



OPUS-Projects and Future Developments

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Geodesist, National Geodetic Survey

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Who is this guy?

Dan Gillins, Ph.D., P.L.S.

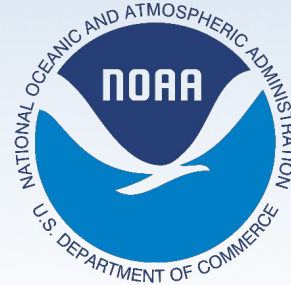
- Geodesist, Observation & Analysis Division, National Geodetic Survey, (2016 – present)

Education

- B.S., M.S., Ph.D., Civil Engineering

Experience

- Assistant Professor, College of Engineering (2013 – 2016)
- Land Surveyor, Survey Technician (2002 – 2012)



Greetings from Home!

Literally every parent trying to work remotely right now

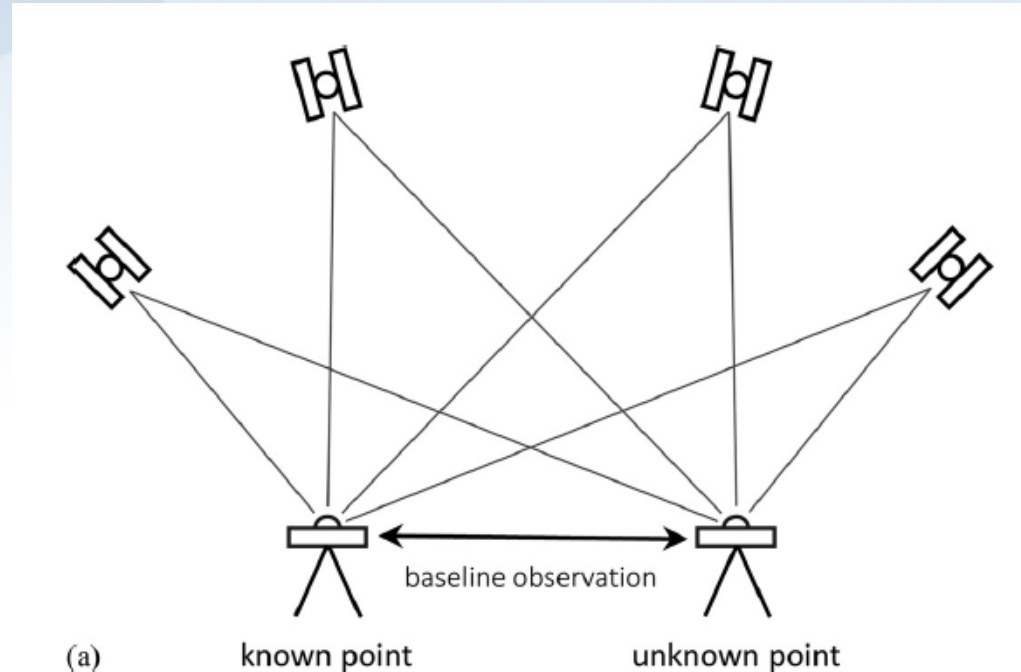


Outline

1. Background on OPUS-Projects
2. Overview on ongoing and future developments of OPUS-Projects
3. Real-Time Kinematic (RTK) Technique and Real-Time Networks (RTNs)
4. GNSS Vector Exchange (GVX) File Format
5. Details on development to OPUS-Projects “for RTK”
6. Future Plans

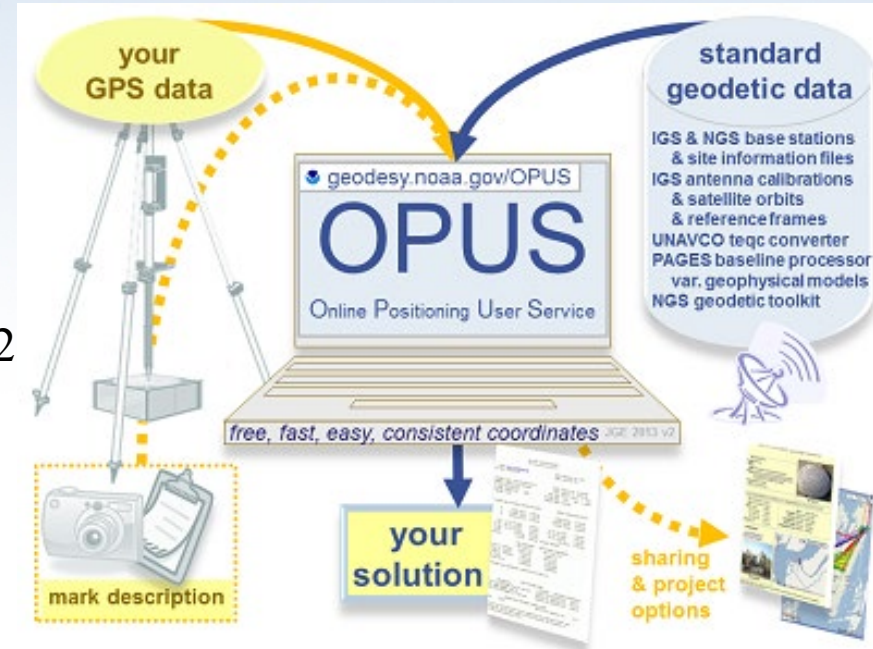
GNSS Errors

- Clock biases
- Orbit errors
- Tropospheric delays
- Ionospheric delays
- Dilution of precision



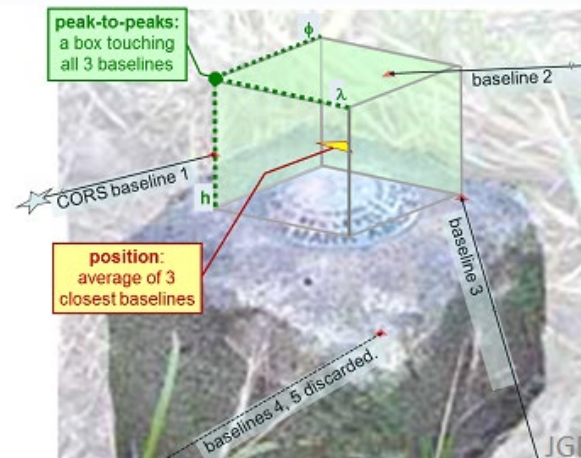
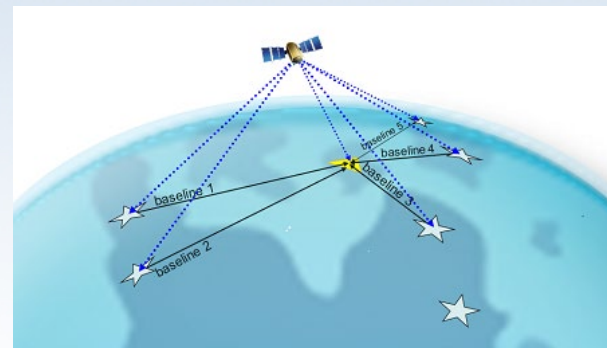
Online Positioning User Service (OPUS)

