

CONSTRAINED ADJUSTMENT GUIDELINES

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INTRODUCTION

The following guidelines should be studied and used when submitting GPS projects to the National Geodetic Survey. If you have corrections, suggestions or questions, notify Julie Prusky at julie.prusky@noaa.gov.

References to "GPS" will be revised to "GNSS" as other satellite constellations become viable and NGS develops procedures to handle the additional data types.

The files in samples.zip, part of [ADJUST_all.zip](#), may be used to practice or test the adjustment sequence. This zip file also includes the format validation ("checking") programs Chkobs and Obschk, as well as other utilities.

In this release updates to these guidelines include:

Network Standard Deviations for CORS revised (section 5-1)

Sigmas for weighting constraints in vertical adjustments (section 6-1)

Use MM3YYY in vertical constrained adjustment

The F statistical hypothesis test (section 5-1)

APPENDIX D, OPUS-Projects for FAA General Guidance

Explanation of Updates moved to Addendum E

Removes the Median Local Accuracy Value

First-time users: Create a C:\ADJUST folder; unzip [ADJUST_all.zip](#) in it, including samples.zip if you want to start developing familiarity with the process using the sample files.

All users: create a root project folder, under which the GPS session folders are placed. File names listed below are suggested, not required. With experience, you may develop or prefer different file names.

If excessive errors are found by NGS during the review of a project, the files will be returned to the submitting agency for corrections.

Add c:\ADJUST to the path (Control Panel->System->Advanced->Environment Variables->New User Variable->Variable = "Path", value = "C:\ADJUST"). Usually the "Path" variable already exists, in which case it can simply be appended with the path where "adjust.exe" is located (e.g., ";C:\ADJUST\"). Doing this will allow ADJUST (and all other programs in that path) to be run from any folder on the computer.

ACRONYMS, TERMINOLOGY

The following acronyms and terminology will be used in this document:

Afile - Adjustment constraints and processing options

Annex - Part of the "Bluebook" such as Annex N

Bfile - Data from observation logs; equipment codes; station designations, positions, heights and related codes

[Bluebook](#) - Federal Geodetic Control Subcommittee document "Input Formats and Specifications of the National Geodetic Survey Data Base

Chapter - Part of the "Bluebook" such as Chapter 4 CORS

- Continuously Operating Reference Station

Dfile - Station descriptions and recovery notes

Gfile - Processed GPS vectors and statistics

Hub - a mark that is preferentially selected for inclusion in baselines

IDB - National Geodetic Survey Integrated Data Base

NAD 83 - North American Datum of 1983

NAD 83(2011) - North American Datum of 1983, 2011 realization, epoch 2010.00

NAVD 88 - North American Vertical Datum of 1988

NGVD 29 - National Geodetic Vertical Datum of 1929

OPUS - Online Positioning User Service

Serfil - Station-specific 4-character identifier and 4-digit serial number list
[Project Tracking - Survey Project Proposal](#)

It is recommended that NGS is contacted prior to beginning the survey. Use the Project Proposal form to impart as much information as possible. Provide the project name, contact information, approximate project start and stop dates, and a list of proposed control. Photos of marks, if any, and a sketch should also be submitted. NGS will review the proposal and provide a tracking number with any suggestions for your project. The tracking number must be submitted with the Bluebook project data. If the review is not desired, a tracking number can be provided with the understanding it is the submitter's responsibility to ensure their survey conforms to all relevant specifications in order to be accepted for publication.

OPUS-Projects Processing (OP)

NGS accepts Bluebook projects created using the OPUS Projects software. This program is **RESTRICTED** to trained project managers. Once a user completes [OPUS Projects](#) training, they are registered and may create a new project. For training opportunities see the [Training Schedule](#). The "[OPUS Projects User Instructions and Technical Guide](#)" and other documents can be found at <ftp://geodesy.noaa.gov/pub/opus-projects/>. Of particular interest will be The "[OPUS Projects Processing Guidance](#)" and the "[OPUS Projects GNSS Background for Surveying](#)".

When using this software to submit data for inclusion into the NGSIDB:

Provide the project ID, manager keyword and the project manager's email address in the Project Report.

All Stations:

- must have at least two hours of usable data per occupation
- must have a minimum of two occupations
- should use fixed height poles (highly recommended)

All sessions:

- must include a long distance CORS between 375 km to 900 km from the hub with 24 hours of data for tropo de-correlation (about 1000 KM away). It is preferable to use the same distant CORS for all sessions
- use a CORS with 24 hours of data as a central Hub in each session. If possible, use the same Hub for all sessions. If this is not possible, include CORS selected as Hubs in all sessions (this will automatically change the "Session Network Baseline Design" tab to USER)
- each session's Hub must connect to all other Hubs and rover stations
- distant CORS (<375 km to <900 km) must connect to the session's Hub
- use the "NORMAL" constraint weight option

NOTE for FAA projects reduced with Opus-Projects for airports inside the contiguous U.S. Additionally, only one set of adjustments will be produced as all stations are processed together.

- o Two 4-hour simultaneous observation sessions on the PACS, HARN, and bench marks involved in the survey with a 30-60 minutes break between sessions is required

- o Two 2-hour observations on the SACS with a 30-60 minutes break between sessions is required. Observations must be simultaneous with the PACS
- o The operator must reset the tripod (take down/set up) between the sessions and document same
- o Start times on subsequent days must be at least 2.5 hours different than the previous start times to incorporate a different satellite geometry
- o Longer occupations are recommended for all other areas outside the contiguous U.S.

SECTION 1, MATERIALS NEEDED TO SUBMIT FOR THE PROJECT

1-1. Use the list below to confirm all items are sent. The file structure for storage is flexible, but it is recommended to submit all files in the project root directory except where "separate folder" is noted. Submit only final files, after errors have been corrected and outputs are clean. Do not submit interim files such as test adjustments or checking program output with errors.

*Project Report

Cover page (see [Appendix C](#))

*Approved NGS Survey Proposal Tracking Number

*Project Instructions or Contract Specifications

*Pertinent Correspondence

*Project Sketch

*+Descriptions/Recoveries (.dsc file)

*Final Bfile (Project and Station Occupation Data)

*Final Gfile (Base Line Vectors w/ proper Reference System Codes see Bluebook Annex N)

^Gfile with HTDP

Adjustments (3 expected)

*Final Free Adjustment

*Final Constrained Horizontal Adjustment

+Final Constrained Vertical Adjustment

+Free Vertical Adjustment

*Chkobs Output (checking program for the Bfile)

Obschk Short Output (checking program for the B/Gfiles)

Obschk Long Output (checking program for the B/Gfiles)

*F-test output and analysis

*Obsdes Output

*Neighbor Output

*Discrep Output

*WinDesc Check

^OPUS Output

^HTDP Output

^Vector Processing Program Output

%[Digital Station Photographs](#) (Photo Submission Guidelines must be followed) (**In its own directory**)

*Observation (Field) Logs (scanned) (**In its own directory**)

%Rubbings

*Raw Data Files in both RINEX and proprietary receiver formats (**Each in its own directory**).

Key:

*Required

%Either Photos or Rubbings are required. (Both are preferred but not necessary)

*+Required in most cases. An exception would be if there is leveling to all GPS stations and descriptions are submitted separately with the leveling portion.

This must be explained in the report.

+Required in most cases. An exception might be if all stations are leveled or the vertical adjustment is delayed awaiting completion of the leveling control observation and adjustment. This must be explained in the report.

^If applicable due to region or project Statement of Work (SOW).

All items listed above are to be submitted electronically including the field logs.

1-2. Keep a project log to document field and office problems, analyze the project and prepare the final report. Note unusual situations or procedures. In the station list, categorize stations as new or recovered, fixed, readjusted, bench marks, etc.

1-3. The project report must include any problems encountered in the field, especially those which affect the adjustment or analysis. Review the output of the format checking programs. Verify final positions and heights submitted in the Bfile to ensure correct adjusted values are present and the final files are free of format errors.

1-4. If the project is in an area known for significant horizontal crustal motion, determine the epoch required for the final positions. Use the Horizontal Time-Dependent Positioning program ([HTDP](#)) to update the observations to the correct epoch. Submit both the original and transformed Gfiles to NGS ensuring the original has all modifications such as rejected vectors.

SECTION 2, PRELIMINARY PROCESSING

**Two checking programs—Chkobs and Obschk, and Make86 (run from the DOS prompt)
Geoid (run from NGS Toolkit website)**

2-1. Files can be managed in one of two ways.

