Static Baseline Accuracies as a Function of Baseline Length, Observation Time and the Effect of using the Precise Ephemeris

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Introduction

Twelve baselines are processed in this report, separated into three groups.

- **Short/Medium Baselines:** 4.9, 19.9, 40.3 and 59.8 km
- **Long Baselines:** 201.3, 297.7, 402.1, 504.3 km
- **Very Long Baselines:** 707.7, 796.4, 918.4 and 1004.1 km

Each baseline is processed with 1, 3, 6, 12 and 24 hours of data. This was done in order to show examples of obtainable accuracies as a function of baseline length given specific observation times. Results using both the broadcast and precise ephemerides are presented in order to gauge at what baseline lengths the use of the precise ephemeris becomes worthwhile.

All data used was downloaded from the IGS network (http://sopac.ucsd.edu/) and processed in GrafNet version 7.60. The quality of the data is thus expectedly high, with each station experiencing low multipath conditions and excellent views of all available satellites. All data was processed using the default options in GrafNet. These options included an elevation mask of 15 degrees and a distance tolerance of 5 km for applying an ionospheric correction. The distance tolerance for choosing between a fixed and a float solution was left at the default 40.0 km. When interpreting the results, it is important to remember that a fixed solution was processed to only two stations below this 40 km level. All data was processed at a 30 second interval.

The station DSHS at Dorsey High School in Los Angeles California was used as the base station in all tests. In order of ascending distance from DSHS, the other stations used in this report are: NOPK, CSDH, SNHS, CTDM, KYVW, RYAN, APEX, CNDR, TUNG, ELKO, COON and PTSG. The published coordinates of each of these stations are entered as checkpoints, which are used in order to compute the error in the solution processed by GrafNet.

Horizontal and vertical residuals for each baseline and for each method of processing (i.e. using broadcast and precise ephemeris) are summarized in the appendices. This data is used to summarize the results graphically both as a function of baseline distance and the length of observation time. In all graphs, the 3D error of the solutions is used. If readers are more interested in specifically the horizontal or vertical components, please refer to the appendices.

Brief Theory

The two main concepts explored in this report are the effect of the orbital error on relative positioning and the level of improvement given longer observation periods. These two concepts are briefly introduced here.

The effect of orbital errors on relative positioning is given by Parkinson and Enge (1996) as:

$$\varepsilon \leq (d / r) \times \delta r$$

Where d is the baseline length in kilometers
r is the range to the satellite (20,000 km)
δr is the magnitude of the error broadcast by the ephemeris

The National Geographic Survey (NGS) gives the accuracy of the broadcast GPS ephemerides to be better than 2.6 meters. Thus some quick calculations show that the expected error on position for baseline lengths of 100, 500 and 1000 kilometers would be no worse than 1.3 cm, 6.5 cm and 13 cm respectively. This report attempts to show if the magnitudes of these errors are seen in practice.

Given a relatively short baseline (40 kilometers or less) and dual frequency data, GrafNet will attempt a fixed static solution. An iono-free float solution is therefore processed for baselines exceeding 40 kilometers in length. Note that this tolerance can be changed by the user within GrafNav/Net and given good observation conditions a fixed static solution can possibly be obtained for baseline lengths that are appreciably longer (up to 50 and possibly 60 kilometers in length). The 40 kilometer default was not modified for this project.

The difference between the float and fixed solutions is that a fixed solution attempts to resolve satellite phase ambiguities to integer values, thus obtaining cm level accuracies provided the correct ambiguity sets were resolved. A float solution is one that does not force the ambiguities to integer values, but given enough time to converge the ambiguities will likely converge to near integer values and approach the same solution as would have been resolved with a correct integer fix. An iono-free solution is a float solution which uses L2 to correct of the ionospheric effect. This is beneficial on long baselines as the amount of ionospheric error that is corrected far exceeds the increase in noise by the addition of another signal.

On long baselines, the limit to how well a solution will converge is usually governed by the amount of un-differenced error between master and remote positions. The un-differenced error includes the error in satellite orbits, noise introduced by using the L2 signal to correct for ionospheric effects, tropospheric effects, multipath and receiver noise. This report will attempt to quantify how much improvement is seen in baselines of constant length given different observation lengths.

