OPUS-Projects and Future Developments

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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)

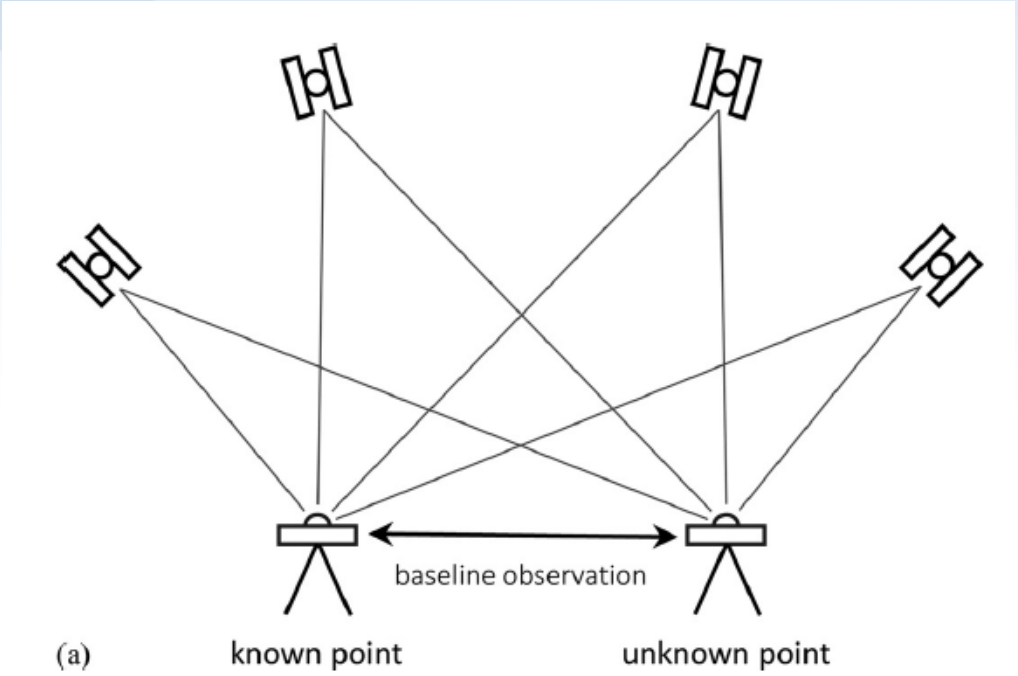
Greetings from Home!

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

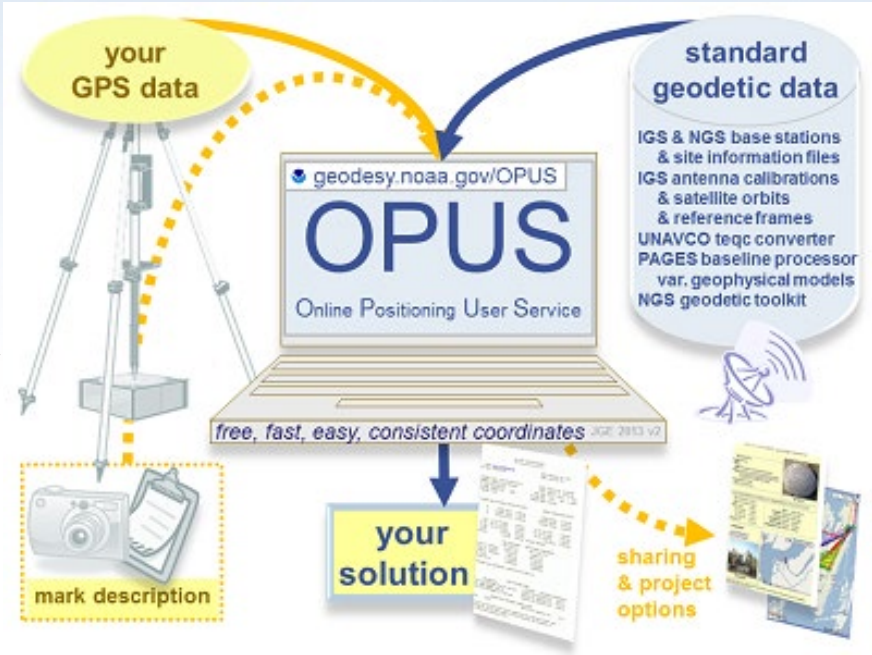
GNSS Errors

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



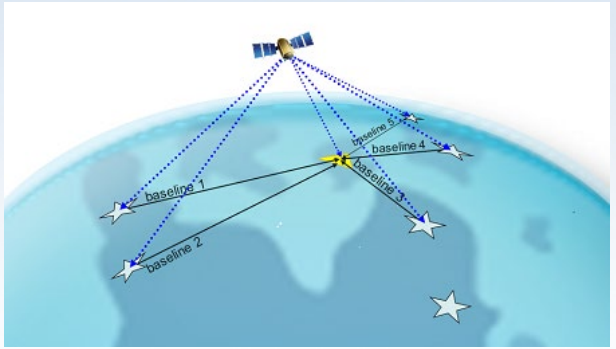
Online Positioning User Service (OPUS)

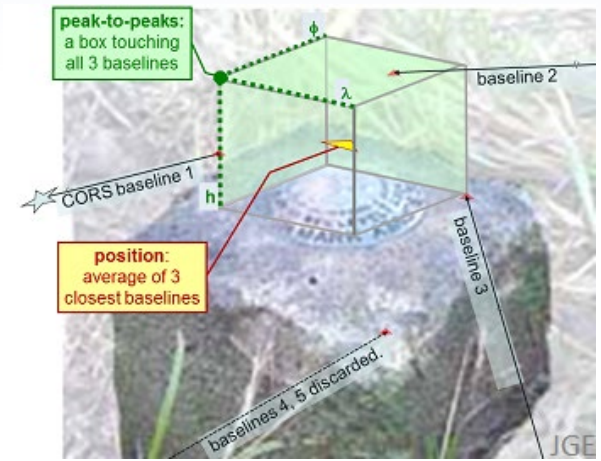
- **OPUS-Static – (2001)**
  - L1/L2 observables
  - Single occupation on a mark, ≥ 2 hours
  - GPS-only (currently true for all versions of OPUS)
- **OPUS-Rapid Static – (2007)**
  - Single occupation on a mark, 15 min < T < 2 hours
  - L1/L2 observables and C1 or P1 and P2
- **OPUS-Projects – (~2012)**
  - 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



