NGS Geodetic Tool Kit, Part II: The On-line Positioning User Service (OPUS)

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The National Geodetic Survey (NGS) officially began public operation of the web-based On-line Positioning User Service (OPUS) in March 2001 as a means to provide GPS users easier access to the National Spatial Reference System (NSRS). Through OPUS, our goal is to provide the means to accurately, reliably, and quickly obtain consistent geodetic positions.

OPUS allows users to submit their GPS data files in receiver independent exchange (RINEX) format to NGS via the Web, whereupon the data will be processed to determine a position using NGS computers and software. Each RINEX file that is submitted will be processed with respect to three reference sites, which may be National Continuously Operating Reference Stations (CORS) or International GPS Service (IGS) sites. OPUS will try to select the three sites nearest to the user’s location but will expand the search based on data availability and quality. NGS has also introduced a new feature where the user may select one, two or all three of the reference sites from a list of available reference stations. This list will soon also include qualifying cooperative CORS sites. If the user specifies less than three sites, then OPUS will select the remaining sites. Currently, a minimum of two hours of data are needed for OPUS to begin.

Positions computed by OPUS are usually e-mailed to the user within a few minutes. The OPUS report contains both the International Terrestrial Reference Frame (ITRF) and North American Datum of 1983 (NAD 83) coordinates, as well as the Universal Transverse Mercator (UTM) and State Plane Coordinates (SPC).

OPUS is completely automatic and requires only a minimal amount of information from the user:

1. The email address where you want the results sent.

2. The RINEX file that you want to process (which you may select using the browse feature).

3. The antenna type used to collect the GPS data in this RINEX file (selected from a list of calibrated GPS antennas).

4. The height of the Antenna Reference Point (ARP) above the monument or mark that you are positioning.

5. As an option, you may also enter the state plane coordinate code if you want SPC northing and easting.

6. As an additional option, you may select one, two, or all three of the reference sites to be used by OPUS.

Wherever possible, OPUS uses drop-down boxes for selections to minimize hand entries by the user and hence reduce the possibility of errors.

A copy of the OPUS submittal page is shown in **Figure 1**. This page can be accessed at *www.ngs.noaa.gov/OPUS/*. OPUS is intended to process only static, dual-frequency, carrier phase observations. Users are cautioned not to submit kinematic data. The NGS software only uses data spaced at 30 second intervals and occurring on the minute and half minute. Users may submit data collected at a faster rate, but only the 30 second data will actually be used. OPUS only accepts RINEX files in ASCII, and compressed or zipped format and following the RINEX naming convention.

OPUS is intended for use in the coterminous United States, Alaska and Hawaii, and most territories. It is NGS's policy to not publish geodetic coordinates outside the United States without the agreement of the affected countries. The OPUS web site contains a set of maps indicating areas where OPUS can be used.

How Are the Solutions Performed?
OPUS-derived ITRF positional coordinates are the average of three distinct single-baseline solutions computed by double-differenced, carrier-phase measurements from

three different reference sites using the program PAGES. The ITRF coordinates for the reference sites have been obtained from the NGS Integrated Data Base (IDB) and have been updated to the midpoint of the time interval when the submitted data were observed. Hence, OPUS-derived ITRF coordinates correspond to the position of the point at this instant in time. Points in the coterminous United States move between 9 and 22 mm/yr horizontally, relative to ITRF. OPUS-derived NAD 83 positional coordinates are also the average of three distinct single-baseline solutions. The procedure followed to compute final NAD 83 coordinates at epoch 2002.0 is as follows:

First, the three derived ITRF inter-site vectors, given at the midpoint of the data time interval, are individually transformed to the NAD 83 reference frame. Second, the NAD 83 coordinates of the three reference stations, retrieved from the NGS IDB, are also updated to the midpoint of the interval by applying the NAD 83 velocities available from the NGS IDB. Each NAD 83 vector is added to the NAD 83 coordinate of the corresponding reference station to determine one of the three different values of the coordinates of the unknown point on the NAD 83 frame at the midpoint epoch. These three quantities are averaged to better estimate the coordinates of the point at this epoch. Finally, these coordinates are then transformed in time to the epoch date of January 1, 2002 by using the NAD 83 velocity for the point as predicted by the HTDP (Horizontal Time-Dependent Positioning) software.

Because NAD 83 positional coordinates in the coterminous United States are referenced to the North American tectonic plate, NAD 83 velocities are typically very small. NAD 83 velocities in excess of 5 mm/yr, however, are prevalent in states along the Pacific Coast. Note that the OPUS-derived NAD 83 positional coordinates are not obtained by a direct transformation of their corresponding ITRF coordinates.

