An On-Line Validation Tool for Real Time GNSS Networks in NOAA's National Geodetic Survey

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SUMMARY

This paper describes the ongoing work to align Real Time Global Navigation Satellite System Networks (RTNs) to our national datums. At this writing, there are currently approximately 107 locally-managed RTNs in use across the United States of America providing substantial economic benefit to a wide variety of geospatial professionals. To facilitate accurate data sharing, it is imperative that the positions generated from these RTNs are homogeneous and reliably accurate, from network to network and observation to observation, for many reasons - including national security, emergency management, transportation and expanding geographic information systems (GIS), to name just a few. The National Geodetic Survey (NGS), a program office of the National Oceanic and Atmospheric Administration (NOAA) in the United States of America, is developing a prototype on-line tool to enable RTN operators to test that their networks are compatible wiTS06F_hendriatiningsih_abdulharis_6064th our national datums contained in the National Spatial Reference System (NSRS) database of active and passive control monumentation. While the use of national datums in RTN reference stations is not federally mandated, NGS will work with public, private, scientific and academic RTN operators to develop a tool they wish to employto obtain self-generated time stamped statements of NSRS compliance at certain horizontal and ellipsoid height parameters. The ultimate goal of this new tool is to provite RTN users with some assurance that the positions they obtain from a particular RTN are in the NSRS at quantifiable levels of accuracy.

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1.   BACKGROUND

In the more than 100 RTNs operating within the United States, a great diversity of administrators and users are found. Indeed, there are combinations of public, private, scientific and academic RTNs in amazing synergy. Almost all states' Departments of Transportation (DOT) are either operating RTNs or planning to do so
(Figure 1), with some being no-cost, some with a time based fee, and others with a one-time fee. Private value-added entrepreneurs and GNSS manufacturers alike operate regional RTNs across many state boundaries or municipal RTNs across metropolitan areas. Also, scientific studies are conducted using real-time data streamed from reference stations – for example in the almost 200 receivers operated in the Plate Boundary Observatory (PBO) by the University Navstar Consortium (UNAVCO) [1]. Many public RTNs are geographically oriented to cover a particular state, and in many areas there is overlapping coverage between various private RTNs and/or public RTNs.
Each RTN, by design, creates its own unique reference frame, from customized adjustment constraints, which may or may not include legacy passive marks. National datum tags are often employed, but no coordinated validation currently exists. Thus, there should be a concern that the positional coordinates produced from each RTN are compatible and accurate (Figure 2). While the International Terrestrial Reference Frame (ITRF) remains the ultimate realization of geometrical datum "truth", and the CORS network is aligned very accurately to ITRF, yielding the best representation of the geometric frame within the NSRS, many users in a plethora of geospatial areas reach out in real time to these RTNs for their day to day data. NGS must position itself to support all RTNs, and promote their alignment to the NSRS at a certain level of accuracy without any competition – perceived or real.
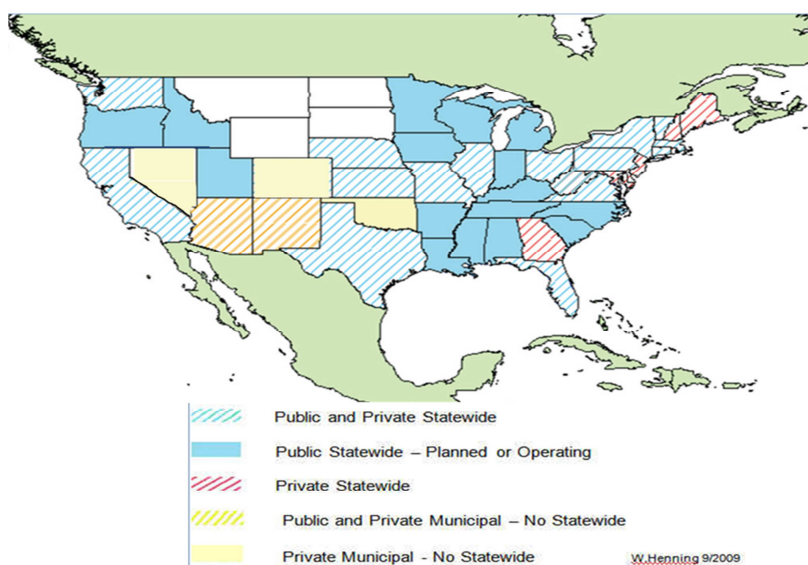

