

National Park Service
Inventory and Monitoring Division



Obtaining and Interpreting GPS Solutions using OPUS and OPUS Projects—Version 1.0

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The following standard operation procedure (SOP) outlines the steps required to obtain GPS (global positioning system) solutions using the web-based processing platforms OPUS (Online Position User Service) and OPUS Projects (OP). Mission planning (see protocol specific methods for instructions) and the theoretical basis for GPS base station surveying are not covered in this SOP. It is expected that the user knows how to download raw GPS data from the receiver. If OP is being used, the user or the project lead needs to have completed OP training (which enables creation and use of an OP Project). A standardized way to assess the quality of CORS stations as well as OPUS and OP solutions is provided. This SOP describes the steps needed to process data collected by Trimble R10 GPS receivers. Detailed care and maintenance of GPS receivers is not covered.

[illegible]

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Required Materials

- Desktop or laptop computer with internet access
- GPS survey data (in .T02 format)
- Trimble “Convert to Rinex” tool*
- Notepad++*
- ArcMap 10.x*
- R statistical software*

*Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Introduction

This standard operating procedure (SOP) outlines the steps required to use OPUS-S (Online Position User Service-Static) and/or OPUS Projects (henceforth OP) to obtain reliable and reproducible position solutions (x, y, and z). Post-processing of GPS data using OPUS-S or OP can greatly increase the repeatability (precision) and accuracy (relative to proximate benchmarks) of the GPS solutions. (**Note:** manual post-processing can meet or exceed OPUS-S and OP accuracies. OPUS-S and OP are suggested post-processing methods for users that do not have the skills required to perform these corrections manually). OPUS-S and OP are web-based processing platforms that utilize the software “PAGES” (Program for the Adjustment of GPS EphemerideS) to process baselines and calculate GPS solutions. Baseline solutions are calculated using double-differenced, carrier-phase measurements.

Double differencing of baseline solutions greatly increases the precision of GPS solutions by eliminating receiver and satellite clock biases (Ogaja 2011). Double-differencing also can significantly reduce the effects of ephemeris, ionospheric, and tropospheric biases. OPUS-S outputs geodetic coordinates for an observed mark by finding the mean of three single-baseline solutions from the mark to three Continuously Operating Reference Stations (CORS). OP goes beyond the original OPUS-S routine by allowing users to create session solutions from multiple receivers running simultaneously (Armstrong et al. 2015). OP defines a session as a group of approximately contemporaneous occupations of marks and CORS in a project. In addition to processing multiple marks at the same time, users can also choose which baselines to process for each session. Least squares adjustments (networks) take advantage of multiple observations to minimize the impact of random errors in the individual measurements (assuming the errors are random).

This SOP describes how to: (1) convert the raw GPS data into RINEX (Receiver Independent Exchange) files; (2) upload RINEX files to OPUS-S and/or OP; (3) interpret OPUS solutions; (4) create and configure a project in OP; (5) select high-quality CORS for OP solutions; and (6) create and interpret session solutions and network adjustments in OP. Mission planning (i.e., occupation time and number of surveys) is not covered in this SOP (see protocol for specific methods for

instructions). If using OP, it is assumed that multiple benchmarks were surveyed simultaneously at least twice and that each survey is at least four hours in duration (though two-hour duration surveys can also be processed using OP).

Convert to RINEX

OPUS-S and OP use the Receiver Independent Exchange (RINEX) format to process the raw GPS data. If the raw GPS data are not in RINEX format, it uses the TEQC program to convert the files to RINEX (Estey and Meertens 1999). The survey data downloaded from Trimble R10 receivers is in .T02 format (which cannot be converted to RINEX by TEQC). The raw .T02 files are named in xxxxyyyz.T02 format, where x represents the antenna number, y represents the Julian day of the survey data, and z represents the daily survey number (0, 1, 2, 3... consecutively). When uploaded to OP, marks will generally be grouped based on the first four characters of the uploaded file (if the position of marks with similar names differs significantly, OP will create a new grouping). Append the appropriate mark name to the beginning of each .T02 file. The resulting file name should be “BM_#_xxxxyyyz.T02”, where # represents the benchmark identifier and xxxxyyyz is the original .T02 filename. Once the files have been renamed, use Trimble’s “Convert to RINEX tool” to convert the .T02 files to RINEX.

To use the “Convert to RINEX tool,” open the program and select “Open” in the “File” menu. Navigate to where the .T02 files are located, select the files, and then select “Open” at the bottom of the dialog box. Once the files have been scanned in, select “Convert Files” in the “File” menu. “Convert to RINEX” will convert the .T02 files into 5 separate files in the folder that the raw .T02 files were held. These files have extensions ending in ‘c’, ‘g’, ‘l’, ‘n’, and ‘o.’ Preceding each letter is a two-digit number signifying the year that the data were collected (e.g., GPS data collected in 2017 would have RINEX files with extensions .17x [where x is one of the 5 RINEX extensions]). The ‘.##o’ file is the only RINEX output that needs to be uploaded to OPUS-S or OP.

Upload to OPUS or OP

Once all of the GPS files are converted to RINEX, they can be uploaded to OPUS-S or OP. Navigate to the [OPUS upload website](#). The OPUS data entry form requires five pieces of information to successfully upload to OPUS-S.

On the OPUS data entry form:

1. Choose file (.##o format);
2. Select the antenna (Trimble R10 - TRMR10 NONE);
3. Antenna Height (in meters, to three decimal places);
 - a. When entering Antenna height for the Trimble R10, be sure to take into account whether the quick-release (Figure 1) was used during the survey. If the quick-release was used, add 5 centimeters (2 inches) to the height displayed on the antenna.



Figure 1. Antenna height that is specified when uploading to OPUS and OP should be the tripod height (TH) plus the 5 centimeter (2 inch) quick release (QR) if it was used.

4. Email to send solution; and
5. Rapid-Static or Static.

Rapid-Static is for data less than two hours in duration. Static is for data with durations between two and forty-eight hours. Benchmark surveys will almost invariably require the ‘Static’ processing routine, thus ‘Static’ should be chosen. When all of the information has been entered, click the upload button to submit the file and metadata to OPUS-S.

If using OP (requires data with durations between two and forty-eight hours), follow the same procedure outlined for OPUS-S but before uploading the entry form, click “Options” (right above the upload buttons). Opening the options menu provides users with a number of additional processing/reporting options. The only information that needs to be entered to use OP is the ‘project identifier.’ (**Note:** the project needs to be created before data can be uploaded. If a project has not yet been created, see the “Create OP projects” section). Once a ‘project identifier’ has been entered, the file and associated metadata can be uploaded. For a detailed explanation of the other options, follow the hyperlinks in the options menu to the [OPUS: Online Positioning User Service page](#). When the data has been successfully uploaded, either enter benchmark specific data into the blue book entry form or click the “skip description” button to return to the OPUS upload page (blue book descriptions can also be entered or edited in OP). If a project has not yet been created in OP, follow the instructions in the section entitled ‘Create an OP project.’

