How Precise is OPUS?

Part 3: The Rest of the Story

This is the third of three articles discussing the precision obtainable with the Online Positioning User Service (OPUS) offered by NOAA's National Geodetic Survey (NGS). The first two articles appeared in preceding issues 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.

While the precision of OPUS-S and OPUS-RS were addressed in the first two articles, there is more to the story. Certainly precision is important, but other factors also serve to distinguish between OPUS-S and OPUS-RS. One factor is that OPUS-RS requires much more computational resources than OPUS-S. Also of particular importance is the success rate of each of these two utilities. While OPUS-S has successfully computed coordinates for over 90% of the data

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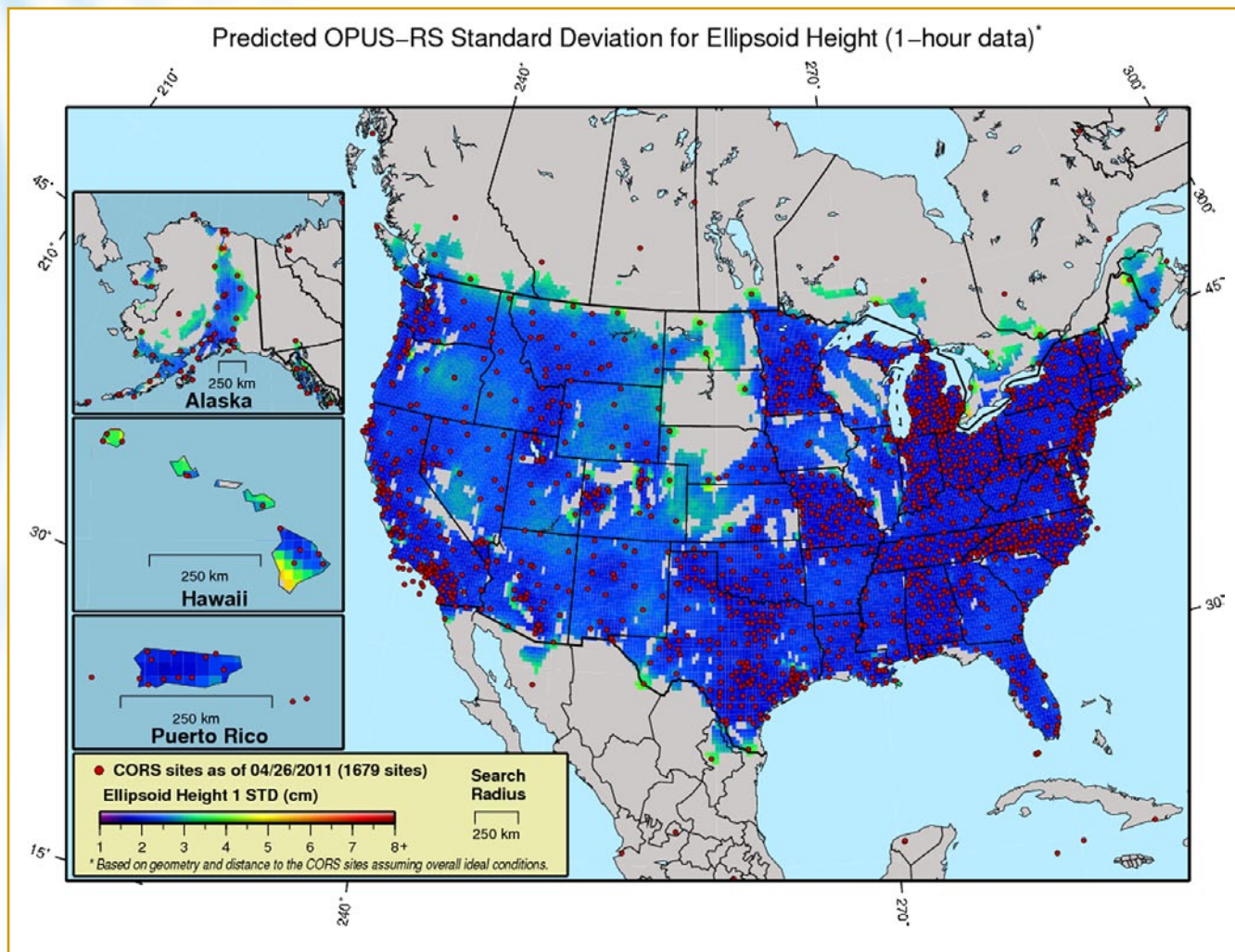
Predicted OPUS–RS Standard Deviation for Ellipsoid Height (1–hour data)*

Figure 1 Map showing predicted standard deviations in ellipsoid height obtainable with OPUS-RS for 1-hour of GPS data collected on April 26, 2011. Red dots represent available CORS/IGS stations on this date. Points located in the gray regions either do not have at least three CORS/IGS stations located within 250 km of them or they are located more than 50 km outside of the smallest convex region that encompasses as many as nine of the closest CORS/IGS stations within 250 km.

sets submitted to it, OPUS-RS has successfully computed coordinates for only approximately 67% of the data sets submitted to it. These success rates do not address the precision of the computed coordinates, just the ability to perform the computation.

