UNAVCO Real-Time GNSS Positioning: High-Precision Static and Kinematic Testing of the Next Generation GNSS Network

Henry Berglund (berglund@unavco.org), Kathleen Hodgkinson, Frederick Blume,
Dave Mencin, David Phillips, Chris Walls, Doerte Mann, Christine Puskas, Otina Fox, Chuck Meertens and Glen Mattioli
UNAVCO, Boulder, CO 80301-5553

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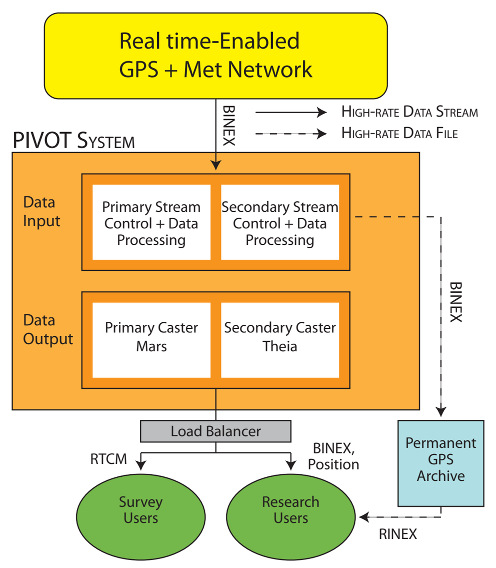
The UNAVCO Real-Time Network

The GAGE facility, managed by UNAVCO, operates a real-time GNSS (RT-GNSS) network of ~450 GNSS stations. The network includes stations that are part of the EarthScope Plate Boundary Observatory (PBO), the Continuously Operating Caribbean GPS/GNSS Observational Network (COCONet), and the Trans-boundary, Land and Atmosphere Long-term Observational and Collaborative Network (TLALOCNet). Following community input from a real-time GNSS data products and formats meeting hosted by UNAVCO in Spring of 2011, UNAVCO now provides real-time PPP positions, and network solutions where practical, for all available stations using Trimble's PIVOT RTX server software.

The UNAVCO real-time system has the potential to enhance our understanding of earthquakes, seismic wave propagation, volcanic eruptions, magmatic intrusions, movement of ice, landslides, and the dynamics of the atmosphere. Beyond the ever increasing applications in science and engineering, RT-GNSS has the potential to provide early warning of hazards to emergency managers, utilities, first responders and others. Recent upgrades to the network include eight Trimble NetR9 GNSS receivers with GLONASS and receiver-based RTX capabilities and ten new collocated MEMS based accelerometers. These new capabilities will allow integration of GNSS and strong motion data to produce broad-spectrum waveforms improving Earthquake Early Warning systems.



Left: A schematic showing UNAVCO's real-time data flow. BINEX streams from telemetered stations are collected by primary and secondary servers in the PIVOT system. At this point the BINEX is sent to the archive for permanent storage and to the primary and secondary castors for streaming to the public. The NTRIP castors distribute RTCM, BINEX, and position streams to registered users. RINEX is also generated and available for download from the archive via FTP.

Right: P484 in Southern California. A MEMS accelerometer is clamped to the vertical leg of the monument. The instrument is connected to the Geodetic Module (below) which is mounted inside the GPS enclosure. The Geodetic Module combines GPS and seismic data on location.

UNAVCO Real-Time Resources:

Network Status:

http://www.unavco.org/instrumentation/networks/status/pbo/realtime

UNAVCO Data Policy:

http://www.unavco.org/community/policies_forms/data-policy/DataStreamingPolicy.pdf

NTRIP Sourcetable:

http://rtgpsout.unavco.org:2101

Request Real-Time Access:

http://www.unavco.org/data/data-help/custom-data-request/custom-data-request.html