Figure 1 – Showing the Diversity of public & private RTNs in the conterminous USA.
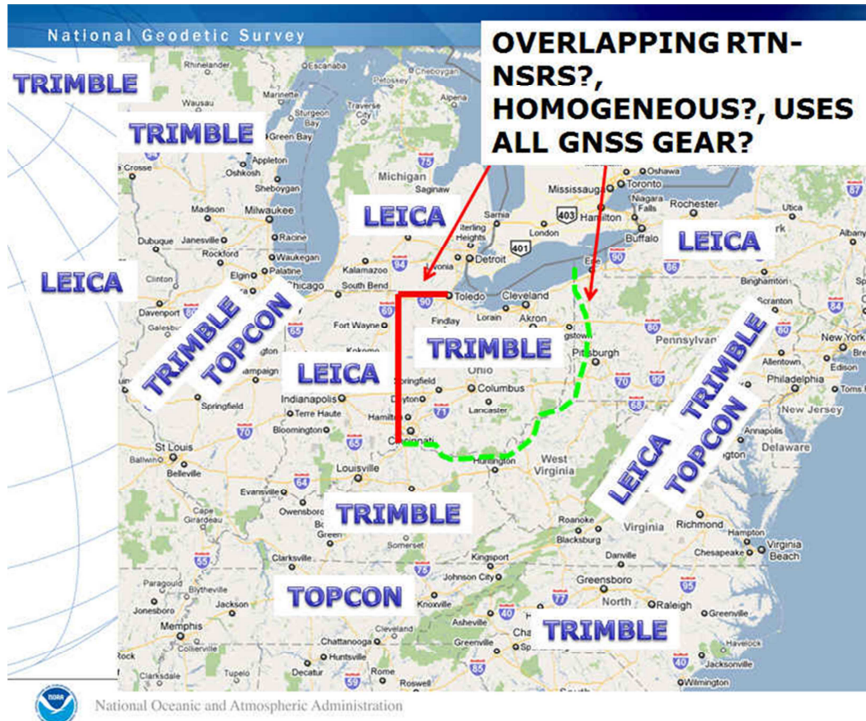
Figure 2 – Overlapping RTNs with different methodologies, datum adjustments and epochs, software, hardware, and constraints, may not provide consistent, accurate NSRS coordinates to the user.

2. THE IMPORTANCE OF THE NATIONAL SPATIAL REFERENCE SYSTEM

The National Spatial Reference System as maintained by NGS, is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States and is designed to meet our nation's economic, social, and environmental needs. NGS provides access to our official national datums, currently represented by NAD 83 (2011) for latitude, longitude and ellipsoid height and NAVD 88 for our orthometric height, and familiar to most geospatial professionals. In addition to supporting traditional land surveying and civil engineering applications, the NSRS has great importance for a diverse set of other geospatial applications. The rapid proliferation of regional and statewide Geographic Information Systems (GIS) warrants seamless connectivity in order to promote functional emergency management, resource management, environmental issues, infrastructure management and national security. RTNs provide an efficient, economical way to capture these various data, populate infrastructures and manage intra county, state and regional systems. Consider, for example, emergency evacuation from flood inundation along coastal

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low-lying areas. Reliable evacuation routes must be planned to ensure elevations high enough to give rapid escape from the impending high water – across state borders and possibly across different RTNs. Incorrect or inconsistent elevation data could result in serious problems. In a more traditional arena, design and construction work typically requires that plans, drawings, and plats for rights-of-way, building, pipelines, roads, bridges and other infrastructure, fit together section to section and year to year. Machine guidance and precision agriculture are now working at the centimeter level and employ real-time positioning from active stations. Rail and water navigation, to and from transportation and commerce centers, benefit from real-time positioning as well. These activities and others require a unified, seamless, accurate basis as supplied by the NSRS and maintained by NGS. NGS is promoting that RTNs be aligned to the NSRS, which contains the consistent nationwide geometric and geopotential datums, at appropriate levels of accuracy.

