Best OPUS Practices

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Introduction

We sell quite a few static receivers every year. Many customers are first time uses of the NGS OPUS system. We have noticed that the same problems occur for most new users. Hopefully this document will answer most of the first time user questions and even if you are an experienced OPUS user, this document might save you some OPUS-Trouble.

1

My OPUS Error Message Joke

If you work for the NGS, please skip over this section. You won't think that this is that funny.

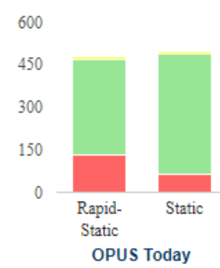
Now, for everyone else, I think that this joke is hilarious:

> "The NGS processing engine has a big fishbowl with 500 possible error messages printed on little slips of paper. If a job fails, the OPUS processor removes the five best error messages from the fishbowl. Next the fishbowl is shaken and three to five slips are pulled from the fishbowl and returned to the user."

OPUS error reporting is getting better. Someday this joke won't be funny anymore.

But you should remember this: you are not alone. Every-Single-Day a substantial portion of all OPUS submissions fail and most fail with a confusing error message.

OPUS-RS is Dicey



When you submit OPUS occupations, there is a graphic that shows the daily number of jobs and the daily success rate. On most days over 25% of all submitted OPUS-RS jobs fail!

This document addresses many of the reasons that both OPUS-RS and OPUS-Static jobs will fail. With a little wisdom, you should be able to stay out of the red zone.

Relatively few OPUS-Static jobs fail. Most of the Static jobs that fail initially will successfully process when resubmitted the following day. Plus you can always trim an OPUS-Static job to make it an OPUS-RS job (in fact you can always split an OPUS-Static job and submit it as two separate OPUS-RS jobs and then compare the three solutions.)

When using OPUS, longer occupations are always better. See also '*Data Availability*' on page 3. They allow you to bridge over times with high DOP. If nothing else, you can cut them up and process them as two OPUS-RS occupations AND an OPUS-Static occupation.

But remember if you are submitting 15 to 30-minute OPUS-RS occupations—they often WILL fail. Don't be surprised and don't blame your receiver.

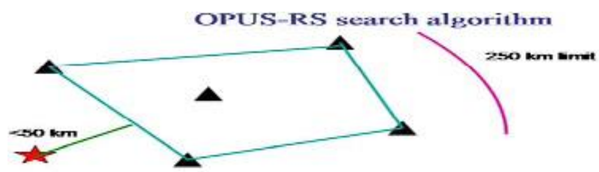
Only Some Submissions are being returned by OPUS

OPUS always returns an email. **<u>Always</u>**. But this is a VERY common issue.

If you are not getting solutions or error messages back, the missing solutions have been trapped in your SPAM filter or you have entered your email address incorrectly on the submission form.

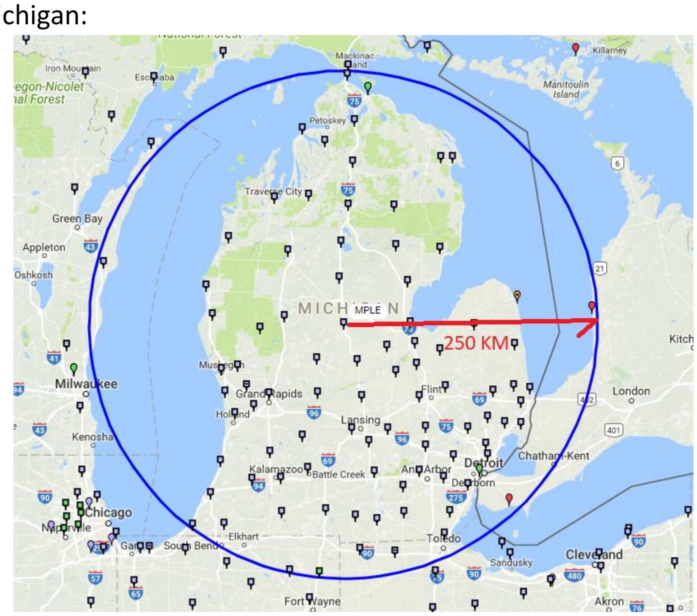
OPUS-RS is Very Dependent on the Number, Availability, Proximity, Distribution and Quality of nearby CORS Stations

The initial stage of OPUS-RS processing determines if a network of three to nine CORS stations within 250 KM of the user location can be built.



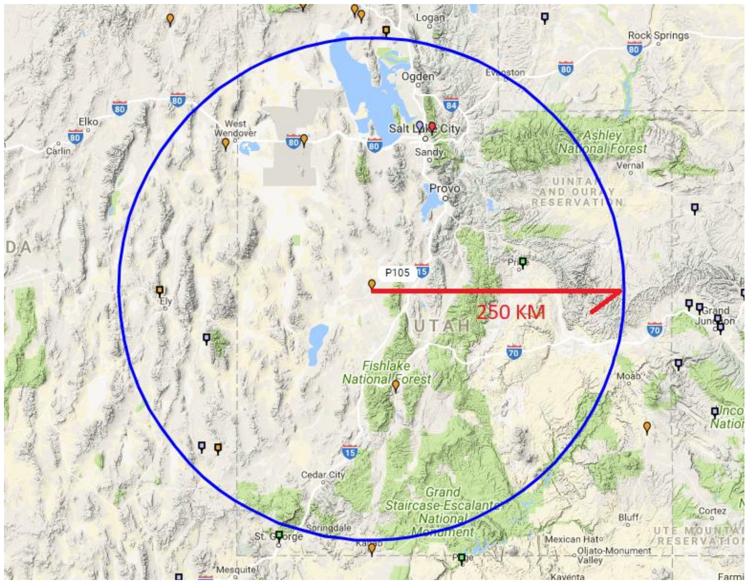
The user location is allowed to be up to 50 KM from the polygon surrounding the selected sites which allows OPUS-RS to succeed in coastal areas where there are no CORS sites offshore. <u>However, every CORS site that is used must be within 250 KM of the user site.</u>

If you are in Michigan:



There are a lot of CORS stations within 250 KM of everywhere. OPUS-RS is likely to always succeed, even if a few of the stations are offline, are missing data or are very noisy and must be discarded.

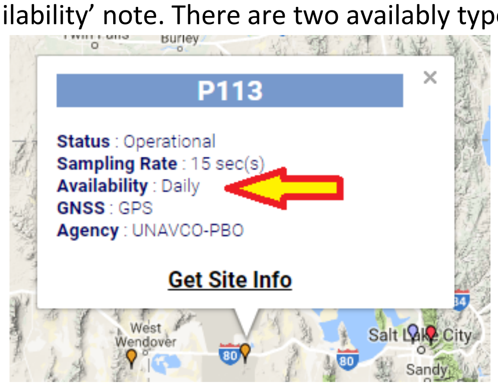
If you are in the middle of Utah there are very few CORS sites available on a good day:



On a bad day, if a few stations are offline or have not archived data yet, then your OPUS-RS solution will fail because there are not enough stations close to your occupation. In many areas a single offline CORS station without data makes OPUS-RS impossible.

Daily vs. Hourly CORS Availability

If you click a CORS station pin on the NGS CORS map, you will get a station summary which includes an ‘Availability’ note. There are two availably types:



Daily

Hourly

Daily means that a full day’s CORS station data is collected sometime after midnight UTC.

Hourly means that the previous hour’s data is collected after the top of each hour.

