UNAVCO Geodetic Data Services Plan for GNSS Modernization: Data Formats and Preprocessing Tools

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Modernization of GNSS

New GPS signals (L2C, L5) and additional GNSS constellations (Galileo, GLONASS, Beidou/Compass, QZSS, SBAS, IRNSS) are changing the landscape for UNAVCO's data handling moving into the future. The transition to utilizing GNSS within the global geodesy community and the UNAVCO community is in its very early stages. However, the need to move ahead has been recognized:

The PBO Futures workshop final report includes recommendations that UNAVCO:

"Move to GNSS by 2018 to maintain relevancy of network."

and

"Upgrade a limited number of GPS stations to full GNSS in strategic target areas of high scientific value, those that support large user communities, and for collection of data for UNAVCO and community-driven development and testing efforts."

UNAVCO's Geodetic Data Services (GDS) division must prepare to manage, archive, and deliver this data. In addition, a model for future support for GNSS data preprocessing tools used by UNAVCO Archive operations and provided to the global community needs to be formulated. The challenges that face GDS in this transition, and our proposed response are the subject of this white paper.

Current and Emerging Formats

RINEX 2.11

The current standard format recognized and disseminated by the International GNSS Service (IGS) is RINEX version 2.11. UNAVCO archives several hundred gigabytes of GPS level 0/1 standard rate (15 s or 30 s sample interval) data per month and delivers approximately five times that to data processors via anonymous ftp. Data are archived in a variety of receiver-specific raw formats, plus BINEX, RINEX 1, and RINEX 2. High rate (1-Hz and 5-Hz) data are also archived. Data archived in BINEX or receiver-specific raw formats are translated to RINEX 2.11 for distribution. While some raw format data are distributed, RINEX 2.11 format is by far the preferred format by customers of the UNAVCO Archive.

RINEX 2.11 incorporates the ability to encode signals from GPS, GLONASS, Galileo and SBAS constellations. An extended version of RINEX 2.11, not recognized by the

IGS, incorporates the ability to encode Beidou/Compass and QZSS constellations, as well as a planned GPS L1C signal and the GLONASS G3 signal.

Table 1 summarizes the signals encoded in RINEX 2.11 and RINEX 2.11 extended. (Note that not all of the signals encoded are currently available, for example, no launches of GPS L1C enabled SVs are expected until after until at least May 2017. The UNAVCO web page GNSS Modernization tracks GNSS constellation status.)

Table 1. RINEX 2.11 official and extended signal codes.

official RINEX 2.11:

GPS	L1	1575.42	C1,P1	L1	D1	S1
	L2	1227.60	C2,P2	L2	D2	S2
	L5	1176.45	C5	L5	D5	S5
GLONASS	G1	1602+k*9/16	C1,P1	L1	D1	S1
	G2	1246+k*7/16	C2,P2	L2	D2	S2
Galileo	E2-L1-E1	1575.42	C1	L1	D1	S1
	E5a	1176.45	C5	L5	D5	S5
	E5b	1207.140	C7	L7	D7	S7
	E5a+b	1191.795	C8	L8	D8	S8
	E6	1278.75	C6	L6	D6	S6
SBAS	L1	1575.42	C1	L1	D1	S1
	L5	1176.45	C5	L5	D5	S5

RINEX 2.11 "extended":

GPS	L1C	1575.42	C7	L7	D7	S7
GLONASS	G3	1202.025	C7	L7	D7	S7
Compass	B1/E2 I/Q	1561.098	C1	L1	D1	S1
	B2/E5b I/Q	1207.14	C7	L7	D7	S7
	B3/E6 I/Q	1268.52	C6	L6	D6	S6
	B1-2/E1I/Q	1589.742	C2	L2	D2	S2
QZSS	L1C/A	1575.42	C1	L1	D1	S1
	L1C	1575.42	C7	L7	D7	S7
	L1-SAIF	1575.42	C8	L8	D8	S8
	L2C	1227.60	C2	L2	D2	S2
	L5 I/Q	1176.45	C5	L5	D5	S5
	LEX S/L	1278.75	C6	L6	D6	S6

In addition, with a small change to RINEX 2.11 extended, the disambiguation of phase values for the following signals can be effected:
-GPS L1C/A, L1P(Y) or GLONASS L1SA, L2HA;
-GPS L2C, L2P(Y) or GLONASS L2SA, L2HA.

