Using and Understanding OPUS

Vermont Society of Land Surveyors
September 16, 2016

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What is OPUS?

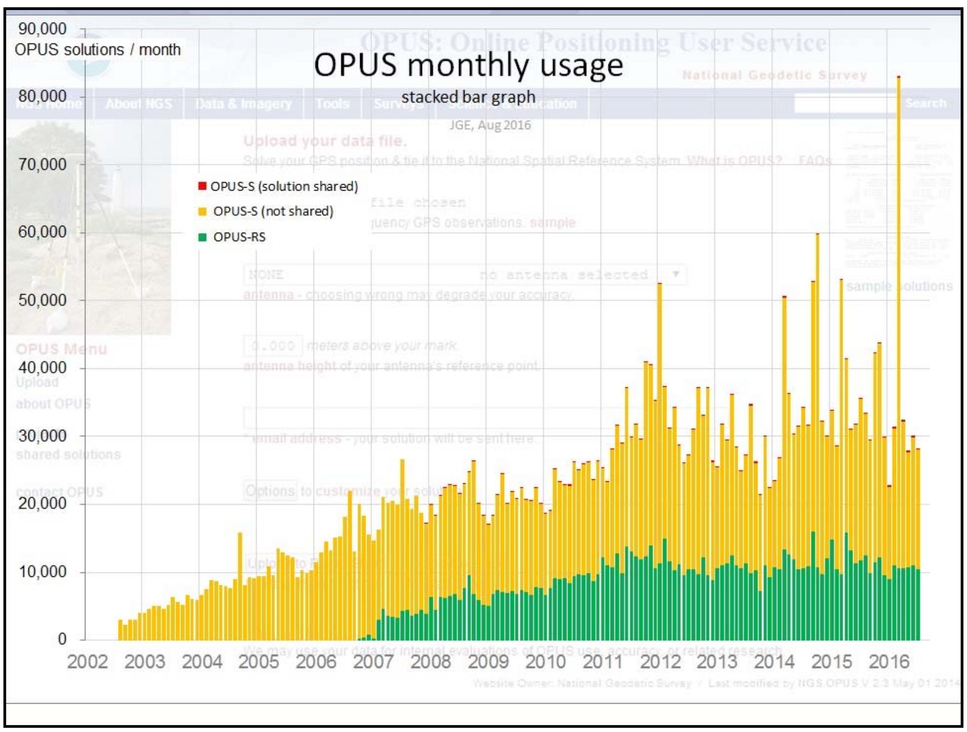
- OPUS, the **On-line Positioning User Service**, is a growing set of applications offering web-based access to the tools and resources provided by the NGS.
- Currently, OPUS is composed of
  - OPUS-S…………static processing
  - OPUS-RS…………rapid-static processing
  - Sharing…………database of solutions
  - OPUS Projects…..campaign survey processing

NOAA's **National Geodetic Survey** Positioning America for the Future — geodesy.noaa.gov

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

3



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The OPUS-S Interface

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.

5

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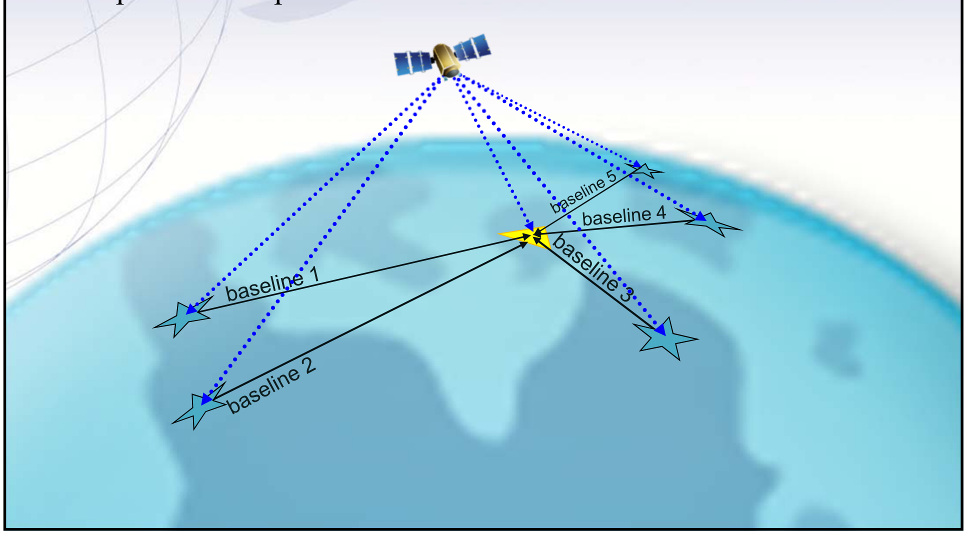
The OPUS-S Interface

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.

6

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.



NOAA's National Geodetic Survey Positioning America for the Future geodesy.noaa.gov

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.

8

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

9

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How Does OPUS-S Work?

OPUS-S modeling highlights:

- Satellite coordinates from the **International GNSS Service** (IGS) precise ephemerides.
  http://igscb.jpl.nasa.gov/components/usage.html.
- 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.
  http://www.iers.org/nn_11216/IERS/EN/Publications/TechnicalNotes/tn32.html.
- Surface met from a climatological model.
  Boehm et al., "Short Note: A global model of pressure and temperature for geodetic applications", J. Geod., 2007.

10

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.

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How Does OPUS-S Work?

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.

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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.

13

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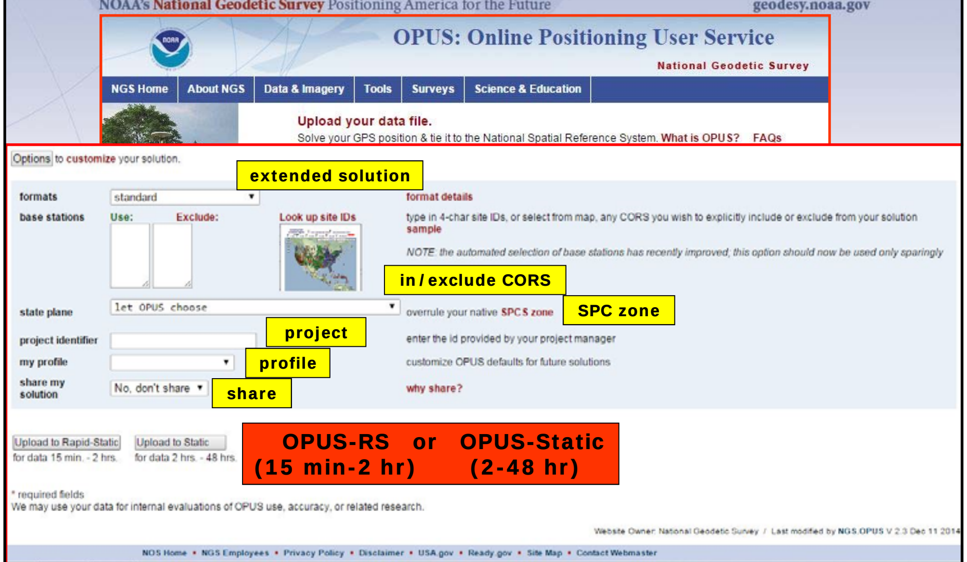

Antenna Type, height – easy, right?

- 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!)

15

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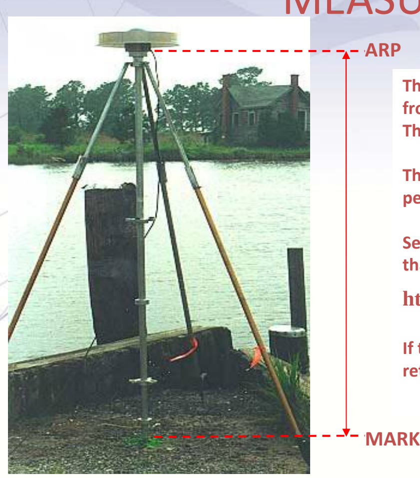
HOW IS THE ANTENNA HEIGHT MEASURED?



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.

16

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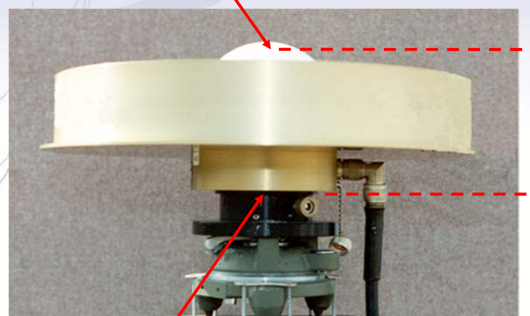
WHY DO I NEED THE ANTENNA TYPE?

The antenna phase centers are located somewhere around here.



phase ctr.