While three single-baseline solutions are computed, these solutions can not be considered as completely independent. Local biases at the user’s submitted station will not be averaged away by the combination. For example, local multipath error or error in the height of the Antenna Reference Point (ARP) will ***not*** be averaged away. On the other hand, use of three single-baselines does provide a gauge of certain error contributions.

What Is the Accuracy of the Result?

Accuracy estimates for GPS reductions obtained by formal error propagation are notoriously optimistic. For this reason, OPUS does not rely only on the formal errors. Instead, the peak-to-peak variation is provided for each coordinate component (XYZ and north-east-up). The peak-to-peak variation is the difference between the maximum and the minimum value of a coordinate obtained from the three baseline solutions. Peak-to-peak variations are more conservative (i.e., greater) than the more conventional root mean square (RMS) estimates of coordinate repeatability. However, given the single file being submitted and the limited number of reference stations used, peak-to-peak variations are a more appropriate choice. A key element, which bears repeating, is that accuracy estimates depend upon freedom from systematic error. For example, if the antenna type is misidentified, then the wrong antenna phase center variation model and the wrong phase center-ARP offsets will be applied to the data. This could lead to errors of 10 cm or more that will not be displayed in the peak-to-peak variation value. Additionally, errors in the submitted antenna height cannot be detected. The accuracy of this information is totally dependent on the user. Additional information on antenna measurements can be found at *www.ngs.noaa.gov/OPUS/Height_measure.html*. Another advantage of these peak-to-peak variations is that the range also directly reflects the errors in the coordinates of the reference stations. Small errors in the reference coordinates can become a relatively more significant component of the total error as the observational time span increases.

While OPUS provides peak-to-peak errors, the ability of OPUS to reproduce known results has also been examined as a mean to estimate accuracy. In one such study, two hours of data were selected from one day for over 200 CORS stations. Since the CORS positions are well known, the OPUS results could be compared with the known values. Plots of the east, north, and up deviations of the OPUS results from the accepted ITRF positions for these stations are shown in **Figure 2.** The mean OPUS positions differ by less than 1 mm in each component and the east, north, and up components showed standard deviations of 1.4, 0.8, and 1.9 cm respectively. In the October 2002 issue of this magazine, Snay and others reported that the positioning accuracy from CORS stations depends primarily on the time span of the data, not the distance from the CORS station. While individual accuracies are not predictable, users should expect their results to improve as the time span of their data is increased.

The OPUS solution report is divided into three main sections. The first section contains information about the software version used to process the dataset, the orbits, the antenna type, and the number of observations used in the solution. The overall RMS of the residuals is also reported in the first section.

The second section reports the computed ITRF and NAD 83 coordinates. Each coordinate is stated with its respective peak-to-peak variation. UTM and SPC coordinates are also reported.

The final section identifies which reference stations were used in the solution. This includes the Permanent Identifier (PID), site designation, latitude, longitude, and distance from the reference site to the observation site. The nearest NGS published control point is also stated at the end of the report.

What Makes a Quality Solution?

There are no absolute rules, but we can certainly provide some guidance on OPUS solutions. First, make sure the antenna type and the ARP height are correct. Next, review the solution statistics: A good OPUS run should typically use 90% or more of your observations. OPUS should have fixed at least 50% of the integer ambiguities. The overall RMS of the residuals should seldom exceed 3 cm. The peak-to-peak variations should seldom exceed 5 cm. (This depends, of course, on the accuracy you are trying to achieve.)

OPUS Usage

Since OPUS' introduction in the early part of 2001, the number of users continues to increase. OPUS submissions from non-governmental users averaged about 3000 per month for the first nine months of 2002. The locations of OPUS submissions for the first nine months of 2002 are shown in **Figure 3.** OPUS is being used to monitor the positions of Cooperative CORS stations and other permanent GPS tracking stations. OPUS is providing positions for temporary GPS base stations used for kinematic, rapid-static, and RTK applications. OPUS is providing constrained positions for local network surveys as well as positions for new monumentation. OPUS has clearly become an important utility for a wide range of surveying applications.

Future

NGS is working to add new features to OPUS. Having just added features allowing users to select their preferred local reference stations and submit compressed files, NGS is now investigating how users might enter selected OPUS results into a data base for sharing results with other users. We are also looking into decreasing the minimum data span required without sacrificing accuracy, providing differential range solutions for users able to extract RINEX files from less expensive GPS navigation receivers, and enabling L1 carrier phase solutions for users who do not have dual frequency GPS receivers. OPUS provides a link to email NGS with other suggestions as well, and we welcome all questions and comments.

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