



Standard Data File Formats for GNSS, Total Stations, Automatic Levels, and Relative Gravimeters

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Outline

1. Background on why we need standard file formats
2. Problem statement and objectives
3. RINEX 3 as standard for raw GNSS data
4. Other XML-based file formats as standards
 1. GVX – GNSS vectors
 2. CVX – Classical (angles/distances)
 3. LVX – Leveling
 4. RGX – relative gravity

Why Standard File Formats?

- Differing instrument manufacturers output data in varying file formats (often proprietary, closed-source)
- Standardization benefits:
 - Broadens use; easier to work with by others who will use the data
 - Easier to share with others
 - Reduces the need to convert from one format to another
 - Data in proprietary format can be converted to open, standard format
 - Increases likelihood critical metadata is captured and accurate; significant figures are preserved
 - Lengthens the preservation of the data
 - Can be made machine-readable

Problem Statement

NGS is developing:

1. **M-PAGES** – baseline processing engine for multi-GNSS data

- M-PAGES provides its best solutions with RINEX 3
- RINEX 3 is the international standard for raw GNSS data, and many IGS stations only provide RINEX 3 files
- **But the NOAA CORS Network currently archives data in RINEX 2, and many current workflows at NGS process RINEX 2 data files**

2. **OPUS** – software for managing, processing, and adjusting survey data

- (Note M-PAGES will become the baseline processing engine in OPUS)
- OPUS-Projects v. 5 supports GNSS vectors, such as Real-time Kinematic (RTK) vectors
- OPUS v. 6 will support survey data from total stations, automatic levels, and relative gravimeters
- **But there is a lack of a well-accepted, industry-wide standard file format for GNSS vectors, total stations, levels, and gravimeters**

Objectives

1. Adopt RINEX 3 as the standard file format for raw GNSS data
 - Require submission/uploading of RINEX 3 data files to NGS

2. Develop new standard file formats:
 - GVX: GNSS Vector Exchange Format
 - CVX: Classical Vector Exchange Format (angles, distances)
 - LVX: Leveling Vertical Exchange Format
 - RGX: Relative Gravity Exchange Format

Background on RINEX 3

- Originally released in 2007
- The international scientific standard for exchanging raw GNSS data
- Endorsed by the IGS and RTCM
- Actively maintained and updated (current version is 3.05)
- Supports all GNSS signals and constellations
- Enables unambiguous use of all observables and application of modern GNSS products (e.g., Bias-SINEX)
- M-PAGES is designed to best support RINEX 3 data files, although it can also process RINEX 2 data files.
 - *If you want the best multi-GNSS solution, you will want to work with RINEX 3*

NGS and RINEX 3

- In the near future (*date to be determined*), NGS will only support RINEX 3 for its products and services which rely upon raw GNSS data, with some exceptions
- NGS will be releasing a Federal Register Notice for notification and public commenting

NOAA CORS Network and RINEX 3

- Each CORS must be capable of providing:
 - RINEX 3 file
 - Binary exchange (BINEX) file
 - Raw proprietary data file
 - NGS will archive the RINEX 3 files at each CORS
 - When necessary, NGS will convert the BINEX file to RINEX 3
 - Raw GNSS data currently stored by NGS will remain in its earlier version of RINEX (no up-conversion)
- For QC purposes and/or when communication link is too slow to upload RINEX 3 directly
- For QC purposes

OPUS and RINEX 3

- NGS will recommend and encourage use of RINEX 3 for OPUS
 - Provides the best multi-GNSS solutions
- NGS will continue to allow use of RINEX 2 in OPUS for legacy data and equipment
- NGS will discontinue support of non-RINEX data submissions to OPUS