The antenna offsets are the distance between the phase centers and the ARP

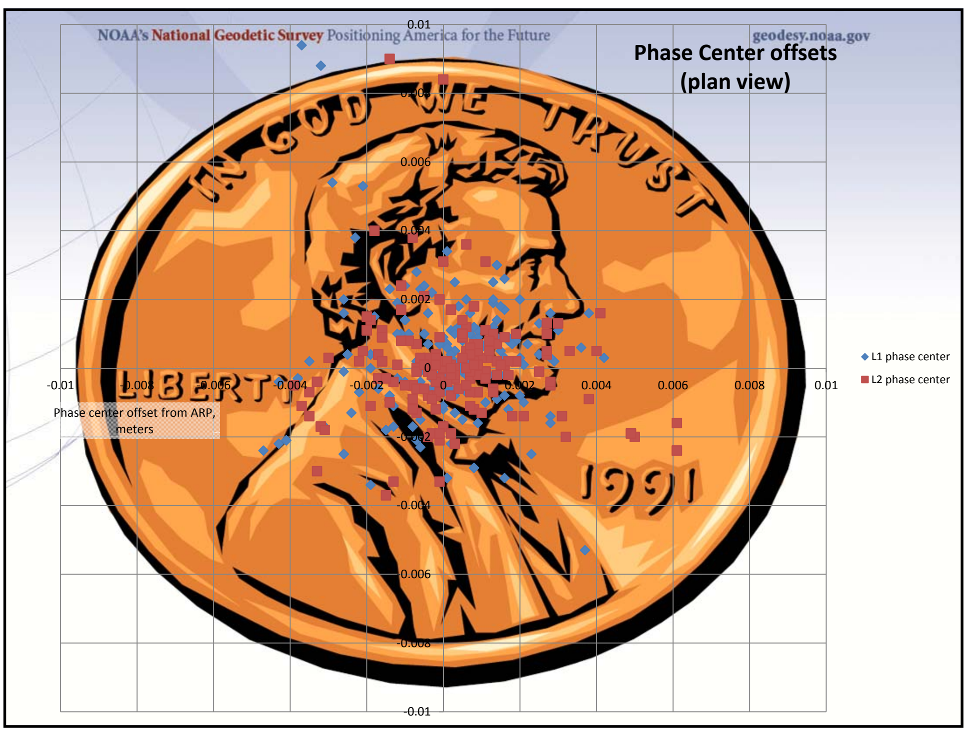
ARP

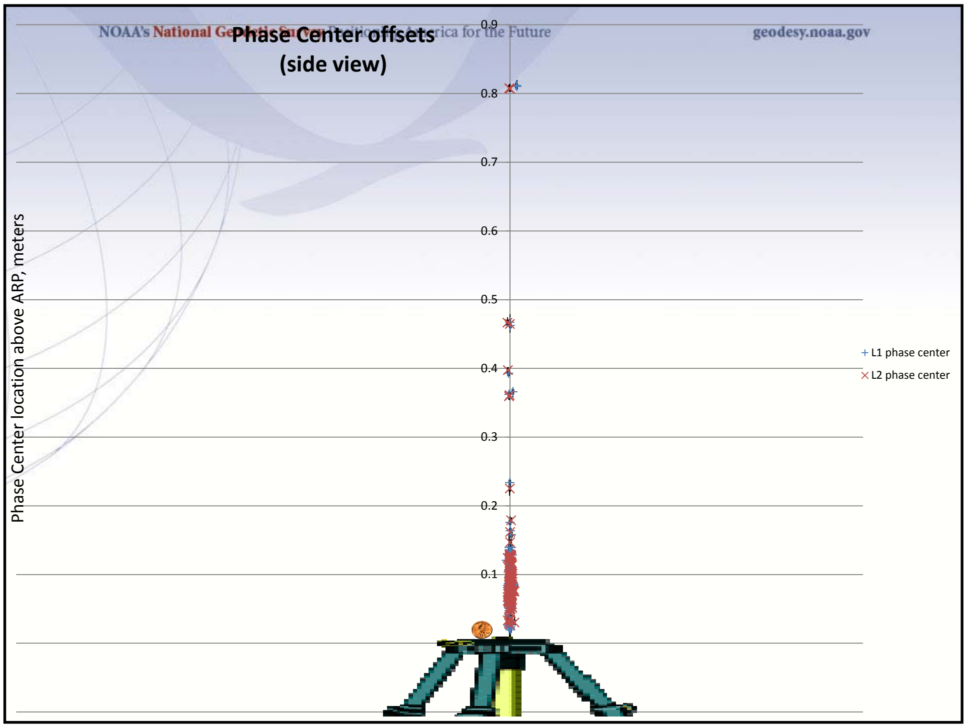
You do not need to know these offsets. They are passed to the processing software through the antenna type

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

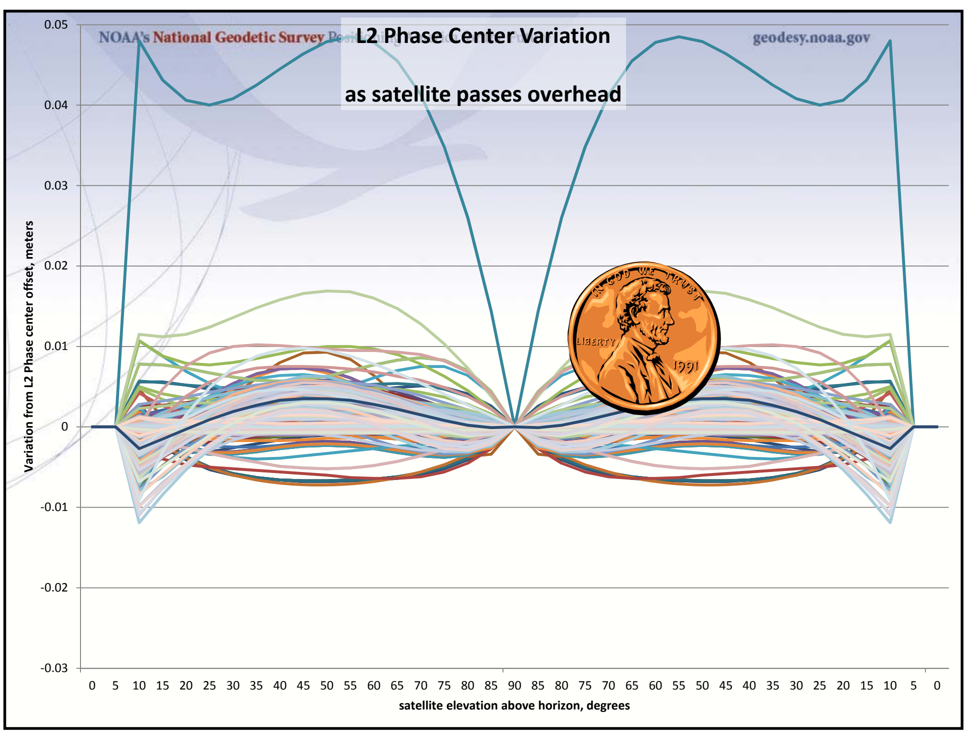
Incorrect or missing antenna type → big vertical errors

17





NOAA's National Geodetic Survey Positioning America for the Future
geodesy.noaa.gov
Phase Center offsets
(side view)
Phase Center location above ARP, meters
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
L1 phase center
L2 phase center



NOAA's National Geodetic Survey
geodesy.noaa.gov
L2 Phase Center Variation
as satellite passes overhead
Variation from L2 Phase center offset, meters
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
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 (≈ 14 days) recommended.

21

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:

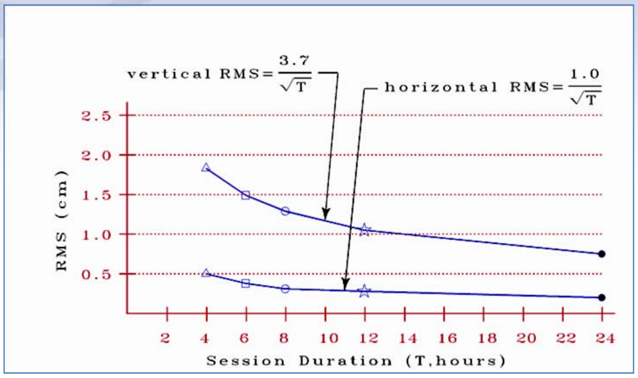
1 – 2 cm horizontally
2 – 4 cm vertically

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.

22

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.



Eckl et al., 2001, "Accuracy of GPS-derived relative positions as a function of interstation distance and observing-session duration", J. of Geod. 75, 633-640).

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

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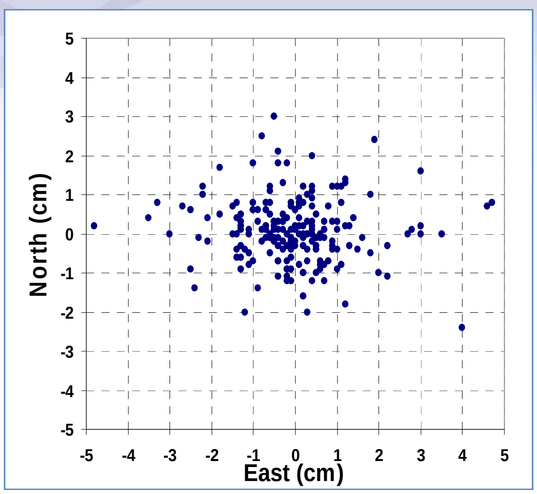
How Good Can I Do With OPUS-S?

