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## Accuracy of OPUS solutions for 1- to 4-h observing sessions

Received: 8 June 2005  
Accepted: 14 June 2005  
Published online: 1 December 2005  
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**Abstract** We processed 30 consecutive days of Global Positioning System (GPS) data using the On-line Positioning Users Service (OPUS) provided by the National Geodetic Survey (NGS) to determine how the accuracy of derived three-dimensional positional coordinates depends on the length of the observing session  $T$ , for  $T$  ranging from 1 h to 4 h. We selected five Continuously Operating Reference Stations (CORS), distributed widely across the USA, and processed the GPS data for each with corresponding data from three of its nearby CORS. Our results support the current

OPUS policy that recommends using a minimum of 2 h of static GPS data. In particular, 2 h of data yielded a root mean square error of 0.8, 2.1, and 3.4 cm in the north, east, and up components of the derived positional coordinates, respectively. Results drastically improve for solutions containing 3 h or more of GPS data.

**Keywords** GPS Processing services · OPUS · Position relative to observation time

### Introduction

For more than a decade, the Global Positioning System (GPS) has been revolutionizing the way surveyors, engineers, GIS professionals, and others measure positional coordinates. In particular, GPS technology is enabling surveying companies to realize greater productivity. These companies, and geospatial professionals in general, are adopting GPS technology and merging it with their standard measuring systems to improve their efficiency and provide better customer services. As more and more surveying companies adopt GPS methodologies, they become the standard for the rest to follow. Currently, three-dimensional (3-D) positional coordinates of points can routinely be determined with centimeter-level accuracy, relative to GPS active control points that are continuously operated (Eckl et al. 2001). The National Geodetic Survey (NGS) a Program Office of the National Oceanic and

Atmospheric Administration (NOAA) manages such a network, the National and Cooperative Continuously Operating Reference Station (CORS), serving a diverse number of applications (Snay et al. 2002b; <http://www.ngs.noaa.gov/CORS/>). This network of active control points forms the basis for the National Spatial Reference System (NSRS) by providing a framework for surveying and mapping activities throughout the USA.

As a means to provide GPS users easier access to the NSRS, NGS developed the Web-based On-line Positioning Users Service (OPUS), which enables its users to submit static GPS observation files to NGS via the World Wide Web; whereby OPUS will compute positional coordinates for the location associated with the data. The OPUS utility uses NGS computers and PAGES (Program for the Adjustment of GPS Ephemerides) software (<http://www.ngs.noaa.gov/GRD/GPS/DOC/toc.html>) to provide geodetic positions consistent with

NSRS. OPUS is automatic and requires the user to input only a minimal amount of information (Mader et al. 2003). It processes submitted GPS data with corresponding data from three nearby CORS sites. Its users receive OPUS-derived positional coordinates via e-mail in a timely fashion, usually a few minutes. The OPUS report provides coordinates for both the current realization of the 3-D International Terrestrial Reference Frame (called ITRF2000) and the current realization of the North American Datum of 1983 (called NAD 83 (CORS96)). The adopted formulation for transforming ITRF2000 coordinates to NAD 83 (CORS96) coordinates is given in Soler and Snay (2004) and is practically implemented through the Horizontal Time-Dependent Positioning (HTDP) software (Snay 1999) (see <http://ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml>). The OPUS standard output also provides the user with 2-D State Plane Coordinates (SPC), Universal Transverse Mercator (UTM) coordinates, and for completeness, includes the convergence, the point scale on the map, and the combined factor involving the elevation reduction factor. For professionals who desire to do their own adjustment of vector components, OPUS also has the option of selecting an extended output containing more detailed information.

This investigation was motivated by the need to address the question of how accurate OPUS solutions are when the duration of the observing session (denoted  $T$ ) spans only a few hours, specifically  $1 \text{ h} \leq T \leq 4 \text{ h}$ . Shortening the total observation time hinders the resolution of integer ambiguities associated with carrier phase GPS data. Shortening  $T$  also provides less data for estimating the nuisance parameters associated with tropospheric refraction.

### OPUS solutions

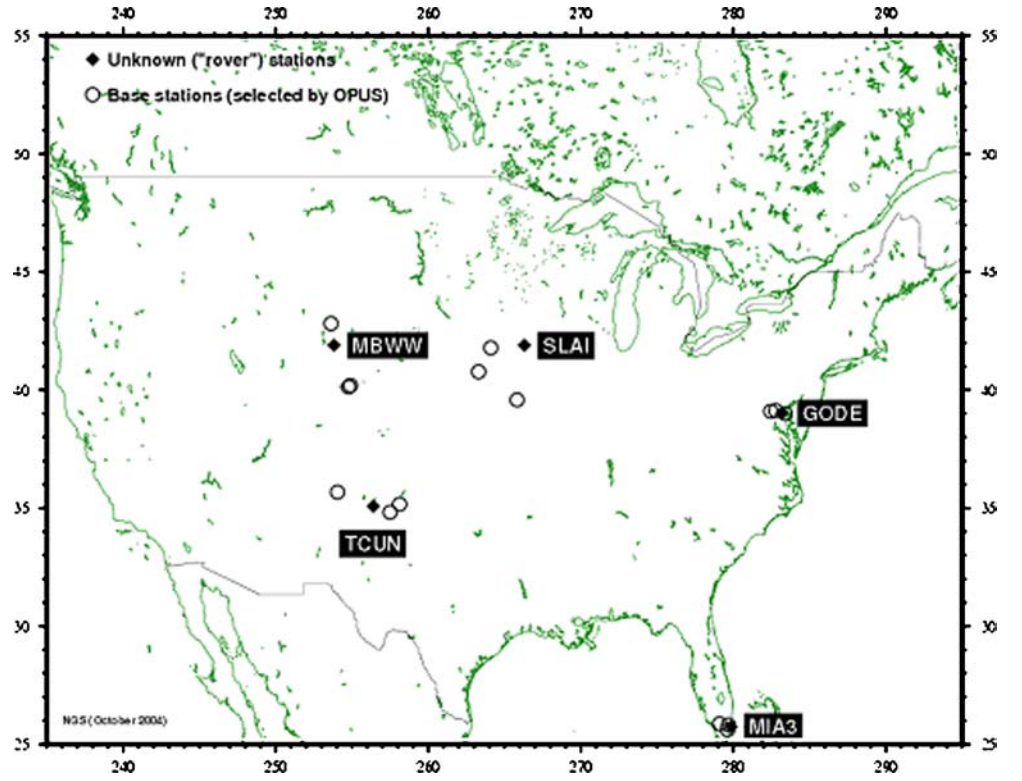
All OPUS solutions for this investigation used the “final” precise orbits disseminated by the International GNSS Service (IGS), which are readily available via the Internet (<http://igsb.jpl.nasa.gov>). The IGS currently disseminates 3-D satellite positions (ephemeris) at a sample interval of 15 min, with accuracies of about 3 cm and a latency of approximately 13 days (<http://igsb.jpl.nasa.gov/components/prods.html>). OPUS solutions use the ionospheric-free model obtained by combining the L1 and L2 carrier phase measurements, and a data-recording interval of 30 s. OPUS derives ITRF2000 coordinates of an unknown point by selecting three CORS sites as reference (fixed) stations. The positional coordinates and velocities of these three sites are extracted from NGS’ Integrated Data Base (IDB). The criteria followed to select the reference stations were primarily based on the quality of archived GPS data during the time span of the observing session. The dis-