> **Comment [DAS1]:** This is too much opinion, and not enough science based policy. Let's not speculate.

3. THE EVOLUTION OF RTNs FOR GEODETIC POSITIONING IN THE USA

There is little doubt that positioning in the United States is rapidly moving away from relying on ground monumentation to control land surveying and engineering work and moving towards trust in active station global navigation satellite system (GNSS) antennas to yield these positional coordinates. Currently, the North American Datum of 1983 serves as the national geometric datum and is realized from transforming the International GNSS Service (IGS) 2008, epoch 2005.00 coordinates and velocities on the national continuously operating reference station (CORS) network, comprised of over 1850 active stations. This new realization on the CORS, denoted as NAD 83(2011), epoch 2010.00, was a significant improvement on the previous adjustment of NAD 83 (CORS96), epoch 2002.00 and was published in July of 2011. The new realization brought increased knowledge of station velocities, absolute antenna calibrations and an 8-year update to the positions [2]. Along with this new realization on the active stations, approximately 80,000 passive marks were readjusted. These marks were those in the NGS integrated database (NGSIDB) which were the result of accepted data from GNSS campaigns across many regions and many years [3]. Because the coordinates on many of these passive control marks will use modeled velocities and historic (sometimes decades old) GNSS observations, it is to be expected that they will not yield completely homogeneous positional coordinates when comparing their data sheet coordinates with those which might be produced from a re-observation of that passive control mark, tied to the CORS network of active stations and whose antenna reference points (ARP) positions and velocities are very accurately known at any point in time. Uplift, subsidence, or other disturbance or instability are conditions that are, to a large degree, essentially unknown for any legacy passive mark. This dichotomy in knowledge of positional coordinates can impact users of a local or regional RTN depending on what is constrained. Adding to this is the fact that RTN adjustments are usually performed more precisely than the surrounding CORS network, whose stations can have up to 2-cm in horizontal deviation and 4-cm in ellipsoid height deviation in the published coordinates. Therefore, as users reach out to the RTNs for fast, repeatable positioning, they will be dealing with three levels of control: local passive marks whose movement over time is unknown and may not be consistent with the RTN's derived coordinates, but may have a history of usage; RTN stations of which datum,

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adjustment or epoch may not be the ones desired for particular work; and the CORS network, reflecting the national geometric datum control – post processed through the NGS Online Positioning User Service (OPUS) [4] for a point position through user submitted data, or processed by the user in proprietary GNSS software as a point position or network adjusted solution.

In addition to considerations in accessing the geometric datum realization, another positioning consideration with which geospatial professionals must deal is the geopotential, referenced through North American Vertical Datum of 1988 (NAVD 88) orthometric heights. Unlike the geometric datum, new point data are accepted into the NGSIDB only through either millimeter-precision geodetic leveling across passive marks, or centimeter-precision GNSS height modernization (HTMOD) [5] procedures. Through the past two decades, NGS has published many hybrid geoid models which allow users to take their NAD 83 ellipsoid heights from Global Positioning System (GPS) observations and produce NAVD 88 orthometric heights [6]. Currently, geospatial professionals have the choice of using this methodology with a RTN or constraining the orthometric heights to trusted passive bench marks around their projects via a site localization procedure. The latter method almost always produces more precise results when using a RTN and allows the added benefit of providing a comparison of how a site's vertical control fits together in a best fit adjustment.
Site localizations, however, will soon not be necessary to align accurately to the vertical datum. In approximately 10 years, NGS will introduce completely new geometric and geopotential datums as new national standards. When this happens, passive marks will be considered entirely as secondary access to the datums and users will perform work based upon them at their own risk. The new geometric datum will remove the non-geocentricity as was the case in the NAD 83 datum definition and use an origin based upon a modern epoch of the ITRF or IGS reference frames. A decision on whether to fix this on the North American plate or allow it to move with the other mentioned world datums will be made. Additionally, a 1-cm accurate gravimetric geoid will be utilized to enable geospatial professionals to bring orthometric heights based on the new datum to their work site to around 2-cm accuracy by GNSS alone- completely without geodetic leveling. The GRAV-D (Gravity for the Redefinition of the American Vertical Datum) project is the foundation for this future [7]. Because users will be able to bring both horizontal and vertical control to their projects with active stations alone, RTNs will be even more important. The ability to provide this control in near real time will trump most post processed methods, as would be necessary from the CORS alone (Figure 3).