For the two sites above:

P113 data is typically available at 09:03 am (UTC) on the following day.

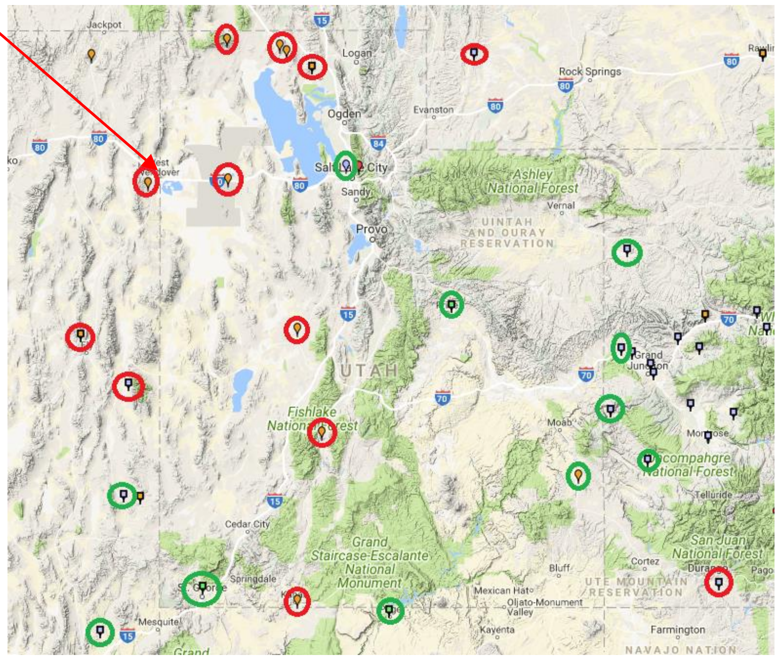
PUC2 data is typically available 35 minutes after the top of each hour.

This means that if your OPUS submission has sufficient nearby hourly stations, then you can probably wait 45 minutes after the top of the hour following your file collection and an OPUS submission will be successful.

However, if you are collecting data in an area where most of the stations have only **daily** availability you will have to wait a longer time before the nearby stations will be available for use.

Some areas of the United States effectively ONLY have Daily Data

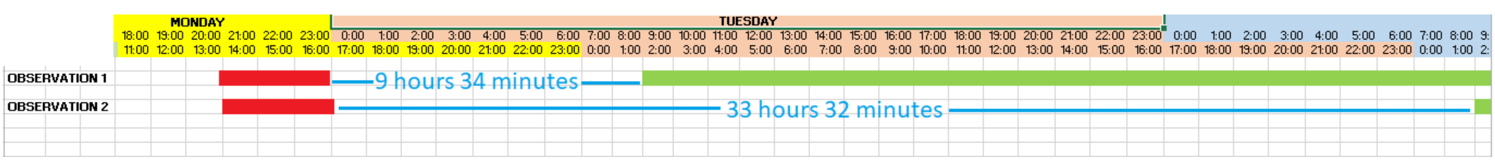
Consider Western Utah:



Daily Stations Red; Hourly Stations Green

If your observation is in the western part of the state, there won't be enough nearby hourly stations to get a quick OPUS-RS or a low noise OPUS-Static solution.

Let's look at an example with two observations collected on the Northwest side of Utah near Wendover:



Timeline showing occupations, UTC time, Local (Mountain) time and availability of daily data

The two observations were performed Monday afternoon (the red bars). One is a section corner, the other is vertical bench mark which is only 400 feet Northeast of the section corner. Both locations enjoy completely open sky – no canopy. Both observations are **exactly** three hours in length.

The first observation starts at 1:59 pm Mountain Time (20:59 UTC) and ends at 4:59 pm Mountain Time (23:59 UTC).

The second observation starts two minutes after the first at 2:01 pm Mountain Time (21:01 UTC) and ends two minutes after the first observation ends at 5:01 pm Mountain Time.

We submit both occupations to OPUS Tuesday morning as soon as we get into the office.

OPUS returns the first solution and it looks fantastic with 98% observations used and an ellipsoid height RMS error estimate of 0.011 meters.

OPUS returns the second solution with an ominous warning 'the observation data is noisy', only 62% of the observations were used and the ellipsoid height RMS error estimate is 0.219 meters!

Is the second receiver defective?

The first OPUS solution was able to use all of the nearby UNAVCO PBO CORS sites which surround Wendover Utah. Data from these sites were available in the archive at 2:35 Mountain (09:35 UTM) on Tuesday; in this case 9 hours and 34 minutes after the end of the first occupation.

The second occupation extended one minute into Tuesday. Data from the UNAVCO PBO sites will not be available until after 2:35 am on **Wednesday**; 33 hours and 32 minutes after the end of the second occupation.

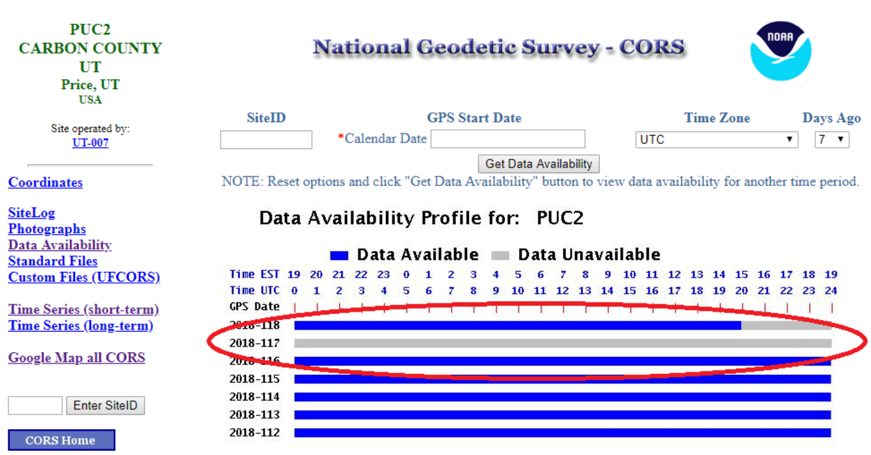
Because no nearby CORS data is available, OPUS has used hourly files from CORS sites over 250 KM away. These long baselines have much higher uncertainty and result in higher RMS estimates. If we resubmit the 2nd occupation on Wednesday, it will have excellent results.

The receivers are identical and neither is defective.

A smart rule-of-thumb is to try to never collect observation data that spans midnight UTC. It causes problems a few days after collection when OPUS is forced to splice ultra-rapid and rapid orbits. It causes additional problems in a few weeks if precise orbits become available for only the 1st portion of an occupation and OPUS has to splice precise orbits for the first portion and rapid orbits for the second portion.

Offline CORS Stations

Often when you look at the 'Data Availability' plot from a CORS station's information page:



You will sometimes find that several hours or an entire day's observation data is unavailable, shown as gray instead of blue.

For a station to be used in a solution, overlapping data for the ENTIRE user occupation must exist. So if you performed an observation on Julian day 117 near the station PUC2 (shown above) and were planning on having PUC2 data available, then you are out of luck. (Although sometimes the data will be re-ingested from the receiver a few days later and subsequently become available.)

NGS CORS Station Quality

When you submit an occupation from your receiver, your receiver's recorded data is compared with the recorded data from the nearby surrounding CORS stations.

OPUS assumes that all CORS data is perfect, so if a baseline solution appears to be noisy, then (obviously) your rover data must be at fault. In other words, any high residuals in the baseline processing are the fault of the user data, not the CORS station data.

