UNAVCO Development and Testing Activities in Support of the IGS GNSS Mission

IGS Workshop 2012 Frederick Blume, Lou Estey, Henry Berglund and Andrea Prantner
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The UNAVCO Facility is actively investigating a number of details critical to the implementation and operation of next generation high-precision GNSS net-works. The addition of new GPS signals and new GNSS constellations to IGS stations will require that new hardware, infrastructure, data formats and software be carefully evaluated and modified. UNAVCO's Development and Testing group is evaluating the current offerings from leading GNSS hardware manufactures. Detailed comparisons of technical features, usability, data quality, and overall performance will be presented. Findings regarding the impacts of critical factors such as near-band RF interference and earthquake ground-motion on tracking characteristics of new hardware will be highlighted.

Many global GNSS stations which are collocated with other space geodetic techniques such as SLR, and VLBI are in need of equipment upgrades, especially antenna and/or antenna/radome replacement. The data from these stations are used in the determination of the Global Geodetic Reference Frame, thus requiring delicate modifications in order to preserve sub-millimeter accuracy in positions. Suitable techniques will be discussed.

The high reliance of data flow on UNAVCO's teqc pre-processing software and the IGS push to embrace RINEX 3.xx have been at odds, as teqc has been limited to RINEX 2.1X. Many new GPS signals and GNSS constellations cannot be handled with current RINEX 2 versions. We will present new options for future teqc development that will implement full GNSS translation, editing, and quality control of all GNSS observables using RINEX 3.XX or enhanced RINEX 2.XX formats. BINEX 7f-05 format enhancements for new observables are also under active development.

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Global GNSS Upgrade Techniques

The Global GNSS Network (GGN) contains some of the longest running GNSS stations to date. A number of these stations are collocated with other space geodetic techniques such as SLR, VLBI, and DORIS. Roughly twenty percent of the GGN stations are IGS stations. The GGN provides infrastructure necessary for very accurate GPS orbit determination and terrestrial reference frame control for a number of NASA missions. There are a number of stations which are in need of equipment upgrades; specifically antenna plus radome upgrades. Changes at these stations require precise and delicate modification in order to preserve sub-millimeter accuracy in positions. Approximately nine reference frame sites continue to use an AOA choke ring antenna, an unsecured and outdated way of mounting the antenna, as well as having an uncalibrated antenna radome combination. These important stations must be modernized as more constellations become available and older equipment begins to fail. Personnel from UNAVCO and JPL have been collaborating on designing, testing, and refining a process that should allow these stations to be upgraded with the least

Quincy, California (QUIN) GNSS station showing mounting ring, AOA antenna, and JPLA radome. Due to the design of the ring and the method by which the antenna was attached to the ring, it is not possible to use a calibrated antenna-radome combination such as a SCIGN radome without moving the antenna off of the ring in which it sits, as shown in the photo above

Santiago, Chile (SANT) GNSS station similar to the other eight stations which are in need of antenna-radome replacement.

North Liberty, Iowa (NLIB)- Wasp hives and broken dome pieces under GPS antenna when AOA antenna was removed for replacement in November 2009. This antenna and radome provided 16 years of continuous service to the user community.

Installation at North Liberty, Iowa (NLIB) November 2009

Photo shows campaign system setup over 'North Liberty 1987 Mark'. System used a Tech2000 mast, Topcon CR-G3 choke ring antenna and an Ashtech CGRS receiver.

NLIB Station Mark (dot inside of triangle)

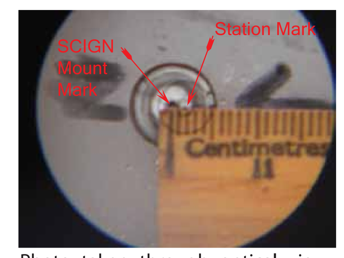


Photo taken through optical viewfinder of tribrach and shows a horizontal offset of roughly 2 mm to the North.