Development of XML-Based Standard File Formats

XML-Based Standard File Formats

| Measurement Type | File Format | File Type | Current Status | Use at NGS |
|--------------------------------------------|-------------|-----------|---------------------------------------------|-----------------------------|
| Reduced GNSS data (GNSS vector) | GVX | XML | Released final version 1.0 on 2/04/2021 | OPUS-Projects v.5, OPUS v.6 |
| Differential leveling (height differences) | LVX | XML | Under development. Version 0.3 under review | OPUS v.6 |
| Classical (angles, distances) | CVX | XML | Under development. Version 0.3 under review | OPUS v.6 |
| Relative gravity (gravity differences) | RGX | XML | Planned for 2022 | OPUS v.6 |

OPUS-Projects v. 5

- Inclusion of previously processed GNSS vectors
 - Single-base RTK vectors
 - Network RTK vectors
 - Vectors processed in other software
- Allows QA/QC of uploaded vectors
- Automatically “weights” uploaded vectors in a network least squares adjustment
- Final adjustment results can be submitted to NGS for publication
- Facilitates collection of RTK data on bench marks; helps with building transformation tools for the modernized NSRS
- Released to Beta for external testing. Available at:
<https://beta.ngs.noaa.gov/OPUS-Projects/OpusProjects.shtml>
- Webinar scheduled for May 20, 2021

GNSS Vector EXchange Format (GVX)

Website: <https://www.ngs.noaa.gov/data/formats/GVX/index.shtml>

- Detailed documentation
- Schema (XSD)
- Example vector file

GVX is written in Extensible Markup Language (XML)

- Designed to store and carry data in plain text format
- Flexible representation of arbitrary data structures
- Extensible – new elements can be added later without breaking applications
- Both machine-readable and human-readable
- Schemas can be used to define “must haves” and “should haves”

GNSS Vector EXchange Format (GVX)

Timeline

- Solicited internal and external feedback for GVX since 8/2019
- Introduced to industry in 10/2019; solicited feedback
- Addressed all comments and feedback
- Released version 1.0 to industry in 02/2021

Some important details due to feedback from industry:

- All start and stop times must be in GPS time
- Distance must be in meters
- Angles must be in decimal degrees
- Follow IGS naming conventions for antenna names
- Follow ISO Geodetic Register for reference systems

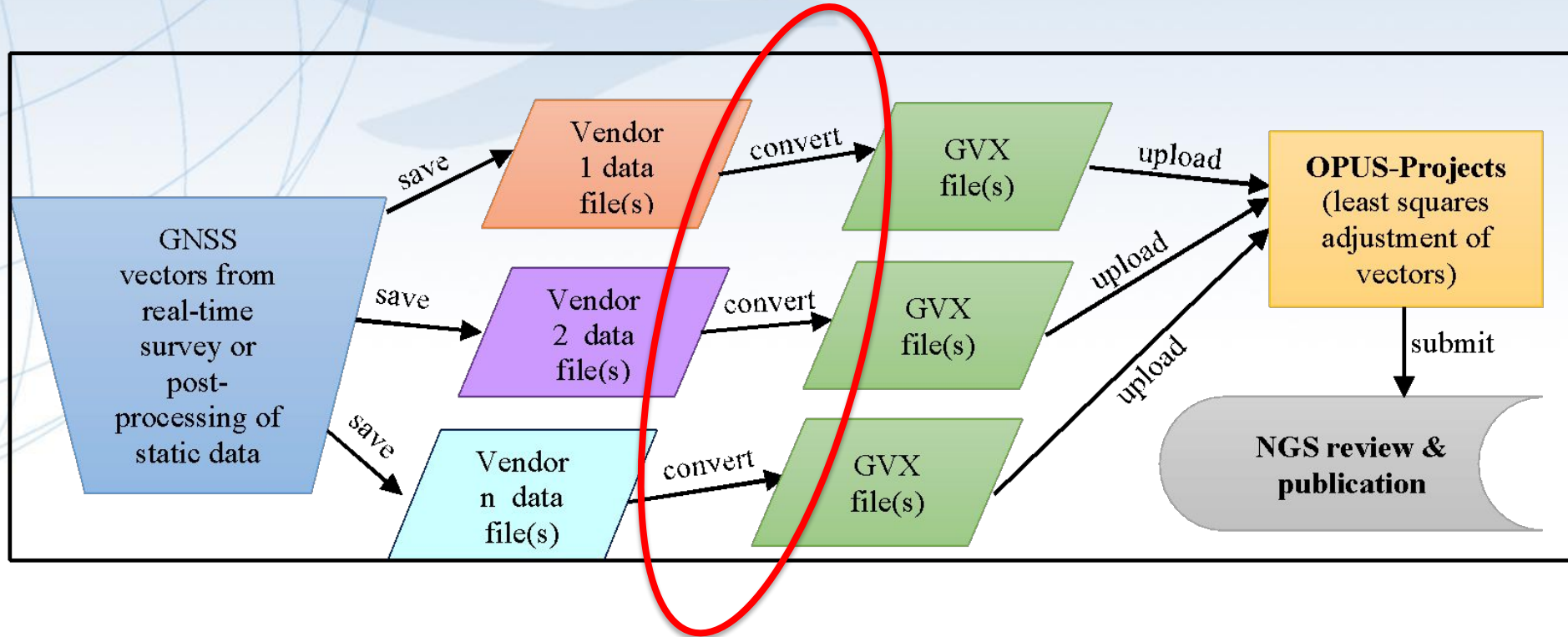
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Industry Invited to Provide Feedback