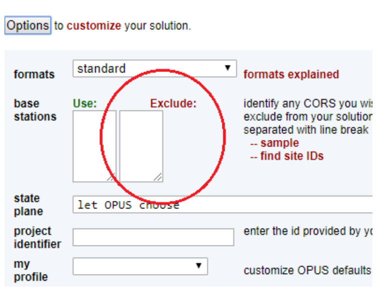
Most OPUS error messages are structured based on this assumption of highest quality CORS data and low expectations of your user data quality.

While most CORS stations are:

- sited at excellent stable locations
- have 100% open sky view above 10 degree elevation in all directions
- have top quality leveling mounts
- are bolted to stable masonry structures or well-engineered ground monuments
- have booked coordinates that are within 2 cm of their apparent actual location
- have state of the art choke ring antenna
- have short, high-quality low-loss coaxial antenna cables with dielectric filled connectors
- enjoy top of the line GNSS receivers with the latest firmware

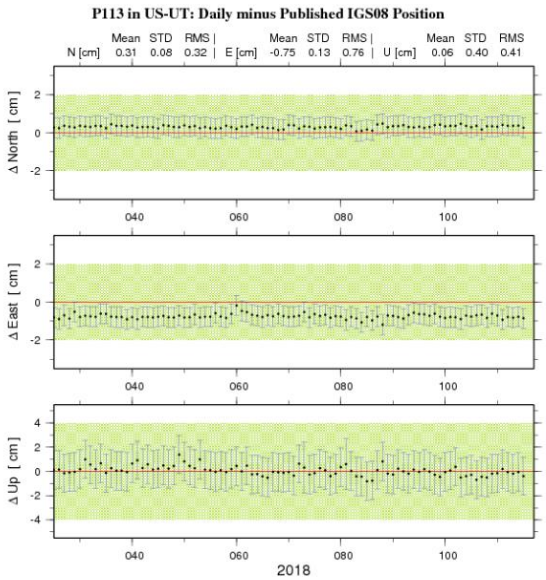
Stuff happens and some of the CORS stations are unreliable. Experience shows that no matter how bad a station might be, NGS CORS will collect the bad data and the OPUS engine will use the bad data.

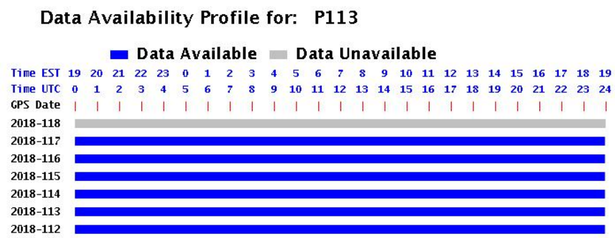
The only effective control that a user has is the 'Exclude' box under 'Options':



How can you determine if a CORS station should be excluded? This is a great question.

Probably the best tool is to click on the 'Time Series (short term)' button. Here is an example of a great station:

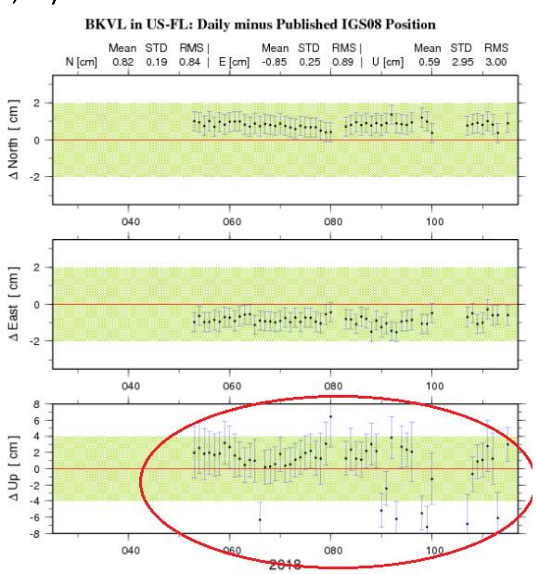




Time Series Short-Term Availability

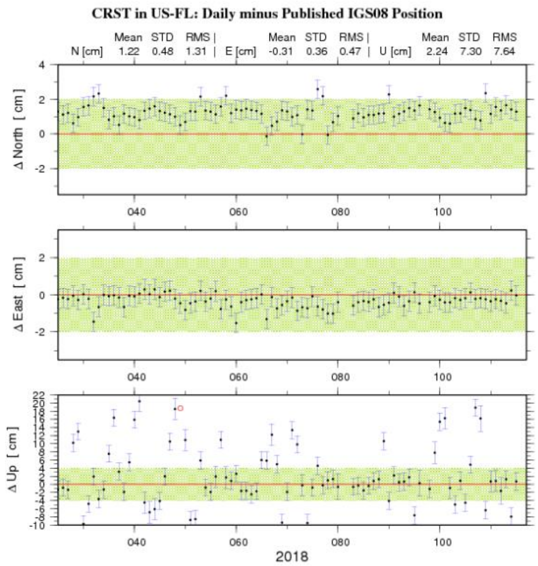
The position trends are very stable and are within 1 cm horizontal and vertical of the published IGS08 positions. The average locations and all of the error bars are fully contained in the green error bands. Coupled with continuous recent Data Availability this station appears be a great CORS resource.

However, if you look at a station's Time Series and it looks like this:



You probably don't want this station to contribute anything to your solutions. EVER. If you catch this site on a bad day (and it has a lot of them) you can expect a 5 cm elevation 'issue.'

Here is another bad site:



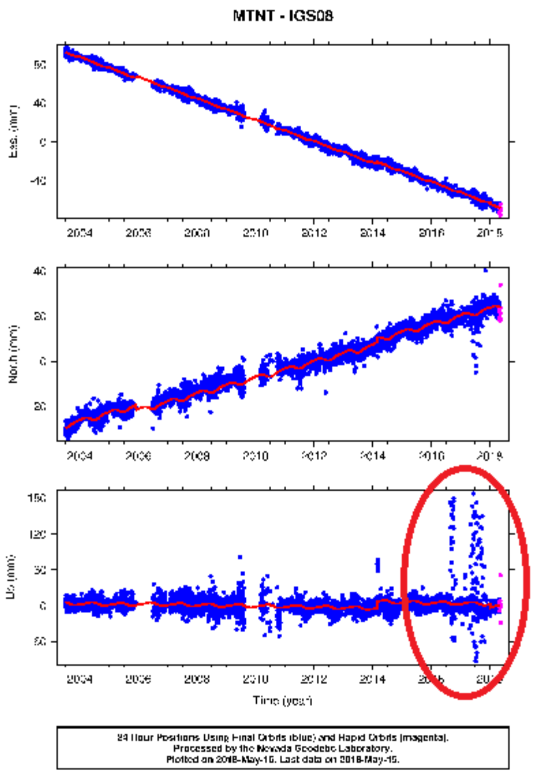
Again, this site should never be used in an OPUS solution. Both of these stations and all the others like them are unsuitable for any processing use.