Observed 3D Error as a Function of Baseline Distance using 24, 12, 6, 3 and 1 Hour of Data

The 3D error is computed as follows:

$$3D\ Error = ((\Delta E)^2 + (\Delta N)^2 + (\Delta U)^2)^{1/2}$$

Where ΔE is the error in East,
ΔN is the error in North,
ΔU is the error in the height component

The following five figures attempt to show what level of accuracy is obtainable given a constant amount of observation time and a variable baseline distance. Additionally, the graphs quantify the level of difference in the solutions obtained using the precise ephemeris. All data was collected on the same day in order to compare results under as similar conditions as possible (such as the available satellite constellation).
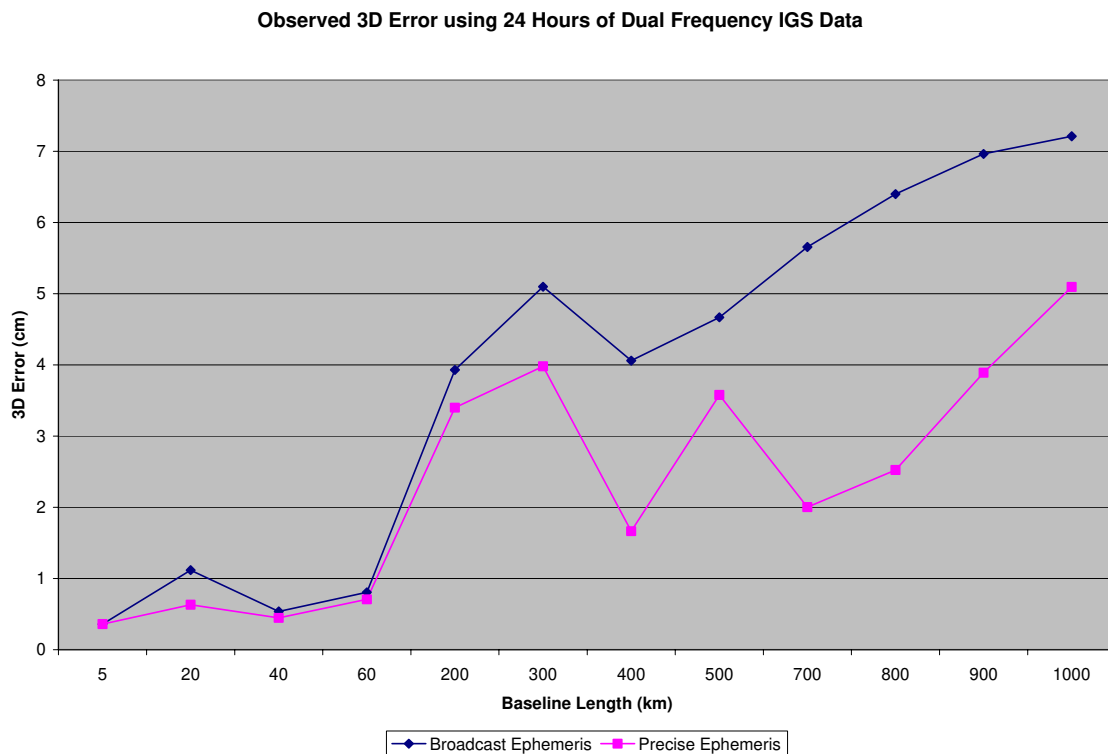
Observed 3D Error using 24 Hours of Dual Frequency IGS Data

Figure 1: Observed 3D Error as a Function of Baseline Length using 24 Hours of Data

Observed 3D Error using 12 Hours of Dual Frequency IGS Data

Figure 2: Observed 3D Error as a Function of Baseline Length using 12 Hours of Data

Observed 3D Error using 6 Hours of Dual Frequency IGS Data

Figure 3: Observed 3D Error as a Function of Baseline Length using 6 Hours of Data

Observed 3D Error using 3 Hours of Dual Frequency IGS Data

Figure 4: Observed 3D Error as a Function of Baseline Length using 3 Hours of Data

