We processed a GPS dataset with and without ionosphere model using broadcast and precise ephemerides. Using the same GPS data with same processing strategy ensures that the effect we find depends only on orbits or ionosphere model. Satellite geometry, troposphere, carefulness of the observer, multipath conditions etc. have the same influence to all solutions and we are able to compare the results between the studied factors.

3.1 Test field and test data

Test field (Figure 1) contains seven reference points forming a set of 18 baselines of different lengths. Test campaign was performed in the test field in May 2007. The observations were made with dual frequency receivers and choke ring antennas using tripods (Figure 2). Same benchmarks were observed during five days using 6-hour observing times.

Baselines lengths vary from 1.8 to 32.5 kilometers. Reference coordinates were processed and adjusted from the whole five-day observation data with Trimble Total control. This was the way to get homogeneous reference coordinates for the test field.

The test data was divided into 10-min, 15-min, 30-min, 1-h, 2-h, 3-h and 6-h observing times. If there was more than 20 sessions per observation time, 20 sessions were selected randomly in order to avoid any systematic errors and to reflect average conditions. This way each base-line length-observing time combination has a similar “weight” as the number of observations is equal. However, for longer observing times there was less sessions available (Table 1). In total almost 8,000 GPS baselines were used in the test.

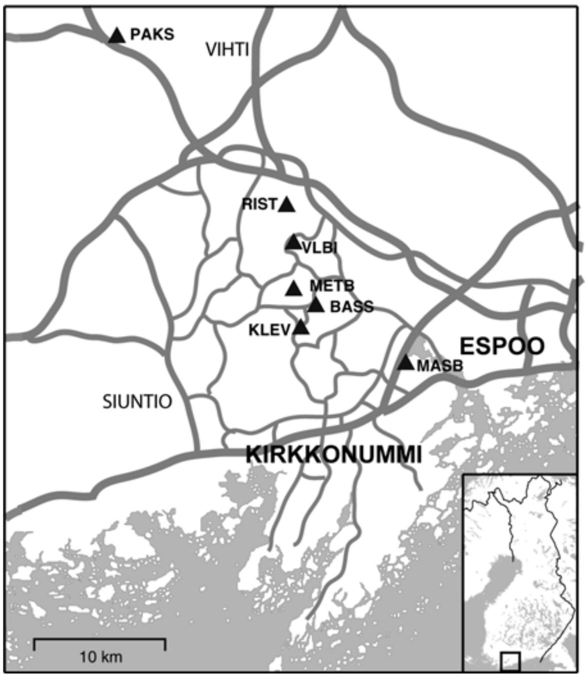

Figure 1. Measurements were performed in the test field in southern Finland. Test field contains seven points and 18 baselines.

Figure 2. Observations were collected with dual frequency receivers and choke ring antennas using tripods.

Table 1. Number of sessions with different observing times.

observing times	10 min	15 min	30 min	1 hour	2 hours	3 hours	6 hours
number of sessions	20	20	20	20	15	10	5

3.2 Data processing

The data was processed with Trimble Total Control (TTC) software and processing interval was 30 seconds. All sessions with different observing times were processed with and without ionosphere model using broadcast and precise (IGS final orbits) ephemerides. We used default processing parameters and NGS antenna model. All vectors were processed individually without network adjustment.

Error vector components (ΔX, ΔY, ΔZ) were computed by comparing baseline results to the reference coordinates. 3D error (ΔS) was calculated from error vector components for each individual solution. Figures 3 and 4 show an example of individual 3D errors for 10- minute sessions with broadcast ephemerides. Figure 3 shows results without and Figure 4 with ionosphere model.

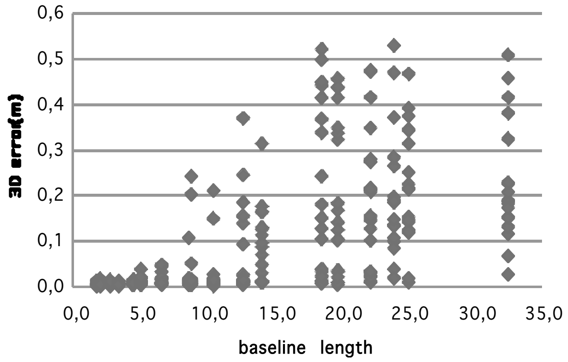

Figure 3. Individual 3D errors for 10-minute sessions processed with broadcast ephemerides. Ionosphere model was not used. 7 gross errors (>1 m) were discarded.