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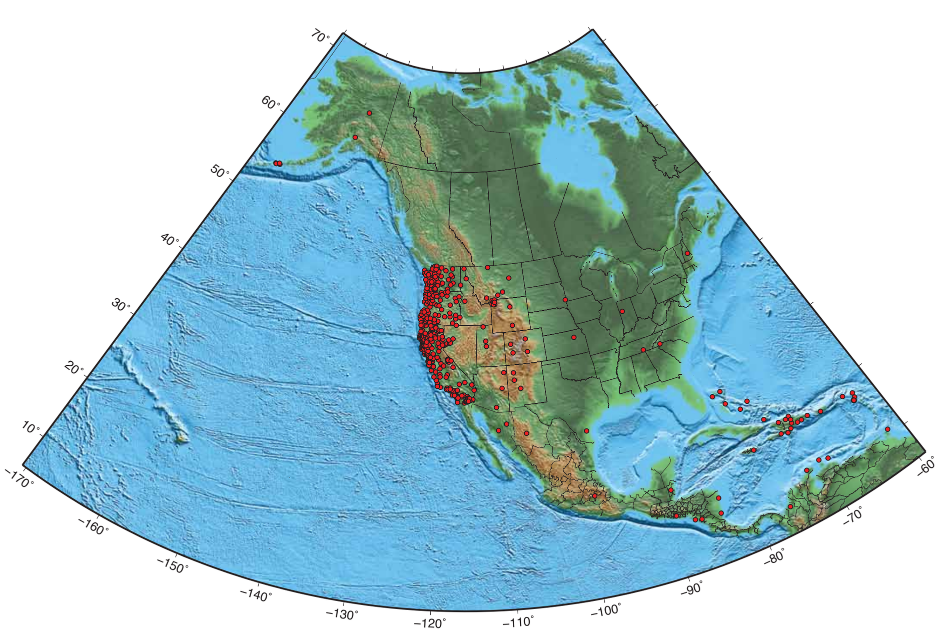
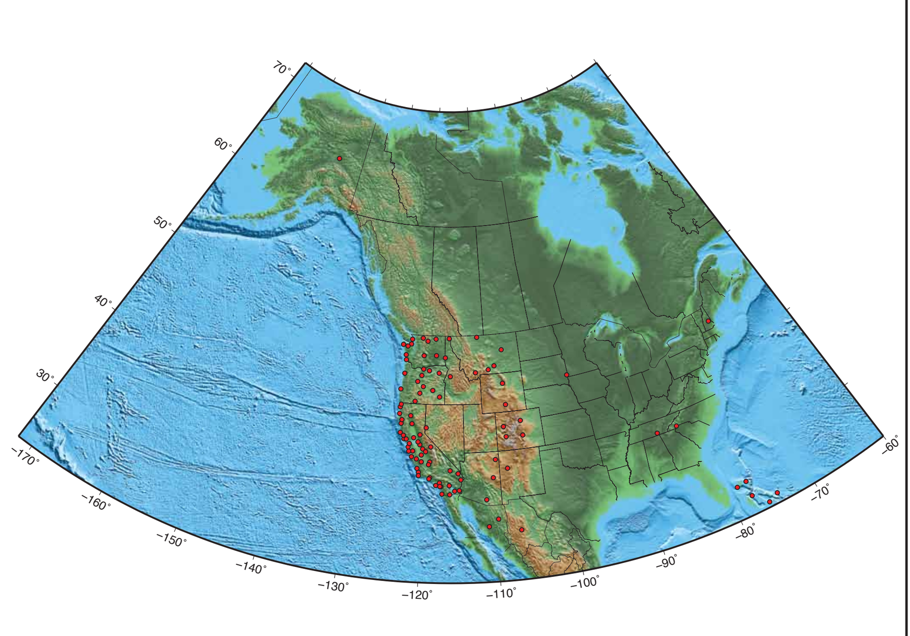
UNAVCO Real-Time GNSS Network