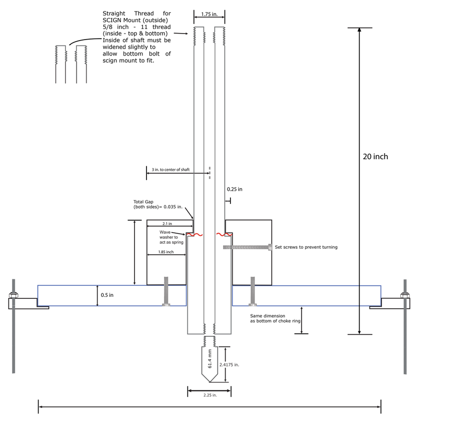
Photo shows spike sitting on edge of mark, indicating that this mount was has introduced a horizontal offset

Once the damaged antenna at NLIB had been removed, a tripod and tribrach were emplaced over the station mark so that the tribrach's optical plummet was centered over the mark. Without touching the tripod or the tribrach, the new antenna mount was installed onto the ring. The bottom plate of the SCIGN mount is marked at it's center allowing for comparisons of the horizontal alignment between the station mark and the new mount. Unfortunately, the new mount introduced a horizontal offset of ~2mm. A redesign of the mount would be required to ensure that the new antenna mount would be horizontally aligned with the old station

Installation at North Liberty, Iowa (NLIB) December 2010

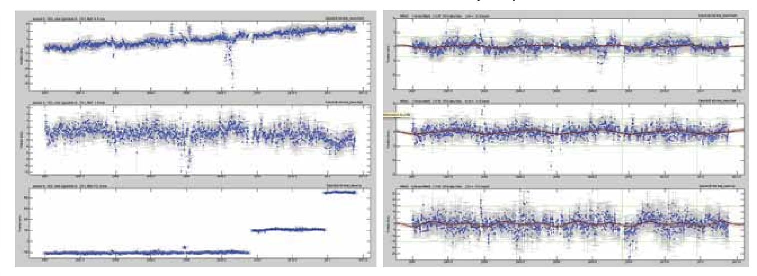
On December 15, 2010, the first prototype was replaced with the redesigned mount. The new mount is now horizontally aligned with the station mark eliminating the horizontal offset between the old and new antenna installations.

Diagram of new Mount



NLIB GNSS Station December 2010

GAMIT time series with and without jumps in vertical

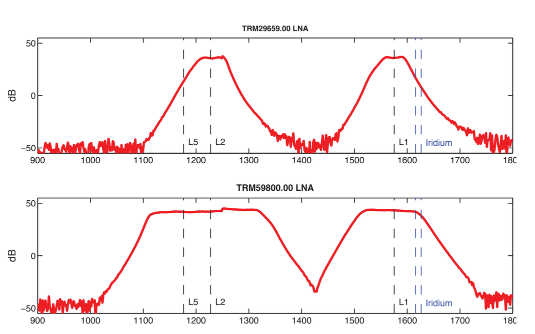


The vertical offsets added up to solve for ARP:
61.4 mm = 061.40 mm or 0.0614 m (ARP #1, 1993-03-05 to 2009-11-16)
61.4 mm + 207.05 mm = 268.45 mm or 0.2685 m (ARP #2, 2009-11-19 to 2010-12-14)
61.4 mm + 207.05 mm + 341.82 mm = 610.27 mm or 0.6103 m (ARP #3, 2010-12-15 to present)

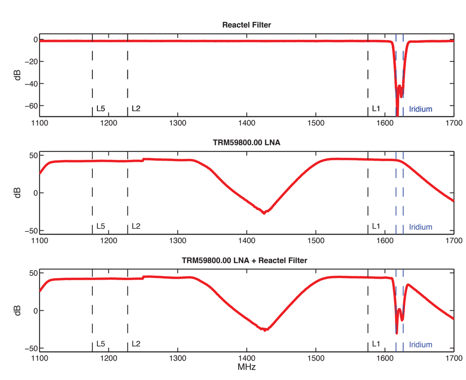
Hardware Evaluations

GPS/GNSS Interference from Iridium Data Transmitters

The higher bandwidth of the Low Noise Amplifiers (LNA) used in many newer GNSS receivers/antennas can increase the impact of near-band RF interference on tracking performance. Our testing has shown that the quality of data collected at sites collocated with iridium communications is highly degraded for antenna separations up to and possibly exceeding 100m. Using older GPS antenna models (e.g. TRM29659.00) with newer GNSS enabled receivers can reduce this effect, due to the narrower bandwidth of the antennas LNA. To mitigate the effects that iridium data transmissions have on receiver tracking performance, we tested a custom cavity-type notch filter designed to attenuate the Iridium RF band. The filter has a >20dB rejection at 1616-1626.5 MHz. Test results with the filter installed have shown excellent GPS data quality at antenna separations of ~30 m.



