Post-processing Emlid GNSS data with OPUS corrections

Precise positioning information is necessary to create accurate geospatial data products from drones, including lidar and photogrammetric data products. Use of RTK/PPK GNSS systems is a standard practice. If the RTK/PPK base station can be set on a survey marker with known location, precise coregistration of products over time is possible.

However, survey points of known location are often not available for many drone applications. In these cases, the base station is usually set at an arbitrary point. Products will be precisely referenced relative to the base station, but the estimated position of the base station itself may be off by several meters, making coregistration difficult over time.

The US National Geodetic Service (NGS) offers the Online Positioning User Service (OPUS) as a free web service to provide accurate location estimates from RTK/PPK base station log files. Using OPUS, it is possible to: 1) correct/improve the base station's position estimates, 2) improve the absolute positioning accuracy of drone data products, and 3) enable better and easier coregistration of geospatial data products over time.

This tutorial will walk through how to:

1. Prepare and submit Emlid GNSS log files to OPUS
2. Interpret the OPUS report
3. Use the OPUS results to PPK correct Emlid survey CSV files

Data and software requirements

To perform OPUS correction with Emlid log files you will need:

1. Emlid Studio (https://emlid.com/emlid-studio/)
2. Internet access to OPUS (https://www.ngs.noaa.gov/OPUS/index.jsp)
3. The RINEX log file (the "O" file) from the Emlid base station
4. The RINEX or UBX log file from the Emlid rover unit (if correcting survey files for ground control points)
5. The CSV file of survey or ground control points (GCPs) exported from Emlid Flow (if correcting survey files for ground control points).

Preparing Emlid log files for OPUS

OPUS uses a network of national continuously operating reference stations (CORS) to correct the calculated location of a local GNSS receiver that is being used as a temporary base station. For instance, if you are doing a drone lidar mapping mission and set up your RTK GNSS as a base station for correcting the lidar trajectories, you can use OPUS to improve the estimate of the base station's location.

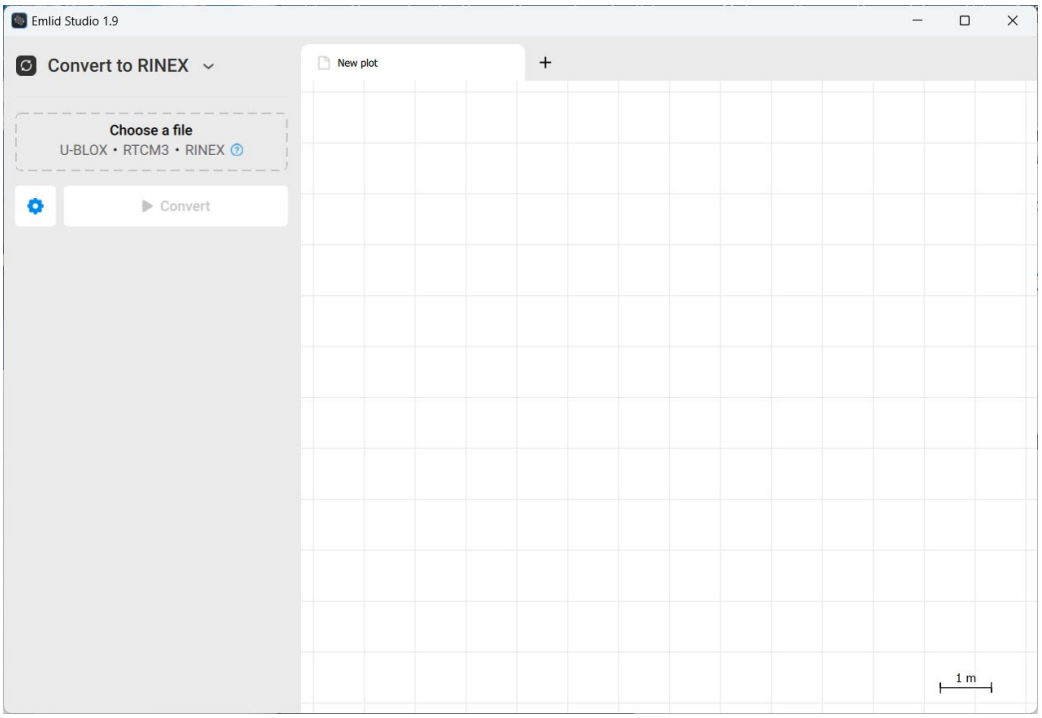
Before preparing and submitting GNSS log files to OPUS, there are a few pre-requisites and considerations:

- *Wait until the following day before submitting your GNSS log files to OPUS for processing* - Because OPUS needs log files from multiple permanent base stations, you must wait until those base station logs are available. While some log files may be available with as short as a 30-minute delay, some CORS sites only publish log files once per day. Accordingly, the NGS recommends you wait until the following day to submit your data to OPUS for processing.
- *OPUS can only work with static GNSS log files* – OPUS computes the location of a GNSS receiver that **is not moving** (i.e., static). Accordingly, you use it only for your base station log files.
- *Your GNSS log files must be at least 15 minutes, but ideally > 2 hours long* – OPUS needs at least 15 minutes of data to compute a solution via its Rapid Static service, and at least 2 hours with its regular Static service. According to the paper by Gillan's et al. (2019), Rapid Static solutions for log files less than an hour are generally poor, and Rapid Static can often throw errors and fail to compute a solution. Thus, the recommendation is to let your local GNSS base station run for at least 2 hours if possible so you can use the regular Static service.
- *Trim the first and last 5-10 minutes from your GNSS log file* – Location estimates when a GNSS is first turned on are notoriously poor, and the process of taking the GNSS down and turning it off can jostle the receiver and cause bad location estimates. For these reasons, it is generally advised to trim about 5 to 10 minutes off the beginning and end of your local GNSS log file.
- *Reduce the sampling rate of your GNSS log file to 1-second* – OPUS will not accept GNSS log files that have a sampling frequency greater than 1 second. The Emlid Reach GNSS units, by default, log at 5Hz (5 readings per second). These will need to be down-sampled to 1-sec sampling rate before upload to OPUS.
- *No special characters in the GNSS log file names* – OPUS will not accept files with special characters in their file name. OPUS considers the hyphen ("-") a special

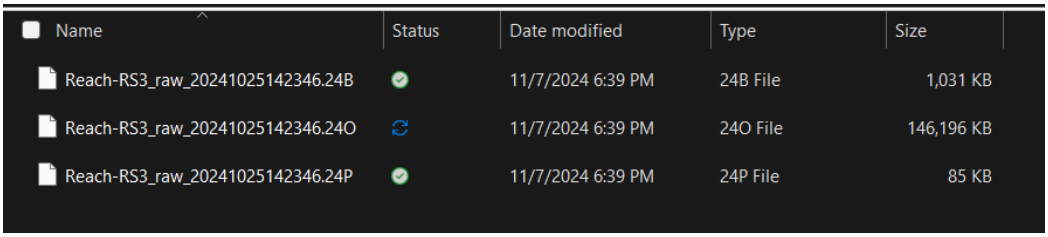
character, so any log files created with Emlid studio will need to be checked and/or renamed to work with OPUS.

With all that out of the way, the first thing to do (once you have downloaded your log files from your Emlid GNSS base station and unzipped them to a directory) is to prep the file for upload to OPUS. The Emlid Reach RS3 base station has the ability to record log files directly in OPUS format. However, I have had best luck with using the default RINEX logging option and using Emlid Studio to prepare a log file for OPUS.

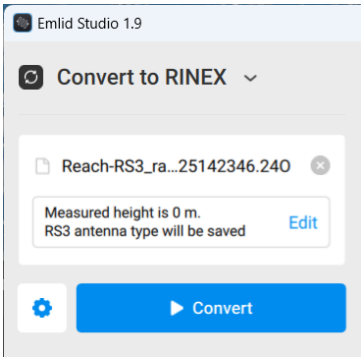
1. Start Emlid Studio and from the drop-down menu in the top-left corner, choose Convert to RINEX.



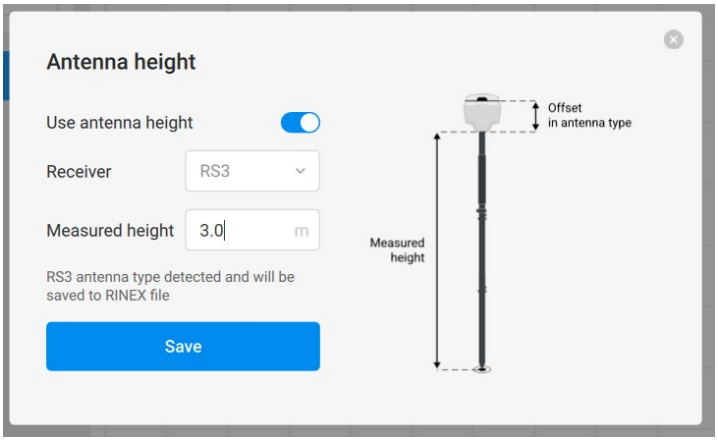
2. Click on the “Choose a file” box and select your log file. The log file will have an extension of two digits (representing the year) followed by “O”, e.g., .24O.