tance between CORS sites is not a major concern; more emphasis is given to the compatibility between the user’s data and the data for the three CORS sites. OPUS applies TEQC (Translate Edit Quality Control) software developed by UNAVCO, Inc. (Estey and Meertens 1999) to check data quality and formatting problems. The OPUS solution is not a solution using all data simultaneously. Instead, it is the (unweighted) mean of three separate single-baseline solutions. Consequently, the choice was made to assume that checking “repeatability” is more important than doing a true multi-baseline solution. The three separate single-baseline solutions yield the peak-to-peak error for the resulting positional coordinates. This peak-to-peak error is thought to provide a more realistic measure of the quality of the determined positional coordinates, than formal errors obtained via a simultaneous solution. Formal error statistics do not account for unmodeled systematic effects due, for example, to orbital, atmospheric, multipath errors, and nonlinear motion of the reference stations. The peak-to-peak error represents the difference between the maximum and minimum value of a positional coordinate, as obtained from the three separate baseline solutions. Also it is always greater in magnitude than the conventional root mean square (RMS) error, preferred by many GPS users.

### Methodology and data processing

We selected five CORS sites throughout the USA to serve as unknown (“rover”) points. We assumed that the “true” coordinates of these rover points were provided by ITRF2000 values at an epoch of 1997.00, which are posted at <http://www.ngs.noaa.gov/CORS/coordinates>. These coordinates are the result of a multi-year solution involving GPS data ranging from 1994 to 2003. For each rover point, we selected 30 days of data observed during June 2004. We subdivided each day’s data into mutually, nonoverlapping sessions for each selected value of  $T$  (1, 2, 3, and 4 h). For each subset of data we computed the positional coordinates of each rover point using OPUS. In each case, and to save time, we allowed OPUS to automatically select a set of three reference stations. Finally, we used only those solutions that, in each case, involved the exact same set of these reference stations. This restriction ensured that certain systematic errors (e.g. errors in the relative positional coordinates among the reference stations) were not introduced into the results. Figure 1 depicts (as black diamonds) the location of rover points, identified by their four-character names. The figure also shows (by open circles) the corresponding CORS sites selected as reference stations by OPUS. For clarity, Table 1 contains the distances and azimuths, from the rovers, to each of their three associated reference stations.

**Fig. 1** Location of the reference stations used in this study



On-line Positioning Users Service computes ITRF2000 positional coordinates at the mean epoch of the observations, denoted  $t$ . Consequently, before comparing results it was necessary to transform these coordinates from epoch  $t$  to a common epoch 1997.00, according to the well-known equation:

$$\begin{Bmatrix} x(t) \\ y(t) \\ z(t) \end{Bmatrix}_{\mathcal{O}} = \begin{Bmatrix} x(1997.00) \\ y(1997.00) \\ z(1997.00) \end{Bmatrix} + (t - 1997.00) \times \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix}_{\mathcal{P}} \quad (1)$$

where the subindices P and O stand for “published” and “OPUS-derived,” respectively, and  $v_x, v_y, v_z$  are the

velocities along the Cartesian components  $x, y$ , and  $z$  on the ITRF2000 frame, as explicitly given in the published coordinate sheet of each CORS station.

Thus, the final coordinates on the ITRF2000 at epoch 1997.00 are:

$$\begin{Bmatrix} x(1997.00) \\ y(1997.00) \\ z(1997.00) \end{Bmatrix}_{\mathcal{O}} = \begin{Bmatrix} x(t) \\ y(t) \\ z(t) \end{Bmatrix}_{\mathcal{O}} + (1997.00 - t) \times \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix}_{\mathcal{P}} \quad (2)$$

The differences between published and OPUS-determined coordinates using Eq. 2 can be written as

$$\begin{Bmatrix} dx(1997.00) \\ dy(1997.00) \\ dz(1997.00) \end{Bmatrix} = \begin{Bmatrix} x(1997.00) \\ y(1997.00) \\ z(1997.00) \end{Bmatrix}_{\mathcal{O}} - \begin{Bmatrix} x(1997.00) \\ y(1997.00) \\ z(1997.00) \end{Bmatrix}_{\mathcal{P}} \quad (3)$$

In order to have a visual representation it is more convenient to plot these differences (residuals) with respect to a local geodetic frame pointing east, north, and up (geodetic vertical).

Therefore, the following well-known transformation is applied:

$$\begin{Bmatrix} de(1997.00) \\ dn(1997.00) \\ du(1997.00) \end{Bmatrix} = [R] \begin{Bmatrix} dx(1997.00) \\ dy(1997.00) \\ dz(1997.00) \end{Bmatrix} \quad (4)$$

**Table 1** Location of base stations with respect to rovers

CORS station (Rover)	Base stations	Distance (m)	Azimuth ( $^{\circ}$ )
SLAI	LTMH	261189.9	188.9208
	NEDR	280708.3	244.4947
	OMH1	184261.9	266.5105
MBWW	CASP	103025.6	350.9761
	TMGO	212628.7	157.5125
	ZDV1	210428.2	154.6049
MIA3	MTNT	76331.5	281.2888
	RMND	26048.3	239.6354
	ZMA1	18916.8	302.5571
TCUN	NMSF	223296.7	287.6911
	SUM1	104313.9	105.7375
	TXAM	157964.6	86.7427
GODE	ANP1	18886.9	93.7874
	GAIT	36312.7	290.1976
	ZDC1	62594.7	278.3690

where  $[R]$  is the  $3 \times 3$  rotation matrix of the transformation between the local global frame  $(x, y, z)$  and the local geodetic frame  $(e, n, u)$ , namely (e.g. Soler and Hothem 1988),

$$[R] = \begin{bmatrix} -\sin \lambda & \cos \lambda & 0 \\ -\sin \phi \cos \lambda & -\sin \phi \sin \lambda & \cos \phi \\ \cos \phi \cos \lambda & \cos \phi \sin \lambda & \sin \phi \end{bmatrix} \quad (5)$$

where  $\phi$  and  $\lambda$  denote the geodetic latitude and longitude of the point in question, respectively.