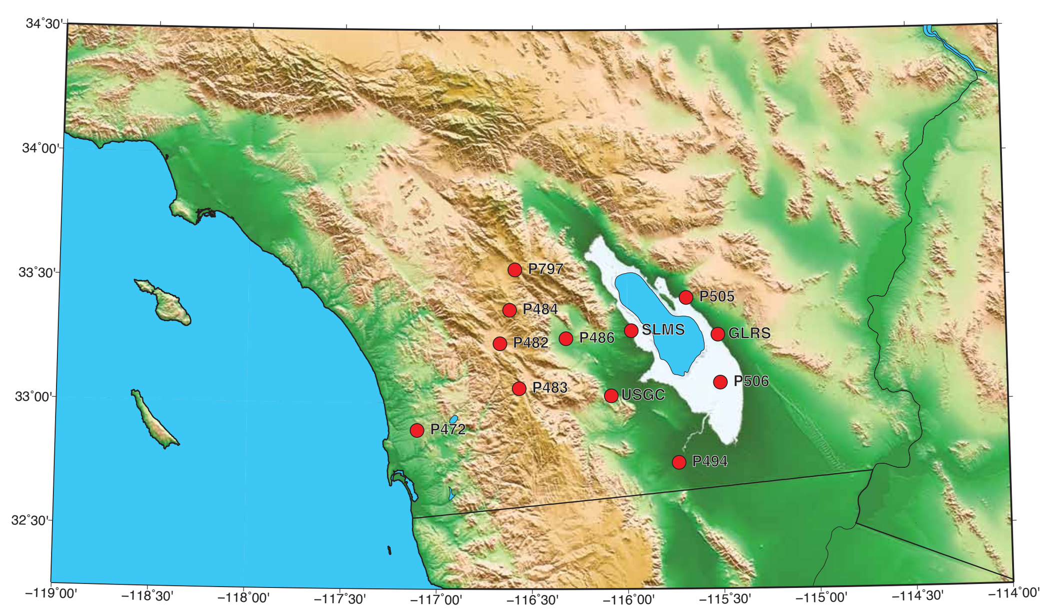
A map of North America showing UNAVCO's current real-time GNSS network of ~450 GNSS stations. The network includes stations that are part of the PBO, COCONet, and TLALOCNet projects.

Real-Time Meteorological Data



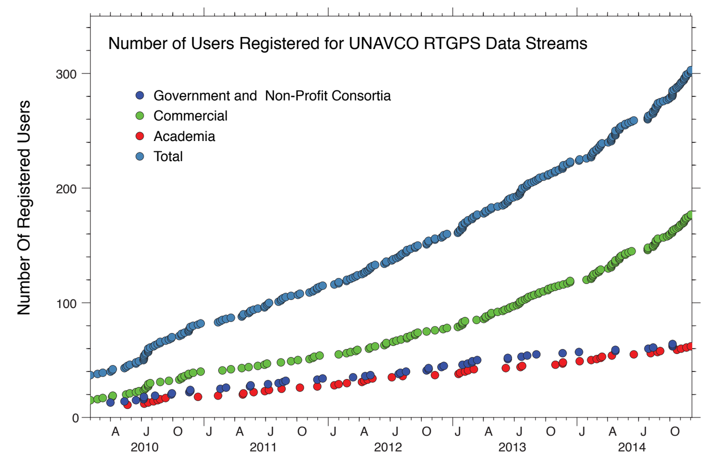
There are approximately 129 Real-time GNSS sites with collocated meteorological instruments. The data from these instruments are made available in near-real-time via BINEX streams, and as RINEX files downloadable from our archive.