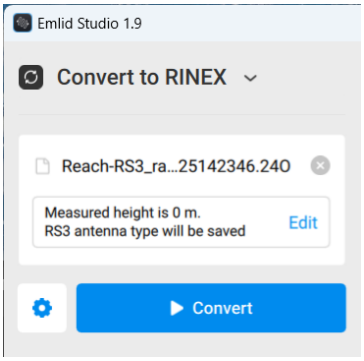
3. Once the log file is loaded, click Edit to set the antenna height.



4. Set the antenna height according to how it was when you set up the base station. Click **Save** when done. *Note: Input the height of the survey pole only. Emlid automatically adds the distance from the base of the GNSS unit to the antenna reference point.*

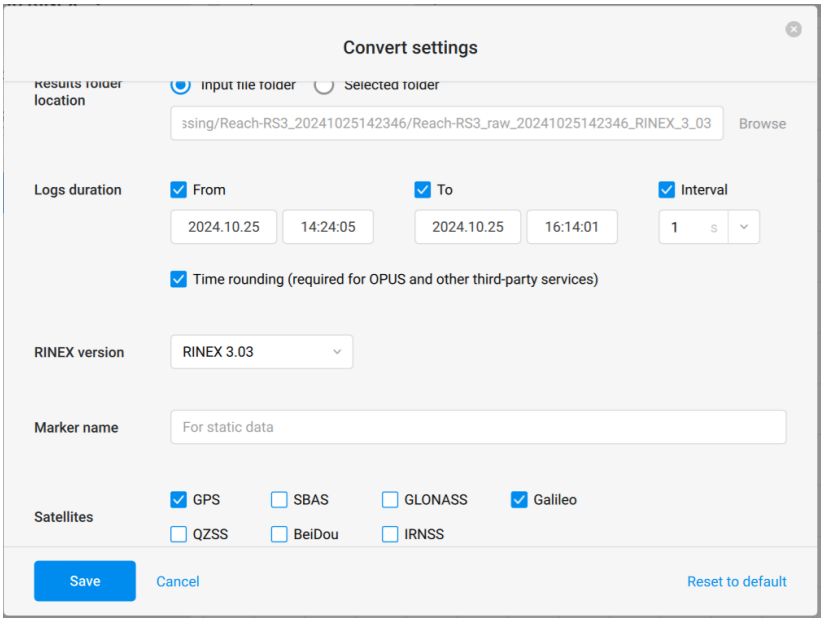


5. Next, click on the Gear icon to adjust the conversion settings.

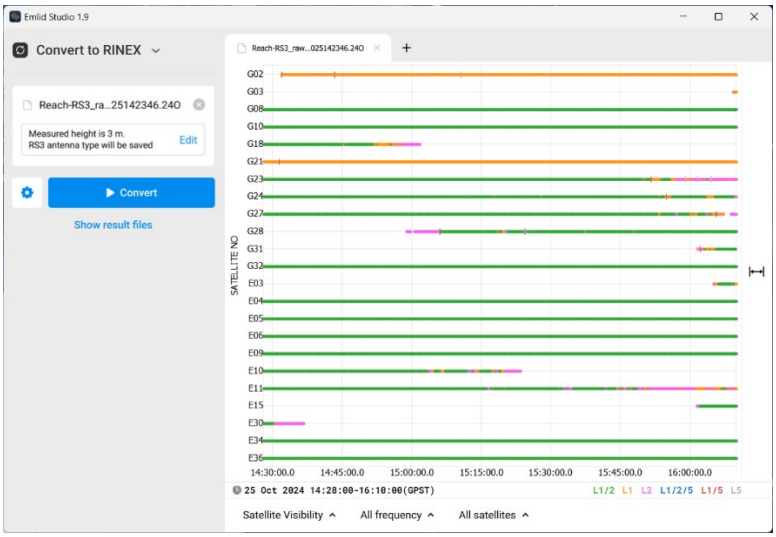


6. Adjust the log duration to trim a few minutes from the beginning and end of the log. Set the interval to **1s**, and make sure that **Time rounding** is checked. For large log files, you can disable all the satellites except GPS. Currently OPUS only uses GPS

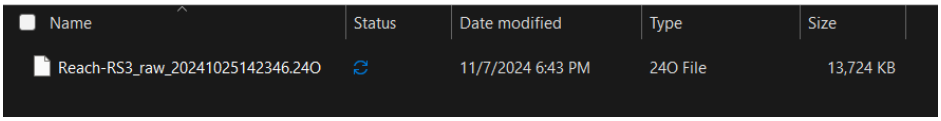
satellites. Future versions will make use of other constellations, but including the other satellites will not affect OPUS processing (it will ignore anything besides GPS). Click **Save** when you are done.