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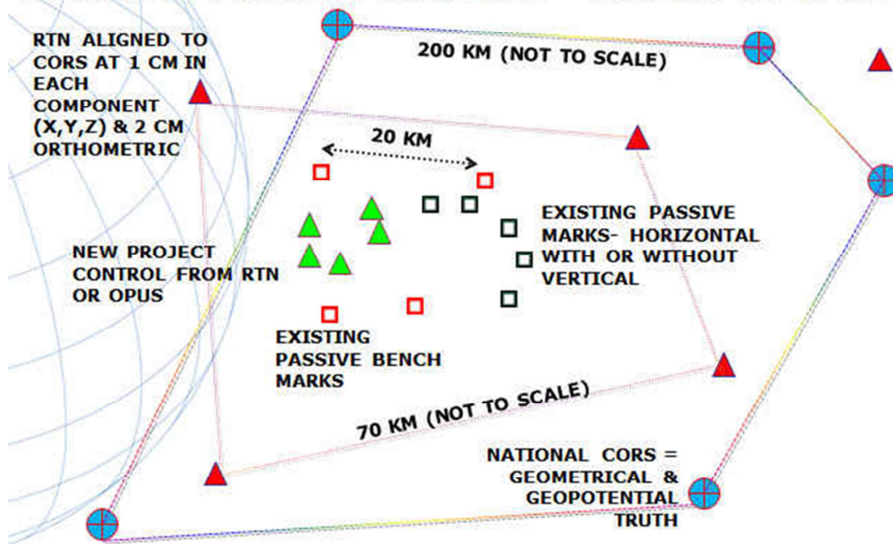Rome, Italy, 6-10 May, 2012

Figure 3- The geospatial professional must decide on the basis for project control: legacy passive marks, RTNs or national CORS.

4. CURRNT THINKING ON NGS RECOMMENDATIONS AND METHODS TO ALIGN TO THE NSRS

Accurate positional coordinates obtained from different RTNs obviously rely on the coordinates of the reference stations and the ability to obtain consistent field results from different GNSS hardware and software. NGS would like to promote the consistent alignment of RTNs to the NSRS, both for the active reference station positional coordinates and especially for the near real time positions produced by the geospatial user in the field. Current thinking is that RTNs should be aligned to the NSRS at no more than 2-cm horizontally (latitude and longitude) and 4-cm ellipsoid height, though tighter accuracies are being strongly considered.

RTN reference station coordinates may be obtained in a number of ways:

- Seeding the original positions with several days of coordinates obtained from OPUS processing. A subsequent network adjustment is usually performed.
- Fully constraining surrounding CORS coordinates in a simultaneous adjustment with all the RTN stations.
- Fully constraining the CORS in an adjustment with one RTN master station. A subsequent adjustment of all the RTN stations is done constraining the master station.
- Weighting the CORS in an adjustment with all the RTN stations.

NGS currently recommends using the last method by weighting the CORS 1-cm in each horizontal component (latitude and longitude) and 2-cm in the ellipsoidal component and

> **Comment [DAS2]:** Not under consideration unless you are talking about updating those passive control mark coordinates. If you're talking about fixing the adjustment to those coordinates, then absolutely not.

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performing a least squares adjustment with all the RTN stations – seeding the RTN reference stations with ten 24-hour data sets from OPUS. RTN stations must have very precise (sub-centimeter error) positional coordinates. Unacceptable strain is put on the adjustment from fully constraining stations with greater error than this and the positional error will be pushed into the atmospheric modeling, introducing error into the interpolated conditions at the rover. Additionally, it is recommended that 10% or 3 (whichever is greater) of the RTNs stations become CORS. This would enable the RTNs to be monitored by producing OPUS positions using the internal CORS stations as fiducial values.

