National Oceanic and Atmospheric Administration
National Ocean Service
Geodetic Support System
006-48-01-15-01-3403-00-117-057
Operational Analysis
2006

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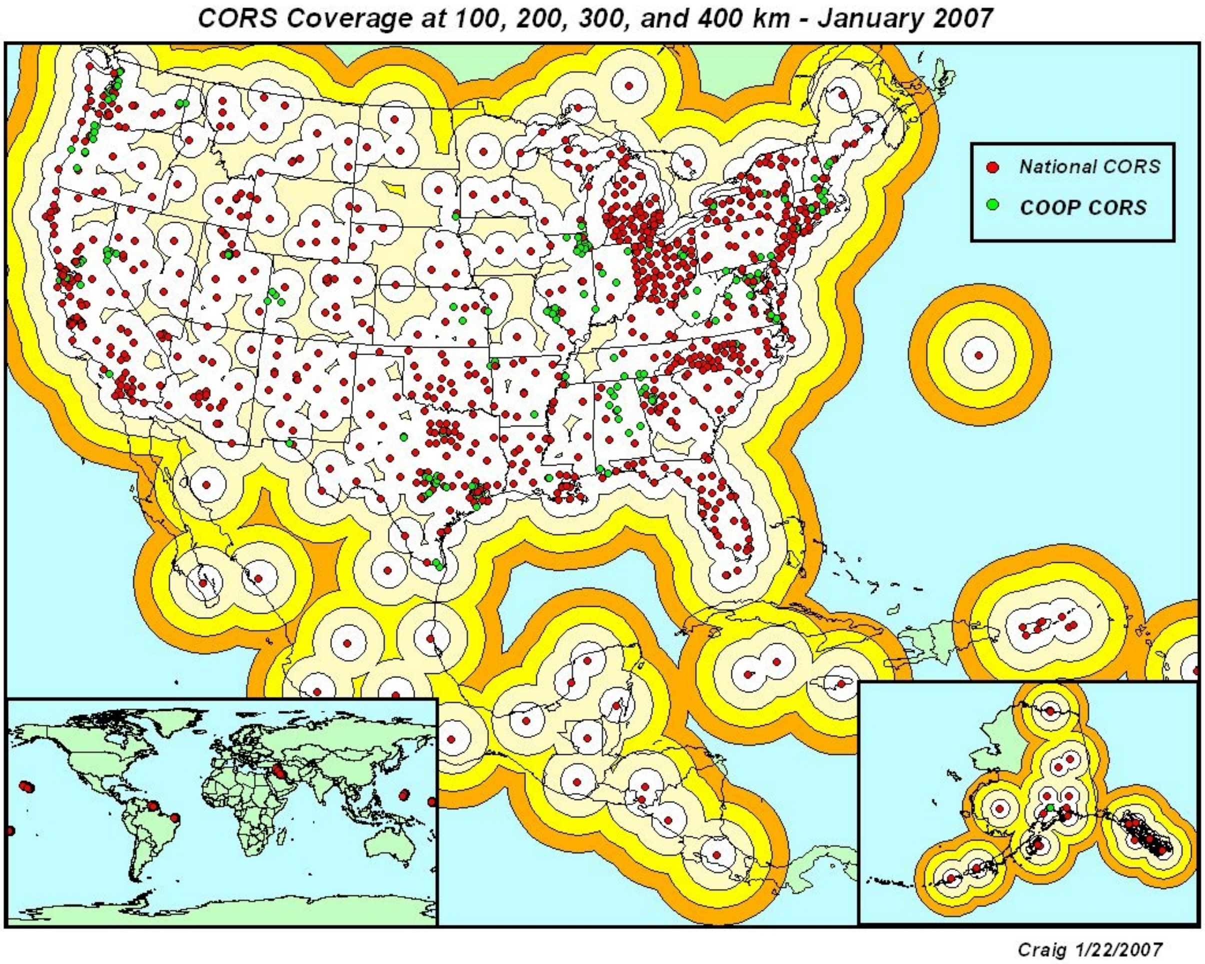
Executive Summary

The Geodetic Support System constitutes the IT component of NOAA's Continuously Operating Reference Station (CORS) program. The CORS program comprises a nationwide network of over 1,000 stations that continuously collect radio signals broadcast from Global Positioning System (GPS) satellites. NOAA's National Geodetic Survey (NGS) provides access to these data free of charge via the Internet. The program's primary goal is to enable GPS users to determine precise positional coordinates relative to the National Spatial Reference System (NSRS). The following figure illustrates the current coverage provided by the CORS network. Additional information may be found in Annex A in at www.ngs.noaa.gov/CORS/ .



This report focuses on the operational state of the program as of December 31, 2006, and is based on guidance developed by the Department of Commerce. The Geodetic Support System directly supports the objective "Enhance the conservation and management of coastal and marine resources to meet America's economic, social, and environmental needs" under the Department of Commerce strategic goal to "Observe, protect, and manage the Earth's resources to promote environmental stewardship." Specifically, this increase supports the NOAA Goal to "Support the Nation's commerce with information for safe, efficient, and environmentally sound transportation." The current program meets established cost, schedule and performance parameters.