To better understand why OPUS-RS experiences so many failures, NGS personnel studied the collection of error messages issued by failed OPUS-RS solutions during the 30-month period from January 2008 to June 2010. A total of 31 different types of error messages were encountered. **Table 1** identifies the top ten types of error messages issued during this 30-month period. These ten

error types account for approximately 86% of the failed OPUS-RS solutions.

According to **Table 1**, the most frequent cause of failure is users submitting more than two hours of GPS data to OPUS-RS. This two-hour limitation is indeed an artificial restriction imposed by NGS. For sure, OPUS-RS could process many more hours of data if NGS allowed it to do so. However, the code within OPUS-RS invokes some simplifying approximations. The most critical of these approximations is based on the assumption that the travel time delay due to the distribution of molecules in the neutral atmosphere (commonly referred to as tropospheric refraction)

remains constant for the entire time span of the data. Hence, the longer the time span, the more likely the tropospheric refraction will vary significantly from a constant value. By way of contrast, OPUS-S partitions the data's total time span into 30-minute segments and assumes that the tropospheric refraction remains constant for each of these segments, but allows this refraction to vary from segment to segment.

As an aside, the assumption that the tropospheric refraction remains constant for a period of time can be the downfall of both OPUS-S and OPUS-RS when trying to process GPS data collected when the weather changes abruptly such as during the onset of a thunderstorm. NGS has experienced many poor OPUS-S and OPUS-RS solutions when trying to process GPS data collected during summer months in subtropical regions like southern Florida.

As mentioned in the second article, NGS is planning to revise the code

DESCRIPTION OF ERROR (COMMENT)	PERCENTAGE OF OPUS-RS FAILURES
Submitted data set spans more than two hours (*New OPUS web page will automatically redirect such data sets to OPUS-S.*)	19.33
Cannot find three CORS/IGS stations within 250 km of rover (*Users should inspect maps at www.geodesy.noaa.gov/OPUSI/Plots/Gmap/OPUSRS_sigmap.shtml to see if there are at least three CORS/IGS stations located within 250 km of the rover.*)	18.61
Less than three CORS/IGS stations remaining after the single baseline analyses (*OPUS-RS will eliminate a CORS/IGS station if its data yield results that differ significantly from the results obtained with data from the other selected CORS/IGS stations.*)	7.43
Submitted data set spans less than 15 minutes (*Although OPUS-RS could attempt a solution for shorter observing sessions, success rates are so low that NGS has implemented a cutoff at 15 minutes for the minimum span of the data set.*)	7.35
Rover is located more than 50 km outside of the smallest convex area on the Earth's surface which encompasses the set of selected CORS/IGS stations (*NGS has found that OPUS-RS will often fail if this utility has to extrapolate atmospheric refraction over distances greater than 50 km from this convex area.*)	6.88
Submitted data set includes data for more than one location	6.64
The submitted RINEX file failed to pass an initial test for one or more of the following reasons: The RINEX file contains data for only a single frequency, The RINEX file is not formatted correctly, One of the lines in the RINEX file is over 80 characters in length.	5.65
The user selected a CORS/IGS station whose GPS data are currently unavailable (*OPUS-RS will allow the user to select one or more of the CORS/IGS stations whose data are to be used in the solution. OPUS-RS will automatically select additional CORS/IGS stations as needed.*)	5.30
GPS data for the CORS/IGS stations are not yet available (*NGS receives data from most CORS/IGS stations only once per hour. Also, it usually takes about 30 minutes after the turn of the hour for NGS to ingest hourly data sets from the entire CORS network. Thus, if the user's observing session ended at 10:15 am, for example; the user should not submit the corresponding data to OPUS-RS until after 11:30 am.*)	4.80
OPUS-RS encountered an unspecified error when trying to process data from the selected CORS/IGS stations (*Such an error message is systematic of a problem with the CORS/IGS data; it does not reflect on the quality of the user-submitted data.*)	4.00

Table 1 Top ten error types experienced by OPUS-RS between January 2008 and June 2010.

behind the OPUS Web page so that the new code will automatically direct submitted data that spans more than two hours to OPUS-S while directing data that spans less than two hours to OPUS-RS. This new code will thus eliminate the most frequent error type causing OPUS-RS to fail.