To facilitate the use of OPUS and the CORS network, NGS is developing an on-line tool (not publically available yet) which will allow RTN operators to demonstrate the coordinate differences between their RTN published station coordinates and the NSRS - as referenced from the OPUS solutions (Figure 4). RTN operators will generate coordinates on their
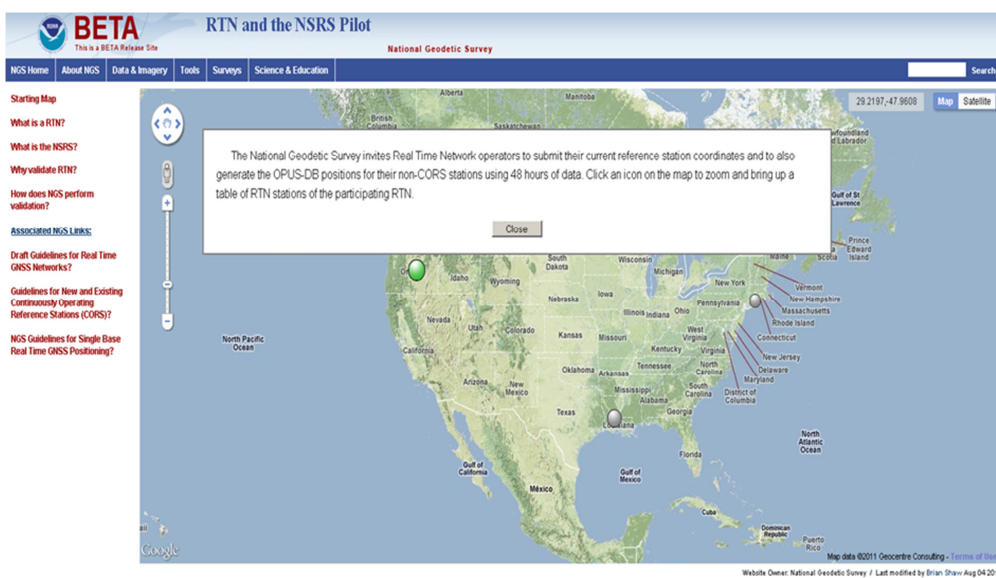
Comment [DAS3]: Do not propogate the term "national" CORS, even parenthetically.

Figure 4 – Each RTN will be represented by a one symbol.

reference stations using the NGS OPUS tool and also will provide NGS with a spreadsheet of the current RTN station coordinates as published to the users of the RTN. NGS will then compute the delta coordinates and generate a scatter plot of all the submitted RTN stations that will easily show the maximum and minimum divergence from the NSRS represented by the OPUS generated positions (Figure 5). To publish their data, RTN operators will upload their base station data to OPUS using the "publish" option (Figure 6). OPUS will accept up to 48-hours of continuous data, crossing midnight only once. Currently, it is recommended to submit 30-hours of station data. This should be more than adequate to produce centimeter level positional coordinates, which will fall well within the goal of 2-cm horizontal and 4-cm

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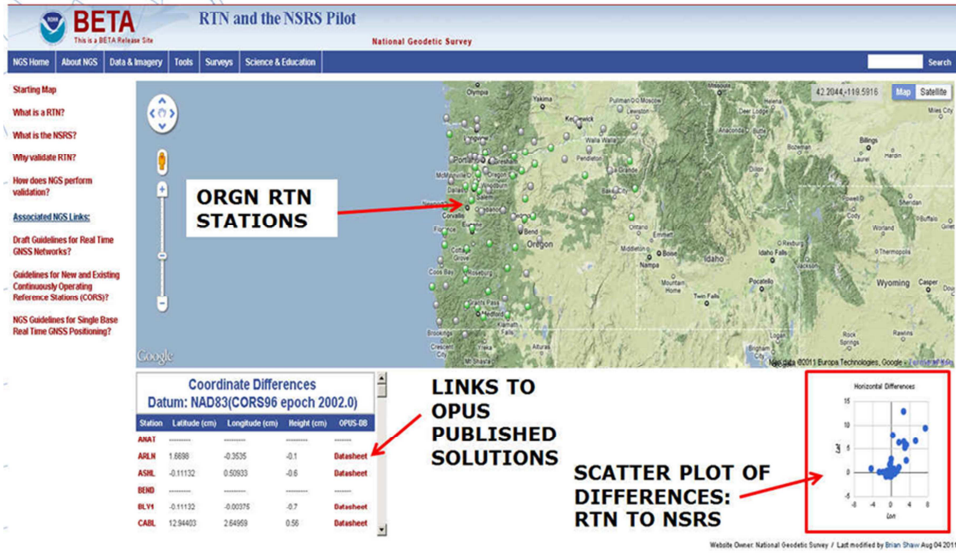Rome, Italy, 6-10 May, 2012

