GAGE
National Science Foundation's Geodetic Facility for the Advancement of Geoscience

Evaluating Anubis software for GNSS data quality control in the GAGE Facility

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1. UNAVCO

GNSS Modernization and the Network of the Americas (NOTA)

- The Network of the Americas (NOTA) is the federation of the Plate Boundary Observatory (PBO), the Trans-boundary, Land and Atmosphere Long-term Observational and Collaborative Network (TLALOCNet), and the Continuously Operating Caribbean GPS Observational Network (COCONet).
- NOTA is managed by the GAGE Facility, which is in turn operated by UNAVCO.
- Modernization of NOTA entails upgrading stations to be fully GNSS-enable. The process will take several years and requires changes to data flow, QC analysis, and processing.
- 1278 stations in NOTA - upgrades occurring every month.

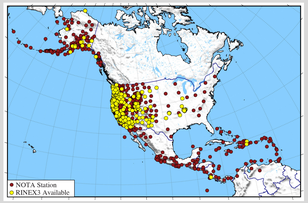

Figure 1. Map of NOTA stations, with fully GNSS-enabled station shown in yellow. These stations have RINEX 3 observation and navigation files as well as RINEX 2 files from UNAVCO as of fall 2019.

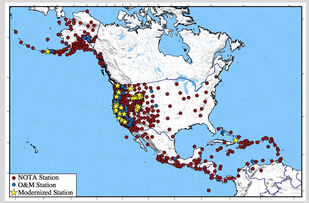

Figure 2. Map of NOTA stations, showing stations that have been upgraded in the last quarter (July-August-September) as part of the ongoing modernization process.

RINEX2 vs. RINEX3

- Receiver INdependent Exchange format originally developed at the Astronomical Institute of the University of Bern to handle GPS data from multiple receiver brands.
- RINEX 2 is currently the standard format for processing GNSS data.
- RINEX 3 was developed to better handle additional GNSS constellations.
  - Different nomenclature for frequency codes
  - Observation file has expanded header, different format for observations at each epoch.
  - Navigation file consolidates satellite data into single file (RINEX2 has separate nav file for each constellation when not using composite nav files).

Table 1. RINEX 2 and RINEX 3 equivalent frequency codes recorded in NOTA observation files. Not all RINEX 3 frequency codes have corresponding RINEX2 codes. Third-generation BeiDou satellite launches began in 2018 and broadcast new frequencies.

GPS		Galileo		GLONASS		SBAS		BeiDou		QZSS	
RINEX2 Code	RINEX3 Code	RINEX2 Code	RINEX3 Code	RINEX2 Code	RINEX3 Code	RINEX2 Code	RINEX3 Code	RINEX2 Code	RINEX3 Code	RINEX2 Code	RINEX3 Code
C1	C1C	C1	C1C	C1	C1C	C1	C1C	C2	C2I	-	C1C
L1	L1C	L1	L1C	P1	C1P	L1	L1C	L2	L2I	-	L1C
S1	S1C	S1	S1C	S1	S1C	S1	S1C	S2	S2I	-	S1C
P1	C1W	C6	C6C	-	S1P	C5	C5I	-	C7I	-	C2L
S2	S1W	L6	L6C	L1	L1C	L5	L5I	-	L7I	-	L2L
P2	C2W	S6	S6C	-	L1P	S5	S5I	-	S7I	-	S2L
L2	L2W	C5	C5Q	C2	C2C			-	C6I	-	C5Q
-	S2W	L5	L5Q	P2	C2P			-	L6I	-	L5Q
C2	C2L/ L2C	S5	S5Q	-	L2C			-	S6I	-	S5Q
		C7	C7Q	L2	L2P			-	C1P		
-	L2L	L7	L7Q	-	S2C			-	L1P		
-	S2L	S7	S7Q	S2	S2P			-	S1P		
C5	C5Q	C8	C8Q	C7	C3Q			-	C5P		
L5	L5Q	L8	L8Q	L7	L3Q			-	L5P		
S5	S5Q	S8	S8Q	S7	S3Q			-	S5P		

Anubis Software

- Anubis software was evaluated as a tool for quality checking RINEX 3 observation files.
- Developed by Geodetic Observatory Pecný at the Research Institute of Geodesy, Topography and Cartography, Department of Geodesy and Geodynamics, University of Pecný, Czech Republic as open source software released under Gnu General Public License version 3.
- Inputs: RINEX observation file (2 or 3), RINEX navigation file, command line options OR control file.
- Outputs: Statistics for frequency codes, satellites, constellations, satellite and station information, Signal-to-Noise (SNR), and Multipath (MP) data. Output encoded in XML format file (machine readable) and XTR text file (human readable).