## Resulting statistics

For each point P and for each considered value of  $T$  (1, 2, 3, and 4 h), the various estimates for the positional coordinates of the “unknown rover” were compared with the published “true” coordinates; and corresponding differences were plotted on the local horizon frame along the components north (n), east (e), and up (u) using the formulation described above. Mean and RMS values in each component were then computed for each site and each value of  $T$ . Any individual component of a positional difference that exceeded its corresponding RMS value by more than a factor of three was then discarded, and the corresponding RMS was recomputed. Table 2 presents the number of solutions used and the total number of rejected solutions (solutions exceeding  $3\text{RMS} +$  solutions with different station set). The plots for station GODE along the north, east, and up components are given explicitly in the Appendix. The

Appendix also contains histograms of the residuals for the four observing times used in this investigation. If desired, the results for all other stations can be checked at <http://www.ngs.noaa.gov/OPUS/Plots/Paper/OPUSPlotsPaper.doc>. Station GODE was selected for presentation in this paper for no particular reason except that it belongs to the IGS network and is considered a reliable station whose history spans several years.

When using GPS, the formal statistics associated with the results are always optimistic because uncertainties assigned to observables usually do not account for various systematic errors such as meteorological conditions, multipath, etc. In the case of OPUS, NGS is studying the possibility of replacing the peak-to-peak values currently given on the output by another statistic able to represent, more realistically, the combined error of any OPUS solution. The first step was taken with this particular investigation where the peak-to-peak error was replaced by the following empirical equation for the standard error denoted  $s$ . This equation involves particular statistics available in the OPUS output:

$$s \text{ (cm)} = \sqrt{\left(\frac{\text{RMS}_\phi}{1.5}\right)^2 \times \left(\frac{k}{\sqrt{T}}\right)^2 + \left(\frac{p}{1.7}\right)^2} \quad (6)$$

$$\begin{cases} \text{east :} & k = 1; \quad p = p_e \\ \text{north :} & k = 1; \quad p = p_n \\ \text{up :} & k = 3.7; \quad p = p_u \end{cases}$$

$\text{RMS}_\phi$  (cm) = overall RMS for the doubly differenced iono-free carrier phase observables for the three single baseline solutions as given in the OPUS output.

**Table 2** The number of solutions performed and other statistics

CORS station	$T$ (h)	Number of all computed solutions	Number of solutions with the same station set	Number of rejected solutions (residual > 3RMS)	Number of used solutions	Rejected solutions (%)
SLAI	1	713	700	24	676	3.4
	2	356	355	15	340	4.2
	3	238	238	9	229	3.8
	4	177	172	4	168	2.3
MBWW	1	708	629	10	619	1.6
	2	354	314	15	299	4.8
	3	237	210	8	202	3.8
	4	179	159	4	155	2.5
MIA3	1	704	556	18	538	3.2
	2	356	283	16	267	5.7
	3	238	224	11	213	4.9
	4	179	136	7	129	5.1
TCUN	1	690	580	22	558	3.8
	2	347	294	13	281	4.4
	3	229	190	6	184	3.2
	4	170	135	6	129	4.4
GODE	1	712	565	22	543	3.9
	2	358	293	17	276	5.8
	3	237	196	10	186	5.1
	4	178	144	7	137	4.9



**Table 3** RMS values (cm) along the n, e, and u components for each point and each observing time window  $T$ . Observations were collected during the month of June 2004

$T$ (h)			GODE	MBWW	MIA3	SLAI	TCUN	MEAN	PRED
1	RMS	$n$	1.92	2.29	2.57	2.21	1.61	2.12	0.95
		$e$	5.28	5.86	8.10	6.85	5.21	6.26	0.99
		$u$	7.31	7.35	12.63	8.12	6.91	8.46	3.65
2	RMS	$n$	0.71	0.67	1.07	0.86	0.55	0.77	0.67
		$e$	1.63	1.45	3.62	2.32	1.52	2.11	0.70
		$u$	2.70	2.74	5.89	3.07	2.47	3.37	2.58
3	RMS	$n$	0.39	0.42	0.67	0.52	0.43	0.48	0.55
		$e$	0.60	0.43	1.48	1.05	0.77	0.87	0.57
		$u$	1.67	1.53	3.30	1.89	1.76	2.03	2.11
4	RMS	$n$	0.30	0.34	0.62	0.41	0.38	0.41	0.48
		$e$	0.83	0.37	0.83	0.60	0.54	0.63	0.50
		$u$	1.27	1.22	3.14	1.64	1.21	1.70	1.83

$T$ =total session duration in hours (1, 2, 3, or 4 h).  $p_e, p_n, p_u$  (cm)=peak-to-peak errors along the east, north, and up components as given in the OPUS output.

Values for  $k$  were derived empirically in a previous study (Eckl et al. 2001; Snay et al. 2002a). See also Eq. 7 later.

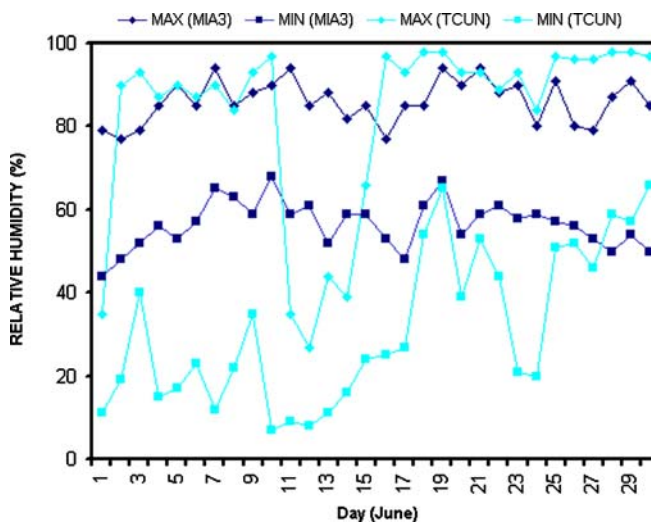
$RMS_{\theta}$  measures how well GPS data (involved in a particular OPUS solution) fit the mathematical model incorporated in PAGES software. This quantity is divided by 1.5 cm, which based on experimental results is considered the average value for a good OPUS solution.