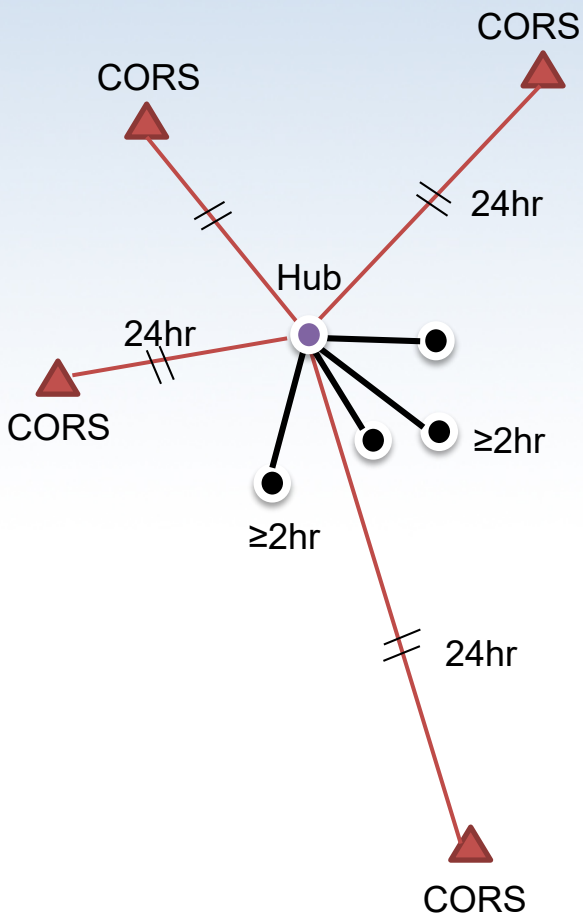


OPUS-Projects

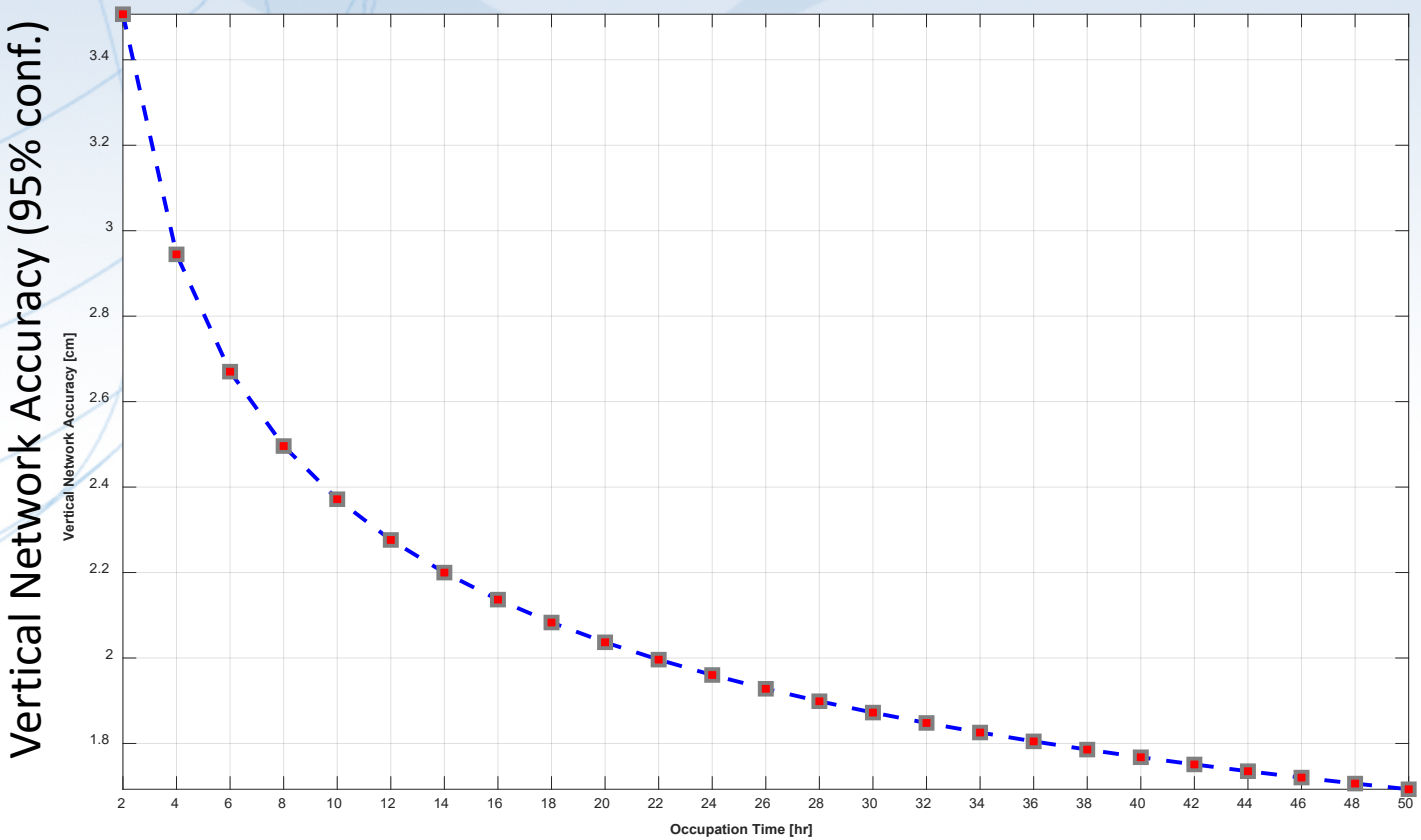
- Free, web-based software
  - Online training available
- Designed for managing campaign-style GPS surveys
  - Multiple repeat occupations of several marks
- Ability to add GPS data from NOAA CORS Network
- Session baseline processing using PAGES
- Customize tropospheric delay models, elevation cutoff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

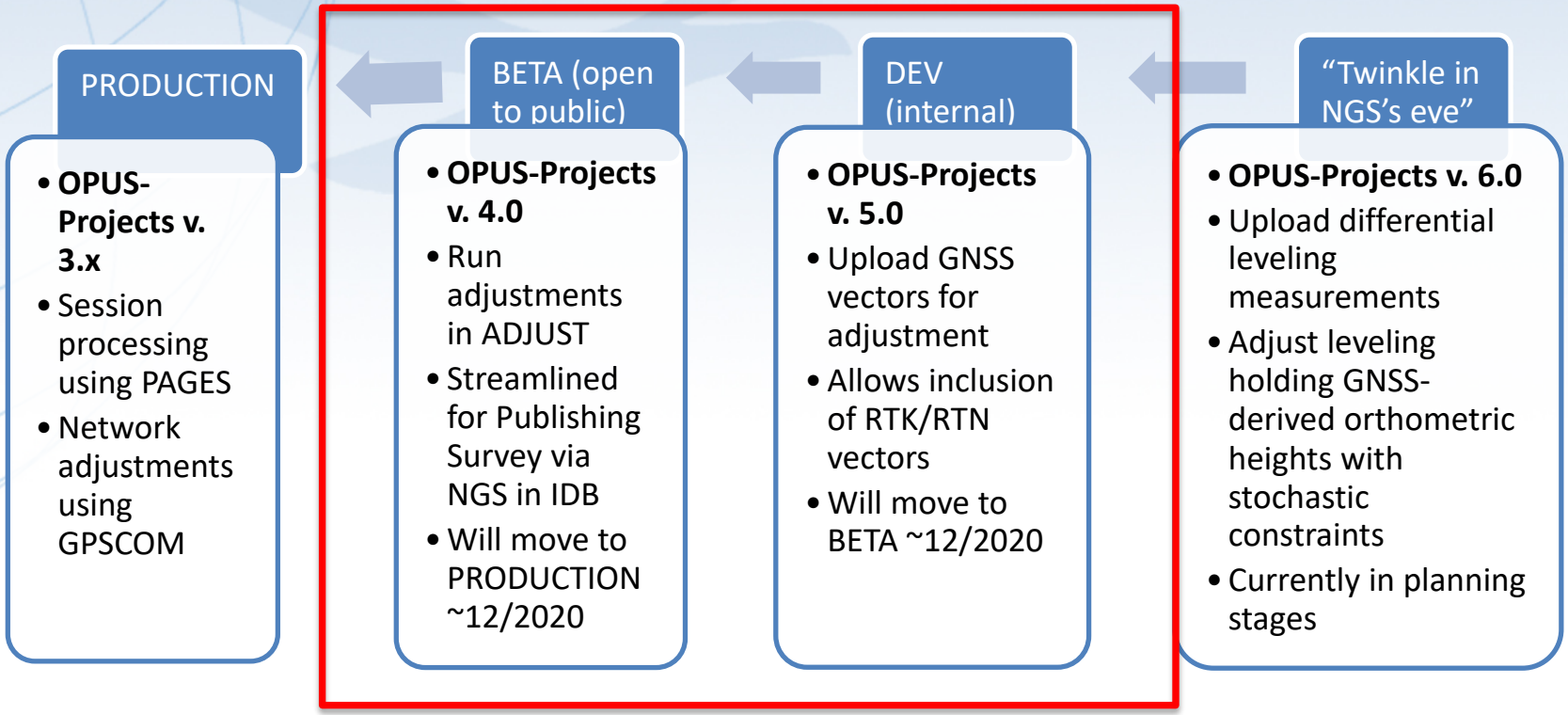


Vertical Accuracy, OPUS-Projects



[Park et al. 2018]