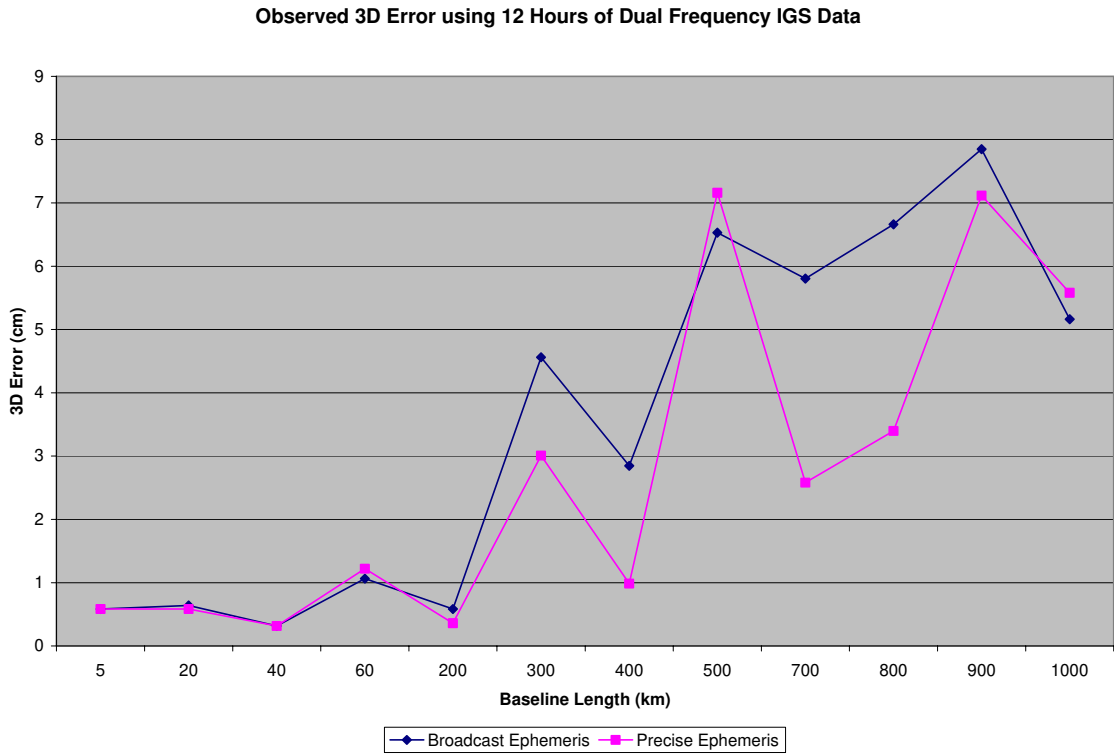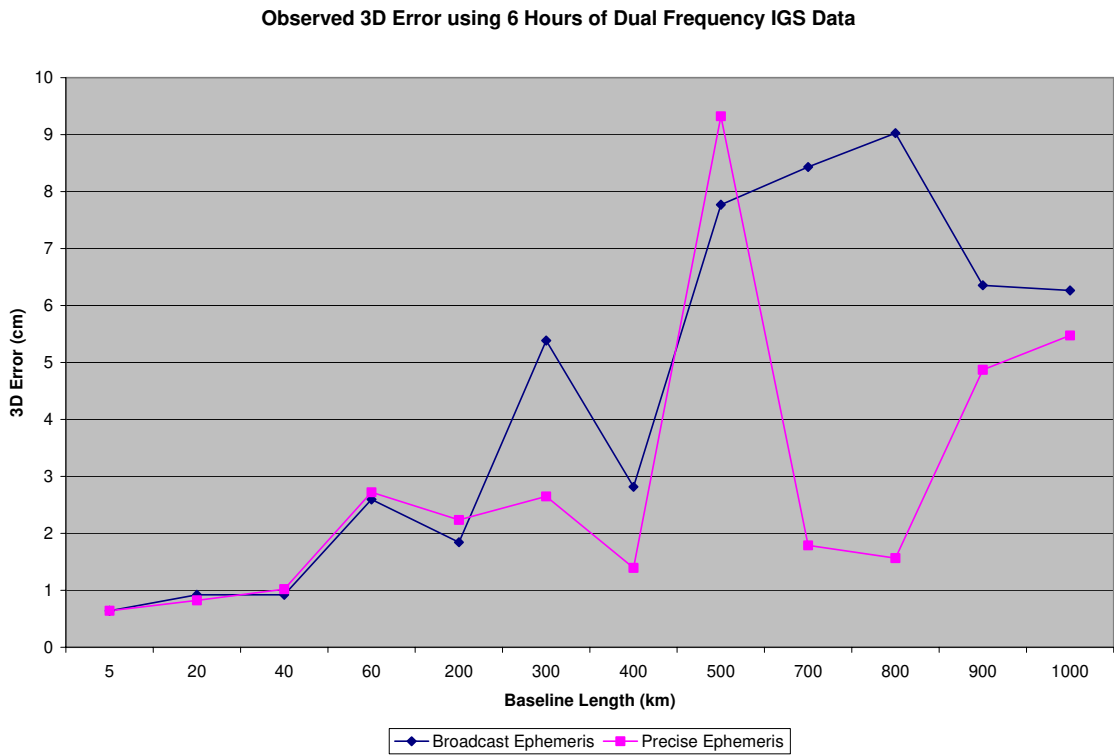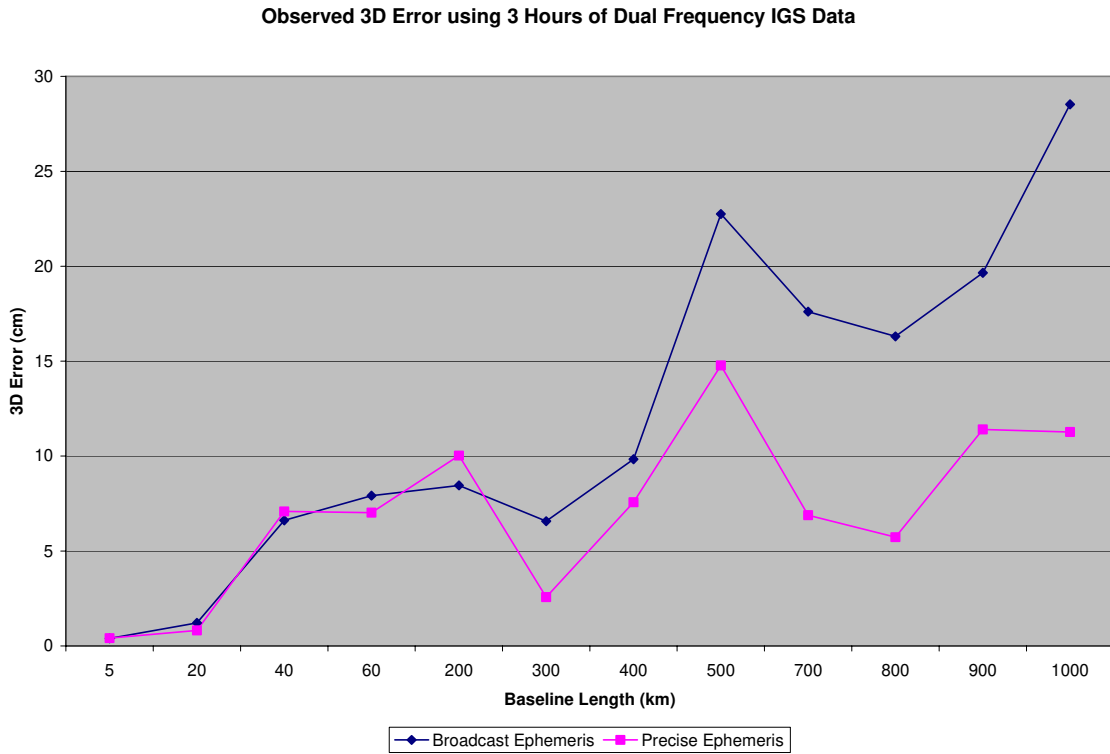**Observed 3D Error using 1 Hour