Rover Station Positional Accuracies from OPUS as a Function of Reference Station Spacing and Rover Station Occupation Time

Neil D. WESTON, Tomás SOLER and Gerald L. MADER, USA

Key words: Baseline processing, occupation time, positional accuracies, dataset duration

SUMMARY

This research is aimed at determining how and to what extent rover station coordinate accuracies, from the Online Positioning User Service (OPUS), at the National Geodetic Survey (NGS), are influenced by reference station spacing and rover station occupation times. The first phase of the experiment was to treat a large number of stations in the CORS network as rover sites by collecting and submitting RINEX datasets of various occupation times to OPUS. The durations of the datasets from each rover station were chosen to be from one to five hours, mainly because datasets of this duration are frequently collected and processed by engineers, surveyors and GIS/LIS professionals. The data were then submitted to OPUS for processing, but only after several specific conditions were met. The foremost requirement was to constrain how far each of the three reference stations could be from the rover. After all datasets were processed, the solutions were analyzed to determine the overall performance of OPUS when constraining parameters such as baseline length and occupation times varied.

Rover Station Positional Accuracies from OPUS as a Function of Reference Station Spacing and Rover Station Occupation Time

Neil D. WESTON, Tomás SOLER and Gerald L. MADER, USA

1. INTRODUCTION

The Online Positioning User Service (OPUS) is a web-based application which processes Global Positioning System (GPS) data to provide accurate, reliable and consistent geodetic quality coordinates. The system was designed by the National Geodetic Survey (NGS) in 2000 and became operational in early 2001. The processing algorithms use obits from the International GNSS Service (IGS), GPS reference station data from a number of regional and global networks and centrally located computers to process user data submitted by surveyors, engineers and GIS/LIS professionals. Although OPUS can process GPS data collected from any part of the world, the majority of submissions routinely come from North America. Today, OPUS typically processes between 15,000 and 18,000 datasets per month and has an annual growth rate of 70 percent.

One of the benefits in using OPUS is that a user can establish geodetic control with one receiver and an antenna. This single site setup can be used to collect dual frequency GPS measurements at a bench mark for a period of time and then submit the data to OPUS where it will be processed with respect to three reference stations from the Continuously Operating Reference Station (CORS) network (Snay et al. 2008). At submission time, a user also has the option to select the reference stations used in the computations as well as requesting extended output which lists additional information about the occupation session. The computation time varies with the system load and duration of the submitted data but usually results are obtained via email in three to four minutes after submission. The results from this work will show that OPUS can be used to establish geodetic control even when the OPUS reference stations are several hundred kilometers away.

2. REFERENCE STATIONS AND ROVER DATASET CHARACTERISTICS

As of September 1st 2008, the NGS's CORS network contained approximately 1270 stations. Each reference station in the CORS network has a geodetic quality receiver and antenna, collects dual frequency GPS observations, has an elevation cutoff angle of 10° and operates on a continuous basis. Hourly and daily RINEX files from each CORS reference station are available, free of charge, shortly after they have been collected from the receivers.

Several stations are added to the CORS reference network on a monthly basis. One of the NGS's long-term goals is to establish permanent reference stations with a spacing of between 50 and 100 kilometers throughout the continental United States. This framework will also be used to establish a National Real Time Network (RTN) as well as the densification of existing RTN's in many metropolitan areas of the country. The map of the United States in Fig.1 illustrates the density of available CORS reference stations within 400 kilometers of a rover.

It is important to note that many additional CORS networks have also been established in the United States and other parts of the world and data from those stations are routinely used by several online processing services as well as for a wide variety of applications.