Development Phases of OPUS-Projects

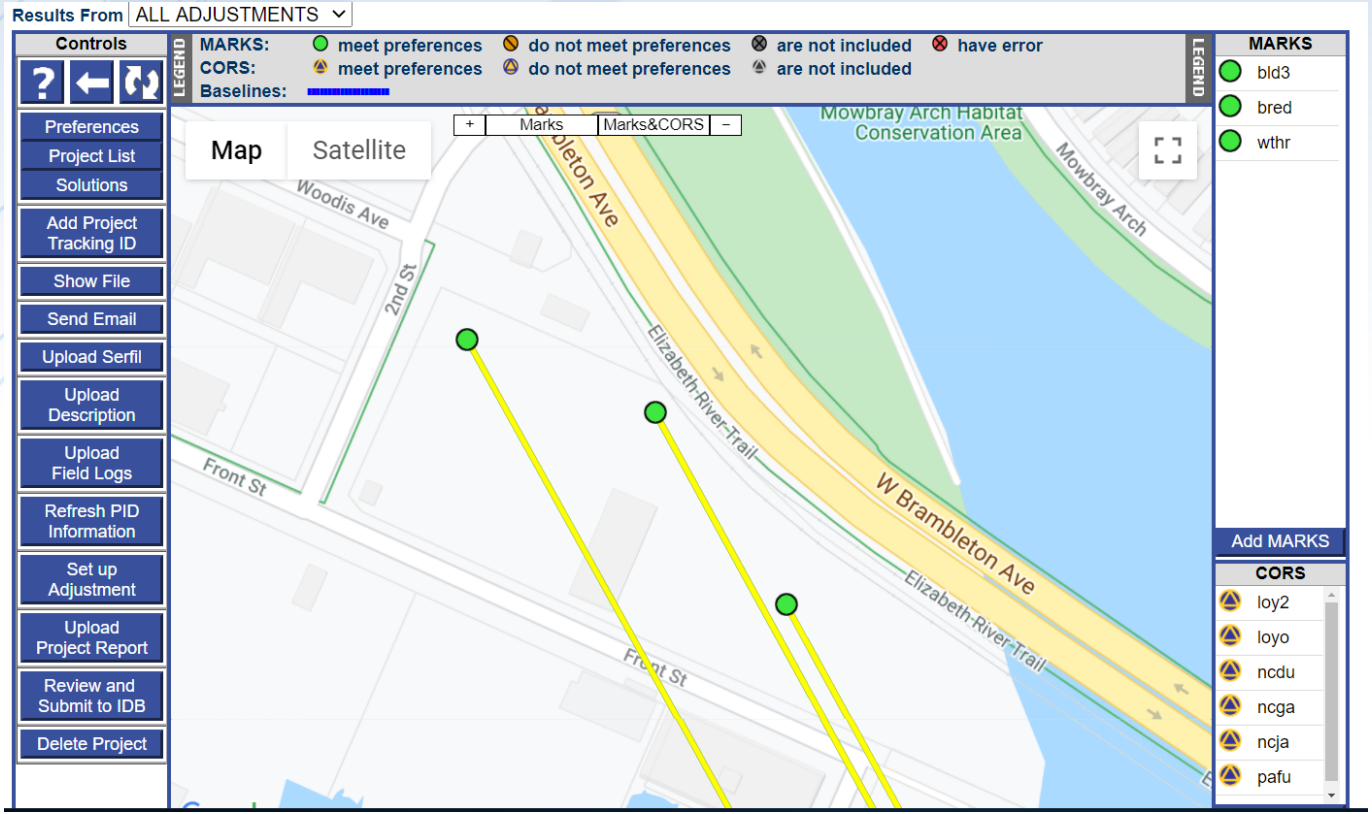


OPUS-Projects v. 4.0 ("BETA OP")

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



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

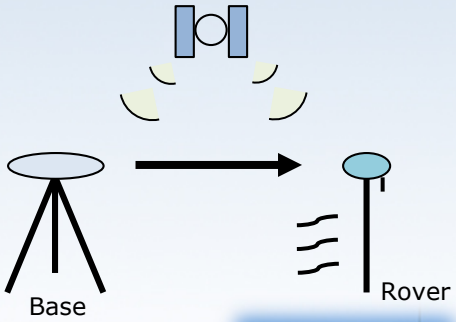
- **Baseline**: the line connecting two GNSS marks
- **Vector**: a mathematical representation of a measurement of the baseline, expressed in delta X,Y,Z components (along with error estimates)

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

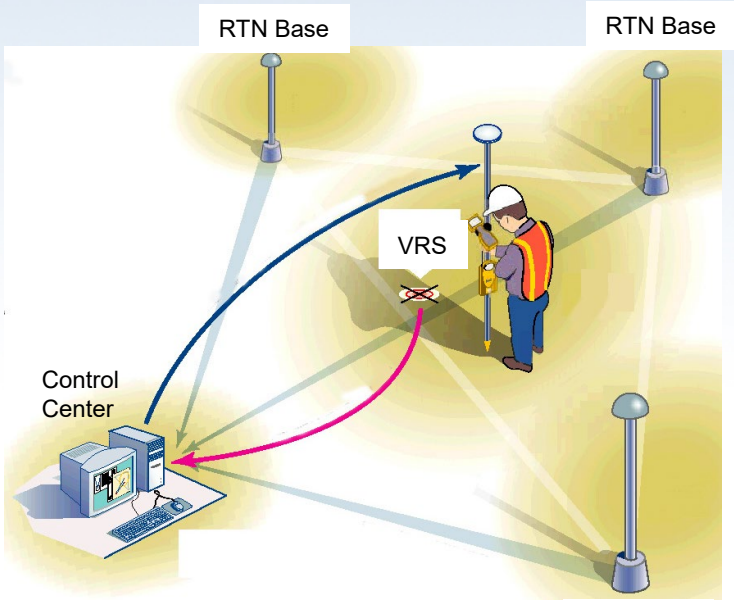
www.gcfarm.com

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

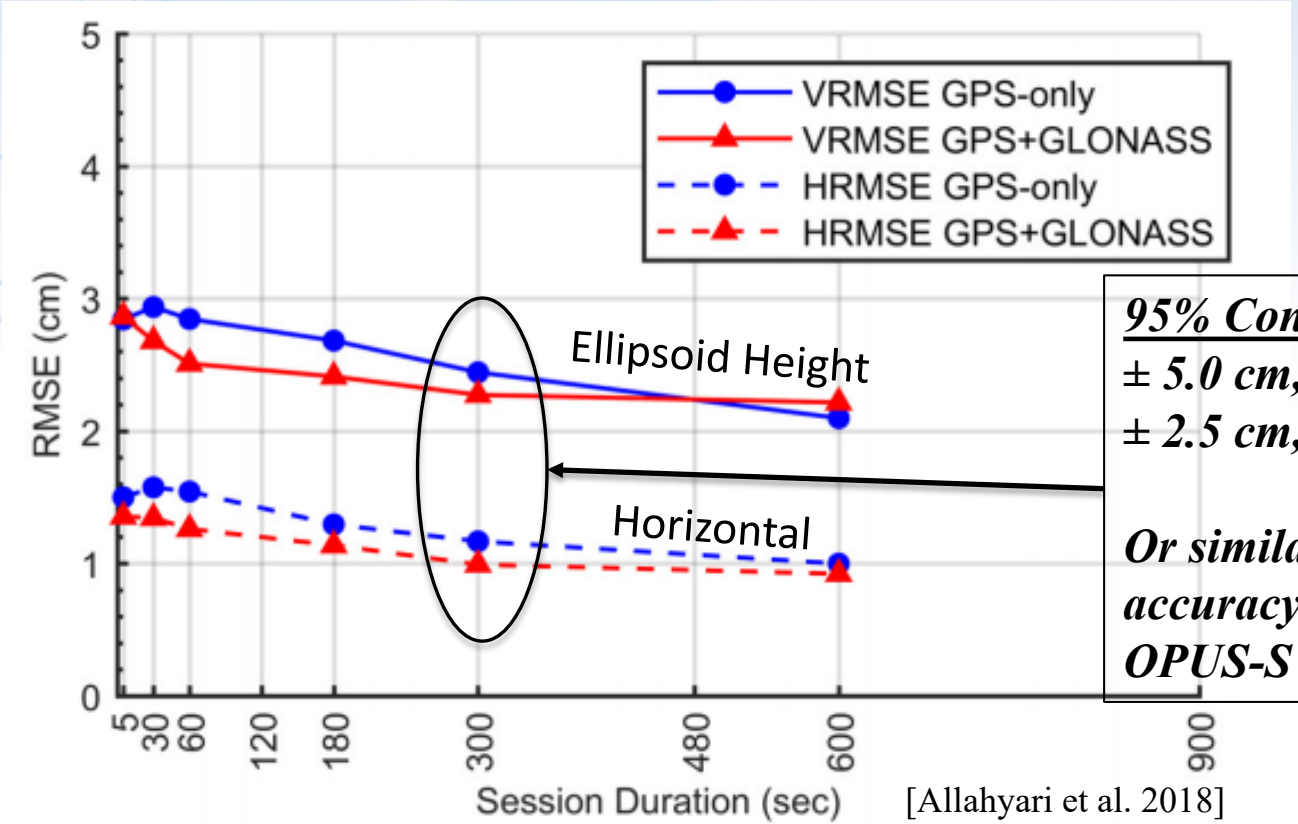


(Landau et al. 2002)