- Released GVX v. 1.0 released to industry on February 4, 2021
- Over 30 people attended mtg

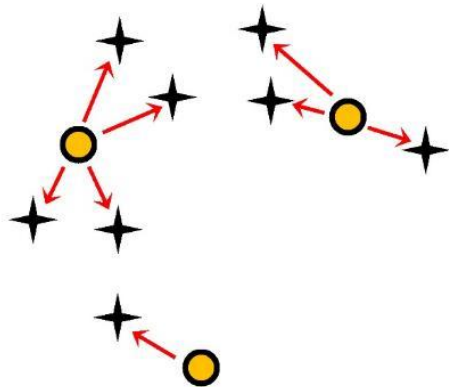


How will NGS use GVX?

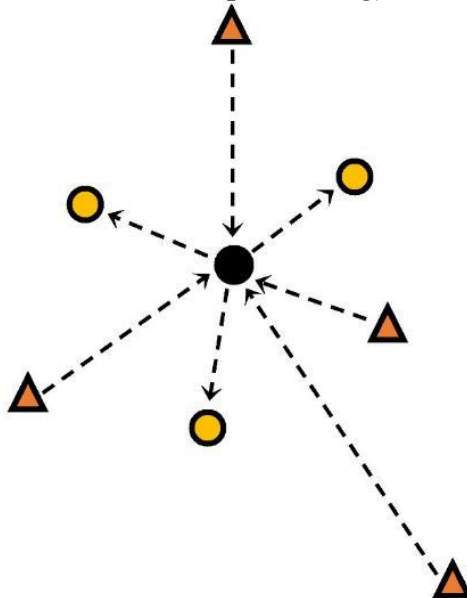


Design for OPUS-Projects and GVX

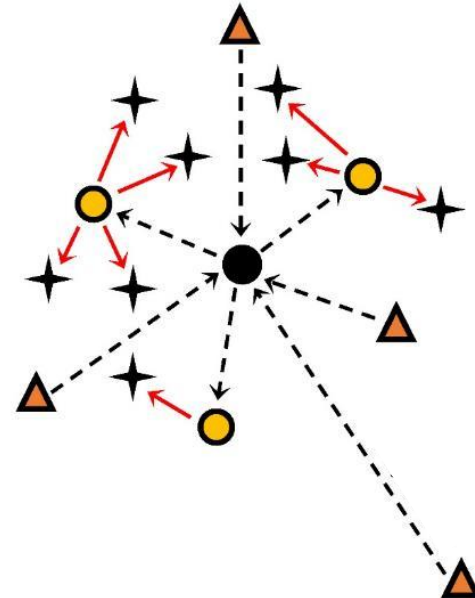
(a) **GVX file** (from RTK survey or baseline processing in other software)