This operational analysis (OA) is an annual, in-depth review of the program's performance based on the following:

- Customer Results
- Strategic and Business Results

- Financial Performance
- Innovation

1.0 Customer Results

Users of CORS data can determine positional coordinates with centimeter- or decimeter-level accuracy by postprocessing several hours or minutes, respectively, of their GPS data with data from the CORS network. Users can also determine the travel path of a moving platform—like an aircraft, a boat, or a land vehicle—with decimeter-level accuracy by postprocessing GPS data from a receiver mounted on this platform with data from the CORS network.

Additionally, CORS data are used by:

- Earth scientists to monitor crustal motion,
- Meteorologists to monitor the distribution of moisture in the atmosphere, and
- Atmospheric scientists to monitor the distribution of free electrons in the ionosphere.

1.1 Customer Requirements and Costs

The principal customers of CORS data include land surveyors, GIS professionals, engineers, scientists and others who process these data with their own GPS data to determine accurate positional coordinates for locations of interest to them, such as property boundaries, transportation arteries, and other map-worthy objects.

Customers obtain CORS data and associated metadata primarily in three ways: (1) via the Internet using the anonymous file transfer protocol (FTP), (2) via the World Wide Web using the "User Friendly" CORS (UFCORS) utility, and (3) via the World Wide Web using the Online Positioning User Service (OPUS) utility. NOAA estimates that (1) each FTP download saves the customer $30 in what it would cost him/her to obtain the information otherwise, (2) each UFCORS download saves the customer $200, and (3) each OPUS solution saves the customer $600. The following table summarizes the financial benefits provided by the CORS program in FY 2006:

4.9M FTP downloads @ $30 per download	$147M
792K UFCORS downloads @ $200 per download	$158M
166K OPUS solutions @ $600 per solution	$100M
Total CORS benefits in FY 2006	$405M

1.2 Performance Measures

In CY 2006, NOAA used two performance measures to quantify the success of the Geodetic Support System: (1) the percent of U.S. counties that were substantially enabled to perform positioning activities relative to the National Spatial Reference System, and (2) the number of CORS data packages downloaded via the UFCORS Web utility.

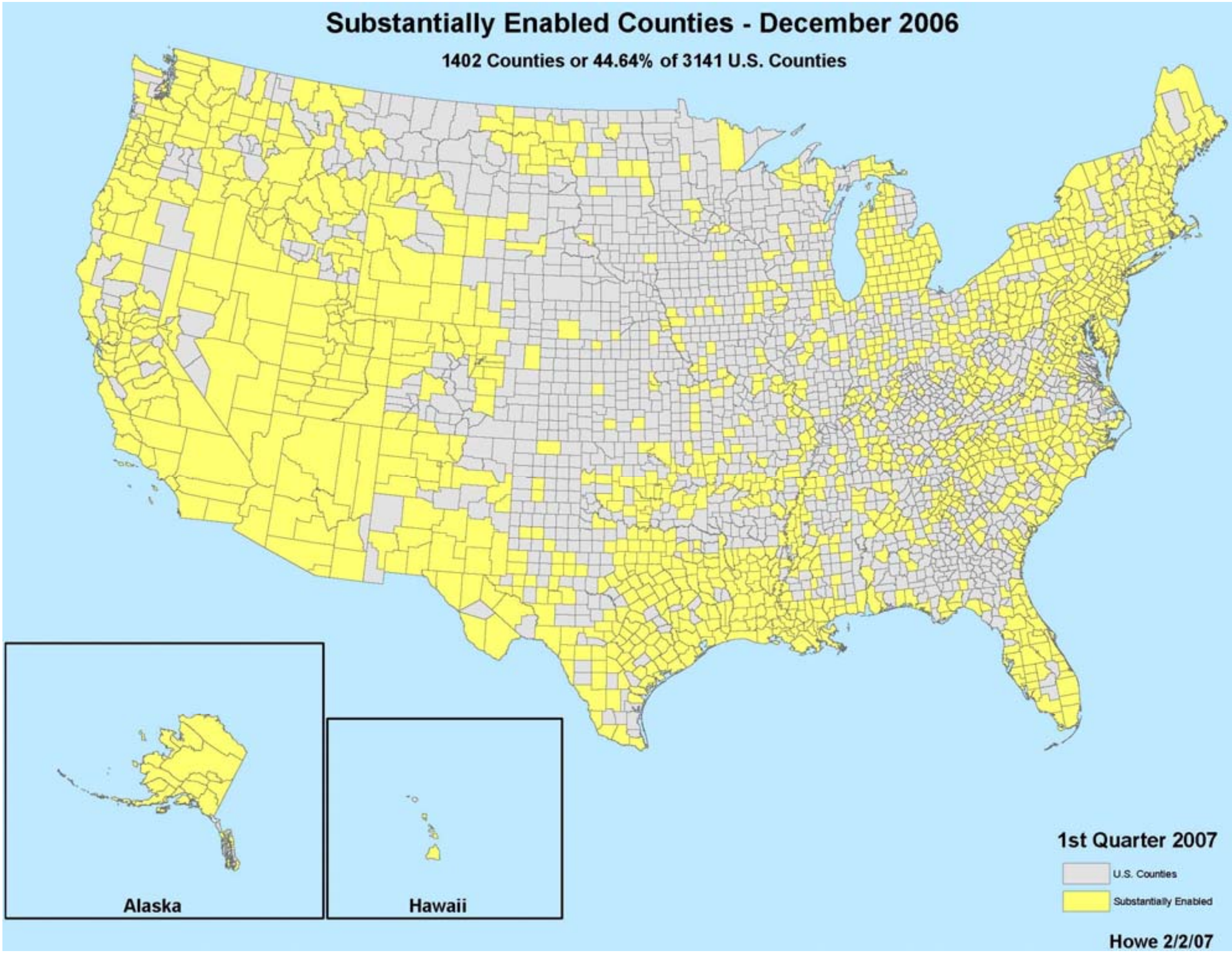
For a county to be substantially enabled, users must have applied the OPUS utility at least 25 times in FY 2006 to accurately position points located within the county. To apply OPUS, a user must collect at least 2-hours worth of GPS data at a site and then submit these data to NOAA via the Web (www.ngs.noaa.gov/OPUS), whereupon NOAA will automatically process the submitted data with data from at least three CORS sites to compute accurate positional coordinates for the location at which the submitted data were collected. NOAA then emails the resulting coordinates to the user in a timely fashion, usually within minutes.