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

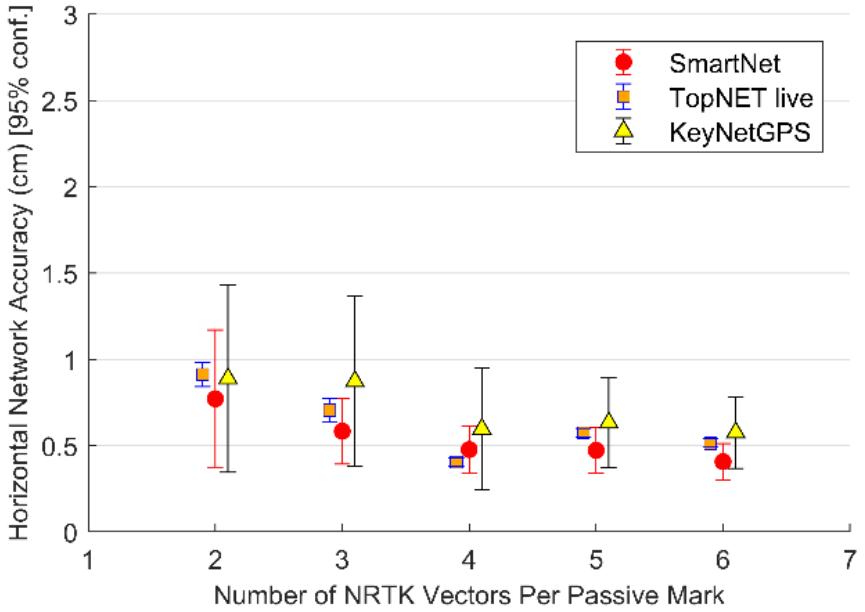


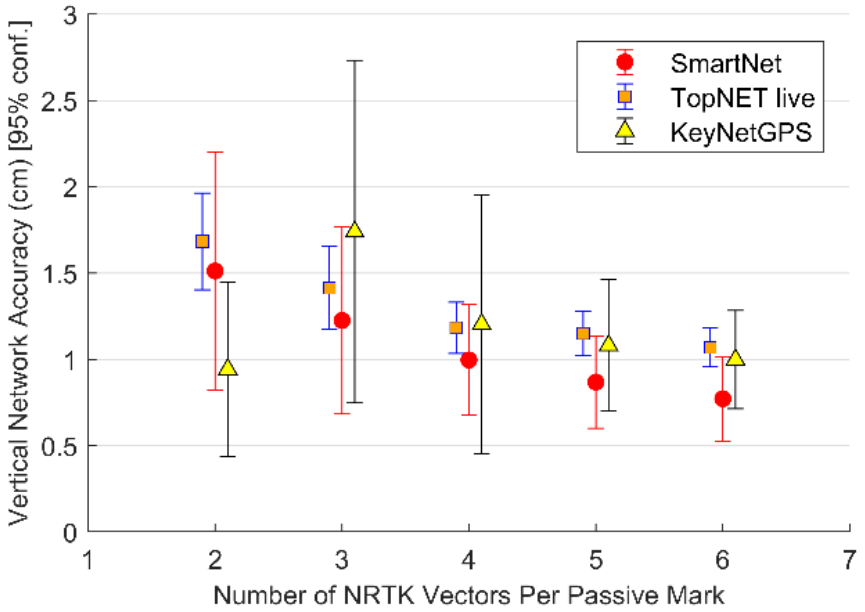
95% Confidence
± 5.0 cm, vertical
± 2.5 cm, horizontal

Or similar to accuracy of a 2-h OPUS-S solution!

[Allahyari et al. 2018]

Formal Error Propagation via Survey Network Least Squares Adjustment





[Gillins et al. 2019]

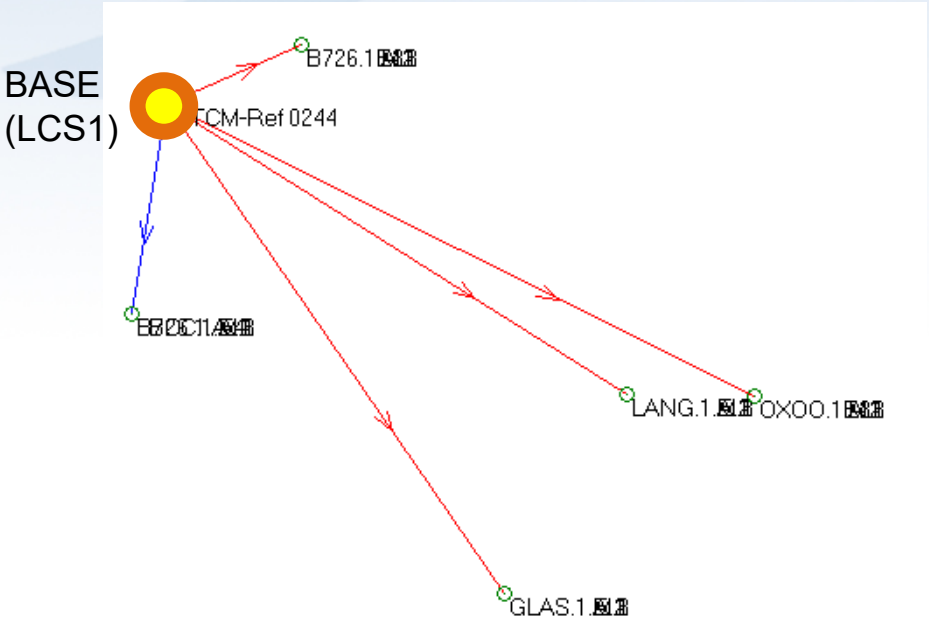
Problem Statement

- 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

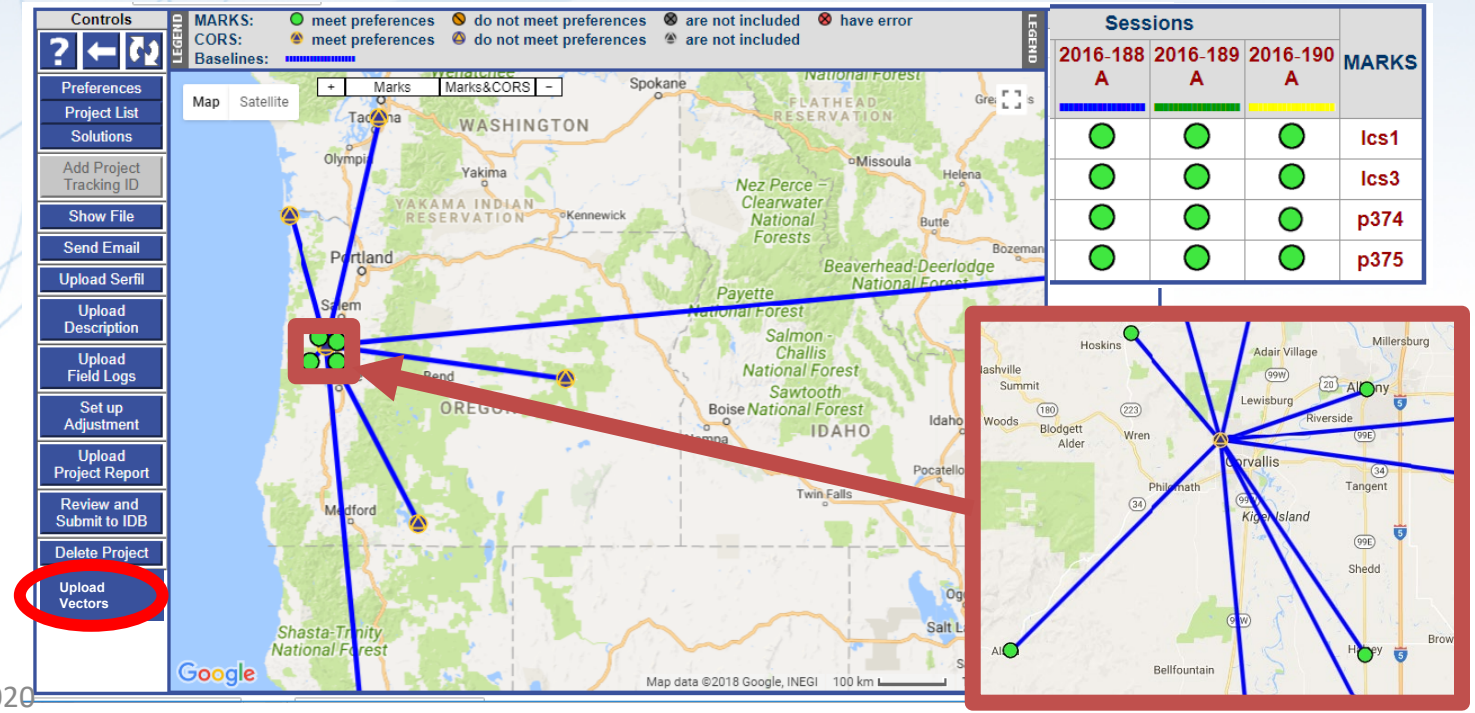
- Develop a standard file format for GNSS vectors
  - Open-source, machine-readable, human-readable
  - Must include all of the necessary information for performing a least squares adjustment
  - Must include important metadata for quality control
- Develop OPUS-Projects so that GNSS vectors from RTK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