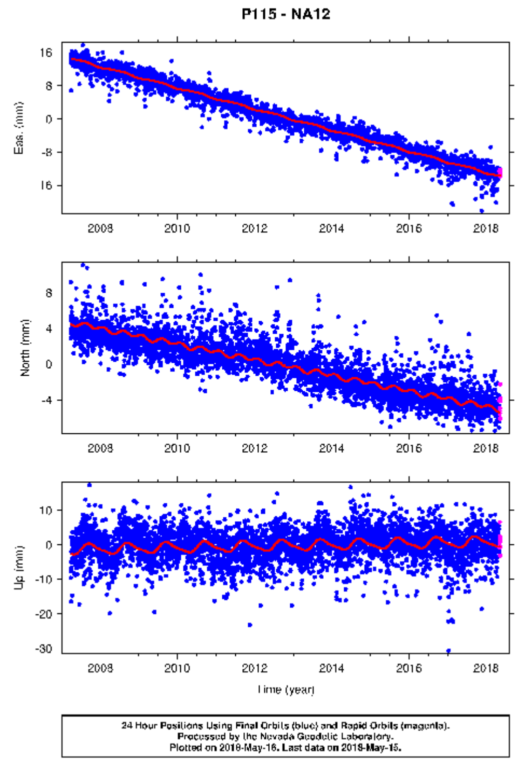
UNR: University Nevada Reno

Another great resource for looking at CORS stations is the UNR Geodesy service:

http://geodesy.unr.edu/NGLStationPages/gpsnetmap/GPSNetMap.html

From this link you can click on most CORS stations and get excellent long term plots:





25 cm elevation range: **BAD** 3 cm height range: **GOOD**

There are even direct links available for seismic events near a station so you can investigate step inputs to positions.

Static Data vs. Kinematic Data

A very common source of rejected OPUS occupations are non-static occupations. There are two kinds:

1. True Static-Occupations that have a errant marker name embedded in the RINEX which makes them look dynamic
2. Files that are marked as static, but have receiver motion

The first kind is a RINEX conversion artifact and can be fixed by manually editing the RINEX file to remove any MARKER events and tags. (A subject for another day.)

The second error happens when the operator turns on the receiver immediately after it is removed from the transport case but prior to it being mounted on the survey mark. The operator messes around at the truck for a few minutes, with the receiver recording data, and then walks over to tripod or pole and screws the antenna down.

Similarly at the end of the occupation, the file should be closed or the receiver should be turned off prior to taking the antenna back to the truck.

We have received several customer files and processed them as kinematic occupations only to find the receiver stored data through the occupation and all the way back to the customer's office!

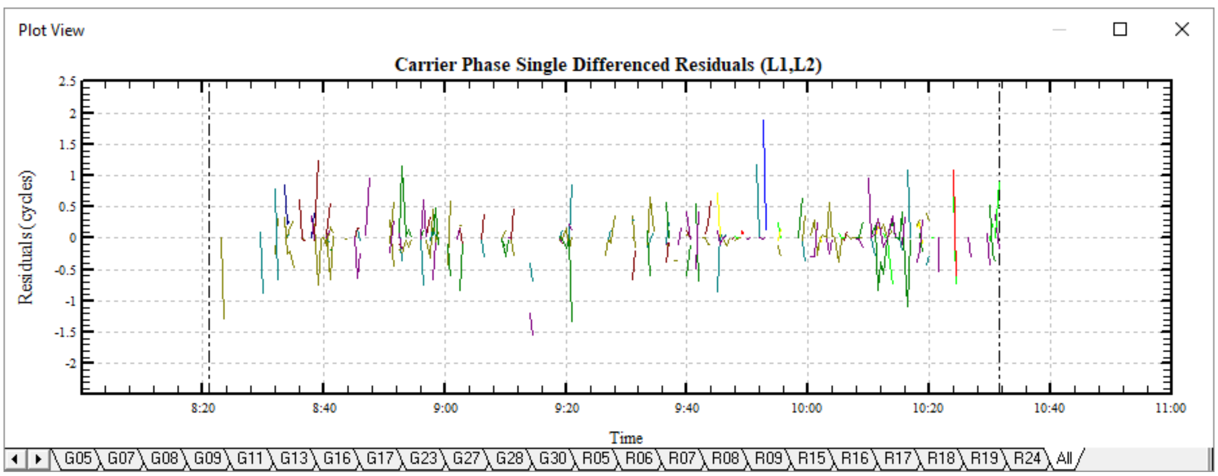
This looks like 'really noisy static data' to the OPUS processing engine and OPUS will refuse to process the submitted files.

This issue is so common that we have built a Trimmer tool into the iGage Download tool so that it is easy to trim the beginning and ending of an occupation. Once the 'motion' parts of a file are removed, the remaining static observations will process normally.

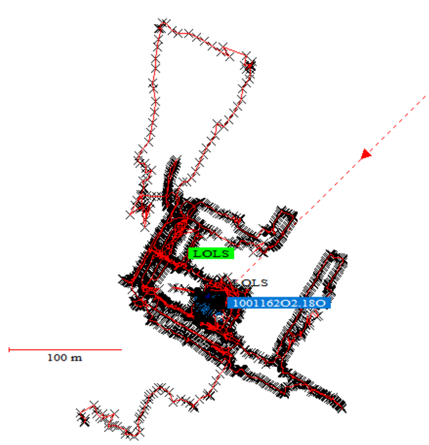
Even though this is easy to fix it really is not that difficult to wait until the receiver is mounted to turn it on or manually start a new file. This error should be easy to avoid.

Submitting Kinematic Rover Data to OPUS

If you accidentally exchange the observation data between the Rover and Base, OPUS will correctly complain that the data is noisy or not static. As an example, here are the residuals for a Rover observation file when processed as a static observation against nearby CORS:



If this same file is processed as kinematic data:



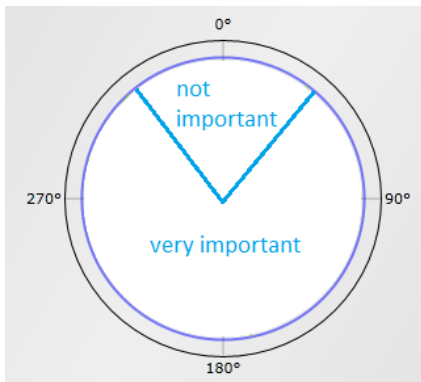
You can retrace the receiver's path throughout the day.

GPS Suitable Locations

The NGS recommends that you submit GPS occupations collected in **GPS suitable locations**. Very little NGS guidance is provided for what is 'GPS suitable' in the context of OPUS. (Excellent guidance is provided for CORS: https://www.ngs.noaa.gov/PUBS_LIB/CORS_guidelines.pdf and the CORS suggestions are certainly applicable to OPUS.)

Best Case Scenario

The best possible site would have a totally clear view of the sky above 10° at all azimuths where there is a possibility of a GPS satellite being in the sky:



Obstructions to the North not important in North America

Note: OPUS will process observations down to 10° elevation so you should set your receiver to start tracking a few degrees below 10°, or just allow you to track all the way to the horizon.

Attributes of a great GPS location:

- No overhead power lines
- No trees: leaves on or leaves off
- No power poles (wood or metal)
- No radar or radio paths that cross over the occupation area
- No chain link fences nearby
- Locations under busy landing paths are undesirable
- No large 'GPS reflective' surfaces nearby: avoid multipath
- Receiver facing correct direction: usually MMI, antenna connector or North fiduciary pointing North.
- Receiver mounted very securely on well braced, fixed-height tripod
- No chance of giant birds sitting on your antenna during occupations:

This picture is an actual crow sitting on an actual CORS antenna!

- No chance of trucks higher than your antenna passing nearby during occupation

Now, I know that users get great results in challenging locations all the time. And you may be lucky, but these are real rules and you should consider respecting them.