Users apply UFCORS to obtain CORS data and related information more conveniently than is possible by using anonymous FTP. Anonymous FTP better serves users who download large volumes of CORS data on a regular basis. UFCORS better serves users who download small volumes of CORS data on an infrequent basis. With anonymous FTP, users must be computer savvy and familiar with the directory structure that NOAA uses to store CORS information. With UFCORS, users submit a CORS data request by simply filling in a Web-based form. UFCORS users do not need to be computer savvy, nor do they need to know the directory structure used to store CORS information.

These measures align with the "Customer Results Measurement Area" of the Performance Reference Model developed by the Federal Enterprise Architecture Program Management Office (FEA-PMO). Table 1 summarizes the performance measures.

Table 1: Customer Results Performance Measure

Measurement Area	Indicator	2005 Baseline	2006 Actual Result	Comments
Customer Requirements	Percentage of counties that are substantially enabled	32.2%	42.7%	Fiscal year numbers
	Number of CORS data packages downloaded via UFCORS	640,980	818,743	Calendar year numbers



2.0 Strategic and Business Results

The Geodetic Support System program is meeting its own goals and objectives as well as those of the agency. Program management and controls are in place to ensure the program continues to meet its goals and objectives and monitor how well the Geodetic Support System program performs.

2.1 Geodetic Support System Helps to Achieve Strategic Goals

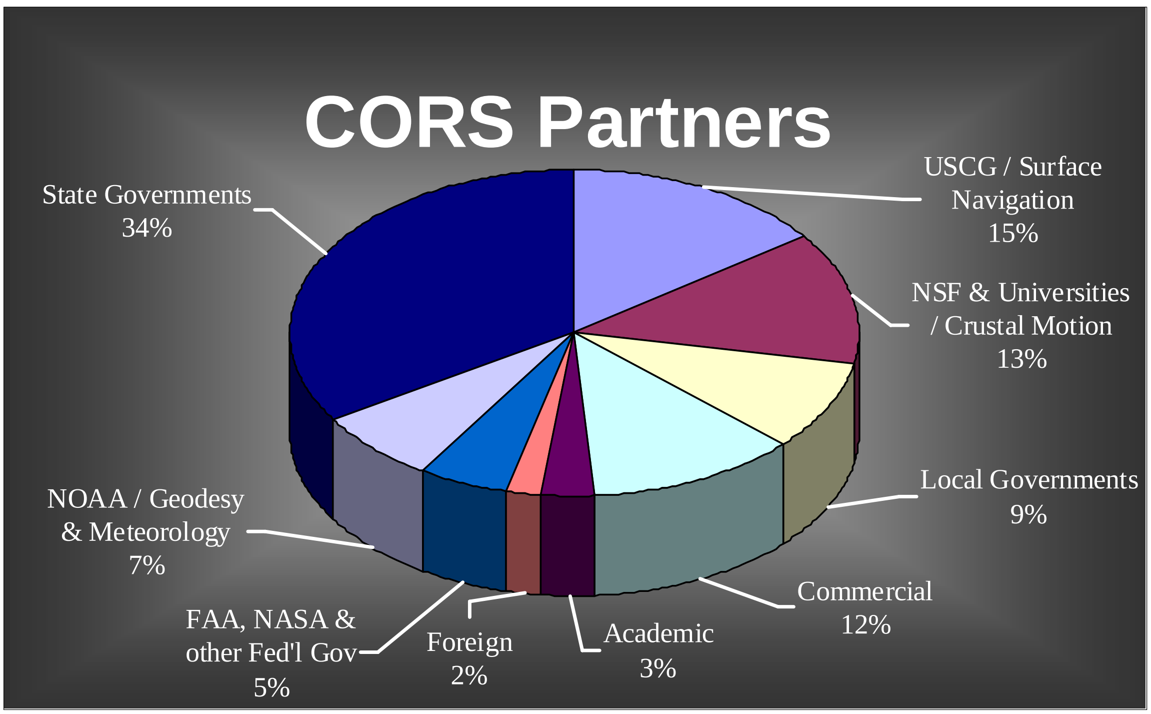
The Geodetic Support System program directly supports the objective "Enhance the conservation and management of coastal and marine resources to meet America's economic, social, and environmental needs" under the Department of Commerce strategic goal to "Observe, protect, and manage the Earth's resources to promote environmental stewardship." Specifically, this program supports the NOAA Goal to "Support the Nation's commerce with information for safe, efficient, and environmentally sound transportation."