Example: Conduct RTK Survey and Download Data

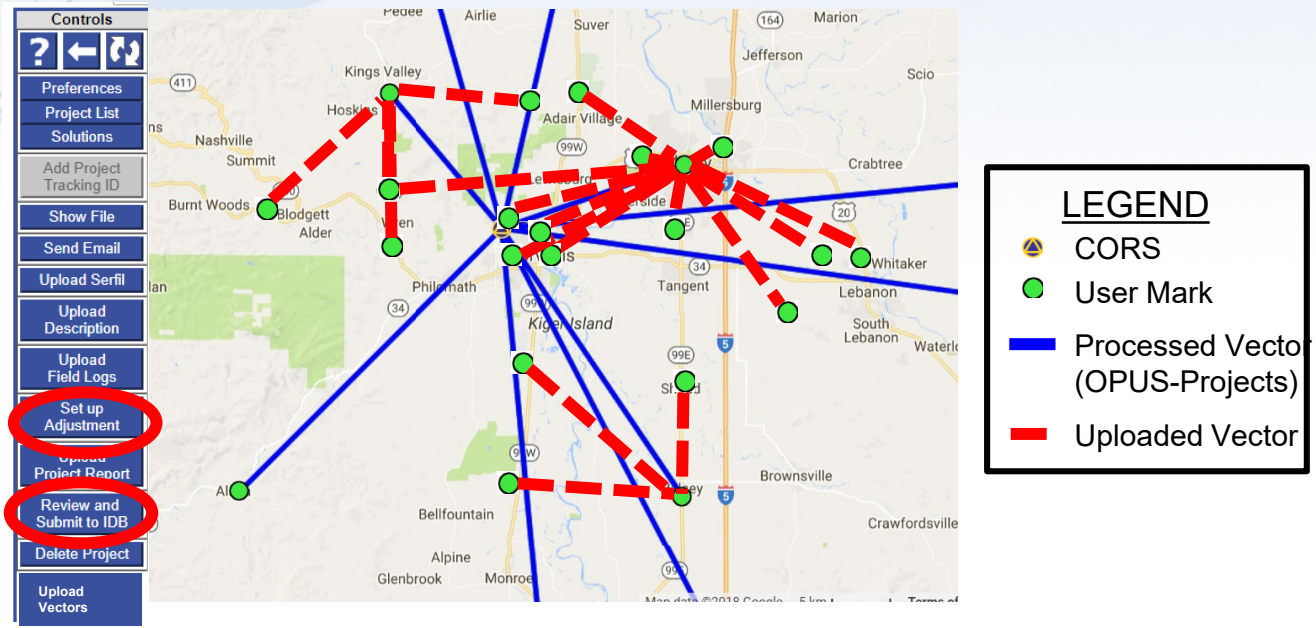


Store your RTK measurements as vectors and not just points!

Example: Process Base Data in OPUS-Projects



Example: Upload RTK Vectors to OPUS-Projects



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)

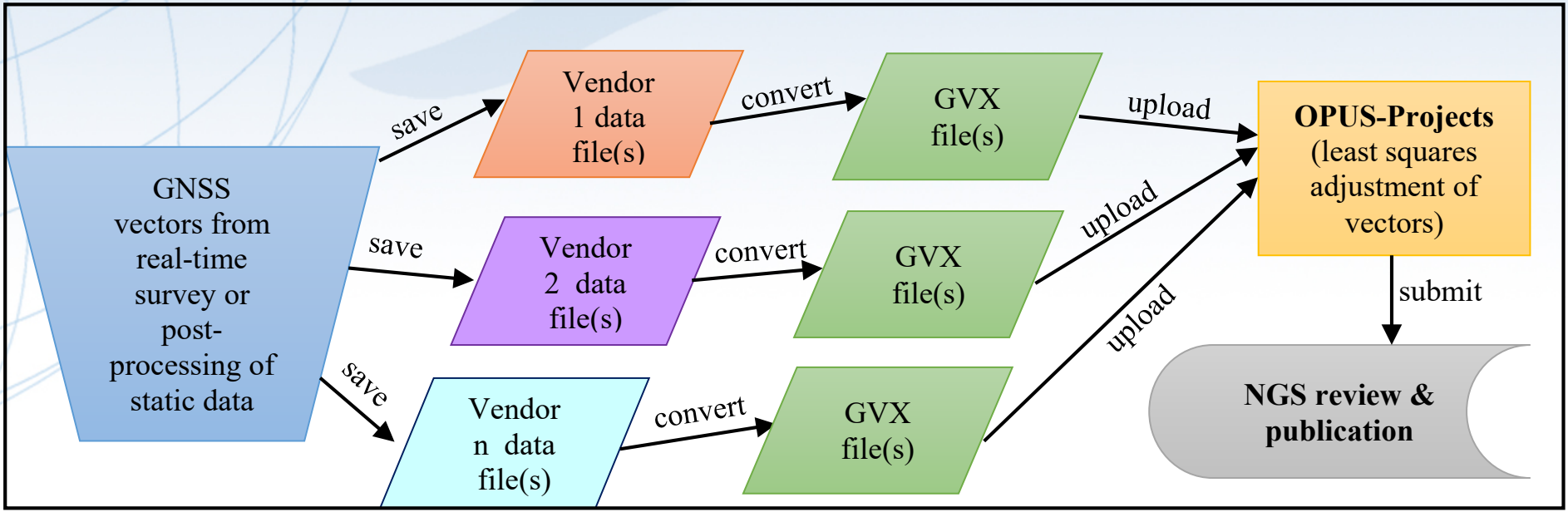
7. GNSS_VECTOR
   - IDs for starting and ending points of the vector
   - ID for survey setup
   - Start and end time of the observation
   - Differential, mark-to-mark vector components (ECEF) or dX, dY, dZ
   - Variance and covariance values
   - QA/QC metadata
     - DOP, RMS, mask settings, number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