A. Move them to the directory where the Adjust executable is located and work with them there, or B. leave them in the project directory and specify the path to them from the ADJUST location (note that if the location of Adjust is specified in the "Path" Environment Variable as described in the Introduction, Adjust and all other executables in that location can be run from any folder without specifying the path). Either way, first copy Bfile and Gfile as Bfile.org and Gfile.org (or similar) in the project folder.

For A, do the following: Move Bfile, Gfile to c:\ADJUST. Run Chkobs and Obschk there. Make changes to Bfile and Gfile as needed. Move them back to the project directory once all errors have been corrected. Run Make86 (see section 2-5) in the project directory (by putting ADJUST in the "Path" Environment Variable).

For B, keep Bfile and Gfile in the project folder after copying them; run the checking programs from this location \Adjust, and specify the full path to the files (only necessary if ADJUST is not in the "Path" Environment Variable).

2-2. Solution Coordinate System Code— Adjust transforms the vectors from the satellite reference frame to NAD 83. Ensure the session header records (B-records), have the appropriate 2-digit code in columns 52-53. Refer to [Annex N](#) in the bluebook formats document and the precise ephemeris (i.e. .sp3 file) used for processing. Note the reference frame listed in cc 47-51 of the first record in the sp3 file; select from the list of codes in Annex N, p. N-6 that matches it. Example: "IGS14" in the sp3 file matches "33 - **IGS14 (epoch 2010.0)**" to put in the Gfile. The PAGES software and SINEX2G automatically insert the correct code. Vendor software may require hand entry. Note: Though very unusual, there are instances where the vectors are already in the NAD 83 coordinate reference system in which case the proper code for (cc) 52-53 of the Gfile can be found in [Annex N](#).

2-3. Examine the Bfile for obvious errors and correct them. Verify that the 6-character organization abbreviation in cc 19-24 of the first [Data Set ID] record exists, and that it matches the corresponding entry in the contrib.dat file for the submitting organization. Request new organization abbreviations (contributor codes) from ngs.annexc@noaa.gov.

2-4. Perform the following series of checking programs.

Run [Chkobs](#). **Input:** Bfile, **Output:** chkobs.out.

Resolve messages and rerun until clean. Note: There may or may not be *86* records in the bfile at this stage. If *86* records exist there may be errors related to fields not yet populated. This will produce errors in Chkobs that can be ignored for the time being.

Run [Obschk](#). **Input:** Bfile, Gfile; **Output:** obschks.out (**s** for short output file name), obschk1.out (**l** for long). As with Chkobs, correct the B and/or Gfiles as needed; rerun Obschk until a clean run is obtained. Warnings should be checked and reported in the project report. All messages must be resolved. OBSCHK should be run each time any changes have been made to either the Bfile or the Gfile.

Obschk mimics the program used for loading the project data into the IDB. Unresolved messages other than warnings in Obschk will cause the data loading process to fail.

Any one type of error appearing consistently through a file may generate voluminous repetitive messages which will all disappear after the corrections are made.

NOTE: If CR8BB, an outdated program, was used to create the B-file, the program will insert one value from the look-up table of antenna offsets, given the other value. If ARP heights are entered (e.g., 2000 with implied decimal point), CR8BB will compute and insert the L1PC height (2068), and conversely. The ARP height is required. Though the L1PC height has been removed from the FGCS Bluebook no error will be produced if it is present.

2-5. Run [Make86](#) if *86* records are not in the Bfile. **Input:** Bfile, **Output:** Bfile.86. The result is a new Bfile with pairs of *80* and *86* such as the following

```
001460*80*0701JAY          36253855817N094470567140W      OK
001470*86*0701          N88          A  A
```

SECTION 3, DETERMINE CONTROL

3-1. Determine which horizontal and vertical datums will control the adjustment and note them in the project report. Currently only NAD 83(2011) and NAVD 88 are allowed to be used in the contiguous US; Outside the contiguous US, check the data sheets in the area to determine valid datums. See also http://www.ngs.noaa.gov/INFO/incorp_data.shtml.

3-2. Retrieve datasheets for the existing marks in the project. Ensure that all published positions, ellipsoid heights and orthometric heights constrained in the project match the values currently published on data sheets.

3-3. Look for CORS which have formal accuracy values provided on the NGS

datasheet as these have accurate velocities values. **NGS suggests using CORS constraints which have these formal sigmas whenever possible.** It is advisable to tie your survey to a minimum of four CORS. Ideally, they should surround the network and include one or more near the center of the network whenever possible. CORS within 300 km of the perimeter of the network would be best. It is recommended to check the CORS' short-term time-series plots to ensure the daily repeatability of a site for the last 90 days with respect to its published position. These time-series plots are updated daily and are corrected for the effect of the published velocity at the CORS. For best results, choose stations with daily solutions that are, on average, less than 1.5 cm horizontally and 2 cm vertically of the published position of the CORS.

3-4. Research orthometric heights. If adequate NAVD 88 vertical control exists, use only that control in the vertical adjustment. Acceptable heights include bench marks and stations with heights determined using height modernization specifications as noted on the data sheet. Usually, 3-4 are considered sufficient for a non-height modernization or non-airport project. If insufficient NAVD 88 control exists (rare) heights can be obtained by the formula $h-N=H$ (Ellipsoid Height-Geoid Height=Orthometric Height). The *86* OH record code cc 24 for the resulting stations will be "E". Document such stations in the project report. Verify height codes for all stations per *86* record formats given in [Chapter 4](#) of the Bluebook.

Constrained leveled heights may be of several types, per the *86* record Table of orthometric height codes. The most common such codes are A, B and L. The use of B, leveled heights not yet in the NGS IDB, must have prior approval from NGS.

If leveled from a known bench mark, the leveled height (generally code L) can be used for control, subject to consistency with other bench mark heights in the project. Discuss any such leveling in the project report.

Orthometric heights determined by GPS observations and a geoid model should have one of four codes: "K" (restricted to height-modernization projects, published to cm), "G" (for regular GPS projects, generally published to dm, and FAA projects published to cm), "E" from the formula $h-N=H$ as mentioned above, or "J" (when the GPS height is only published to a meter--as in Alaska for some projects). The orthometric heights of airport stations designated as PACS and SACS are published to cm in order to maintain the required differential relationship between the stations. Therefore, "G" would be the correct code unless other circumstances exist (e.g. the station is a bench mark).

Leveling to be included in the IDB should be discussed with NGS. Contact Vasanthi Kammula: Vasanthi.Kammula@noaa.gov.

3-5. Station names in the Bfile *80* records must match those in the Dfile (see naming conventions per [Annex D](#), e.g. remove dates and agency abbreviations). If a change from a published name is needed, include the changed designation in both files and note it in the project report. **Recommended:** Sort the *80* records alphabetically. Follow each *80* record with its associated *86* record, one pair for each SSN (Make86 does this automatically).

3-6. Order and type (OT) and order class codes are no longer required for horizontal position and ellipsoidal height classifications.

3-7. PACS and SACS-Supplemental Guidance for GPS Observation and Adjustment of Airport Geodetic Control

When the PACS is found in good condition and its unmoved position verified, but one or more new SACS are to be established, **a minimum of two GPS observation sessions of all SACS are required along with simultaneous observations of the PACS.** Follow the guidance provided in the Adjustment Section 4 through Section 7.

When determining the position of one or more new SACS in a survey involving a published PACS and one published SACS, analysts should include the position and ellipsoid height of the published SACS as a constraint in the Horizontal Constrained adjustment when it fits well with the published PACS. Likewise, include well-fitting orthometric heights as constraints during the Constrained Vertical Adjustment.

For SACS horizontal adjustments, the 2 cm horizontal and 4 cm ellipsoid height "rule of thumb" values mentioned in Section 5-2 of this document may not allow the required SACS accuracy standards to be maintained. Additional guidance follows.

Horizontal Adjustments: Run the horizontal free adjustment, constraining the published position and ellipsoid height of the PACS. Compute the inverse between the output position and ellipsoid height of the SACS and its published values. For adjusted vs. published differences exceeding either 1 cm in horizontal position or 1.5 cm in ellipsoid height, readjust the SACS. Otherwise, include the published SACS as a constraint during the constrained horizontal adjustment.

Vertical Adjustments: Run the vertical free adjustment constraining the published position and height of the PACS. Compare the adjusted heights of SACS with published values. For adjusted vs. published GPS-derived height differences exceeding 2 cm, readjust the height. Otherwise, hold the published height fixed.

