A Near Real-time GPS Interference Detection System in the United States Using the National CORS Network

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SUMMARY

The National Geodetic Survey, NOAA, routinely collects data in the Receiver Independent Exchange Format (RINEX) from approximately 1400 CORS stations to support numerous surveying, engineering and scientific applications. These data are collected continuously and packaged into hourly and daily files. In this study, we investigate the feasibility of using the National CORS Network in the United States as a means to detect temporary GPS interference on a regional basis.

To evaluate the GPS interference detection system, hourly RINEX files from numerous CORS stations were processed, shortly after they were collected, to compute positions on an epoch-by-epoch basis. The computed epoch positions, along with the mean position for each hour of data submitted, were then compared to the accepted or published values. A time series of position estimates for each of the CORS stations was then analyzed to identify outliers and to determine if a significant change from the accepted position was observed. The time series positions were plotted to also aid in identifying any trends which may be occurring at the CORS stations.

The initial results from this investigation show that it is possible to identify if a CORS, or any permanent reference site, is experiencing temporary, regional interference which results in the receiver losing lock for some period of time. The latency between the times when the receiver data were collected and the interference was identified was typically one hour. The long term goal of this project is to make the GPS data from the National CORS Network available in real time, thereby supporting epoch-by-epoch position monitoring.

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1. Introduction

The Global Positioning System (GPS) we know today is an accurate and cost-effective positioning, timing and navigation system which supports a wide range of military and civilian applications. Some of the advantages, relative to other positioning systems, of using GPS are: 1) the system is available worldwide; 2) the accuracy is significantly better than other types of positioning and navigation systems as well as regional implementations like Loran; 3) concurrent experiments can be conducted; and 4) the experimental and operational domains can be extensive and very large. With the number of applications growing and the complexity of their implementations increasing, it is vital that the accuracy, reliability and integrity of the GPS signals are monitored and preserved. This is especially true where GPS is used for the transportation industry, airborne guidance and navigation systems, mobile communications networks and safety of life applications.

There are numerous approaches to addressing the issues associated with GPS integrity and signal availability. With respect to monitoring the availability of the GPS signals, two of the most popular approaches can be broken into stages. The first approach tries to: 1) determine if the GPS signals are available or if interference is present, 2) identify the type of interference – electromagnetic, physical etc. 3) locate the source, and 4) eliminate the source. The second approach accepts the fact that electromagnetic interference can be present. One therefore tries to mitigate the effects by improving or building newer components for the GPS infrastructure such as enhancing antenna gain patterns, boosting the signal to noise ratio (S/N) or modeling the types of interference that can exist and eliminating them through digital signal processing. In this paper we concentrate primarily on determining if the GPS signals are available or being jammed, by using a network of GPS receivers located throughout a specific region.

2. National CORS Network as an Array of Sensors

The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service, coordinates a network of Continuously Operating Reference Stations (CORS) located throughout the United States and its territories. Figure 1 shows the stations comprising the National CORS Network in the U.S. The network is a multi-purpose cooperative endeavor involving numerous governmental, academic, commercial and private institutions. As of January 12th, 2010, the network contained approximately 1400 reference stations, each of which provide GPS carrier phase and code range measurements in support of 3-dimensional positioning activities.

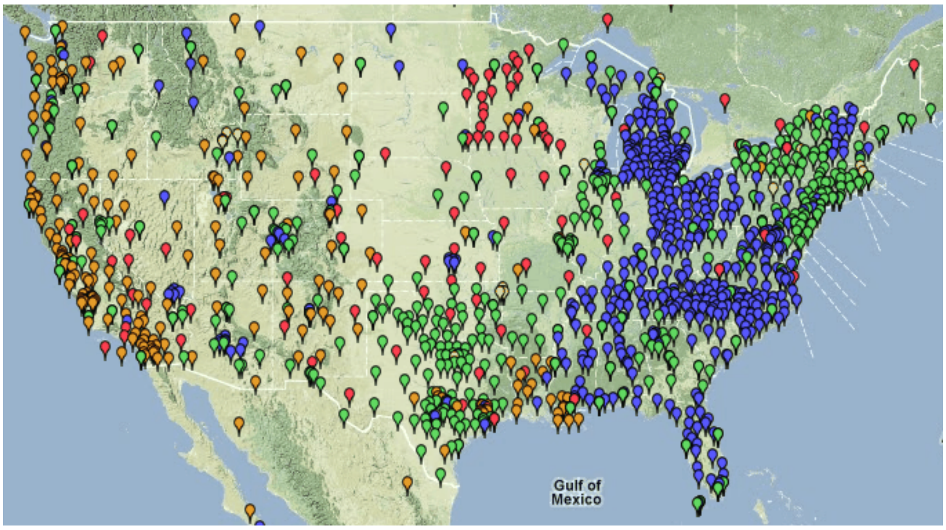


Fig. 1. The National CORS Network (January, 2010).

Although the CORS network is rather heterogeneous, each site must meet and adhere to a minimum set of installation and operational requirements. Each participating CORS station should: 1) be on geologically stable ground, 2) have a geodetic antenna on a rigid antenna mount, 3) have an L1/L2 GPS receiver capable of tracking satellites down to 10˚ above the horizon, 4) log data at ≤ 30 second interval, 5) have a source of clean, uninterruptible power, and 6) allow for pushing or pulling of data. As an example, Fig. 1 shows the station configuration for a site in the Earthscope Plate Boundary Observatory (PBO) Network. Many of the PBO stations also contribute GPS observables, in the form of RINEX data, to the National CORS Network.