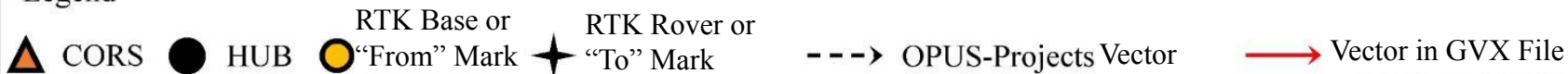
(b) **OPUS-Projects** (from static GNSS session processing)



(c) Combined Hybrid Network



Legend



[Adapted from Weaver et al. 2018]

Step 1: Upload Static GNSS Data Collected at Base Stations; Post-process with CORSs

The screenshot displays the NOAA National Geodetic Survey web interface. The left sidebar contains a 'Controls' panel with various options. The 'Upload GNSS Vectors' button is highlighted with a red box. The main map area shows a map of the Eastern United States with several green dots representing base stations and blue lines connecting them to a central point in Washington, D.C. The right sidebar contains a 'MARKS' list and a 'CORS' list.

Controls

- Preferences
- Project List
- Solutions
- Add Project Tracking Number
- Show File
- Send Email
- Upload Serfil
- Upload Description
- Upload Field Logs
- Refresh PID Information
- Upload GNSS Vectors**
- Set up Adjustment
- Upload Project Report
- Review and Submit to IDB
- Delete Project

LEGEND

MARKS:

- CORS
- GNSS Static Surveys only
- Other GNSS Surveys only
- Mixed GNSS Surveys

STATUS:

- meet preferences
- do not meet preferences
- are not included
- have error

Baselines:

- Network Adjustment
- GNSS Session
- RTK
- Other GNSS

Map **Satellite**

MARKS

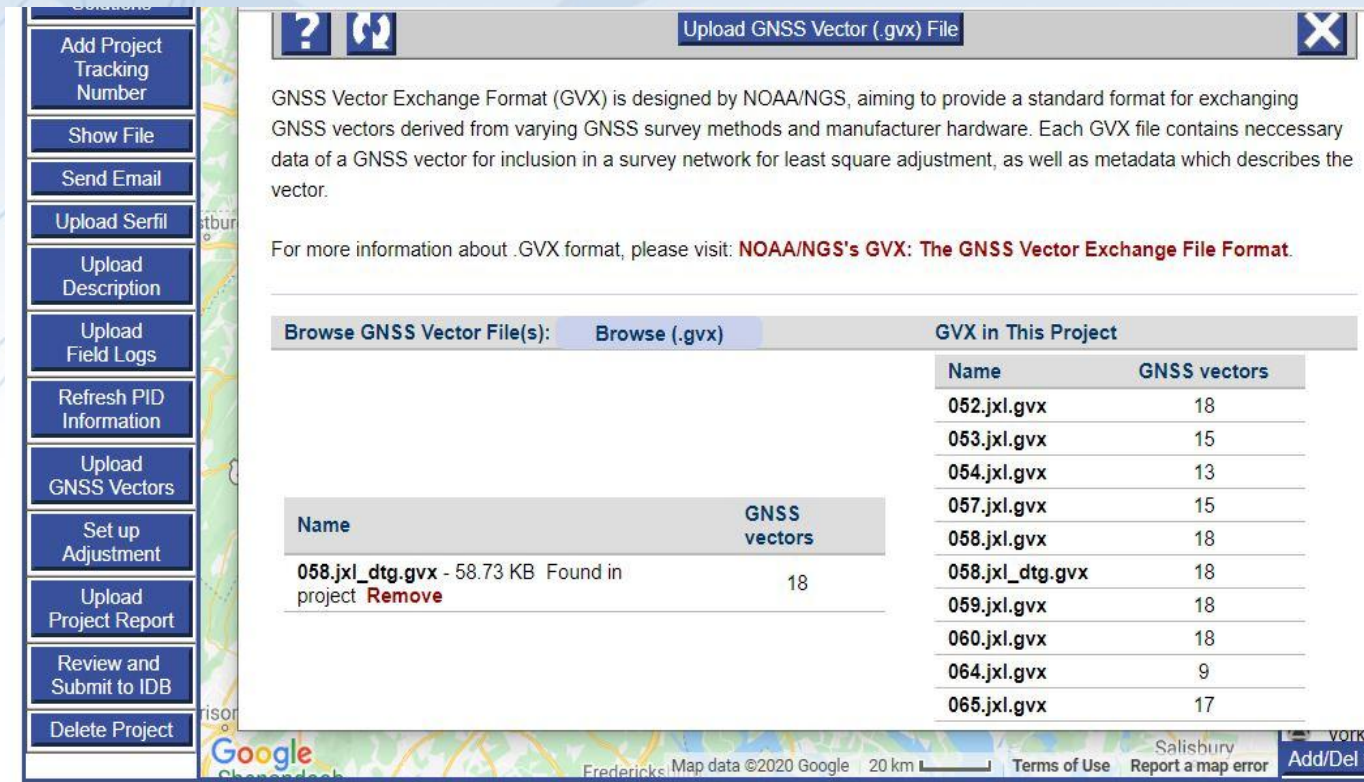
- baco
- bcc1
- dew1
- jmt2
- mas2
- paac
- pacb
- umbc