- **OPUS-Static – (2001)**
 - L1/L2 observables
 - Single occupation on a mark, ≥ 2 hours
 - GPS-only (currently true for all versions of OPUS)
- **OPUS-Rapid Static – (2007)**
 - Single occupation on a mark, $15 \text{ min} < T < 2$ hours
 - L1/L2 observables and C1 or P1 and P2
- **OPUS-Projects – (~2012)**
 - Multiple occupations on numerous marks
 - Survey network least squares adjustments
 - Static GPS survey campaigns



How does OPUS-S work?

- Uses software called PAGES for processing baselines
- Uses single-baseline solutions from 3 of 5 “best-fitting” CORS. The 3 CORS are held to their published positions
 - Being closest to the user’s site.
 - Having common satellite visibility with the user data.
 - Having low multipath measures
- Coordinates at your station are derived by simply averaging the results of the 3 baselines
- Peak-to-Peak errors are given in the solution

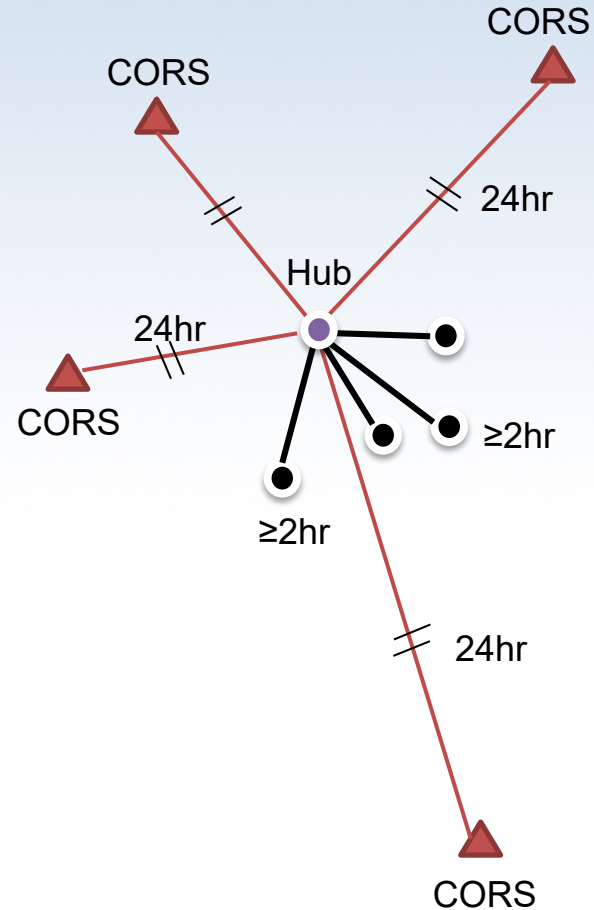


OPUS-Projects

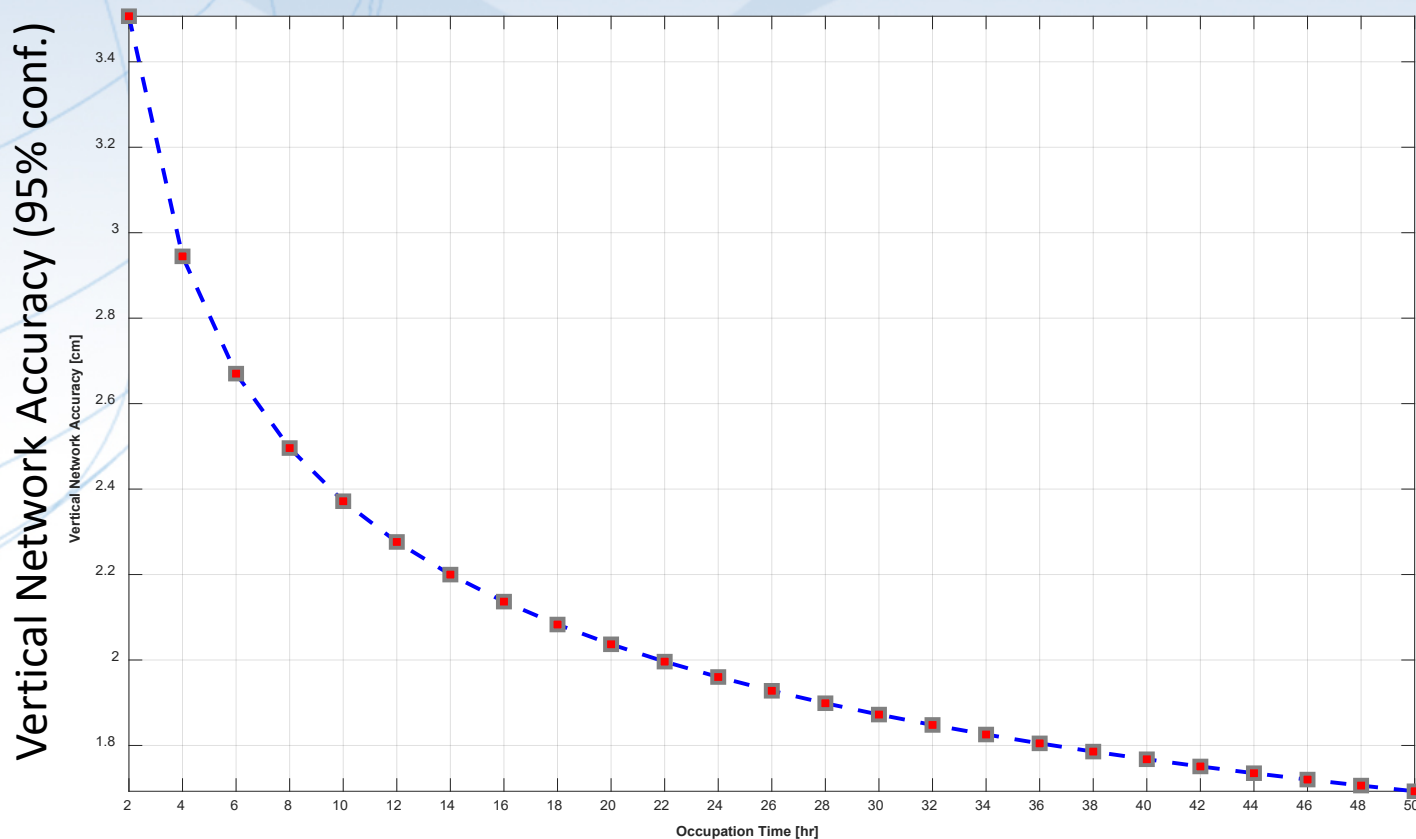
- Free, web-based software
 - Online training available
- Designed for managing campaign-style GPS surveys
 - Multiple repeat occupations of several marks
- Ability to add GPS data from NOAA CORS Network
- Session baseline processing using PAGES
- Customize tropospheric delay models, elevation cutoff masks, constraint weighting
- Network least squares adjustments of multiple sessions
- Choice of reference frames and geoid models
- Currently requires ≥ 2 -hour static GPS observation for post-processing