Worst Case Scenarios

All of the sites presented below are actual customer sites (or in some cases slightly obfuscated locations to save embarrassment.)

Remember that during times of low DOP (see the mission planning section of this document) you may get reasonable OPUS-Static and OPUS-RS solutions at these challenging locations. Longer (3-hour) and very long occupations (over 8-hours) may be dependable because the high-DOP conditions are bridged with times of good coverage. However, in general, you should avoid the following scenarios.

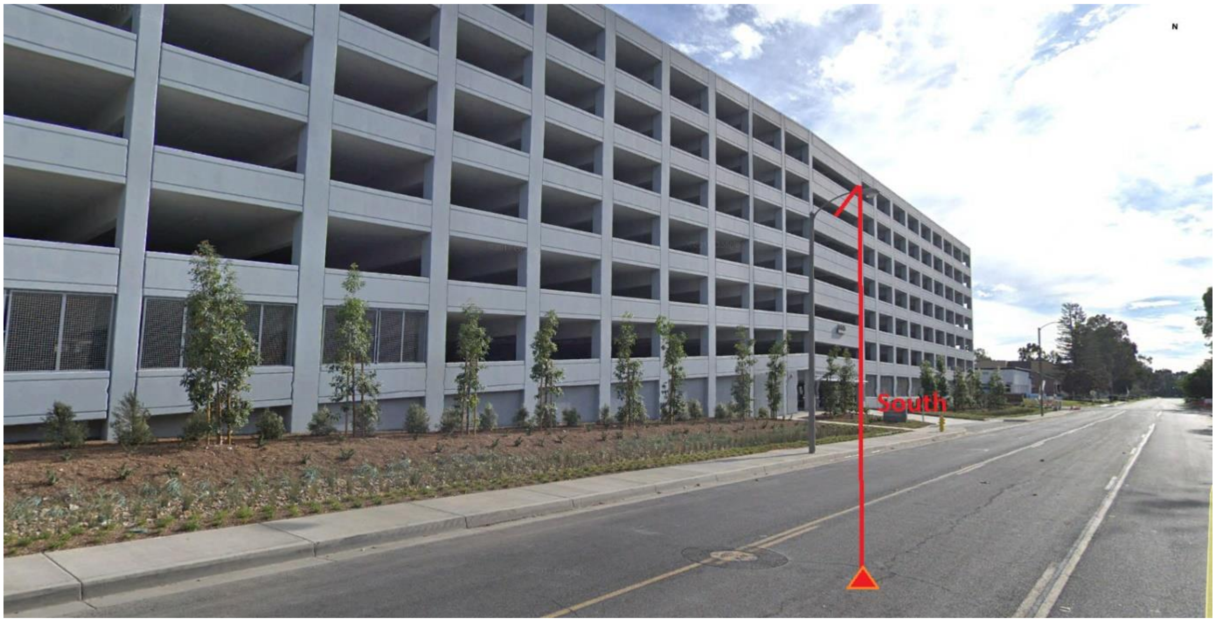
Semi-Trucks and Trains

This bench mark is 1-meter north of the eastbound edge-of-pavement of I80 near Green River Wyoming:

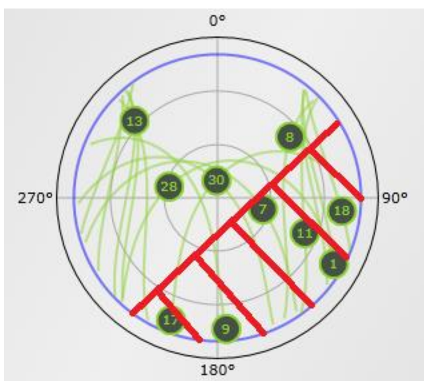
It has fantastic views in all directions, unfortunately a semi-truck drives by every 10-seconds and completely obscures a receiver's view of the southern sky. This forces the receiver (and OPUS) to lose lock. This is a **BAD** location and will greatly increase the RMS error estimates and drop the percentage of observations used.

Large Structures to the South

This 8-story parking garage is 10-meters to the southeast of the brass rivet in the street.

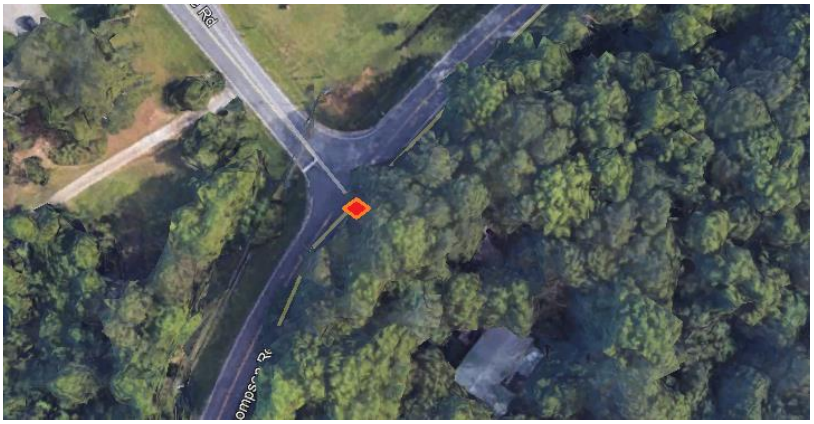


This is a **bad** location because the structure completely blocks the antenna's view to the South and East:



Huge Trees to the South

BAD: This site is not suitable for GPS observation because of large trees to the south:



Southern sky is fully blocked^

We can debate:

- leaves on, leaves off
- pine needles vs. broad leaves
- length of pine needles
- size of tree-trunks
- size of branches

But trees above 10° to the East, South or West are bad and 100% canopy just won't work.

Huge Trees Overhead

Trees (with or without leaves) directly above the antenna prevent the receiver from having a clear view of the sky. Even though this location has open water to the South, it is directly underneath large trees. Water can also be a source of significant multipath (see the next section). This is a **BAD** location:

Large Reflective Surfaces Nearby

Your receiver trusts that the signals that it receives have traveled directly from the satellite to your antenna. Large nearby surfaces present opportunities for the receiver to have signals arrive having taken multiple paths (multipath) or entirely the wrong path.

Not only do these tanks block the view to the South, but they also have metal-reflective surfaces that provide a multiple length signal path for every signal from every satellite to the observation area:

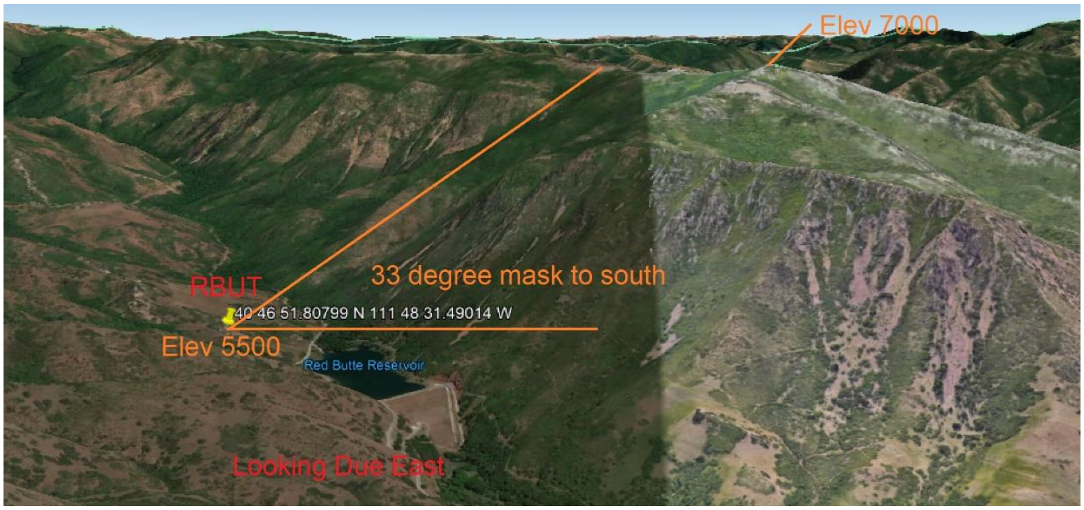
this image is looking south.