Add MARKS

CORS

- algo
- corb
- dene
- gode
- pafu
- pass
- vork

Step 2: Upload GVX Files (Vectors)



Upload GNSS Vector (.gvx) File

GNSS Vector Exchange Format (GVX) is designed by NOAA/NGS, aiming to provide a standard format for exchanging GNSS vectors derived from varying GNSS survey methods and manufacturer hardware. Each GVX file contains necessary data of a GNSS vector for inclusion in a survey network for least square adjustment, as well as metadata which describes the vector.

For more information about .GVX format, please visit: [NOAA/NGS's GVX: The GNSS Vector Exchange File Format](#).

Browse GNSS Vector File(s): **Browse (.gvx)**

| Name | GNSS vectors |
|-----------------|--------------|
| 052.jxl.gvx | 18 |
| 053.jxl.gvx | 15 |
| 054.jxl.gvx | 13 |
| 057.jxl.gvx | 15 |
| 058.jxl.gvx | 18 |
| 058.jxl_dtg.gvx | 18 |
| 059.jxl.gvx | 18 |
| 060.jxl.gvx | 18 |
| 064.jxl.gvx | 9 |
| 065.jxl.gvx | 17 |

GVX in This Project

| Name | GNSS vectors |
|-----------------------------------------------------------|--------------|
| 058.jxl_dtg.gvx - 58.73 KB Found in project Remove | 18 |

Step 2: Upload GVX File

- Preferences
- Project List
- Solutions
- Add Project Tracking Number
- Show File
- Send Email
- Upload Serfil
- Upload Description
- Upload Field Logs
- Refresh PID Information
- Upload GNSS Vectors
- Set up Adjustment
- Upload Project Report
- Review and Submit to IDB
- Delete Project