The error bars depicted on the graphs are based on Eq. 6. Notice that they are primarily impacted by peak-to-peak errors, which are the most pessimistic of the sample statistics contained in Eq. 6. It is also apparent from the plots that the OPUS software has difficulty fixing integer ambiguities to their correct values when the time span of the observation is 1 h or 2 h. Hence, peak-to-peak errors are sometimes small, but the plotted point is located relatively far from the “true” value.

Table 3 summarizes the RMS errors. A perusal of Table 3 immediately reveals that station MIA3 has the largest RMS errors among the five rover points. In particular the vertical component is systematically larger by a factor of about two when compared to the other tabulated values. Although no detailed investigation to understand this dilemma was undertaken, the tropical weather in Florida, marked by high humidity, and the strong possibility that OPUS does not correctly model for tropospheric effects, may have contributed to the larger than usual RMS error for the height component at station MIA3.

In order to understand the possible tropospheric influence on the solutions obtained for this investigation, Figs. 2 and 3 show the daily maximum and minimum relative humidity and mean daily temperature for the month of June for stations TCUN and MIA3, which according to Table 3 are considered the best and worst

solutions of all the sites investigated. A cursory check on the humidity plot reveals that the overall humidity for MIA3 is larger than TCUN every day of the month. Furthermore, the range between the max. and min. humidity in the case of MIA3 always ranges between about 50% and 90%. The temperature graph also corroborates the fact that higher humidity and temperatures (such as MIA3) may produce the muggy conditions directly affecting the behavior of the troposphere which, at present, is very difficult to model. Many researchers are investigating this particular topic, trying to fully understand the real impact of humid weather on the troposphere and GPS observations. In any case, based on the empirical results of this exercise, cautions are in order when using GPS observations in general, and OPUS in particular, during summer months in tropical areas.



**Fig. 2** Daily maximum and minimum relative humidity for the month of June at MIA3 and TCUN

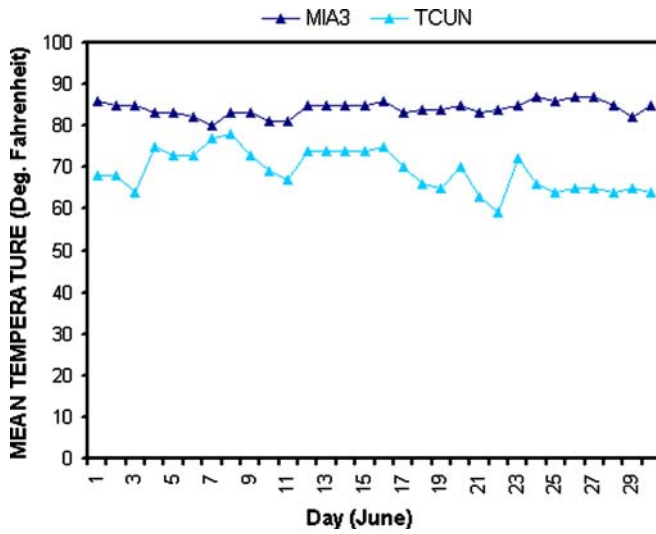


Fig. 3 Mean daily temperature at MIA3 and TCUN during the month of June

The overall systematic improvement of the solutions when observation time exceeds 1 h was expected. Also accuracy for the northward component is usually better

than that for the eastward component which, in turn, is better than the accuracy for the upward (vertical) component. The first NGS objective, while developing OPUS, was to simplify the labor of its constituency by freeing it from having to process GPS data. In fact OPUS can be used as a “black box” alternative for determining positional coordinates referred to the NSRS with relatively minor decision-making from a user. However, as Table 3 shows, the amount of total observing time in the field should be carefully considered, to attain prespecified accuracies like those required for some engineering/surveying projects. For example, to obtain sub-centimeter RMS error in the horizontal components, the observation time span should be at least 3 h. Assuming standard weather conditions, a 3 h observing session should yield ellipsoidal heights with an RMS error of about 2 cm.

Figure 4 displays the mean RMS error of the five tests performed for this investigation (Table 3). The predicted results (PRED in Table 3) were determined using the empirical formula presented in Eckl et al. (2001) and Snay et al. (2002a). According to these authors the RMS errors (expressed in cm) can be computed by the “simple-to-remember rule of thumb” equation:

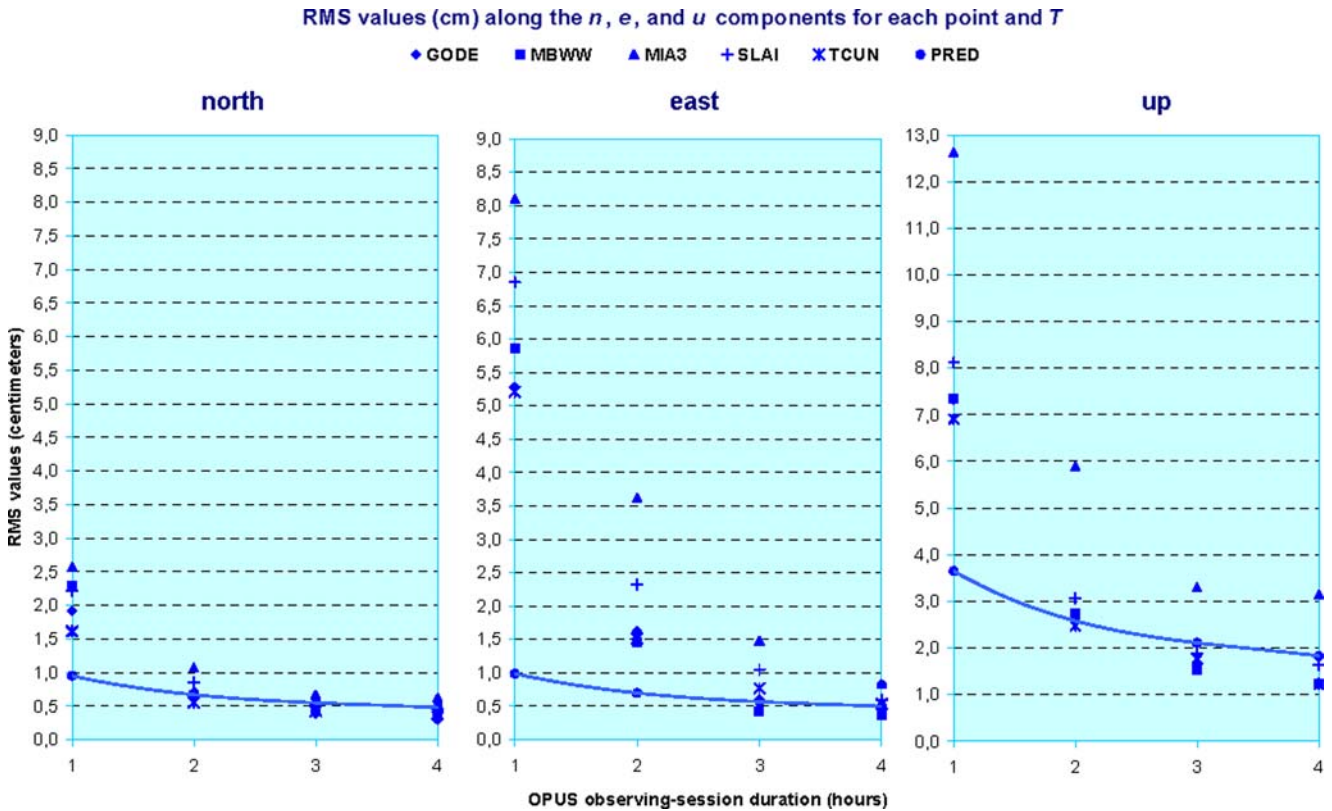


Fig. 4 OPUS results plotted against the predicted curve (Eq. 7). Note that the scale of the “up” plot differs from that of the “north” and “east” plots

$$\text{RMS (cm)} = \frac{k}{\sqrt{T}} \begin{cases} k = 1.0; & \text{horizontal (north and east)} \\ k = 3.7; & \text{vertical} \end{cases} \quad (7)$$

where  $T$  denotes the duration of the observing session expressed in hours and  $k$  is a free parameter in units of  $\text{cm}\sqrt{T}$ . The efficacy of Eq. 7 rests in its ability to predict RMS errors for other possible session duration, from 4 h to 24 h. As Fig. 4 and Table 3 shows, this empirical formula extrapolates well to sessions of 3 h, however, for 2 h and less, Eq. 7 should not be applied ‘ because of the difficulty of fixing integer ambiguities. Notice that the curve of Fig. 4 does not fit well the east component for  $T < 4$  h.

As Fig. 4 show, the following conclusion can be drawn: the RMS error for the north component fits well the predicted curve, except for the 1 h case, however, even when using only 1 h of observation time, the RMS error in the north component is about 2 cm, which is more than desirable for most surveying applications. With the exception of the station located in Miami (MIA3), the height (up) component fits the predicted graph well, except for GPS observations lasting 1 h. Finally, the east component is the weakest of the three when the observations span a short time. This is clearly seen in Fig. 4, where the RMS error (excluding MIA3) for 2 h of data jumps to about 2 cm and, more importantly, the 1-h case gives an average RMS error of about 6.5 cm. Thus, the RMS errors of the east and up components are greatly worsened for observation spans of 1 h or less.

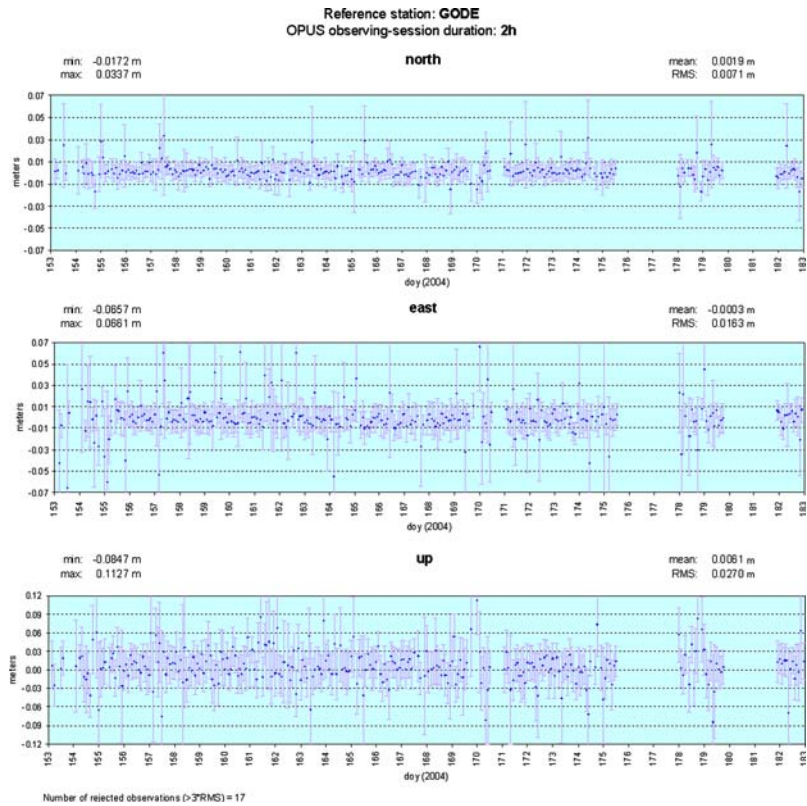
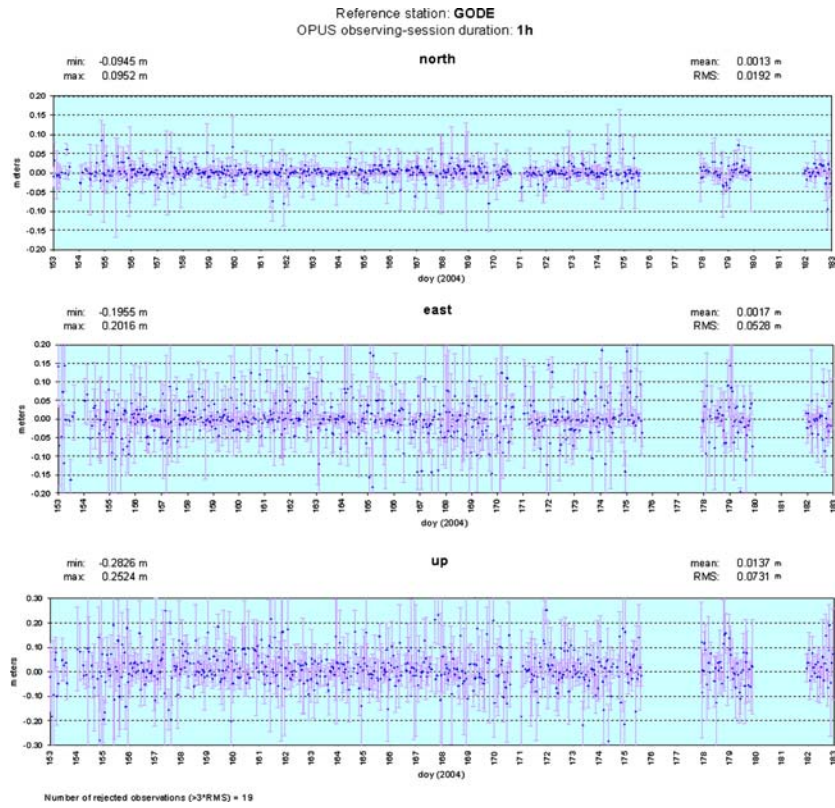
This expected degeneration of results when the observing time is 1 h or less, is not unique to OPUS. The majority of on-line services, such as AUSPOS, SCOUT, Auto-GIPSY, and PPP, give large errors when short periods of time are observed (Ghoddousi-Fard and Dare 2005; Tétreault et al. 2005), corroborating, primarily, that due to little or no change in geometry and anomalous atmospheric conditions, when the observation span is short it is very difficult to fix integers properly.

