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Development of the National Spatial Reference System

David R. Doyle

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David R. Doyle

Senior Geodesist

National Geodetic Survey

Coast and Geodetic Survey

ABSTRACT

Significant improvements in Geographic/Land Information Systems (G/LIS), and surveying and mapping technologies during the last decade have dictated a reassessment of the role of the National Geodetic Reference System (NGRS). The National Geodetic Survey (NGS), a component of the Coast & Geodetic Survey (C&GS), is responding to demands from a wide range of users for improved three dimensional positional accuracy and accessibility to the reference system by developing the National Spatial Reference System (NSRS). The NSRS will improve the availability and accuracy of positional information necessary for the development of accurate parcel based G/LIS, active Global Positioning System (GPS) navigation and surveying activities, and improve our understanding of the geophysical dynamics of the planet we live on.

National Geodetic Reference System

The National Geodetic Reference System (NGRS) exists as a collection of discreet geodetic elements. Horizontal positions (latitude and longitude, State Plane Coordinates) referenced to a two-dimensional datum, the North American Datum of 1983 (NAD 83), and elevations (Helmert orthometric heights) referenced to a one-dimensional datum, the North American Vertical Datum of 1988 (NAVD 88) define the major components of the NGRS. Both datums are the latest definitions of systems that began with the first geodetic surveys conducted by the Survey of the Coast, founded in 1807 (later renamed the Coast Survey-1836, U. S. Coast and Geodetic Survey-1878, and National Ocean Service-1970). NGS, a component of C&GS/NOS, is responsible for most of NOS' geodetic mission. These geodetic systems were developed independently with little regard to being correlated. That is, a survey monument that provided accurate horizontal coordinates was not normally connected to the vertical network, nor were vertical points related to the horizontal reference network. Today (1994), the NGRS contains information on approximately 300,000 horizontal control points and 600,000 vertical control points.

In addition, horizontal stations were often located on high mountains or hilltops to decrease the need to construct observation towers usually required to provide line-of-sight for triangulation, traverse and trilateration measurements. Vertical control points however, were established by the technique of spirit leveling which is more suited to being conducted along gradual slopes such as roads and railways that seldom scale mountain tops. Consequently, approximately less than 10 percent of the horizontal and vertical reference systems coincide.

Distribution of NGRS data has also traditionally been confined to geodesists, surveyors, and cartographers in the Federal, state, local, and private mapping communities. While requests for geodetic information have always been numerous, much of the mapping and surveying conducted in the United States has not been referenced to NGRS. Federally funded topographic mapping

(Geological Survey and Soil Conservation Service) and aeronautical and nautical charting (NOS and Defense Mapping Agency) have always been referenced to NGRS. However, Federal cadastral surveying and mapping (Bureau of Land Management, Forest Service, and the Park Service) have only recently adopted this convention. Inaccessibility of NGRS control points and the expenses associated with such surveys have often been cited as prime reasons for not connecting to the networks.

Social, ecological, and environmental changes of the last decade have increased the need for more accurate geospatial information. Dramatic technological advances in computers, scanning devices, satellite positioning/navigation systems, and remote sensing techniques have provided access by mapping professionals and the general public to a wide range of geo-referenced data that never existed before. Prior to the advent of GPS, obtaining accurate three-dimensional coordinate information (latitude, longitude, and height) was very expensive, and could only be provided by a small group of highly trained geodesists and geodetic surveyors. Today, a little spare change (approximately $500) can equip anyone with the ability to determine their location, anywhere on the planet to levels of accuracy that are better than most printed map or chart products.

National Spatial Reference System

To address the changing requirements for positional information, NGS began a strategic planning evaluation in 1992. Formally adopted in March 1994 (NGS 1994), this plan details, in a series of 15 strategic goals, the steps necessary to accomplish the transition from NGRS to NSRS.