Program management controls are in place to ensure that the Geodetic Support System program continues to meet these goals and objectives and to monitor how well this program is performing.

2.2 Business Results

2.2.1 Program Management and Controls

The CORS program is a highly leveraged system that benefits from voluntary contributions from over 185 partner organizations. These organizations include foreign, federal, state and local government agencies, as well as academic and commercial institutions. The non-NOAA partners sponsor and/or operate 93% of the stations contained in the CORS network. That is, NOAA currently sponsors and/or operates only 7% of the stations. The following pie chart summarizes the composition of the CORS partners.



NOAA has not entered into formal agreements with any of the CORS partners, except in two cases: (1) the U.S. Coast Guard in connection with the Maritime Differential GPS program and (2) the U.S. Department of Transportation and others in connection with the Nationwide Differential GPS program.

NOAA's National Geodetic Survey (NGS) coordinates the contributions of the 185+ partner organizations through its CORS Web site (www.ngs.noaa.gov/CORS/) which features the electronic CORS Newsletter and other pertinent information. The CORS Newsletter is updated immediately whenever a news-worthy event occurs. NGS emails the latest CORS Newsletter to several hundred addresses every Sunday, but anyone can download the most current edition via the CORS Web site at any time.

On a daily basis, NGS checks incoming GPS data provided by the CORS partners and will contact a partner directly (by phone or email) if one of their stations is not performing up to specified criteria (see www.ngs.noaa.gov/PUBS_LIB/CORS_guidelines.pdf for criteria).

NOAA operates two parallel CORS Data Management Facilities: one (CORS-East) located in Silver Spring, MD which is hosted by NGS, and the other (CORS-West) located in Boulder, CO which is hosted by NOAA's National Geophysical Data Center (NGDC). Both facilities independently collect, store, and distribute all CORS data. Annex B contains a copy of the formal agreement between NGS and NGDC for the operation of all essential CORS activities in Boulder during FY 2004 through FY 2006 time frame. The FY 2007 agreement is currently in preparation.

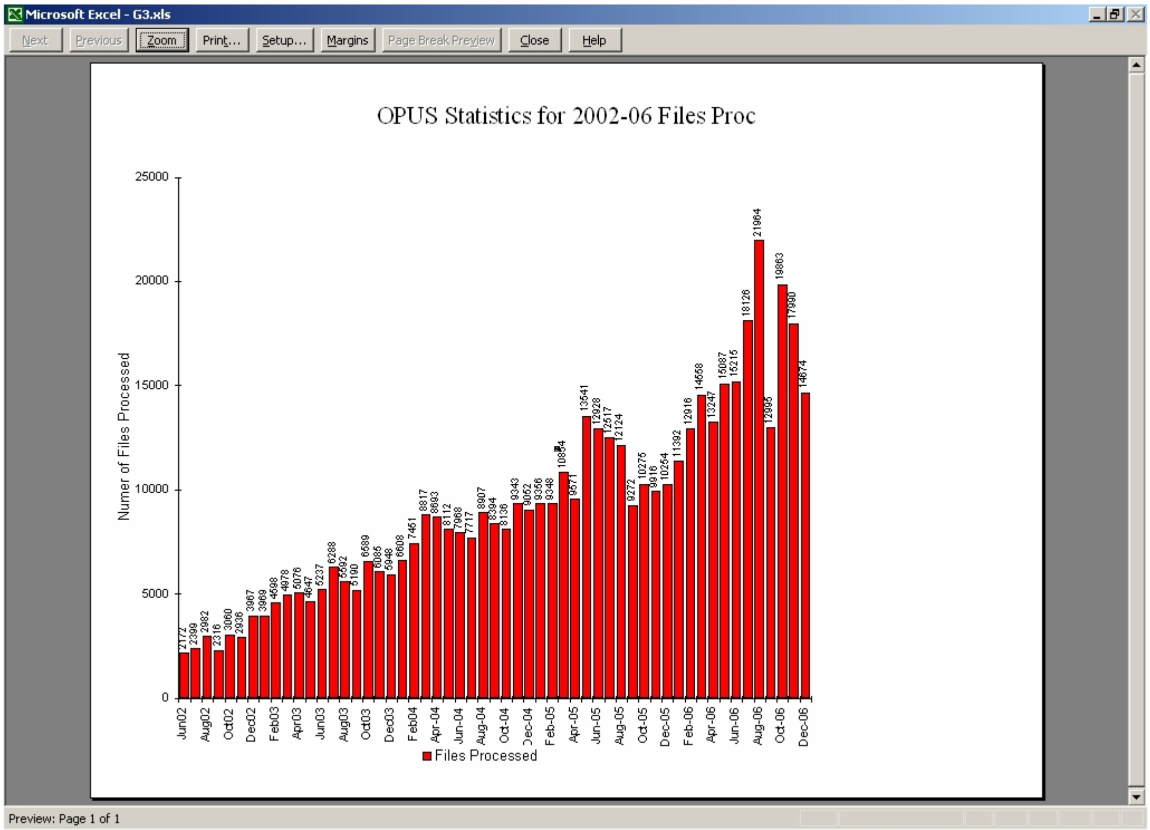
The overall CORS program is managed within NGS, primarily through a Program Manager and several informal teams: CORS Site Management Team, CORS Data Management Team, CORS West Team, CORS Data Analysis Team, CORS Systems Development Team, CORS Technical Innovation Team, and CORS Outreach Team. Members from all of the teams meet jointly once per month at the CORS All-Hands meeting to coordinate their activities. Numerous other meetings occur regularly among various team representatives to address specific issues. In addition, the CORS Program Manager attends weekly meetings of the NGS Director's staff and bi-monthly meetings of the NGS Executive Steering Committee.