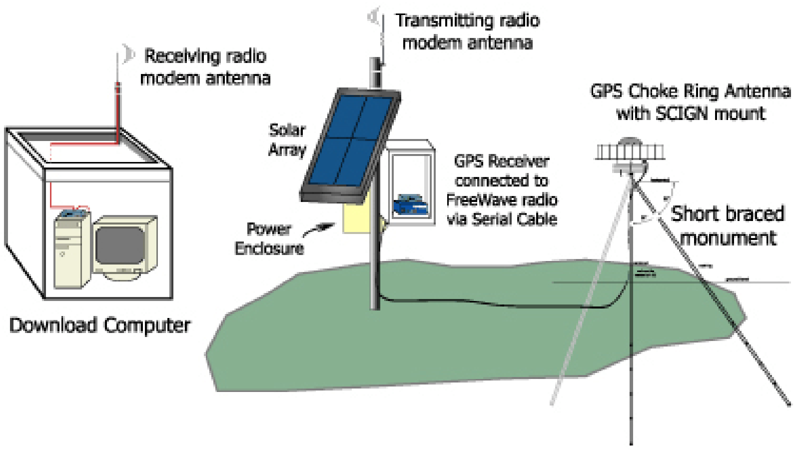


Fig.2 Station configuration for sites in the PBO Network. Courtesy UNAVCO, CO.

Engineers, surveyors, GIS/LIS professionals, scientists and others can access or download CORS data to position points at which they have collected GPS data. The CORS system enables users to achieve horizontal and vertical positioning accuracies that approach a few centimeters relative to the International Terrestrial Reference Frame (ITRF) and to the National Spatial Reference System (NSRS). The data from all sites are processed each day for quality control by monitoring the antenna locations by comparing their calculated and accepted positions and flagging outliers. Any discrepancy from a site's accepted position is flagged and investigated to determine if any operating parameters or the local environment has changed. The National CORS Network is also used to support Web-based positioning tools, atmospheric modeling, and the development of a number of products from the International GNSS Service (IGS) such as satellite ephemerides and real-time data streams. Additional information on the National CORS Network and access to the data are available by visiting www.ngs.noaa.gov/CORS.

3. Detecting and Evaluating GPS Interference

GPS interference is often categorized as one of two types – intentional or accidental. The number of intentional jamming incidents continues to rise mainly because of the availability of jamming hardware which is easy to build, fairly cheap and often commercially available. One of the simplest examples of a GPS jammer is a signal generator that emits a frequency spectrum which overlaps portions of the GPS L1 or L2 spectrums. The transmitted waveforms from the GPS satellites are, by design, very low power and they incur additional strength diminishment from free space loss and to a lesser extent, from losses due to the electronics in the space and user segments. Therefore, a relatively low power transmitter, emitting at frequencies similar to L1 or L2, can disrupt or even knock out reception for nearby GPS receivers. In this case, the severity of the jamming depends on the characteristics of the electromagnetic interference, the type and location of the jammer and the power which is being transmitted.

Unintentional or accidental sources typically come from ultra-wide band devices, harmonic bands from other emitters, and spectrum encroachment, as well as from electronic equipment that is not maintained in proper working order. One example of accidental interference involve certain directional television antennas which use an amplifier to boost the signal. The amplifier occasionally emits an electromagnetic signal which has characteristics similar to the GPS L1 signal and at power levels that can disrupted GPS reception for several hundred meters. Although there are many isolated incidents similar to the example given, it does illustrate that disruptions to the GPS signals occur and the severity of the impact depends on the applications for which GPS is being used and the characteristics of the interference.

To determine how susceptible the GPS signals are to interference, the 746th Test Squadron from Holloman Air Force Base (AFB), New Mexico, built a test facility on White Sands Missile Range to plan and execute elaborate GPS jamming scenarios in a realistic environment. The program was designed to provide a regional electronic warfare environment for testing GPS positioning and navigation systems and to evaluate anti-jamming technologies for customers from the Department of Defense (DoD), numerous defense contractors, civilian organizations and members from the transportation industry. In November 2009, NGS also was invited to participate in one of the electronic warfare campaigns and was asked to determine if electronic interference could be detected by using a temporary reference station as well as stations from the National CORS Network.

4. Electronic Warfare Environment and Jamming Scenarios

Although there were a number of test objectives planned for the November 2009 campaign, this paper will primarily focus on tests which were designed to deliberately jam the GPS signals. The jamming tests used 20 GPS jammers located throughout the White Sands Missile Range which were activated individually, and in groups during a number of scenarios which took place over several days. Figure 3 shows the locations of most of the jammers and the closest CORS station named Socorro (SC01), which operated continuously during the campaign,, recording data at a 30 second interval. The terrain in the test area is predominantly a vast open desert basin, accented by some mountains and ridges.