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



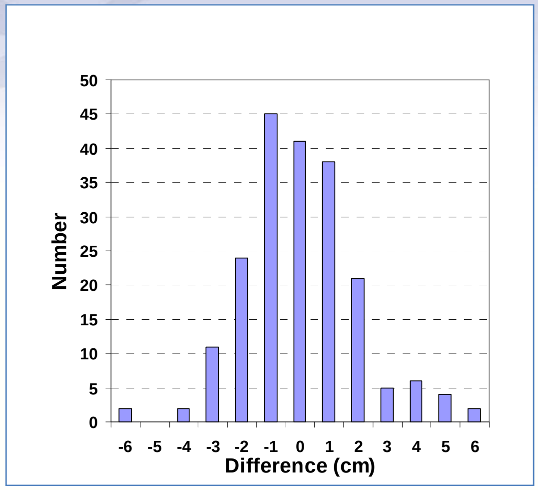
Weston, N. "OPUS: Online Positioning User Service", CGSIC USSLS MEETING, 2008-07-08, NEW ORLEANS, LA.

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", CGSIC USSLS MEETING, 2008-07-08, NEW ORLEANS, LA

A Quick Example

```
      USER: mark.schenewerk@noaa.gov                    DATE: March 31, 2010
RINEX FILE: corv059f.09o                                TIME: 19:43:42 UTC


  SOFTWARE: page5  0909.08 master40.pl 081023      START: 2009/02/28  05:00:00
 EPHEMERIS: igs15206.eph [precise]                  STOP: 2009/02/28  06:59:00
  NAV FILE: brdc0590.09n                        OBS USED:  5984 /  6181   :  97%
  ANT NAME: ASH700936C_M    NONE             # FIXED AMB:    31 /    31   : 100%
ARP HEIGHT: 1.521                            OVERALL RMS: 0.009(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)              ITRF00 (EPOCH:2009.1596)

         X:     -2498422.603(m)   0.011(m)          -2498423.344(m)   0.011(m)
         Y:     -3802821.159(m)   0.007(m)          -3802819.941(m)   0.007(m)
         Z:      4454736.661(m)   0.021(m)           4454736.734(m)   0.021(m)

       LAT:   44 35  7.91060      0.016(m)        44 35  7.92618      0.016(m)
     E LON:  236 41 43.48046      0.013(m)       236 41 43.42207      0.013(m)
     W LON:  123 18 16.51954      0.013(m)       123 18 16.57793      0.013(m)
    EL HGT:         106.011(m)   0.014(m)               105.627(m)   0.014(m)
 ORTHO HGT:         128.542(m)   0.020(m) [NAVD88 (Computed using GEOID09)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 10)         SPC (3601 OR N)
Northing (Y) [meters]     4936954.909           105971.559
Easting (X)  [meters]      475821.304          2277335.367
Convergence  [degrees]    -0.21381419          -1.98897513
Point Scale                0.99960719           0.99994603
Combined Factor            0.99959057           0.99992941

US NATIONAL GRID DESIGNATOR: 10TDQ7582136954(NAD 83)



                             BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DH4503 P376 EOLARESVR_OR2004 CORS ARP      N445628.313 W1230608.100   42648.2
DE6258 MCSO MARION CNTY COOP CORS ARP      N445825.701 W1225720.639   51226.8
DG5352 STAY STAYTON COOP CORS ARP          N444950.530 W1224915.036   47030.9
```

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.

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```

Again, I'm assuming familiarity with the report, but …

… at the risk of stating the obvious, there are a few items I want to draw attention to.

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I apologize for stating the obvious, but …

When reviewing your OPUS solution, double check that the information you provided is correct.

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```

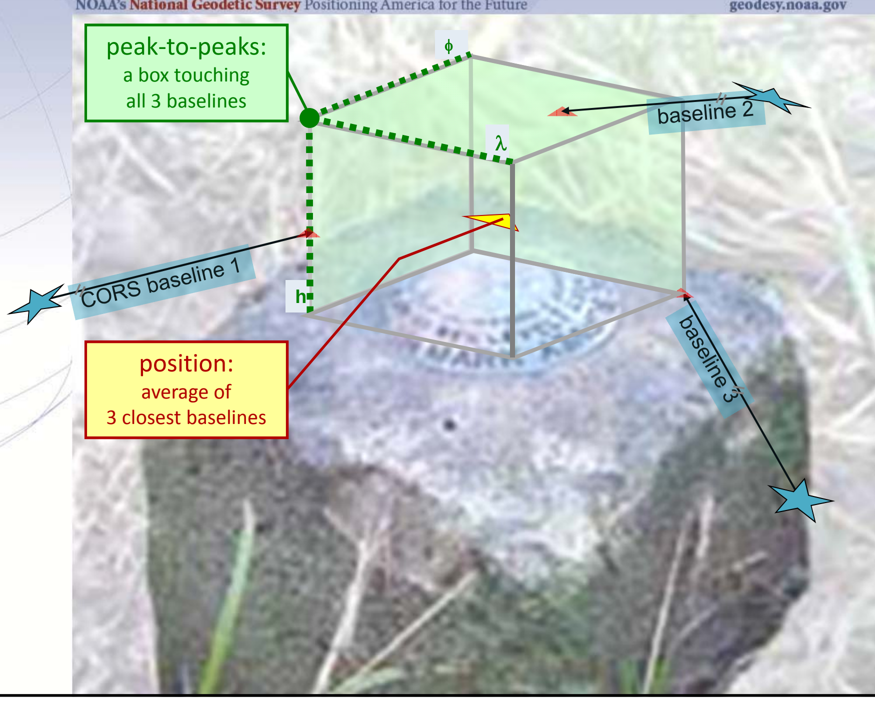
I apologize for stating the obvious, but …

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 .

29



The Extended Report

```
                    BASE STATION INFORMATION

 STATION NAME: p376  a    2 (EOLARESVR_OR2004; Salem, OR  United States)
  MONUMENT: NO DOMES NUMBER
 XYZ  -2469806.7634  -3788348.6049   4482853.4377  MON @ 1997.0000 (M)
 XYZ        -0.0141         0.0030        -0.0043  VEL (M/YR)
 NEU        -0.0000         0.0000         0.0083  MON TO ARP (M)
 NEU         0.0009         0.0009         0.1068  ARP TO L1 PHASE CENTER (M)
 NEU         0.0002         0.0017         0.1251  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.1715         0.0365        -0.0523  VEL TIMES 12.1597 YRS
 XYZ        -0.0032        -0.0049         0.0059  MON TO ARP
 XYZ        -0.0402        -0.0633         0.0761  ARP TO L1 PHASE CENTER
 XYZ  -2469806.9782  -3788348.6366   4482853.4674  L1 PHS CEN @ 2009.1596
 XYZ         0.0000         0.0000         0.0000  + XYZ ADJUSTMENTS
 XYZ  -2469806.9782  -3788348.6366   4482853.4674  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2469806.9381  -3788348.5733   4482853.3913  NEW ARP @ 2009.1596
 XYZ  -2469806.9348  -3788348.5684   4482853.3855  NEW MON @ 2009.1596
 LLH  44 56 28.32921  236 53 51.83975    180.9607  NEW L1 PHS CEN @ 2009.1596
 LLH  44 56 28.32918  236 53 51.83971    180.8539  NEW ARP @ 2009.1596
 LLH  44 56 28.32918  236 53 51.83971    180.8456  NEW MON @ 2009.1596

 STATION NAME: mcso  a    1 (MARION CNTY COOP; Salem, Oregon, U.S.A.)
  MONUMENT: NO DOMES NUMBER
 XYZ  -2458668.9460  -3792427.4770   4485327.2930  MON @ 1997.0000 (M)
 XYZ        -0.0131         0.0018        -0.0047  VEL (M/YR)
 NEU         0.0000         0.0000         0.0000  MON TO ARP (M)
 NEU         0.0025         0.0013         0.1065  ARP TO L1 PHASE CENTER (M)
 NEU        -0.0007         0.0013         0.1254  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.1593         0.0219        -0.0572  VEL TIMES 12.1597 YRS
 XYZ         0.0000         0.0000         0.0000  MON TO ARP
 XYZ        -0.0389        -0.0624         0.0770  ARP TO L1 PHASE CENTER
 XYZ  -2458669.1442  -3792427.5176   4485327.3129  L1 PHS CEN @ 2009.1596
 XYZ        -0.0000        -0.0000        -0.0000  + XYZ ADJUSTMENTS
 XYZ  -2458669.1442  -3792427.5176   4485327.3129  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW ARP @ 2009.1596
 XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW MON @ 2009.1596
 LLH  44 58 25.71729  237  2 39.30118     52.9227  NEW L1 PHS CEN @ 2009.1596
 LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW ARP @ 2009.1596
 LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW MON @ 2009.1596
```

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.