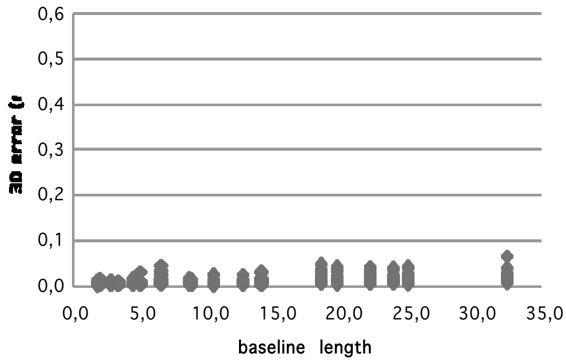

Figure 4. Same as figure 3 but with ionosphere model. One gross error (>1 m) was discarded.

3.3 Pre-processing of the results

By including short observing times it was anticipated that data contains gross errors. Gross errors were not discarded during the processing even if the GPS software warned sometimes from bad quality. This reflects reality and elimination could have biased the results. Gross errors were thus taken into account only in pre-processing of the results.

We tested several methods for cleaning the raw results from gross errors. In the first method we eliminated gross errors that were bigger than one meter (Figures 5 and 6). One meter error cannot be considered as geodetic accuracy under any circumstances. In the second method errors larger than 3*rms were discarded (Figures 7 and 8). Rms was computed for each baseline length-observing time combination (including 20 baselines) separately. In case of systematic errors, rms value increases leading to less sensitive elimination of gross errors. Therefore the third elimination method using standard deviation (   ) was tested. In the third method we eliminated data points that are outside the 3   (approximately 99.7 %) and thus deviate significantly from the rest of the data (Figures 9 and 10). Both methods 2 or 3 include as pre-elimination the method 1.

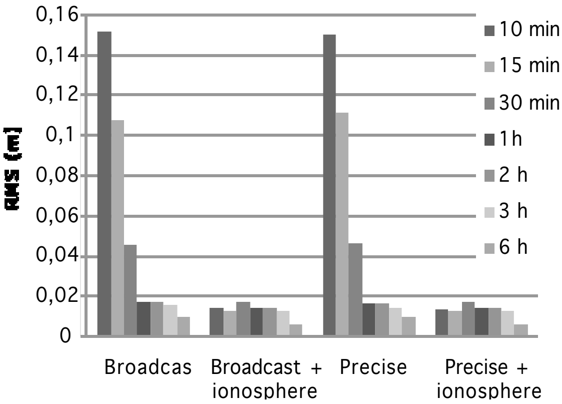

Figure 5. rms accuracy for all baseline lengths if only gross errors larger than one meter are eliminated.

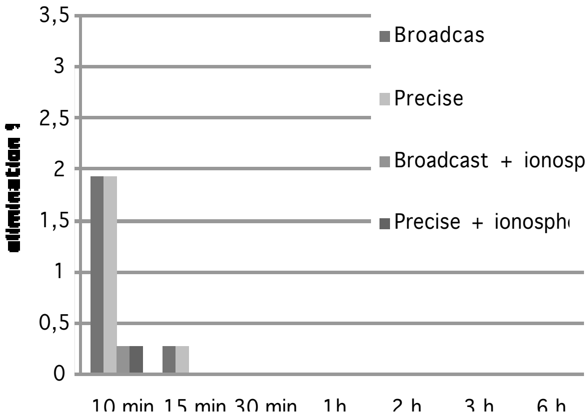

Figure 6. Percentage of discarded vectors. Errors larger than one meter are eliminated.

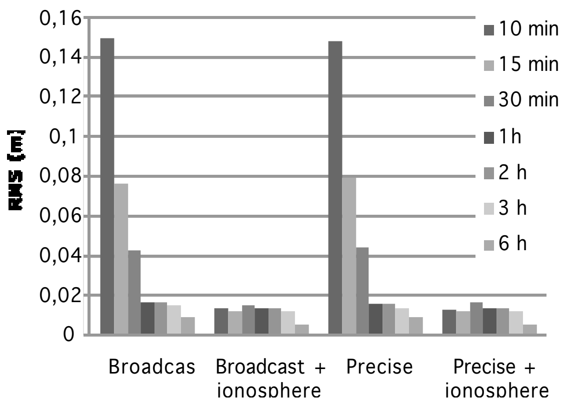

Figure 7. rms accuracy for all baseline lengths if errors larger than 3*rms are eliminated.