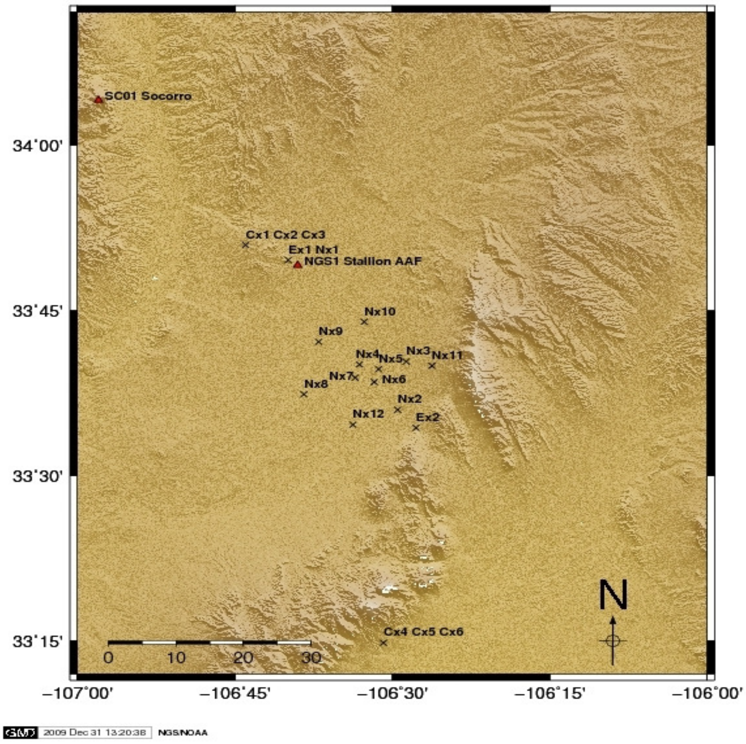


Fig. 3. GPS jammer locations within the White Sands Missile Range, New Mexico.

An additional temporary CORS station (NGS1) was also installed within the test range and was programmed to collect 5 second data for the duration of the test campaign. The purpose of installing NGS1 was two-fold: 1) operate a GPS receiver in close proximity to a number of jammers, and 2) compare the performance of NGS1 to that of SC01 which was much further away. The distance from CORS station SC01 to the approximate center of the jammers (near Nx6) was 62 km while the distance from NGS1 to Nx6 was 23 km. The distance between the two CORS stations was approximately 38 km. The elevation of SC01 is approximately 615 m higher than NGS1.

For most of the test scenarios, directional jammers with a 30° beam width were programmed to turn on and off at specific times and to transmit either broadband noise (BBN), binary phase shift keyed (BPSK) waveforms, continuous wave or a knock out pulse (KO) at a specific power. One scenario used a low power jammer (37 dBm) with an omni-directional antenna to transmit BBN and BKSP noise and another used multiple jammers with a noise ramp, in which the power was increased every five minutes. A partial listing of the test scenarios is listed in Table 1, and Table 2 lists the jammers that were used in each of the scenarios.

Scenario	Duration (min)	Monday	Tuesday	Wednesday
1	20	Low power omni, BBN	Low power omni, BBN	Low power omni BPSK
2	30	Crossroads, BBN, CW	Crossroads, BBN, CW	All noise ramp
3	30	Crossroads, BPSK	Crossroads, BPSK	Crossroads, BBN
4	30	ET #1, KO pulse	ET #1, KO pulse	KO pulse

Table 1. Partial listing of the test scenarios for the GPS jammers.

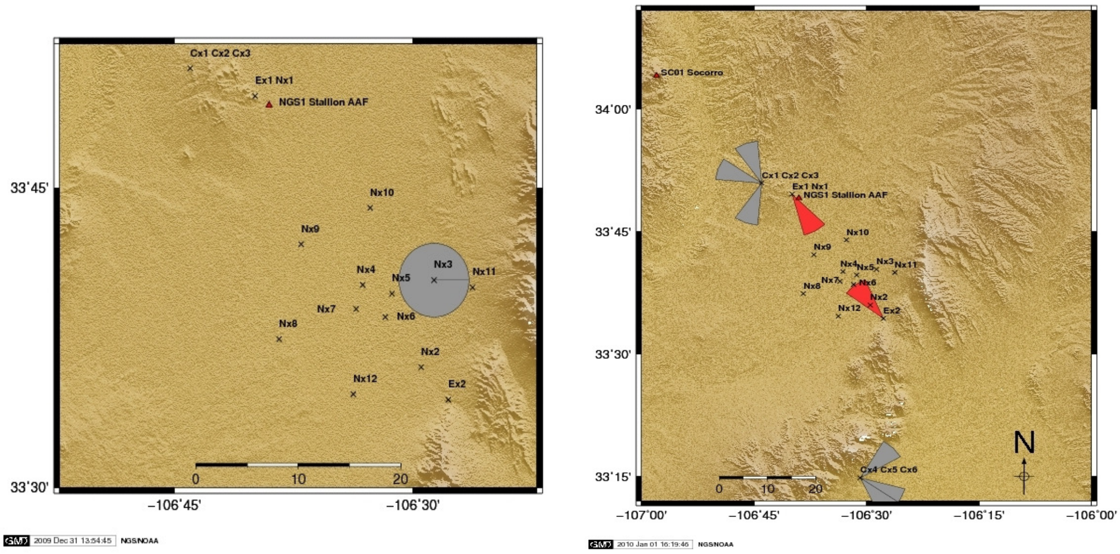
Scenario	Low power omni	Crossroads	All noise ramp	ET 1, KO pulse	ADAP BBN
1	Nx3				
2		Nx4 – Nx7	Nx1-Nx12		
3		Nx4-Nx7			
4		Nx1-Nx12		Cx1-Cx6, Ex1	

Table 2. Jammers that were activated for each of the scenarios.