SECTION 4, MINIMALLY CONSTRAINED (FREE) HORIZONTAL ADJUSTMENT

4-1. Create the horizontal free Afile (Afilehf). This can be done in two ways. Either use an existing Afile and edit it for the new project, or use WinDesc->File->Export->GPS Project Files. Exercise caution when editing Afiles as data written to Afile option records are column sensitive. Afile option records are defined in file "ADJUST_supplemental.txt."

In the Afile, constrain only one station position and ellipsoid height (EH) per component, using published values from a datasheet. (Multiple components occur in rare cases when disjointed networks are combined in one adjustment.)

Generally, a CORS will be constrained; but in principle, any well positioned mark can be constrained in the free adjustment. The latitude, longitude and EH can all refer to the same mark (usual procedure), or the EH can be from a different mark. All three data elements for a station can be in one CC record, or the lat/long and EH can appear in separate CC. An EH is indicated by "E" in column 77.

The VV record (defined below) is on a separate line at the end of the Afile. Since it affects the distribution of residuals, the VV record should be used for all free adjustments. In some cases, such as when large blunders occur, the VV record may prevent ADJUST from converging to a solution. The VV record can be disabled to resolve such issues, or to expedite the initial adjustment of large projects, but it should ultimately be used as part of the final run of the free adjustment to determine the sigma scale factors used in the Afile's VS record (defined in Section 5) for all subsequent adjustments. Comments can be added to the Afile by placing two asterisks, "***", in cc 1-2.

The VVHU record is a special application of the VV (Variance Factor Indicator and Constraint) record, which is defined in "ADJUST_supplemental.txt." The observation type code "HU" is used to solve for variance factors for the horizontal and vertical components of the GPS observations. This is done by computing the sum of squares of the residuals for the horizontal and vertical observations separately, computing the redundancy numbers of the horizontal and vertical components of the observations, and estimating the standard deviation for each. The resulting adjustment will produce a variance of unit weight equal

to 1.00.

Example Afile:

```
CC          1001  0.71  0.58  2.82                37312217766N092421254079W 360616E
**1001 CNWM CORS ARP lat, long & EH constrained
```

DD3

II109999999

NLY (Optional in the free adjustment - see Section 5-1)

MM3YY

PP22

VVHU

70-76 Height, units of millimeters (integer)

77-77 Height Code E ---- ellipsoidal height

The 0.71, 0.58, and 2.82 values are standard deviations of the latitude, longitude, and ellipsoid height. These are described in [Section 5](#).

As mentioned above, the position and EH may be broken into two lines:

```
CC          1001  0.71  0.58                37312217766N092421254079W
CC          1001                2.82                360616E
```

4-2. Run [Adjust](#) in 3D with minimum constraints. Respond to the prompts:

Input: Bfile.86, Afilehf, Gfile, **Output:** adjhf.out, Bfilehf

Run all adjustments in mode 3 (normalized residuals). Do this by coding the MM record in the Afile as "MM3". This mode computes residuals scaled relative to the standard deviation of the residual (normalized residuals).

View output file adjhf.out with a text editor. Check for a successful run indicated by "HAVE A NICE DAY" message at the end of file. If the Adjust run failed, review the output file for error messages and verify that program input filenames were correctly entered. Other causes of failure, such as a singularity, may require more analysis. Note the variance of unit weight and degrees of freedom for the report. The variance of unit weight should equal 1.00 since the VVHU option is used.

Programs [CompVecs](#) and [PrePlt2](#) may be useful for analysis purposes. CompVecs finds differences among redundant vectors in a G-file. Inputs are the B- & G-files. Preplt2 reads ADJUST output files and writes residual components, baseline length, SSNs and designations to an output file in tabular format. In adjustments containing numerous vectors, sorting columns of DN, DE, or DU residuals will help locate large residuals.

Inspect individual computed-observed (C-O) residuals in adjhf.out. Investigate large residuals to rule out blunders in the processing. The RESIDUAL STATISTICS section of the output file contains summaries displaying the observation numbers of the 20 greatest component residuals. Sample summaries follow.

```
OBSERVATION NUMBERS OF 20 GREATEST GPS DU COMPONENT RESIDUALS (V)
54   48   66   72   69   15   36   12   27   75   24
OBSERVATION NUMBERS OF 20 GREATEST GPS DL COMPONENT RESIDUALS (V)
69   48   51   42   63   24   12   54   33   36   30
```

"LARGE MISCLOSURE" messages: Generally ignore these, as opposed to the computed-observed (C-O) residuals. They are only the shift between positions in the input Bfile and adjusted positions. Unless the position in the Afile is wrong, they do not indicate a problem. To see this is so, re-run the adjustment, using the output from the first adjustment as input to the second; those messages will not appear. The "LARGE MISCLOSURES" are in units of .0001

m, tenths of mm—thus a small distance like 2 cm can look large (200.0). Ellipsoid heights that start off as blanks or zeroes in the input Bfile will shift to their adjusted values in the output Bfile, with correspondingly “large misclosures” reported.

Compare the results of the free adjustment with the published positions. This will help in the analysis of the horizontal constrained adjustment. List outliers in the project report.

Attempt to reduce large residuals (exceeding 2 cm horizontal and 4 cm vertical) by reviewing vector processing for blunders such as incorrect antenna height, improper antenna pattern, etc. and reprocess any affected sessions. Other reprocessing options to consider include raising the elevation mask or deleting noisy satellite data. Before adding a reprocessed vector solution to the Gfile, delete the original vector solution.

With reprocessing completed to correct the blunders and tweak the processing options, reject observations which continue to have a high residual (rule of thumb, over 2 cm horizontal and 4 cm vertical). Reject a vector by entering “R” in column 58 of the G-file C or column 64 of the F record for the affected vector--see example below. Do not, however, allow rejections to result in a new station being no-check (only one observation). Remaining large residuals may indicate the need for reobservations.

Example portion of a Gfile, showing one rejected vector, the third C record, with R in column 58:

```

AXE2012030720120307
B2012 3 716582012 3 722 0 3 page5 v0708.16IGS 126 1 2 27NCGS 2012 411IFDDPF
C01000005 -174930970 12 -3224990 26 47107500 19 R067210100R067210005
C01000003 -104942635 11 -44430269 26 -27797463 19 R067210100R067210003
C01000001 137309864 11 -11638474 24 -55689308 18RR067210100R067210001
D 1 2 -5723833 1 3 5025210 1 4 5613055 1 5 -2179673 1 6 2882670
D 1 7 1165649 1 8 -2571102 1 9 3029782 2 3 -8854411 2 4 -3123343
D 2 5 4961192 2 6 -4373273 2 7 -2910199 2 8 3982316 2 9 -3397965
D 3 4 2662336 3 5 -4427962 3 6 4806815 3 7 3053212 3 8 -3505623
D 3 9 3938813 4 5 -6271706 4 6 6563317 4 7 2220115 4 8 -2615862
D 4 9 2912531 5 6 -8778901 5 7 -3346597 5 8 3920148 5 9 -3267809
D 6 7 2552310 6 8 -3546802 6 9 4188493 7 8 -6345931 7 9 5391172
D 8 9 -8733045

```

Ensure no blunders or preventable outliers exist before continuing to the next section.

SECTION 5. CONSTRAINED HORIZONTAL ADJUSTMENT

5-1. Horizontal Constrained Afile (Afilehc)

Constrain all currently published positions and ellipsoid heights from the data sheet retrieval. (In crustal motion areas, it may be necessary to update these positions with HTDP). As with the free adjustment, lat/long and EH can be combined on one CC record for each station or separated--lat/long on CC records in one group, EH in another.

Weight the Constraints

Add the network (point) standard deviations (sigmas) found on the datasheets.