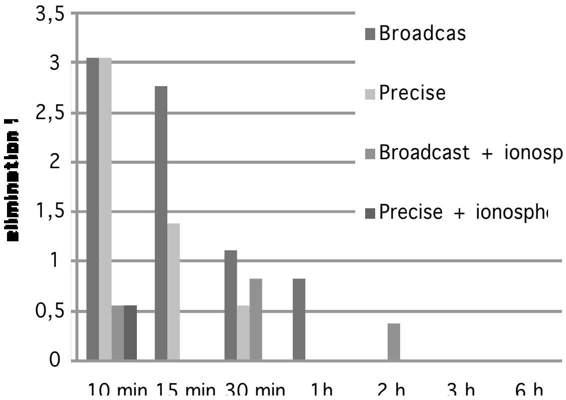

Figure 8. Percentage of discarded vectors. Errors larger than 3*rms are eliminated.

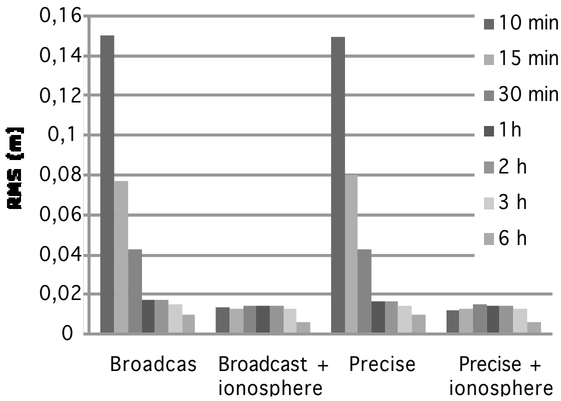

Figure 9. rms accuracy for all baseline lengths if errors larger than 3 are eliminated.

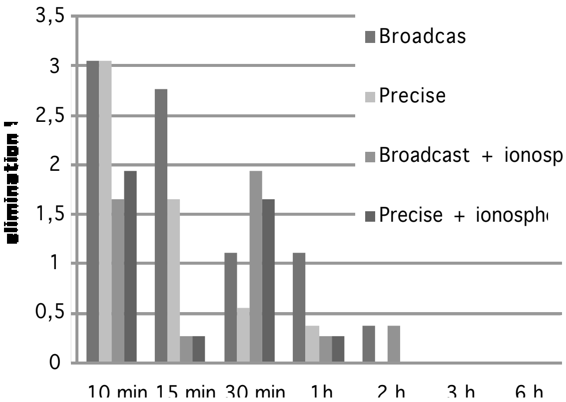

Figure 10. Percentage of discarded vectors. Errors larger than 3 are eliminated.

From the Figures 6, 8, 10 it is obvious that the method 3 detects more outliers than the other methods. However, these observations differ statistically significantly from the rest of the dataset and can be considered as gross errors. Method 3 discards up to 3% of the vectors. Most vectors are discarded with the shortest observing time when there is not enough data for reasonable GPS solution. Percentage of rejected vectors indicates the reliability of results. From Figures 5, 7 and 9 can be seen that the elimination methods have only minor effects to accuracy. From now on all the results are pre-processed using method 3. rms (root mean square) value was chosen as accuracy measure.

4. RESULTS

4.1 Influence of orbits

Different ephemerides were studied with and without ionosphere model. Results without ionosphere model are shown in Figure 11 for broadcast and in Figure 12 for precise orbits. In both cases results are similar and improvement of rms accuracy was less than 3 mm for all observing times. Improvement of accuracy was on average 2.0% if precise ephemerides were used instead of broadcast ephemerides without ionosphere model. With ionosphere model the difference between broadcast and precise ephemerides is even smaller (see Table 2).

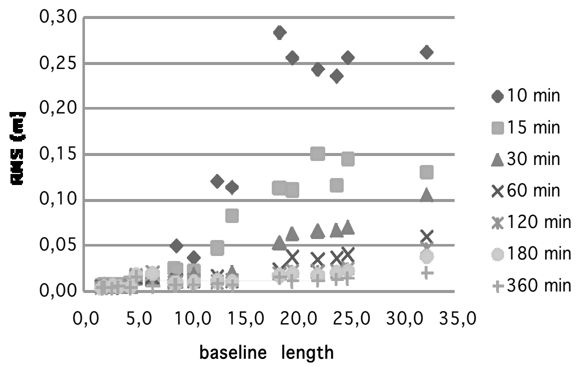

Figure 11. rms accuracy with broadcast ephemerides and without ionosphere model.