7. From the main window, click Convert. The result will show each of the satellites recorded in the log and the duration of its use by the GNSS receiver.



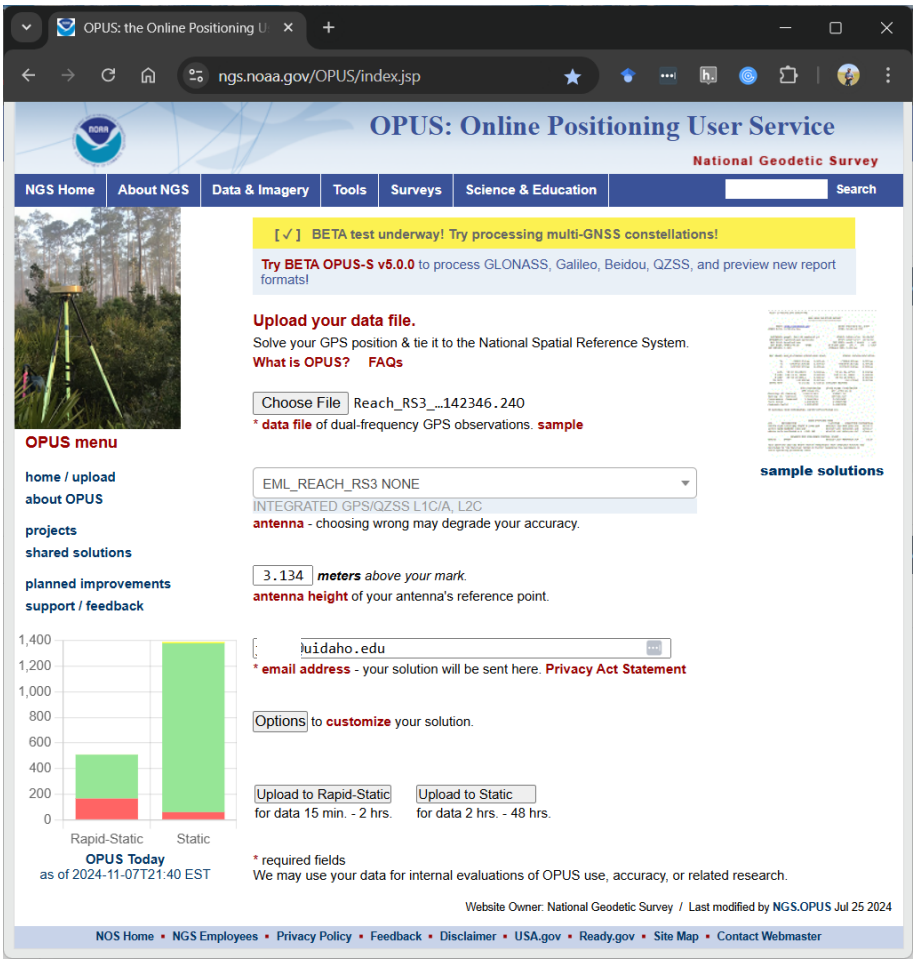
The converted log file is stored in a subdirectory of the folder of your original log file. It will also have the ".24O" extension. This is the file you will upload to OPUS.



Submitting RINEX log files to OPUS

Once you have your resampled RINEX log file, you can submit it to OPUS.

1. Open a web browser and navigate to OPUS at https://ngs.noaa.gov/OPUS/index.jsp.



2. Click Choose File and upload your RINEX log file.
   NOTE: OPUS will reject any file greater than 100MB in size, or that has special characters (including hyphens) in the file name.