5. Results

To determine if GPS interference could be detected at the two CORS sites, NGS developed prototype software to process hourly RINEX data shortly after its collection. The software was designed to calculate the position of the CORS antenna, for each epoch of data, and then compare those results to the accepted position. A time series of position estimates for the two CORS sites was then analyzed to identify outliers and to determine if significant difference from the mean had been observed. The time series of position offsets, which coincided with several test scenarios, was plotted also to see if the receivers at the CORS stations were affected by a particular type of interference or noise waveform.

The objective of the first scenario was to determine if a low power (37 dBm), omni-directional broadband noise signal could interfere with GPS tracking within the White Sands Missile Range. Figure 4a shows the location and direction of the jammer's transmission used in the first scenario. The radius of the gray circle is not associated with the interference range or area of coverage.



Figs. 4a and 4b. Location and direction of jammer transmissions for scenarios 1 and 4.

Figures 5 and 6 show the time series plots of the north, east and up offsets from the true antenna position for SC01 and NGS1, computed during scenario 1. The distances from SC01 and NGS1 to the jammer are 62 km and 23 km respectively. With the exception of one epoch jump, Fig. 4 illustrates that there was no apparent effect from interference at SC01. This is most likely due to the distance from the jammer. However, the GPS receiver at NGS1 was not able to track any satellites during the 20 minute period when the jammer was on. Once the jammer was turned off, the receiver quickly began to acquire data. The slope of the up component plot for SC01 is due to the changing ionosphere, one of several external effects which were not modeled in the positioning program.

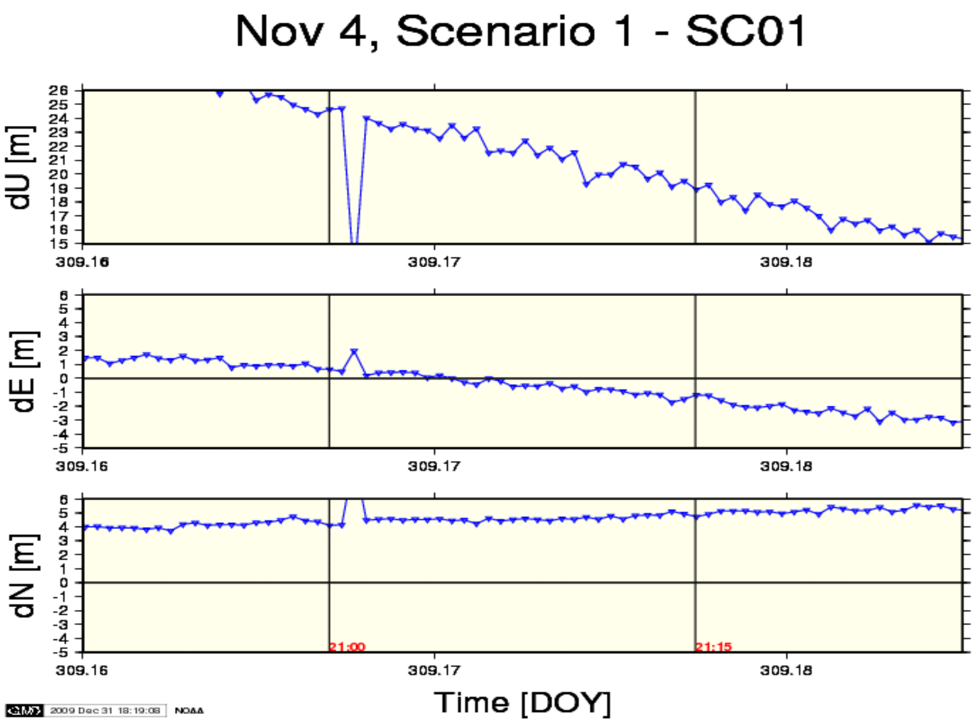


Fig 5. SC01 - Low power omni (37 dBm, broadband noise)