NOAA's National Geodetic Survey Positioning America for the Future geodesy.noaa.gov

The Extended Report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                    BASE STATION INFORMATION

 STATION NAME: p376  a    2 (EOLARESVR_OR2004; Salem, OR  United States)
  MONUMENT: NO DOMES NUMBER
 XYZ  -2469806.7634  -3788348.6049   4482853.4377  MON @ 1997.0000 (M)
 XYZ        -0.0141         0.0030        -0.0043  VEL (M/YR)
 NEU        -0.0000         0.0000         0.0083  MON TO ARP (M)
 NEU         0.0009         0.0009         0.1068  ARP TO L1 PHASE CENTER (M)
 NEU         0.0002         0.0017         0.1251  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.0032        -0.0049         0.0059  MON TO ARP
 XYZ        -0.0402        -0.0633         0.0761  ARP TO L1 PHASE CENTER
 XYZ  -2469806.9782  -3788348.6366   4482853.4674  L1 PHS CEN @ 2009.1596
 XYZ         0.0000         0.0000         0.0000  + XYZ ADJUSTMENTS
 XYZ  -2469806.9782  -3788348.6366   4482853.4674  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2469806.9381  -3788348.5733   4482853.3913  NEW ARP @ 2009.1596
 XYZ  -2469806.9348  -3788348.5684   4482853.3855  NEW MON @ 2009.1596
 LLH  44 56 28.32921  236 53 51.83975    180.9607  NEW L1 PHS CEN @ 2009.1596
 LLH  44 56 28.32918  236 53 51.83971    180.8539  NEW ARP @ 2009.1596
 LLH  44 56 28.32918  236 53 51.83971    180.8456  NEW MON @ 2009.1596

 STATION NAME: mcso  a    1 (MARION CNTY COOP; Salem, Oregon, U.S.A.)
  MONUMENT: NO DOMES NUMBER
 XYZ  -2458668.9460  -3792427.4770   4485327.2930  MON @ 1997.0000 (M)
 XYZ        -0.0131         0.0018        -0.0047  VEL (M/YR)
 NEU         0.0000         0.0000         0.0000  MON TO ARP (M)
 NEU         0.0025         0.0013         0.1065  ARP TO L1 PHASE CENTER (M)
 NEU        -0.0007         0.0013         0.1254  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.1593         0.0219        -0.0572  VEL TIMES 12.1597 YRS
 XYZ         0.0000         0.0000         0.0000  MON TO ARP
 XYZ        -0.0389        -0.0624         0.0770  ARP TO L1 PHASE CENTER
 XYZ  -2458669.1442  -3792427.5176   4485327.3129  L1 PHS CEN @ 2009.1596
 XYZ        -0.0000        -0.0000        -0.0000  + XYZ ADJUSTMENTS
 XYZ  -2458669.1442  -3792427.5176   4485327.3129  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW ARP @ 2009.1596
 XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW MON @ 2009.1596
 LLH  44 58 25.71729  237  2 39.30118     52.9227  NEW L1 PHS CEN @ 2009.1596
 LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW ARP @ 2009.1596
 LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW MON @ 2009.1596
```


This section includes a priori information.

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The Extended Report

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                         BASE STATION INFORMATION

STATION NAME: p376  a    2 (EOLARESVR_OR2004; Salem, OR  United States)
 MONUMENT: NO DOMES NUMBER
XYZ  -2469806.7634  -3788348.6049   4482853.4377  MON @ 1997.0000 (M)
XYZ        -0.0141         0.0030        -0.0043  VEL (M/YR)
NEU        -0.0000         0.0000         0.0083  MON TO ARP (M)
NEU         0.0009         0.0009         0.1068  ARP TO L1 PHASE CENTER (M)
NEU         0.0002         0.0017         0.1251  ARP TO L2 PHASE CENTER (M)
XYZ        -0.1715         0.0365        -0.0523  VEL TIMES 12.1597 YRS
XYZ        -0.0032        -0.0049         0.0059  MON TO ARP
XYZ        -0.0402        -0.0633         0.0761  ARP TO L1 PHASE CENTER
XYZ  -2469806.9782  -3788348.6366   4482853.4674  L1 PHS CEN @ 2009.1596
XYZ         0.0000         0.0000         0.0000  + XYZ ADJUSTMENTS
XYZ  -2469806.9782  -3788348.6366   4482853.4674  NEW L1 PHS CEN @ 2009.1596
XYZ  -2469806.9381  -3788348.5733   4482853.3913  NEW ARP @ 2009.1596
XYZ  -2469806.9348  -3788348.5684   4482853.3855  NEW MON @ 2009.1596
LLH  44 56 28.32921  236 53 51.83975    180.9607  NEW L1 PHS CEN @ 2009.1596
LLH  44 56 28.32918  236 53 51.83971    180.8539  NEW ARP @ 2009.1596
LLH  44 56 28.32918  236 53 51.83971    180.8456  NEW MON @ 2009.1596

STATION NAME: mcso  a    1 (MARION CNTY COOP; Salem, Oregon, U.S.A.)
 MONUMENT: NO DOMES NUMBER
XYZ  -2458668.9460  -3792427.4770   4485327.2930  MON @ 1997.0000 (M)
XYZ        -0.0131         0.0018        -0.0047  VEL (M/YR)
NEU         0.0000         0.0000         0.0000  MON TO ARP (M)
NEU         0.0025         0.0013         0.1065  ARP TO L1 PHASE CENTER (M)
NEU        -0.0007         0.0013         0.1254  ARP TO L2 PHASE CENTER (M)
XYZ        -0.1593         0.0219        -0.0572  VEL TIMES 12.1597 YRS
XYZ         0.0000         0.0000         0.0000  MON TO ARP
XYZ        -0.0389        -0.0624         0.0770  ARP TO L1 PHASE CENTER
XYZ  -2458669.1442  -3792427.5176   4485327.3129  L1 PHS CEN @ 2009.1596
XYZ        -0.0000        -0.0000        -0.0000  + XYZ ADJUSTMENTS
XYZ  -2458669.1442  -3792427.5176   4485327.3129  NEW L1 PHS CEN @ 2009.1596
XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW ARP @ 2009.1596
XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW MON @ 2009.1596
LLH  44 58 25.71729  237  2 39.30118     52.9227  NEW L1 PHS CEN @ 2009.1596
LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW ARP @ 2009.1596
LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW MON @ 2009.1596
```

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

33

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The Extended Report

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                         BASE STATION INFORMATION

STATION NAME: p376  a    2 (EOLARESVR_OR2004; Salem, OR  United States)
 MONUMENT: NO DOMES NUMBER
XYZ  -2469806.7634  -3788348.6049   4482853.4377  MON @ 1997.0000 (M)
XYZ        -0.0141         0.0030        -0.0043  VEL (M/YR)
NEU        -0.0000         0.0000         0.0083  MON TO ARP (M)
NEU         0.0009         0.0009         0.1068  ARP TO L1 PHASE CENTER (M)
NEU         0.0002         0.0017         0.1251  ARP TO L2 PHASE CENTER (M)
XYZ        -0.1715         0.0365        -0.0523  VEL TIMES 12.1597 YRS
XYZ        -0.0032        -0.0049         0.0059  MON TO ARP
XYZ        -0.0402        -0.0633         0.0761  ARP TO L1 PHASE CENTER
XYZ  -2469806.9782  -3788348.6366   4482853.4674  L1 PHS CEN @ 2009.1596
XYZ         0.0000         0.0000         0.0000  + XYZ ADJUSTMENTS
XYZ  -2469806.9782  -3788348.6366   4482853.4674  NEW L1 PHS CEN @ 2009.1596
XYZ  -2469806.9381  -3788348.5733   4482853.3913  NEW ARP @ 2009.1596
XYZ  -2469806.9348  -3788348.5684   4482853.3855  NEW MON @ 2009.1596
LLH  44 56 28.32921  236 53 51.83975    180.9607  NEW L1 PHS CEN @ 2009.1596
LLH  44 56 28.32918  236 53 51.83971    180.8539  NEW ARP @ 2009.1596
LLH  44 56 28.32918  236 53 51.83971    180.8456  NEW MON @ 2009.1596