Interpreting the quality of OPUS-S solutions

Whether using OPUS-S or OP, when a RINEX file is uploaded, an OPUS-S solution will be emailed to the email entered on the OPUS entry form (Figure 2). OPUS-S solutions from OPUS Projects come in formatted .txt format. If the solution is not in .txt format, copy the OPUS-S solution from the email into Notepad++ (start from the line reading “NGS OPUS SOLUTION REPORT”). Every OPUS-S solution will include information about the quality of the solution, the solution coordinates, and information about the quality of the CORS baselines that were used to create the solution. Prior to using the solution ‘as is’ or including it in further processing, the quality of the solution needs to be assessed.

Solution quality can be assessed by using the following criteria:

1. Observations used (OBS USED [line 13]),
2. Percent of the ambiguities that have been fixed (# FIXED AMB [line 14]), and
3. Overall root mean squared error (OVERALL RMS [line 15])
4. Peak-to-peak errors of the solution (after each coordinate solution [lines 24, 26, and 27])

OPUS: Online Positioning User Service
National Geodetic Survey

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Create Project

* Email address
Refers to Project Manager who must be registered with OPUS-Projects

* Project title

* Project type ☐ HtMod ☐ FAA ☒ Other

* Approx. location Latitude: Ndd:mm and Longitude: Wdd:mm

* Anticipated start

* Approx. size Stations: and Duration: days

* required fields

Website Owner: National Geodetic Survey / Last modified by NGS.OPUS V 2.3 Jul 07 2016

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Figure 2. The “Create Project” dialog window. Fill in all of the information to create a workspace that will be used to process the raw GPS data. The “Project type” should be kept as ‘Other.’

The OBS USED value quantifies the percent of the survey observations that were used to calculate the solution. A good solution has an OBS USED value greater than 70%. The second criteria, # FIXED AMB, quantifies the percent of the ambiguities that were fixed. Similar to OBS USED, a solution with greater than 70% # FIXED AMB is of high enough quality to use. The OVERALL RMS value is the root mean square error of the solution. An acceptable RMS is dependent on the goals of the project but the lower the RMS the better (greater than 3 centimeters [1.2 inches] may indicate a low quality solution). Peak-to-peak (p2p) errors for each coordinate are the range of disagreement between the three single-baseline solutions from the CORS. Acceptable p2p errors are less than or equal to 4 centimeters (1.6 inches) for latitude/longitude and less than or equal to 8 centimeters (3.1 inches) for ellipsoid height. In Figure 3, the p2p error for latitude is 0.008 meters (0.026 feet; line 24), 0.02 meters (0.07 feet) for W longitude (line 26), and 0.025 meters (0.082 feet) for ellipsoid height (line 27). A high p2p may be due to a displaced CORS. To determine if a high p2p is due to a displaced CORS, check the ‘REMOTE STATION INFORMATION’ section at the end of the OPUS-S file (this portion of the solution is only available in the OPUS-S solution from OPUS Projects). Compare the last lines describing each baseline (“LLH... NEW MON...”) to determine if one of the CORS is giving a solution that is significantly different from the other stations. If one of the baselines is significantly different (greater than 0.04 meters [0.13 feet] horizontal and/or greater than 0.08 meters [0.26 feet] vertical), go back to the OPUS upload page, in the options menu exclude the displaced CORS, and resubmit the RINEX file to calculate a new solution. Solutions that meet all of the above criteria are acceptable to be used “as is” (only OPUS-S processing) or can be further processed in OP.

```

1  NGS OPUS SOLUTION REPORT
2  =====
3
4  All computed coordinate accuracies are listed as peak-to-peak values.
5  For additional information: https://www.ngs.noaa.gov/OPUS/about.jsp#accuracy
6
7  USER: jacob_mcdonald@contractor.nps.gov      DATE: August 18, 2017
8  RINEX FILE: bm_0044n.17o                     TIME: 13:33:01 UTC
9
10
11  SOFTWARE: page5 1603.24 master90.pl 160321    START: 2017/02/13 13:31:00
12  EPHEMERIS: igs19361.eph [precise]            STOP: 2017/02/13 17:31:00
13  NAV FILE: brdc0440.17n                      OBS USED: 9597 / 10819 : 89%
14  ANT NAME: TRMR10 NONE                       # FIXED AMB: 60 / 71 : 85%
15  ARP HEIGHT: 1.922                           OVERALL RMS: 0.018 (m)
16
17
18  REF FRAME: NAD_83 (2011) (EPOCH:2010.0000)    IGS08 (EPOCH:2017.1196)
19
20  X: 612632.440 (m) 0.021 (m) 612631.614 (m) 0.021 (m)
21  Y: -5264312.130 (m) 0.020 (m) -5264310.648 (m) 0.020 (m)
22  Z: 3536994.259 (m) 0.018 (m) 3536994.130 (m) 0.018 (m)
23
24  LAT: 33 53 46.23583 0.008 (m) 33 53 46.26074 0.008 (m)
25  E LON: 276 38 16.50264 0.020 (m) 276 38 16.47737 0.020 (m)
26  W LON: 83 21 43.49736 0.020 (m) 83 21 43.52263 0.020 (m)
27  EL HGT: 180.961 (m) 0.025 (m) 179.588 (m) 0.025 (m)
28  ORTHO HGT: 209.868 (m) 0.045 (m) [NAVD88 (Computed using GEOID12B)]
29
30  UTM COORDINATES STATE PLANE COORDINATES
31  UTM (Zone 17) SPC (1002 GA W)
32  Northing (Y) [meters] 3753156.108 432280.001
33  Easting (X) [meters] 281578.194 774415.127
34  Convergence [degrees] -1.31783074 0.44872887
35  Point Scale 1.00018816 0.99996824
36  Combined Factor 1.00015975 0.99993983
37
38  US NATIONAL GRID DESIGNATOR: 17SKT8157853156(NAD 83)
39
40
41  BASE STATIONS USED
42  PID DESIGNATION LATITUDE LONGITUDE DISTANCE(m)
43  DF9211 GACC COLUMBIA COUNTY CORS ARP N333244.705 W0820801.700 120295.9
44  DF2590 GACC ATHENS CORS ARP N325709.800 W0821820.865 7100.6

```

Figure 3. Example OPUS solution. Additional information about the base stations and quality of the baseline solutions is provided after line 40. Screen shot of solution opened in Notepad++.

Creating OP projects

In order to use OP, a project must be created by someone who has completed OP training and has had their email registered by the OP management team. Once the training has been completed and an email has been registered, go to the [OPUS Projects page](#) and click on the “Create” button to bring up the Create Project window (Figure 3).