Real-Time Sites With MEMS



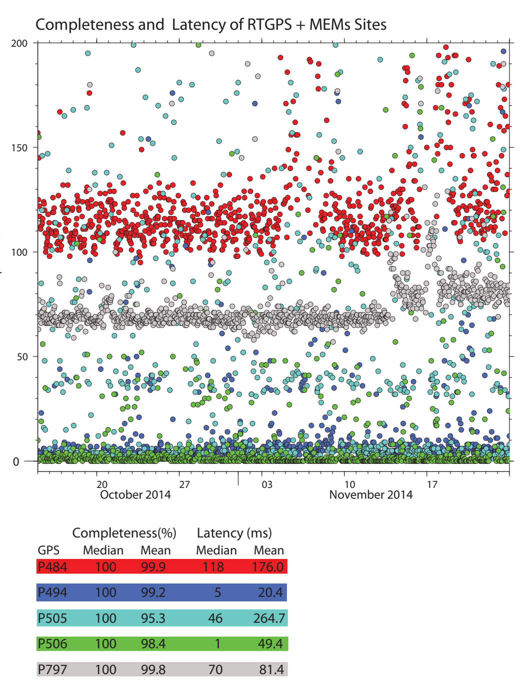
A map of Southern California showing ten sites with recently installed Micro-Electro-Mechanical Systems (MEMS) based accelerometers.

Who's Using The Data?

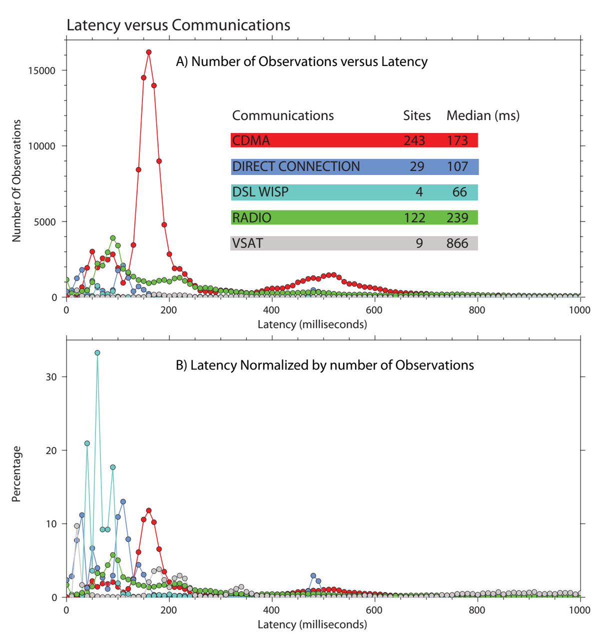


Plot of the number of users requesting access to UNAVCO's real time data streams. Non-profit consortia include entities such as NOAA or UCAR.

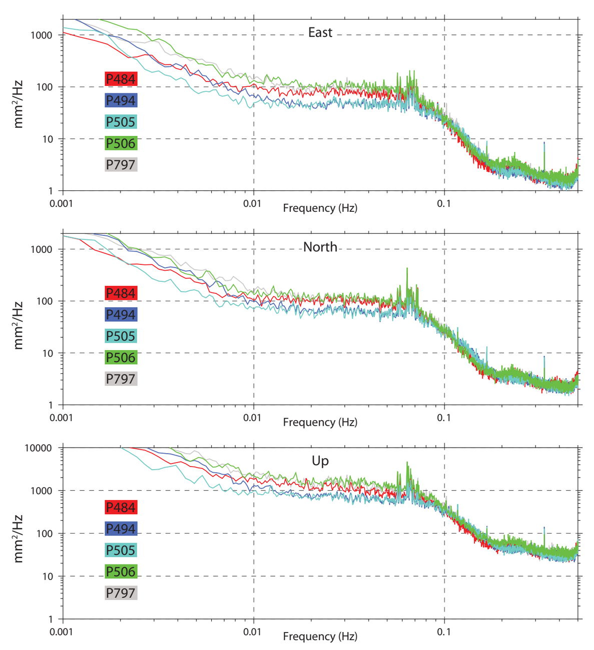
Examples Of Network Performance



Latency and completeness of the MEMS sites in Anza. The figure shows the latency at 1 hour interval for the 1-sps RTGPS data. The table below the plot summarizes the completeness of the data at 1 hour intervals and the latencies using both the median and the mean.