3. Set the Antenna to **EML_REACH_RS3 NONE**

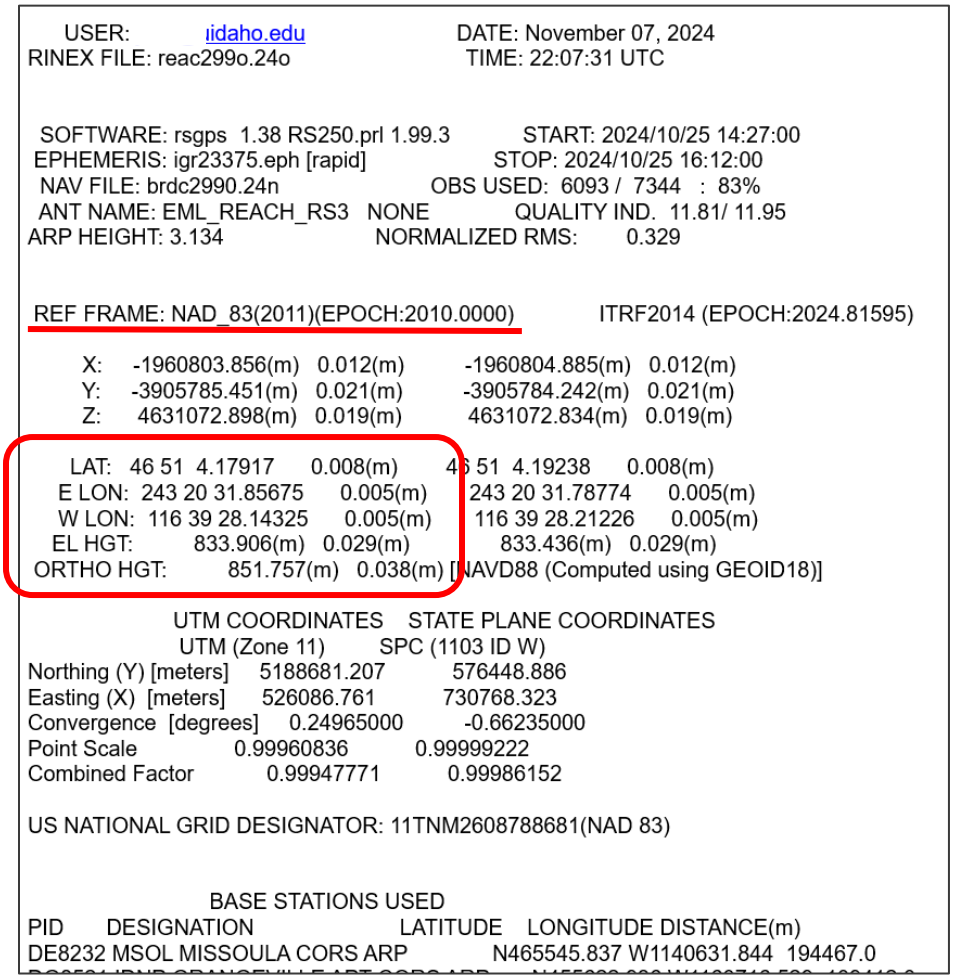
4. Set the antenna height to whatever height you had the base station survey pole (in meters) **plus 0.134** (antenna reference point for the Emlid Reach RS3).

5. Enter the email where you want the results sent.

6. If your log file is less than 2 hours long, click Rapid-Static. If longer than 2 hours, click Static.

Interpreting OPUS results

If OPUS runs successfully, you will get an email with the results, including the post-processed, calculated position of the base station. This email will look like the following example:



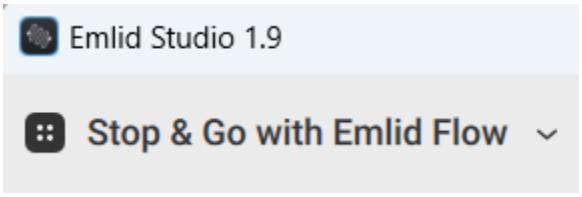
```
    USER:          iidaho.edu                    DATE: November 07, 2024
RINEX FILE: reac299o.24o                         TIME: 22:07:31 UTC


  SOFTWARE: rsgps  1.38 RS250.prl 1.99.3          START: 2024/10/25 14:27:00
 EPHEMERIS: igr23375.eph [rapid]                  STOP: 2024/10/25 16:12:00
  NAV FILE: brdc2990.24n                      OBS USED:  6093 /  7344   :  83%
  ANT NAME: EML_REACH_RS3   NONE              QUALITY IND.  11.81/ 11.95
ARP HEIGHT: 3.134                          NORMALIZED RMS:       0.329


 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)          ITRF2014 (EPOCH:2024.81595)

      X:    -1960803.856(m)   0.012(m)        -1960804.885(m)   0.012(m)
      Y:    -3905785.451(m)   0.021(m)        -3905784.242(m)   0.021(m)
      Z:     4631072.898(m)   0.019(m)         4631072.834(m)   0.019(m)

     LAT:   46 51  4.17917      0.008(m)       46 51  4.19238      0.008(m)
   E LON:  243 20 31.85675      0.005(m)      243 20 31.78774      0.005(m)
   W LON:  116 39 28.14325      0.005(m)      116 39 28.21226      0.005(m)
  EL HGT:         833.906(m)   0.029(m)           833.436(m)   0.029(m)
 ORTHO HGT:       851.757(m)   0.038(m) [NAVD88 (Computed using GEOID18)]

                  UTM COORDINATES    STATE PLANE COORDINATES
                   UTM (Zone 11)        SPC (1103 ID W)
Northing (Y) [meters]     5188681.207          576448.886
Easting (X)  [meters]     526086.761           730768.323
Convergence  [degrees]    0.24965000           -0.66235000
Point Scale               0.99960836           0.99999222
Combined Factor           0.99947771           0.99986152

US NATIONAL GRID DESIGNATOR: 11TNM2608788681(NAD 83)


                     BASE STATIONS USED
PID       DESIGNATION                    LATITUDE    LONGITUDE DISTANCE(m)
DE8232 MSOL MISSOULA CORS ARP           N465545.837 W1140631.844  194467.0
```