STATION NAME: mcso  a    1 (MARION CNTY COOP; Salem, Oregon, U.S.A.)
 MONUMENT: NO DOMES NUMBER
XYZ  -2458668.9460  -3792427.4770   4485327.2930  MON @ 1997.0000 (M)
XYZ        -0.0131         0.0018        -0.0047  VEL (M/YR)
NEU         0.0000         0.0000         0.0000  MON TO ARP (M)
NEU         0.0025         0.0013         0.1065  ARP TO L1 PHASE CENTER (M)
NEU        -0.0007         0.0013         0.1254  ARP TO L2 PHASE CENTER (M)
XYZ        -0.1593         0.0219        -0.0572  VEL TIMES 12.1597 YRS
XYZ         0.0000         0.0000         0.0000  MON TO ARP
XYZ        -0.0389        -0.0624         0.0770  ARP TO L1 PHASE CENTER
XYZ  -2458669.1442  -3792427.5176   4485327.3129  L1 PHS CEN @ 2009.1596
XYZ        -0.0000        -0.0000        -0.0000  + XYZ ADJUSTMENTS
XYZ  -2458669.1442  -3792427.5176   4485327.3129  NEW L1 PHS CEN @ 2009.1596
XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW ARP @ 2009.1596
XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW MON @ 2009.1596
LLH  44 58 25.71729  237  2 39.30118     52.9227  NEW L1 PHS CEN @ 2009.1596
LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW ARP @ 2009.1596
LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW MON @ 2009.1596
```

And the coordinates at the mean epoch of the data.

34

The Extended Report

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                    BASE STATION INFORMATION

STATION NAME: p376  a    2 (EOLARESVR_OR2004; Salem, OR  United States)
 MONUMENT: NO DOMES NUMBER
XYZ  -2469806.7634  -3788348.6049   4482853.4377  MON @ 1997.0000 (M)
XYZ        -0.0141         0.0030        -0.0043  VEL (M/YR)
NEU        -0.0000         0.0000         0.0083  MON TO ARP (M)
NEU         0.0009         0.0009         0.1068  ARP TO L1 PHASE CENTER (M)
NEU         0.0002         0.0017         0.1251  ARP TO L2 PHASE CENTER (M)
XYZ        -0.1715         0.0365        -0.0523  VEL TIMES 12.1597 YRS
XYZ        -0.0032        -0.0049         0.0059  MON TO ARP
XYZ        -0.0402        -0.0633         0.0761  ARP TO L1 PHASE CENTER
XYZ  -2469806.9782  -3788348.6366   4482853.4674  L1 PHS CEN @ 2009.1596
XYZ         0.0000         0.0000         0.0000  + XYZ ADJUSTMENTS
XYZ  -2469806.9782  -3788348.6366   4482853.4674  NEW L1 PHS CEN @ 2009.1596
XYZ  -2469806.9381  -3788348.5733   4482853.3913  NEW ARP @ 2009.1596
XYZ  -2469806.9348  -3788348.5684   4482853.3855  NEW MON @ 2009.1596
LLH  44 56 28.32921  236 53 51.83975    180.9607  NEW L1 PHS CEN @ 2009.1596
LLH  44 56 28.32918  236 53 51.83971    180.8539  NEW ARP @ 2009.1596
LLH  44 56 28.32918  236 53 51.83971    180.8456  NEW MON @ 2009.1596

STATION NAME: mcso  a    1 (MARION CNTY COOP; Salem, Oregon, U.S.A.)
 MONUMENT: NO DOMES NUMBER
XYZ  -2458668.9460  -3792427.4770   4485327.2930  MON @ 1997.0000 (M)
XYZ        -0.0131         0.0018        -0.0047  VEL (M/YR)
NEU         0.0000         0.0000         0.0000  MON TO ARP (M)
NEU         0.0025         0.0013         0.1065  ARP TO L1 PHASE CENTER (M)
NEU        -0.0007         0.0013         0.1254  ARP TO L2 PHASE CENTER (M)
XYZ        -0.1593         0.0219        -0.0572  VEL TIMES 12.1597 YRS
XYZ         0.0000         0.0000         0.0000  MON TO ARP
XYZ        -0.0389        -0.0624         0.0770  ARP TO L1 PHASE CENTER
XYZ  -2458669.1442  -3792427.5176   4485327.3129  L1 PHS CEN @ 2009.1596
XYZ        -0.0000        -0.0000        -0.0000  + XYZ ADJUSTMENTS
XYZ  -2458669.1442  -3792427.5176   4485327.3129  NEW L1 PHS CEN @ 2009.1596
XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW ARP @ 2009.1596
XYZ  -2458669.1053  -3792427.4551   4485327.2358  NEW MON @ 2009.1596
LLH  44 58 25.71729  237  2 39.30118     52.9227  NEW L1 PHS CEN @ 2009.1596
LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW ARP @ 2009.1596
LLH  44 58 25.71721  237  2 39.30112     52.8162  NEW MON @ 2009.1596
```

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.

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The Extended Report

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REMOTE STATION INFORMATION

 STATION NAME: corv       1
  MONUMENT: NO DOMES NUMBER
 XYZ  -2498423.7849  -3802820.9571   4454737.7025  MON @ 2009.1595 (M)
 NEU        -0.0014         0.0010         1.5210  MON TO ARP (M)
 NEU         0.0014        -0.0010         0.1089  ARP TO L1 PHASE CENTER (M)
 NEU         0.0010         0.0005         0.1274  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.5945        -0.9067         1.0667  MON TO ARP
 XYZ        -0.0429        -0.0635         0.0774  ARP TO L1 PHASE CENTER
 XYZ  -2498424.4223  -3802821.9273   4454738.8466  L1 PHS CEN @ 2009.1596

 BASELINE NAME:   p376  corv
 XYZ         0.4450         1.0132        -0.9754  + XYZ ADJUSTMENTS
 XYZ  -2498423.9773  -3802820.9141   4454737.8713  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9344  -3802820.8506   4454737.7938  NEW ARP @ 2009.1596
 XYZ  -2498423.3399  -3802819.9439   4454736.7271  NEW MON @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    107.2518  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92597  236 41 43.42234    107.1429  NEW ARP @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    105.6219  NEW MON @ 2009.1596

 BASELINE NAME:   mcso  corv
 XYZ         0.4343         1.0202        -0.9746  + XYZ ADJUSTMENTS
 XYZ  -2498423.9880  -3802820.9071   4454737.8721  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9451  -3802820.8436   4454737.7946  NEW ARP @ 2009.1596
 XYZ  -2498423.3506  -3802819.9369   4454736.7279  NEW MON @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    107.2523  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92599  236 41 43.42176    107.1434  NEW ARP @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    105.6224  NEW MON @ 2009.1596

 BASELINE NAME:   stay  corv
 XYZ         0.4437         1.0153        -0.9543  + XYZ ADJUSTMENTS
 XYZ  -2498423.9786  -3802820.9120   4454737.8923  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9357  -3802820.8485   4454737.8149  NEW ARP @ 2009.1596
 XYZ  -2498423.3412  -3802819.9418   4454736.7482  NEW MON @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    107.2658  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92648  236 41 43.42224    107.1569  NEW ARP @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    105.6359  NEW MON @ 2009.1596
```

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

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REMOTE STATION INFORMATION

 STATION NAME: corv       1
  MONUMENT: NO DOMES NUMBER
 XYZ  -2498423.7849  -3802820.9571   4454737.7025  MON @ 2009.1595 (M)
 NEU        -0.0014         0.0010         1.5210  MON TO ARP (M)
 NEU         0.0014        -0.0010         0.1089  ARP TO L1 PHASE CENTER (M)
 NEU         0.0010         0.0005         0.1274  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.5945        -0.9067         1.0667  MON TO ARP
 XYZ        -0.0429        -0.0635         0.0774  ARP TO L1 PHASE CENTER
 XYZ  -2498424.4223  -3802821.9273   4454738.8466  L1 PHS CEN @ 2009.1596

 BASELINE NAME:   p376  corv
 XYZ          0.4450         1.0132        -0.9754  + XYZ ADJUSTMENTS
 XYZ  -2498423.9773  -3802820.9141   4454737.8713  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9344  -3802820.8506   4454737.7938  NEW ARP @ 2009.1596
 XYZ  -2498423.3399  -3802819.9439   4454736.7271  NEW MON @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    107.2518  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92597  236 41 43.42234    107.1429  NEW ARP @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    105.6219  NEW MON @ 2009.1596

 BASELINE NAME:   mcso  corv
 XYZ          0.4343         1.0202        -0.9746  + XYZ ADJUSTMENTS
 XYZ  -2498423.9880  -3802820.9071   4454737.8721  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9451  -3802820.8436   4454737.7946  NEW ARP @ 2009.1596
 XYZ  -2498423.3506  -3802819.9369   4454736.7279  NEW MON @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    107.2523  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92599  236 41 43.42176    107.1434  NEW ARP @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    105.6224  NEW MON @ 2009.1596

 BASELINE NAME:   stay  corv
 XYZ          0.4437         1.0153        -0.9543  + XYZ ADJUSTMENTS
 XYZ  -2498423.9786  -3802820.9120   4454737.8923  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9357  -3802820.8485   4454737.8149  NEW ARP @ 2009.1596
 XYZ  -2498423.3412  -3802819.9418   4454736.7482  NEW MON @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    107.2658  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92648  236 41 43.42224    107.1569  NEW ARP @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    105.6359  NEW MON @ 2009.1596
```

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.

37

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The Extended Report


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REMOTE STATION INFORMATION

 STATION NAME: corv       1
  MONUMENT: NO DOMES NUMBER
 XYZ  -2498423.7849  -3802820.9571   4454737.7025  MON @ 2009.1595 (M)
 NEU        -0.0014         0.0010         1.5210  MON TO ARP (M)
 NEU         0.0014        -0.0010         0.1089  ARP TO L1 PHASE CENTER (M)
 NEU         0.0010         0.0005         0.1274  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.5945        -0.9067         1.0667  MON TO ARP
 XYZ        -0.0429        -0.0635         0.0774  ARP TO L1 PHASE CENTER
 XYZ  -2498424.4223  -3802821.9273   4454738.8466  L1 PHS CEN @ 2009.1596

 BASELINE NAME:   p376  corv
 XYZ          0.4450         1.0132        -0.9754  + XYZ ADJUSTMENTS
 XYZ  -2498423.9773  -3802820.9141   4454737.8713  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9344  -3802820.8506   4454737.7938  NEW ARP @ 2009.1596
 XYZ  -2498423.3399  -3802819.9439   4454736.7271  NEW MON @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    107.2518  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92597  236 41 43.42234    107.1429  NEW ARP @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    105.6219  NEW MON @ 2009.1596

 BASELINE NAME:   mcso  corv
 XYZ          0.4343         1.0202        -0.9746  + XYZ ADJUSTMENTS
 XYZ  -2498423.9880  -3802820.9071   4454737.8721  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9451  -3802820.8436   4454737.7946  NEW ARP @ 2009.1596
 XYZ  -2498423.3506  -3802819.9369   4454736.7279  NEW MON @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    107.2523  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92599  236 41 43.42176    107.1434  NEW ARP @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    105.6224  NEW MON @ 2009.1596