Summary of the latencies across the network. 1-hour latencies were extracted for all PBO MEMs sites between 11/1/2014 and 11/24/2014 from the RTGPS database. The sites were sorted by telemetry type. Offline sites were excluded. There are two side peaks on the CDMA trace, one at ~75 ms and another at 500 ms. This may indicate a regional network issue.



Power spectral density plots for the MEMs sites. This analysis was done with data collected from Nov. 1-2. The vertical component is much noisier, as expected. All the site have similar noise characteristics. However, P494 and P505 are quieter in the 0.1 to 0.01 Hz band. The calculations were made using a 1 hour, 50% overlapping window, with a Welch estimator.

Outdoor Kinematic Testing

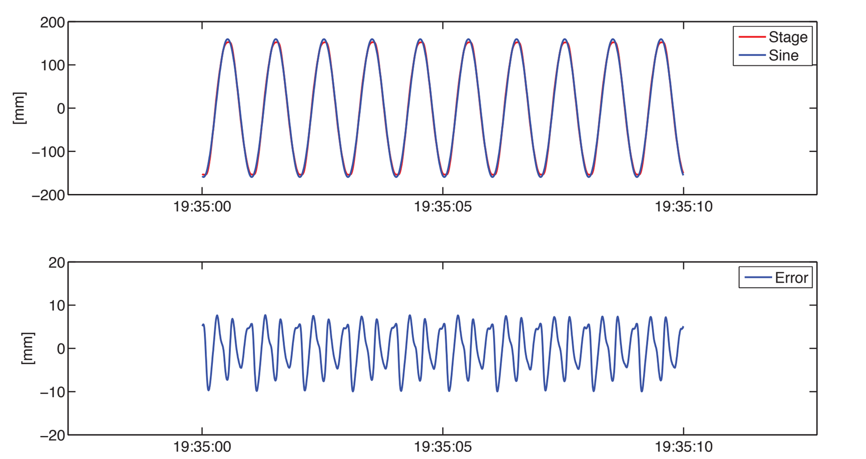
Controlled outdoor kinematic and static experiments provide a useful method for evaluating and comparing real-time systems. At UNAVCO, we have developed a portable antenna actuator to characterize kinematic performance of receiver- and server-based real-time positioning algorithms and identify system limitations. We have performed initial tests using controlled 1-d antenna motions and present recent test results in this poster.

GNSS instruments are being used to record large displacements and accelerations from earthquakes that exceed M7. A few researchers have conducted tests to independently characterize GNSS instrument response over seismic frequencies [e.g. Ebinuma and Kato, 2012; Elosegui et al., 2006; Wang et al., 2012; Langbein et al., 2012]. Previous work has shown that receiver response is not frequency independent for signals greater than 1 Hz, and receiver response varies with receiver make and model. In addition, user selectable tracking parameters may affect a receiver's response. In this paper, we show the response of Trimble's receiver-based RTX real-time positioning service to frequencies from 0.2-6.0 Hz. UNAVCO will continue evaluations of new commercial and open-source real-time positioning services as they become available.

In addition to kinematic testing, long-term static testing of Trimble's RTX service is ongoing at UNAVCO and will be used to characterize the stability of the position time-series produced by RTX.

Test Apparatus

Above: UNAVCO's low-cost antenna actuator. The antenna carriage rides on plastic linear bearings. We employ a 500 mm double-action pneumatic cylinder with position feedback to drive the system. A servo pneumatic proportional control valve provides position control using a 0-10 V command signal. The carriage position is logged at 200 Hz using a Kinemetrics Basalt data recorder. Compressed air is provided by a portable consumer-grade air compressor.



An example of carriage displacement error while reproducing a 1 Hz sinusoid. We will be adding an accumulation tank to the system to increase positioning accuracy.

References:

Ebinuma, T. and T. Kato, Characteristics of Very-High-Rate GPS for Seismology, Earth Planets and Space, 64, 2012.