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## Conclusions

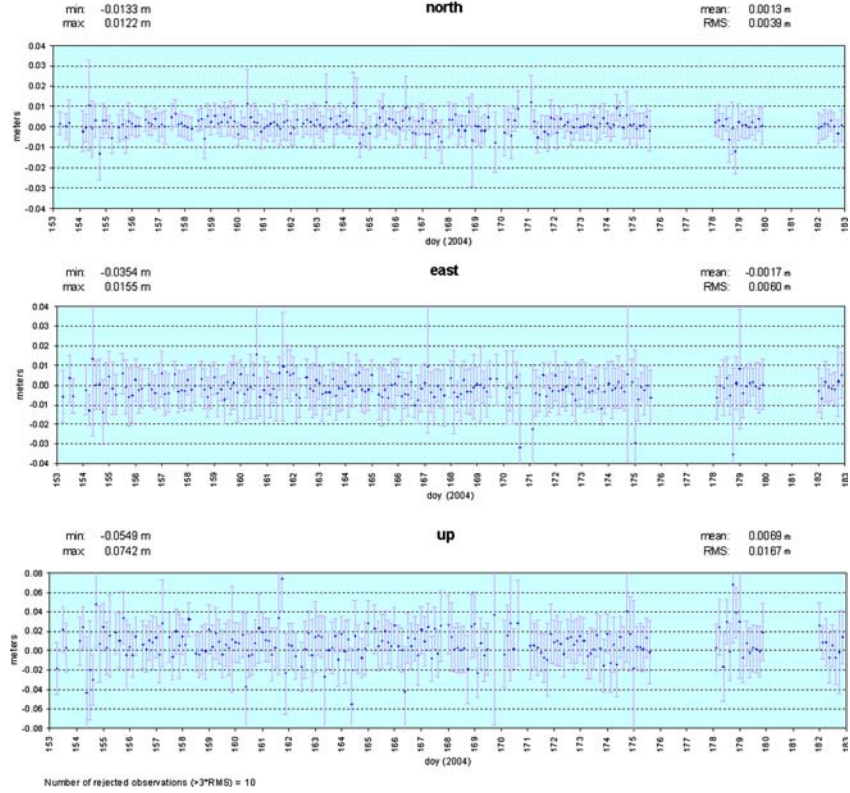
Since 2002, NGS has been providing the GPS community with OPUS processing, free of charge. Among the limitations for using OPUS, the time duration of the GPS data set was always emphasized. A minimum of 2 h of data is recommended to obtain results sufficiently accurate for surveying applications. The results of this investigation indicate, when using 2 h of data, results in the north, east, and vertical (up) components have experimentally determined RMS errors of 0.8, 2.1, and 3.4 cm, respectively. Reducing the observation span to less than 2 h drastically increases uncertainties due to difficulty in fixing integer ambiguities as consequence of poor geometry and local atmospheric disturbances. NGS is currently trying to develop alternative software capable of reliably fixing integer ambiguities for time periods of 15 min and less (Kashani et al. 2005).

