How Precise is OPUS?

Part 2: Available Precision Estimates

This is the second of three articles discussing the precision obtainable with the Online Positioning User Service (OPUS) offered by NOAA's National Geodetic Survey (NGS). The first article appeared in the immediately preceding issue of this magazine. OPUS is a Web-based utility available at www.geodesy.noaa.gov/OPUS to which surveyors and others can submit a dual frequency GPS data set and quickly receive an email containing positional coordinates for the location where their data were collected. OPUS computes these coordinates by processing the submitted data together with GPS data from the U.S. Continuously Operating Reference Station (CORS) network and/or the International GNSS Service (IGS) network. Actually, there are two OPUS processing engines. One engine is called OPUS-S, where "S" stands for *static*, which is designed for use with GPS data spanning more than two hours. The second engine is called OPUS-RS, where "RS" stands for *rapid static*, which is designed for use with GPS data spanning between 15 minutes and two hours.

In the first article, it was stated that the precision of coordinates computed with OPUS-S depends primarily on only one variable--the duration of the observing session. On the other hand, the precision of coordinates computed with OPUS-RS depends primarily on three variables: (1) the duration of the observing session, (2) the geometry of the CORS/IGS stations being used for the OPUS-RS solution (as measured by a quantity called IDOP), and (3) the distances from the user's GPS receiver (hereafter called the *rover*) to the various CORS/IGS stations being used for the OPUS-RS solution (as measured by a quantity called RMSD). OPUS-RS depends on network geometry and the distances from the rover to the CORS/IGS stations because it interpolates (or extrapolates) the atmospheric refraction values experienced at the CORS/

>> By Richard Snay, Kevin Choi, Gerald Mader,
Charles Schwarz, Tomás Soler and Neil Weston

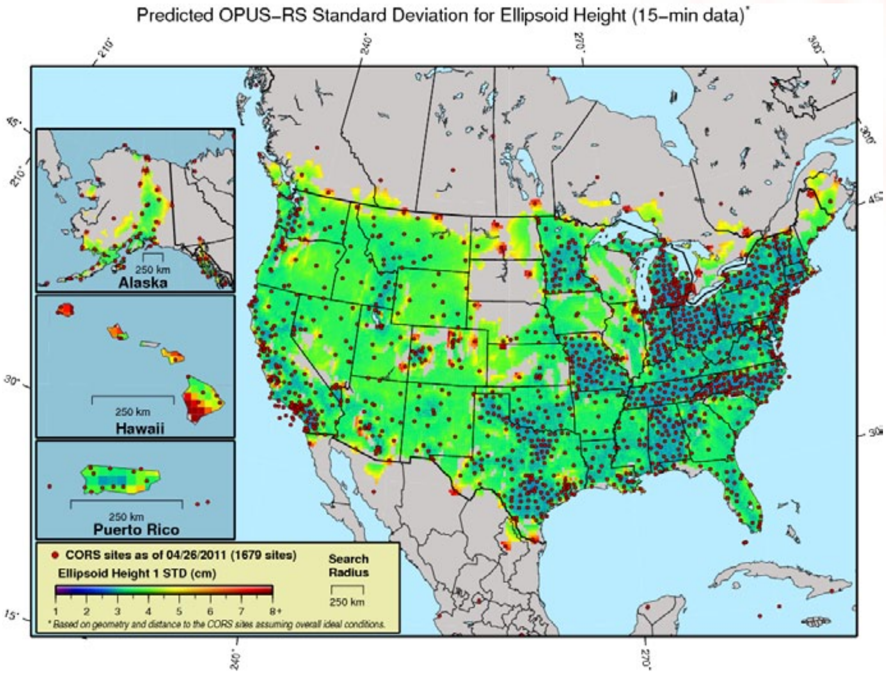

Figure 1. Map showing predicted standard deviation in ellipsoid height obtainable with OPUS-RS for 15-minutes of GPS data collected on April 26, 2011. Red dots represent available CORS/IGS stations on this date.

IGS stations to estimate the corresponding values at the rover.

As a result of the experiments described in the first article, NGS developed empirical formulas to estimate the standard deviations of OPUS-RS solutions as a function of both IDOP and RMSD. These formulas have the general form

$$\sigma = \sqrt{(\alpha \bullet \mathrm{IDOP})^2 + (\beta \bullet \mathrm{RMSD})^2 + \gamma^2}$$

where σ represents the standard deviation (for a particular dimension and a particular observing-session duration) and where α, β and γ are parameters whose values are estimated from several thousand OPUS-RS solutions. The values of α, β and γ vary depending on whether σ represents the standard deviation in a horizontal dimension or in ellipsoid height. Also, these values vary depending on the duration of the observing session.