Elósegui, P., J. L. Davis, D. Oberlander, R. Baena, and G. Ekström. "Accuracy of high-rate GPS for seismology." Geophysical research letters 33, no. 11 (2006).

Langbein, J. O., J. R. Evans, F. Blume, and I. A. Johanson. "Tests of GNSS receivers for dynamic, high sample rate response using controlled sources of displacement, velocity, and acceleration." In AGU Fall Meeting Abstracts, vol. 1, p. 1122. 2012.

Wang, G., F. Blume, C. Meertens, P. Ibanez, and M. Schulze. "Performance of high-rate kinematic GPS during strong shaking: observations from shake table tests and the 2010 Chile earthquake." Journal of Geodetic Science 2, no. 1 (2012): 15-30.

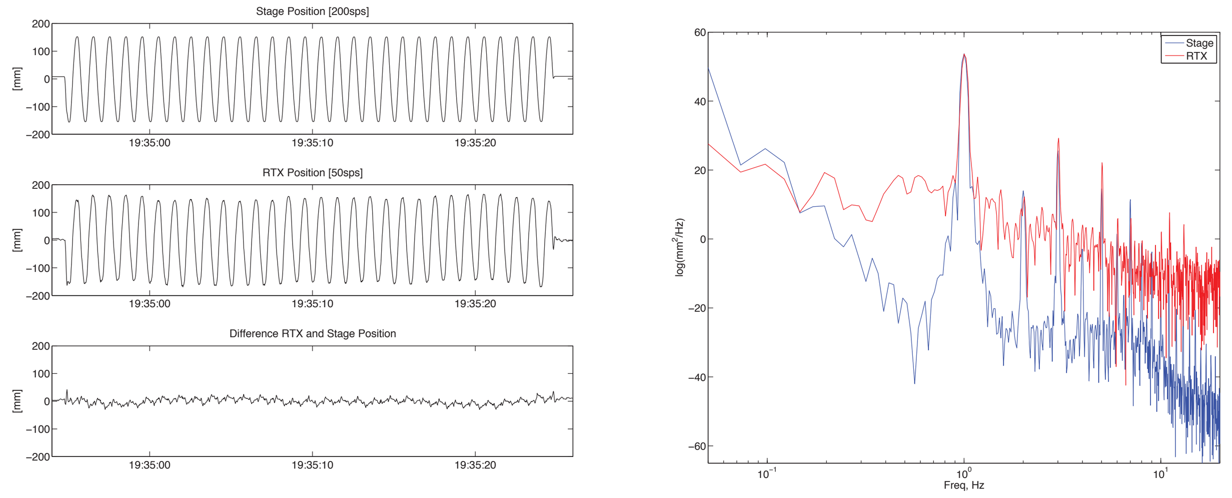
RTX Testing Results:

Frequency [Hz]	Stage Amplitude [mm]	RTX Amplitude [mm]	Phase Difference [deg]
0.2	156.7	155.14	0.77
0.2	157.46	156.6	0.897
0.5	157.51	158.81	1.211
0.5	157.82	159.6	1.266
1	159.41	162.24	2.85
2	104.37	119.6	11.395
3	50.183	82.809	5.85
4	31.46	51.933	-7.55
5	41.631	64.086	-21.423
6	39.22	58.455	-29.8