Flat metal surfaces are bad. Corrugated metal surfaces (like corrugated roofing) are even worse. Some mirrored glass windowing used on building exteriors is reflective at microwave frequencies. Box truck bodies, metal buildings, metal roofs and open water are all potential sources of multipath.

Deep Canyons

Locations at the bottom of deep canyons, especially East-West trending canyons will present full, 100% obstruction below the ridge line. [Also: check out the Fresnel section at the end of this document.]

This location is actually a long term CORS site (RBUT) which enjoys a 30° mask to the South. This could be a challenging location for GPS observations and in my experience using RBUT in any solution is just inviting problems:

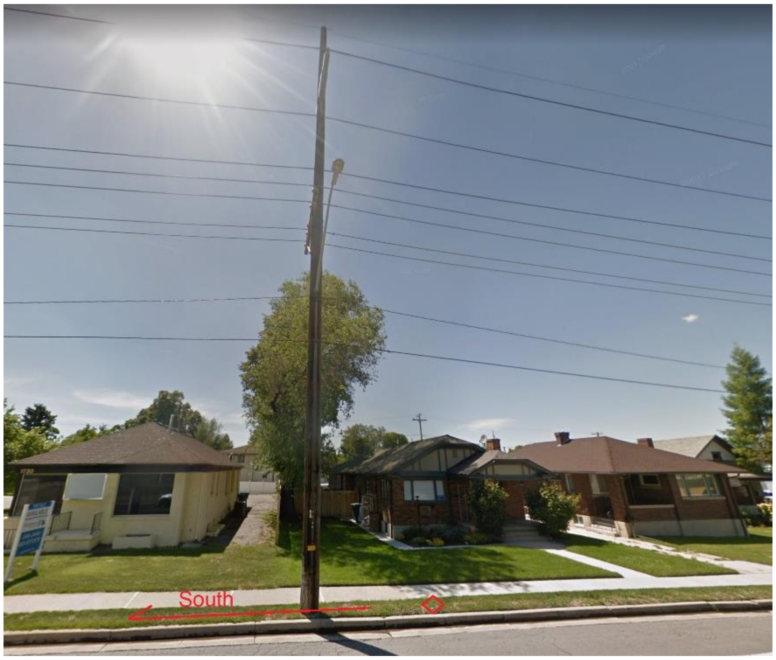


Power Poles

I actually have occupied this bench mark:

The OPUS result was not horrible. These are 500 kilovolt DC lines, not AC; so it could have been worse. But in any case, you should avoid locations that are under transmission lines and have large steel towers directly to the south.

Even smaller power poles and lines are unacceptable, especially if they are south of the site:



This location sucks ^

Optimizing Occupations in the Real-World

Receiver Placement

In North America, the most important sky is to the East, South and West (because there are never any GPS satellites directly north.) So, if you are setting up in a field that is surrounded by large trees, locations in the middle of the North side of the open area are preferable because the southern sky effectively opens up:

Longer Observations

OPUS-RS is especially vulnerable to bad sites. If you think a site may have problems, try to collect over two hours of data so that you will have the option of using OPUS-Static. You can always cut the 2-hour observation file in half and submit it as RS.

A six-hour occupation may return great results at a site where 2-hour occupations fail. More-time in adverse locations is more-better.

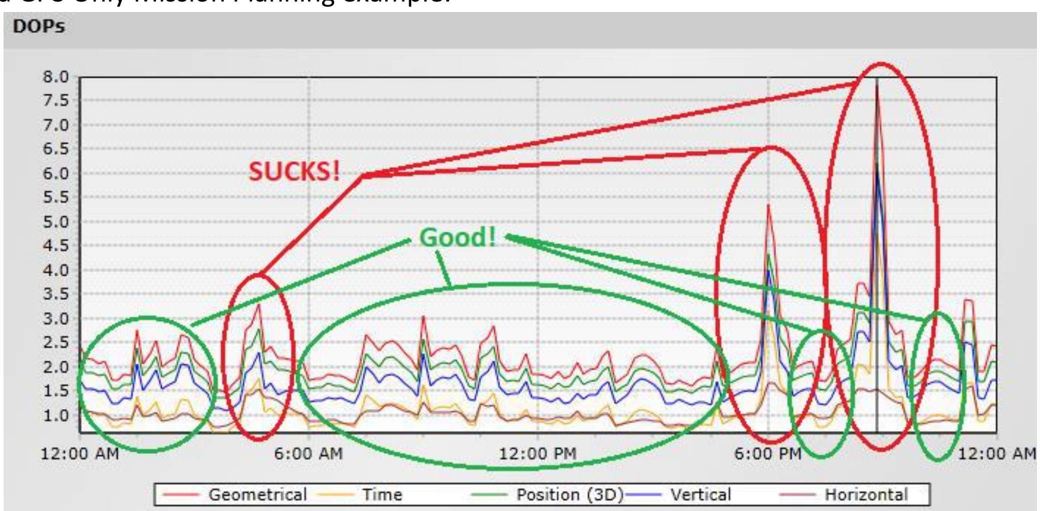
Mission Planning

With modern GNSS RTK receivers that track lots of satellite constellations and lots of signals, mission planning is no longer common.

However, OPUS is **GPS only** and mission planning can be used to select better times to occupy sketchy locations.

Mission Planning performed after an occupation is called 'Post-Mortem' and can be used to explain why an occupation has failed.

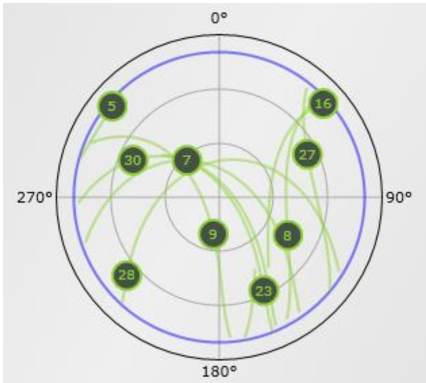
Here is a GPS Only Mission Planning example:



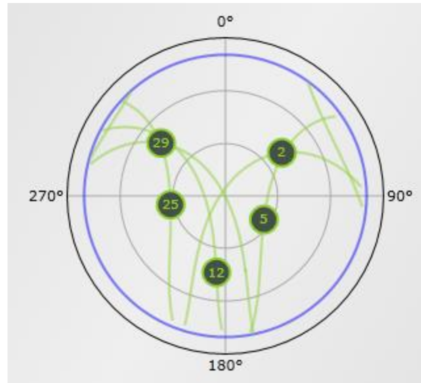
Lower DOP is better than higher DOP. You can see that most of the day, DOP is excellent. Most OPUS submissions will be successful. However starting at 5:30 pm there are large DOP spikes.

At this location, on this day, any one-hour OPUS-RS occupation from 5:30 pm to 9:30 pm will certainly **fail**. However a one-hour OPUS-RS occupation from 11:30 am to 12:30 pm (or most of the rest of the day) will probably be **successful**.