OPUS-Projects

- "Hub design" recommended by NGS
- Hub to project marks recommended to be ~100 km
- Use multiple CORSs
- Use one very long baseline from hub to CORS (improves tropospheric modeling)
- OPUS-Projects does session baseline processing

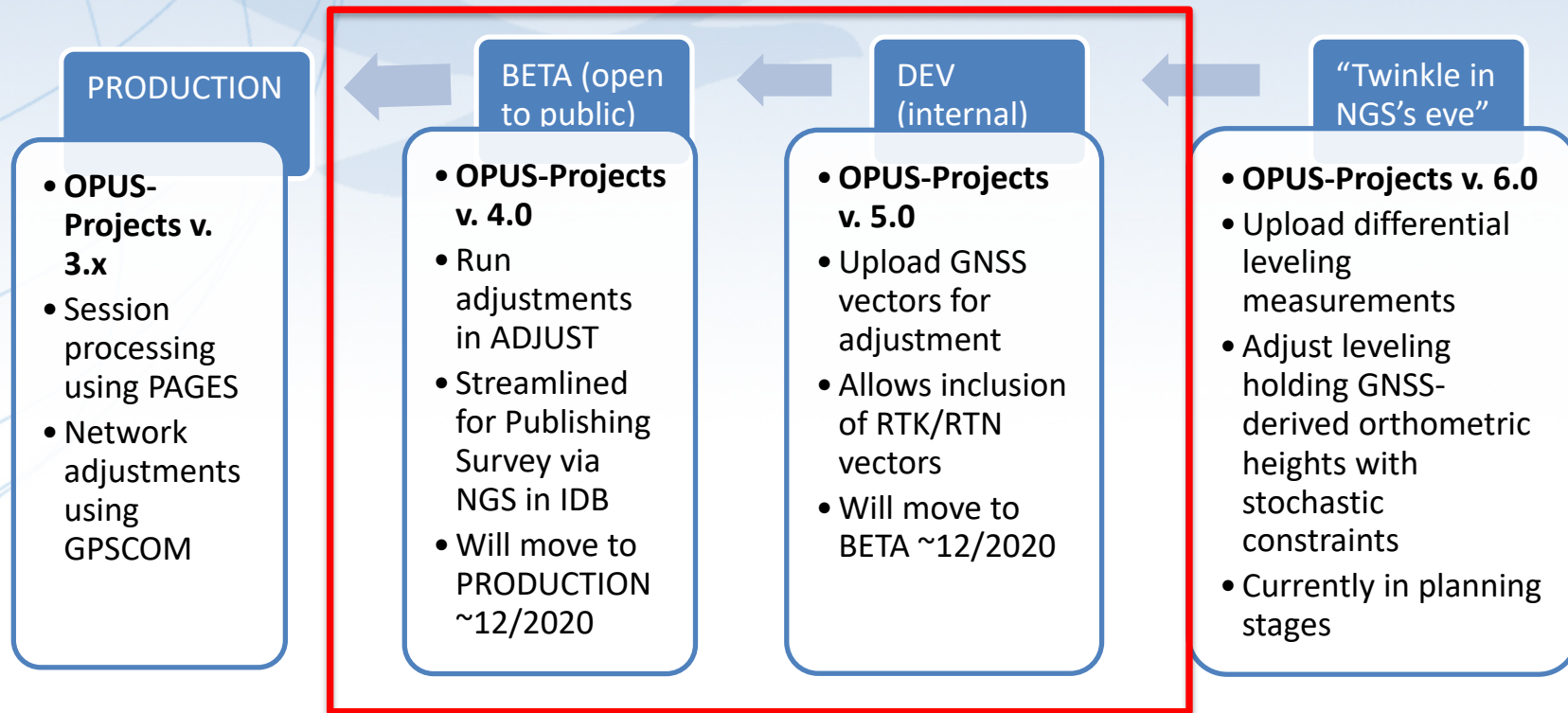


Vertical Accuracy, OPUS-Projects



[Park et al. 2018]

Development Phases of OPUS-Projects



OPUS-Projects v. 4.0 (“BETA OP”)

<https://beta.ngs.noaa.gov/OPUS-Projects/>

- Newest version of OPUS-Projects available to public
- Buttons for users to upload photos and descriptions
- Prepares files for publication (Blue Booking)
- Ability to run ADJUST within OPUS-Projects
- Button to submit survey to NGS for review and publication in NGS Integrated Database
- User manual will be released soon!