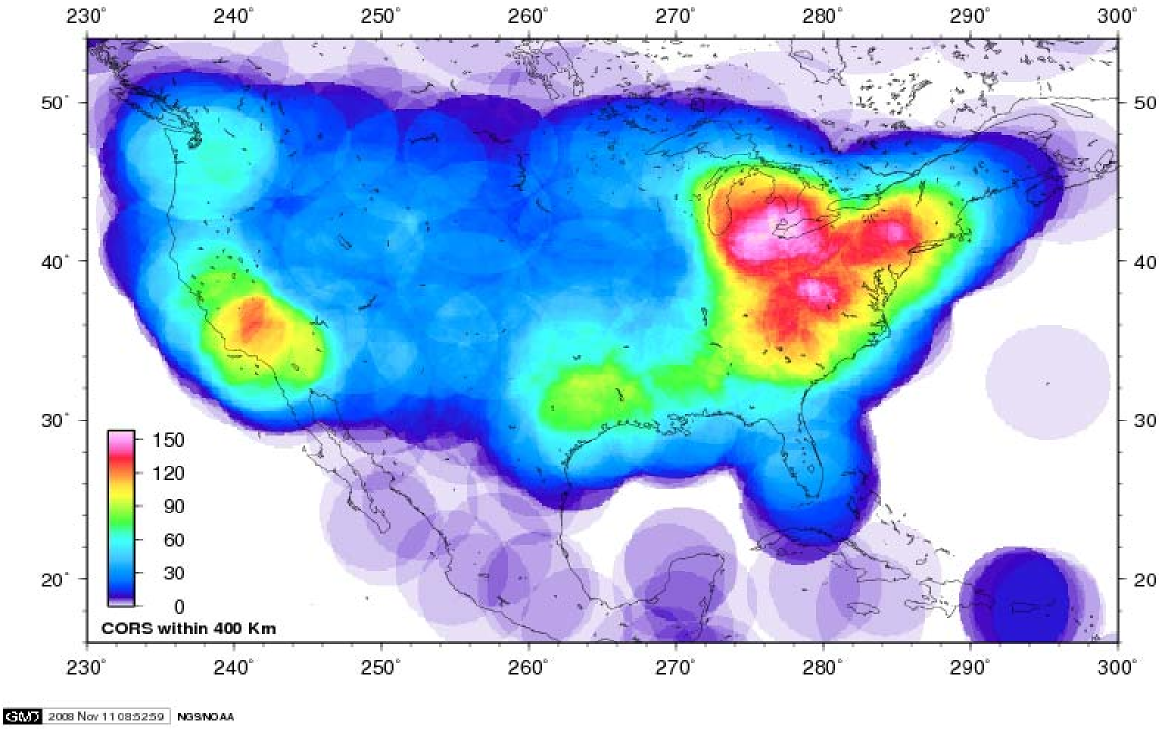

Fig. 1. Number of CORS Reference stations available to OPUS within 400 kilometers of a rover station located in the lower 48 states, Mexico and the Caribbean.

From the NGS's CORS network, 781 reference stations were arbitrarily chosen to be rover stations for this experiment. All of the selected stations are located in the continental United States, Alaska, Hawaii, Mexico and the Caribbean, the most common regions where GPS data are collected and submitted to OPUS. With the exception of a few regions, the distribution and spacing for each of the rover stations with respect to their neighboring CORS reference stations provided several cases where baselines between 100 and 600 kilometers in length can be formed. For this particular study, data from each of the CORS reference stations, collected on day 034 of 2007, were then used to generate multiple rover datasets from one to five hours in duration. Each of the datasets was then submitted to OPUS for processing and further analysis.

3. REFERENCE STATION SELECTION

The OPUS software suite uses several criteria in determining which CORS reference stations to select during baseline processing (see Figs. 2 and 3). A list of available reference stations is first sorted based on distance from the rover. Then each is checked for data availability, common observation times and high observation to cycle slip ratios. The first five reference stations which meet all the requirements are then selected for processing. Each of the first three reference stations will form single baselines with the rover and the remaining two will be available as spares should one or more of the initial baselines fail to give satisfactory results.