OPUS reports results for the calculated base station location in 4 different coordinate systems. For use with post-processing GCP data with other Emlid receivers or for use with GCPs in Metashape or Pix4D, we will most commonly use the NAD_83(2011) coordinates reported in degrees, minutes, and seconds. We will also most commonly use the ellipsoid height (EL HGT) rather than the orthometric height.

Correcting Emlid survey files

Once you have your OPUS solution, you can use this information to post-process/correct the Emlid rover unit(s) you used to collect GCP data and correct the GCP CSV files themselves.

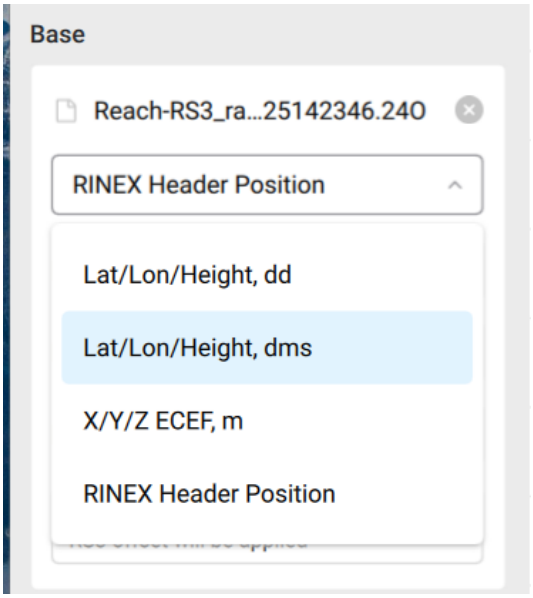
1. Open Emlid Studio and select Stop and Go with Emlid Flow from the top-left dropdown.



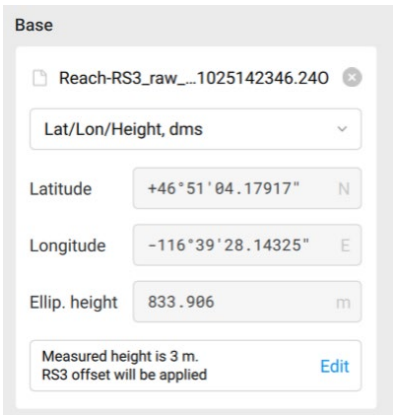
2. Select the rover log file (either a .UBX file or a .O file).

3. Load the original base station log file, and set the antenna height.

4. For the base station, change the location option from RINEX Header Position (what was calculated by the base station itself) to **Lat/Lon/Height, dms.**