2.2.2 Monitoring Cost, Schedule and Performance

Cost – The CORS Program Manager and the NGS Financial Officer meet monthly to review the CORS budget.

Schedule – The NGS Annual Execution Plan is used to track the progress of key milestones. The CORS Program Manager reports quarterly to the NGS Director on the status of all CORS-related milestones. All FY 2006 milestones were met except one: to implement the OPUS-DB Web based utility. This utility allows its users to archive their work in the NGS Integrated Data Base. The implementation of OPUS-DB suffered a severe setback when one of the key software developers unexpectedly died from a heart attack. Currently, NGS is reallocating resources from other projects to meet this milestone by the spring of 2007.

Performance – On a monthly basis, NGS monitors (1) the percentage of counties that are substantially enabled to perform positioning activities relative to the National Spatial Reference System, (2) the number and distribution of operational CORS sites, and (3) the volume of CORS data being downloaded by CORS users, and (4) the number of times that people use CORS-related tools such as UFCORS and OPUS. The first item is reported to NOAA as a GPRA measure. The latter three items are reported publicly in the CORS Newsletter. The following graph was extracted from the CORS Newsletter on February 2, 2007. This graph displays the number of files processed each month by OPUS during the past few years. It should be noted that the Department of Commerce showcased the OPUS utility as its primary E-Gov success in its annual report to the Office of Management and Budget, submitted in October 2006.



2.3 Reviews

The Geodetic Support System is scheduled to be reviewed for the first time by the NITRB on September 11, 2007.

2.4 Security

The CORS is accredited under requirements spelled out in Office and Management and Budget Circular A-130, NIST Special Publication 800-37 and the Department of Commerce policy on security accreditation. System Security Plans, Risk Assessments, and Contingency Plans were certified and approved for CORS in September 2005. Management, operational, and technical security controls are adequate to ensure the confidentiality, integrity and availability of information.

2.5 Performance Measures

The performance measures in Table 2 show the Geodetic Support System's performance with respect to Strategic and Business Results. Strategic and Business Results performance measures introduced in 2006 include "the number of CORS/OPUS workshops presented" and "the number of new CORS sites added to the network". These measures align with the "Mission and Business Results Measurement Area," "Processes and Activities Measurement Area" and the "Technology Measurement Area" of the Performance Reference Model developed by the FEA-PMO.

Table 2: Business Results Performance Measures

Measurement Area	Indicator	2005 Baseline	2006 Actual Result	Comments
Strategic and Business Results	Number of CORS/OPUS workshops presented	6	7	Fiscal year numbers
	Number of new stations added to the CORS network	221	189	Fiscal year numbers

2.6 Other

NGS organizes several public meetings each year to receive feedback on the CORS program from partners, stakeholders, and users. In particular, NGS organizes an annual CORS Users Forum. In each of the past four years, this Forum has been an integral part of the Civil GPS Service Interface Committee's annual meeting that is organized by the U.S. Coast Guard and the U.S. Department of Transportation. Annex C contains a copy of the final report for the 6th Annual CORS Users Forum which was held in Fort Worth, TX in September 2006.

3.0 Financial Performance

3.1 Current Performance vs. Baseline

The Geodetic Support System had a modest budget of $1,530K in FY 2006. The expenses are dominated by the salaries (and benefits) of 5.0 Government FTE's and 4.8 contractors ($1,100K). Other expenses include a contract with NOAA's National Geophysical Data Center to operate the Parallel CORS Data Management Facility in Boulder, CO ($240K), telecommunications ($100K), the procurement of IT equipment ($60K), and travel ($30K). The budget remains relatively constant from year to year, once it is normalized for the influence of inflation.