of Dual Frequency IGS Data**
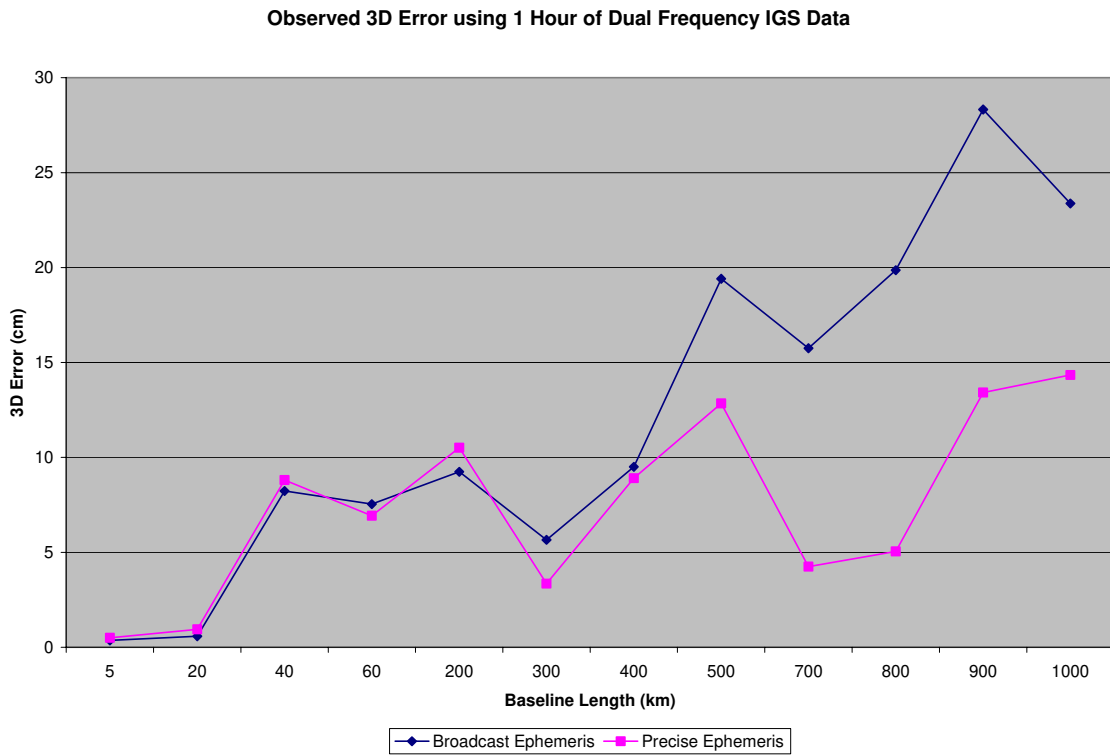
Figure 5: Observed 3D Error as a Function of Baseline Length using 1 Hour of Data