 BASELINE NAME:   stay  corv
 XYZ          0.4437         1.0153        -0.9543  + XYZ ADJUSTMENTS
 XYZ  -2498423.9786  -3802820.9120   4454737.8923  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9357  -3802820.8485   4454737.8149  NEW ARP @ 2009.1596
 XYZ  -2498423.3412  -3802819.9418   4454736.7482  NEW MON @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    107.2658  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92648  236 41 43.42224    107.1569  NEW ARP @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    105.6359  NEW MON @ 2009.1596
```


In the associated "blocks", the estimated adjustment and resulting coordinates from each baseline solution are shown.

38

The Extended Report

```
REMOTE STATION INFORMATION

 STATION NAME: corv       1
  MONUMENT: NO DOMES NUMBER
 XYZ  -2498423.7849  -3802820.9571   4454737.7025  MON @ 2009.1595 (M)
 NEU        -0.0014         0.0010         1.5210  MON TO ARP  (M)
 NEU         0.0014        -0.0010         0.1089  ARP TO L1 PHASE CENTER (M)
 NEU         0.0010         0.0005         0.1274  ARP TO L2 PHASE CENTER (M)
 XYZ        -0.5945        -0.9067         1.0667  MON TO ARP
 XYZ        -0.0429        -0.0635         0.0774  ARP TO L1 PHASE CENTER
 XYZ  -2498424.4223  -3802821.9273   4454738.8466  L1 PHS CEN @ 2009.1596

 BASELINE NAME:   p376  corv
 XYZ         0.4450         1.0132        -0.9754  + XYZ ADJUSTMENTS
 XYZ  -2498423.9773  -3802820.9141   4454737.8713  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9344  -3802820.8506   4454737.7938  NEW ARP @ 2009.1596
 XYZ  -2498423.3399  -3802819.9439   4454736.7271  NEW MON @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    107.2518  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92597  236 41 43.42234    107.1429  NEW ARP @ 2009.1596
 LLH  44 35  7.92601  236 41 43.42229    105.6219  NEW MON @ 2009.1596

 BASELINE NAME:   mcso  corv
 XYZ         0.4343         1.0202        -0.9746  + XYZ ADJUSTMENTS
 XYZ  -2498423.9880  -3802820.9071   4454737.8721  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9451  -3802820.8436   4454737.7946  NEW ARP @ 2009.1596
 XYZ  -2498423.3506  -3802819.9369   4454736.7279  NEW MON @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    107.2523  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92599  236 41 43.42176    107.1434  NEW ARP @ 2009.1596
 LLH  44 35  7.92603  236 41 43.42171    105.6224  NEW MON @ 2009.1596

 BASELINE NAME:   stay  corv
 XYZ         0.4437         1.0153        -0.9543  + XYZ ADJUSTMENTS
 XYZ  -2498423.9786  -3802820.9120   4454737.8923  NEW L1 PHS CEN @ 2009.1596
 XYZ  -2498423.9357  -3802820.8485   4454737.8149  NEW ARP @ 2009.1596
 XYZ  -2498423.3412  -3802819.9418   4454736.7482  NEW MON @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    107.2658  NEW L1 PHS CEN @ 2009.1596
 LLH  44 35  7.92648  236 41 43.42224    107.1569  NEW ARP @ 2009.1596
 LLH  44 35  7.92653  236 41 43.42219    105.6359  NEW MON @ 2009.1596
```

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.

The Extended Report

```
                              G-FILES

Axx2009 228   9 228
B2009 228 5 0   9 228 659 1 page5 v0909.08IGS     226 1 2 27NGS   2010 7 9IFDDFX
Iant_info.003        NGS   20100616
C00090001  286164051   30  144713755   32  281166583   28 X0599ACORVX0599AP376
D  1  2  9032521  1  3 -2281991  2  3 -5618980

Axx2009 228   9 228
B2009 228 5 0   9 228 659 1 page5 v0909.08IGS     226 1 2 27NGS   2010 7 9IFDDFX
Iant_info.003        NGS   20100616
C00090002  397542453   32  103924818   30  305905079   27 X0599ACORVX0599AMCSO
D  1  2  8318045  1  3 -1709106  2  3 -6334467

Axx2009 228   9 228
B2009 228 5 0   9 228 659 1 page5 v0909.08IGS     226 1 2 27NGS   2010 7 9IFDDFX
Iant_info.003        NGS   20100616
C00090003  425824609   35  -48539879   22  193670380   18 X0599ACORVX0599ASTAY
D  1  2  6847311  1  3 -1553171  2  3 -7047523
```

Following the baseline information are some Bluebook records…

The Extended Report

```
                    POST-FIT RMS BY SATELLITE VS. BASELINE

            OVERALL     03     06     07     08     10     13     16     19
p376-corv|   0.009  0.010  0.016    ...  0.007  0.014  0.005  0.015  0.009
                20     23     25     27     28
p376-corv|     ...  0.008  0.005    ...  0.010

            OVERALL     03     06     07     08     10     13     16     19
mcso-corv|   0.009  0.010  0.014    ...  0.010  0.011  0.006  0.015  0.012
                20     23     25     27     28
mcso-corv|     ...  0.008  0.005    ...  0.010

            OVERALL     03     06     07     08     10     13     16     19
stay-corv|   0.010  0.014  0.016    ...  0.009  0.014  0.006  0.013  0.012
                20     23     25     27     28
stay-corv|     ...  0.011  0.005    ...  0.012

                         OBS BY SATELLITE VS. BASELINE

            OVERALL     03     06     07     08     10     13     16     19
p376-corv|    2000    238    237    ...    238    169    238     99    187
                20     23     25     27     28
p376-corv|     ...    227    238    ...    129
            OVERALL     03     06     07     08     10     13     16     19
mcso-corv|    1973    238    234    ...    238    169    238     93    185
                20     23     25     27     28
mcso-corv|     ...    211    238    ...    129
            OVERALL     03     06     07     08     10     13     16     19
stay-corv|    2011    238    238    ...    238    169    238     99    199
                20     23     25     27     28
stay-corv|     ...    229    238    ...    125
```

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

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The Extended Report

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.

POST-FIT RMS BY SATELLITE VS. BASELINE

	OVERALL	03	06	07	08	10	13	16	19	20	23	25	27	28
p376-corv|	0.009	0.010	0.016	...	0.007	0.014	0.005	0.015	0.009	...	0.008	0.005	...	0.010
mcso-corv|	0.009	0.010	0.014	...	0.010	0.011	0.006	0.015	0.012	...	0.008	0.005	...	0.010
stay-corv|	0.010	0.014	0.016	...	0.009	0.014	0.006	0.013	0.01	...	0.011	0.005	...	0.012

OBS BY SATELLITE VS. BASELINE

	OVERALL	03	06	07	08	10	13	16	19	20	23	25	27	28
p376-corv|	2000	238	237	...	238	169	238	99	187	...	227	238	...	129
mcso-corv|	1973	238	234	...	238	169	238	93	185	...	211	238	...	129
stay-corv|	2011	238	238	...	238	169	238	99	199	...	229	238	...	125

The Extended Report

```
 Covariance Matrix for the xyz OPUS Position
(meters^2).
    0.0000069978      0.0000004873     -0.0000000972
    0.0000004873      0.0000053511     -0.0000002879
   -0.0000000972     -0.0000002879      0.0000040822

 Covariance Matrix for the enu OPUS Position
(meters^2).
    0.0000060540      0.0000007189     -0.0000006244
    0.0000007189      0.0000048712     -0.0000010998
   -0.0000006244     -0.0000010998      0.0000055059

 Horizontal network accuracy =    0.00573 meters.
 Vertical network accuracy   =    0.00460 meters.
```

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.

The Extended Report.

```
                    Derivation of NAD 83 vector components


 Position of reference station ARP in NAD_83(CORS96)(EPOCH:2002.0000).
                Xa(m)           Ya(m)           Za(m)
     P376  -2469806.16816  -3788349.79220   4482853.31622    2002.00
     MCSO  -2458668.34414  -3792428.66602   4485327.16392    2002.00
     STAY  -2455840.11392  -3807675.15002   4474103.71103    2002.00

 Position of reference station monument in NAD_83(CORS96)(EPOCH:2002.0000).
                Xr(m)           Yr(m)           Zr(m)
     P376  -2469806.16496  -3788349.78730   4482853.31032    2002.00
     MCSO  -2458668.34414  -3792428.66602   4485327.16392    2002.00
     STAY  -2455840.11392  -3807675.15002   4474103.71103    2002.00

 Velocity of reference station monument in NAD_83(CORS96)(EPOCH:2002.0000).
                Vx (m/yr)       Vy (m/yr)       Vz (m/yr)
     P376         0.00440         0.00380         0.00560
     MCSO         0.00550         0.00260         0.00520
     STAY         0.00460         0.00290         0.00490

 Vectors from unknown station monument to reference station monument
 in NAD_83(CORS96)(EPOCH:2002.0000).
              Xr-X= DX(m)     Yr-Y= DY(m)     Zr-Z= DZ(m)
     P376     28616.43804     14471.37170     28116.64932    2002.00
     MCSO     39754.25886     10392.49298     30590.50292    2002.00
     STAY     42582.48908     -4853.99102     19367.05003    2002.00
```

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.

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
```