The sigmas for a given station are entered in centimeters in columns 15-32 of the constraint record as shown below. For example the values from the datasheet for PID=[AE8289](#), as of this document’s publication date, are

StdN	StdE	Stdh
0.15	0.12	0.27

```

0           1           2           3           4           5           6           7           8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CC          0005  0.15  0.12  0.27                    46462910992N092053738770W 156085E

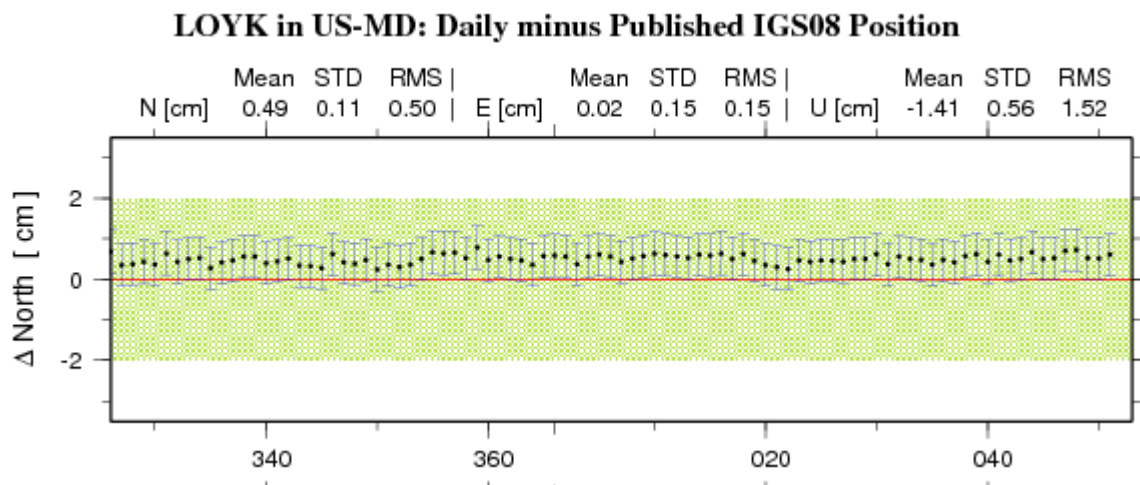
```

The network sigmas can also be generated in Afile format using the NGS program WinDesc. Once station PIDs have been added to the WinDesc description (*.des) file, the sigmas can be populated under the WebTools > Get > Positions for all PIDs.

Network Standard Deviations for CORS

As noted above, **NGS suggests using CORS constraints which have the formal sigmas whenever possible.** However, rather than using the published sigma values, the RMS value from the short-term time series plots provide a more realistic weighting. Additionally, it is best to use the same source for weights for all CORS rather than mixing RMS value with published formal accuracy values. Above the time series plots are the root mean square error (RMSE).

See the short-term time series for the LOYK CORS, shown partially below.



For tighter CORS constraints, the time series standard deviations can be used directly rather than the RMSE values. However, RMSE is more representative of accuracy with respect to the published coordinates. For either approach a screen capture of the time series at the epoch of observations, or as close as possible, should be provided in the project report or in a directory aptly named.

AFILE: Include "Y" in cc 6 of the MM record. This writes the non-shifted constraints to the output b-file rather than those shifted by the sigmas (required for final submission to NGS).

MM3YYY

Add a VS record on a separate line at the end of the Afile, using the sigma scale factors computed in the final free adjustment. The *93* record of the output Bfile contains these values (they are also given in the ADJUST output file). This scales the uncertainty of the horizontal and vertical components of the GPS vectors before beginning the adjustment.

Compute Local and Network Accuracies: Add a line in the Afile with the codes NLY. This will compute network and local accuracies and write them to the Bfile as *91* and *92* records (see [Chapter 4](#) of the Bluebook).

Example Afile:

0	1	2	3	4	5	6	7	8
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890								
CC	0001	0.21	0.18	0.27		36244466001N077260841822W		5614E
CC	0003	0.15	0.14	0.45		36263621507N077422648858W		43435E
CC	0005	0.17	0.16	0.54		36313793277N077462610205W		65158E
CC	0200	0.85	0.76	3.40		36243056335N077261530879W		13257E
CC	0032	0.50	0.21	4.20		38434202176N077110229814W		-1556E
DD3								
II109999999								
MM3YYY								
PP22								
NLY								
VS	4.000	4.333						

An example of the network (*91*) and local (*92*) records in the output Bfile is given below, along with associated *80* and *86* records. Program Adjust populates columns 1-6 of the *91* and *92* records with the sequence number in column 1-6 of the *80* record (of the "from" station for the *92* record). Similarly, Adjust populates columns 71-76 of the *92* record with the sequence number in column 1-6 of the *80* record of the "to" station. These sequence numbers provide a convenient means of searching the Bfile for network and local accuracy values associated with specific stations. The 4-digits Station Serial Numbers (SSNs) can also be used for searching, but they may not form unique strings within a Bfile, especially for large projects. This use of sequence numbers is included in these but is optional. (NOTE: LOYOLA K CORS ARP is omitted below. It was included to show commenting and the RMS values from the short term plots.)

0	1	2	3	4	5	6	7	8
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890								
000750*80*0001	JACKSON AZ MK				36244465989N077260841820W			NC
000760*86*0001	40014A22Y88NGS			-344006	5614A A			
000770*80*0002	JOYNER				36274043492N077361617205W			NC
000780*86*0002	38300A22Y88NGS			-340686	4232A A			
000790*80*0003	ROANPORT				36263621510N077422648864W			NC
000800*86*0003	77390A21Y88NGS			-339546	43436A A			
000810*80*0004	TOM				36280817246N077364177672W			NC
000820*86*0004	44811A22Y88NGS			-340426	10769A A			
000830*80*0005	VULTARE AZ MK 2				36313793282N077462610199W			NC
000840*86*0005	98939A22Y88NGS			-337816	65158A A			
000850*80*0100	ROANOKE RAPIDS CORS ARP				36282912720N077345660637W			NC
000860*86*0100	44652K N88NCGS			-340666	10586A A			
000870*80*0200	JACKSON CORS ARP				36243056300N077261530868W			NC
000880*86*0200	47662K Y88NGS			-344056	13257A A			
000750*91*0001		0.16		0.18-.10308822	0.28	Y		
000770*91*0002		0.23		0.21-.01402805	0.86	Y		
000790*91*0003		0.14		0.13 .01151952	0.44	Y		
000810*91*0004		0.23		0.21-.00539402	0.86	Y		
000830*91*0005		0.15		0.15-.07689758	0.51	Y		
000850*91*0100		0.21		0.19-.02570723	0.83	Y		
000870*91*0200		0.25		0.26-.20512389	0.96	Y		
000750*92*0001	0100	0.21		0.19-.11268980	0.83	Y	000850	
000750*92*0001	0005	0.19		0.23-.21783842	0.51	Y	000830	
000750*92*0001	0003	0.18		0.20-.06874055	0.44	Y	000790	
000770*92*0002	0100	0.09		0.07 .06230800	0.83	Y	000850	
000770*92*0002	0004	0.10		0.07 .09238057	0.86	Y	000810	
000790*92*0003	0100	0.20		0.20 .00264948	0.83	Y	000850	
000790*92*0003	0005	0.17		0.16-.04880625	0.51	Y	000830	
000810*92*0004	0100	0.10		0.07 .11677967	0.83	Y	000850	
000830*92*0005	0100	0.21		0.21-.07626602	0.83	Y	000850	
000850*92*0100	0200	0.14		0.18-.52775622	0.96	Y	000870	

5-2. Run Adjust. **Input:** Bfilehf, Afilehc, Gfile, **Output:** adjhc.out, Bfilehc

Things to check in the adjustment

- Ensure the constraints are error free including the sigmas.
- Ensure the variance factor(s) was applied correctly; look for the following message in the output. "GPS SESSION COVARIANCE MATRICES INPUT IN THE G-FILE WILL BE SCALED AS FOLLOWS:"
- Run DIFLATLON on the output free bfile and constrained bfile to compare the results.
 - Any shifts of horizontal control exceeding the recommended values of 2 and 4 cm in horizontal and vertical respectively should probably not be constrained. Careful consideration should be taken when freeing either the lat/long or EH. Only in extraordinary circumstances would one component be freed up but not the other and the reasons must be clearly documented in the report.
 - Run horizontal constrained freeing these stations. If the resulting shifts from the freed stations relative to the published values are insignificant, the stations can probably be constrained.
 - Take note of the changes in the F-test results. See next bullet.
- **F statistical hypothesis test**, provided in the Adjust Suite, is a statistical test which helps determine if the variance from a fully constrained adjustment is significantly different from the variance of a minimally constrained adjustment. The variance of unit weight is a critical statistic and should be looked at carefully when evaluating adjustment results. Typically, the value should be close to the variance of unit weight of the minimally constrained adjustment (which should be exactly 1). The F-test should be performed using a 99.9% confidence level.