Figure 5- Clicking on a RTN symbol will expand the RTN to show all submitted reference stations.
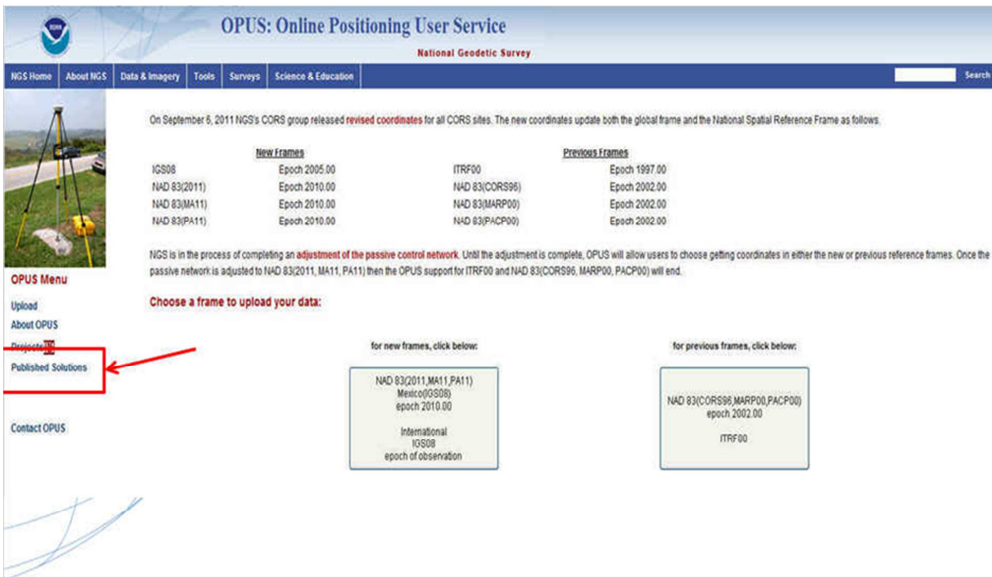

Figure 6 – The means to retrieve archived OPUS solution data is highlighted. Note the two different datum realizations in place until April 2012.