Beta OPUS-Projects

Results From ALL ADJUSTMENTS

Controls

Legend: MARKS: ● meet preferences ○ do not meet preferences ⊗ are not included ⊗ have error
 CORS: ● meet preferences ○ do not meet preferences
 Baselines: —

Map Satellite

Legend: MARKS: ● bld3 ● bred ● wthr

Add MARKS

CORS: ▲ loy2 ▲ loyo ▲ ncdu ▲ ncga ▲ ncja ▲ pafu

Map Satellite

Woodis Ave 2nd St Front St Elizabeth-River-Trail W Brambleton Ave Elizabeth-River-Trail

Legend: MARKS: ● bld3 ● bred ● wthr

Add MARKS

CORS: ▲ loy2 ▲ loyo ▲ ncdu ▲ ncga ▲ ncja ▲ pafu

Preferences

Project List

Solutions

Add Project Tracking ID

Show File

Send Email

Upload Serfil

Upload Description

Upload Field Logs

Refresh PID Information

Set up Adjustment

Upload Project Report

Review and Submit to IDB

Delete Project

OPUS-Projects v. 5.0 (“OP4RTK”)

- Previously processed GNSS vectors
 - Single-base RTK vectors
 - Network RTK vectors
 - Vectors processed in other software

*Scheduled for
public release
in Dec. 2020*

Brief on Terminology

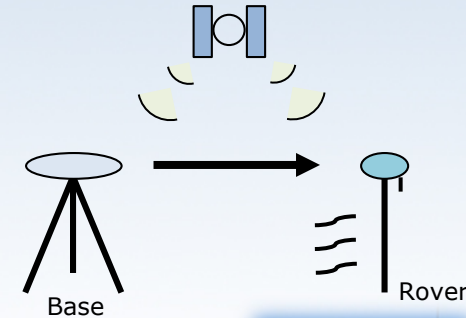
- **Baseline:** the line connecting two GNSS marks
- **Vector:** a mathematical representation of a measurement of the baseline, expressed in delta X, Y, Z components (along with error estimates)

So, one baseline measured repetitively seven times will have seven vectors

Real-Time Kinematic (RTK) Surveying

Single-Base RTK

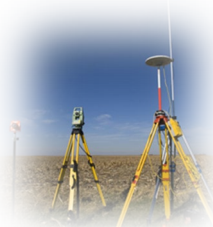
- Single “base” or reference station
- Transmits precise coordinates and GNSS observables to moving “rover” using wireless communication
- Baselines processed in “real-time” and stored on a data collector
- Produces vectors from base to rover
- < 20 km baseline length



www.alberding.eu



www.gcfarm.com



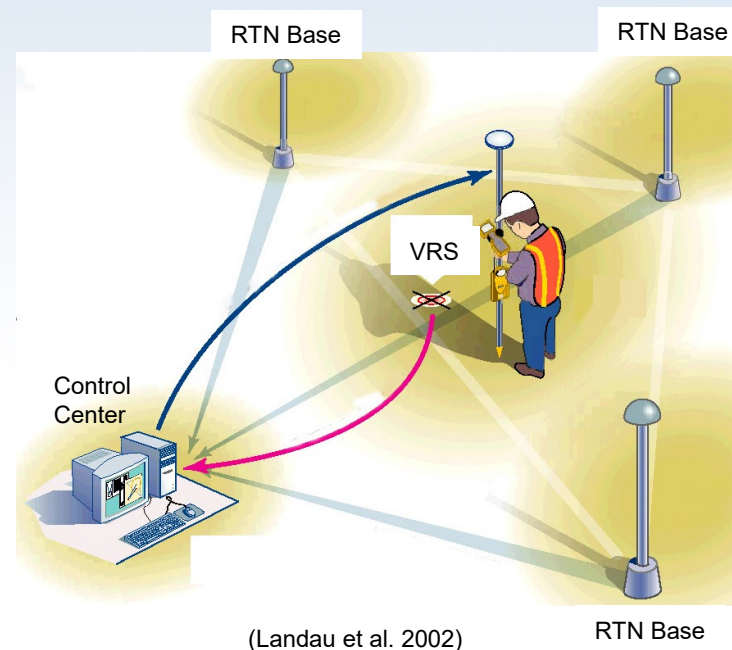
www.steckbeck.net



www.positionpartners.com.au

Real-Time Networks (RTNs)

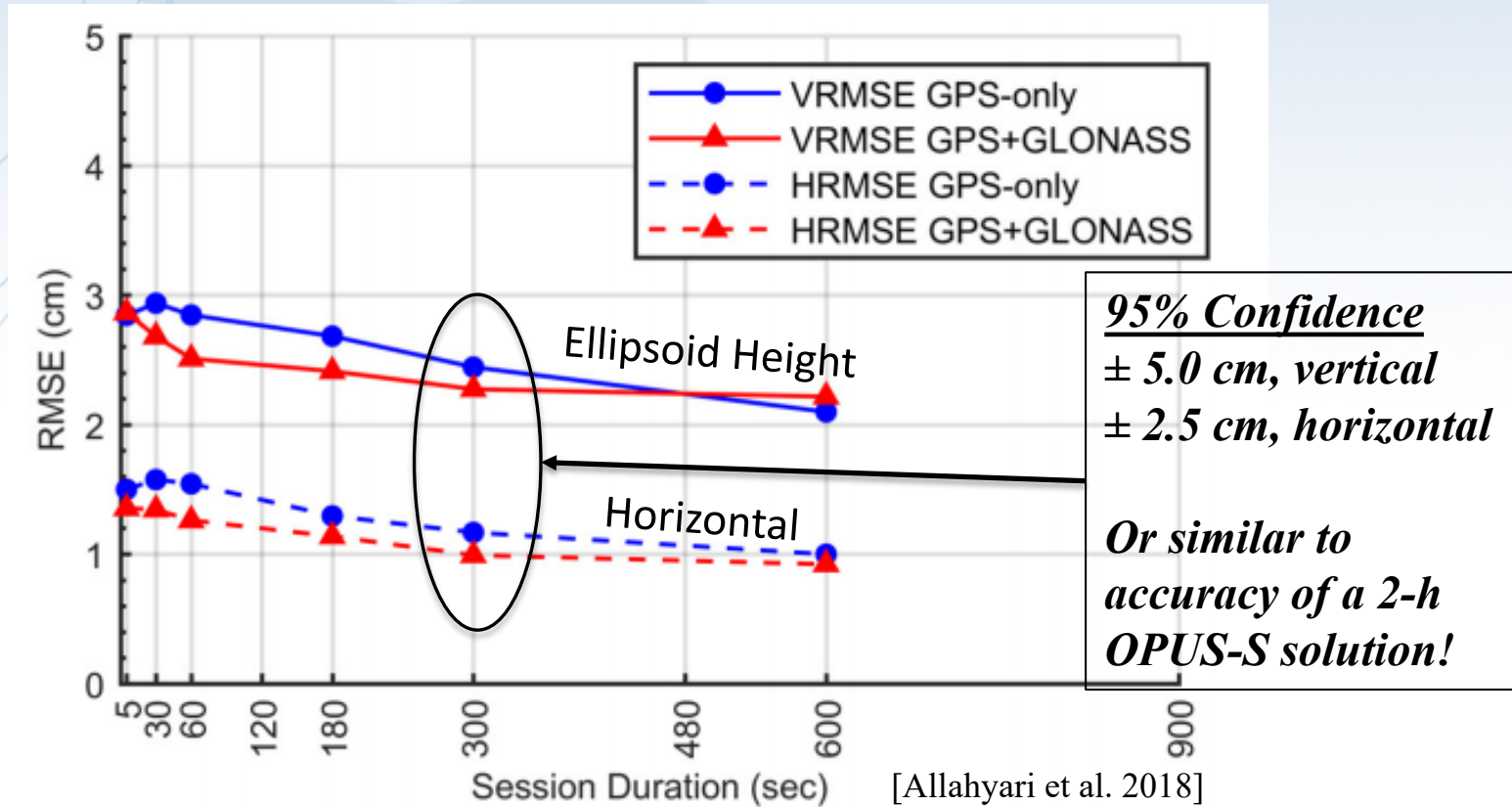
- Network of “permanent” GNSS base stations
 - < 70 km spacing between base stations
 - < 40 km maximum baseline length
- Atmospheric and orbital corrections are transmitted to rover via mobile data link