Gain vs. frequency for a Trimble GPS Choke Ring antenna LNA compared with a Trimble GNSS Choke Ring LNA. The bandwidth of the newer GNSS choke ring has been increased to improve the tracking of GPS signals.



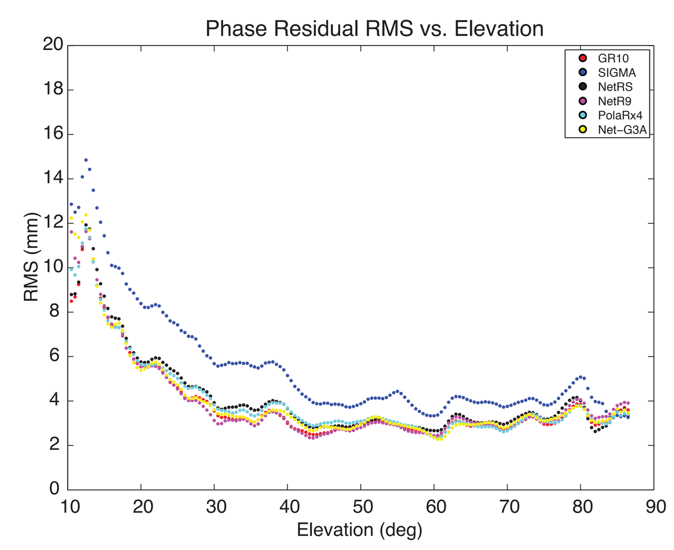
Gain vs. frequency for Trimble GNSS Choke Ring LNA with custom cavity-type notch filter placed in line.

A custom cavity-type notch filter designed to mitigate the interference caused by Iridium communication.

GNSS Receiver Hardware Evaluations

Phase Residuals

Phase residuals from double-differenced carrier-phase processing from 5 receiver manufactures are compared. Each of the 5 receivers tested shared the same antenna using a powered splitter from GPS Source. Daily phase residuals from five days of GAMIT processing were interpolated onto an elevation and azimuth grid. The five daily grids were then averaged to mitigate the influence of non-multipath error sources. The Javad Sigma receiver showed the highest calculated phase residual RMS at all elevation angles . The phase residual RMS from the remaining receivers were similar for all elevation angles. The increase in phase residual RMS for the Javad Sigma could be the result of differences in the tracking loop bandwidth, or a greater sensitivity to multipath when compared to other tested receiver models. Only three of the five tested models allowed for adjustments to the tracking loop parameters. For this study we applied the default tracking loop parameters to all receiver models tested.



Septentrio	PolaRx4				
	MP1	MP2	Percent Complete	slips < 10 deg	slips > 10 deg
	0.3	0.2	100.0	63.0	0.0
	0.3	0.2	100.0	52.0	0.0
	0.3	0.2	100.0	65.0	0.0
	0.3	0.2	100.0	56.0	1.0
	0.3	0.2	100.0	63.0	14.0
	0.3	0.2	100.0	61.0	1.0
	0.3	0.2	96.0	58.0	0.0
	0.3	0.2	100.0	66.0	2.0
	0.3	0.2	100.0	37.0	0.0
Average	0.3	0.2	99.6	57.9	2.0

Javad	Sigma				
	MP1	MP2	Percent Complete	slips < 10 deg	slips > 10
	0.6	0.7	100.0	216.0	1.0
	0.6	0.7	100.0	174.0	1.0
	0.6	0.6	100.0	146.0	0.0
	0.6	0.7	100.0	197.0	1.0
	0.6	0.7	100.0	170.0	18.0
	0.6	0.7	100.0	166.0	1.0
	0.6	0.7	100.0	194.0	1.0
	0.6	0.7	100.0	230.0	2.0
	0.6	0.7	100.0	193.0	1.0
Average	0.6	0.7	100.0	187.3	2.9