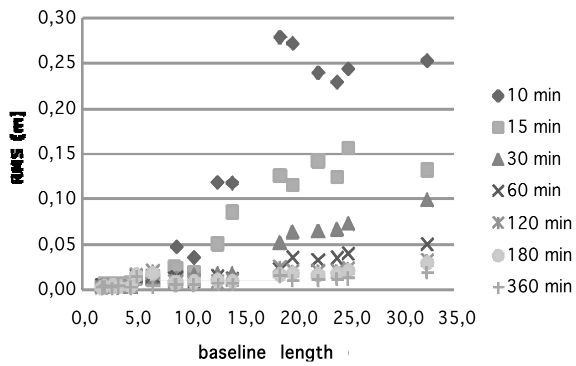

Figure 12. rms accuracy with precise ephemerides and without ionosphere model.

4.2 Influence of ionosphere model

The influence of ionosphere model was studied with both broadcast and precise orbits. Results with broadcast orbits and without ionosphere model are shown in Figure 13. Corresponding results with ionosphere model are given in Figure 14. From the figures can be seen that ionosphere model improves accuracy considerably. The distance-dependency almost vanishes. Accuracy improves significantly especially for shorter observing times, even more than 90 % for 10-minute observing time (see Table 2). The table shows that the results are similar for precise orbits and the difference between orbits is insignificant. With longer baselines and short observing times the rms accuracy improves from decimeter level to centimeter level.

Improvement is smaller with longer observing times. Nevertheless in every case the improvement was over 10 %. The improvement is significant for observing times less than 2 hours being at least 1 cm in rms accuracy. The improvement is only a few millimeters for longer observing times.

Figures 13 and 14 show also that the deviation between the different observing times reduces noticeably and the observing time-dependent part of error almost disappears when global ionosphere model is added to GPS processing (see columns 3 and 6 in Table 2). The results indicate that one may obtain same accuracy with only 10-min observing time than with 3-h observing sessions if ionosphere model is used. Only 6-h observing times give significantly better results compared to other observing times.

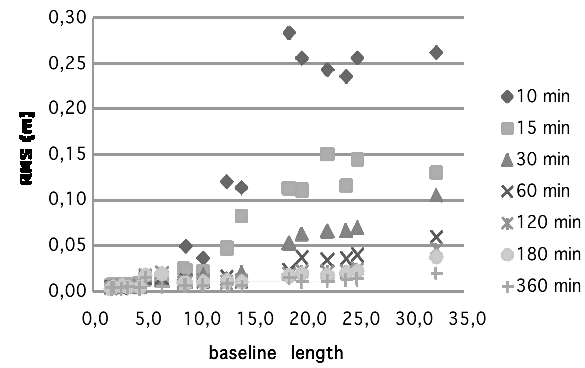

Figure 13. rms accuracy with broadcast ephemerides and without ionosphere model.

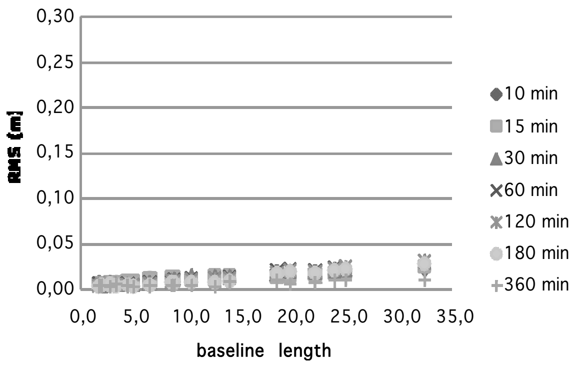

Figure 14. rms accuracy with broadcast ephemerides and ionosphere model.

Table 2. Accuracies (rms) with different observing times. Percentage (%) indicates the improvement of rms when ionosphere model is used.

	Broadcast RMS (mm)	Broadcast+ionosphere RMS (mm)	%	Precise RMS (mm)	Precise+ionosphere RMS (mm)	%
10 min	151.3	13.7	90.9	150.1	12.2	91.9
15 min	77.2	12.9	83.3	80.4	13.0	83.9
30 min	43.2	14.1	67.2	42.7	15.1	64.6
60 min	24.3	14.7	39.3	23.3	15.0	35.7
120 min	17.5	14.0	19.9	16.3	13.9	14.7
180 min	15.4	12.8	17.1	14.5	12.9	10.6
360 min	9.7	6.0	37.7	9.7	6.3	35.2

5. CONCLUSIONS

This study shows that ionosphere model improves accuracy of static GPS surveying. Accuracy improves significantly especially for shorter observing times, even more than 90 % for 10-minute observing time. With longer baselines and short observing times the rms accuracy improves from decimeter level to centimeter level and observing time-dependent part of error almost disappears. With ionosphere model one may get similar results with drastically shorter observing times. However, one must keep in mind that the reliability decreases with short observing times. Use of precise orbits instead does not improve accuracy significantly.

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