If the F-test fails, it is due either to the constrained sigmas being overly optimistic (too small) or the constrained coordinates not agreeing with the observations (causing excessively large shifts of the constrained coordinates). Failure of the F-test does not automatically mean the constrained adjustment should be rejected. It is a flag that indicates there may be a problem with the constraints, and that they should be investigated. In addition, the F-test is based on the assumption of a normal ("bell-shaped") probability distribution. So networks with a distribution that is significantly non-normal may fail for that reason, even when a constrained adjustment is acceptable.

Since the F-test only gives information about the entire network, if it fails, it is necessary to inspect the network for specific stations that may be causing the failure. A convenient way to do that is provided in the next item.

- **Constrain ratio (CR)** is the absolute values of the shift of the constrained coordinates divided by the sigma (standard deviation) used to constrain the station. It is computed for each component (north, east, and height):

$$CR = \text{ABS}(\text{adjusted coordinate} - \text{published coordinate}) / \text{sigma}$$

CR > 3 for any of the three components indicates there may be a problem with the constrained station (this corresponds to a 99.7% confidence level, similar to the F-test). If the station is unconstrained, in most cases all three components should be unconstrained. In some rare cases only the two horizontal are freed up while holding the ellipsoid height. Or only the height component is unconstrained but this is highly discouraged. In any case, there should be a specific reason for such a partial release of constraints (e.g., if only the height is

unconstrained, there is evidence that the published height of the mark is in error).

Failure of the F-test or $CR > 3$ does not necessarily require removal of constraints. Both tests are analysis tools that only indicate potential problems; they are not substitutes for professional judgment. However, the reason for either occurring in the final constrained adjustment should be explained in the report. NGS does NOT recommend increasing the constraint sigmas to force these statistics to pass, except in certain unusual circumstances (such as a very small time-series RMSE value on a constrained CORS component). If any constraint sigmas are changed, it must be clearly justified in the report.

- Comparison of Adjusted and Constrained Coordinates and Heights section (see more details about this below)
- Run PrePlt2 to list and sort residuals
- Check position shifts and residuals in adjust output file (decide whether or not to readjust certain stations)
- A worse-than-expected network accuracy would tend to favor readjusting a station assuming good quality and quantity of new observations.
- Residuals which increased markedly from the free to constrained adjustment require specific investigation. The increase results from problems with the constraints. **Do not reject any observations due to constraints.**
- Verify that the control positions and heights used are correct and are all on a consistent datum realization (e.g. do all positions have the NAD 83(2011) datum tag with a 2010.00 epoch?).

For observations with large residuals check for misidentifications. A wrong SSN in the Afile, for example, can cause residuals so large that they overflow the field and cause ***** to be written in place of actual values. If no problems can be identified and solved, determine whether published positions and/or EH should be readjusted. Consider the requirements of the project. Save the adjusted positions (output Bfile) from the final constrained run.

Because weighted (stochastic) constraints are used for adjustments, the adjusted coordinates of the constrained stations will not equal the constrained values. The magnitude of the coordinate change (shift) will depend mostly on the standard deviations (sigmas) used for the weights. These shifts are shown in the ADJUST output section titled COMPARISON OF ADJUSTED AND CONSTRAINED COORDINATES AND HEIGHTS given below the adjusted positions. As a general rule, if the adjusted values of the constrained coordinates of a station shift by more than 2 cm horizontally and/or 4 cm in height, its horizontal coordinates and ellipsoid height, respectively, should be unconstrained. It is important to realize that this threshold is merely a "rule of thumb." For individual projects, unconstraining a station may be necessary if shifts are less than the "rule of thumb" threshold, and in some cases it can remain constrained even if shifts slightly exceed the threshold. The decision to constrain or not constrain also depends on other factors, such as the statistics of the adjustment, residuals, shifts at other stations, and station accuracies. It requires judgment and should not simply be an automatic response to constrained station shifts.

Discuss all readjusted (freed) stations in the project report in addition to any investigations and conclusions reached as a result of the analysis. As mentioned, do not just free up the ellipsoid height and hold the latitude and longitude or conversely, free up the latitude and longitude and hold the ellipsoid height.

5-3. Run Geoid. After the horizontal adjustments have been completed, run the [Geoid](#) program appropriate for your area to add geoid heights to the final constrained adjustment Bfile output. This can be done conveniently by using the [NGS Geodetic Tool Kit](#). Another method would be from one's own PC by downloading

the "Intg.exe" program along with the appropriate data models for the project area and then running Intg.exe. More information, such as comparing various models, is available on the [Geoid](#) web page. The example below shows -28769 geoid height (implied 3 decimal places) and "6" geoid ht code (for Geoid12B).

Run Geoid. Input: Bfilehc, Output: Bfileght

```
001470*86*0701          N88          -287696    237794A  A
```

SECTION 6, VERTICAL ADJUSTMENTS (FREE AND CONSTRAINED)

6-1. Create the vertical free Afile (Afilevf). Fix one position and one published orthometric height. They can be from the same station or different stations (e.g., good horizontal position in one CC record for a CORS, good OH in separate CC record for a bench mark). Leaving column 77 of the CC record blank indicates the record contains an orthometric height value.

```
70-76 Height, units of millimeters      (integer)
77-77 Height Code      blank -- orthometric height
```

Include the VS record from the horizontal constrained Afile.

6-2. Run Adjust with minimum constraints. **Input:** Bfileght, Afilevf, Gfile, **Output:** adjvf.out, Bfilevf

Assuming the adjustment ran to completion, the statistics of this run will be identical to those of the horizontal free adjustment. Check adjvf.out for big shifts between published and free-adjusted heights.

It is helpful to compute the shifts between the results of the vertical free adjusted and the published heights. Additionally, plot these shifts on a project sketch to determine if several heights near each other are shifting consistently or a height appears to be an outlier and therefore should not be used as control. For inconsistent shifts use resources available such as recovery notes, photographs, and rubbings of the mark. Possible causes could include movement, an unintended mark was observed such as the underground mark instead of the surface mark, or occupying a reference mark rather than the parent station. Look for inconsistent shifts as opposed to areas where the shifts, even high shifts, are consistent. Likewise, look at the geoid heights to ensure they are consistent. If no cause for the shift can be found, the orthometric height may need to be readjusted.

6-3. Create the vertical constrained Afile (Afilevc). Constrain all previously adjusted orthometric heights as indicated above and one NAD 83 adjusted position. The same comments about CC records apply. All GPS-derived Ht Mod heights should be constrained along with bench marks. For ht mod stations the datasheet will read:

```
HT_MOD      - This is a Height Modernization Survey Station.
```

Include the VS record with its appropriate values.

It is now desirable to include sigmas on the vertical control. This will help the vertical adjustments pass the F-test. Vertical heights determined by leveling will have specific sigmas and those determined by GPS will be calculated.

GPS derived heights are noted on the datasheet by source: GPS OBS or h-N COMP
 Heights established by leveling with the vertical source noted on the datasheet as ADJUSTED or ADJ UNCH

The vertical sigma is assigned based on vertical order and class which is found on the datasheet.

Vertical source on datasheet	Vertical sigma (cm)
ADJUSTED or ADJ UNCH*	
VERT ORDER - FIRST CLASS 0	0.2
VERT ORDER - FIRST CLASS I	0.3
VERT ORDER - FIRST CLASS II	0.5
VERT ORDER - SECOND CLASS I	0.7
VERT ORDER - SECOND CLASS II	0.9
VERT ORDER - SECOND CLASS 0	0.9
VERT ORDER - THIRD	1.3
RESET or N HEIGHT	1.3
POSTED or GPSCONLV	1.5
GPS OBS and Height Modernization station (as indicated by HT_MOD special category at top of datasheet)	$\text{SQRT}[(\text{SD}_h)^2 + 1]$ where SD_h is ellipsoid height standard deviation

* **ADJ UNCH** stations are referenced to local mean sea level or the Guam Vertical Datum of 1963 (GUV63). There are only 1001 of these stations.

Program WINDESC afile creation option is being updated to calculate the sigmas. It is important to double check that the heights suggested are actually the currently published heights.

CORS with no Published Accuracies

For the rare occasion when no published sigmas exist, use the RMS value from the 90-day short-term plot and apply the above equation.

6-4. Run Adjust with vertical constraints. **Input:** Bfilevf, Afilevc, Gfile, **Output:** adjvc.out, Bfilevc

AFILE: Include "Y" in cc 6 of the MM record. This writes the non-shifted constraints to the output b-file rather than those shifted by the sigmas (required for final submission to NGS).