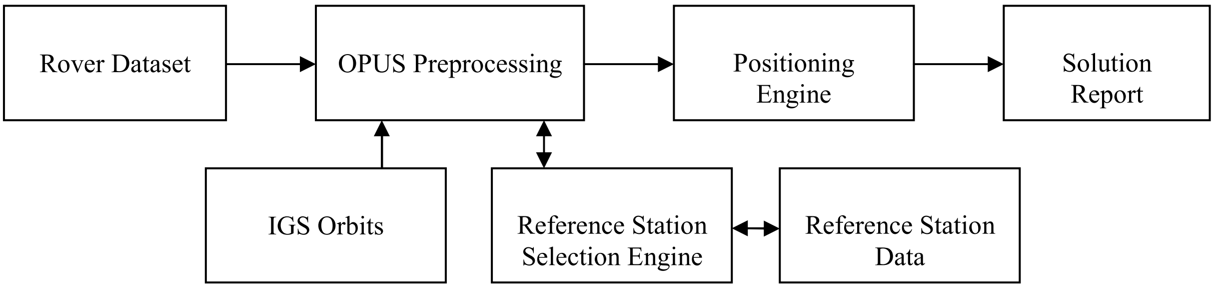

Fig. 2. Flow diagram showing the various processing stages of OPUS.

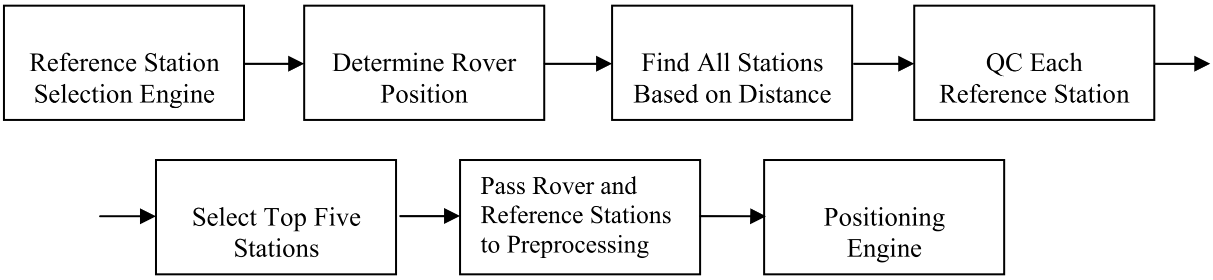

Fig. 3. Principle processing stages for the reference station selection algorithm.

To determine what effect baseline length has on a GPS double difference solution from OPUS, the reference station selection algorithm was modified to select stations where the baseline length between the rover and each of the reference stations was restricted to one of six specified ranges (100-200, 200-300,…, >600 km). As an example, two cases using MIA3 as a rover are illustrated in Fig. 4. Baselines illustrated in blue and red were selected by the algorithm when the constraining ranges were 100-200 and 200-300 kilometers respectively.