Using these formulas, NGS then created maps that illustrate expected OPUS-RS standard deviations as a function of the geographic location of the rover. **Figure 1** illustrates such a map for the case of the vertical standard deviation obtainable with 15 minutes of observed data. NGS has developed an interactive Web-tool residing at www.geodesy.noaa.gov/OPUSI/Plots/Gmap/OPUSRS_sigmap.shtml which presents similar maps, some illustrating horizontal standard deviations and others illustrating vertical standard deviations, some for 15-minute observing sessions and others for one-hour observing sessions. With this tool users may specify a geographic location, whereby this tool will display the numerical value of the standard deviation in each dimension which may be expected with OPUS-RS for GPS data collected at that location. Because the contents of these maps depend highly on the number of available CORS/IGS stations and their geographic distribution, NGS updates the maps on this Web page on a weekly basis to keep pace with the rapid growth of the CORS/IGS network.

In yet another experiment, NGS researchers conducted a head-to-head comparison by processing each of several data sets with both OPUS-S and OPUS-RS, comparing both solutions to coordinates previously published by NGS. Both one-hour data sets and two-hour data sets were processed. OPUS-RS was the clear winner for one-hour data sets, primarily because OPUS-S could not reliably resolve the associated integer ambiguities. For two-hour data sets, the OPUS-RS results were only marginally more precise than the corresponding OPUS-S results, with a few exceptions when OPUS-S yielded slightly more precise results.

As a result of all the experiments, NGS recommends that users utilize OPUS-RS for observing sessions between 15 minutes and two hours and utilize OPUS-S for observing sessions longer than two hours. Actually, NGS is planning to revise the code for the OPUS web page so that data submissions will be directed automatically to either OPUS-S or OPUS-RS in accordance with this recommendation.

In actuality, the precision of both OPUS-S and OPUS-RS also depends on several additional variables including satellite geometry, multipath, GPS signal obstructions, and errors in the published CORS/IGS coordinates. Thus, the results presented so far provide only nominal values for expected precision. The actual precision of the coordinates realized for a particular OPUS-S solution, or a particular OPUS-RS solution, may differ from the results yielded by the equations and graphics previously presented here and in the first article. Hence, the output of each OPUS-S solution, as well as the output of each OPUS-RS solution, provides an independently determined measure of precision for each component of its computed coordinates (latitude, longitude, ellipsoid height, X, Y, and Z). This article discusses, in some detail, the precision measures reported in the outputs of OPUS-S and OPUS-RS.

In the case of the OPUS-S utility, its output reports what is known as the *peak-to-peak error* in each coordinate dimension and for the particular solution (see **Figure 2**). The peak-to-peak error is roughly 1.7 times larger than the corresponding standard deviation of the coordinates computed by OPUS-S. A characteristic of peak-to-peak errors is that they reflect inconsistencies existing among the CORS/IGS coordinates being used for the OPUS-S solution. As a result, some OPUS-S users have noticed rather large inconsistencies among certain published CORS/IGS coordinates. For this and other reasons, NGS and IGS have undertaken a project to compute new coordinates for CORS/IGS stations using all pertinent GPS data collected since 1994 and using current models for the phenomena that affect GPS accuracy. This project has gone by a few names, but mostly has come to be called the *Multi-Year CORS Reprocessing Solution.* These new coordinates should become available sometime in 2011, at which time users should notice smaller

How Does OPUS-S Compute Errors?