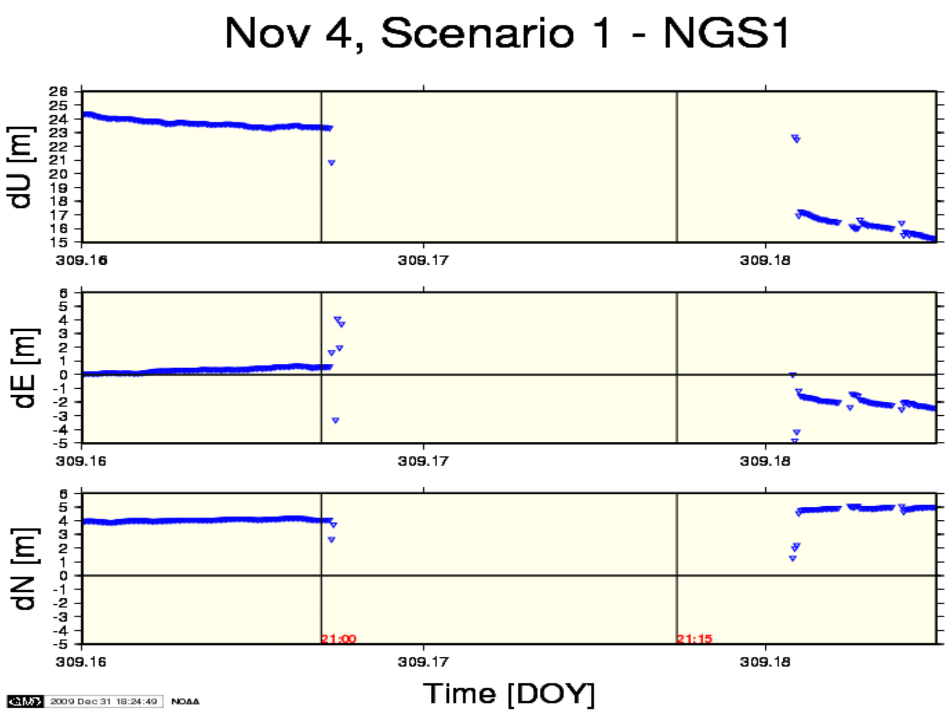


Fig 6. NGS1 – Low power omni (37 dBm, broadband noise)

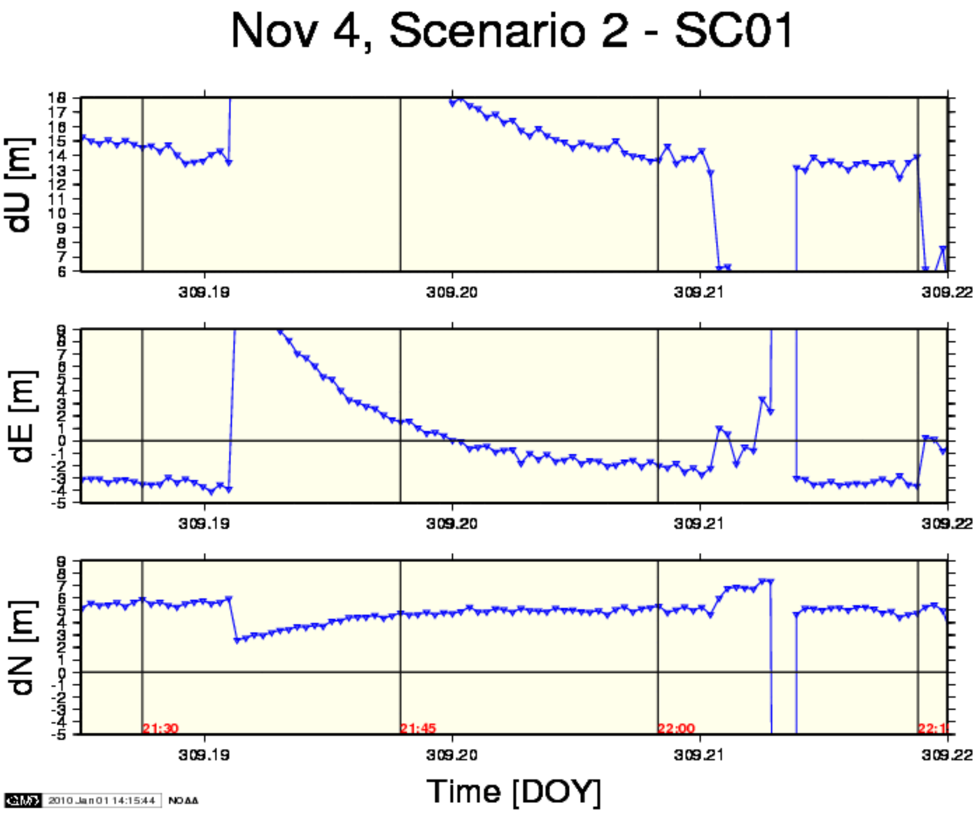


Fig. 7. Effects at SC01 from an all noise ramp powered from 0 to 48.5 dBm over a 30 minute period.

Scenario 2 on November 4th used four directional jammers (Nx4–Nx7) and transmitted the same waveform (either BBN or BPSK) as a noise ramp for a period of 30 minutes starting at 21:35 local time. The *all noise ramp* for scenario 2 increased the power from 0 dBm to 48.5 dBm at 1 dBm increments every 15 seconds. The orientation of the jammers was such that each was a mile from, and pointed inward towards the center of the intersection of two roads. The orientation of jammer Nx6 pointed in the direction of SC01 and NGS1.

During the *all noise ramp* jamming period, SC01 did track satellites and did show a few significant position changes from one epoch to the next. NGS1 was able to track satellites at the start of the scenario but roughly 15 minutes later, the receiver was not able to track at least four satellites. The gradual power increase for all jammers and the direction in which jammer Nx6 was pointing probably affected the tracking capabilities of the receiver at NGS1. Once the jammers were turned off, the receiver at NGS1 resumed tracking.