DOP is a function of where the satellites are in the sky. We prefer more satellites, spread over a larger portion of the sky, with two satellites in every quadrant:



11:30 am **Great**



8:50 pm **Bad**

One pitfall of OPUS-RS is very short occupations may entirely fall into a very high-DOP period. As you can see from the DOP plot above, high DOPs rarely last for more than an hour or two and longer OPUS-Static occupations will usually have some periods of low DOP and excellent coverage.

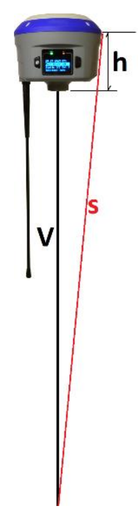
The change in satellite constellation, which determines PDOP is why a receiver will work one day and then not work in the same location at a different time.

How to Screw-Up an Occupation

Assuming that your receiver is in a location that is suitable for GPS observations, there are several little procedural things that you can do to make a bad occupation:

- Mounting system is not level and receiver is not centered over the ground mark.
- Antenna height (HI) is wrong.
- Antenna is mis-rotated, doubling antenna compensation errors.
- Wrong antenna type is selected.
- Batteries In or Batteries Out?

Use a Fixed Height Tripod, Get the HI Correct!



The #1 OPUS procedure failure is a mis-recorded instrument height. The ONLY HI that OPUS will accept is the vertical height above ground to the ARP (Antenna Reference Point) which is almost always the imaginary point at the bottom of the antenna in the center of the mounting hole.

If you use a tribrach, you are going to have to make a slant measurement and then reduce the slant distance and SHMP (Slant Height Measurement Point) vertical offset to a metric vertical height.

As you can see from the diagram at the right, you will need to know the radius (r) of the antenna at the slant measurement point, the height of the slant measurement height above the bottom of the antenna (h) and the slant distance (s):

$$v = \sqrt{s^2 - r^2} - h$$

Slant reduction error is a very common source of bad instrument height. If you don't explicitly understand the slant measurement process, you absolutely should be using a fixed height pole.

Transposition of digits in random heights that occur with tribrachs on tripods is a common source of error. Measurement to the wrong place on the antenna is a common source of error. Mixing slant measurements in feet with metric SHMT and radius constants is a common source of error. Confusing slant heights between multiple occupations is a common source of error.

Consider using a fixed height tripod or a 2-meter pole with a Hold-a-Pole or Stedi-Rest for every static occupation. You can check the bubble centering and calibrate the pole bubble before every single occupation, adjusting the vial if needed.

If you feel that a pole bubble is not accurate enough, replace the standard 40 or 20-minute vial with a fast 8-minute vial. If you insist on using a tribrach, use one with a long bubble so you can check the tribrach bubble calibration before each use.

Check your pole length routinely, replace or shim worn-down pole tips so that your 2-meter pole really is 2.000 meters.

Using a fixed height mount and checking the leveling bubble on every occupation will solve a whole bunch of problems, and the HI will ALWAYS be 2.0 meters. Which is easy to remember.

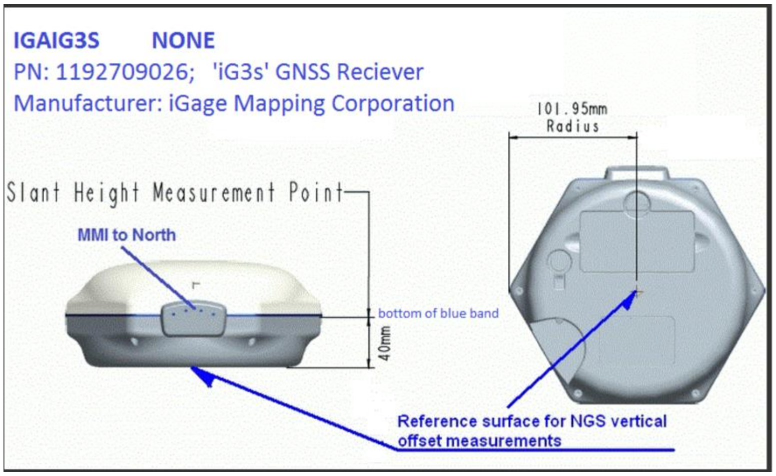
Rotate your Receiver Correctly

Every antenna has a 'correct' rotation. It is VERY important to spin the antenna so that it faces the correct direction.

You can determine the correct rotation by looking up the antenna definition on the NGS Antenna Calibration website: https://www.ngs.noaa.gov/ANTCAL/index.xhtml

Some antennas like the ProMark 700 above have a North Arrow fiduciary mark which is rotated so the mark is to the north. Some antennas like the iG3s:

![iGage logo]



Have the MMI (Man-Machine-Interface) rotated to the north.

What happens if you don't rotate the antenna correctly? OPUS has a calibration file that relates a change in L1 height offset by the position of the satellite in the sky and the XY offset of the center of the antenna from the center of the mounting nut.

Here is the calibration file for the ProMark 700:

```
SPP89823_10      NONE ProMark 700, 220 channel GPS/GLONASS L1/ NGS (   3) 12/09/18
        5.0       -1.7        60.0
   0.0    1.4    2.1    2.3    2.2    1.9    1.4    1.0    0.8    0.7
   0.7    0.9    0.9    0.7    0.4   -0.2   -1.3    0.0    0.0
       0.5         3.7        54.5
   0.0    0.7    1.2    1.6    1.8    1.8    1.6    1.3    0.9    0.5
   0.1    0.0   -0.0    0.2    0.4    0.7    1.3    0.0    0.0
```

The second line describes the centering error: 5 mm northing and -1.7 mm easting. If you orient the antenna rotation correctly, OPUS compensates for the northing and easting error. However, if you were to rotate the antenna 180°, so that the North Arrow is pointing to the South, then the offset error is doubled and your final solution will be off by 1 cm!

Bad rotation alignment can also be responsible for making an occupation appear to be noisy too. OPUS compensates for the antenna vertical offset changes depending where satellites are in the sky. If you mis-rotate the antenna then the compensation will be applied incorrectly.

Use the Correct Antenna Model

Make sure that you have the correct antenna model selected. Some antennas will have multiple radomes and revisions listed.

For example: the Ashtech version of the Dorne Margolin chokering (which is a replacement of ASH700936 which has even more models and revisions) has 10 revision / dome combinations:

ASH701945B_M	NONE
ASH701945B_M	SCIT
ASH701945B_M	SCIS
ASH701945B_M	SNOW
ASH701945C_M	OLGA

ASH701945C_M	SCIS
ASH701945C_M	SNOW
ASH701945C_M	SCIT
ASH701945C_M	PFAN
ASH701945C_M	NONE

You must select the correct model or you will introduce substantial height uncertainty and raise the apparent RMS.

We (iGage) have taken to putting large model numbers on the sides of our receivers. Here is a side view of the iG3s:

This exact case style has been used on these five receivers which have been sold in the USA:

CHC X900B, CHC X900R, CHC X900S-OPUS, CHC X900U and the IGA IG3S

Each device has a different GNSS engine and a unique antenna calibration. Hopefully the large iG3s label on the instrument side will help make the model obvious in your site pictures.

Batteries In or Batteries Out?

Every single thing inside an antenna changes the effective antenna calibration. Everything.