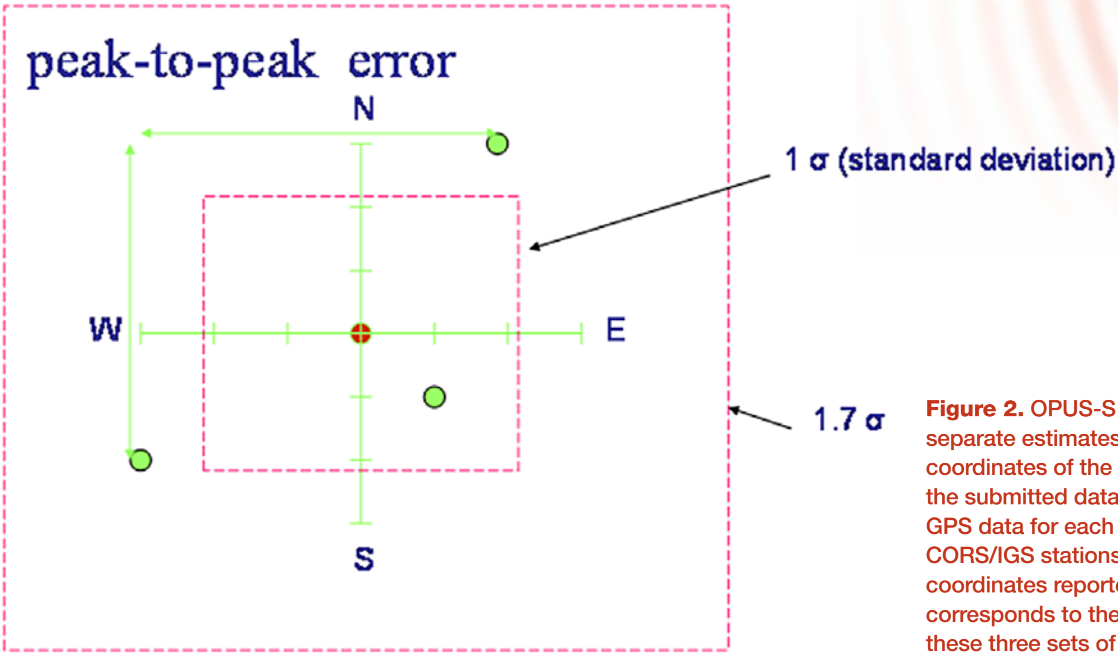

Figure 2. OPUS-S computes three separate estimates (green dots) for the coordinates of the rover by processing the submitted data with corresponding GPS data for each of three selected CORS/IGS stations separately. The coordinates reported by OPUS-S corresponds to the average (red dot) of these three sets of coordinates. The peak-to-peak error (green arrows) in a particular dimension (X, Y, Z, latitude, longitude, or ellipsoid height) is the difference between the largest and smallest of the three estimates for the coordinate value in that dimension. For a sample of size 3, the peak-to-peak error is approximately 1.7 times larger than its corresponding standard deviation, on average.

peak-to-peak errors in their OPUS-S solutions.

In the case of OPUS-RS, its output reports a *root-mean-square difference* (RMS difference) for each component of its computed coordinates and for the particular solution. To understand this measure, it is important to know that OPUS-RS selects between three and nine CORS/IGS stations located within 250 km of the rover, and that it will use data from all of these stations to compute the rover's coordinates in a simultaneous least squares process. In a separate process, OPUS-RS computes several additional estimates for the rover's coordinates, based on single baseline solutions, where each such estimate uses the submitted data with GPS data from only one of the selected CORS/IGS stations. The coordinates, obtained by using data from all selected CORS/IGS stations simultaneously, serve as the reported values for the solution. The reported precisions of these coordinates equal the root-mean-square value of computed differences where each difference is obtained by subtracting the reported coordinates from the corresponding coordinates that were computed using only the user-submitted data processed in combination with data from an individual CORS/IGS station. NGS performed experiments indicating that actual errors in the coordinates reported by OPUS-RS are less than the reported RMS differences more than 95 percent of the time. That is, each reported RMS difference approximates the half-width of the 95% confidence interval centered on the reported coordinate.

In most cases, the RMS differences provided by OPUS-RS yield more robust error measures than the peak-to-peak errors provided by OPUS-S, because the RMS differences are based on as many as nine separate solutions, whereas the reported peak-to-peak errors are based on only three separate solutions. As with OPUS-S precisions, OPUS-RS precisions reflect discrepancies among the published coordinates for the selected CORS/IGS stations. Thus, OPUS-RS results should also improve in precision after NGS and IGS update their published CORS/IGS coordinates sometime in 2011.

Note that with both OPUS-S and OPUS-RS, it is possible to compute "formal" error statistics in accordance with the theory of least squares estimation. NGS, however, has found that these formal error statistics usually provide much smaller values than the actual standard deviations associated with the computed coordinates. Hence, NGS has chosen to provide the more realistic peak-to-peak errors for coordinates computed with OPUS-S and the more realistic RMS differences for the coordinates computed with OPUS-RS. Nevertheless, neither the peak-to-peak errors, nor the RMS differences, can account for such errors (blunders) as those due to processing the data using an erroneous antenna height or antenna type.

Also, some users have questioned why OPUS-S performs three separate solutions rather than a single least squares solution simultaneously using GPS data from the three selected CORS/IGS stations. NGS has carefully considered this feedback and is researching computational engines that perform such a simultaneous solution for their viability as a formal NGS product.

The third article in this series will address factors, other than precision, which serve to distinguish between OPUS-S and OPUS-RS. This article, to appear in the next issue of this magazine, will also discuss what constitutes a "good" OPUS solution.

For author bios see Part 1.