45

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OPUS Output - *Standard*

OPUS Output - *XML*

FILE: corv0590.05o 000416827


```
<?xml version="1.0" encoding="UTF-8"?>
<OPUS_SOLUTION>
  <USER_INFORMATION>
    <USER_EMAIL>          joe.evjen@gmail.com     </USER_EMAIL>
    <SOLUTION_DATE>       February 19, 2008       </SOLUTION_DATE>
    <SOLUTION_TIME>       01:16:22 UTC            </SOLUTION_TIME>
    <RINEX_FILE_NAME>     zzyy1500.07o            </RINEX_FILE_NAME>
  </USER_INFORMATION>
  <DATA_INFORMATION>
    <SOFTWARE>
      <PAGES_VERSION>     page5  0612.06          </PAGES_VERSION>
      <OPUS_VERSION>      master3.pl              </OPUS_VERSION>
    </SOFTWARE>
    <EMPHEMERIS>          igs14293.eph [precise]  </EMPHEMERIS>
    <NAV_FILE>            brdc1500.07n            </NAV_FILE>
    <ANTENNA_NAME>        TRM41249.00     NONE    </ANTENNA_NAME>
    <ARP_HEIGHT>          0.0                     </ARP_HEIGHT>
    <START_TIME>          2007/05/30  00:00:00    </START_TIME>
    <END_TIME>            2007/05/30  23:59:00    </END_TIME>
    <OBS_USED>
      <NUMBER_USED>       52955                   </NUMBER_USED>
      <TOTAL_OBS>         55069                   </TOTAL_OBS>
      <PERCENTAGE>        96                      </PERCENTAGE>
    </OBS_USED>
    <FIXED_AMB>
      <NUMBER_FIXED>      218                     </NUMBER_FIXED>
      <NUMBER_AMB>        242                     </NUMBER_AMB>
      <PERCENTAGE>        90                      </PERCENTAGE>
    </FIXED_AMB>
    <OVERALL_RMS UNIT="m"> 0.021                  </OVERALL_RMS>
  </DATA_INFORMATION>
  <POSITION>
    <REF_FRAME>           NAD_83(CORS96)          </REF_FRAME>
    <EPOCH>               2002.0000               </EPOCH>
    <COORD_SET>
      <RECT_COORD>
        <COORDINATE AXIS="X" UNIT="m" UNCERTAINTY="0.003"> -496255.901 </COORDINATE>
        <COORDINATE AXIS="Y" UNIT="m" UNCERTAINTY="0.022"> -5510741.494 </COORDINATE>
        <COORDINATE AXIS="Z" UNIT="m" UNCERTAINTY="0.017"> 3162058.243 </COORDINATE>
      </RECT_COORD>
      <ELLIP_COORD>
        <LAT>
          <DEGREES> 29 </DEGREES>
          <MINUTES> 54 </MINUTES>
          <SECONDS> 48.44070 </SECONDS>
```

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.

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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 OPUS-RS Interface

http://geodesy.noaa.gov/OPUS/

The same interface is used except one clicks the "Upload to RAPID-STATIC" button instead.

53

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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.

54

How Does OPUS-RS Work?

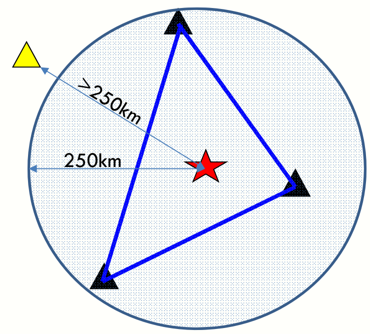
OPUS-RS selects three to nine "best" CORS based upon:

- 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.



Choi, 2010, personal communication.

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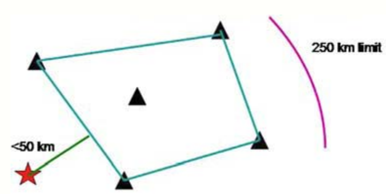
How Does OPUS-RS Work?

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.

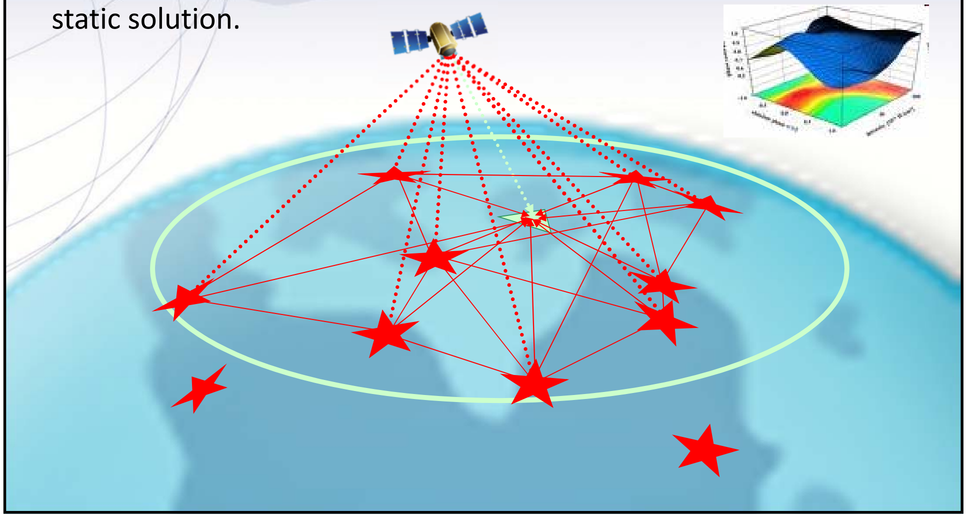
If the user's site, the star, is more than 50 km outside this polygon, alternate CORS will be considered. If none can be found, the processing will abort.



Schwarz et al., "Accuracy assessment of the National Geodetic Survey's OPUS-RS utility", 2009, *GPS Solutions*, 13(2), 119-132.

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.

Schwarz et al., "Accuracy assessment of the National Geodetic Survey's OPUS-RS utility", 2009, *GPS Solutions*, 13(2), 119-132.

A Quick Example

```
     USER: mark.schenewerk@noaa.gov                  DATE: April 01, 2010
RINEX FILE: corv059f.09o                             TIME: 16:17:51 UTC

  SOFTWARE: rsgps  1.35 RS11.prl 1.57               START: 2009/02/28 05:00:00
 EPHEMERIS: igs15206.eph [precise]                   STOP: 2009/02/28 06:59:30
  NAV FILE: brdc0590.09n                         OBS USED:  5652 / 11169   :  51%
  ANT NAME: ASH700936C_M                      QUALITY IND.  48.23/108.85
ARP HEIGHT: 1.521                          NORMALIZED RMS:        0.280

 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2009.15959)

        X:     -2498422.589(m)   0.015(m)          -2498423.330(m)   0.015(m)
        Y:     -3802821.147(m)   0.012(m)          -3802819.929(m)   0.012(m)
        Z:      4454736.644(m)   0.021(m)           4454736.717(m)   0.021(m)

      LAT:   44 35  7.91061      0.004(m)        44 35  7.92619      0.004(m)
    E LON:  236 41 43.48069      0.011(m)       236 41 43.42230      0.011(m)
    W LON:  123 18 16.51931      0.011(m)       123 18 16.57770      0.011(m)
   EL HGT:           105.986(m)  0.026(m)                105.602(m)  0.026(m)
 ORTHO HGT:          128.517(m)  0.030(m) [NAVD88 (Computed using GEOID09)]

                          UTM COORDINATES    STATE PLANE COORDINATES
                           UTM (Zone 10)         SPC (3601 OR N)
Northing (Y) [meters]     4936954.909           105971.559
Easting (X)  [meters]      475821.309          2277335.372
Convergence  [degrees]    -0.21381414          -1.98897509
Point Scale                0.99960719           0.99994603
Combined Factor            0.99959058           0.99992942

US NATIONAL GRID DESIGNATOR: 10TDQ7582136954(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DH4503 P376 EOLARESVR_OR2004 CORS ARP      N445628.313 W1230608.100   42648.2
DG5352 STAY STAYTON COOP CORS ARP          N444950.530 W1224915.036   47030.9
DE6258 MCSO MARION CNTY COOP CORS ARP      N445825.701 W1225720.639   51226.8
DI7529 P367 NEWPRTAIR_OR2007 CORS ARP      N443506.870 W1240341.598   60113.5
                                      ⋮
```

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.