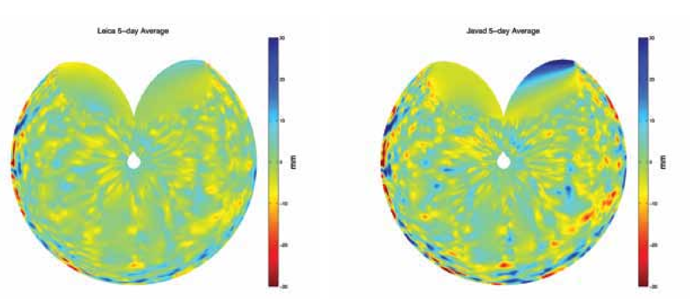
Leica	GR10				
	MP1	MP2	Percent Complete	slips < 10 deg	slips > 10
	0.2	0.3	100.0	597.0	12.0
	0.2	0.3	100.0	548.0	13.0
	0.2	0.3	100.0	554.0	9.0
	0.2	0.3	100.0	544.0	7.0
	0.2	0.3	100.0	543.0	22.0
	0.2	0.3	100.0	579.0	11.0
	0.2	0.3	100.0	542.0	9.0
	0.2	0.3	100.0	608.0	15.0
	0.2	0.3	100.0	490.0	13.0
Average	0.2	0.3	100.0	556.1	12.3

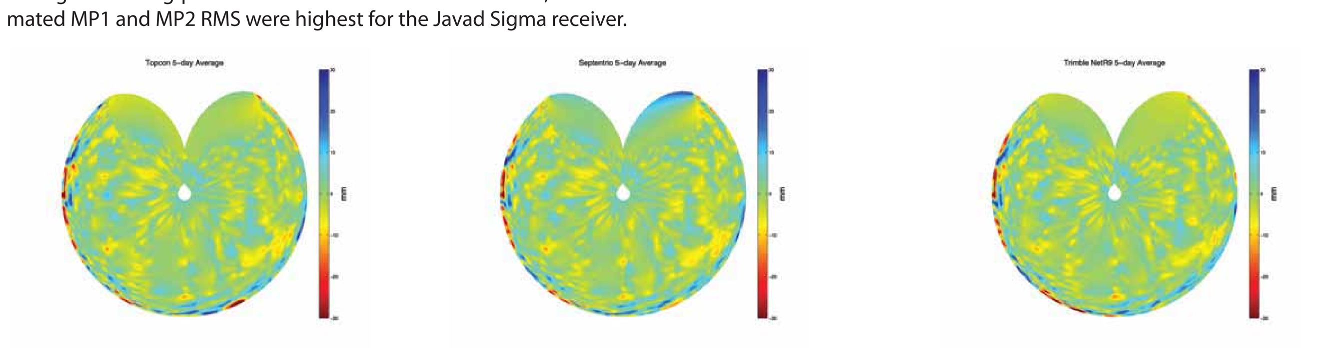
Trimble	NetR9				
	MP1	MP2	Percent Complete	slips < 10 deg	slips > 10 deg
	0.5	0.4	98.0	352.0	1.0
	0.5	0.4	100.0	302.0	3.0
	0.5	0.4	99.0	349.0	4.0
	0.5	0.4	100.0	390.0	2.0
	0.5	0.4	100.0	343.0	25.0
	0.5	0.4	99.0	335.0	4.0
	0.5	0.4	100.0	349.0	9.0
	0.5	0.4	99.0	433.0	8.0
	0.5	0.4	100.0	428.0	7.0
Average	0.5	0.4	99.4	364.6	7.0

Topcon	Net-G3A				
	MP1	MP2	Percent Complete	slips < 10 deg	slips > 10
	0.4	0.4	100.0	108.0	0.0
	0.4	0.4	100.0	67.0	0.0
	0.4	0.4	100.0	67.0	0.0
	0.4	0.4	100.0	92.0	0.0
	0.4	0.4	100.0	53.0	7.0
	0.4	0.4	100.0	81.0	1.0
	0.4	0.4	100.0	88.0	0.0
	0.4	0.4	99.0	84.0	2.0
	0.4	0.4	100.0	92.0	0.0
Average	0.4	0.4	99.9	81.3	1.1

Teqc QC results

To evaluate receiver performance we tabulated QC results from Teqc for nine 1-second, 24-hour RINEX files translated from each of the five test receivers. All of the receivers were connected to an 8-way splitter and shared the same antenna during the test. The following results were tabulated and averaged: MP1, MP2, Percent Complete, number of slips < 10 deg, and number of slips > 10 deg. All of the tested receivers tracked more than 99% of the expected observables. As expected, more slips occurred for elevation angles less than 10 degrees. The Leica GR10 had the highest number of total slips during the testing period. The Septentrio had the least number of total slips during the testing period. Out of the five tested receivers, the estimated MP1 and MP2 RMS were highest for the Javad Sigma receiver.