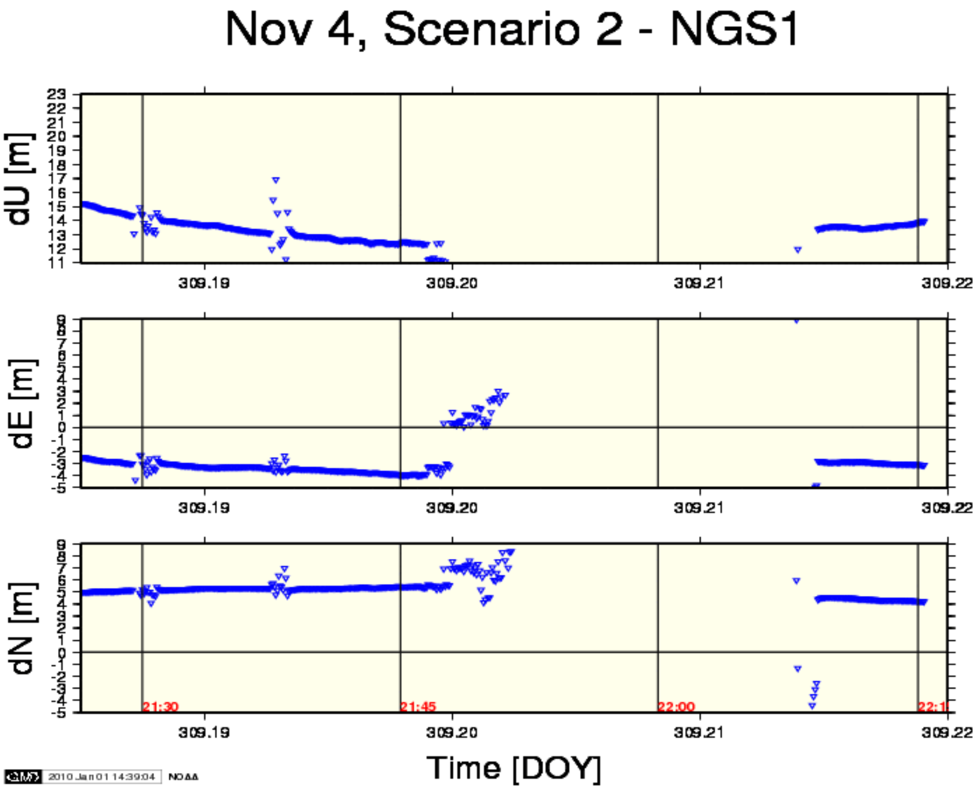


Fig. 8. Effects at NGS1 from an all noise ramp powered from 0 to 48.5 dBm over a 30 minute period.

Scenario 3 used the same jammers and orientations that were used in scenario 2 but instead of using an *all noise ramp*, the interference was generated by a binary phase shift waveform. The power for the jammers was set to 48.5 dBm and the duration of the test was 30 minutes starting at 22:15 local time. The plots in Figs. 9 and 10 show that BPSK interference had a significant effect on the receivers at SC01 and NGS1. Neither CORS station was able to track satellites during the jamming period.

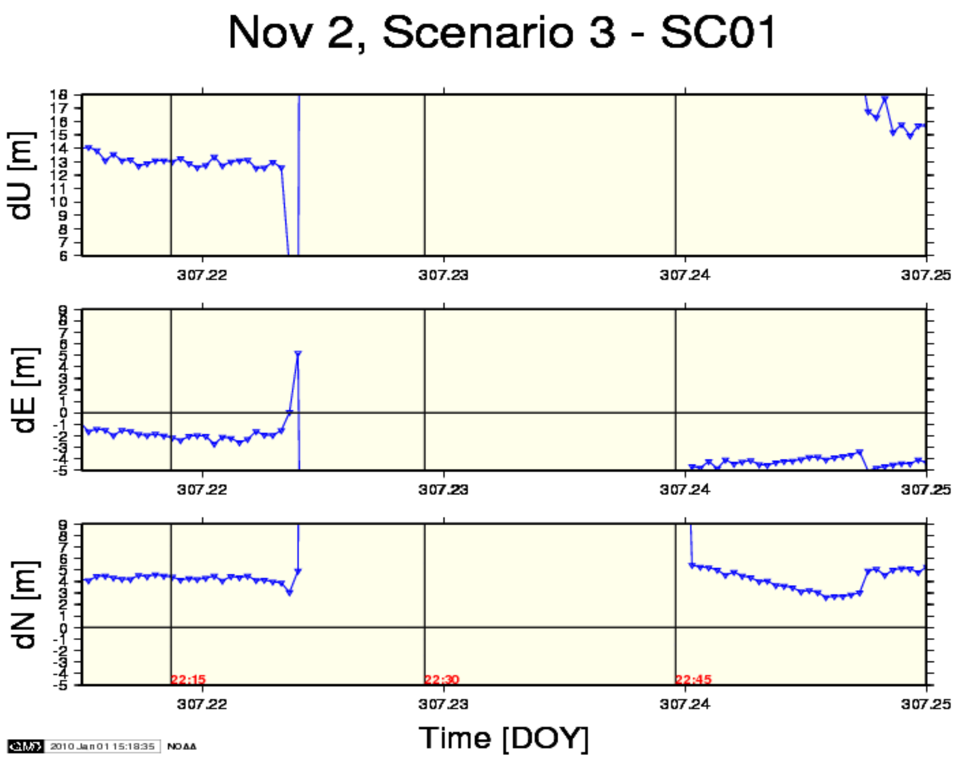


Fig. 9. Effects at SC01 from interference generated by a BPSK waveform (48.5 dBm).