Observed 3D RMS Error as a Function of Observation Time using 24, 12, 6, 3 and 1 Hour of Data

The RMS error in the 3D position for each group of baselines (grouped by baseline length) was calculated and graphed to show the improvement in position as a function of time. These graphs can also be used to quantify the level of improvement of the solutions when using the precise ephemeris.

Observed 3D RMS Error on Very Long Static Baselines (700 to 1000 km)

Figure 6: Observed 3D RMS Error as a Function of Time for Baseline Lengths of 700 to 1000 km

Observed 3D RMS Error on Long Static Baselines (200 to 500 km)

Figure 7: Observed 3D RMS Error as a Function of Time for Baseline Lengths of 200 to 500 km
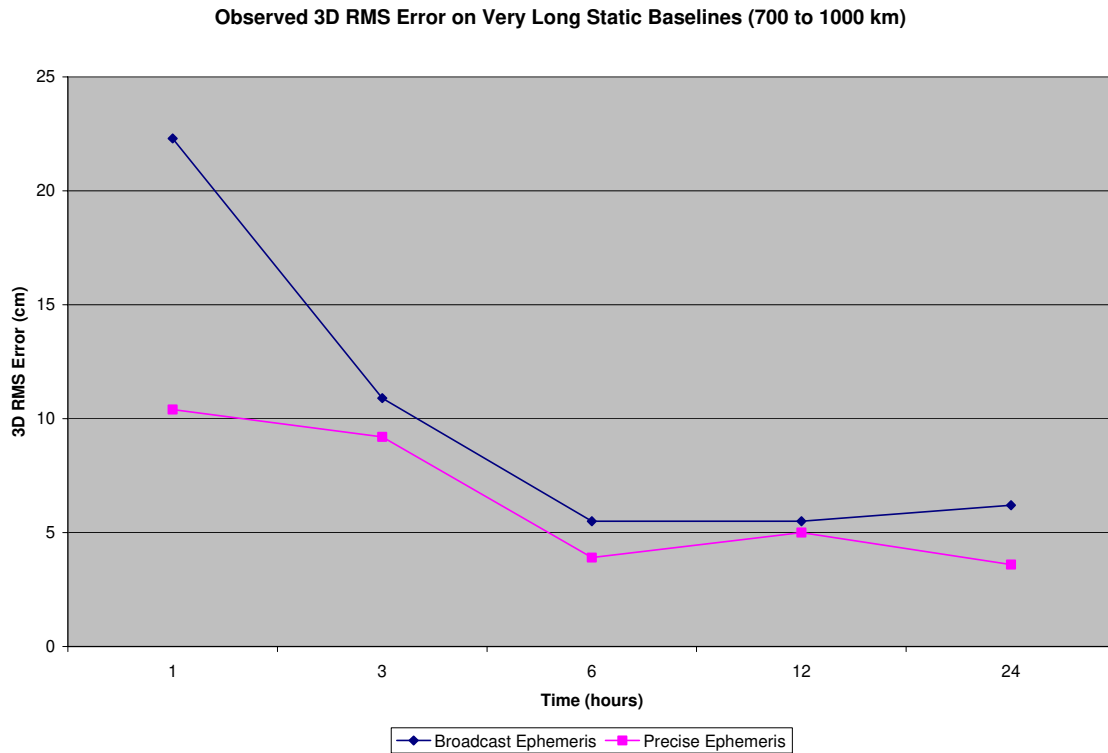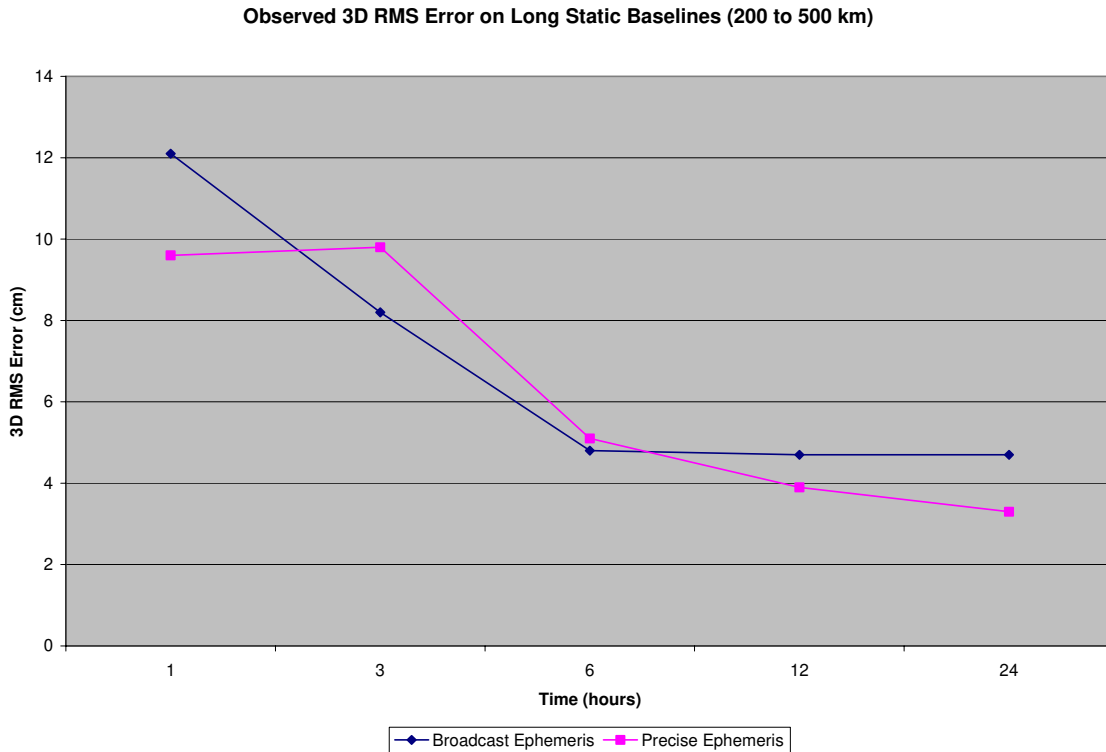
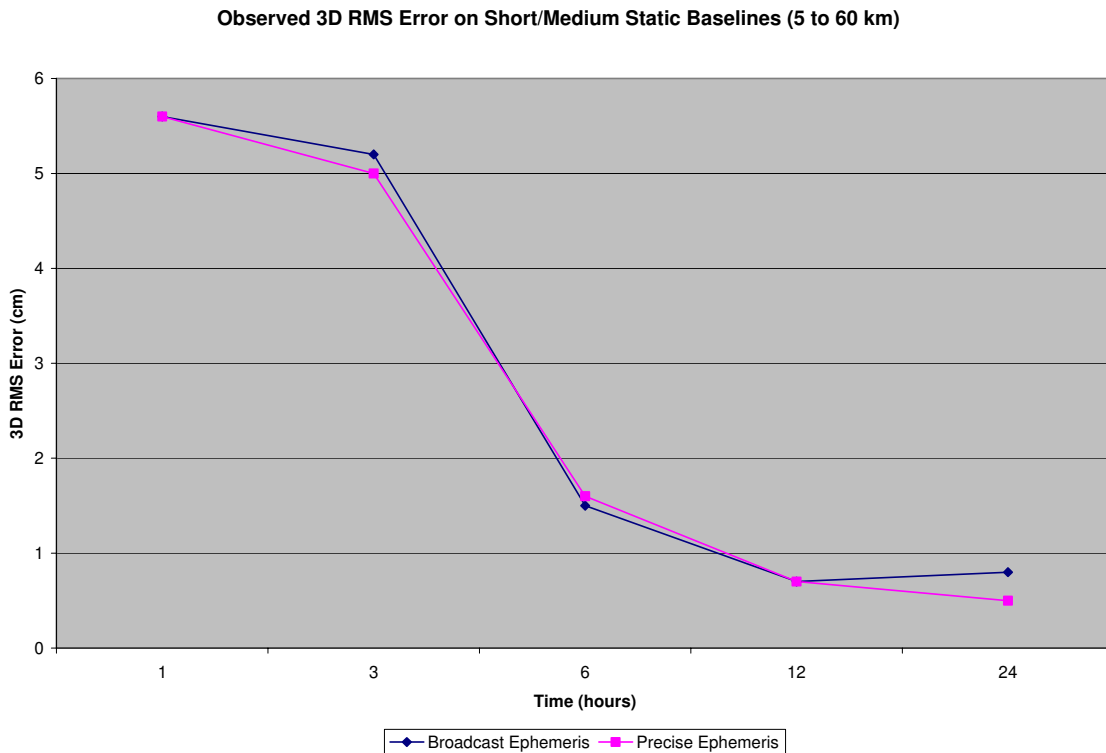**Observed 3D RMS Error on Short/Medium Static Baselines (5 to 60 km)**