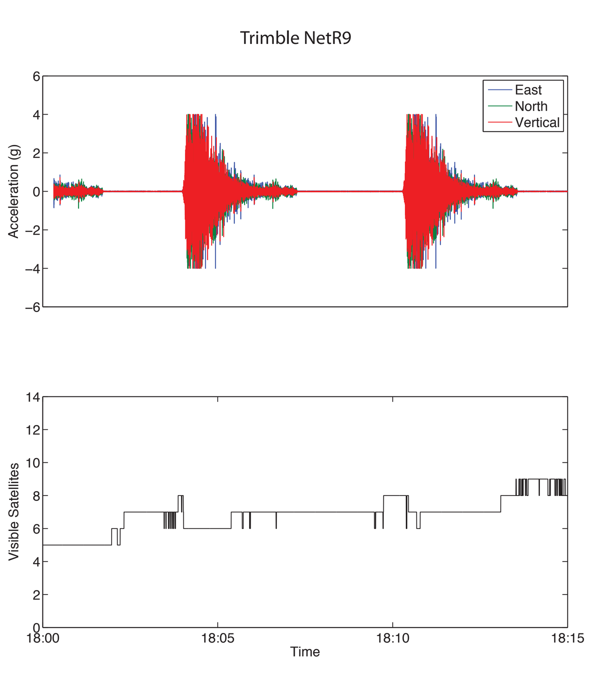


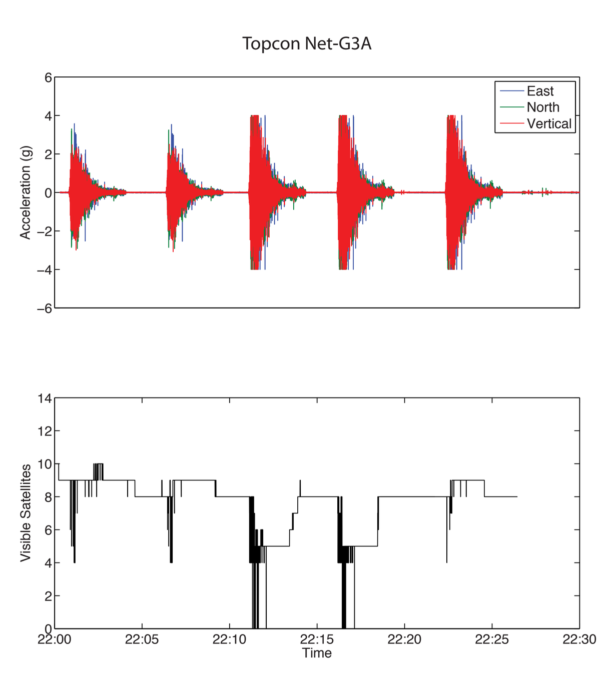
Receiver Tracking Performance During Simulated Earthquakes

Five receiver/antenna pairs were shaken using a 3-axis all-electric servo-motor driven shake table. Acceleration data from the 2010 Chile earthquake were used at three different magnitudes to drive the table (maximum accelerations of 0.6g, 3g, and 6g). A 40Hz high-pass filter was used to remove the high-amplitude low frequency component due to limitations in the range of the table. We used a Kinemetrics Episensor sensor to simultaneously log acceleration at a 100 samples per second. Initial results show that for some receiver models the number of tracked satellites decreased during 3g and 6g shaking events. One of the tested models lost lock on all satellites for several periods during the largest shaking events (>6g). Two preliminary results are shown to the right.

RIGHT: Results from a Trimble NetR9 receiver. The test receiver continued to track 6 or more satellites throughout two shaking tests, which exceeded 6g.