MM3YYY

F statistical hypothesis test: Using the values from the free and constrained vertical adjustments ensure the F-test is satisfied. Include the spreadsheet results in the project report. Note: In some instances, an adjustment may fail the F-test, but the network may be fine. This too should be explained in the report. If this is the case, analysts should still carefully examine if the failure is due to use of bench marks as control with incorrect orthometric heights.

Run PrePlt2 to list and sort the residuals. Investigate observations with large shifts or residuals to see if any heights should be readjusted. Apply the same rule as in the horizontal constrained adjustment: no rejections due to constraints. Free any heights in question and rerun as a test. Note the

differences between the published and readjusted heights obtained from the vertical constrained adjustment. Consider the requirements of the project before deciding whether to readjust additional points. Save the output Bfile from the final constrained vertical adjustment.

SECTION 7, COMBINING THE HORIZONTAL AND VERTICAL RESULTS

7-1. When the constrained horizontal and vertical adjustments are complete, run [Elevup](#) to combine the positions and ellipsoid heights from the horizontal adjustment with the orthometric and geoid heights from the vertical adjustment into a final Bfile. This will be the file, after final editing ensuring the orthometric height codes are indeed correct, that will be loaded into the IDB. The file name should indicate that it is indeed the final one.
Input - Bfilehc, Bfilevc; Output - Bfile.fnl; SSN length 4.

SECTION 8, POST-ADJUSTMENT PREPARATION FOR SUBMISSION

8-1. Write report--See FGCS Bluebook [INTRODUCTION](#).

8-2. Double check all output. Ensure the final coordinates in the final adjustments are those in the final bfile. Ensure the heights and their associated codes and NGS IDB indicator are correct.

8-3. Rerun checking programs on final files--there should be no errors.

8-4. Process Descriptions

Descriptions--Use [WinDesc](#) to create the Dfile for recovery notes and new mark descriptions. Verify and change, if necessary, the SSNs in the Dfile to match the B- and Gfiles. Make sure the full station names in the Dfile and *80* records of the Bfile are correct and match (e.g. do not use 4-character IDs for station names in the Bfile, not even for the CORS). Run Obsdes and WinDesc Check (see below) and resolve error messages and inconsistencies.

A description or recovery note does not need to be submitted for CORS currently published by NGS. If one is submitted, uncheck the load option. Messages about missing descriptions for these CORS are allowed in the Obsdes output. CORS which are expected to be published by NGS in the future should have a minimal description for the purpose of assigning a permanent identifier (PID) in the IDB.

[WinDesc](#) uses a proprietary file type *.des which must be converted to D-file *.dsc before submission to NGS. Within program Windesc, run Neighbor, Discrep, Windesc Check and the spell checker on the .des file. Neighbor and Discrep access the IDB to check for stations not assigned a PID but which might be already in the IDB (Neighbor) and any code mismatches between the IDB and the recovery notes (Discrep). WinDesc Check performs a format and information check on the Dfile. WinDesc Check 'ERROR' messages are not allowed and **MUST** be corrected--the loading programs will not accept a D-file which resulted in even one error message. The only exception is an error due to the lack of an assigned GPS number. Leave this field blank and ignore the error message. 'WARNING' messages must be checked, and corrected if appropriate.

The .dsc file must be corrected to conform to current acceptable codes as noted in the checking program output. After all changes have been made, analysis completed, and a clean run has been obtained (with the one exception noted above) export the *.des file to *.dsc inside WinDesc (File->Export->D-file) for submission to NGS.

After a checking program has identified errors and these have been corrected, run the checking program again to confirm that the needed corrections occurred

with no new errors. Run the checking programs on the final files to assure that all applicable codes have been added.

8-6. Prepare the final Bfile for submission. Most of these items will have been completed before the final adjustment, but should be double-checked at this time. Use the checklist in [Appendix B](#).

A. Identify horizontal and vertical no-check stations in the project. In the *80* record, change cc 6 to 'N' for horizontal no-checks. For an orthometric height, change cc 5 to N in the *86* record. A new station is no-check when all of its observations get a zero residual in the constrained adjustment. This SHOULD not happen and will be especially scrutinized by NGS and will not be able to be assigned as a ht mod station. The 'N' in the observational summary is a means of identifying stations which have only one vector but this may not correctly identify a no-check station. For example, in a GPS project, a station determined by only one vector might be correlated with other vectors resulting in a non-zero residual. The observational summary will show an 'N' but unless the residuals on all components of the vector are zero, the station is checked. Document any no-check cases in the report.
(See information in Section 4-2).

B. Verify that station names conform to the bluebook naming conventions, e.g., no dates or agency abbreviations, and a published station's designation matches that on the datasheet. [Annex D](#) discusses designations.

C. Check all height codes as discussed in [Section 3-3](#). It is important to ensure all orthometric height codes are correct, as they affect future publication on the datasheet. For example, **if a bench mark was not held fixed**, it should not carry a leveled code (A, B or L) in the final Bfile. Similarly a leveled height held fixed should not have a GPS code (G or K) but rather a leveled code.

D. Verify state abbreviations in cc 77-78 of the *80* records.

E. The first record in the Bfile must contain the NGS provided agency code of the observing organization (left-justified). This organization must be listed in [Annex C](#). If the organization is not listed, request an addition to the contributor table as noted in [Section 2](#))

8-7. Organize files for submission to NGS.

APPENDIX A, Processing Programs

ADJUST - required. Performs a least-squares adjustment in 3 dimensions using the Bfile and Gfile.

Input - Bfile (observations, positions and heights), Afile (ADJUST instruction parameters), Gfile (GPS vectors), Output - adjustment output (messages, results and statistics) and Bfile (positions updated with adjusted values), if requested.

CHKOBS - required. Bfile validity check.

Input - Bfile
Output - listing of format error messages

CLUSTER - optional. Compares *80* records between files, e.g. Bfile and an IDB retrieval file or another Bfile.

Input - 2 Bfiles or files of *80* format records
Output - list showing the positional and height differences between the same stations in the 2 files and a file of common stations

CR8BB - optional - Bfile creation program.

DIFLATLON - optional. Computes differences between stations with the same SSN in two different Bfiles, e.g. free versus constrained adjustment. Lists the differences in latitude, longitude, ellipsoid height, and orthometric height as well as the shift in meters.

Input - two Bfiles or files of *80* records
Output - listing of differences between corresponding stations

DISCREP - required as part of description submission. Run from WinDesc->WebTools. Identifies differences between codes in the Dfile and those in the IDB for all stations with PIDs. It is important to understand values from the user file will override the database value, such as for stamping, agency code, setting, etc. Make sure the file information is correct, especially when it disagrees with the existing database information.

Output - listing of comparisons between codes in IDB and those in file

ELEVUP - required. Combines results of the constrained horizontal adjustment with the vertical adjustment to produce a final Bfile containing the final adjusted positions and heights to be loaded into the IDB.

Input - two Bfiles, one with adjusted positions and ellipsoid heights and one with orthometric and geoid heights
Output - one updated Bfile containing all adjusted values

F-Test - required. Statistical analysis of variance of unit weights between free and constrained adjustments.

GEOID - required. Updates *86* records with geoid heights from the latest geoid model, whichever is appropriate for the region.

Input - Bfile
Output - updated Bfile

HTDP - optional (see comments in [Section 1-4](#)).

Predicts and updates coordinates and/or observations to a user-specified date to facilitate adjusting survey data to particular epochs in crustal motion areas.

Input -Interactive or Bfile, Gfile

Output - updated coordinates or Bfile, Gfile

MAKE86 - optional. Creates *86* records in Bfile. Will not remove existing *86* records; uses orthometric heights from the *80* records if present.

Input - Bfile

Output - updated Bfile

NEIGHBOR - required as part of description submission. Run from WinDesc->WebTools. Compares description/recovery notes within a specified radius to aid in identifying marks already in the IDB.

Output - listing of IDB matches with each description/recovery note

OBSCHK - required; checks formats in a Bfile and Gfile as well as the relationship between the two files.

Input - Bfile, Gfile

Output - listing of validity check errors in a short and long formats

OBSDES - required as part of description submission. Checks the Bfile against the .dsc description file (or older "unified" format)

Input - .dsc Dfile or older .ha unified format description file, Bfile

Output - listing of inconsistencies

SPCS83 (not required for submission to NGS). Computes state plane coordinates from geodetic positions (or vice versa) on the NAD 83 datum. (Also SPCS83EH, showing ellipsoid heights).

Input -Interactive, or file of coordinates

Output - file of computed state plane coordinates or NAD 83 positions.