Figure 8: Observed 3D RMS Error as a Function of Time for Baseline Lengths of 5 to 60 km (note float solutions were processed to two of four baselines included in these results)

Conclusions

From examining figures 1 to 5, it is evident that there is no clear benefit to using the precise ephemeris for baselines of 200 km or less. At these distances, larger 3D errors were actually observed on some of these baselines when using the precise ephemeris as apposed to the precise ephemeris (albeit the differences in solutions were typically sub-centimeter and thus of no practical concern).

Improvements on the order of 1 cm or better are seen only on baselines of 300 km or longer. This suggests that the actual error in the broadcast ephemeris is better than the 2.6 meters given by the NGS, as centimeter differences were not observed on baselines of 100 km as discussed in the section of this report titled "Brief Theory".

Figures 1 through 5 generally suggest that the benefits of using the precise ephemeris are largest for longer baseline lengths and shorter observation periods. When using the full 24 hour data set, the differences between the broadcast and precise solutions were at most about 3.5 centimeters for any baseline length. When using 12 hours of data, the largest improvement from the use of the precise orbits is about 7.5 centimeters. Using only 1 hour of data, the largest improvement is approximately 15 centimeters.

Figures 6 though 8 re-enforce the above findings. For baselines of 60 kilometers and less, the precise and broadcast 3D RMS values are virtually identical. The largest difference is seen when processing 1 hour of data for the 700 to 1000 km baseline group. A 3D RMS improvement of approximately 12 cm is seen at this level in the solution that used the precise ephemeris. This is in contrast to an improvement of less than 3 cm when 24 hours of data are used. It is thus evident then that in practice both baseline distance and the length of data collection are factors in determining when it is beneficial to use the precise ephemeris.

The best level of observed 3D accuracy was 0.5 cm for the short/medium baseline group, and was limited to approximately 3.5 cm for both long and very long baseline groups using 24 hours of data and the precise ephemeris.

Figures 6 through 8 also generally show that substantial improvements are seen when collecting three hours of data as opposed to one, and six hours of data as apposed to three for all baseline groups. Minimal differences are seen in all three baseline groups from 24 hours of data collection to six hours. Therefore this suggests that even at baseline lengths exceeding 1000 km, little benefit is seen when collecting more than six hours of data.

The results of this test are not suggested to apply in all situations, and it is always safest to collect more data than needed. The data used in this report is of high quality in that it is subject to low multipath conditions and has no unusual satellite drop outs or data gaps. The results shown in this report are likely only to be duplicated with data collected under similarly responsible conditions.

Appendix A Very Long Baseline Results (700 to 1000 km)

Processing Time: 1 Hour

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
TUNG	707.7	12.0	10.2	2.8	3.2
ELKO	796.4	18.9	6.1	5.0	-0.7
COON	918.4	26.1	11.0	12.1	5.8
PTSG	1004.1	12.1	20.0	11.0	9.2
RMS (cm)		18.2	12.9	8.7	5.7

Processing Time: 3 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
TUNG	707.7	12.2	12.7	4.4	5.3
ELKO	796.4	12.8	10.1	4.0	4.1
COON	918.4	15.0	12.7	5.3	10.1
PTSG	1004.1	14.1	24.8	4.8	10.2
RMS (cm)		9.8	4.7	4.7	7.9

Processing Time: 6 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
TUNG	707.7	7.0	-4.7	1.6	0.8
ELKO	796.4	7.0	-5.7	1.4	0.7
COON	918.4	6.2	-1.4	1.6	4.6
PTSG	1004.1	6.0	-1.8	0.9	5.4
RMS (cm)		2.8	4.7	1.4	3.6

Processing Time: 12 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
TUNG	707.7	5.7	-1.1	2.1	1.5
ELKO	796.4	6.6	-0.9	2.3	2.5
COON	918.4	6.5	4.4	2.1	6.8
PTSG	1004.1	5.1	0.8	3.3	4.5
RMS (cm)		2.8	4.7	2.5	4.3