3.2 Performance Measures

Given the small size of its budget and the fact that this budget is dominated by salaries, no financial performance measures have been established for the Geodetic Support System. Nevertheless, the CORS network continues to grow by about 200 stations per year. This growth may require that the staff of this program be increased in number in the near future.

3.3 Cost Benefit Analysis

As reported in Section 1.1 of this report, the total benefits provided by the CORS program in FY 2006 amounted to $405M. The FY 2006 cost to NGS for managing the CORS program (of which the Geodetic Support System constitutes the IT component) was $3M. This yields a benefit-to-cost ratio of 135-to-1. The primary reason that NGS has been able to achieve this impressive benefit-to-cost ratio relates to the fact that 93% of the stations in the CORS network are sponsored and/or operated by other organizations, often for purposes not directly related to CORS activities. For example, the U.S. Coast Guard and the U.S. Department of Transportation jointly sponsor a network of about 170 stations to provide real-time navigation information for maritime vessels and land vehicles. NGS has incorporated these 170 stations into the CORS network to also enable after-the-fact positioning activities. Also, the National Science Foundation is sponsoring a network that will include over 1,100 continuous GPS base stations to monitor crustal motion in the western United States. NGS will incorporate many of these stations into the CORS network, again to also enable after-the-fact positioning activities.

3.4 Financial Performance Review

Financial performance is typically subjected to a periodic review for reasonableness and cost efficiency. Monthly budget reviews are held with the CORS Program Manager and the NGS Financial Officer. A detailed review of work and priorities is undertaken if cost is significantly above base lined values. Also, any necessary corrective actions are identified and implemented.

4.0 Innovation to Meet Future Customer Needs

During the next few years, NGS will introduce several variations of the highly successful OPUS Web-based utility. These include:

- OPUS-DB (data base)
- OPUS-RS (rapid static)
- OPUS-Projects, and
- OPUS-GIS (geographic information system).

4.1 Number and Types of Users

As mentioned earlier, NGS had hoped to have implemented OPUS-DB by this time, but this project suffered a severe setback when its leading data-base software developer unexpectedly died from a heart attack. Additional resources have been allocated to implement OPUS-DB by the spring of 2007. This new utility will enable users to archive their OPUS-derived positional coordinates in the NGS integrated data base (NGSIDB). OPUS-DB will enable the surveying community to conveniently document their work and to share their work with others, thereby reducing unnecessary duplication of effort.

On January 31, 2007, NGS declared its OPUS-RS utility as "initially" operational. OPUS-RS enables users to submit as little as 15 minutes worth of (dual frequency) GPS data to NGS via the Web, whereupon NGS will process these data with data from the CORS network to provide users with accurate positional coordinates for the location associated with the submitted data. Hence, OPUS-RS provides the same service as the standard OPUS utility, but the standard OPUS requires users to submit at least two hours worth of (dual frequency) GPS data, whereas OPUS-RS requires them to submit only 15 minutes worth of these data. Hence, NGS expects that OPUS-RS usage will exceed OPUS usage by a factor of ten. NGS, with the help of researchers at The Ohio State University, have designed and implemented several new GPS-processing algorithms to create OPUS-RS. Also, NGS anticipates that its personnel will be revising OPUS-RS significantly during the next couple of years to improve this utility's performance before it is declared "fully" operational.

NGS has developed a working prototype of the OPUS-Projects utility, and the agency is testing it on a FEMA-sponsored $3M surveying project to upgrade the National Spatial Reference System in the Gulf States. This project will assist reconstruction efforts in the areas required by the devastation caused by Hurricanes Katrina and Rita in 2005. OPUS-Projects differs from the standard OPUS utility in that it enables users to submit GPS data from several simultaneously-deployed receivers as well as data from multiple observation sessions, whereby OPUS-Projects will compute positional coordinates for all locations associated with the submitted data and in a manner that these coordinates are consistent with all submitted data. Recall that the standard OPUS utility computes positional coordinates for only one location using data from only one observation session. NGS expects to declare the OPUS-Projects utility to be "initially" operational in FY 2008.

NGS is now developing OPUS-GIS to process GPS code data, as well as GPS carrier phase data. The standard OPUS utility processes only GPS carrier phase data. Although GPS code data does not provide positioning accuracy as good as carrier phase data, people can purchase GPS code-data instrumentation for only a few hundred dollars to obtain results at the sub-meter level. The GPS carrier-phase-data instrumentation, by way of contrast, cost several thousands of dollars. Hence, OPUS-GIS will serve a much larger community than the standard OPUS utility. NGS has not established a target date for declaring OPUS-GIS operational, but the agency hopes to have a version ready to help the Census Bureau collect critical spatial data during the 2010 census.