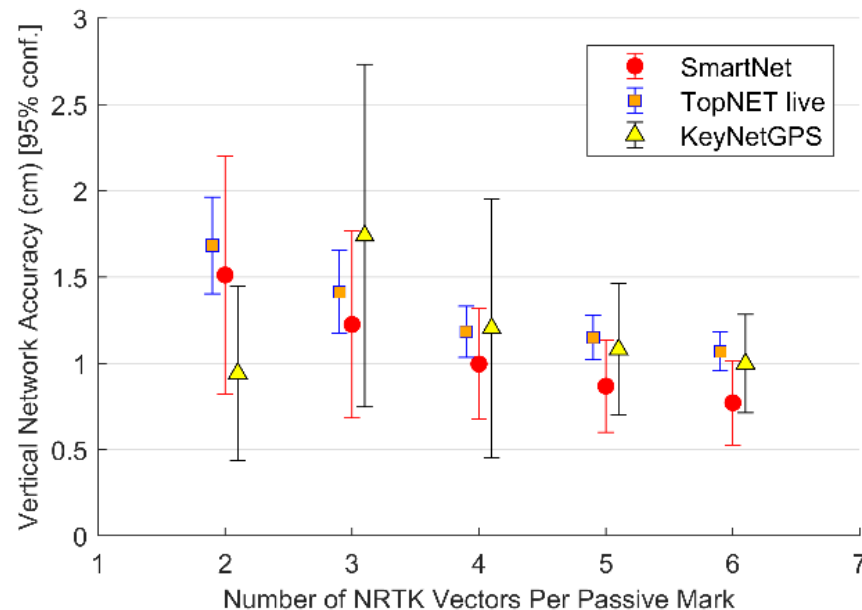
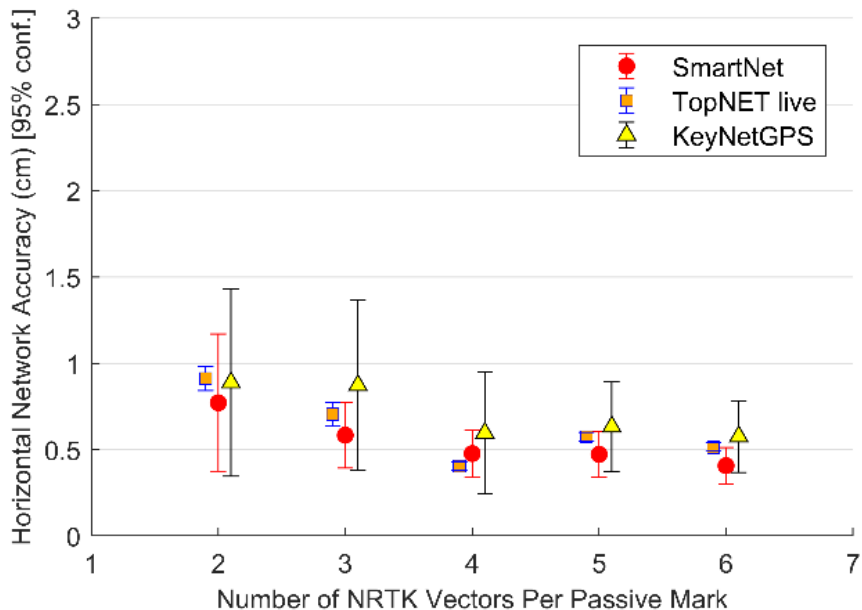
Pros and Cons of RTNs

Benefits	Concerns
FAST. Could reduce field observations from several hours to just a few minutes	RTN may not be aligned with the National Spatial Reference System
Can evaluate data quality in real time	Ideally, survey should be tied to NOAA CORS Network
Easy to obtain additional observations	More prone to multipathing errors
Only a single receiver (i.e., rover) is needed during a session	Baselines must be kept short (i.e., < 40 km)