Fill in the following information:

- Email Address—needs to be an email that has been registered by the OP management team (someone that completed OP training).
- Project Title—dependent on project.
- Project Type—do not change from “Other.”
- Approx. Location—use the interactive map on the left side of the page to navigate to your study area and double click on the map to get an approximate location.
- Anticipated Start—click in the empty space and use the interactive calendar to pick the date that the surveys began.
- Approximate Size—specify the number of marks and the number of days that were surveyed.

Once all of the information has been entered, click “Create” to create a project within OP. If the project was successfully created, OP will generate project keywords including the Project ID, a Manager Keyword, and a Session Keyword. There is no need to write down these temporary keywords, they will be emailed to the project manager and will be changed later. Click on the option to go to the ‘Manager’s page’ and wait for the page to load. Once the ‘Manager’s page’ has loaded, click on the “Preference” button on the left-side of the page (Figure 4) to configure the project.

OPUS Projects - Manage "Accuracy Assessments"

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OPUS-Projects Alert: an update was deployed March 1 A new OPUS Projects release was deployed on March 1. This release addresses the constraint issue and updates the processing software. Please contact the **OPUS Projects team** if you have any questions. (2016-03-01)

OPUS-Projects Alerts

Results From network-4hr 1d all days min con 3D

Controls

1 Preferences

2 Project List

Design

Serfil

3 Solutions

4 Show File

5 Send Email

6 Set up Adjustment

Review and Share

7 Delete Project

LEGEND

MARKS: meet preferences do not meet preferences are not included have error

CORS: meet preferences do not meet preferences are not included

Baselines:

Map Satellite

Zoom to all Marks

Zoom to all Marks & CORS sites

Show Results from specific Solution(s)

Phoenix Rd

Phoenix Rd

1. Manager Preferences

2. Project List (email all projects created by Manager)

3. Solutions (rename Solutions)

4. Show File (OPUS, Session, and Network Solutions)

5. Send Email

6. Set up Adjustment (combines multiple sessions to create a Network Adjustment)

7. Delete Project

LEGEND

MARKS

bm1_

bm2_

bm3_

Marks

Add MARKS

CORS

arfy

gaee

gaat

gabn

gacc

lyco

CORS

Add CORS

Add Marks (this closes OPUS Projects so better to Add Marks in a different window/tab)

Add CORS (opens new window)

Google

Map data ©2016 Google 2 m

Terms of Use Report a map error

Sessions & Solutions

Sessions & Solutions Table					
n	n	n	n	n	n
e	e	e	e	e	e
t	t	t	t	t	t
w	w	w	w	w	w
o	o	o	o	o	o

Figure 4. OPUS projects manager's page. This page contains links to all of the data that have been uploaded to the project.

Configuring OP Projects

On the “Preferences” page (Figure 5), change the project ID so that it can be easily remembered and is meaningful. **Note:** Make sure the project ID is unique, though OP will not allow users to change projects IDs to another that already exists.

The screenshot shows the "Manager Preferences" page with several sections highlighted by text labels:

- Project Title, ID and Keywords**: This section is highlighted in yellow. It contains a "Project Title" field with the value "Accuracy Assessments", and "Project ID", "Manager Keyword", and "Session Keyword" fields, each with a "Confirm" field. The "Project ID" field contains "sech-aaa".
- CC and Manager Emails**: This section is highlighted in orange. It contains a "CC Manager Emails To:" field with the value "CC and Manager Emails", and "Add To CC List" and "Remove From CC List" buttons.
- Data & Solution Quality Thresholds**: This section is highlighted in green. It contains various input fields for thresholds such as "Minimum ARP Height (m)", "Minimum Observations (sec)", "Minimum Ambiguity Fixed (%)", "Maximum Solution Ratio", "Maximum Height Uncertainty (m)", "Maximum Latitude Uncertainty (m)", and "Maximum Longitude Uncertainty (m)".
- Data Processing Defaults**: This section is highlighted in green. It contains various input fields for defaults such as "Output Ref Frame", "Output Geoid Model", "GNSS", "Tropo Model", "Tropo Interval (s)", "Elevation Cutoff (deg)", "Constraint Weights", and "Network Design".
- Session Definition**: This section is highlighted in yellow. It contains a "Minimum Data Duration (s)" field with the value "1800" and a "Minimum Session Overlap Multiplier" field with the value "0.5".
- Mark Co-location Definition**: This section is highlighted in yellow. It contains a "Group By" field with the value "Mark ID" and a "Maximum Position Difference (m)" field with the value "1.000".

At the bottom of the page, there is a footer with the text: "Website Owner: National Geodetic Survey / Last modified by OPUS Projects team Jul 13 2011" and a navigation bar with links: "NGS Home", "NGS Employees", "Privacy Policy", "Disclaimer", "USA.gov", "Ready.gov", "Site Map", and "Contact Webmaster".

Figure 5. Manager “Preferences” page. Make sure to change the project ID and passwords, as well as the data processing defaults and Mark Co-location Definition.

Use the correct naming convention. For projects done by the Southeast Coast Network, use “secn-“ followed by a three letter string that identifies the survey area. For example, when a survey is done at Cape Hatteras National Seashore the project ID is named “secn-hat.” Prior to changing the project ID, make sure another project with that same name does not already exist. Clicking the ‘Project List’ button on the ‘Manager’s page’ will send an email to the manager with a list of all of the projects the manager has on OP. While all OP projects should be deleted after the data has been processed and the solutions have been downloaded, make sure to check. (**Note:** Though extremely unlikely, there is a chance that some other OPUS user could be using your project ID. If this were to happen, change the name to something similar and make sure to record the new project ID.)

Change both the “Manager Keyword” and “Session Keyword” to names unique to your project. These new keywords will be used to access your OP project in the future. The other options on the ‘Preferences’ page relate to quality thresholds, processing defaults, and how sessions and marks are defined. Change the quality thresholds and how sessions and marks are defined as required by the data/project. (**Note:** Marks can be used if they exceed quality thresholds. Changing quality thresholds will only change how OP symbolizes high and low quality marks.) The data processing defaults should be changed to the specifications outlined below to keep processing consistent and replicable between projects.

Change the data processing defaults (Figure 6) to:

- Tropo Model: Piecewise Linear,
- Tropo Interval (s): 7200, and
- Constraint Weights: NORMAL

The ‘Tropo Model’ is used to correct the effects water vapor has on satellite signals as they pass through the troposphere. The piecewise linear option calculates a number of linear corrections (at 7200 second intervals) and connects them to create a correction curve (Armstrong et al. 2015). The piecewise linear option is a good choice when clouds and mask obstructions (i.e., trees or tall grass) are influencing the satellite signal. The last option, ‘Constraint Weights,’ will affect the way that CORS sites are handled during processing. Select the ‘NORMAL’ option. When using a ‘NORMAL’ constraint, the location of the constrained mark (most commonly a CORS) is allowed to ‘float’ up to 1 centimeter (0.4 inch) around their defined positions. A ‘NORMAL’ constraint allows OP to provide the best solution by adjusting the ‘known’ CORS points to fit the data.