Project to Address Challenge: Customer Support

As a result of introducing several new variations of OPUS, NGS expects that its day-to-day customer base will grow, perhaps by a factor of 100, over the next few years. It will be a challenge to provide quality customer support to this large of a community.

4.2 Additional Global Navigation Satellite Systems

Other countries are now developing various Global Navigation Satellite Systems (GNSS) that emulate the U.S.-sponsored Global Positioning System (GPS). In particular, Russia is developing GLONASS, several European countries are jointly developing "Galileo", and China is developing BEIDOU. Of these three, GLONASS is farthest along and the Russians hope to have it fully operational by 2010. Currently, the GLONASS constellation includes about 16 operational satellites, whereas no operational satellites have been launched for either the Galileo constellation or for the global component of the BEIDOU constellation.

In December 2006, NGS installed its first GPS+GLONASS receiver to establish a CORS site collocated with the tide gauge station in Key West, FL. NGS will install several additional GPS+GLONASS receivers in the future, and the agency will encourage our CORS partners to do likewise. Also, NGS has started to develop software that will process both GPS and GLONASS data. Together, GPS and GLONASS will provide more than 50 satellites enabling users to obtain positional coordinates more accurately and more reliably.

Project to Address Challenge: Technical Expertise

To keep pace with technological progress, NGS will need to recruit additional scientists, engineers, and IT-personnel who are familiar with space-based positioning and modern telecommunications.

4.4 Funding Levels

NGS expects to serve many more customers in the near future by offering several variations of the popular OPUS utility and by providing GLONASS data, as well as GPS data, to CORS users. NGS expects that it can meet the challenges associated with this new level of service with a modest 20 percent increase to its base budget by 2010.

Annex A

The Evolution of the National Geodetic Survey's Continuously Operating Reference Station Network and Online Positioning User Service

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***Abstract*-The United States Department of Commerce's National Geodetic Survey (NGS) has developed a nationwide network of continuously operating reference stations (CORS) designed to support the broad spectrum of post-processed, relative Global Positioning System (GPS) techniques and applications. This network now comprises more than 900 permanent, geodetic-quality GPS receivers, in various installation configurations. The network was established through an exemplary cooperative effort, involving nearly 200 organizations from various government levels, academia, and the private sector. CORS GPS observational data are freely provided to the user community via the Internet and are capable of supporting high-accuracy positioning requirements. In addition to enhancing geospatial positioning, applications of CORS data include the following: a critical role in defining the nation's geodetic reference system; the ability to characterize the free electron content of the ionosphere; and an important source of precipitable water vapor input to meteorological forecasts. Associated with the CORS network, the Online Positioning User Service (OPUS) is a free, automated Web-based utility that processes submitted GPS observation data with respect to the CORS network, providing corresponding positional coordinates, via email, usually in minutes. This powerful tool has proven to be very popular with the geospatial community and is changing the way NGS is able to provide access to the National Spatial Reference System.**

I. INTRODUCTION

The National Geodetic Survey (NGS), an office of the United States Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), defines and manages the National Spatial Reference System (NSRS) – the nation's geographic coordinate system. Through its definition of latitude, longitude, and height (and other geodetic parameters), the NSRS provides a multi-purpose, coordinate-based foundation that supports the broad spectrum of today's three-dimensional positioning applications.

February 10, 2007, marks the two-hundredth anniversary of the establishment of NGS (previously called the Survey of the Coast and, later, the Coast and Geodetic Survey), which came into being as a direct result of the success of Lewis and Clark's Corps of Discovery expedition through western America. During most of the two-century evolution of the NSRS, access to the system has been provided by a network of passive, monumented ground control points. These geodetic control stations have historically had their horizontal and/or height coordinates determined by conventional optical and mechanical surveying techniques and geodetic computations. Although ground control points are still in use today, the realization of, and access to, the NSRS has been dramatically modernized by surveying applications of the Global Positioning System (GPS).

Since the mid-1980s, the use of GPS for the establishment of precise geodetic control has grown steadily. Today, conventional horizontal-positioning techniques and equipment are rarely used for such work. Since 1994, NGS has managed the development and operation of a multi-organization network of permanently installed, survey-grade GPS reference stations, known as continuously operating reference stations (CORS). The CORS network supports three-dimensional, centimeter-accuracy GPS positioning and other GPS-based applications in the United States and its territories, as well as in several collaborating foreign countries. Furthermore, this system represents a modernized means for surveyors, geographic information system (GIS) professionals, researchers, and others to actively access the NSRS through computed station coordinates and velocities, and GPS observational data, available free of charge, for post-processed GPS applications.

In 2001, NGS furthered the functionality and value of the CORS network by developing a related Web-based utility, the Online Positioning User Service (OPUS), to provide an automated method of determining user positions relative to the CORS network. OPUS provides fast, accurate, reliable, and consistent access to the NSRS via a simple Web interface. OPUS requires a user to simply collect dual-frequency GPS data at a location whose coordinates are desired, then upload the observations to the utility. Within minutes, the user will receive an email containing the OPUS-derived coordinates for the submitted GPS data file.

