Using and Understanding OPUS

Vermont Society of Land Surveyors
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What is OPUS?

• OPUS, the On-line Positioning User Service, is a growing set of applications offering web-based access to the tools and resources provided by the NGS.

• Currently, OPUS is composed of
  – OPUS-S…………static processing
  – OPUS-RS..........rapid-static processing
  – Sharing…………database of solutions
  – OPUS Projects…..campaign survey processing
What is OPUS?

• On-line Positioning User Service
  – Submit dual frequency (GPS) Data
  – 15 min - 2 hours data OPUS_RS (Rapid Static)
  – 2 hours - 48 hours data OPUS_S (Static)
  – Processed by NGS computers relative to CORS
  – Results received in minutes via e-mail
  – Provides consistent access to NSRS
Beautiful in its simplicity, the user need only provide:

- Their email address.
- The antenna type.
- The offset to the **antenna reference point** (ARP).
- 2- to 48-hours of GPS L1 + L2 data.

In turn, the user receives:

- Coordinates accurate to a few centimeters.

This is the OPUS home page used to submit data to the OPUS processing queues. To use OPUS-S, complete the four fields, then click the “Upload to STATIC” button. In a few minutes, an email arrives with the results.
Static: OPUS determines your position with a differential GPS static solution, using hours of data. This process is repeated four more times from other CORS.

How Does OPUS-S Work?

The primary steps of OPUS-S processing are:

1. Prepare and quality control the submitted data.
2. Estimate a crude point-position using TEQC.
3. Compute distances to every available CORS.
4. Select the three “best” CORS based upon:
   • Being closest to the user’s site.
   • Having common satellite visibility with the user data.
   • Having more than 80% of the possible data available.
   • Having low multipath measures.
5. Complete the single-baseline processing using PAGES.
6. Check the solution quality and replace a CORS if needed.
7. Generate and email the report to the user.
How Does OPUS-S Work?

OPUS-S uses PAGES for data processing.

PAGES is a state-of-the-art processing engine developed by the NGS.

Besides OPUS-S, PAGES is used for orbit production, reference frame definition, network monitoring and many other GPS data processing tasks.

http://geodesy.noaa.gov/GRD/GPS/DOC/toc.html
http://igscb.jpl.nasa.gov/igscb/center/analysis/noaa.acn

How Does OPUS-S Work?

OPUS-S modeling highlights:

• Satellite coordinates from the International GNSS Service (IGS) precise ephemerides.
• CORS coordinates and hardware histories from the NGS site information data base.
• Receiver antenna phase center offsets and variations from the NGS absolute antenna model data base.
  http://geodesy.noaa.gov/ANTCAL/.
• International Earth Rotation Service (IERS) 2003 solid Earth tide model.
• Surface met from a climatological model.
How Does OPUS-S Work?

OPUS-S processing highlights:

• Everything is “done” in the **IGS08 Reference Frame**.
• SV coordinates are held rigidly fixed.
• CORS coordinates are heavily constrained.
• Neutral atmosphere (tropo) dry component modeled.
• Neutral atmosphere (tropo) wet component estimated.
• Double-differenced, ion-free carrier phase observable.
• Carrier phase ambiguities are fixed to their integer values where possible; float ambiguities are estimated otherwise.
• Individual baselines are processed and the results combined generating mean coordinates and peak-to-peak uncertainties.

Some thoughts on phase ambiguity integer fixing.

The ambiguities, (charged and neutral) atmosphere delays and station heights strongly alias into each other.

There are really only two ways to “break” this aliasing:

1. Introduce more data.
2. Introduce additional information.
How Does OPUS-S Work?

OPUS-S uses the former strategy.

Depending upon the circumstances, 1- to 2-hours of observations are sufficient to decorrelate the ambiguities, atmosphere and heights allowing reliable estimation of all. Thus the requirement for a minimum of 2-hours in OPUS-S.

As an aside, be aware that while simply having more data helps, it is actually the change in orientation of the satellites over the data span that forces the decorrelation.
Antenna Type, height – easy, right?

- **Type?**
  - Verify by looking up in ANTCAL
  - Orient the antenna indicator to true north
  - Centered over the mark? (check plummet or bubble)

- **Height?**
  - Height to what? (antenna ARP, not L1-phase center)
  - Fixed-height tripods are easier than slip-legs.
  - Vertical, NOT slant-height.
  - Is your fixed-height tripod really fixed? (measure!)

**HOW IS THE ANTENNA HEIGHT MEASURED?**

The height is measured vertically (NOT the slant height) from the mark to the ARP of the antenna. The height is measured in meters.