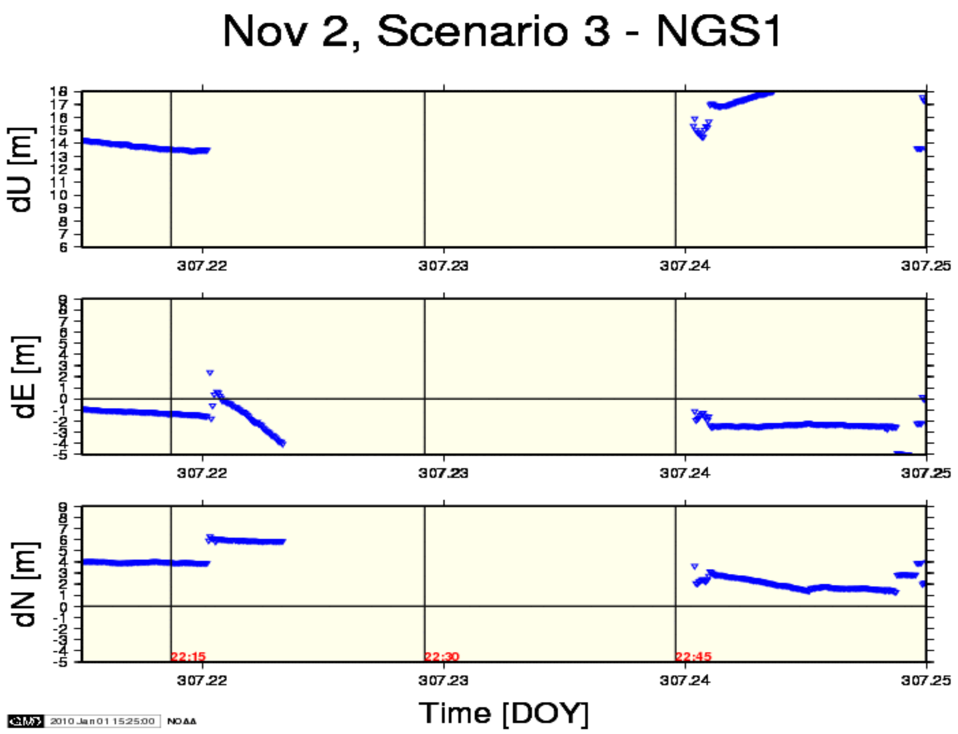


Fig. 10. Effects at SC01 from interference generated by a BPSK waveform (48.5 dBm).

Scenario 4 was designed to simulate a 30 minute *emerging threat* by generating either a single knock out pulse or a continuous repetition of pulses (48.5 dBm) from jammers Cx1–Cx6, Ex1-Ex2 and Nx1. Figure 4b shows the jammers and the orientation of the directional beams used for most cases of scenario 4. The one exception was with the first case, in which jammer Ex2 was not used; the results are illustrated below in Figs. 11 and 12. Jammers Cx1-Cx3 point towards the west and to the northwest in the direction of SC01. The distance between this group of jammers and SC01 is approximately 32 km. Jammers Ex1 and Nx1 are at the same location as NGS1 but point away from the GPS antenna and to the southeast. Once the jammers were turned on, the receiver to the northwest at SC01 lost lock on all satellites for the duration of the test. The receiver at NGS1 initially lost lock on all satellites but acquired them shortly after and was able to continue tracking. Tracking at NGS1 was possible because the directional interference beams pointed away from the GPS antenna but for SC01, the CORS site lay in the direction of the interference beams.

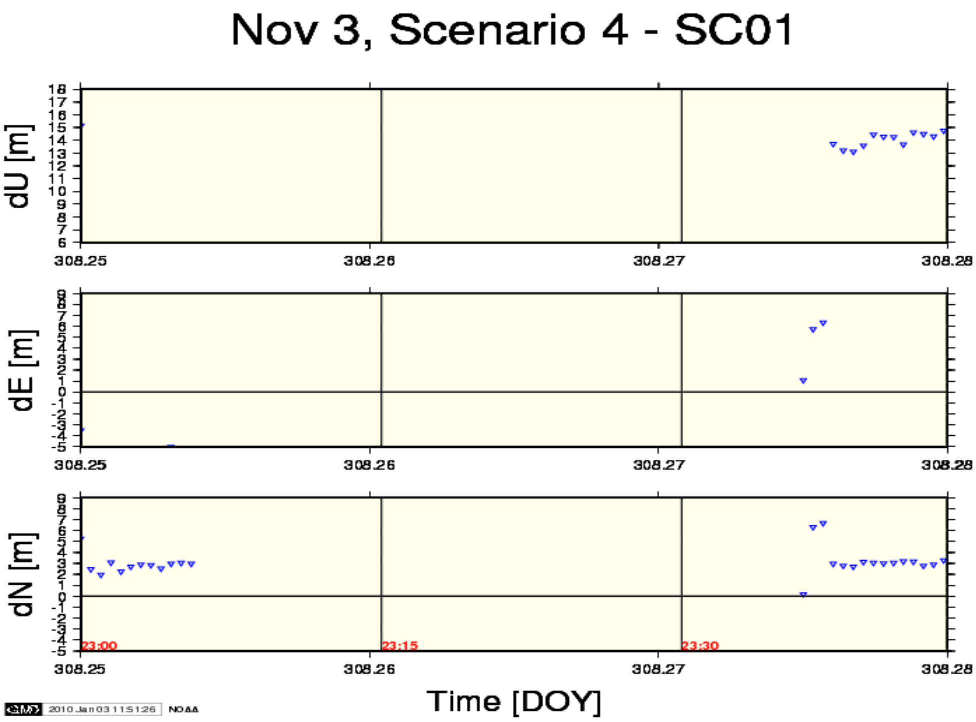


Fig. 11. Effects at SC01 from interference generated by a series of knock out pulses.