TEQC Software

- Proprietary but free software developed at UNAVCO to manage RINEX 2 files.
  - Translate manufacturer-specific raw data from GNSS receiver to RINEX 2 format.
  - Produce QC files.
  - Edit RINEX2 files, with options for users to customize output.
- TEQC has reached end-of-life with final release on 2019-02-25.
  - Final release will be available for foreseeable future.
  - UNAVCO will continue to host teqc email forum, archives, documentation.
  - UNAVCO will continue to use teqc for foreseeable future.
- Inputs: RINEX observation file (RINEX 2 only), RINEX navigation file, command line options OR control file. Can also read most manufacturer-specific formats and BINEX/IGS/SOC.
- Outputs (for QC mode): QC time plot, summary report with statistics for standard QC files available from UNAVCO web site. Additional output may be specified by users in custom runs.

Anubis vs. TEQC for Quality Analysis

- Both provide statistics on observation/observable counts, cycle slips, SNR and MP values - but differences in encoding and calculations mean values will not be the same.
- TEQC combines multiple constellations (if available) in MP and SNR calculations.
- Anubis reports statistics for constellations, frequency code,s and satellites, depending on settings.

Table 2. RINEX 2 frequency codes and constellations used to calculate MP values in teqc.

Daily Avg MP	RINEX2 code used in calculations
MP12	C1, L1, L2 (GPS)
MP21	C2, L2, L1 (GPS)
MP15	C1, L1, L5 (GPS, GAL, SBS)
MP51	C5, L5, L1 (GPS, GAL, SBS)
MP16	C1, L1, L6 (GAL)
MP61	C6, L6, L1 (GAL)
MP17	C1, L1, L7 (GAL)
MP71	C7, L7, L1 (GAL)
MP18	C1, L1, L8 (GAL)
MP81	C8, L8, L1 (GAL

Table 3. RINEX 2 frequency codes and constellations used to calculate SNR values in teqc.

Daily Avg SNR	RINEX2 codes used in calculations
S1	S1 (GPS, GAL, GLO)
S2	S2 (GPS, GLO)
S5	S5 (GPS, GAL, SBS)
S6	S6 (GAL)
S7	S7 (GAL, GLO)
S8	S8 (GAL)

Table 4. Operating systems on which teqc and Anubis have been tested and run successfully. Anubis is Linux-based and has been compiled on Mac OS from 10.10.5 to 10.14, but test runs were not always successful.

Software	Operating Systems
teqc	Linux x86 Solaris Sparc 2.3 and higher Solaris x86 2.6 and higher HP-UX 10.20 and higher (PA-RISC platforms) DEC Digital-UNIX OSF1 V4.0 DEC Alpha Linux IBM AIX 4.3 SGI IRIX 5.3 Macintosh OSX Microsoft (95/98/NT/2000/XP)
Anubis	CentOS 6.6 and 6.10* CentOS 7.6 and higher

*The CentOS 6 compiler is not compatible with Anubis libraries and cannot be updated without introducing new incompatibilities in existing libraries. There is a way to work around this, but the process is complicated and not recommended for most users.

Anubis vs. TEQC for Quality Analysis (continued)

- Compare teqc and Anubis output at station P802 in North Dakota. P802 has a clear sky view and no technical problems since upgrade to multi-GNSS equipment and data flow.
- Look at observation counts/statistics, MP, SNR.

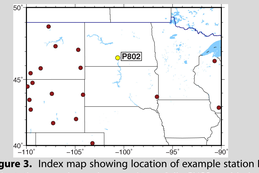

Figure 3. Index map showing location of example station P802 This station was chosen because it was fully GNSS-enabled.

Figure 4. Photo of P802, with no trees or buildings to obstruct the sky view.

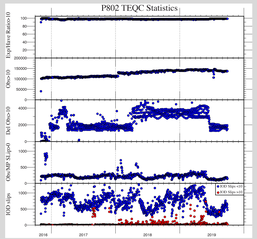

Figure 5. Sample statistics for all observations from all constellations as calculated with teqc.

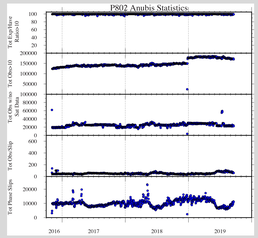

Figure 6. Sample statistics for all observations from all constellations as calculated with Anubis.

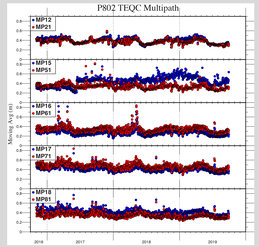

Figure 7. Daily MP values calculated by teqc for selected frequency combinations. Note that units are in meters.