NOAA's National Geodetic Survey Positioning America for the Future   geodesy.noaa.gov

A Quick Example


```
     USER: mark.schenewerk@noaa.gov                  DATE: April 01, 2010
RINEX FILE: corv059f.09o                             TIME: 16:17:51 UTC

  SOFTWARE: rsgps  1.35 RS11.prl 1.57               START: 2009/02/28 05:00:00
 EPHEMERIS: igs15206.eph [precise]                   STOP: 2009/02/28 06:59:30
  NAV FILE: brdc0590.09n                         OBS USED:  5652 / 11169   :  51%
  ANT NAME: ASH700936C_M                      QUALITY IND.  48.23/108.85
ARP HEIGHT: 1.521                          NORMALIZED RMS:        0.280

 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2009.15959)

        X:     -2498422.589(m)   0.015(m)          -2498423.330(m)   0.015(m)
        Y:     -3802821.147(m)   0.012(m)          -3802819.929(m)   0.012(m)
        Z:      4454736.644(m)   0.021(m)           4454736.717(m)   0.021(m)

      LAT:   44 35  7.91061      0.004(m)        44 35  7.92619      0.004(m)
    E LON:  236 41 43.48069      0.011(m)       236 41 43.42230      0.011(m)
    W LON:  123 18 16.51931      0.011(m)       123 18 16.57770      0.011(m)
   EL HGT:           105.986(m)  0.026(m)                105.602(m)  0.026(m)
 ORTHO HGT:          128.517(m)  0.030(m) [NAVD88 (Computed using GEOID09)]

                          UTM COORDINATES    STATE PLANE COORDINATES
                           UTM (Zone 10)         SPC (3601 OR N)
Northing (Y) [meters]     4936954.909           105971.559
Easting (X)  [meters]      475821.309          2277335.372
Convergence  [degrees]    -0.21381414          -1.98897509
Point Scale                0.99960719           0.99994603
Combined Factor            0.99959058           0.99992942

US NATIONAL GRID DESIGNATOR: 10TDQ7582136954(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DH4503 P376 EOLARESVR_OR2004 CORS ARP      N445628.313 W1230608.100   42648.2
DG5352 STAY STAYTON COOP CORS ARP          N444950.530 W1224915.036   47030.9
DE6258 MCSO MARION CNTY COOP CORS ARP      N445825.701 W1225720.639   51226.8
DI7529 P367 NEWPRTAIR_OR2007 CORS ARP      N443506.870 W1240341.598   60113.5
                                      ⋮
```


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

```
     USER: mark.schenewerk@noaa.gov                  DATE: April 01, 2010
RINEX FILE: corv059f.09o                             TIME: 16:17:51 UTC


  SOFTWARE: rsgps  1.35 RS11.prl 1.57               START: 2009/02/28 05:00:00
 EPHEMERIS: igs15206.eph [precise]                   STOP: 2009/02/28 06:59:30
  NAV FILE: brdc0590.09n                         OBS USED:  5652 / 11169   :  51%
  ANT NAME: ASH700936C_M                     QUALITY IND.  48.23/108.85
ARP HEIGHT: 1.521                          NORMALIZED RMS:        0.280


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2009.15959)

        X:     -2498422.589(m)   0.015(m)          -2498423.330(m)   0.015(m)
        Y:     -3802821.147(m)   0.012(m)          -3802819.929(m)   0.012(m)
        Z:      4454736.644(m)   0.021(m)           4454736.717(m)   0.021(m)

      LAT:   44 35  7.91061      0.004(m)        44 35  7.92619      0.004(m)
    E LON:  236 41 43.48069      0.011(m)       236 41 43.42230      0.011(m)
    W LON:  123 18 16.51931      0.011(m)       123 18 16.57770      0.011(m)
   EL HGT:          105.986(m)   0.026(m)              105.602(m)   0.026(m)
 ORTHO HGT:          128.517(m)   0.030(m) [NAVD88 (Computed using GEOID09)]

                         UTM COORDINATES    STATE PLANE COORDINATES
                          UTM (Zone 10)         SPC (3601 OR N)
Northing (Y) [meters]     4936954.909           105971.559
Easting (X)  [meters]      475821.309          2277335.372
Convergence  [degrees]    -0.21381414          -1.98897509
Point Scale                0.99960719           0.99994603
Combined Factor            0.99959058           0.99992942

US NATIONAL GRID DESIGNATOR: 10TDQ7582136954(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DH4503 P376 EOLARESVR_OR2004 CORS ARP      N445628.313 W1230608.100    42648.2
DG5352 STAY STAYTON COOP CORS ARP          N444950.530 W1224915.036    47030.9
DE6258 MCSO MARION CNTY COOP CORS ARP      N445825.701 W1225720.639    51226.8
DI7529 P367 NEWPRTAIR_OR2007 CORS ARP      N443506.870 W1240341.598    60113.5
                                       ⋮
```

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.

61

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).

62

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 that - estimates. Confirming the quality of the OPUS solution remains the user's responsibility.

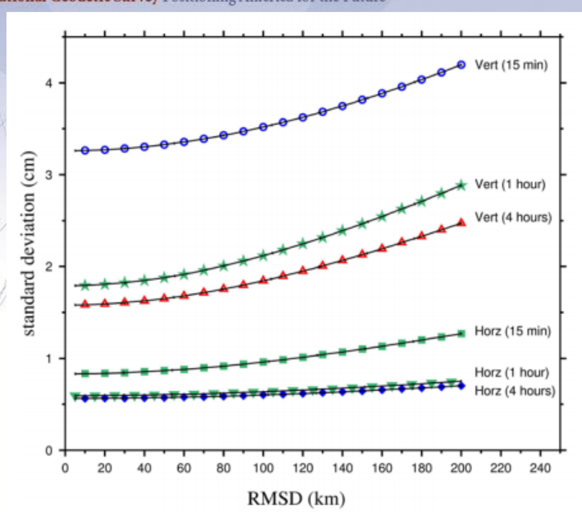
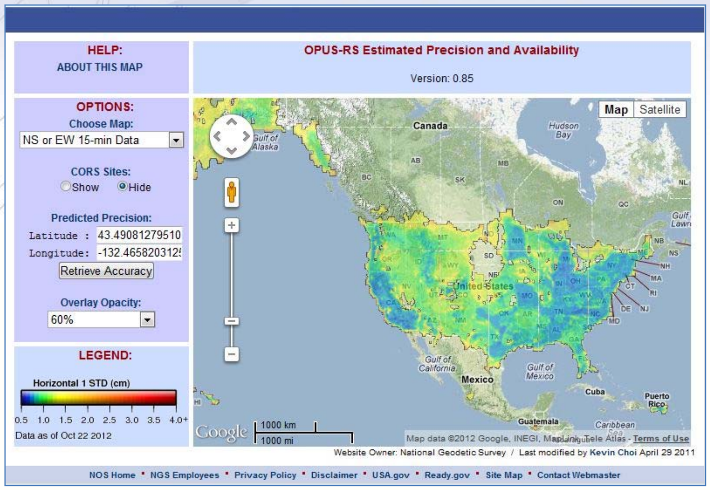


Figure 3. Predicted standard deviations in the vertical (ellipsoid height) and in each horizontal dimension (north-south or east-west), achievable with OPUS-RS, as a function of RMSD for data spans of 15 minutes, 1 hour and 4 hours and an IDOP value of 0.45.

Snay, R., K. Choi, G. Mader, C. Schwarz, T. Soler, and N. Weston (2011). How precise is OPUS? Part 1: Experimental results, *The American Surveyor,* 8(5), 49-50, 52, 53-54.

How Good Can I Do With OPUS-RS?

The OPUS-RS Accuracy and Availability Tool.



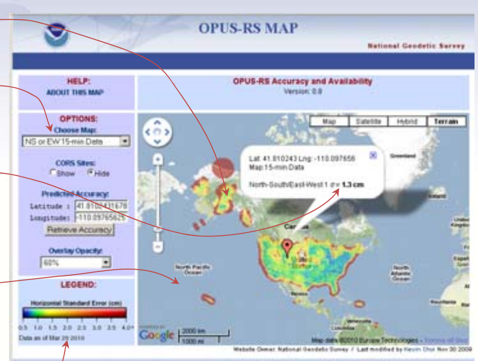
http://www.ngs.noaa.gov/OPUSI/Plots/Gmap/OPUSRS_sigmap.shtml

65

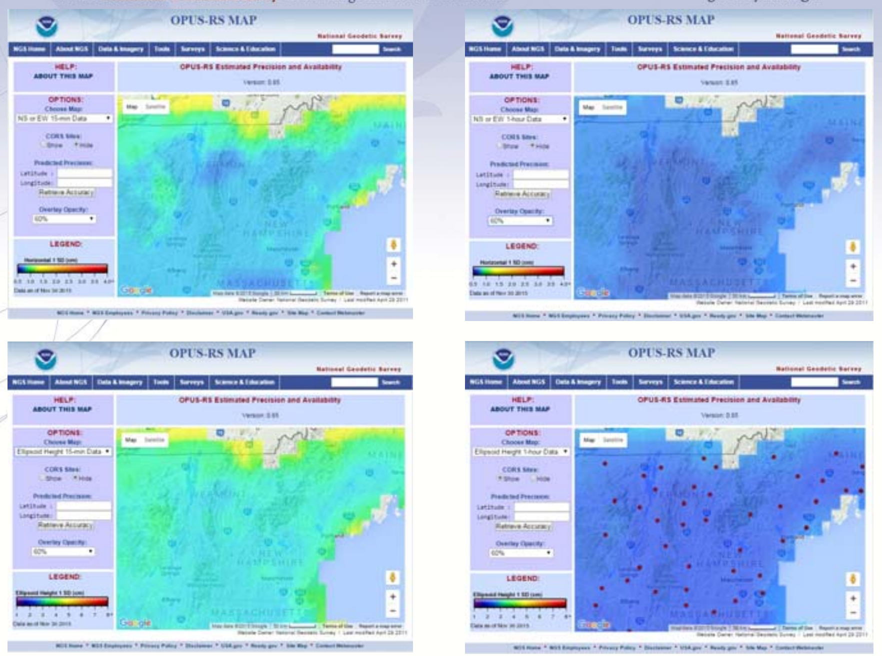
NOAA's National Geodetic Survey Positioning America for the Future geodesy.noaa.gov

How Good Can I Do With OPUS-RS?

- 1 σ 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.



66



OPUS static vs. rapid static

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