UTMS (not required for submission to NGS). Computes UTM coordinates from geodetic positions and vice versa for NAD 27 and NAD 83.

Input - Interactive or file of UTM coordinates or geodetic positions

Output - file of updated positions or coordinates

VERTCON - optional. Transforms NGVD 29 heights to NAVD 88

WINDESC CHECK - required as part of description submission. Description file validity check, part of WinDesc

Output - listing of format error messages

APPENDIX B, Final Bfile Checklist

1. The first record contains the observing organization's agency code provided by NGS.
2. Antenna heights and types match field logs. (if errors found project will be returned)
3. Names of new stations follow current conventions and names of existing stations match data sheets.
4. State codes in *80* records and height codes in *86* records are correct.
5. *80* records exist for the marks at both ends of leveled height differences.
6. In the rare case of horizontal and/or vertical no-checks, they have been identified with 'N' in cc 6 of the *80* for the position and ellipsoid height, and cc 5 in the *86* record for the orthometric height.
7. *80* records are sorted alphabetically (recommended, optional).
8. *86* records are interleaved with *80* records, one pair for each SSN.
9. Checking programs have been run on the final B-, D- and Gfiles and show no errors except those noted above.
10. New Positions and heights match final submitted adjustments.

APPENDIX C, Project Report Checklist

Title Pages

Project Title

Location

Agency for which the work was conducted (and NGS provided [agency code](#))Agency conducting the survey (and NGS provided [agency code](#))Agency conducting the adjustment (and NGS provided [agency code](#))

Email contact for questions concerning the adjustment

Statistics Page

Datum (Horizontal and Vertical)

Geoid Model used

Latitude/Longitude Project Boundaries (nearest minute)

Observation start and stop dates

Number of new, existing stations (other than CORS)

Number of CORS

Original Project Plan and NGS approval

Sketch

Number and type of antennas and receivers, serial numbers

Purpose of project

Problems encountered in the field and resolution

Procedural changes (not expected); if so, process of approval by NGS

List all software used

Checking program results

Results of free, horizontally constrained, and vertically constrained adjustments

F-test analysis

Horizontal and vertical fixed control and source of each

Accuracies which fall below expectations, and discussion

Any readjusted stations and discussion

Overall results

Notes on description file - CORS not included, changes to the IDB revealed by Discrep, unusual designations, etc.

Submit final report in PDF format.

Submit only final files.

APPENDIX D, OPUS-Projects for FAA General Guidance

The NGS Airport Survey Program is currently developing specific guidance for projects to be processed with OPUS Projects.

The RINEX files for the PACS & SACS are to be uploaded to OPUS using the project keyword and processed together **resulting in one Bfile and one Gfile.**

A Precise Ephemeris must be used in processing. This should be available 12 to 14 days after the last GPS Observation. When an OPUS solution returns, the ephemeris used will be shown in the header information. Verify the EPHEMERIS used is "[precise]"

- Two 4-hour simultaneous observation sessions on the PACS, HARN, and bench marks involved in the survey with a 30-60 minutes break between sessions is required. Observations must be simultaneous with the PACS.
- Two 2-hour observations on the SACS with a 30-60 minutes break between sessions is required. Observations must be simultaneous with the PACS.
- The operator must reset the tripod (take down - set up) between the sessions and document same.
- Start times on subsequent days must be at least 2.5 hours different from the previous start times to incorporate a different satellite geometry.
- If the OPUS-S report is "bad" (low % obs or low % fixed or high overall RMS or any uncertainties > 4 cm) **reoccupy - no exceptions.** OPUS-Projects can, on occasion, "recover" data that OPUS-S could not process as successfully as we might like, but if OPUS-S struggles, chances are significantly higher that OPUS-Projects will too. OPUS-S is your first Quality Control stage: use it.
- Review the video: <https://www.youtube.com/watch?v=KLCDQ8yafY0> to Minimize Errors during GNSS Data Collection.
- Remember that OPUS-S will not allow less than 2 hrs of usable data.
- NGS recommends collecting and processing GPS data at a 10° elevation mask.

Once the project is created, edit the project preferences to the following:

Tropo Model: Piecewise Linear

Tropo Interval: 7200

Constraint Weights: Normal

Network Design: User

Prior to uploading to OPUS, edit (or verify) the Rinex file to follow the standard format of:

AAAADDDS.xxo where AAAA is the unique 4-character ID, DDD is the Julian Day (Day of Year), S is the session (letter or number is fine), and xx is the last two digits of the year of the observation. Ensure the correct information is shown in the RINEX header prior to uploading to OPUS.

As stations are uploaded to OPUS and the Project identifier is specified, the solutions will begin to appear in the OPUS Projects Manager Page. For each solution, verify the ARP heights, Antenna and Receiver information (Name and Serial Numbers), and 4-character IDs are correct.

Investigate any solutions that do not meet the OPUS Projects Quality Thresholds. Obstructed stations are not recommended, but if unavoidable, NGS advises extended observation times/multiple observations. The user's ability to manipulate processing settings are limited in OPUS Projects when compared to PAGE-NT.

Prior to session processing, verify that each CORS automatically selected by OPUS has data for every session in the project. If not, those CORS will need to be manually deselected by the user for each processing session.

In addition, lookup each CORS from the NGS CORS Page and verify that it has either formal Network Accuracy Values (sigmas) or has short term time series sigmas available. For CORS with short term time series sigmas, (see section 5.1) these appear as RMS Error for N, E and U. A screen capture of the time series should be provided in the project report or in a directory aptly named. Exclude any CORS without either one of these values.

All processing sessions must include a distant CORS for tropo de-correlation (between 375 and 900 KM from the hub). The same distant CORS should be used for all sessions. It helps to verify that data is available for the distant CORS from the NGS CORS Page prior to adding it to OPUS Projects.

Use a local CORS as a central Hub in each session (do not use the PACS as a Hubsite). Use the same Hub for all sessions.

After processing each session, verify that the Data Quality Thresholds are met. Investigate any solutions out of tolerance.

In addition to the required deliverables in Section 10 of the AC-16A, provide all OPUS-Projects output files in well-organized folders.

OPUS Solutions

OPUS Projects Session Processing output

123A

123B

124A...

OPUS Projects Network Adjustment

Submitters must provide the OPUS Projects "Project ID" and the Manager's email address. The Manager's Keyword is also a requested deliverable.

Use the output Bfile, Gfile, and Serfil to create the Constrained Adjustment input files.

Only one set of adjustments are needed for PACS & SACS when using OPUS-Projects. The resulting Bfile and Gfile from OPUS Projects must be used as initial input files for the Constrained Adjustments.

The Gfile may require edits to the C Record, cc 59 and 69. To assign the appropriate Receiver Manufacturer Code, use the table in Annex N, pg. N-7 of the FGCS bluebook. Use **extreme caution** when editing the Gfile. Extra characters/deleted characters/mis-alignment can cause Adjust to not read the file properly.

It is very useful to complete all Dfile records for all stations in Windesc. For published control, you can select File > Import > From Internet > By List of PIDs > PUB to import all published control and CORS. Create descriptions for all new stations as well. Use the Serfil to match SSNs to each station.

The Afiles used in the Constrained Adjustments can be created by Windesc as well. To export these files, use File > Export > GPS Project Files. Follow the prompts to get all positions, ellipsoid heights, and network accuracies from the NGS IDB.

AfileHF - Follow the prompts to make the appropriate selections for control. Use the CORS selected as the Hub in processing as the constraint in the Horizontal Free Afile.

AfileHC - Constrain all CORS (except the distant CORS) and the HARN in the Horizontal Constrained Adjustment. (Note: when performing the Horizontal Free Adjustment, some non-CORS and non-HARN stations with published NAD83(2011) Lat/Lon, Ellipsoid Height, and Network Accuracies may be constrained if fitting well in the adjustment. Refer to the Constrained Adjustment Guidelines for specifics regarding each adjustment.

AfileVF - Constrain the orthometric height of only one NAVD88 1st or 2nd Order bench mark. Constrain the Lat/Lon of the Hub CORS.

AfileVC - Constrain the orthometric height for all NAVD88 1st or 2nd Order bench marks. Constrain any applicable Height Mod stations. Constrain the Lat/Lon of the Hub CORS.