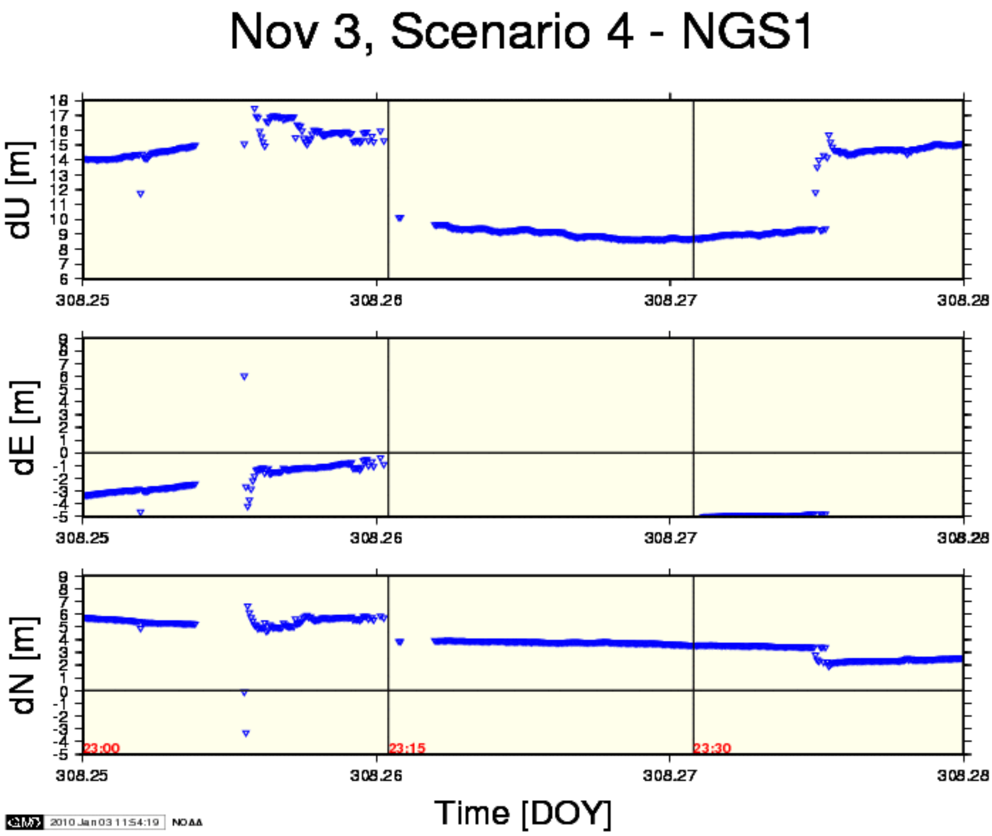


Fig. 12. Effects at NGS1 from interference generated by a series of knock out pulses.

6. Conclusion

The initial results from four test scenarios performed during November 2-4, 2009 show that it is possible to determine if one or more CORS stations are experiencing temporary regional interference. The broadband noise signal from the low power-omni jammer was too weak to have any effect on the CORS station located 60 km away but the power was sufficient to interfere with the GPS reception 20 km away. The noise generated by the binary phase shift waveforms also had a significant effect essentially preventing the two CORS receivers from tracking enough satellites to get a fix. The *all noise ramp* scenario clearly illustrated that if enough power was emitted, the tracking capabilities of the GPS receiver would be impaired. Although we were not trying to identify the type of interference that was present during the tests, we could clearly see when the GPS receivers were impacted by electromagnetic interference with characteristics similar to that of the GPS frequency spectrum. The four test cases also showed that the capability of a GPS receiver to track satellites while operating in a region with electromagnetic interference depends on 1) the characteristics of the noise signal, 2) the distance between the receiver and the emitter, 3) the direction of the beam and 4) the signal strength. It would therefore be possible to use a network of GPS receivers to aid in detecting GPS interference as long as the station spacing is sufficient that one or more receivers can pick up the interference once a certain power threshold was achieved. Many regions of the National CORS Network meet the spacing requirement, especially in large metropolitan areas where the CORS density can be quite high.

ACKNOWLEDGEMENTS

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REFERENCES

Brown, A., Atterburg, S., and Gerein, N., (2000), Detection and Location of GPS Interference Sources Using Digital Receiver Electronics, *Proceedings of ION Annual Meeting*, June 2000.

Parkinson, B., Spilker Jr, J., Axelrad, P., and Enge, P., (1996), Global Positioning System: Theory and Applications Vol. II, American Institute of Aeronautics and Astronautics, Inc.

Snay, R. and Soler, T., (2008), Continuously Operating Reference Station (CORS): History, applications and future enhancements, *J. Surv. Eng.*, 134 (4): 95-104.

Stone, W., (2006), The Evolution of the National Geodetic Survey's Continuously Operating Reference Station Network and Online Positioning User Service, *ION-IEEE Position, Location, and Navigation Symp.*, 653-663.

BIOGRAPHICAL NOTES

Neil D. Weston is the operations and software development manager for OPUS. His interests are in GNSS software development, 3-D imaging and motion analysis. He currently works in the Geosciences Research Division of the National Geodetic Survey.

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