Data Processing Defaults

These are the defaults used in data processing. They can still be changed on a case-by-case basis during processing setup.

Output Ref Frame: LET OPUS CHOOSE ▼

Output Geoid Model: LET OPUS CHOOSE ▼

GNSS: G (GPS-only) ▼

Tropo Model: Piecewise Linear ▼

Tropo Interval (s): 7200

Elevation Cutoff (deg): 15.0

Constraint Weights: ☐ LOOSE ☒ NORMAL ☐ TIGHT

Network Design: ☒ USER ☐ CORS ☐ MST ☐ TRI

Figure 6. Data Processing Defaults. Change the Tropo Model to Piecewise Linear, the Tropo Interval to 7200, and the Constraint Weights to NORMAL.

Baseline Network Design

When creating a session solution or network adjustment in OP, the user specifies the design of the network used to calculate the control-to-unknown baseline solutions. Each baseline network is composed of control points (CORS), survey marks, and one or more hub(s). A baseline will be calculated from the hub to every other control point and survey mark in the network. The network design recommended by Armstrong et al. (2015) is a single hub network. The single hub network connects all survey marks and control points (CORS) to a single hub (usually a CORS). The hub should be within 100 kilometers (62.1 miles) of the survey marks and should be reliable (CORS that are in operation greater than 7 years are preferred). If survey marks are widespread, it is better to have one hub that is greater than 100 kilometers (62.1 miles) distant from the survey marks than to have multiple hubs. In addition to the hub, at least four high quality control points (CORS) should be included in each baseline network. Armstrong et al. (2015) suggests adding at least one additional CORS that is 375 to 800 kilometers (233 to 497 miles) distant from the study area to help correct tropospheric errors. This SOP uses four ‘distant’ CORS (one in each cardinal direction) to ensure that the survey marks and at least one distant CORS are observing the same satellites for the entire duration of the survey. For additional information about the single hub network see Mader (2014a) and Mader (2014b).

In order to make the session solutions and network adjustments as reproducible and robust as possible, the quality of each CORS included in the project will be evaluated throughout the process. CORS quality will be based on the length of time it has been operating and evaluated using constraint ratios (Gillins and Eddy 2016). Constraint ratios (CR) are calculated for each CORS station based on the northing (N), easting (E), and elevation (Z, ellipsoid height) of the network adjustment compared to the published N, E, Z, and standard deviation of each coordinate.

The equation is in the form of:

$$CR_x = \frac{|x_{adj} - x_{pub}|}{\delta x_{pub}} \quad (1)$$

Where ‘x’ is one of the coordinates (N, E, or Z), ‘adj’ is the coordinate from the adjustment, ‘pub’ is the published coordinate, and δ is the standard deviation of the coordinate. The following sections describe how to select a potential set of CORS, process preliminary session solutions and a minimally constrained network adjustment, compute constraint ratios to evaluate the quality of the potential set of CORS, and create final session solutions and a final network adjustment from the verified set of CORS.

CORS Selection

CORS quality will initially be evaluated based on the number of years the station has been online. The first step is to determine which CORS were used to produce the initial OPUS solutions. From the ‘Manager’s page’ in OP, navigate to an unprocessed session page (coded green in Figure 7). On the right-hand side of the map is a list of the CORS used to create the OPUS solution for each survey mark. Record all of the CORS used (for each unprocessed session) and then use the drop-down menu at the top of the map to navigate to the other sessions and repeat the process of recording their CORS (record the repeats). Once all of the initial CORS have been identified, go to the ‘Manager’s page’ and click on ‘Add CORS’ (on the right side of the map) to bring up the ‘Add CORS’ window. Navigate the map and click on each initial CORS to determine how long each station has been in operation. Optimally, only CORS that have been online for five or more years should be included in your project. If any of the CORS that were included in the initial solutions have been online for less than five years, do not include them in any further processing.