| Baselines | GVX Baseline Statistics | | | | | |
|-----------|-------------------------|-------------|--------------|--------------|----------|----------|
| | vector count | vector used | Span Min (s) | Span Max (s) | PDOP Min | PDOP Max |
| bell-jmt2 | 6 | 6 | 301 | 319 | 1.32 | 1.66 |
| bell-baco | 13 | 13 | 301 | 362 | 1.26 | 2.12 |
| brun-mas2 | 18 | 12 | 301 | 301 | 1.36 | 2.3 |
| calv-dew1 | 16 | 15 | 301 | 333 | 1.36 | 2.2 |
| e087-umbc | 15 | 11 | 301 | 797 | 1.35 | 4.31 |
| e087-mas2 | 3 | 3 | 301 | 301 | 1.65 | 2.34 |
| fran-mas2 | 3 | 3 | 301 | 301 | 1.27 | 1.38 |
| fran-paac | 15 | 13 | 301 | 301 | 1.26 | 3.34 |
| gorf-umbc | 17 | 17 | 301 | 301 | 1.45 | 2.27 |
| n102-bcc1 | 18 | 18 | 301 | 349 | 1.24 | 2 |
| pond-baco | 11 | 7 | 301 | 512 | 1.44 | 2.35 |
| pond-jmt2 | 6 | 6 | 301 | 592 | 1.46 | 2.4 |
| tane-paac | 6 | 6 | 301 | 326 | 1.34 | 2.3 |
| tane-pacb | 12 | 12 | 301 | 325 | 1.49 | 2.09 |

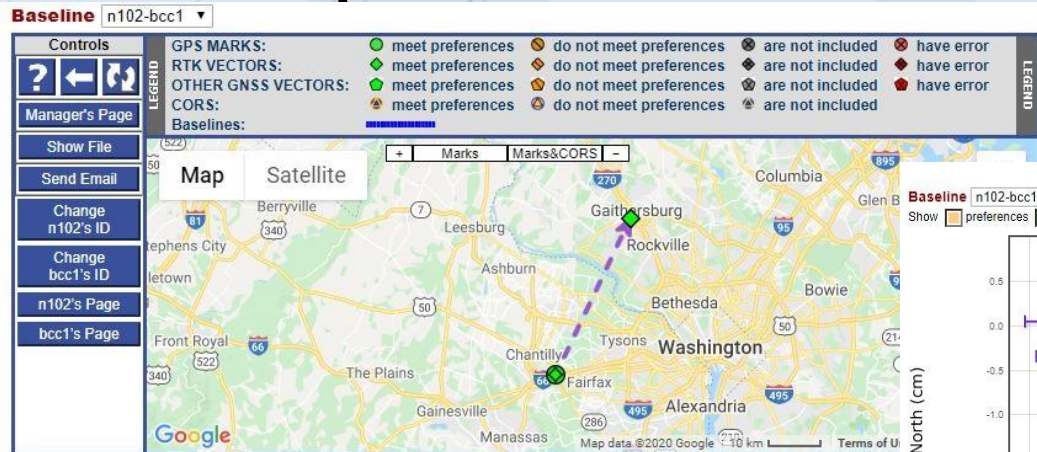
- jmt2
- mas2
- n102
- paac
- pacb
- pond

Add MARKS

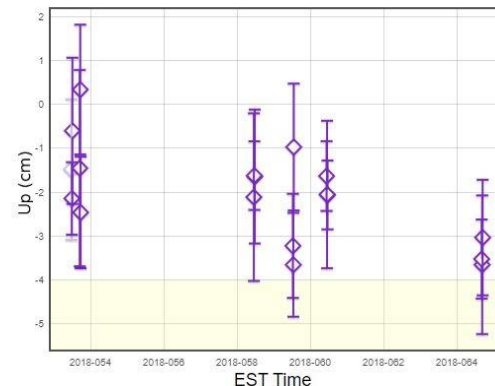
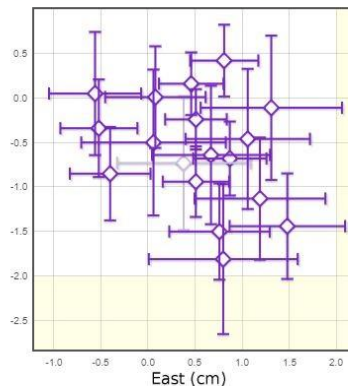
CORS

- algo
- corb
- dene
- gode
- pafu
- pass
- work

Step 3: Review and QA/QC Vectors







Baseline n102-bcc1 **Rover Repeatability Plots**
 Show preferences network session OPUS RTK Other GNSS published.