Inspect each Afile to verify the correct SSNs, Positions, Ellipsoid Heights, orthometric Heights, and Network Accuracy Standard Deviations (sigmas) (Horizontal Afiles only) were written properly. For CORS with no formal network accuracies, the short term time series sigmas must be hand entered (take care to not misalign any columns)

The Bfile.86 file Windesc will create can be used to add the *25*, *26*, *27*, *70*, and *72* records from the OPUS Projects output Bfile. Use **extreme caution** when editing the Bfile. Extra characters/deleted characters/mis-alignment can cause Adjust to not read the file properly.

Move the Afiles, Bfile.86, Serfil, and Gfile to an ADJUST folder. Keep all input and output Adjust files in this folder. Do not rename or duplicate any of these files. Verify all edits to these file prior to performing the Constrained Adjustments.

Prior to performing the constrained adjustments, it is recommended to compare the Gfile vectors using the Adjust Utility "COMPVECS." This will compare redundant baselines and provide useful information on the repeatability of the vectors.

APPENDIX E, CORS Selection Guidance

This document is meant to serve as a "working document" for coming up with a list of criteria specifically for adding CORS to a project in OPUS-Projects. But the general message should apply to all projects... The quality of the CORS is important.

This is a time consuming process, and simply stated, it is a result of the fact that not every CORS is "equal" or should be used during post-processing.

Note that for this document, a "CORS" is any active station that contributes to the NGS CORS Network and/or the IGS Network.

The following steps are recommended:

1. Tabulate a list of approximately 6 to 15 "candidate" CORS for potential use as control in the GPS survey project. It is best practice to identify these 6 to 15 candidates prior to the survey campaign. Planning and studying the CORS prior to the survey will prevent the blind belief that particular CORS are functioning properly or operational during the survey (which unfortunately is not always reality).
2. It is best practice for the 6 to 15 candidates to meet the following criteria:
 - a. Have computed (i.e., measured) velocities rather than modeled velocities. CORS with computed velocities are tabulated in the "composite coordinate tables" at: ftp://cors.ngs.noaa.gov/cors/coord/coord_08/igs08_geo.comp.txt. A CORS with computed velocities will also have formal network accuracies published on its datasheet.
 - b. Be designated as "operational" or as an "IGS station not CORS" (in other words, it is currently an operational CORS/IGS Reference Station).
 - c. Have network accuracies estimated to be less than ~2 to 3 cm in ellipsoid height and ~1 to 1.5 cm horizontally (95% confidence).
 - d. Have "consistent" data depicted in short-term time-series plots. NGS processes each day of GPS data collected at each CORS, and plots the differences between the resulting coordinates and the published coordinates on short-term time-series plots (in terms of delta northing, easting, and up). CORS with plots that depict significant biases from the published coordinates (more than 2 cm in northing, easting, or up), spikes or data gaps should be avoided.
 - e. A subset of candidates fall within each of the following three zones:
 - a. Zone A – draw a 200-km radius circle around each of the nearby candidates. Candidates with a 200-km circle that encapsulates all of the observed passive marks in a session could serve as a HUB during session processing. Plan which CORS will function as the HUB for each session. Often, a single station can serve as the HUB for the entire project. One HUB should be identified per session, although it is best practice to plan "backup" station(s) as possible use as a HUB during session processing.
 - b. Zone B – draw a 500-km radius circle around the planned HUB from the previous step. Candidates within this circle should be identified as possible use as control during future network adjustments in OPUS-Projects. Ideally, candidates in this zone should

“surround” the survey project area. A minimum of three candidates should be identified, although it is recommended to identify additional backup candidates.

- c. Zone C – draw a 500 to 900 km radius circle around the planned HUB. Select at least one candidate (recommend planning two or three) within this zone for use as a distant CORS. Distant CORS should not be held as control; rather, they are used to de-correlate the wet component of the tropospheric delay modeling within OPUS-Projects. Consider choosing an IGS station within this zone.

4. Once a list of candidates are compiled, download and save their short-term time-series plots. NGS produces these plots for every CORS, but only provides to the public the most recent 90 days. It is best practice to download these plots ~45 days after the middle session of the survey project. In this way, the time-series plot is now “centered” over the time period of the survey project.

5. Using the downloaded short-term time-series plots, select which of the candidate CORS will be ultimately used during post-processing of the static survey campaign.

- a. Using the centered time-series plots, select the candidates with daily solutions that are generally consistently within ~1 cm of the published coordinate (i.e., the red line on the plot). Candidates with large spikes, data gaps, or discontinuities should be rejected. Selecting candidates in this manner will provide some assurance that the published coordinates + velocities at the CORS are in agreement with the daily solutions for the CORS.

- b. Select one and only one candidate to function as the HUB for each session. In most cases, the same HUB can be used for every session in a survey project. It must be within 200 km of all marks in the session. (Note that for large survey projects where the passive marks cover an area greater than 200 km in diameter, it may be necessary to designate more than one CORS to function as the HUB for a particular session.)

- c. Select at least one long-distance CORS for the tropo modeling. Check that there wasn't any extreme weather at this distant CORS (i.e., lightning storms, hurricanes) by checking weather data

- d. During session processing, only hold the HUB with 3-D constraints. During network adjustments, hold all selected CORS except the distant CORS with 3-D constraints.

UPDATES

January, 2018

Introduction. Added more guidance for FAA using OPUS Projects.
 Section 3-3. Network Standard Deviations for CORS computation method update.
 Added link to F-test
 Section 6-1. Sigma values for vertical constraints
 Afile use of MM3YYY in Vertical Costrained Adjustment
 Link provided for Photo Submission Guidelines
 Provide addendum for FAA Opus-Projects
 Appendix E. Provide guidance in selecting CORS for OPUS-Projects and in general.

October, 2016

Section 1-1. Changed the title of the "Approved NGS Survey Proposal Form" to "Approved NGS Survey Proposal Tracking Number."
 Guidance for airport surveys using OPUS-Projects.
 Listed specific metadata to be included in the project report.
 Section 3-6. Guidance for PACS/SACS adjustments was added for newly established SACS when there is an existing PACS and SACS.
 Section 5-1. New requirement: Use MM3YYY in the A-file when running the constrained horizontal adjustment. The Y in cc6 allows the program to write non-shifted constraints to the output bfile.
 Section 5-3. The Geoid Model example was updated to Geoid12B.
 Section 8. Identifying vertical no-check stations. Vertical orthometric height no-checks must be indicated in the *86* record cc 5 rather than the *80* record.

July, 2015

Change the computation of horizontal and vertical project error scale factors, use of variable weights on constrained stations, determination of network and local accuracies in program ADJUST.
 Add new files to samples.zip. Update adjust_supplemental.txt. Include NOAA Technical Memorandum NOS NGS-47. Remove reference to superseded sections of the FGCS Bluebook.

Add specifications and links for OPUS-Projects. OPUS-Projects can now be used to create B- & G-files for input into ADJUST.

November, 2012

Add new procedures to scale the project, weight the constraints, and compute local and network accuracies. Add examples in body. Add new sample files to sample.zip.

December, 2010

Remove confusion of when to run Geoid. Clean up some confusing language. Add information about description processing.

February, 2010

Delete section 2-7 about running Geoid [before any adjustments]; leave this step only in section 5-3 [after good positions have been obtained through the horizontal adjustments].

October 2009

Add information about rejecting a vector; include example Gfile--p. 8 of document, section 4-2.

January 2009

Rewrite to address only GPS projects.

Delete references to scaling project.
Delete programs only available for in-house users.
Delete reference to programmers for each software program. Delete
APPENDIX B-Processing Outline (duplicate of step-by-step) Delete
most references to in-house processing for loading.
Include ATTACHMENT 1-step-by-step (revised)

November 2004

Changes in procedures resulting from update to Adjust to identify ellipsoid height constraints.
Changes to text to clarify procedures and other instructions.
New contact for guidelines.
Refer to Bluebook for orbit codes.
Refer to Bluebook for detailed project report instructions.

February 2003

Remove references to OBSDESED; program is obsolete.
Added information to Appendix A identifying which programs are appropriate for in-house use, and which programs were required for project submission.

Update Appendix A, Adjustment Processing Programs.

July 2002

Recommended filenames removed since they are inconsistent with other documentation and therefore confusing.

Appendix describing description processing removed. These procedures are no longer used since new description formats have been in place. Refer to instructions which come with WDDPROC software.

Add Solution Coordinate Reference System Codes 21 and 22 to Section One.

September 2000

Section 7, step added to process Adjust using a-posteriori standard deviation of unit weight for A- and B-order projects to assure the accuracies are computed correctly.

Input Bfile name changed from final.bfl to cons1.bfl.
Add Solution Coordinate Reference System Codes 18-20 to Section One.