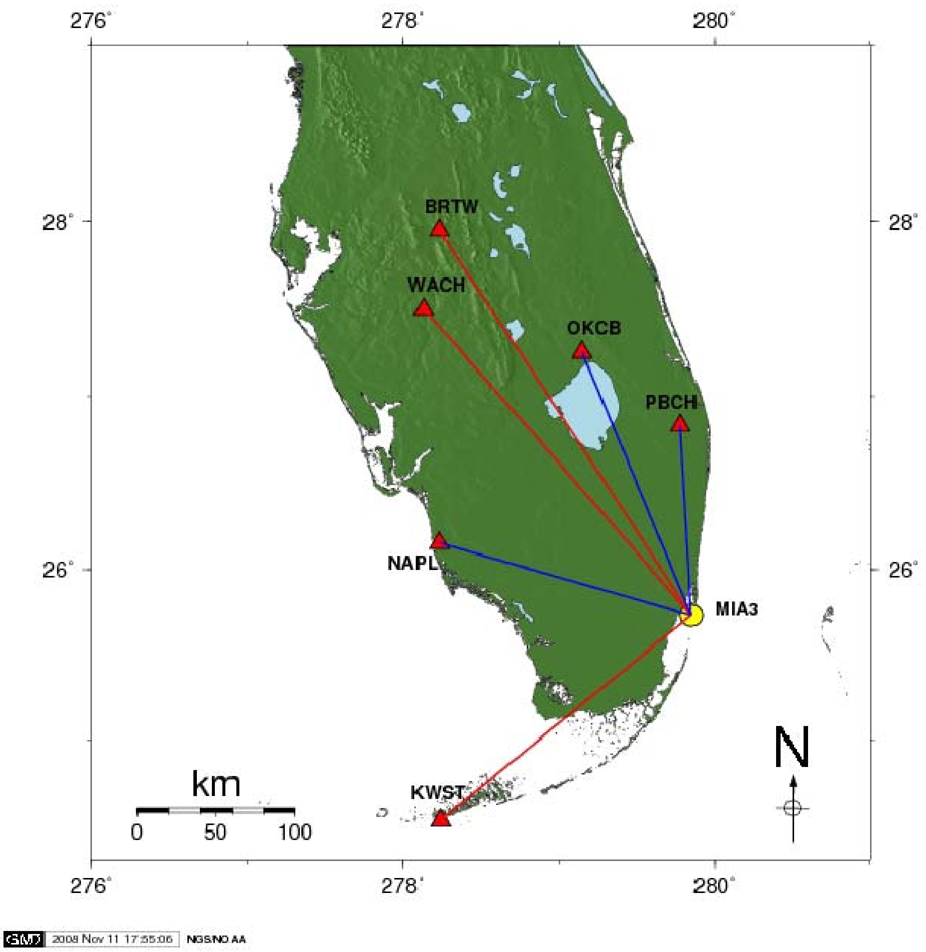

Fig. 4. Reference station selection by OPUS based on constraining baseline ranges. Reference stations connected with blue baselines were chosen when 100-200 km was the constraining range while red baselines connect reference stations 200-300 km away.

4. OPUS PROCESSING METHODOLOGY

In the processing phase, rover datasets for each occupation were checked against a set of initial conditions before they were submitted to OPUS. The foremost condition was to constrain how far each of the three reference stations could be from the rover. In all, six cases were performed where OPUS constrained the rover-reference station baselines to be 100-200, 200-300,…, >600 kilometers respectively. The procedure was then repeated until all datasets of varying durations were processed for the six cases of baseline length ranges. This resulted in 23,430 unique solutions - 781 rover stations having five different occupation times for each, which were then submitted to each of the six baseline length cases.

The GPS processing engine within OPUS uses the PAGES software suite (geodesy.noaa.gov/GRD/grddatasoftware.shtml) and the best available IGS products. Integer fixing, relative troposphere modeling (GMF *a priori* model) (Boehm, 2006) and relative antenna patterns are typically implemented for baseline processing of this nature. For each dataset, three single-baseline solutions were computed using an ion-free linear combination of the L1 and L2 carrier phase data with an elevation-dependent weighting scheme from the rover and the three reference stations to determine a set of ITRF2000 coordinates by averaging the results from each solution.

For each determination, the baselines were not considered to be independent because local biases from the rover datasets, such as multi-path, were not averaged out (Leick, 1995). This approach does, however, allow a submitter to identify problems pertaining to specific baselines. Peak-to-peak variations, the maximum range between each 3-D component among the three baselines, were reported by OPUS for *XYZ* and *north, east, up* components and can be considered as a more conservative measure than the root mean square (RMS) agreement among the three reference baselines (Schwarz 2006). Another benefit in using peak-to-peak errors is its ability to estimate the accuracy from known results. CORS coordinates are considered to be accurate to a few centimeters at any given epoch, after the application of secular velocities, though this is beginning to be limited by unknowns in GPS processing. Since the rover datasets in this experiment are actually subsets from 24-hour CORS datasets, the computed coordinates from OPUS for each submitted rover were then compared to the accepted coordinates for the subsequent CORS station.

5. COORDINATE COMPONENT ERRORS VERSUS BASELINE LENGTH

Each of the solution reports from the baseline constraining portion of the experiment were analyzed to determine the local *north, east and up* coordinates for all of the rover datasets. The mean absolute values between the accepted and computed local coordinates for the 781 rover stations observed for each of the five durations were tallied and are listed in Table 1.