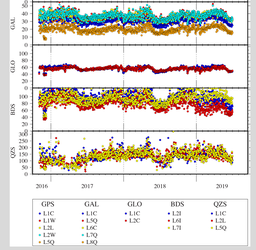

Figure 8. Daily MP values calculated by Anubis for each constellation and frequency code. Units are in cm.

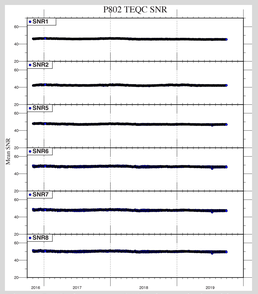

Figure 9. Daily average SNR values calculated by teqc for selected frequency combinations.

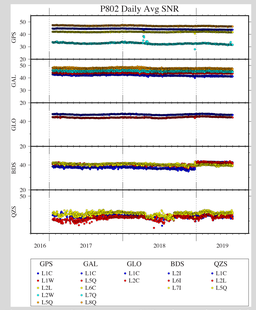

Figure 10. Daily average SNR values calculated by Anubis for each constellation and frequency code.

Anubis Customized Example

- Anubis settings allow greater levels of detail to be saved to the output file.
  - Statistics/MP/SNR/satellite elevation+azimuth can be calculated at each epoch, or user-specified intervals.
- Example: P612 to the south of the Cajon Pass through the San Gabriel/San Bernardino Mountains, California has unusual winter scatter in the north component of the position time series
  - Hypothesis: Scatter is linked to Santa Ana conditions, where either
    1. Strong pressure gradient north and south of the mountains increases atmospheric errors.
    2. Dust kicked up from strong winds interferes with GNSS signals.
  - Use Anubis to see if low SNR values are correlated with high winds at nearby met stations.

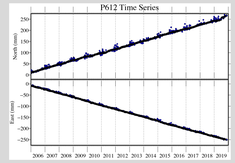

Figure 11. Horizontal components of P612 position time series. Note increased scatter in north component in winter months.

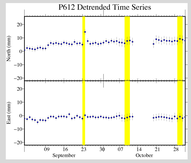

Figure 12. Detrended position time series for September-October 2019. Santa Ana conditions are shown in yellow. Only the September event correlates to a time series outlier.

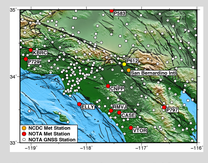

Figure 13. Map of southern California showing P612 and nearby met stations as well as other GNSS stations. The San Andreas fault divides the San Gabriel mountains from the San Bernardino mountains at Cajon Pass.

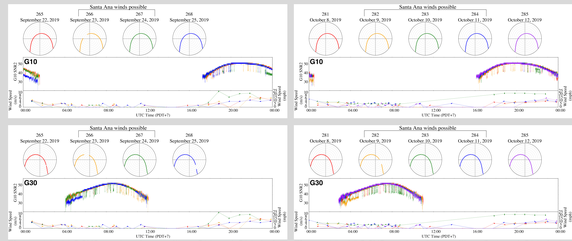

Figure 14. L2C SNR vs. time for satellites G10 and G30 during the September 23-24 Santa Ana conditions, along with hourly wind speed measurements at San Bernardino Airport. Multiple days are superimposed. There is not a clear correlation between SNR and wind speed. Wind speeds are from NOAA National Centers for Environmental Information.

Figure 15. L2C SNR vs. time for satellites G10 and G30 during the October 9-11 Santa Ana conditions, along with hourly wind speed measurements at San Bernardino Airport. Multiple days are superimposed. There is not a clear correlation between SNR and wind speed.

Summary

- Anubis is open-source software for QC analysis of RINEX files, available from the Geodetic Observatory Pecný.
  - Developed for multi-constellation GNSS.
  - Calculates the same or similar QC statistics and parameters as teqc, but output is organized based on constellations and frequency codes.
- UNAVCO plans to use Anubis for RINEX 3 QC as NOTA is modernized to be fully GNSS-enabled.
- Anubis can be used for custom analysis of MP and SNR.
  - Custom runs can take a long time to run - up to 2 hours per RINEX file.
  - SNR and MP at each satellite at each epoch are rounded to integers - may affect analysis.
- TEQC has reached end of life and is no longer being updated.
  - Executable files still work and are available; some support is available through the mailing list forum, archives, and documentation.
  - TEQC-generated QC files are still available for NOTA stations.
- More information: **"UNAVCO Geodetic Data Services Plan for GNSS Modernization: Data Formats and Preprocessing Tools" (March 2016), https://www.unavco.org/community/publications_and_reports/archived-docs/papers/GDS%20Plans%20for%20GNSS%20Modernization.pdf**

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