The ARP is almost always the center of the bottom-most, permanently attached, surface of the antenna.

See GPS Antenna Calibration for photo’s and diagrams that show where the ARP is on most antennas:

http://geodesy.noaa.gov/ANTCAL/

If the default height of 0.0000 is entered, OPUS will return the position of the ARP.
WHY DO I NEED THE ANTENNA TYPE?

The antenna phase centers are located somewhere around here.

The Antenna Reference Point (ARP) is almost always located in the center of the bottom surface of the antenna.

Incorrect or missing antenna type → big vertical errors

Phase Center offsets (plan view)

Phase center offsets from ARP, meters

L1 phase center
L2 phase center
Phase Center offsets (side view)

Phase Center location above ARP, meters

L1 phase center
L2 phase center

Variation from L2 Phase Center offset, meters

L2 Phase Center Variation as satellite passes overhead

satellite elevation above horizon, degrees
What else can go wrong?

- Site
  - instability, multi-path
  - mark ID (search database, check stamping)
- Weather
  - wild, local troposphere issues?
  - space weather: ionospheric issues?
- “Truth” (orbits, CORS, etc.)
  - Rapid (next-day) orbits required for publishing,
    Final Precise ($\approx 14$ days) recommended.

How Good Can I Do With OPUS-S?

OPUS-S reliably addresses the more historically conventional requirements for GPS data processing. It typically yields accuracies of:

- $1 - 2$ cm horizontally
- $2 - 4$ cm vertically

However, there is no guarantee that this stated accuracy will result from any given data set.
Confirming the quality of the OPUS solution remains the user’s responsibility. That’s the “price” for automated processing.
How Good Can I Do With OPUS-S?

More generally, Eckl et al. (NGS, 1999) preformed a similar but more extensive test using the same software but outside OPUS.

Their results provide a good “rule of thumb” for accuracy versus session duration when using OPUS-S and in many other applications.

How Good Can I Do With OPUS-S?

As a quality test, 2-hour data sets from more than 200 CORS were submitted to OPUS-S and the results compared to the accepted coordinates.

Mean: <0.1 cm
N-S RMS: 0.8 cm
E-W RMS: 1.4 cm

Weston, N. "OPUS: Online Positioning User Service", CGSIC/USL'S MEETING, 2008-07-08, NEW ORLEANS, LA.
How Good Can I Do With OPUS-S?

Same data sets. Same analysis but for the vertical.

The vertical is always a little more interesting.

Mean: <0.1 cm  
U-D RMS: 1.9 cm

Weston, "OPUS Online Positioning User Service", CGSC USSS MEETING, 2008-07-08, NEW ORLEANS, LA

A Quick Example

Here is part of the report for this submission.

FYI, these results differ 2.1 cm horizontally and 1.6 cm vertically from the accepted position projected to the epoch of the data.
A Quick Example

I apologize for stating the obvious, but...

When reviewing your OPUS solution, double check that the information you provided is correct.
I apologize for stating the obvious, but...

Check the quality control measures provided:

- **OBS USED**: > 90%
- **# FIXED AMB**: > 50%
- **OVERALL RMS**: < 3 cm
- **peak-to-peak**: < 5 cm

In this example, we have a 😊.
The Extended Report

If the extended report option was selected, next you’ll see the BASE STATION section.

Here, the components contributing to the base stations’ coordinates are shown in detail. These and the following information are expressed in the ITRF currently in use.

This section includes a priori information.
The Extended Report

Computation of the coordinates at the mean epoch of the data.

And the coordinates at the mean epoch of the data.
The Extended Report

So, if you add the a priori coordinates + ARP TO L1, + MON TO ARP + VEL offsets, you will get the coordinates at the mean epoch of the data, shown here highlighted in yellow, used in the processing.

Next are summaries of the solutions relative to each base station.

We’ll discuss this a few minutes, but, for now, simply be aware that OPUS “solves” each baseline separately, then compares and averages these results to create the report.
The Extended Report

Here we see the best guess for "my" site's a priori information. This is based upon the information I provided when I uploaded the data file to OPUS-S and a crude point position solution. Remember that these are also in the IGS08.
The Extended Report

Near the top, in light blue, you can see the pieces need to compute the estimated (NEW) L1 phase center.

Below, in light green, are the three estimates from the each baseline.

Following the baseline information are some Bluebook records...
The Extended Report

Following the Bluebook information are solution statistics and observation counts in tabular form ordered by satellite (rows) and baseline (columns).