Processing Time: 24 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
TUNG	707.7	5.6	-0.8	2.0	0.1
ELKO	796.4	6.4	0.0	2.1	1.4
COON	918.4	6.7	1.9	1.7	3.5
PTSG	1004.1	7.2	0.4	4.9	1.4
RMS (cm)		4.1	4.7	3.0	2.0

Appendix B Long Baseline Results (200 to 500 km)

Processing Time: 1 Hour

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
KYVW	201.3	4.8	7.9	3.8	9.8
RYAN	297.7	5.6	-0.8	1.5	-3.0
APEX	402.1	4.8	8.2	4.8	7.5
CNDR	504.3	8.8	17.3	6.8	10.9
RMS (cm)		6.2	10.4	4.6	8.4

Processing Time: 3 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
KYVW	201.3	3.5	7.7	3.2	9.5
RYAN	297.7	5.9	2.9	2.5	0.6
APEX	402.1	7.2	6.7	4.2	6.3
CNDR	504.3	8.5	21.1	4.4	14.1
RMS (cm)		6.7	4.7	3.6	9.1

Processing Time: 6 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
KYVW	201.3	0.4	1.8	0.4	2.2
RYAN	297.7	1.4	-5.2	0.5	-2.6
APEX	402.1	2.5	-1.3	0.5	1.3
CNDR	504.3	4.1	6.6	1.5	9.2
RMS (cm)		1.0	4.7	0.9	5.0

Processing Time: 12 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
KYVW	201.3	0.5	-0.3	0.2	-0.3
RYAN	297.7	2.0	-4.1	0.8	-2.9
APEX	402.1	2.7	-0.9	0.9	0.4
CNDR	504.3	3.0	5.8	1.5	7.0
RMS (cm)		0.3	4.7	0.9	3.8

Processing Time: 24 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
KYVW	201.3	1.0	-3.8	0.0	-3.4
RYAN	297.7	2.2	-4.6	0.8	-3.9
APEX	402.1	3.2	-2.5	0.9	-1.4
CNDR	504.3	3.4	3.2	1.6	3.2
RMS (cm)		0.5	4.7	1.0	3.1

Appendix C Short/Medium Baseline Results (5 to 60 km)

Processing Time: 1 Hour

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
NOPK	4.9	0.2	0.3	0.3	0.4
CSDH	19.9	0.5	0.3	0.5	0.8
SNHS	40.3	5.3	6.3	5.6	6.8
CTDM	59.8	2.8	7.0	3.1	6.2
RMS (cm)		3.0	4.7	3.2	4.6

Processing Time: 3 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
NOPK	4.9	0.4	0.0	0.4	0.1
CSDH	19.9	0.2	-1.2	0.2	-0.8
SNHS	40.3	2.3	6.2	2.3	6.7
CTDM	59.8	3.5	7.1	3.1	6.3
RMS (cm)		2.1	4.8	1.9	4.6

Processing Time: 6 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
NOPK	4.9	0.5	0.4	0.5	0.4
CSDH	19.9	0.2	-0.9	0.2	-0.8
SNHS	40.3	0.2	0.9	0.2	1.0
CTDM	59.8	1.2	2.3	0.8	2.6
RMS (cm)		0.7	1.3	0.5	1.5

Processing Time: 12 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
NOPK	4.9	0.5	0.3	0.5	0.3
CSDH	19.9	0.4	-0.5	0.3	-0.5
SNHS	40.3	0.3	-0.1	0.3	-0.1
CTDM	59.8	0.8	0.7	0.7	1.0
RMS (cm)		0.5	0.5	0.5	0.5

Processing Time: 24 Hours

Base Station: DSHS		Broadcast Ephemeris		Precise Ephemeris	
Name	Length (km)	DHz (cm)	DHt (cm)	DHz (cm)	DHt (cm)
NOPK	4.9	0.3	0.2	0.3	0.2
CSDH	19.9	0.5	-1.0	0.2	-0.6
SNHS	40.3	0.2	-0.5	0.2	-0.4
CTDM	59.8	0.7	0.4	0.5	0.5
RMS (cm)		0.5	0.6	0.3	0.4

References

Parkinson, Bradford W., and Per Enge (1996). Differential GPS, in *Global Positioning System: Theory and Applications, Vol. II*, B. Parkinson, J. Spilker, P. Axelrad, and P. Enge (Eds.), American Institute of Aeronautics and Astronautics, pp 3-50