# Appendix

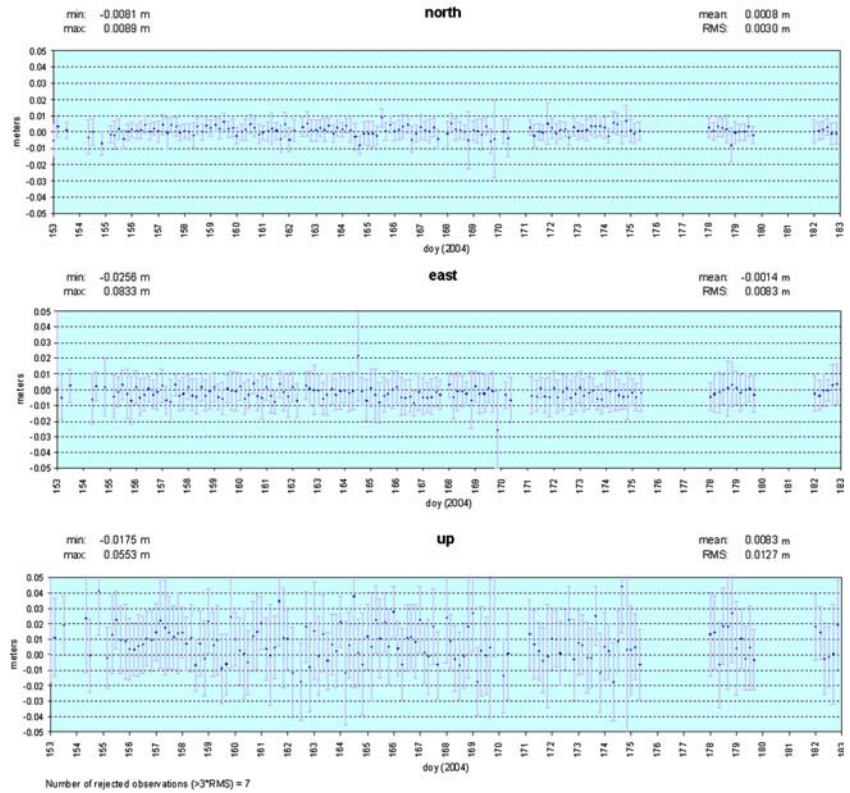


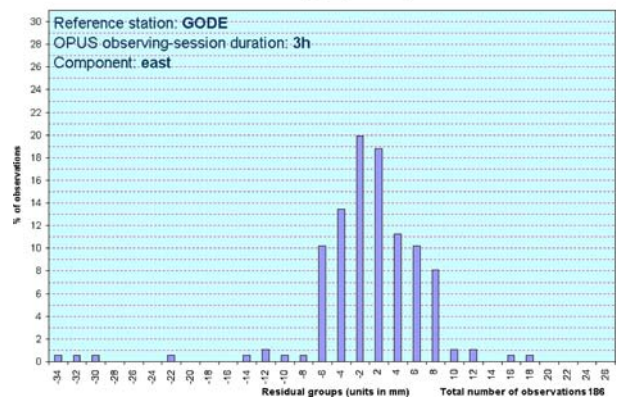
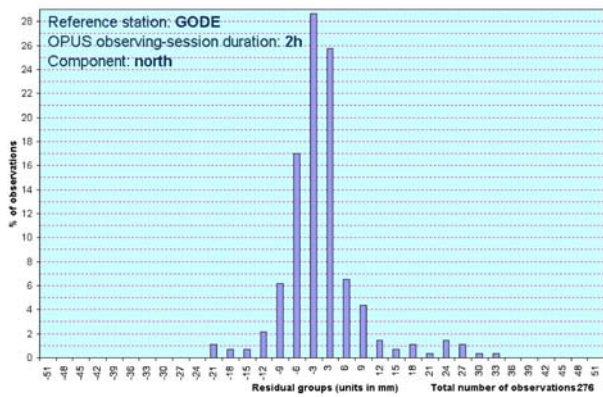
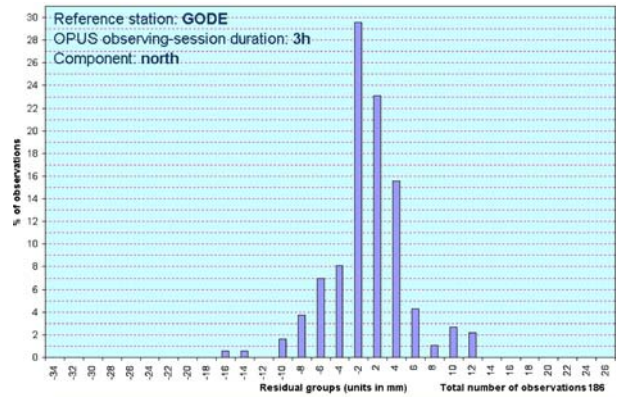
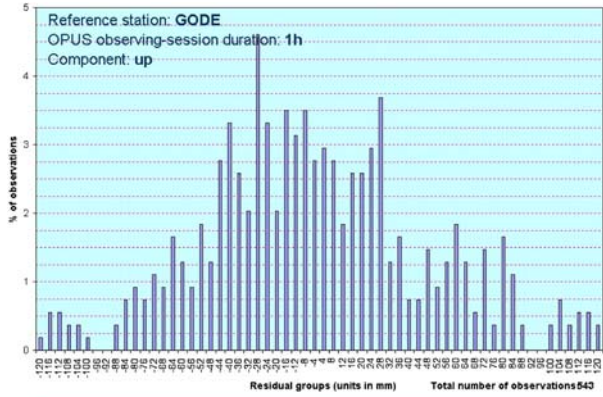
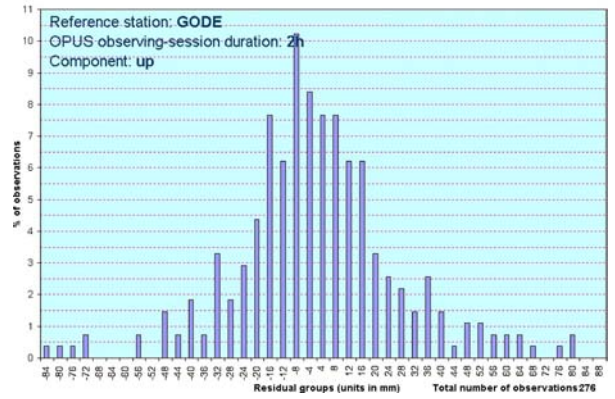
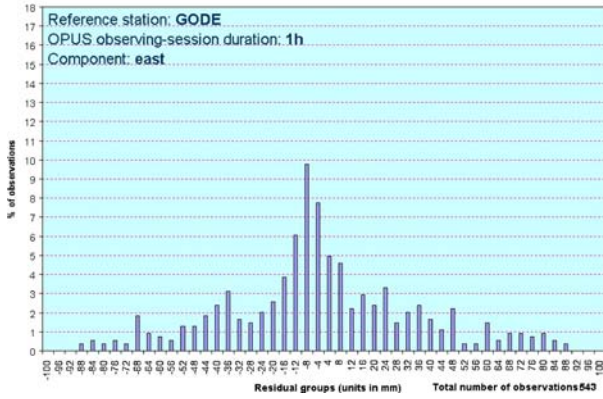
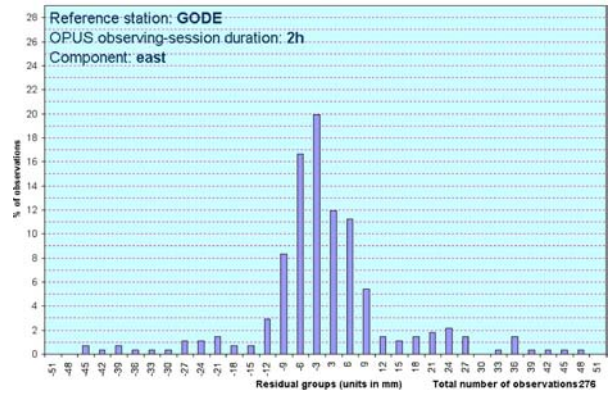
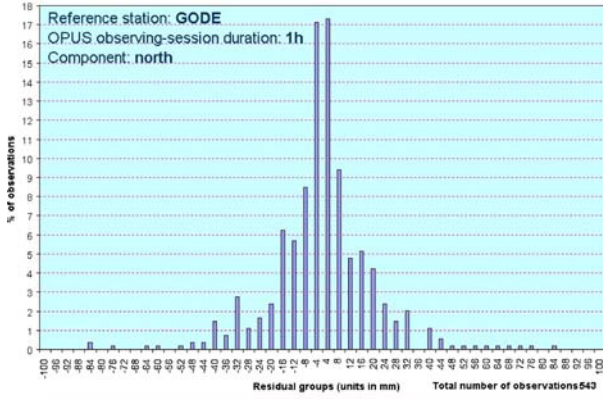