<table>
<thead>
<tr>
<th>POST-FIT RMS BY SATELLITE VS. BASELINE</th>
</tr>
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<tbody>
<tr>
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<tr>
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These tables can be a challenge to read, especially for longer data spans, because the lines wrap in the standard 80-column format. Here’s the same table without line-wrapping and with the extra header lines removed.

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The Extended Report

Next are covariance matrices for the XYZ and NEU vectors, and the network horizontal and vertical accuracy...

The network horizontal and vertical accuracies are a relatively new addition and will become the standard in the future.

Because of the way OPUS-S works (now), these values are derived from empirically determined relationships in the CORS network plus statistics from the individual baseline solutions.

Additional information related to the derivation of NAD 83(2011) vector components...

You’ll see four “blocks”: the reference sites’ ARP and MON coordinates, their velocities and the solution vector components all expressed in the NAD 83(2011) frame.

Covariance Matrix for the xyz OPUS Position (meters²).

\[
\begin{bmatrix}
0.0000069978 & 0.0000004873 & -0.0000000972 \\
0.0000004873 & 0.0000053511 & -0.0000002879 \\
-0.0000000972 & -0.0000002879 & 0.0000040822
\end{bmatrix}
\]

Covariance Matrix for the enu OPUS Position (meters²).

\[
\begin{bmatrix}
0.0000060540 & 0.0000007189 & -0.0000006244 \\
0.0000007189 & 0.0000048712 & -0.0000010998 \\
-0.0000006244 & -0.0000010998 & 0.0000055059
\end{bmatrix}
\]

Horizontal network accuracy = 0.00573 meters.
Vertical network accuracy = 0.00460 meters.
The Extended Report

The state plane coordinates expressed using the international foot or US Survey foot (depending on state legislation) rather than meters ...

STATE PLANE COORDINATES - International Foot
SPC (3601 OR N)
Northing (Y) [feet] 347675.719
Easting (X) [feet] 7471572.725
Convergence [degrees] -1.98897513
Point Scale 0.99994603
Combined Factor 0.99992941

...
OPUS-RS. . .rapid-static processing

- A Little OPUS-RS History.
- The OPUS-RS Interface.
- How Good Can I Do With OPUS-RS?
- A Quick Example (cont.).
- The Extended Report (cont.).
- How Does OPUS-RS Work?
- OPUS-S and OPUS-RS Uploads By Month.

A Little OPUS-RS History

Although successful, OPUS obviously does not satisfy the needs of all users. Discussions with the user community about future development began almost immediately after OPUS was made public.

These early discussions clearly indicated that the most desired enhancement would be a tool capable of producing a similar quality result from a shorter data span.
A Little OPUS-RS History

Work by several groups demonstrated that reliably producing results of similar quality to OPUS from shorter data spans was possible.

Collaboration between the NGS and the Satellite Positioning and Inertial Navigation (SPIN) group at The Ohio State University enabled Schwarz to implement a new processing engine capable of generating those results.

In early 2007, OPUS-RS was made publically available after its own trial period. To better delineate uses, the original OPUS processing stream was renamed OPUS-S.

RSGPS

- Based (conceptually) on OSU MPGPS program
- Similar to Wide Area Rapid Static and Virtual Reference Station (VRS) computations
- 96 subroutines (21 in LAMBDA)
  - Least squares Ambiguity De-correlation Adjustment
- 9739 lines of code (1336 from LAMBDA)
OPUS-RS

• Uses RSGPS program instead of PAGES (based on OSU MPGPS program)
• Uses P1 and P2 as well as L1 and L2 obs
• Resolves all ambiguities with LAMBDA
• Geometry free linear combination used to determine DD ionospheric delays

The OPUS-RS Interface

With OPUS-RS, the beautiful simplicity remained. In fact the entry form is the same as for OPUS-S. The user provides:

• Their email address.
• An antenna type.
• The vertical offset to the ARP.
• 15-minutes to 2-hours of GPS L1 + L2 data.

The user receives:

• Coordinates accurate to a few centimeters.
The same interface is used except one clicks the “Upload to RAPID-STATIC” button instead.

How Does OPUS-RS Work?

OPUS-RS uses the RSGPS program which was developed specifically for this purpose.

Like OPUS-S, OPUS-RS uses state-of-the-art models, but the strategy to fix phase ambiguities to their integer values differs.

To fix integers, OPUS-RS introduces more information:

- Pseudorange and carrier phase.
- More reference stations if possible.
How Does OPUS-RS Work?