Baseline Length Groups (km)

	>100<	>200<	>300<	>400<	>500<	>600<
δ north (m)	0.009±0.003	0.009±0.003	0.010±0.004	0.010±0.004	0.011±0.004	0.011±0.004
δ east (m)	0.014±0.009	0.015±0.009	0.015±0.009	0.017±0.011	0.017±0.011	0.017±0.010
δ up (m)	0.034±0.016	0.035±0.016	0.037±0.019	0.039±0.020	0.039±0.019	0.039±0.018

Table 1. Mean and std. deviations of the north, east and up component differences for 781 rover stations as a function of baseline length for all five data duration groups.

The horizontal and vertical component differences for all computed datasets are also illustrated as a function of baseline length in Fig. 5. Selecting baselines with lengths up to 600 kilometers had minimal effect on the *north* component. However, when the one-hour duration datasets were processed and analyzed, the *north* component errors were at least 1.6 times larger than those for datasets with an observation duration of two or more hours.

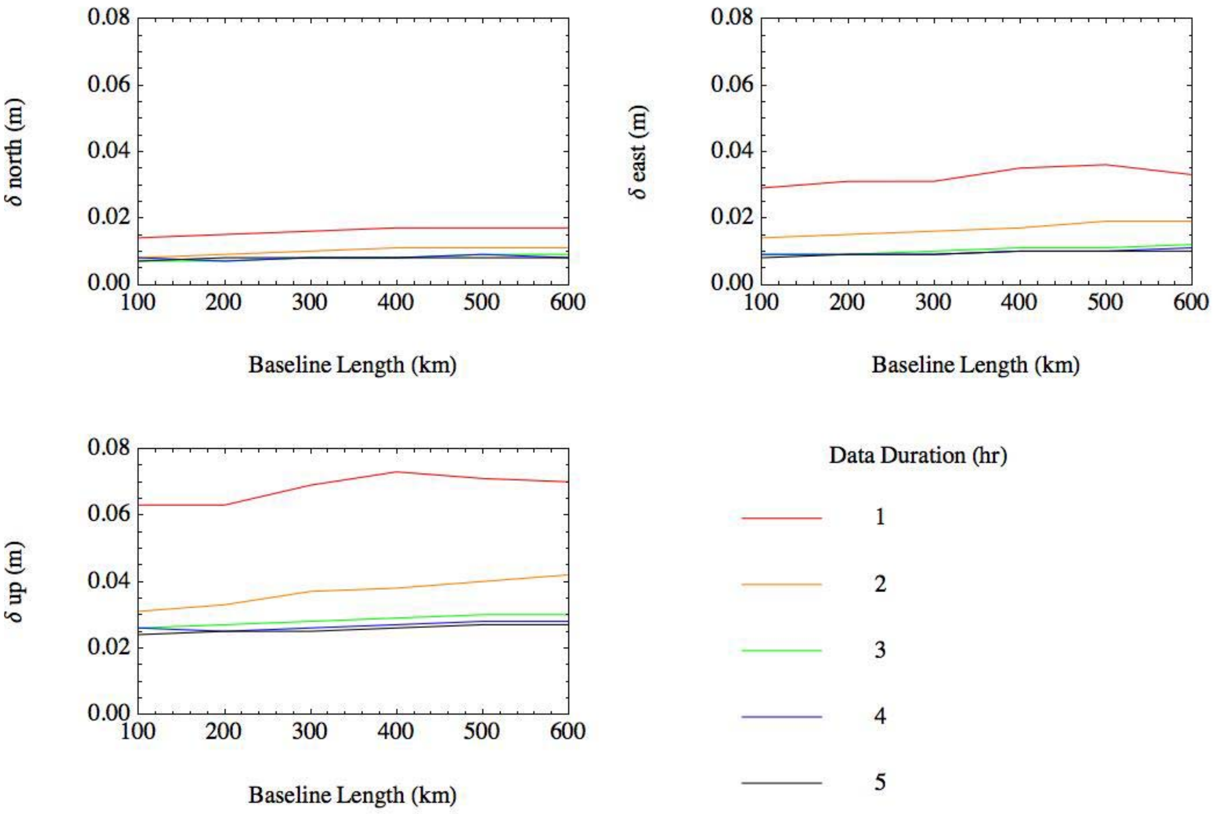

Fig. 5. Local *north*, *east* and *up* component errors when baseline lengths were constrained.