Empirical Evaluation of the Accuracy of RTNs



Formal Error Propagation via Survey Network Least Squares Adjustment



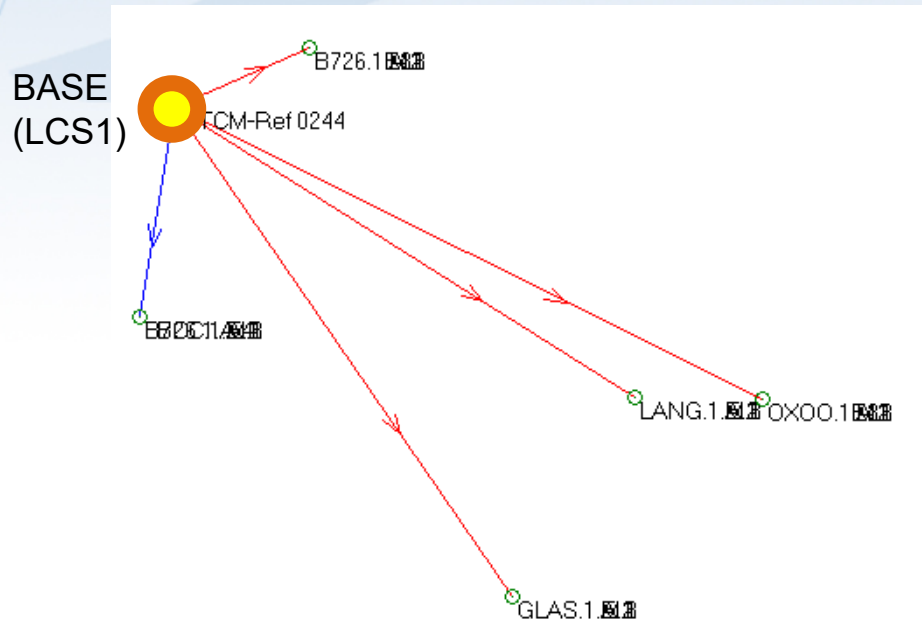
Problem Statement

- NGS does not have a simple mechanism for accepting data resulting from Real-time Kinematic (RTK) surveys
- RTK surveys are very popular (more than static surveys)
 - Highly efficient—measurements done in seconds to minutes
- RTK vectors and metadata are generally stored in a proprietary format
- There lacks an industry standard file format for any type of GNSS vector, whether the vector was derived in real-time or by post-processing

Objectives

- Develop a standard file format for GNSS vectors
 - Open-source, machine-readable, human-readable
 - Must include all of the necessary information for performing a least squares adjustment
 - Must include important metadata for quality control
- Develop OPUS-Projects so that GNSS vectors from RTK surveys can be uploaded, checked, adjusted, and submitted to NGS

Example: Conduct RTK Survey and Download Data



Store your RTK measurements as vectors and not just points!

Example: Process Base Data in OPUS-Projects

The screenshot displays the OPUS web interface. On the left is a 'Controls' sidebar with various project management options. The main area shows a map of Washington and Oregon with several base stations marked. A red box highlights a cluster of four green 'meet preferences' markers near Corvallis, Oregon. A red-bordered inset map provides a detailed view of this network, showing a central base station (yellow triangle) connected to four other stations (green circles). A table in the top right corner summarizes the session data for these stations.

Sessions			MARKS
2016-188	2016-189	2016-190	
A	A	A	Ics1
●	●	●	Ics3
●	●	●	p374
●	●	●	p375

LEGEND
MARKS: ● meet preferences ● do not meet preferences ⊗ are not included ⊗ have error
CORS: ▲ meet preferences ▲ do not meet preferences ⊗ are not included
Baselines: ————

Controls: ? ← ↻
 Preferences
 Project List
 Solutions
 Add Project Tracking ID
 Show File
 Send Email
 Upload Serfil
 Upload Description
 Upload Field Logs
 Set up Adjustment
 Upload Project Report
 Review and Submit to IDB
 Delete Project
 Upload Vectors

Example: Upload RTK Vectors to OPUS-Projects

The screenshot displays the OPUS web interface. On the left is a 'Controls' sidebar with various menu items. The main area shows a map of a region in Ohio with several green circular 'User Marks' and a network of blue and red lines representing RTK vectors. A legend on the right explains the symbols: a yellow triangle for CORS, a green circle for User Mark, a blue line for Processed Vector (OPUS-Projects), and a red dashed line for Uploaded Vector. Two items in the sidebar, 'Set up Adjustment' and 'Review and Submit to IDB', are circled in red.

Controls

- ?
- ←
- ↺
- Preferences
- Project List
- Solutions
- Add Project Tracking ID
- Show File
- Send Email
- Upload Serfil
- Upload Description
- Upload Field Logs
- Set up Adjustment
- Upload Project Report
- Review and Submit to IDB
- Delete Project
- Upload Vectors

LEGEND

- CORS
- User Mark
- Processed Vector (OPUS-Projects)
- Uploaded Vector

But but but...

Differing GNSS equipment and software vendors output data in varying file formats (often proprietary, closed-source)

Examples of Standard File Formats

- **RINEX** = Receiver Independent Exchange Format
 - Version 1 proposed in 1989 by Werner Gurtner (University of Bern)
 - Version 2 proposed in 1990 by Gurtner and Gerald Mader (NGS)
 - Aimed for the easy exchange and processing of raw GNSS data
 - GNSS carrier-phase and pseudorange (code) measurements, and time
- **LAS** = LASer format
 - Proposed by the American Society of Photogrammetry and Remote Sensing (ASPRS) in 2003
 - Open format used for exchanging point cloud data

Why Standard File Formats?

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

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”

Industry Invited to Provide Feedback



GVX Remains Under Development

- Received feedback from numerous individuals, companies, governments, and organizations
 - Revising GVX to address this feedback
- Desire to make it compatible with GeodesyML (international efforts)
- Stay tuned for updates!

GNSS Vector EXchange Format (GVX)

1. SOURCE_DATA

- Information on the source of the GVX file, such as the name of the original data file, conversion software to make the GVX file, etc.

2. PROJECT_INFORMATION

- Information on the survey project, points of contact, start and end date of the survey

3. REFERENCE_SYSTEM

- Specifies the reference frame and units for data in the file

GNSS Vector EXchange Format (GVX)

4. EQUIPMENT

- Defines all GNSS equipment utilized to create the data in the file, including all antennas and receivers, serial numbers, firmware versions, antenna phase center calibration models

5. SURVEY_SETUP

- Information on how the vectors were collected or derived, such as settings for single-base RTK, RTN settings, post-processing settings, etc.
- Operator name(s)

GNSS Vector EXchange Format (GVX)

6. POINT

- Geodetic coordinates for all start and end points of every vector
- Names/codes
- Antenna heights
- Point type (fixed/float/code/keyed-in, etc.)