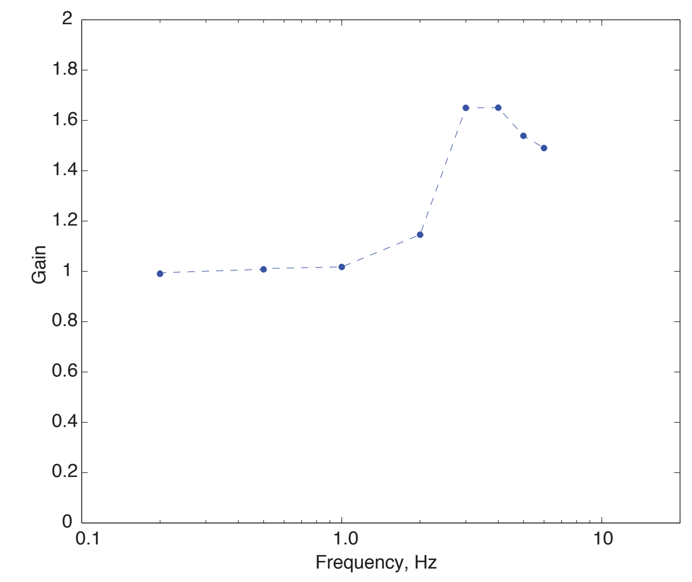
Test Configuration:

Receiver Type: NetR9
Antenna Type: Trimble Zephyr
Position Solution: RTX receiver based PPP service
Receiver Motion: Kinematic (not filtered)
RTK Engine Motion: Kinematic
Constellations: GPS + GLONASS
Sinusoidal Test Duration: 30 seconds

1.0 Hz Sinusoidal shaking (RTX)

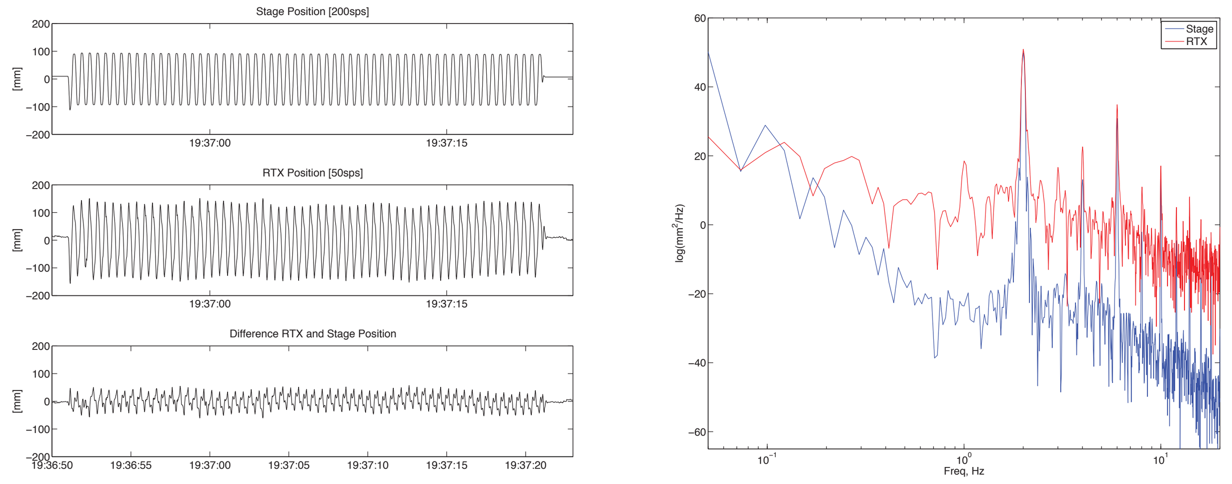


Left: Small differences between RTX measured position and true stage position at 1 Hz. Right: The displacement spectrum of the stage (blue) and RTX (red).