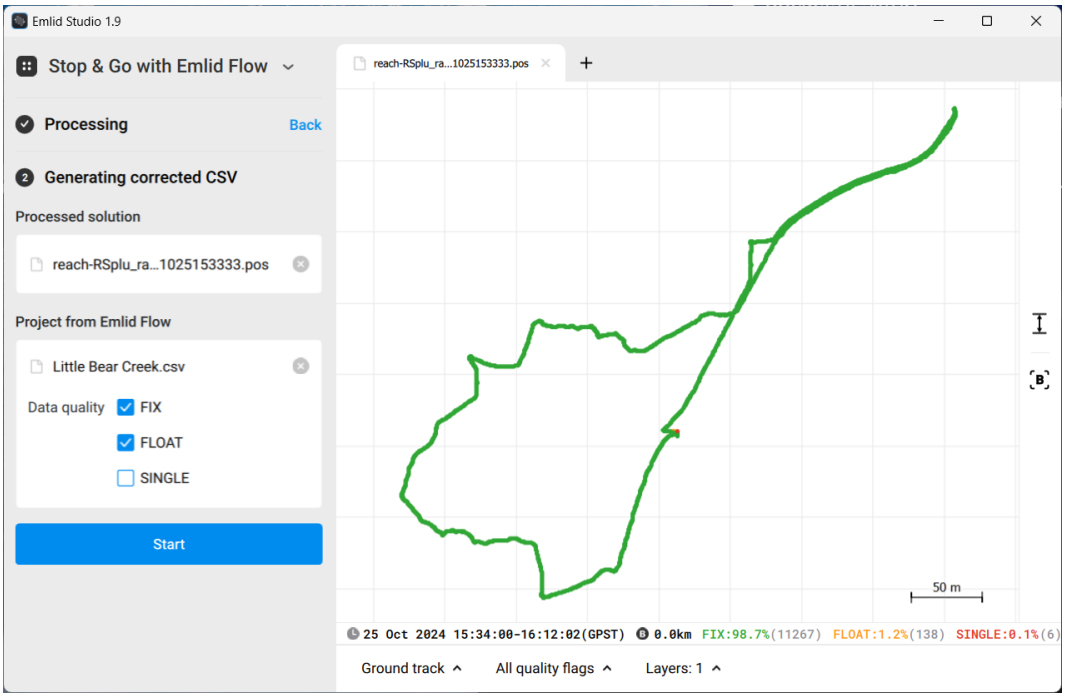


5. Enter the latitude, longitude, and ellipsoid height values from your OPUS solution here.

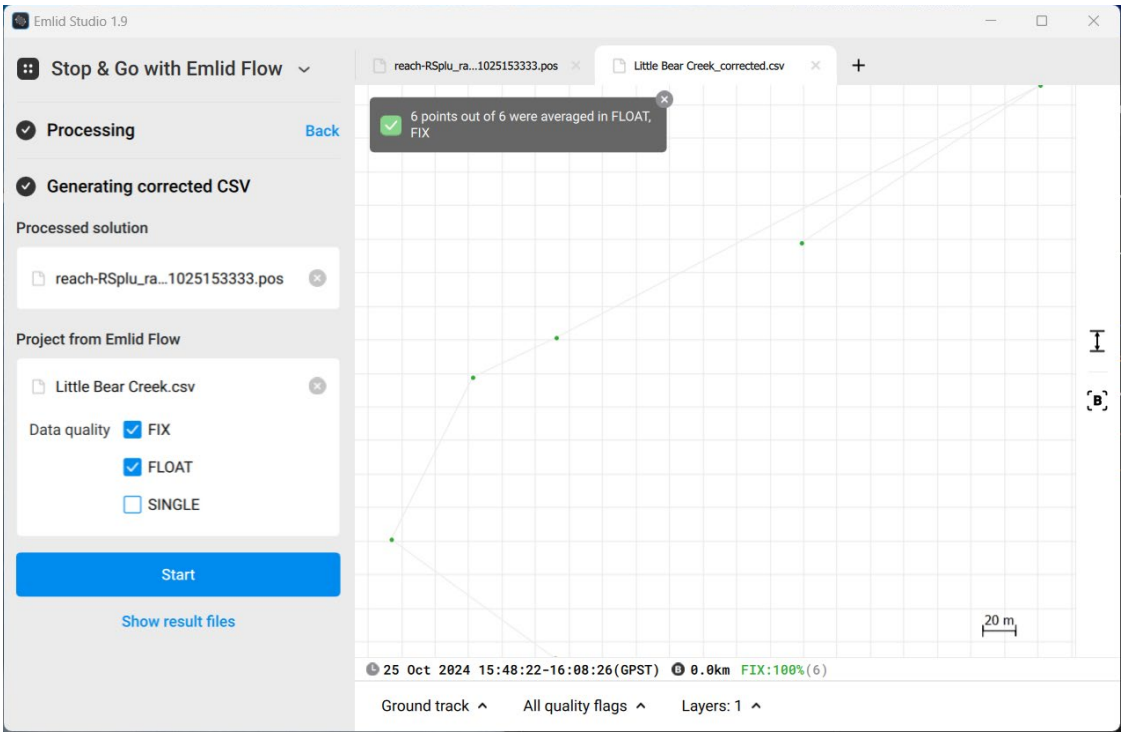


6. The navigation file should have automatically populated. **Click Process to post-process the rover log file with the updated OPUS location.**