Baseline length also had minimal effect on the *east* and *up* components when the dataset durations were greater than two hours. East and up component errors for one hour datasets were 3.3 and 2.4 times larger than those for datasets with three or more hours while errors for two hour datasets were only 1.7 and 1.3 times larger. The results reported in Table 1 show, as anticipated, the *north* component is the most accurate and the vertical the least. This is primarily due to the satellite motion viewed from a fixed point on the earth. Satellite paths are nearly N-S rather than E-W and therefore the phase change is more sensitive in the N-S direction. A slight decrease in accuracies for the *north, east* and *up* components as the baseline lengths increase is also evident. Similar results have been reported by other investigators using similar network scenarios and processing methodologies (Eckl et al. 2001, Snay et al. 2002 and Soler et al. 2005). In Eckl et al. (2001) only 11 specific baselines ranging from 26 to 300 kilometers were examined while the duration of the datasets collected from the reference and rover stations varied from 4 to 24 hours. Although the length of the baselines are more typical of those encountered during GPS campaign practices, the duration of the occupations, at least for surveying, has significantly decreased during the last few years. This trend can be attributed to improvements in GPS receiver and antenna technologies as well as to numerous enhancements made to processing software packages and modeling.

6. COORDINATE COMPONENT ERRORS VERSUS OCCUPATION DURATION

Solutions from the rover occupation duration portion of the experiment were also analyzed in a similar fashion to those of Creager and Maggio (1998). The statistics reported were based on the mean absolute value between the accepted and computed coordinates for the same 781 rover stations used in all baseline constraining ranges for all durations.

The data reported in Table 2 and Fig. 6 show that the local *north*, *east* and *up* component errors improved (decreased) by 37, 48 and 46% respectively when the dataset durations increased from one to two hours. The six baseline length curves also converged for each component after about three hours of data. Very little improvement in component error occurred when three or more hours of data were processed. However, the results reported in this paper for datasets of three to five hours in duration are more accurate than those reported by Eckl et al. (2001). In their study, they report horizontal differences between the calculated and true positions for the rovers (4 hr datasets) varied by ± 1.2 cm while those for the vertical component varied by ± 3.8 cm. One possibility for the improvements in this study, at least for the vertical component, was that the experiment outlined used elevation-dependent weighting of GPS data observed down to a cutoff angle of 10º while Eckl et al. (2001) ignored phase measurements below 15º. Although GPS measurements observed from low elevation-angle satellites are noisier, improvements to baseline processing make the choice of including additional data more attractive.

	Data Duration (hrs)				
	1	2	3	4	5
δ north (m)	0.016±0.001	0.010±0.001	0.008±0.001	0.008±0.001	0.008±0.001
δ east (m)	0.033±0.003	0.017±0.002	0.010±0.001	0.010±0.001	0.009±0.001
δ up (m)	0.068±0.004	0.037±0.004	0.028±0.002	0.027±0.001	0.026±0.001

Table 2. Mean and std. deviations of the north, east and up component errors for 781 rover stations as a function of data duration.

Additionally, the solutions which had baselines less than or equal to 200 kilometers had slightly less *up* component error when the datasets were less than three hours. This was primarily due to the ease of fixing most of the integer ambiguities on shorter baselines. However, integer ambiguity resolution was less effective on short duration datasets when processed with longer baselines such as those whose length exceeds 300 or 400 kilometers.

During the data analysis phase, several rover stations in Alaska, Hawaii, Bermuda and Puerto Rico showed particularly larger than normal horizontal displacement errors. Most of these discrepancies were traced back to poor *a priori* coordinates and velocities for the reference stations. While every effort is made to monitor the reference station coordinates on a daily basis, the continuous increase in the number of stations has made the processing and analysis effort more intensive.