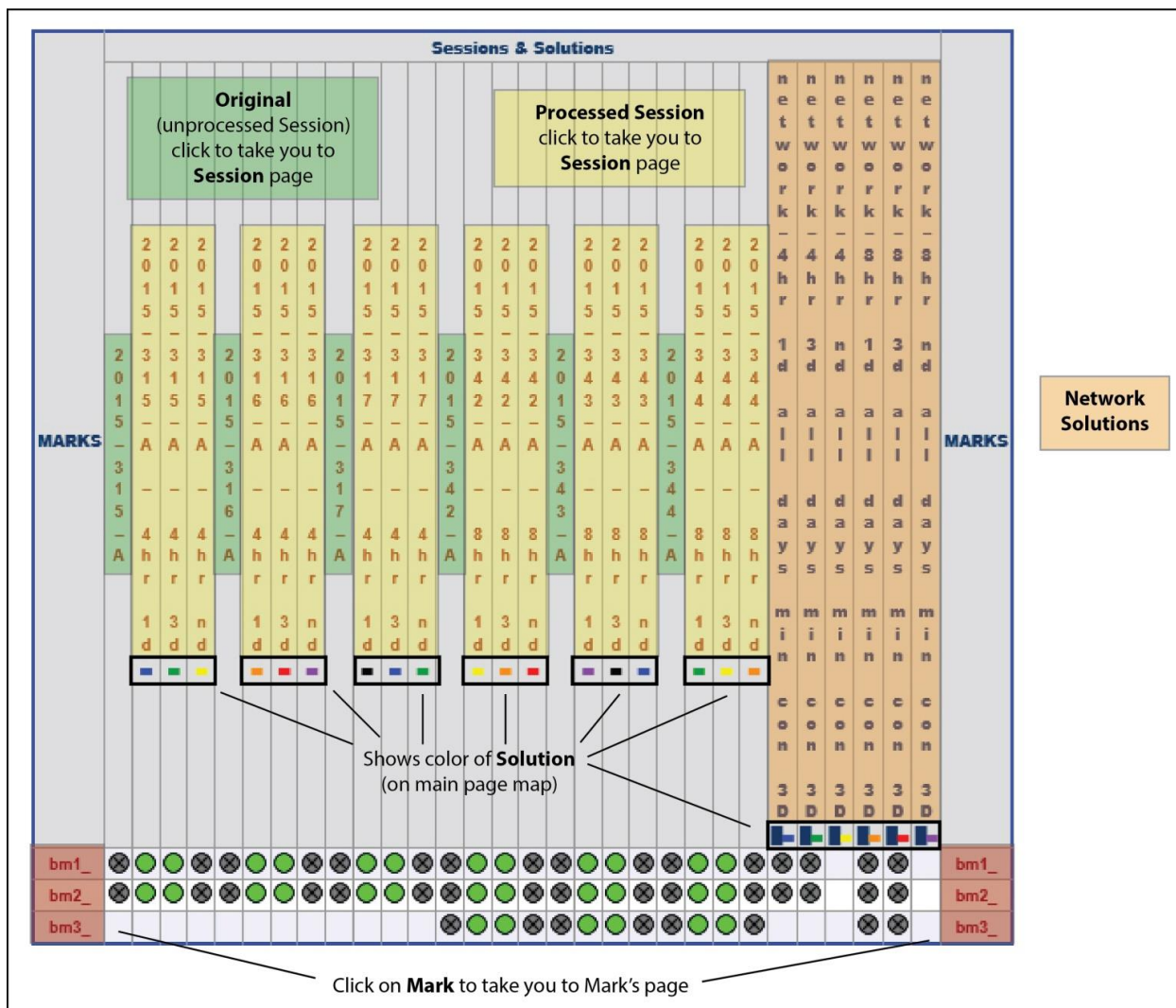


Figure 7. Sessions and Solutions links at bottom left of Manager's page. **Note:** Session solutions and network adjustments do not follow the naming conventions outlined in this SOP. See 'Initial Session Solutions', 'Initial Network Adjustment', and 'Final Solutions' sections for the proper naming conventions.

After identifying the age of the initial set of CORS, identify and add an additional six to eight CORS (for a total of up to fourteen 'near' CORS [including initial set of CORS]) that have existed for greater than five years and are within 150 kilometers (93.2 miles) of the study area (if CORS are limited, CORS up to 250 kilometers [155.3 miles] can be added). These additional CORS are added because length of record is not the only criteria that will be used to assess CORS quality.

Additionally, not all of the CORS may be available for each day of survey because they need to be online and observing the same satellites as the survey receivers. To determine what CORS are within 150 to 250 kilometers (93.2 to 155.3 miles) of the study area(s) use the "CORS_sites_ON.shp" shapefile located on the SECN GIS server at:

\\INPSECNS01\GIS\GIS\projects\Other\AccuracyAssessments_shp. This shapefile ("CORS_sites_ON.shp") was downloaded from the [CORS map page](#) as a .kmz and was queried in

ArcMap to remove the CORS that have been decommissioned (processing done 20170823). Update CORS shape prior to processing.

In ArcMap, create a point shapefile and place a point in the approximate center of the study area. Use the “Multiple Ring Buffer” tool to create a set of buffers around the center of the study area at 75, 150, 250, and 300 kilometers (46.6, 93.2, 155.3, and 186.4 miles). When choosing the additional CORS, make sure not to cluster the stations. Try to cover as much of the area surrounding the survey marks as possible. Use the map in the ‘Add CORS’ window to check the age of each potential CORS. Once the additional CORS have been identified, go to the [CORS website](#), and check ‘data availability’ on each CORS page. Only include CORS that were operating during the period of survey. Next, make sure that “Formal positional accuracy estimates” have been calculated for the CORS (so that constraint ratios can be calculated).

On each CORS page, click ‘Coordinates’ and then ‘Data Sheet for Position at ARP’. This datasheet will have the N, E, Z, and standard deviation of the coordinates for the CORS. If the positional accuracy of the coordinates has not been calculated, the data sheet will say “Formal position accuracy estimates are not available for this CORS...” (around LINE 32). If no standard deviations are available, discard this CORS. If standard deviations have been calculated, copy this datasheet starting with the line that starts with “Program = datasheet...” and paste it into a new Notepad++ document. Name the file “CORS_datasheet” (where CORS is the name of the station) and save it to the working directory. One thing to check before selecting each CORS is to determine whether the CORS is behaving erratically (producing coordinate solutions outside of accepted thresholds).

To determine how the CORS is behaving, go back to the CORS page and click on ‘Time Series (short-term).’ If the CORS is behaving erratically (outside of the 2 centimeter [0.8 inch] horizontal/4 centimeter [1.6 inch] vertical tolerance), discard this CORS. Ideally, use CORS varying within 1 centimeter (0.4 inch) horizontally and 2 centimeters (0.8 inches) vertically. After checking each potential ‘near’ CORS, open Notepad (or similar program) and make a list of the CORS with each CORS on its own line (Figure 8). Name the .txt file “ProjectName-Potential-CORS.txt” (where ProjectName is the name of the project in OP) and save it to the working directory.

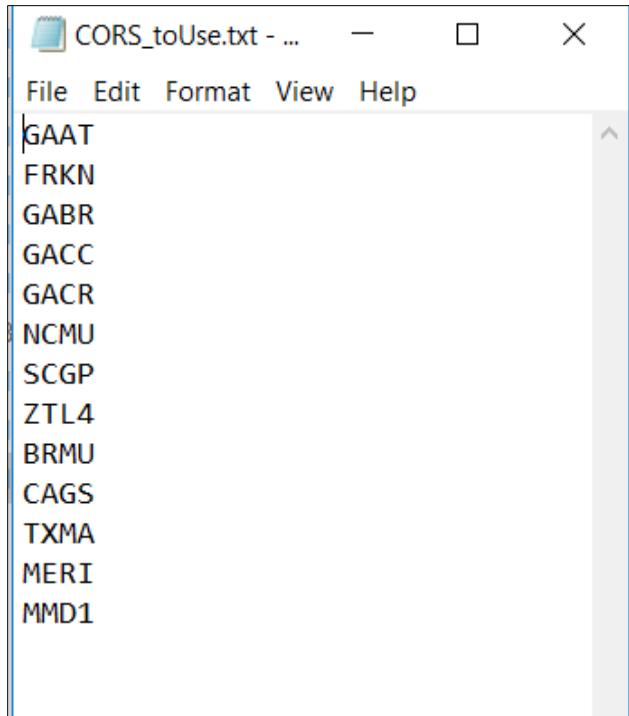


Figure 8. List of potential CORS were recorded in Notepad so that they could easily be copied and pasted into each unprocessed session's page.

Once 'near' sites have been chosen, zoom out and add four distant (350 to 800 kilometers [217.5 to 497.1 miles]) CORS. Select one distant CORS in each general compass direction. Similar to the 'near' CORS, determine if the standard deviations have been calculated and determine if the CORS is stable. If processing data collected in a park unit in the Southeast Coast Network, four distant CORS that are reliable and have been online for greater than 10 years are BRMU (Bermuda, BD, United Kingdom), CAGS (Canadian Absolute Gravity Station, QC, Canada), TXMA (Marshall, TX, USA), and MERI (Merida, YU, Mexico). Add the four distant CORS to the potential CORS .txt file. If possible (based on the location of the park), use distant CORS that are owned by the United States to make sure they are operated using the same set of practices and procedures.