A case can be made that the change to NSRS is simply a name change, and that the NGRS already incorporates the features necessary to support the integrity of the National Spatial Data Infrastructure. In part this is true. However, the term Geodetic has often been intimidating to many data users, implying a somewhat mystic science that almost no one understood. Changing the name to Spatial is intended to be more consistent with the needs of the public and should not require data users to run for their dictionaries to find out what the term means.

The change is not just cosmetic. It represents a fundamental change by NGS to understand the needs of geospatial data users, and to restructure its surveying operations, research and development activities, and data distribution, some of which have changed only slightly in over 180 years. These changes include development of the Federal Base Network (FBN), Cooperative Base Network (CBN), User Densification Network, Continuously Operating Reference Stations (CORS), GPS Orbits, a high accuracy geoid, and improved data access.

Federal Base Network

Development of GPS as a primary tool for geodetic surveying indicated in the late 1980s that the existing horizontal and vertical control networks (NGRS) did not adequately support satellite techniques. These networks were developed using classical methods of triangulation, traverse, trilateration, and spirit leveling, where the line-of-sight direction between control points was more important than the clearance above the horizon required for satellite signal acquisition. Consequently many geodetic survey points were not directly "GPSable".

Horizontal coordinates were also a problem. Prior to GPS, surveys designed to obtain first-order (FGCC 1984) positions were performed by very few agencies or private firms, using very expensive surveying equipment, and requiring significant training and education in geodesy and least squares adjustment theory. By 1985, GPS could easily outperform first-order horizontal accuracy, and was becoming increasingly more affordable and accessable to the average surveyor. To accommodate the improved positional capability of GPS, new standards for horizontal data were submitted for adoption to the Federal Geodetic Control Committee (FGCC 1989b). A- and B-orders of accuracy specify horizontal positional tolerances of 5 mm + 1:10,000,000 of the observed base line, and 8 mm + 1:1,000,000 of the observed base line, respectively. There is no vertical accuracy implied by A- or B-order.

Improvements to the horizontal reference system began with the first High Precision GPS Network (HPGN) observed under contract for the Tennessee Department of Transportation and adjusted by NGS in 1990 (Strange and Love 1991). Subsequent surveys in Florida (1990), Delaware, Maryland, Oregon, Washington, and Wisconsin (1991) initiated the current program that will define an improved reference frame for every state by the end of 1996. The acronym HPGN first evolved into High Accuracy Reference Networks (HARN) (Doyle 1992) and now FBN/CBN.

While changing names and acronyms may seem like a way to confuse the user, the intent is to provide a definition of both positional accuracy and financial responsibility. Stations defined as FBN will be established at the expense of NGS, at1^{o} x 1^{o} (75 to 125 km) nominal spacing that will provide minimum accuracies of B-order horizontal; second-order, class I vertical (FGCC 1984); gravity at 50 microgals; and horizontal and vertical crustal motion at 1 mm/year relative accuracy. NGS will be responsible for replacing destroyed or disturbed stations and will revisit each FBN station on a rotating 3 - 5 year basis. A portion of the FBN nominally spaced at 3^{o} x 3^{o} (250 km to 300 km) will provide

A-order horizontal and first-order, class II vertical accuracies.

COOPERATIVE BASE NETWORK

NGS encourages the densification of FBN to a nominal station spacing of approximately 15' x 15' (25 to 30 km) in cooperation with various Federal, state, local, and private sector groups. The CBN will provide minimum accuracies of B-order, horizontal, third-order vertical, gravity at 50 microgals, and horizontal and vertical crustal motion at 1 mm/year relative accuracy. CBN development is usually accomplished at the State level, often coordinated by NGS and usually in cooperation with major state agencies such as the Departments of Transportation. Every effort is made to combine the interests of a wide range of users such as the Professional Land Surveyors societies and county or municipal agencies involved in G/LIS. A very important difference between FBN and CBN is that funding and network maintenance of CBN stations must come from the state and local groups.