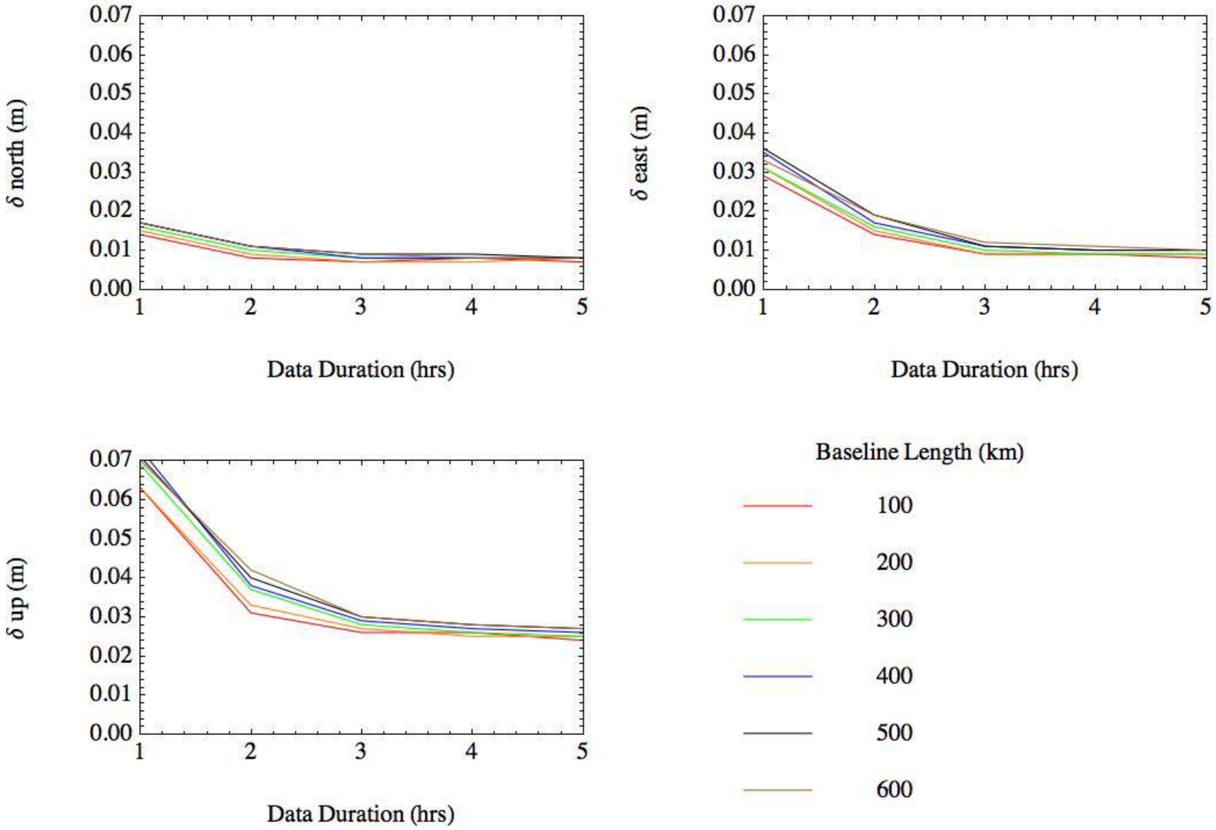

Fig. 6. Local *north*, *east* and *up* component errors as a function of rover occupation time for the six reference baseline distances.