And and and…

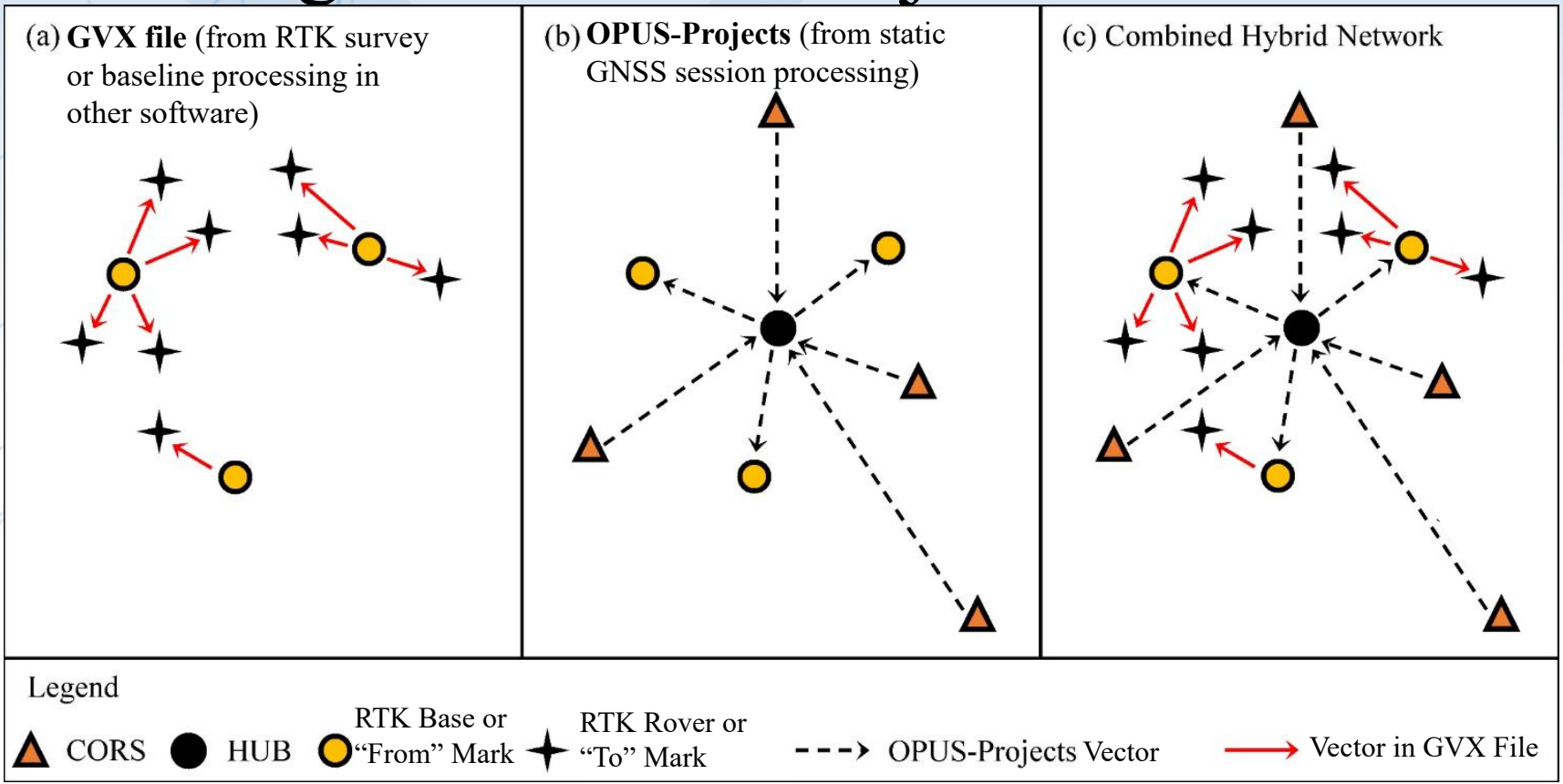
Although the original objective was to develop tools for RTK surveys, GVX supports all types of GNSS vectors