Slight changes in the PCB's, UHF radio being in or out, changing the cellular modem: they all result in a change in antenna calibration. Sometimes the change is small and other times a seemingly innocuous change will result in a substantial phase center change.

Even changing the mounting pole diameter and mounting equipment under the antenna will make a substantial antenna offset change.

In a combination receiver / antenna batteries in or out will make a change to the antenna calibration. If a receiver was calibrated with batteries in then you should keep batteries in when in use—even if the receiver is connected to external power.

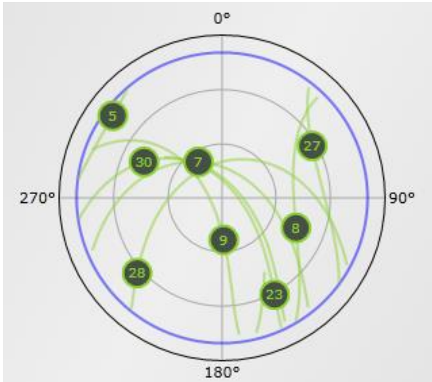
Why does Modern RTK work where OPUS fails?

Yes, OPUS is substantially more finicky than modern GNSS RTK. OPUS jobs routinely fail in places and at times that RTK works flawlessly. There are two primary reasons.

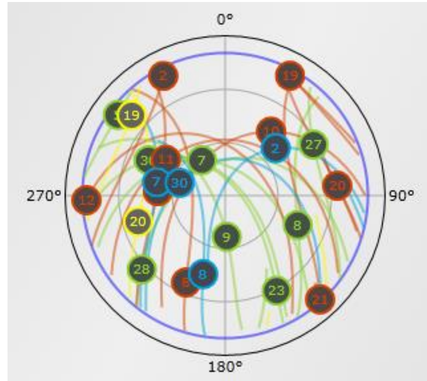
Number of Satellites and Signals

OPUS is GPS only. Modern GNSS RTK uses additional satellites (GLONASS, Galileo, BeiDou) and additional signals like GPS L2C, GPS L5 and GLONASS L3.

Compare these two sky plots (same time, same location):



GPS Only



GPS + GLONASS + GALILEO + BeiDou

More satellites is more better. More signals is more better.

More satellites make RTK more likely to succeed in difficult locations. More satellites also makes manual processing with third party tools more likely to succeed where OPUS fails.

Baseline Distance

OPUS processes GPS baselines from your receiver all the way back to each individual CORS station. Typically these will be 45 KM (28 miles) to 150 KM (93 miles) baselines. In some areas the nearest CORS station might be 250 KM distant!

RTK processes the baseline from your RTK Base to your RTK Rover which typically will be less than 10 KM (6 miles.)

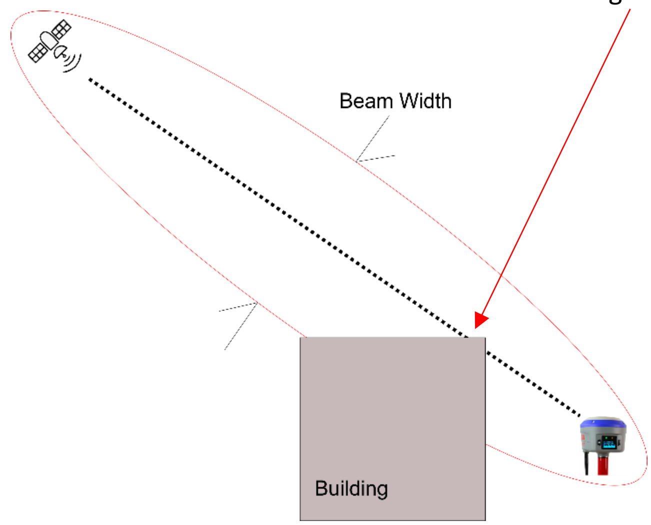
Short baselines 'Fix' more easily and have substantially less noise.

Fresnel Zone Considerations

Most GPS users think of the radio path from their receiver to each of the satellites is like a small laser beam. This is incorrect.

The GPS beam width is spread out in a cigar shaped area known as the Fresnel Zone (Fresnel is pronounced with a silent-s: Frenel), named after French physicist Monsieur Fresnel. Wikipedia has an excellent article on the Fresnel effect: https://en.wikipedia.org/wiki/Fresnel_zone; checkout the section on 'Fresnel Zone Clearance' mid-article.

The Fresnel effect explains for why your GPS receiver will track a satellite which is behind a building:



The beam width is wide enough that a portion of the signal reaches the GPS receiver, even though the beam's center is fully blocked by the building.

Tracking a satellite means that the satellite is 'visible' to your receiver, however just tracking is not sufficient to accurately evaluate a carrier-phase position.

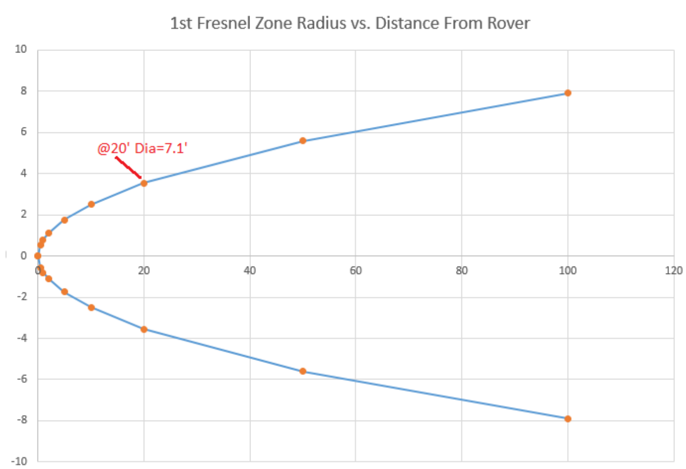
To compute an accurate position, your receiver needs a very clean signal with few reflections, obstructions or delays. Any object blocking a part of the beam can be a source of reflection, attenuation or delay.

Clear path means that you don't just need a small opening in the trees for a laser beam to shoot through. You need an opening in the trees large enough that most of the energy which is spread out over the Fresnel beam width reaches the receiver with no obstructions.

How wide is the Fresnel beam along the path? Much wider than you think!

Here are some charts for GPS L1 (1.575 GHz):

Distance	1st Fresnel Dia
0.0	0.0
0.5	1.1
1.0	1.6
2.0	2.2
5.0	3.5
10.0	5.0
20.0	7.1
50.0	11.2
100.0	15.8
33000000.0	6414.3



1 foot above your GNSS antenna, the beam width is 1.6' in diameter. 20 feet above the rover antenna (perhaps the midpoint of tree canopy), the 1st Fresnel beam diameter is 7 feet! A clearing in the treetops 100' above your antenna needs to be 16' in diameter.

At the midpoint between your receiver and the satellite, the Fresnel beam is over 6,000 feet in diameter!

Multiply this requirement by all the satellites that are used in a solution and you really need a lot of clear sky to get a clean observation.

Conclusion

There are lots of things that can go wrong with OPUS occupations. Some you can control, some you can't.

If you stack multiple problems:

Bad Constellation + Short Occupation + Moderate Canopy => FAILURE

Your OPUS solutions will fail or have high RMS estimates and the time you spent collecting the observation will be wasted from an OPUS perspective (your job might be successfully processed using a 3rd-party tool).

The OPUS family of online tools is amazing. It allows users to generate reliable X, Y and Height coordinates for GPS suitable locations, anywhere in the world. Hopefully if you follow a few simple rules, all your jobs will be OPUS-Successful!

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