After the potential 'near' CORS and the four distant CORS have been identified, use the 'Add CORS' button on the 'Manager's page' to add all of the CORS to the project. Check each session to determine which CORS were not added by OP. If a CORS was not added to a session, it means that CORS was not operating or it did not observe the same satellites as the survey marks during the period of survey. If it is not possible to find four distant CORS that were collecting data on each survey day, then fewer distant CORS can be used. All of the CORS that are available for all of the sessions will be used in the initial session solutions and will also be used to create a minimally-constrained network adjustment(s). Minimally-constrained network adjustments are used to further assess the quality of the CORS using constraint ratios (Gillins and Eddy 2016).

Initial Session Solutions

Once the set of potential CORS has been added to each session, determine which of the near CORS will be used as the ‘hub’ in all of the session solutions and network adjustment(s). This station should be close to the survey area (less than 100 kilometers [62.1 miles]), be available (online and recording) on all survey days, and reliable enough to be used during subsequent surveys (check the [CORS page](#) for long-term availability). If survey marks are more than 100 kilometers (62.1 miles) apart, multiple hubs may need to be selected. As mentioned earlier, it is often better to have the hub be greater than 100 kilometers (62.1 miles) from some survey marks than to have multiple hubs.

After the hub has been determined, navigate to each survey days’ session page and click on “Set up Processing” (Figure 9). Name the solution to identify which survey day and the duration of the survey (e.g., an eight-hour survey on day one would be named D1H8 [if multiple surveys are done on the same day, add an ‘a’ to the end of the first survey and a ‘b’ to the end of the second survey, and so on]). Only include the CORS from the set of potential CORS (they are available for all survey days and standard deviations have been calculated). To exclude a CORS uncheck the box to the left of the station. Make sure only the chosen hub has the ‘hub’ checkbox checked. Use a ‘3-D’ constraint for the hub. Change the constraint of all of the other marks to ‘NONE.’ Finally, check the “Processing Preferences” at the bottom of the page to make sure that they are correct (Tropo Model: Piecewise Linear, Tropo Interval (s): 7200, and Constraint Weights: NORMAL) and then click “Perform Processing” to calculate the session solution. An email will be sent with the session solution to the OP project manager. Repeat these steps for each unprocessed session.

"2017-044-A" Session Processing - Google Chrome
 https://www.ngs.noaa.gov/OPUS-Projects/templates/Process.shtml

"2017-044-A" Session Processing

?
Perform Processing
X

SOLUTION NAME (30 char max): D1H8

SOLUTION SPAN
 2017-02-13T13:31:00 GPS to 2017-02-13T17:31:00 GPS

MARK	HUB	CONSTRAINT	HEIGHT (m)	LATITUDE (° ' ")	LONGITUDE (° ' ")	REF. FRAME
☒ bm_0		NONE	EL HGT	179.588	N33:53:46.26074	W083:21:43.52263 IGS08 (2017.1196)
☒ bm_1		NONE	EL HGT	179.808	N33:53:46.38815	W083:21:43.89534 IGS08 (2017.1196)
☒ bm_2		NONE	EL HGT	179.770	N33:53:46.51332	W083:21:44.25062 IGS08 (2017.1196)
☒ bm_3		NONE	EL HGT	179.802	N33:53:46.62067	W083:21:44.61300 IGS08 (2017.1196)

CORS	HUB	CONSTRAINT	HEIGHT (m)	LATITUDE (° ' ")	LONGITUDE (° ' ")	REF. FRAME
☒ brmu		NONE	EL HGT	-11.621	N32:22:13.43546	W064:41:46.58322 IGS08 (2005.0000)
☒ cags		NONE	EL HGT	234.947	N45:35:06.07476	W075:48:26.38042 IGS08 (2005.0000)
☒ frkn		NONE	EL HGT	619.560	N35:11:30.71136	W083:23:41.76628 IGS08 (2005.0000)
☒ gaat		3-D	EL HGT	221.641	N33:57:08.82442	W083:19:30.98397 IGS08 (2005.0000)
☒ gabn		NONE	EL HGT	277.232	N34:08:07.10733	W083:46:38.51918 IGS08 (2005.0000)
☒ gabr		NONE	EL HGT	515.498	N34:51:51.94555	W084:19:37.62972 IGS08 (2005.0000)
☒ gacc		NONE	EL HGT	98.493	N33:32:44.73012	W082:08:01.71813 IGS08 (2005.0000)
☒ gacr		NONE	EL HGT	97.787	N32:22:51.45850	W083:20:46.42432 IGS08 (2005.0000)
☒ gamb		NONE	EL HGT	242.290	N33:25:03.52932	W084:09:54.26484 IGS08 (2005.0000)
☒ meri		NONE	EL HGT	7.848	N20:58:48.16326	W089:37:13.14167 IGS08 (2005.0000)
☒ mmd1		NONE	EL HGT	28.687	N20:55:54.87351	W089:39:46.22391 IGS08 (2005.0000)
☒ ncmu		NONE	EL HGT	474.789	N35:04:06.80259	W083:57:59.38148 IGS08 (2005.0000)
☒ scgp		NONE	EL HGT	278.053	N34:56:15.71359	W082:13:57.28675 IGS08 (2005.0000)
☒ txma		NONE	EL HGT	79.113	N32:32:07.14544	W094:17:19.11202 IGS08 (2005.0000)
☒ ztl4		NONE	EL HGT	260.698	N33:22:46.87867	W084:17:48.20896 IGS08 (2005.0000)

PROCESSING PREFERENCES

Output Ref Frame: LET OPUS CHOOSE

Output Geoid Model: LET OPUS CHOOSE

GNSS: G (GPS-only)

Tropo Model: Piecewise Linear

Tropo Interval (s): 7200

Elevation Cutoff (deg): 15.0

Constraint Weights: ☐ LOOSE ☒ NORMAL ☐ TIGHT

Network Design: ☒ USER ☐ CORS ☐ MST ☐ TRI

Website Owner: National Geodetic Survey / Last modified by OPUS Projects team Jun 27 2018

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Figure 9. Session processing window. The solution name indicates that this solution is for day one of the survey and the survey is eight hours in duration. Only one hub was chosen and given a '3-D' constraint. All of the other CORS were given a 'NONE' constraint. This is an example from an 'initial' Session so all CORS are included. If this were a final session and some of the CORS did not meet the constraint ratio requirements, the CORS can be excluded by unchecking the box to the left of the CORS ID.