7. CONCLUSIONS

The initial results from this experiment show that the accuracies derived from OPUS processing depend primarily on the duration of a dataset, and to a much lesser extent, the length of the baselines between the rover and the reference stations. The duration of the submitted data had a more significant impact on the coordinate component errors, with the *up* component being affected the most when short (less than two hours) duration datasets were used. Coordinate accuracies for one-hour datasets had larger peak-to-peak deviations while datasets that had between two and six hours of data showed significantly smaller peak-to-peak variations. The effect from rover to reference station separation was only noticeable after the baseline between the two started to exceed 500 kilometers. This may indicate that the tropospheric refraction model used in OPUS loses validity for longer distances. Poorer troposphere modeling for datasets less than two hours in duration was a significant contributor to the large errors seen for the vertical component. Another possibility may be due to the single baseline processing mode rather than performing a network adjustment with the rover and several reference stations. Although not mentioned in this work, a future study will likely focus on very short baseline length (up to 25 km) computations by OPUS. In this case, the processing will possibly be single frequency (L1) where common atmospheric effects are present at the rover and reference stations.

Investigations to improve the data processing algorithms, atmospheric modeling, along with solving integer ambiguities for long baselines are still ongoing at NGS as well as at many other research institutions. Any positive results with respect to this effort will be seen as significant and should help to determine if it is feasible to offer OPUS for international usage where the baselines will often be significantly longer.

The authors would like to thank the anonymous reviewers for their comments and helpful suggestions during the review process.

REFERENCES

Boehm, J., Niell, A., Tregoning, P. and Schuh, H., (2006), Global mapping function (GMF): A new empirical mapping function based on numerical weather model data, *Geophys. Res. Lett.*, vol. 33.

Creager, G.J. and Maggio, R.C., (1998), How long must we wait? Duration of GPS observations for long GPS baselines. *Proc Navigation's 54th Annual Meeting*, Denver, 467-475.

Eckl, M., Snay, R., Soler, T., Cline, M. and Mader, G.L., (2001), Accuracy of GPS-derived relative positions as a function of interstation distance and observing-session duration, *J. Geod.*, 75 (12): 633-640.

Leick, A., (1995), GPS satellite surveying (2nd edition). John Wiley, New York, New York.

Mader, G., Weston, N.D., Morrison, M. and Milbert, D., (2003), The On-line Positioning User Service (OPUS), *Professional Surveyor*, 23 (5): 26-30.

Schwarz, C.R., (2006), Statistics of range of a set of normally distributed numbers, *J. Surv. Eng.*, 132 (4): 155-159.

Snay, R. and Soler, T., (2008), Continuously Operating Reference Station (CORS): History, applications and future enhancements, *J. Surv. Eng.*, 134 (4): 95-104.

Snay, R., Soler, T. and Eckl, M., (2002), GPS precision with carrier phase observations: does distance and/or time matter? *Professional Surveyor*, 22 (10): 20-24.

Soler, T., Michalak, P., Weston, N.D., Snay, R. and Foote, R., (2005), Accuracy of OPUS solutions for 1- to 4-h observing sessions, *GPS Solutions*, 10 (1): 45-55.

Soler, T., Weston, N.D., Snay, R., Mader, G.L. and Foote, R., (2006), Precise georeferencing using on-line positioning user service (OPUS), *Proc., XXIII FIG Congress*, Fédération Internationale des Géometrès (FIG), Frederiksberg, Denmark.

BIOGRAPHICAL NOTES

Dr. **Neil D. Weston** is the operations and software development manager for OPUS. His interests are in GNSS software development, 3-D imaging and motion analysis. He currently works in the Geosciences Research Division of the National Geodetic Survey.

Dr. **Tomás Soler** is the chief technical officer in the Spatial Reference Systems Division. His research interest covers coordinate systems and transformations of reference frames.

Dr. **Gerald L. Mader** serves as the chief of the Geosciences Research Division. His research interests include kinematic GPS positioning, antenna calibrations and automated GNSS data processing.

CONTACTS

Dr. Neil D. Weston, Dr. Tomás Soler and Dr. Gerald L. Mader
National Geodetic Survey, NOAA
1315 East West Hwy, SSMC#3, Rm 8113

Silver Spring, MD
USA
Tel. +1 301 713 2847
Fax +1 301 713 4475
Email: neil.d.weston@noaa.gov
Web site: www.ngs.noaa.gov