RINEX 3

The IGS has introduced a new RINEX 3 format as its standard for handling GNSS that is quite different from the RINEX 2 format. The IGS periodically releases updated definitions of RINEX 3. The current definition is at ftp://igs.org/pub/data/format/rinex303.pdf. The IGS is currently running a Multi-GNSS Pilot Project, with over 130 GNSS enabled stations. Data in RINEX 3 format are being made available regularly through IGS data centers. The UNAVCO community can access IGS RINEX 3 data from for example ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/daily/rinex3/2016/080/15s/. Clock and orbit products are also available from the IGS.

Preprocessing Tools for GNSS Level 0/1 Data

RINEX 2.11

For nearly 20 years UNAVCO has supported TEQC (Translation, Editing, Quality Checking) software for preprocessing and quality checking GPS data. TEQC has broad utility for translating raw (receiver-manufacturer proprietary formats) into RINEX 2, for windowing and splicing together RINEX 2 files, for editing out unneeded observables, for decimation, and for basic signal QC. The TEQC executable code in a variety of architectures is provided by UNAVCO; TEQC is downloaded around 50 times per day from UNAVCO and is in widespread use globally. Within UNAVCO's internal GDS operations, numerous file and metadata data management activities rely on TEQC. Calls to TEQC occur over 60,000 times per day as part of the UNAVCO Archive's operational automated data handling, archiving and distribution activities.

With the utilization of RINEX2.11 extended format, TEQC can be supported to provide full functionality, including QC of data from six GNSS constellations (GPS, Galileo, GLONASS, Beidou/Compass, QZSS, and SBAS). This functionality exists today.

To date, UNAVCO has not received any community-contributed data in RINEX 3 format for archiving. We have received raw data with GLONASS, Galileo, Beidou/Compass, and/or SBAS signals. When raw data is received for archiving having Galileo, GLONASS, and/or SBAS enabled, the raw data has been archived as is, and we have used TEQC for translation to the RINEX 2.11 standard for data distribution, with GNSS encoding as shown in Table 1.

RINEX 3

Although there is currently no functionality in TEQC for handling preprocessing functions with RINEX 3, there are other tools that are available from third parties to handle all of the various preprocessing functions:

- Raw to RINEX 3 Translation: Receiver manufacturer tools; GPS Solutions for selected receiver formats and BINEX

- RINEX 3 to RINEX 2.11 and vice versa: Options are available including gfzrnx (from GeoForschungsZentrum) and GPS Solutions' translation tools

- RINEX 3 Editing: gfzrnx

- RINEX 3 QC: GNUT/ANUBIS (from University of Pecny, Czech Republic)

These tools provide options for the present for UNAVCO GDS and for the community for RINEX 3 data handling and QC. The UNAVCO Archive has utilized receiver-manufacturer tools and gfzrnx for RINEX 3 generation and file renaming to conform with the IGS Standard and is distributing RINEX 3 for several stations as a pilot project. RINEX 3 format data are being made available (ftp://data-out.unavco.org/pub/rinex3/) so that community members can start experimenting with the file naming, file contents, and QC, and also in anticipation of the incorporation of RINEX 3 into the main processing software used within the UNAVCO community, i.e. GAMIT, maintained by MIT, and GIPSY, maintained by JPL, in the near future.

Challenges and Options for UNAVCO in Supporting TEQC Functionality in the GNSS Era

UNAVCO has reached a crossroads with respect to future support of TEQC as a preprocessing tool. We see a need for increased resources to support the functionality of TEQC because of the complexities of the additional GNSS constellations and the attendant new level of complexity of RINEX 3. We also must plan for the eventual loss of current expertise to retirement.