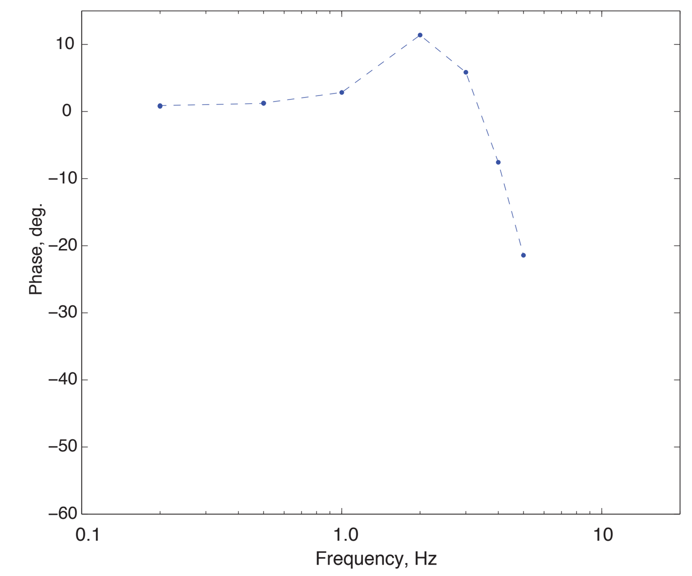


Similar to the post-processed results of Ebinuma and Kato (2012) and Langbein et al. (2012) we observe that RTX has a frequency-dependent response when the antenna undergoes sinusoidal motion.

2.0 Hz Sinusoidal shaking (RTX)

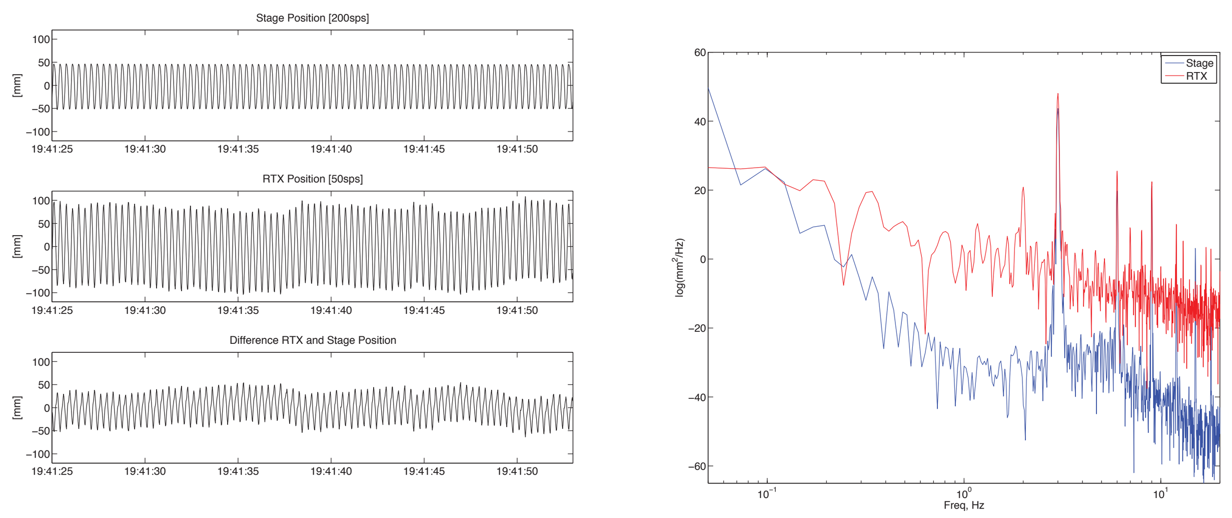


Left: Increasing difference between the RTX measured position and true stage position at 2 Hz. Right: The displacement spectrum of the stage (blue) and RTX (red).



We also observe a frequency-dependent response in the phase of the estimated displacement of the antenna while undergoing sinusoidal shaking.

3.0 Hz Sinusoidal shaking (RTX)



Left: The magnitude of the difference between the RTX measured position and true stage position peaks near 3 Hz. Right: The displacement spectrum of the stage (blue) and RTX (red).

Summary:

Our preliminary testing indicates that the response of RTX is not frequency independent and care must be taken with interpreting observations that contain frequencies greater than 1Hz. Our future testing will compare RTX performance with and without GLONASS. As new commercial and open-source real-time positioning services become available, they will be included in our testing. In addtion we will evaluate the response of receivers to shaking, as all testing to date has been conducted with only the antenna undergoing motion.