GNSS Vector EXchange Format (GVX)

7. GNSS_VECTOR

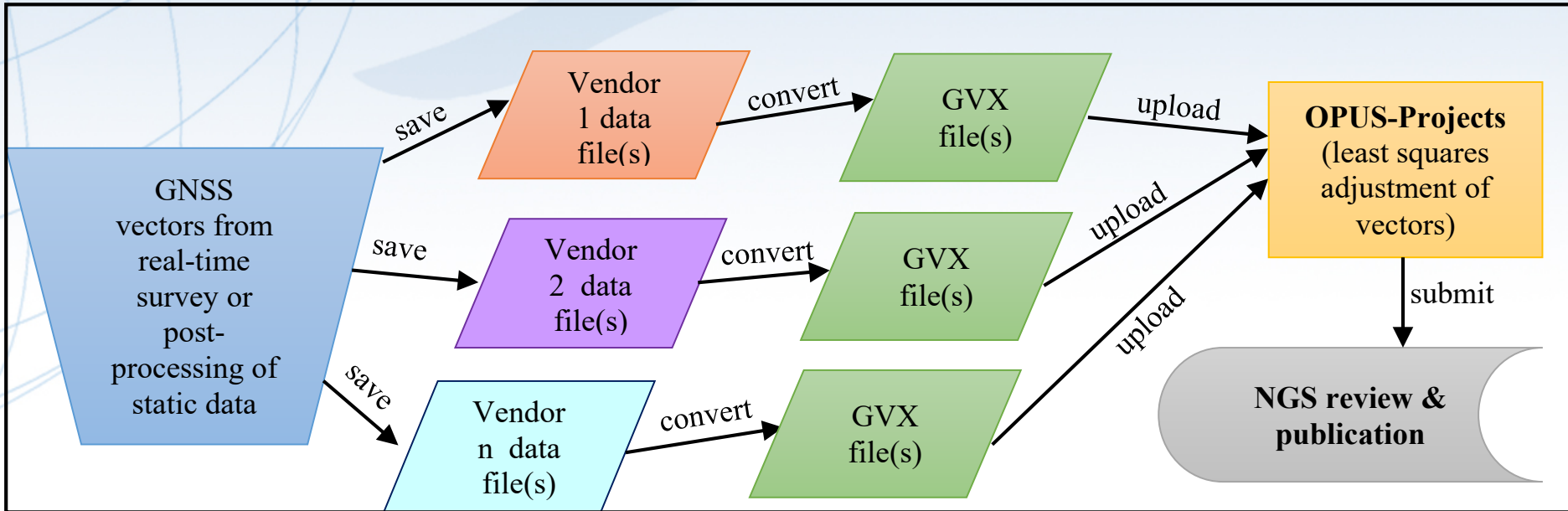
- IDs for starting and ending points of the vector
- ID for survey setup
- Start and end time of the observation
- Differential, mark-to-mark vector components (ECEF) or dX, dY, dZ
- Variance and covariance values
- QA/QC metadata
 - DOP, RMS, mask settings, number of satellites used by GNSS type, orbit types and sources, RTCM age

And and and...

Although the original objective was to develop tools for RTK surveys, GVX supports all types of GNSS vectors

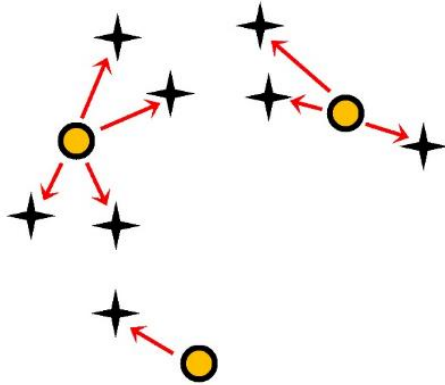
- Real-time vectors
- Post-processed vectors

GVX Flow Chart

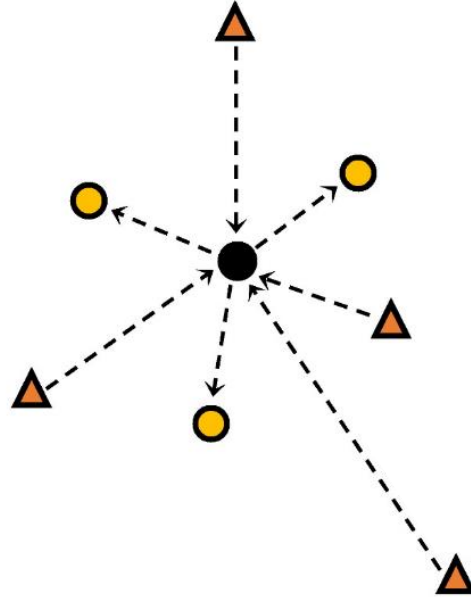


Design for OPUS-Projects and GVX

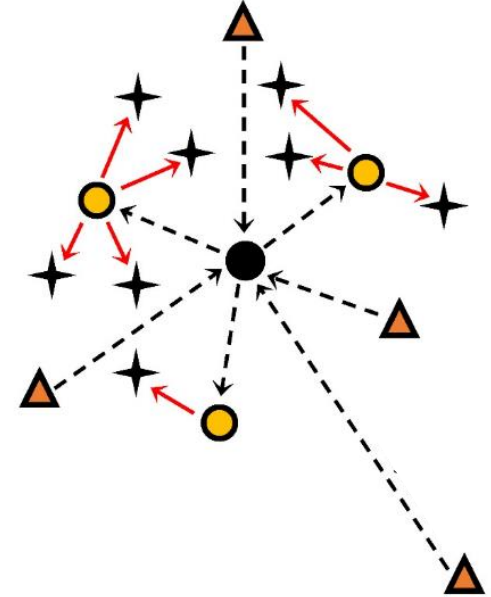
(a) **GVX file** (from RTK survey or baseline processing in other software)









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



(c) Combined Hybrid Network



Legend

-  CORS
-  HUB
-  RTK Base or "From" Mark
-  RTK Rover or "To" Mark
-  OPUS-Projects Vector
-  Vector in GVX File

[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 software interface. The main map shows the Washington, DC metropolitan area with several GNSS base stations marked by green circles and connected to a central point in Washington by blue lines. The interface includes a left-hand menu with various options, a top legend, and a right-hand legend.