Interpreting the Quality of Session Solutions

When OP has finished processing each session, the solution will be emailed to the project manager (or the person that is doing the work) and added to the OP manager's page (Figure 4). The session solution provides two measures of the overall quality of the solution, STANDARD ERROR OF UNIT WEIGHT (Line 15) and OVERALL RMS (Line 20). The standard error of unit weight (SEUW) indicates the degree with which the solution and a priori errors agree (Sturges and Veatch 1994). Simply put, the SEUW reports whether the input observational uncertainties and model uncertainties agree with the noise in the data. A standard error of unit weight close to 1 indicates a high quality solution. A SEUW significantly different from one (e.g., 0.03 or 3) indicates there is a fundamental problem with the data or processing model. The second measure, overall RMS, is the root mean squared error of the solution. The lower the RMS the better. There is no set 'acceptable' value for either of these measures. It is up to the project manager to decide the acceptable quality/error threshold for any given project. The last measure that should be checked prior to using the session solution is the amount of shift in the constrained marks.

The 'NORMAL' constraint weight used to process the session solutions allows the CORS to 'float' up to approximately 1 cm around their published coordinates. (**Note:** Even with a 'NORMAL' constraint weight, CORS can still move more than 1 centimeter [0.4 inch] from their published coordinates.) Near the end of the session solution text file, under the 'CONSTRAINED MARKS' section, the amount of shift that was applied to each CORS is recorded (Figure 10). In the example provided in Figure 10, CORS mark BRMU shifted 0.008 m N, 0.004 m E, and -0.01 m H (ellipsoid height). These values are less than the 1 centimeter (0.4 inch) allowed by the 'NORMAL' constraint weight so the solution is a good fit. If the values are greater than 1 centimeter (0.4 inch) there may be a problem with one or more of the CORS in the solution. There is no set cut-off to determine whether to keep a CORS in the solution. It is up to the project lead to determine whether to keep CORS with large 'shifts' in their adjusted locations.

```

171 ++++++
172 CONSTRAINED MARKS
173 ++++++
174
175 MARK:      brmu (brmu a      2; Bermuda, UK)
176 CONSTRAIN: 3-D NORMAL
177 ADJUST X:    0.001m (0.000m)  Y:    0.006m (0.001m)  Z:    0.006m (0.001m)
178 ADJUST N:    0.008m (0.000m)  E:    0.004m (0.000m)  H:   -0.001m (0.001m)
179
180 REF FRAME:      NAD_83(2011) (2010.0000)                IGS08 (2017.1193)
181 X:              2304704.164 m      0.000 m                2304703.318 m      0.000 m
182 Y:              -4874818.765 m      0.001 m                -4874817.172 m      0.001 m
183 Z:              3395187.075 m      0.001 m                3395187.038 m      0.001 m
184 LAT:            32 22 13.40881      0.000 m                32 22 13.43910      0.000 m
185 E LON:          295 18 13.41463      0.000 m                295 18 13.41142      0.000 m
186 W LON:          64 41 46.58537      0.000 m                64 41 46.58858      0.000 m
187 EL HGT:         -10.093 m      0.001 m                -11.635 m      0.001 m
188 ORTHO HGT:      20.923 m      0.025 m      (H = h - N WHERE N = GEOID12B HGT)
189
190 UTM COORDINATES
191 UTM (Zone 20)
192 NORTHING (Y)    3582756.958 m
193 EASTING (X)     340415.297 m
194 CONVERGENCE     -0.90836072 deg
195 POINT SCALE     0.99991406
196 COMBINED FACTOR 0.99991564
197
198 ++++++
199
200 MARK:      cags (cags a      1; Gatineau; Gatineau, Quebec Canada)

```

Figure 10. Example of the amount of 'shift' applied to one of the constrained marks [see Line 178].

Initial Network Adjustment

Once the sessions have been processed and the solutions show up in the OP window (the user may have to refresh the Manager's page), a network adjustment can be created (Figure 11). The initial network adjustment will be a minimally-constrained adjustment (only the hub will be constrained) so that the quality of the other control points (CORS) can be evaluated. The adjusted coordinates of each CORS will be used to calculate CR to determine the reliability of each potential control point. On the Manager's page click on "Set up Adjustment" on the left side of the page (Figure 4). Change 'Adjustment Name' to identify the days that were used to create the network solution (e.g., if days 1, 2, and 4 were used, name the Network Ns1s2s4 [s refers to session]). Add the session solutions to the "Included Solutions" window by highlighting the session(s) and clicking the left (add) arrow. Once the sessions are added, change the 'CONSTRAINT' of each CORS (except for the hub) to 'NONE.' Make sure the hub's 'CONSTRAINT' is set to '3-D' and then check the "Processing Preferences" at the bottom of the page to make sure that they are correct (Output Ref Frame: LET OPUS CHOOSE, Output Geoid Model: LET OPUS CHOOSE, and Constraint Weights: NORMAL) and then hit "Perform Processing" to create the network adjustment.

"Replicability - 4hr" Network Adjustment - Google Chrome

https://www.ngs.noaa.gov/OPUS-Projects/templates/Adjustment.shtml

"Replicability - 4hr" Network Adjustment

Perform Adjustment

Adjustment Name (30 char max): Ns1s2s3

Included Solutions

2017-044-P1-D1
2017-047-P1-D2
2017-054-P1-D3

Available Solutions

2017-059-P2-D1
2017-061-P2-D2
2017-068-P2-D3
2017-079-P3-D1
2017-080-P3-D2
2017-081-P3-D3
2017-101-P4-D1
2017-102-P4-D2
2017-103-P4-D3
2017-115-P5-D1

MARK	CONSTRAINT	HEIGHT (m)	LATITUDE (° ' ")	LONGITUDE (° ' ")	REF. FRAME	
bm_0	NONE	EL HGT	179.588	N33:53:46.26074	W083:21:43.52263	IGS08 (2017.1196)
bm_1	NONE	EL HGT	179.808	N33:53:46.38815	W083:21:43.89534	IGS08 (2017.1196)
bm_2	NONE	EL HGT	179.770	N33:53:46.51332	W083:21:44.25062	IGS08 (2017.1196)
bm_3	NONE	EL HGT	179.802	N33:53:46.62067	W083:21:44.61300	IGS08 (2017.1196)