- Real-time vectors
- Post-processed vectors

GVX Flow Chart

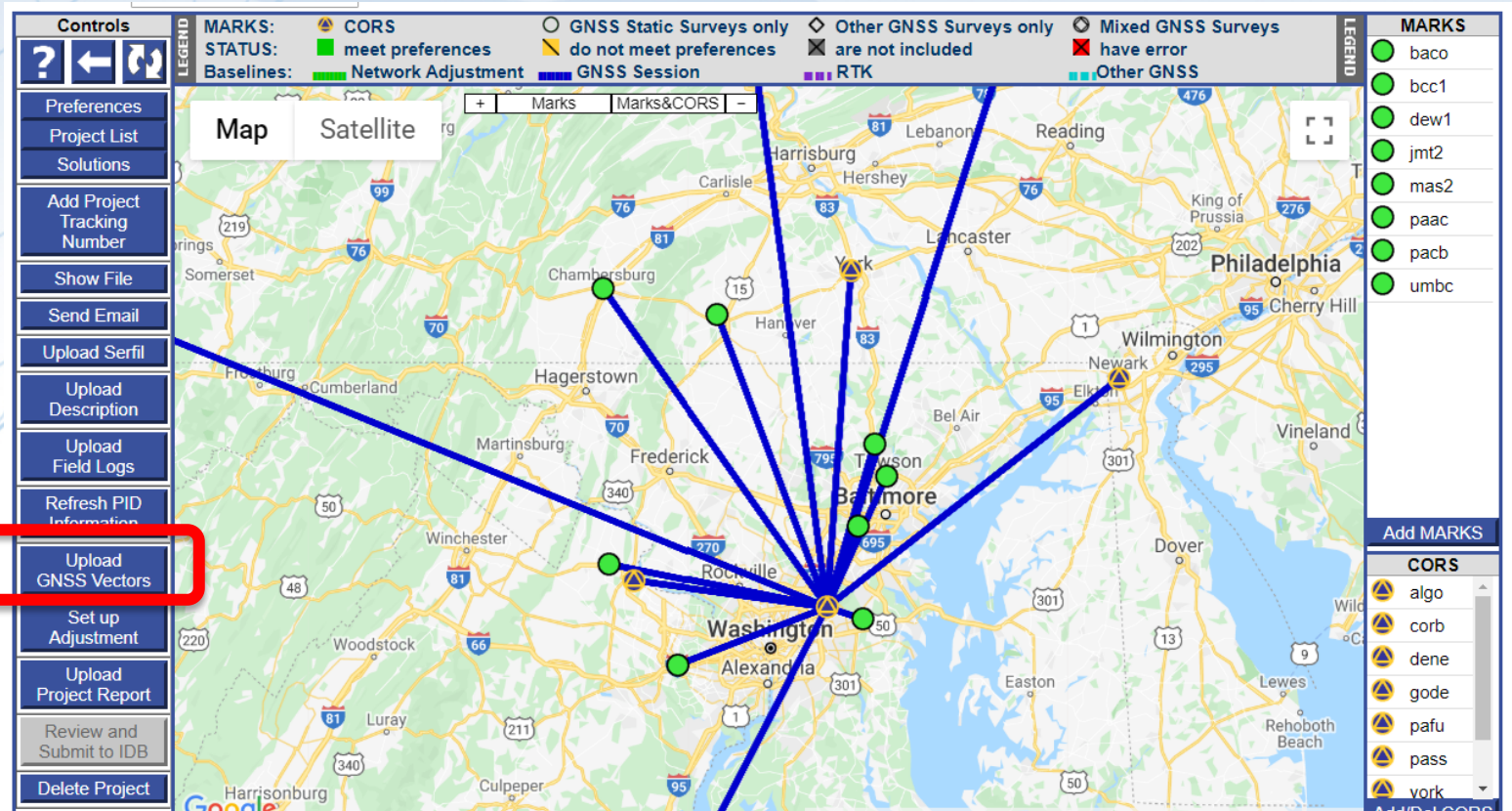


Design for OPUS-Projects and GVX

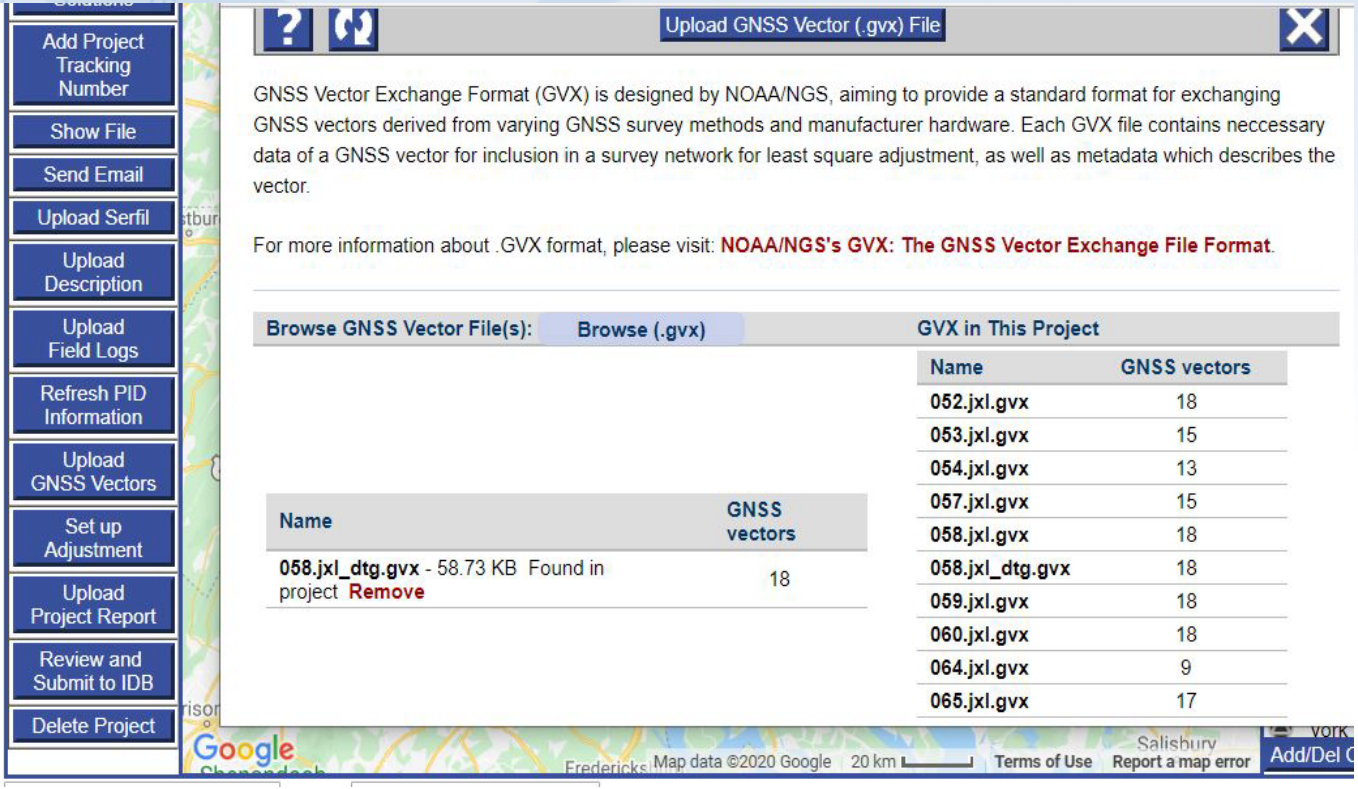


[Adapted from Weaver et al. 2018]

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

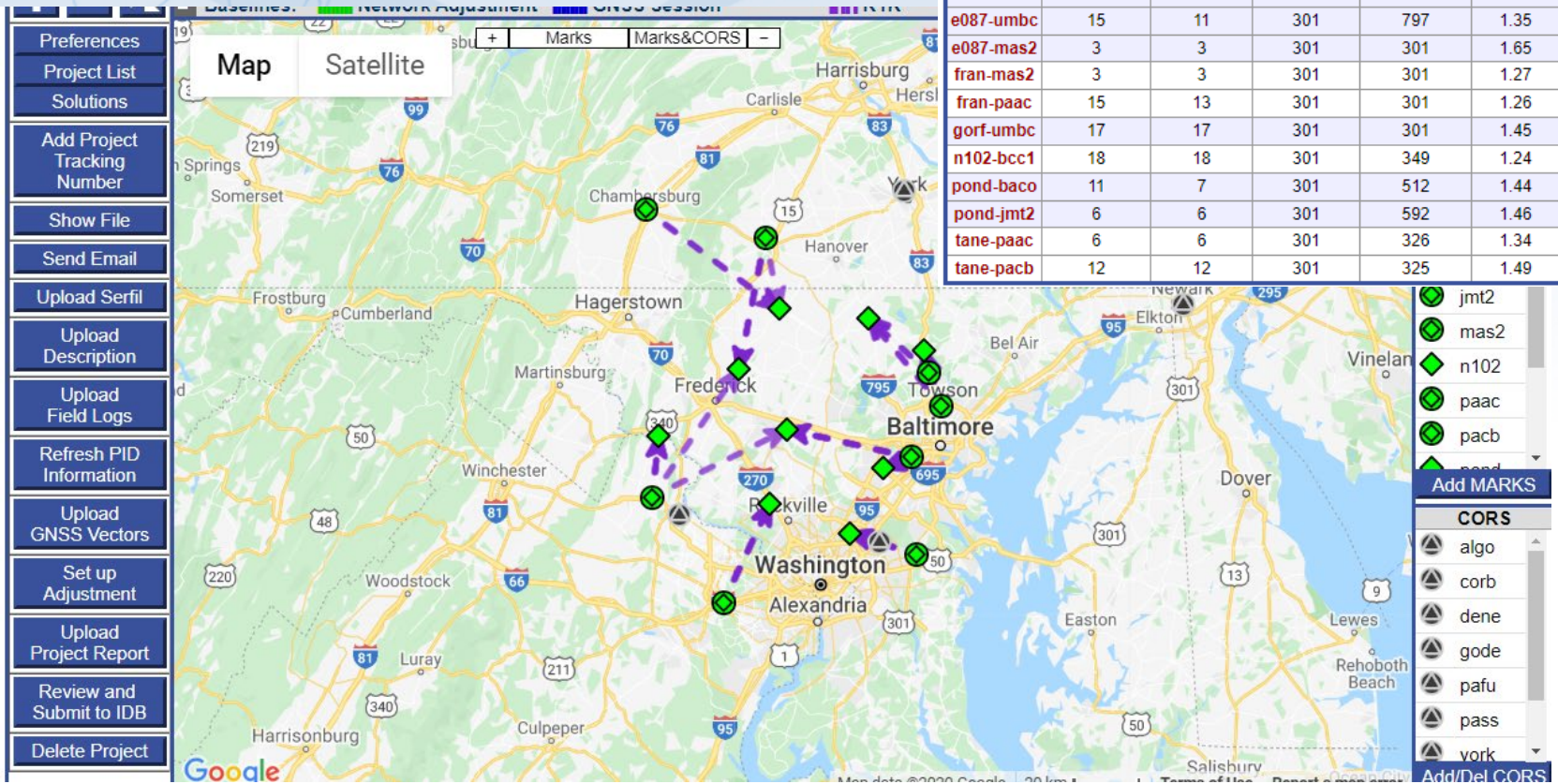


Step 2: Upload GVX Files (Vectors)