Left-hand menu (Navigation and Actions):

- 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** (highlighted with a red box)
- Set up Adjustment
- Upload Project Report
- Review and Submit to IDB
- Delete Project

Top Legend:

- MARKS:
 - CORS (Yellow triangle)
 - GNSS Static Surveys only (White circle)
 - Other GNSS Surveys only (White diamond)
 - Mixed GNSS Surveys (White circle with X)
- STATUS:
 - meet preferences (Green square)
 - do not meet preferences (Yellow square)
 - are not included (Grey square)
 - have error (Red square with X)
- Baselines:
 - Network Adjustment (Green line)
 - GNSS Session (Blue line)
 - RTK (Purple line)
 - Other GNSS (Cyan line)

Right-hand Legend:

- MARKS:
 - baco (Green circle)
 - bcc1 (Green circle)
 - dew1 (Green circle)
 - jmt2 (Green circle)
 - mas2 (Green circle)
 - paac (Green circle)
 - pacb (Green circle)
 - umbc (Green circle)
- Add MARKS:
 - CORS:
 - algo (Yellow triangle)
 - corb (Yellow triangle)
 - dene (Yellow triangle)
 - gode (Yellow triangle)
 - pafu (Yellow triangle)
 - pass (Yellow triangle)
 - work (Yellow triangle)

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):

GVX in This Project	
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

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

Step 2: Upload GVX File

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

Step 3: Review and QA/QC Vectors

Baseline n102-bcc1

Controls

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

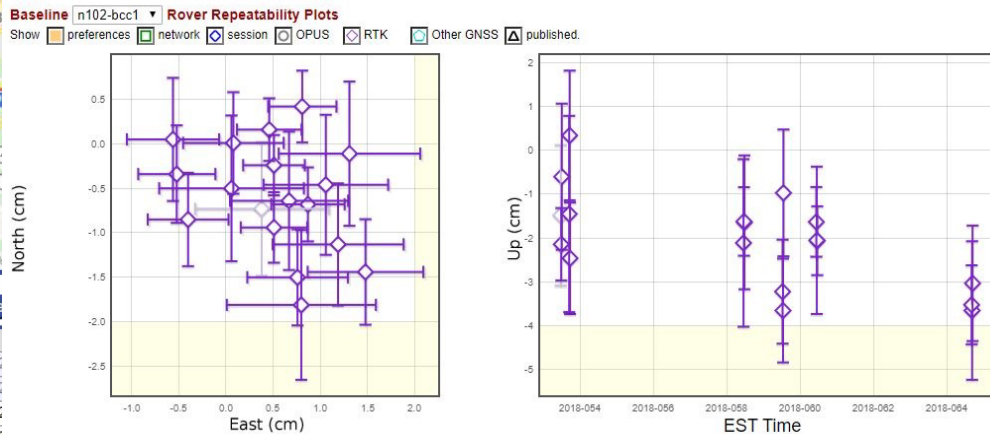
RTK VECTORS: ◆ meet preferences ◆ do not meet preferences ◆ are not included ◆ have error

OTHER GNSS VECTORS: ▲ meet preferences ▲ do not meet preferences ▲ are not included ▲ have error

CORS: ● meet preferences ● do not meet preferences ● are not included ● have error

Baselines: —

Map Satellite



Baseline n102-bcc1 **Occupation Summary** Save

USE	VECTOR	GVX ID	DURATION (s)	SPAN	HARDWARE
<input 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"/>	◆ 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"/>	◆ 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"/>	◆ 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"/>	◆ 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"/>	◆ 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** Save USE Changes

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)	LOX (m)	HGT (m)
<input type="checkbox"/>	◆ V5	053.jxl.gvx	TRMR10	NONE	2.000	301	Ultra-rapid predicted half	15=C0:E0:G9:J0:R6	Fixed	NetworkRTK	Trimble VRS3Net	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	15=C0:E0:G10:J0:R5	Fixed	NetworkRTK	Trimble VRS3Net	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	15=C0:E0:G9:J0:R6	Fixed	NetworkRTK	Trimble VRS3Net	VRS_RTCM3	0.006	0.009	0.011
<input checked="" type="checkbox"/>	◆ V7	058.jxl.gvx	TRMR10	NONE	2.000	301	Ultra-rapid predicted	14=C0:E0:G9:J0:R5	Fixed	NetworkRTK	Trimble VRS3Net	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 window shows a map of the Washington, D.C. region with a network of GNSS baselines. The baselines are color-coded: blue for GNSS Sessions, purple for RTK, and green for Network Adjustment. The network is centered on Washington, D.C., with baselines extending to various stations including York, Baltimore, and Alexandria. The left sidebar contains a list of navigation buttons, with 'Set up Adjustment' and 'Review and Submit to IDB' highlighted in red. The top toolbar includes map controls like 'Map' and 'Satellite'. The right sidebar shows a list of stations (e.g., bcc1, bell, brun) and CORS stations (e.g., algo, corb, dene).

Example: Adjust Static + RTN Network

- Run least squares adjustment(s) of the combined static data and RTN vectors in the survey network
- Hold CORS (and possibly other published coordinates on passive marks) as control in network adjustments
 - Ensures survey is aligned to the National Spatial Reference System
- Check quality of results
- Submit survey project to NGS for review and publication in national database

Ongoing and Future Work

- Release newly developed OPUS-Projects to BETA for public testing and commenting (est. December 2020)
- Update OPUS-Projects User Manual
- Finish writing new specifications for establishing geodetic control with static GNSS and/or RTK/RTNs

Future of OPUS-Projects

- Differential leveling → **OPUS-Projects v. 6.0**
- Classical observations (angles, distances)
- Relative gravity (discrete)
- Relative gravity (continuous)
- Absolute gravity

How to Move Forward?

- Provide feedback! Send to ngs.feedback@noaa.gov
 - What are we missing?
 - What is unnecessary?
 - How can GVX be improved?
 - How can OPUS-Projects be further developed for uploaded GNSS vectors?

For More Technical Details, Refer to...

- Gillins, D.T., Kerr, D., and Weaver, B. (2019). "Evaluation of the Online Positioning User Service for Processing Static GPS Surveys: OPUS-Projects, OPUS-S, OPUS-Net, and OPUS-RS," *J. Surv. Eng. (ASCE)*, 145(3):05019002.
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- Park, J., Kim, S., Shahbazi, A., Gillins, D., and Dennis, M. (2018). "Evaluation of Static GPS Surveying Campaigns Processed in OPUS-Projects," *Final Technical Report FY17 NA293P*, National Geodetic Survey, 58 pp.
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Questions?

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