Baseline n102-bcc1 **Occupation Summary**

| USE | VECTOR | GVX ID | DURATION (s) | SPAN | HARDWARE |
|-------------------------------------|-----------------------------------------|-------------|--------------|------------------------------------------------------------|--------------------------------------------------------------------------------------|
| <input type="checkbox"/> | <input checked="" type="checkbox"/> V5 | 053.jxl.gvx | 301 | Start: 2018-053T11:14:15 EST End: 2018-053T11:19:15 EST | Antenna: Model: TRMR10 NONE S/N: 563146593 Receiver: Model: TRMR10 S/N: 563146593 |
| <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> V6 | 053.jxl.gvx | 301 | Start: 2018-053T11:34:46 EST End: 2018-053T11:39:46 EST | Antenna: Model: TRMR10 NONE S/N: 563146593 Receiver: Model: TRMR10 S/N: 563146593 |
| <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> V7 | 053.jxl.gvx | 322 | Start: 2018-053T11:52:07 EST End: 2018-053T11:57:28 EST | Antenna: Model: TRMR10 NONE S/N: 563146593 Receiver: Model: TRMR10 S/N: 563146593 |
| <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> V13 | 053.jxl.gvx | 310 | Start: 2018-053T16:43:42 EST End: 2018-053T16:48:51 EST | Antenna: Model: TRMR10 NONE S/N: 563146593 Receiver: Model: TRMR10 S/N: 563146593 |
| <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> V14 | 053.jxl.gvx | 301 | Start: 2018-053T17:01:15 EST End: 2018-053T17:06:15 EST | Antenna: Model: TRMR10 NONE S/N: 563146593 Receiver: Model: TRMR10 S/N: 563146593 |
| <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> V15 | 053.jxl.gvx | 301 | Start: 2018-053T17:18:02 EST End: 2018-053T17:23:02 EST | Antenna: Model: TRMR10 NONE S/N: 563146593 Receiver: Model: TRMR10 S/N: 563146593 |

Baseline n102-bcc1 **Solution Quality Indicators**

| USE | VECTOR | GVX ID | ROVER ANTENNA | | ROVER HEIGHT (m) | EPOCHS USED | EPH TYPE | PDOP | SATELLITES USED | TYPE | SOLUTION TYPE | PROCESSOR NAME | MOUNT POINT | LAT (m) | LOn (m) | HGT (m) |
|-------------------------------------|----------------------------------------------------------------------------------------|-------------|---------------|------|------------------|-------------|----------------------------|------|--------------------|-------|---------------|----------------|-------------|---------|---------|---------|
| <input type="checkbox"/> |  V5 | 053.jxl.gvx | TRMR10 | NONE | 2.000 | 301 | Ultra-rapid predicted half | 1.88 | 15=C0:E0:G9:J0:R6 | Fixed | NetworkRTK | Trimble VR3Net | VRS_RTCM3 | -0.000 | -0.001 | 0.002 |
| <input checked="" type="checkbox"/> |  V6 | 053.jxl.gvx | TRMR10 | NONE | 2.000 | 301 | Ultra-rapid predicted half | 1.28 | 15=C0:E0:G10:J0:R5 | Fixed | NetworkRTK | Trimble VR3Net | VRS_RTCM3 | 0.000 | 0.004 | -0.005 |
| <input checked="" type="checkbox"/> |  V7 | 053.jxl.gvx | TRMR10 | NONE | 2.000 | 322 | Ultra-rapid predicted half | 1.45 | 15=C0:E0:G9:J0:R6 | Fixed | NetworkRTK | Trimble VR3Net | VRS_RTCM3 | 0.006 | 0.009 | 0.011 |
| <input checked="" type="checkbox"/> |  V7 | 058.jxl.gvx | TRMR10 | NONE | 2.000 | 301 | Ultra-rapid predicted | 1.30 | 14=C0:E0:G9:J0:R5 | Fixed | NetworkRTK | Trimble VR3Net | VRS_RTCM3 | -0.011 | 0.003 | -0.005 |