Up to now there has not been an urgent need to make any changes to UNAVCO's support of TEQC within the context of RINEX 2.11. This condition will continue for as long as the RINEX 2.11 extended format meets community needs. An estimate of 1-2 years of development time is envisioned to develop in-house RINEX 3 preprocessing tools with similar functionality to TEQC. In order to commit to such development, we would need to be confident of the availability of resources and expertise for the development and also in the longer term for supporting this functionality.

In making the leap to RINEX 3 support, we see a need as well as an opportunity to change the model that has served UNAVCO and the community for close to 20 years, i.e. software development by a single skilled, committed individual with Development & Testing support, to one of development and support drawn from UNAVCO Software and Development & Testing staff, along with utilization of third party tools, and community contributions to open source projects such as QC software for RINEX 3. This model replaces the single integrated TEQC tool with

multiple tools; though not as convenient as TEQC, this model spreads out the development and support of the required functionality, and may be the most sustainable way forward.

Raw-to-RINEX Translation

Currently, a highly demanding function of TEQC that relies on proprietary information is raw-to-RINEX translation for raw data from many receivers. The consistency of TEQC output and having a single tool for this has been very beneficial for GDS and community members. Supporting this function involves maintaining close interfacing with receiver manufacturers to understand their raw formats. Acquiring sufficiently detailed and correct documentation has been an issue in some cases, requiring intensive, time-consuming interactions between UNAVCO staff and the manufacturers. Meanwhile the additional GNSS constellations and the attendant additional complexity of raw receiver encodings to maintain is likely to make this task grow well out of proportion to UNAVCO's ability to support this function from both resource and expertise perspectives.

One option for UNAVCO and the community is to rely on the receiver manufacturer-provided translation tools. All manufacturers provide executable software that allows users to translate their output from their proprietary format to RINEX 2. As manufacturers add GNSS capability, they are similarly providing (in some cases) an on-board option to output RINEX 3 and/or external translation tools to RINEX 3.

For some users, including UNAVCO GDS operations as well as many in the UNAVCO community, having the raw-to-RINEX translation capability within TEQC has been highly beneficial for a few reasons including eliminating the need to learn more than one tool, and consistency of the output. Also TEQC has been available in a wide variety of server architectures meeting the needs of many users whereas the manufacturer tools are generally limited in this respect.

For the future, UNAVCO expects to support raw-to-RINEX translation for a limited set of receivers selected with the advice of the community.

Other Translation Capabilities

Third party tools already exist for handling BINEX-to-RINEX 3 translation and RINEX 2 to RINEX 3 translation and vice versa, including the GFZ Potsdam's gfzrnx tool and GPS Solutions' tools.

An Open Source Pre-processing Tool for Editing and Quality Checking

Related to removing or reducing the number of proprietary raw formats supported for translation would be decoupling the proprietary part of TEQC code so that the editing and QC functionality could be provided separately, as open source projects. The idea here would be to spread out the support and development of the code to

persons in the community with the expertise and desire to contribute, thereby (ideally) reducing the burden on UNAVCO staff. The University of Pecny has already established an open source software project for QC of RINEX 3 GNSS data with the GNUT/Anubis software.

Conclusions

UNAVCO has taken steps toward providing GNSS constellation data within RINEX 2.11 extended format and through establishing procedures for RINEX 3 handling, archiving and distribution. UNAVCO support for a single tool that provides GNSS translation, editing, and quality checking along the model of TEQC is becoming increasingly difficult to assure. For the future, a model that relies on multiple tools, some provided through open source development and through third parties, as well as through UNAVCO and community support, is likely to be the most sustainable for the long term.

(This document has been reviewed by the UNAVCO Geodetic Infrastructure and Geodetic Data Services Advisory Committees.)