CORS	CONSTRAINT	HEIGHT (m)	LATITUDE (° ' ")	LONGITUDE (° ' ")	REF. FRAME	
brmu	NONE	EL HGT	-11.621	N32:22:13.43546	W064:41:46.58322	IGS08 (2005.0000)
cags	NONE	EL HGT	234.947	N45:35:06.07476	W075:48:26.38042	IGS08 (2005.0000)
frkn	NONE	EL HGT	619.560	N35:11:30.71136	W083:23:41.76628	IGS08 (2005.0000)
gaat	3-D	EL HGT	221.641	N33:57:08.82442	W083:19:30.98397	IGS08 (2005.0000)
gabr	NONE	EL HGT	515.498	N34:51:51.94555	W084:19:37.62972	IGS08 (2005.0000)
gacc	NONE	EL HGT	98.493	N33:32:44.73012	W082:08:01.71813	IGS08 (2005.0000)
gacr	NONE	EL HGT	97.787	N32:22:51.45850	W083:20:46.42432	IGS08 (2005.0000)
meri	NONE	EL HGT	7.848	N20:58:48.16326	W089:37:13.14167	IGS08 (2005.0000)
ncmu	NONE	EL HGT	474.789	N35:04:06.80259	W083:57:59.38148	IGS08 (2005.0000)
scgp	NONE	EL HGT	278.053	N34:56:15.71359	W082:13:57.28675	IGS08 (2005.0000)
txma	NONE	EL HGT	79.113	N32:32:07.14544	W094:17:19.11202	IGS08 (2005.0000)
ztl4	NONE	EL HGT	260.698	N33:22:46.87867	W084:17:48.20896	IGS08 (2005.0000)

Processing Preferences

Output Ref Frame: LET OPUS CHOOSE

Output Geoid Model: LET OPUS CHOOSE

Constraint Weights: ☐ LOOSE ☒ NORMAL ☐ TIGHT

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Figure 11. Network Adjustment processing window. The solution name indicates that this solution is using days one, two, and three (**Note:** Session names do not follow the naming convention suggested by this SOP). Only the hub was given a '3-D' constraint (because this is an example of the initial minimally-constrained network). All of the other CORS were given a 'NONE' constraint. If this were the final adjustment, the CORS would have a constraint based on their constraint ratios (see Table 1).

Interpreting the quality of Network Adjustments

When OP has finished processing each network adjustment, the solution will be emailed to the project manager and added to the OP manager's page (Figure 4). The overall quality of the network adjustments is reported as the STANDARD ERROR OF UNIT WEIGHT (Line 15). Similar to the session solutions, a standard error of unit weight close to 1 indicates a high quality solution. The network adjustment also provides a root mean squared error for each benchmark. Benchmark RMS can be found after line 33 and before the line with UNCONSTRAINED MARKS. The lower the RMS the better. The results of the network adjustment can also be accessed by clicking "Show File" on the 'Manager's page' and selecting the 'Summary' of the appropriate network adjustment. There is no set 'acceptable' value for either of these measures. It is up to the project manager to decide the acceptable error threshold for any given project. Typically, RMS should be less than 2.5. If the RMS is greater than 2.5, check the session solutions to determine the repeatability of the baseline solutions (horizontal and vertical solutions). If there are significant differences, check antenna heights to make sure an incorrect height was not entered.

Constraint Ratios

Once the minimally-constrained network adjustment has been created, CRs can be calculated to evaluate the quality of the potential control points (from the set of potential CORS). The first step is to populate a Microsoft Excel worksheet with the adjusted N, E, and Z (ellipsoid height – EL HGT) of the unconstrained CORS. These coordinates can be found in the 'network-*"name"*.txt' sent to the project manager. The coordinates can also be found by clicking "Show File" on the 'Manager's page' and selecting the 'Summary' of the appropriate network adjustment.

Use the 'Data Sheet for Position at ARP' downloaded during the initial CORS selection process to determine the published N, E, Z, and standard deviation of the coordinates for the CORS. The line numbers that the data are located on vary depending on the amount of information included for each station. Ellipsoid height ("ELLIP HT") is approximately on Line 16. The UTM (Universal Transverse Mercator) N and E for the CORS specific zone is located approximately on Line 64 (make sure it is the same UTM zone as the network adjusted coordinates). The standard deviation of the coordinates will be around Line 32. Standard deviations are reported in centimeters. Make sure to convert the standard deviations to meters (cm/100) prior to calculating CRs.

Once all of the adjusted and published coordinates are transcribed into a Microsoft Excel worksheet, calculate CRs using equation (1). Constraint ratios indicate the number of standard deviations apart the adjusted coordinates are from the published coordinates (Gillins and Eddy 2016). Constraint ratios greater than 2 indicate a potentially inconsistent coordinate, and CORS with CR greater than 3 should be avoided for use as a control. Use Table 1 to decide how to handle each potential CORS.

Final Solutions

Once reliable CORS and proper constraints have been identified, final session solutions and a fully-constrained network adjustment can be created. First, create new sessions using only the finalized set of CORS. Name the final session solutions using the same naming convention as the initial session solutions and add ‘_final’ to the end of the name to distinguish them from the initial sessions (e.g., an eight-hour survey on day one would be named D1H8_final). Exclude all of the CORS that did not meet reliability standards by unchecking the box to the left of the CORS ID. Make sure only the chosen hub has the ‘hub’ box checked. Apply a ‘3-D’ constraint to the hub and select ‘NONE’ constraint for the rest of the CORS. When the hub has been identified and the constraints have been chosen, check the “Processing Preferences” at the bottom of the page to make sure that they are correct (Tropo Model: Piecewise Linear, Tropo Interval (s): 7200, and Constraint Weights: NORMAL). Click “Perform Processing” to calculate the session solution. Again, an email will be sent with the session solution to the OP project manager or user. Repeat these steps for each unprocessed session.

When the final session solutions are available in OP, click ‘Set up Adjustment’ on the Manager’s page. Under ‘Adjustment Name,’ name the final network adjustment to identify the days that were used and an additional letter to signify it is not the minimally-constrained adjustment (e.g., if days 1, 2, and 4 were used, name the Network Ns1s2s4b [s refers to session and ‘b’ distinguishes it from the initial adjustment]). Include only your final session solutions in the ‘Included Solutions’ window. All CORS that were used in the session solutions will be included in the processing window. Make sure only the chosen hub has the ‘hub’ box checked. Set all of the ‘near’ CORS to the appropriate constraint (Table 1). Use a ‘NONE’ constraint for all of the ‘distant’ CORS. Check that the Processing Preferences are properly set and then click ‘Perform Adjustment.’ The final network adjustment will be emailed to the project manager or user and will be available in OP by selecting ‘Show Files’ on the ‘Manager’s page.’ When the final adjustments have been received, see protocol/project specific methods for proper storage of the results.

Table 1. Potential combinations of constraint ratios. ¹Highlighted cells indicate acceptable constraint ratio.

Potential Outcome	CRN	CRE	CRZ	Exclude	Constraint
1	> 3	> 3	> 3	Y	N/A
2	< 3 ¹	> 3	> 3	Y	N/A
3	> 3	< 3 ¹	> 3	Y	N/A
4	> 3	> 3	< 3 ¹	N	N/A
5	< 3 ¹	< 3 ¹	> 3	N	HOR-ONLY
6	< 3 ¹	> 3	< 3 ¹	N	VER-ONLY
7	> 3	< 3 ¹	< 3 ¹	N	VER-ONLY
8	< 3 ¹	< 3 ¹	< 3 ¹	N	3-D

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