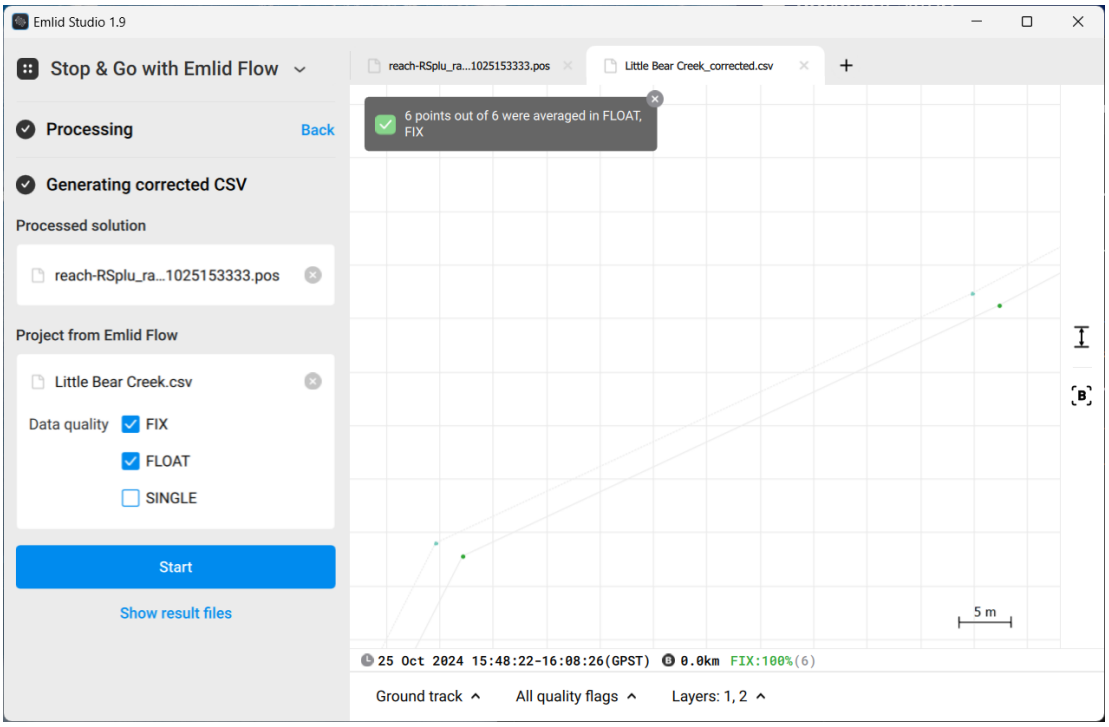
   The result will show the track of the rover unit color coded by receiver status (FIX, FLOAT, SINGLE). *NOTE: If you have a large portion of FLOAT or SINGLE readings, that indicates a situation where good PPK solutions were not possible, and you may get poor location accuracy.*



7. Next, add the GCP file exported from the Emlid Flow app. Click **Start** to post-process the GCP points from the corrected log file. The resulting map will show the corrected point locations according to their status. A CSV file of the corrected points will also be generated (by default in the same directory as the rover log file).



8. By clicking on “Layers” at the bottom of the map window, you can add in the original (uncorrected) GCP points to observe how they changed following OPUS correction.



Troubleshooting

Rapid-static aborting

I have experienced issues occasionally with OPUS Rapid-Static (base station log files shorter than 2 hours) aborting and not returning a solution. My understanding is there may be multiple causes of this issue, and Gillins et al. (2019) reported this happening for between 5% and 10% of the time with Rapid-Static (in my experience, though, the frequency of aborted runs with Rapid-Static is higher). In these cases, you can try one of the OPUS alternatives below. In situations where I have not been able to get a solution from OPUS, I have been able to get one with either CSRS-PPP or AusPOS. Note, even though these services are based in other countries, they are valid for US locations and use many of the same reference stations as OPUS but use different processing procedures.

Alternatives to OPUS

CSRS-PPP – Canadian Spatial Reference System.

AusPOS – Geoscience Australia

References

Gillins, Daniel T., Darren Kerr, and Brian Weaver. "Evaluation of the Online Positioning User Service for Processing Static GPS Surveys: OPUS-Projects, OPUS-S, OPUS-Net, and OPUS-RS." Journal of Surveying Engineering 145, no. 3 (August 2019): 05019002. https://doi.org/10.1061/(ASCE)SU.1943-5428.0000280.