FAR RIGHT: Results from a Topcon Net-G3A receiver. The number of tracked satellites decreased to four during two events with maximum accelerations exceeding 3g. The number of tracked satellites decreased to zero during two events with maximum accelerations exceeding 6g. For the last event we removed the Net-G3A receiver from the table and repeated the 6g event with only the antenna fixed to the table. The tracking performance improved.





Future TEQC Development

Recently Added:

Orbit Calculations:
GLONASS using ephemerides in RINEX 2.10 (=2.11)
Galileo/GIOVE using ephemerides in quasi-RINEX (2.30)
QZSS using ephemerides in quasi-RINEX (2.13)

BINEX 0x7f-03 read/write for all GNSS systems
BINEX 0x7f-05 read for all GNSS systems

Upcoming:

Orbit Calculations:
SBAS using ephemerides in RINEX 2.11
Investigate new methodologies for position + velocity (+ acceleration)
Using fewer epochs for each GLONASS or SBAS SV
Using above for SP3 orbits (any GNSS SV)

Improvements in Point-Positioning

Needs Investigating:

- Possible remapping of RINEX 1 and 2.xx data structure to one that would support RINEX 3.xx

Current Data Structure:

index= obs.observation.observable.index[X],
X= L1, C1, P1, S1, D1, L2, C2, P2, S2, D2, L5, C5, S5, D5, L6, C6, S6, D6, L7, C7, S7, D7, L8, C8, S8, D8

n = nth satellite currently being tracked

```
obs.observation.constellation.satellite[n].data[index].u.pseudorange (union real8)
obs.observation.constellation.satellite[n].data[index].u.phase       (union real8)
obs.observation.constellation.satellite[n].data[index].u.doppler     (union real8)
obs.observation.constellation.satellite[n].data[index].u.snr         (union real8)
obs.observation.constellation.satellite[n].data[index].sn            (uint1)
obs.observation.constellation.satellite[n].data[index].lli           (uint1)
```

teqc user interface: -O.obs x1+x2+x3+... to set observables X= x1, x2, x3, ...

Possible Changes to Data Structure to Support RINEX 3.xx:

systems S= GPS, GLONASS, SBAS, Galileo, Compass, QZSS

teqc user interface ...
-O.obs x1+x2+x3+...

... sets X= x1, x2, x3, ...

----

systems S= GPS, GLONASS, SBAS, Galileo, Compass, QZSS

sf= signal_frequency= obs.observation.observable.system[S].signal_frequency[SF],
sf= L1, L2, L5, L5, L7
(currently only need 5, so Galileo "L8" -> L2)

sc= signal_component= obs.observation.observable.system[S].signal_component[SC],
sc= unknown, P-code/HA/A, CA/SA/B, M-code/C, Y-code/A+B, Med/I/D/S/B+C, Long/Q/P/L/A+B, Med+Long/I+Q/D+P/S+L/A+B+C
(currently only need 7 + allow 1 for unknown)

n = nth satellite currently being tracked

```
obs.observation.constellation.satellite[n].data[sf][sc].pseudorange  (real8)
obs.observation.constellation.satellite[n].data[sf][sc].phase        (real8)
obs.observation.constellation.satellite[n].data[sf][sc].doppler      (real8)
obs.observation.constellation.satellite[n].data[sf][sc].snr          (real4)
obs.observation.constellation.satellite[n].data[sf][sc].sn           (uint1)
obs.observation.constellation.satellite[n].data[sf][sc].lli          (uint1)
```

Implications:

- Would re-map or ignore all RINEX 3.xx "tracking modes" = Z-tracking, semi-codeless, codeless (e.g. if qc-ing: Z-tracking -> Y-code, semi-codeless -> P-code, codeless -> unknown)

- New teqc user interface for observables:
-O.freq l1,l2,l5 -> SF
-O.sign py,ca,c,cm+cl,i+q -> SC
-O.meas r,p,s,d

- Old -O.obs flag would be discontinued

- New user interface would not not directly specify observables. There will be a loss of user fine-control on observables

- Would require expert user knowledge of GNSS signals (even for GPS)

- Estimated development time required: at least a year

- Dubious benefit: with actual GNSS receivers available, there isn't much benefit over a simple expansion of exiting RINEX 2.xx (mostly to disambiguate GPS L1 and L2 signals)