ellipsoid height alignment to the NSRS. A side benefit of using the OPUS tool will be to produce a database archive of all the listed RTN stations, including site photos, for future reference (Figure 7). Because the OPUS solutions will show the station's positional coordinates at the datum epoch [NAD 83 (2011), epoch 2010.00 currently], any different adjustment and/or data epoch will be within the result along with the deviations to the datum itself. Additionally, a time series plot, similar to the CORS time series plots (Figure 8) could be developed if these data are submitted on a regular basis – say every 4-months.
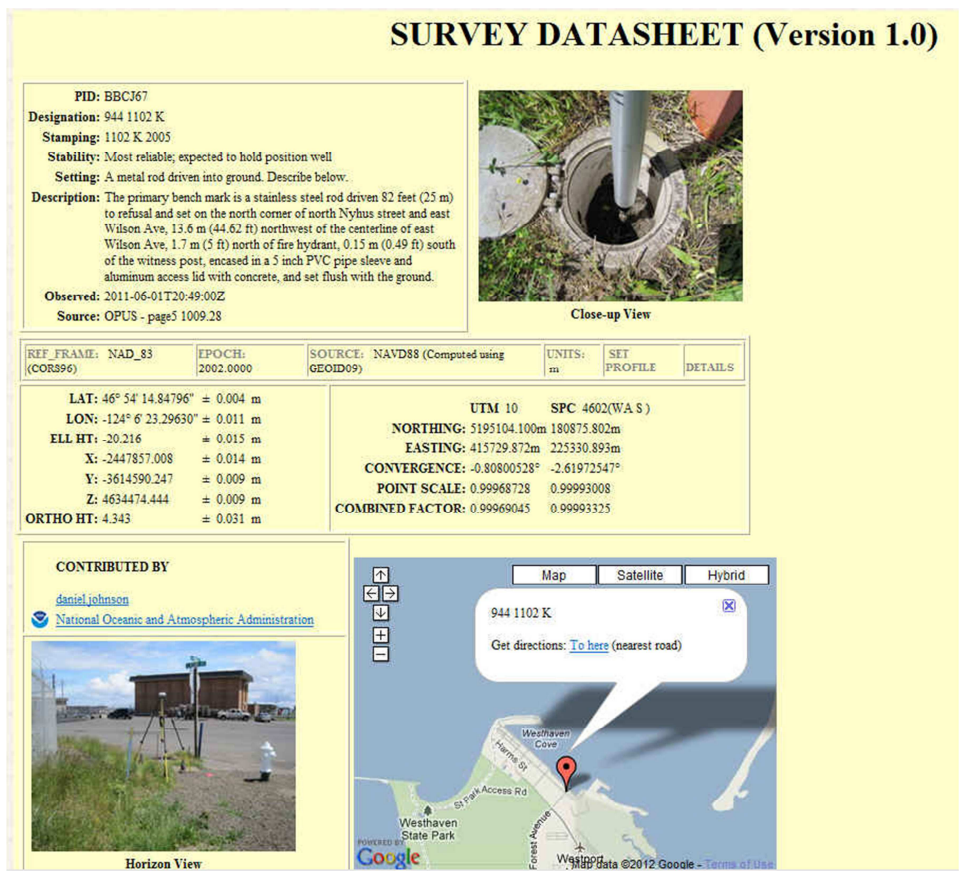
Figure 7- An OPUS published mark [with coordinates in the NAD 83 (CORS 96) epoch 2002.00 adjustment]

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BACO: Daily minus Published IGS08 Position

N [cm] = 0.15(± 0.12) E [cm] = -0.07(± 0.10) U [cm] = -0.25(± 0.54)
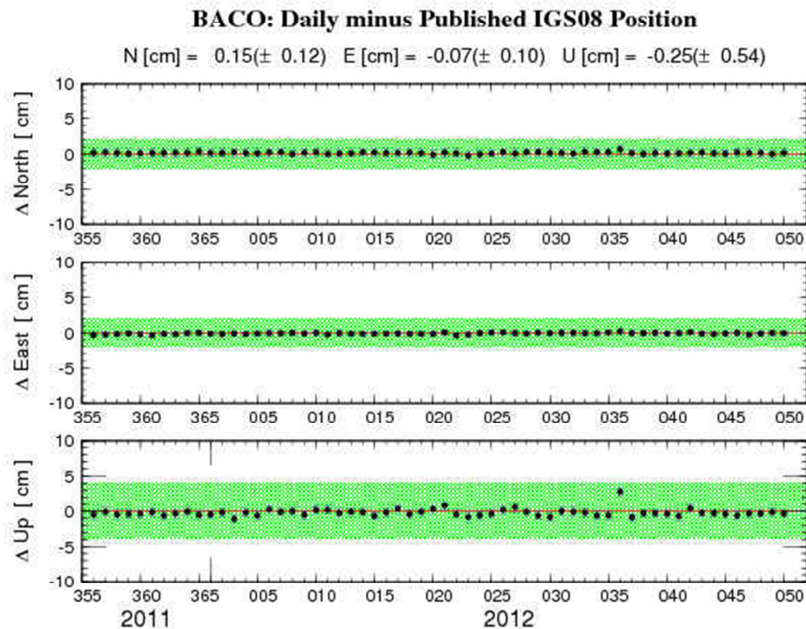