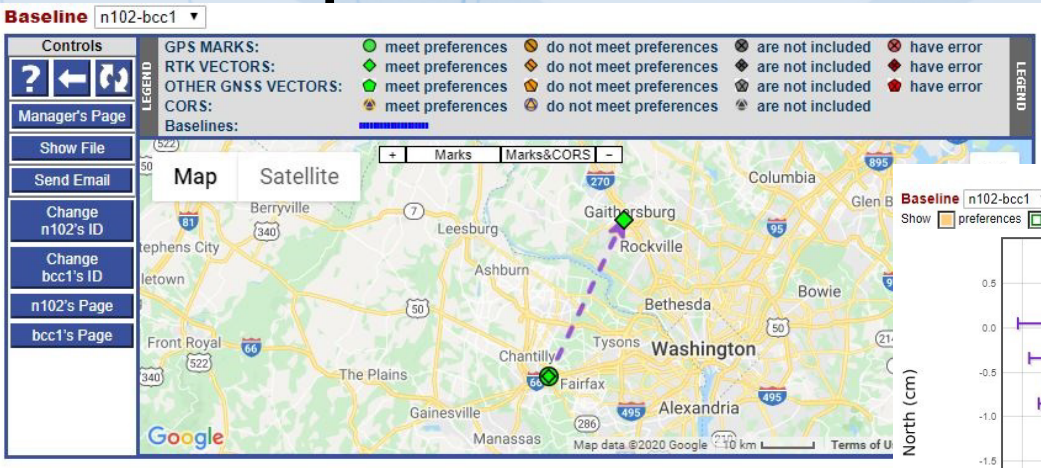


Step 2: Upload GVX Fi

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

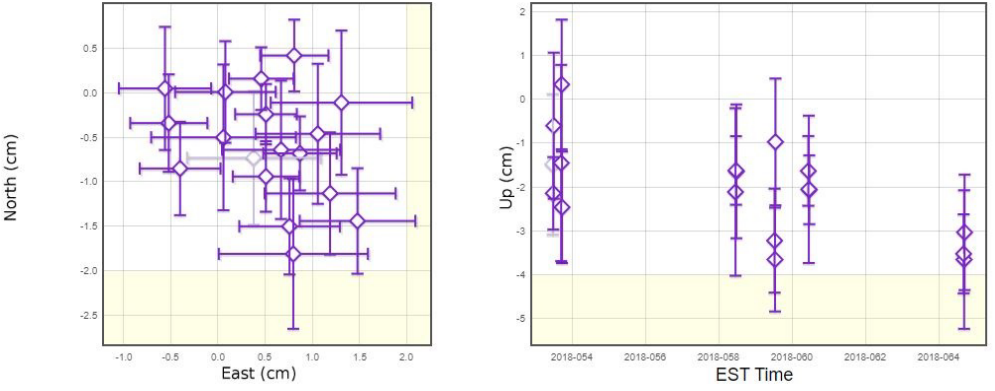


Baseline n102-bcc1 ▾ **Occupation Summary** Save

USE	VECTOR	GVX ID	DURATION (s)	SPAN		HARDWARE		
☐	V5	053.jxl.gvx	301	Start: 2018-053T11:14:15 EST	Antenna: Model:	TRMR10	NONE	S/N: 5631465932
				End: 2018-053T11:19:15 EST	Receiver: Model:	TRMR10		S/N: 5631465932
☑	V6	053.jxl.gvx	301	Start: 2018-053T11:34:46 EST	Antenna: Model:	TRMR10	NONE	S/N: 5631465932
				End: 2018-053T11:39:46 EST	Receiver: Model:	TRMR10		S/N: 5631465932
☑	V7	053.jxl.gvx	322	Start: 2018-053T11:52:07 EST	Antenna: Model:	TRMR10	NONE	S/N: 5631465932
				End: 2018-053T11:57:28 EST	Receiver: Model:	TRMR10		S/N: 5631465932
☑	V13	053.jxl.gvx	310	Start: 2018-053T16:43:42 EST	Antenna: Model:	TRMR10	NONE	S/N: 5631465932
				End: 2018-053T16:48:51 EST	Receiver: Model:	TRMR10		S/N: 5631465932
☑	V14	053.jxl.gvx	301	Start: 2018-053T17:01:15 EST	Antenna: Model:	TRMR10	NONE	S/N: 5631465932
				End: 2018-053T17:06:15 EST	Receiver: Model:	TRMR10		S/N: 5631465932
☑	V15	053.jxl.gvx	301	Start: 2018-053T17:18:02 EST	Antenna: Model:	TRMR10	NONE	S/N: 5631465932
				End: 2018-053T17:23:02 EST	Receiver: Model:	TRMR10		S/N: 5631465932

Baseline n102-bcc1 ▾ **Rover Repeatability Plots**

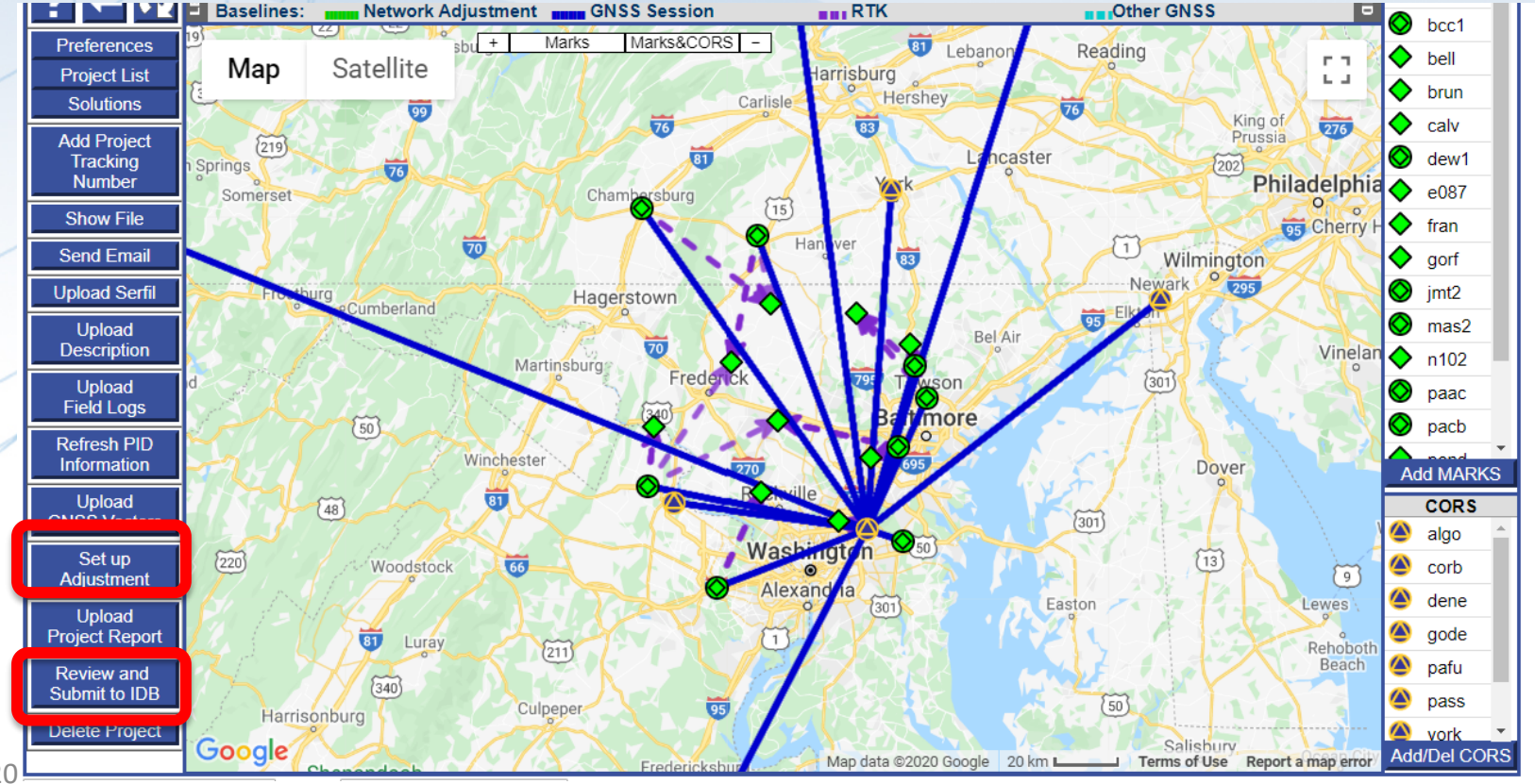
Show preferences network session OPUS RTK Other GNSS published.



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)	LON (m)	HGT (m)
☐	V5	053.jxl.gvx	TRMR10	NONE	2.000	301	Ultra-rapid predicted half	1.88	15=C0:E0:G9:J0:R6	Fixed	NetworkRTK	Trimble VRS3Net	VRS_RTCM3	-0.000	-0.001	0.002
☑	V6	053.jxl.gvx	TRMR10	NONE	2.000	301	Ultra-rapid predicted half	1.28	15=C0:E0:G10:J0:R5	Fixed	NetworkRTK	Trimble VRS3Net	VRS_RTCM3	0.000	0.004	-0.005
☑	V7	053.jxl.gvx	TRMR10	NONE	2.000	322	Ultra-rapid predicted half	1.45	15=C0:E0:G9:J0:R6	Fixed	NetworkRTK	Trimble VRS3Net	VRS_RTCM3	0.006	0.009	0.011
☑	V7	058.jxl.gvx	TRMR10	NONE	2.000	301	Ultra-rapid predicted	1.30	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



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.
- Gillins, D.T., Heck, J., Scott, G., Jordan, K., and Hippenstiel, R. (2019). "Accuracy of GNSS Observations from Three Real-time Networks in Maryland, USA," *Proc. 2019 FIG Working Week, Hanoi, Vietnam*, April 2019, 15 pp.
- 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.
- Jamieson, M., and Gillins, D.T. (2018). "Comparative Analysis of Online Static GNSS Post-Processing Services." *J. Surv. Eng*. (ASCE), 144(4):05018002.
- Allahyari, M., Olsen, M., Gillins, D.T., and Dennis, M. (2018). "A Tale of Two RTNs: Rigorous Evaluation of GNSS Survey Observations in Real-time Networks," *J. Surv. Eng.* (ASCE), 144(2):05018001.
- Weaver, B., Gillins, D.T., and Dennis, M. (2018). "Hybrid Survey Networks: Combining Real-time and Static GNSS Observations for Optimizing Height Modernization," *J. Surv. Eng.* (ASCE), 10.1061/(ASCE)SU.1943-5428.0000244, 144(1):05017006.
- Gillins, D., and Eddy, M. (2017). "Comparison of GPS Height Modernization Surveys using OPUS-Projects and Following NGS-58 Guidelines," J. Surv. Eng. (ASCE)., 143(1):05016007.

Acknowledgements

OPUS-Projects v. 5.0 Development Team:

- Ira Sellars
- Mark Schenewerk
- Weibing Wang
- Jay Howard

Questions?

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