Reference station: GODE  
OPUS observing-session duration: 3h

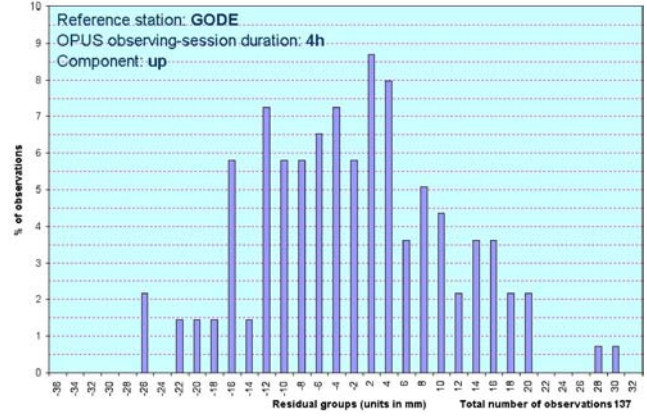
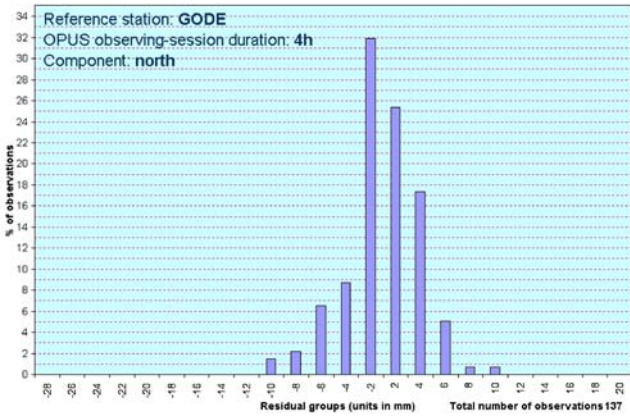
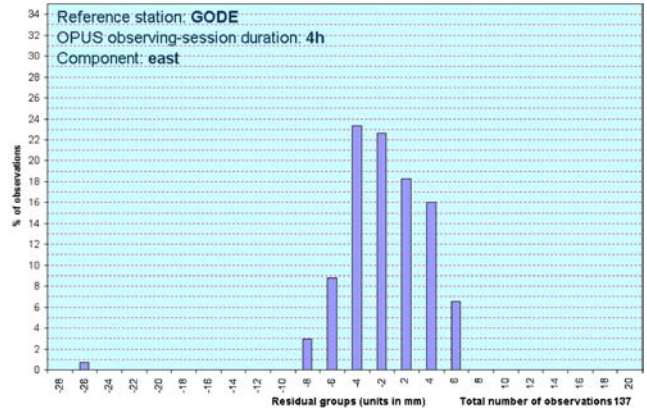
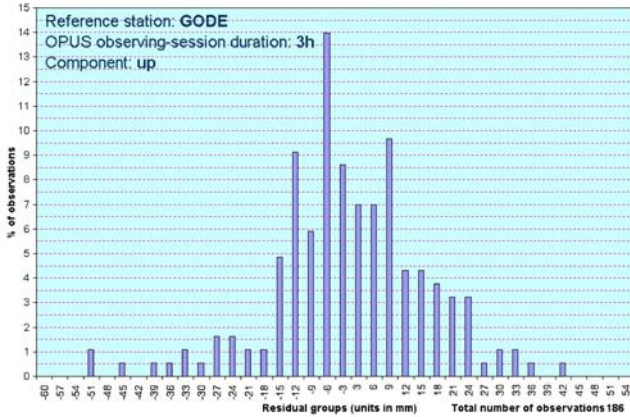


Reference station: GODE  
OPUS observing-session duration: 4h









References

Eckl MC, Snay R, Soler T, Cline MW, Mader GL (2001) Accuracy of GPS-derived relative positions as a function of interstation distance and observing-session duration. *J Geodesy* 75(12):633–640

Estey LH, Meertens CM (1999) TEQC: the multi-purpose toolkit for GPS/GLONASS data. *GPS Solutions* 3(1):42–49

Ghoddousi-Fard R, Dare P (2005) Online GPS processing services: an initial study. *GPS Solutions* 9(3) (in press)

Kashani I, Wielgosz P, Grejner-Brzezinska DA, Mader GL (2005) A new network-based rapid-static module for the NGS Online Positioning User Service—OPUS-RS. ION 61st Annual Meeting, June 27–29, Cambridge, MA, (Abstract)

Mader GL, Weston ND, Morrison ML, Milbert DG (2003) The On-line Positioning User Service (OPUS). *Prof Surv* 23(5):26, 28, 30

Snay RA (1999) Using HTDP software to transform spatial coordinates across time and between reference frames. *Surv Land Inf Syst* 59(1):15–25

Snay RA, Soler T, Eckl M (2002a) GPS precision with carrier phase observations: does distance and/or time matter? *Prof Surv* 22(10):20, 22, 24

Snay RA, Adams G, Chin M, Frakes S, Soler T, Weston ND (2002b) The synergistic CORS program continues to evolve. In: *Proceedings of the ION GPS 2002 (CD-ROM)*, Institute of Navigation, Alexandria, VA, pp2630–2639

Soler T, Hothem LD (1988) Coordinate systems used in geodesy: basic definitions and concepts. *J Surv Eng* 114(2):84–97

Soler T, Snay RA (2004) Transforming positions and velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983. *J Surv Eng* 130(2):49–55

Tétreault P, Kouba J, Héroux P, Legree P (2005) CSRS-PPP: an Internet service for GPS user access to the Canadian Spatial reference Frame. *Geomatica* 59(1):17–28