**Figure 8 – A graph similar to the one depicted above could be generated for RTN
reference stations if data are uploaded regularly.**

Of course, of real importance to all geospatial users is accurate coordinates produced in the
field from the RTNs. NGS recommends that all users are able to access the RTNs with all
major GNSS manufacturers' rover receivers. To further this goal, the use of the open, generic,
freely available RTCM 3.x format in the communication to the rover is recommended. This
format is developed by Radio Technical Commission for Maritime Services [8] (RTCM)
Special Committee 104 (SC-104) on Differential Global Navigation Satellite Systems
(DGNSS) and specifically addresses current and future GNSS RTN usage. Most RTNs in the
United States have this format available to users through the open source Network Transport
of RTCM via Internet Protocol (NTRIP) software developed for RTN use by the German
Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie –
BKG) [9]. NGS is also currently considering a recommendation that RTNs establish *and*
reobserve (on a frequent basis) high accuracy passive marks, well-spaced within the RTN –
perhaps at 20 Km or less. These marks should be as stable as possible and should be
positioned by GNSS static observations. Geodetic leveling connections between marks may
also prove useful[10] . If this recommendation were to come to pass, NGS envisions that these
data would be submitted to NGSfor inclusion in the RTN-verification service.. These marks
would serve as NSRS-compliance testing stations within the RTN. Although NGS envisions
that these marks would be visited and regularly tested by the RTN operator, users could also
visit these stations with their GNSS rover, connect to the RTN and produce a coordinate. This

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coordinate could then be readily compared to the published coordinates to see what deviation is present between the RTN and the NSRS in the near real time observation, and compare their in-field deviation estimate to that being stated by the RTN operator.

5. CONCLUSION

RTNs should be aligned to national datums in a consistent, accurate manner to facilitate many diverse geospatial applications. NGS is working with RTN operators to develop a robust NSRS-alignment and verification service. As of now, some of the ideas which NGS feels should be part of this are:
- RTN operators should configure their service by aligning RTNs to the national datums via the NGS on-line validation tool to produce a plot demonstrating the compliance level of each RTN's reference station's positional coordinates vis a vis the NSRS.
- RTN operators should use the NGS on-line validation tool to produce a plot demonstrating the compliance level of each RTN's reference station's positional coordinates vis a vis the NSRS.
- RTN operators should establish or validate high accuracy, stable passive monuments well-spaced within the RTN at 20 Km or less to verify the NSRS-compliance level of their own RTN. Although NGS sees RTN-users as fully capable of using these marks, NGS does not view the responsibility of NSRS-validation falling upon the RTN user.
- RTN users understand what conditions and methods might yield unsatisfactory results and employ the best methods possible with their work by reviewing the NGS real time user guidelines [11].
- RTN operators review important considerations before and during their build-out and operations in the NGS RTN guidelines [12] and other RTN documents, such as the RTN accuracy studies in Great Britain [13] .
- RTNs make available open, generic formats for real time data dissemination. NGS promotes the use of RTCM 3.x format data using NTRIP protocol.

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BIOGRAPHICAL NOTES

Mr. Henning is a Registered Professional Land Surveyor with over 44 years of active experience in all phases of surveying technology. He has been the project lead for height modernization projects in the eastern U.S., where he planned, observed, adjusted and managed new geodetic network control systems. He has been actively involved with education/outreach to the geospatial community for almost 20 years, presenting over 100 talks and workshops on surveying and GNSS technology. He has 18 years experience working with various GNSS manufacturers' real time positioning systems. Mr. Henning is Past President of the American Association for Geodetic Surveying (AAGS) and is an ACSM/AAGS Fellow. He has recently been presented with the NOAA Administrator's Award for outstanding accomplishment in producing real time GNSS positioning guidelines. He is currently employed by NOAA's National Geodetic Survey (NGS) as a Geodesist, where he is helping to develop guidelines and support methodology for real time GNSS positioning with state, national and international organizations.

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