OPUS-RS selects three to nine “best” CORS based upon:
- Having common satellite visibility with the user data.
- Having distances from the user’s site <250 km.

This is shown here graphically. The star represents the user’s site. The triangles are CORS.

No CORS farther than 250 km from the user’s site will be included.

The three CORS minimum is shown. No more than nine are used.

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How Does OPUS-RS Work?

In addition, user’s site must be no more than 50 km from the (convex) polygon created by the selected CORS.

Again in this figure, the star represents the user’s site; the triangles are CORS. Five CORS and their resulting polygon are shown in this example.

If the user’s site, the star, is more than 50 km outside this polygon, alternate CORS will be considered. If none can be found, the processing will abort.

Rapid-static: OPUS first creates an atmospheric delay model from surrounding CORS data.

Your position is then quickly determined by differential GPS static solution.

How Does OPUS-RS Work?

OPUS-RS uses no less than 1-hour of CORS data and no more than the submitted data's span plus 15-minutes before and after.

The CORS data are used to estimate the atmospheric delays at each CORS and predict them at the user's site.

OPUS-RS then processes each baseline to the user’s site individually to produce an improved a priori position.

Switching modes, the previously determined values and all data are used in an “integer-fixed” solution for the user's site.

A Quick Example

Shown here is part of the OPUS-RS report for the same CORV data discussed earlier.

The results differ by 2.4 cm horizontally and 0.2 cm vertically from the accepted position projected to the epoch of the data.

Note that the solution quality measures are slightly different.

OBS USED > 50%
QUALITY IND. > 3
NORM. RMS ≈ 1
Uncertainties < 5 cm

The uncertainties are standard deviations from the solution, not the peak-to-peak values reported by OPUS-S.
A Quick Example

Although the quality indices, normalized RMS and uncertainties are OK, the percentage of observations used gives this solution a 😞.

If you are uncomfortable with your solution, the same diagnostic steps discussed for OPUS-S can be applied here too.

The Extended Report

Of necessity, the OPUS-RS extended report is larger than the corresponding OPUS-S solution. Too large to be conveniently shown here. But while seemingly intimidating, the OPUS-RS extended report sections are basically the same as those in the OPUS-S extended report.

Some additional sections include:

- A covariance matrix for the reference-station-only solution.
- A correlation as well as a covariance matrix.
- Various Dilutions Of Precision (DOPs).
How Good Can I Do With OPUS-RS?

OPUS-RS can produce quality results from more challenging “short” data sets, but it is slightly more restrictive in the data sets allowed. Because of the restrictions, which will be discussed later, the NGS recently made available the “OPUS-RS Accuracy and Availability” tool (Choi, NGS).

Typical estimated and empirical accuracies within the continental U.S. are comparable to OPUS-S.

Remember that the estimated accuracies suggested by this tool are just estimates. Confirming the quality of the OPUS solution remains the user’s responsibility.

How Good Can I Do With OPUS-RS?

The OPUS-RS Accuracy and Availability Tool.

- 1σ for each 0.2 degree grid.
- Horizontal and vertical standard errors for 15 minutes and 1-hour length data.
- Inverse Distance Weighting method to interpolate the sigmas.
- Areas outside the color overlay are where there are less than three active CORS sites within 250 km range. OPUS-RS will usually fail at these locations.
- Automated Weekly update
  - Use updated CORS list and observation data availability
- Global coverage including non-US territories.
### OPUS static vs. rapid static

<table>
<thead>
<tr>
<th></th>
<th>static</th>
<th>rapid static</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>input</strong> (dual-frequency GPS)</td>
<td><strong>2-48 hours</strong></td>
<td><strong>15 minutes-2 hours</strong></td>
</tr>
<tr>
<td><strong>output</strong></td>
<td>normal, extended, XML datasheet, project</td>
<td>normal, extended, XML</td>
</tr>
<tr>
<td><strong>accuracy</strong> (95% confidence)</td>
<td>1-2 cm horizontal 3-6 cm ellipsoidal height</td>
<td>1-2 cm horizontal 4-8 cm ellipsoidal height</td>
</tr>
<tr>
<td><strong>network geometry</strong></td>
<td>3 CORS, preferably within 1000 km of rover</td>
<td>3-9 CORS, surrounding &amp; within 250 km of rover</td>
</tr>
<tr>
<td><strong>availability</strong></td>
<td>global</td>
<td>90% of CONUS (subject to CORS configuration)</td>
</tr>
</tbody>
</table>