USER DENSIFICATION NETWORK

As in the past, NGS will continue to accept horizontal and vertical geodetic surveys for inclusion in the national reference system provided they are connected to the FBN/CBN. Often referred to as "Blue Book" surveys, these projects are usually densification surveys to support G/LIS activities performed by or under contract to Federal, state, county, or municipal agencies. This service provides quality assurance, data archival, and distribution to the user community. All horizontal surveys must be at least first-order (FGCC 1989b), while vertical control projects must be a minimum of second-order, class II (FGCC 1984) conventional leveling surveys. All data must be submitted to NGS in computer-readable form (FGCC 1980, FGCC 1989a) using NGS approved software, and be adjusted and ready to be loaded in the NGS data base. While NGS will provide a pre-review service prior to field observations to ensure network integrity, NGS will not provide financial or network maintenance assistance for these data.

CONTINUOUSLY OPERATING REFERENCE STATIONS

Establishment of a national network of GPS Continuously Operating Reference Stations (CORS) will make both pseudo-range and carrier-phase measurements accessible to the public for use in a wide range of geodetic, cadastral, and engineering surveying applications, mapping and charting, as well as air, land, and sea navigation. Each CORS will consist of at least one permanent GPS receiver, a computer, and a telecommunications support system, correlated with a FBN/CBN station located in a secured environment such as an airport, Coast Guard station, or other protected location. Data from those sites supported by the Coast Guard and Federal Aviation Administration will provide position and elevation correctors for real-time pseudo-range observations to improve accuracies for a variety of applications to the sub-meter level up to 200 kilometers away from the station.

Carrier-phase observables will also be provided by NGS via INTERNET for post processing observed data to satisfy those applications requiring higher accuracies such as geodetic and land surveying. Availability of CORS will reduce the requirements for additional GPS receivers for differential positioning problems. Connections derived from two or three CORS will ensure positional integrity without the expense of sending additional receivers and personnel into the field.

GPS Orbits

Access to worldwide ephemeris derived from the observations provided through the International GPS Geodynamics Service (IGS) will enhance post-processed GPS data to achieve accuracies of $1:10^7$ of the orbit radius with efforts aimed at achieving $1:10^8$. These data are made available to users within 72 hours. Such orbits will be essential for effective use of CORS.

Data Access

Distribution of geodetic data transitioned from paper copy, hand edited, manually typed data sheets of the 1960s and 70s to the NGS Integrated Data Base (NGSIDB), arguably the most sophisticated geodetic surveying data base in the world. All NGS historical horizontal and vertical data were automated from original field observations during the 1970s and

80s to support the NAD 83 and NAVD 88 readjustments. These data include positions, elevations, angles, distances, GPS vectors, elevation differences, and station descriptive text dating back to some of the original surveys of the Survey of the Coast (now NOS) in 1817.

Hundreds of daily telephone and mail requests for data products (including original field observations as well as coordinates) are currently supported on paper, 3.5 and 5.25 inch floppy disks, and Compact Disc - Read Only Memory (CD-ROM). The transition to NSRS will include direct read-only access by the public to the NGSIDB via modem connection through a bulletin board and/or other telecommunications connections.

CONCLUSION

Redefining the NGRS is the product of an intensive 2-year study by NGS management and senior staff, supported and reviewed by all NGS employees using Total Quality Management techniques. This plan was reviewed by the National Academy of Science and a special committee of nationally recognized professionals from the surveying and mapping community (National Spatial Reference Committee 1994). The NSRS will incorporate state-of-the-art positioning and computer technology directed at supporting a wide range of activities and users. Crustal dynamics studies, intelligent vehicle/highway systems, air, rail and marine transportation needs, academia, governmental agencies, private industry, and families trying to find the nearest burger or taco carry-out will all directly or indirectly benefit from current and accurate geospatial data that are easily accessible to the public.

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