According to **Table 1**, the second most frequent cause of OPUS-RS failure is the unavailability of at least three CORS/IGS stations within 250 km of the rover. Without at least three CORS/IGS stations, OPUS-RS cannot effectively interpolate/extrapolate the effect of atmospheric refraction to the rover. Maps, such as **Figure 1**, can help users identify the geographic regions where OPUS-RS is doomed to failure due to a lack of CORS/IGS stations in those regions. NGS creates such maps on a weekly basis to reflect the latest distribution of available CORS/IGS stations. Users may view these maps at *www.geodesy.noaa.gov/OPUSI/Plots/Gmap/OPUSRS_sigmap.shtml*. These maps, however, do not show the temporary outages occasionally experienced by individual CORS/IGS stations. Such temporary outages may cause the number of available CORS/IGS stations to drop below the magic number of three during a particular observing session. The remedy to this type of failure is simple in concept: increase the number of CORS/IGS stations in the United States and its territories. Indeed, the CORS network has been growing rapidly at a rate of more than 200 new stations per year during the past few years, thanks to contributions from more than 200 organizations that have built these stations and allowed NGS to freely provide their GPS data to the public.

Further examination of **Table 1** provides additional insights as to how to reduce the number of OPUS-RS failures. Some failures can be eliminated by improving OPUS-RS and others by improving the users' understanding of how OPUS-RS works. Simply by reducing the top two error types, the success rate of OPUS-RS will improve significantly, because these two error types have accounted for approximately 38% of the OPUS-RS failures during recent times.

Coordinate precisions discussed in these two articles are contingent on obtaining a "good" OPUS solution. So it may be asked, what constitutes a good

solution? In the case of OPUS-S, NGS has suggested the following criteria:

- correct antenna type and antenna height used
- precise or rapid orbit from IGS used
- > 90% observations used
- > 50% ambiguities fixed
- RMS of residuals < 3 cm
- peak-to-peak error < 5 cm in latitude, longitude, and ellipsoid height.

In the case of OPUS-RS, similar criteria apply with the following differences. OPUS-RS requires that ALL integer ambiguities be fixed to their correct value, and so this utility employs a numerical measure called the W-ratio. Tests indicate that it is highly likely that all ambiguities have been correctly fixed if the W-ratio exceeds 3.0 in value. Otherwise, one or more of the ambiguities may have been fixed to an incorrect value. The OPUS-RS output actually reports two W-ratio values (or two "quality indicators" as they are referred to in the OPUS-RS output). The first W-ratio is for the process involving only CORS/IGS data when estimating the ambiguities and the values for the atmospheric refraction at the CORS/IGS stations. The other W-ratio is for the process that uses the rover's data, together with the CORS/IGS data, to estimate the rover's coordinates. Both W-ratios should be greater than 3.0 for a good OPUS-RS solution. Furthermore for OPUS-RS, the RMS difference of the computed coordinates (rather than the peak-to-peak error) should be less

than 5 cm in each dimension (except the RMS difference should be less than 10 cm in ellipsoid height when the duration of the observing session is less than 30 minutes). Moreover for OPUS-RS, the RMS of the *normalized residuals* should be less than 1.0, rather than the RMS of the residuals being less than 3 cm as is the criterion for OPUS-S. OPUS-RS computes normalized residuals by dividing each residual by its assumed standard deviation. The OPUS-RS output reports the RMS of the normalized residuals because this utility uses both carrier phase data and pseudorange data (with the latter having much larger standard deviations). OPUS-S uses only carrier phase data.

In summary, the suggested criteria for a good OPUS-RS solution are as follows:

- correct antenna type and antenna height used
- precise or rapid orbit from IGS used
- > 90% observations used
- both W-ratios exceed 3
- RMS of normalized residuals < 1
- RMS difference < 5 cm in latitude, longitude, and ellipsoid height (except for sessions shorter than 30 minutes in which case the RMS difference in ellipsoid height should be less than 10 cm).

Another criterion for a good OPUS solution, which NGS has yet to study, is the need for good satellite geometry as may be measured, for example, by the *geometric dilution of precision* (GDOP). For observing sessions exceeding two hours in duration, the value of GDOP probably does not matter much because of the volume of available GPS data. However, the value of GDOP during a 15-minute observing session probably does strongly influence the precision of the coordinates computed with OPUS-RS. So research on this topic remains on NGS' "to do" list.

Moreover, with either OPUS-S or OPUS-RS, it is a good idea to conduct multiple observing sessions at the same location and to compare OPUS-generated coordinates among the different sessions to see if separate values agree with each other within their specified error estimates.

More detailed information about OPUS and its precision may be found in OPUS-related articles available on the Web at *www.geodesy.noaa.gov/CORS/Articles* and in a collection of scientific papers written by several authors and published by the American Society of Civil Engineers under the title, *CORS and OPUS for Engineers: Tools for Surveying and Mapping Applications.*

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