Step 4: Combine Post-processed Vectors and Uploaded Vectors (from GVX) in Survey Network for Adjustment

The screenshot displays the NOAA National Geodetic Survey software interface. The main map shows a survey network centered on Washington, D.C., with points connected by lines. The network includes points like Chambersburg, Hagerstown, Frederick, Winchester, Woodstock, Luray, Culpeper, Alexandria, and Baltimore. The interface features a sidebar on the left with various options, a map view, and a list of points on the right.

Baselines: Network Adjustment (green line), GNSS Session (blue line), RTK (purple line), Other GNSS (cyan line).

Map: Map, Satellite.

Left Sidebar:

- Preferences
- Project List
- Solutions
- Add Project Tracking Number
- Show File
- Send Email
- Upload Serfil
- Upload Description
- Upload Field Logs
- Refresh PID Information
- Upload GNSS Metadata
- Set up Adjustment** (highlighted with a red box)
- Upload Project Report
- Review and Submit to IDB** (highlighted with a red box)
- Delete Project

Right Panel:

- Points list: bcc1, bell, brun, calv, dew1, e087, fran, gorf, jmt2, mas2, n102, paac, pacb, ...
- Add MARKS** button
- CORS** list: algo, corb, dene, gode, pafu, pass, vork, ...
- Add/Del CORS** button

Bottom: Map data ©2020 Google, 20 km scale bar, Terms of Use, Report a map error.

Other XML-based File Formats

- GVX sets template for other XML standard file formats
 - CVX = classical (angles/distances)
 - LVX = leveling
 - RGX = relative gravity
- Desire industry to adopt all of these common file formats, and goal is to make OPUS v.6 capable of using them
- Aim to take these files to international community for adoption or inclusion in GeodesyML

CVX: Classical Vector Exchange

1. **SOURCE_DATA**
2. **PROJECT_INFORMATION**
3. **REFERENCE_SYSTEM**
4. **UNITS** (*global definition of units in the file*)
5. **CLASSICAL_EQUIPMENT** (*instrument make/model, white paper specifications, target make/model*)
6. **INSTRUMENT_CORRECTIONS** (*compensator, vertical index, automatic pointing, collimation, etc.*)
7. **POINT**
8. **CLASSICAL_SET** (*weather, ppm, horizontal and vertical angles, distance, sigmas, instrument faces, target offset, measurement mode, distance type*)

LVX: Leveling Vertical Exchange

1. **SOURCE_DATA**
2. **PROJECT_INFORMATION**
3. **REFERENCE_SYSTEM**
4. **VERTICAL_DATUM** (*datum for heights with IDs per ISO Geodetic Registry*)
5. **UNITS**
6. **LEVELING_EQUIPMENT** (*instrument make/model, serial number, white paper specifications, and rod(s) make/model/material, white paper specs., calibration info.*)
7. **COLLIMATION** (*applied collimation value from peg test*)
8. **FIELD_ACCURACY_TEST** (*results of a field test on accuracy of leveling equip.*)
9. **POINT**
10. **LEVELING_SECTION** (*elevation difference, running distance, running imbalance, operator, start and stop time, temp. probes, maximum instrument height, weather, total setups, leveling method, individual setups with backsight, foresight, stadia wires, and reading mode*) □ (NOTE: supports electronic, optical, 3-wire, and micrometer)

Summary

- Modern receivers need to output RINEX 3
 - Requesting industry to adopt these XML-based file formats
 - GVX: GNSS Vectors (released in 02/2021) ← Desire industry to build convertors to GVX
 - CVX: Classical (angles/distances)
 - LVX: Leveling
 - RGX: Relative Gravity
 - Schemas will be written for all
 - Feedback and ideas are welcome!
- Plan to release in 2022;
desire industry to
provide feedback

Questions?

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