Reference [1] discusses the status of CORS and OPUS in 2002 and helps provide a perspective to the evolution of these programs in the past few years. As the basic technology of GPS has improved with time, CORS and OPUS have both grown and matured as well.

II. CONTINUOUSLY OPERATING REFERENCE STATION NETWORK

A. Network Development

The CORS network began with NGS' early 1994 installation of a permanent GPS station on the Gaithersburg, MD, campus of today's National Institute of Standards and Technology – an appropriate site for the nascence of what has evolved into the de facto national positioning infrastructure standard. By the end of 1994, the CORS network had grown modestly to a total of five stations, located around the country. The network's growth has accelerated substantially with time and in 2005 more than 200 additional stations were incorporated into the system, edging the total toward the 1,000-site milestone, which will soon be achieved. Fig. 1 is a map of CORS locations, showing the network status in April, 2006.

Personnel involved in the development of the CORS network realized, from the program's outset, that with its limited, small-agency resources, NGS would be unable to single-handedly build the envisioned network. Consequently, the program continues to rely on successful partnerships with other organizations to help realize the goal of building a national, multiple-use, and robust reference station network. NGS presently owns and operates less than three percent of the sites. The majority of the stations were installed by various local, state, and federal government agencies, academic institutions, and the private sector. CORS-collaborating organizations, now numbering close to 200, establish permanent reference stations to support their own varied requirements and applications – surveying and mapping, real-time navigation, geophysical research, and atmospheric modeling, to name some of the more prevalent uses. By participating in the CORS program, these site collaborators can realize a number of added direct benefits to their GPS programs – including data quality control, distribution, and archive functions.

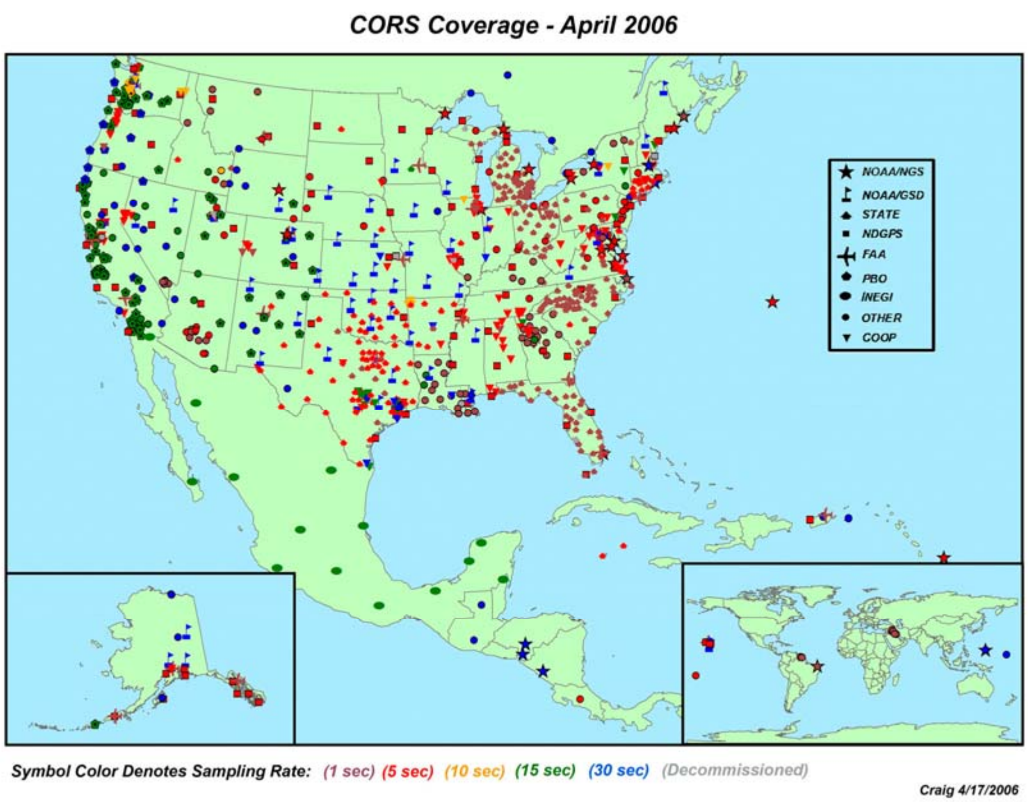


Fig. 1. Map of CORS locations (April, 2006). Station symbols and colors indicate the establishing organization and data sampling rate, as noted. Legend acronyms are defined in the text (except COOP (Cooperative CORS)).

There are far too many CORS network collaborators to discuss them and their sub-networks individually; however a few of the participating programs and organizations will be mentioned, due to the scale of contributions they are making to the program.

First, the United States National Science Foundation has funded an ambitious, multi-year research effort – EarthScope – with goals aimed at furthering our understanding of the physical processes involved in the structure and evolution of North America. One component of EarthScope, the Plate Boundary Observatory (PBO), is designed to be a geodetic observatory focused on studying the inter-tectonic plate, deformation-induced strain field in the western United States. A crucial observational tool of PBO is a network of continuous GPS sites that will eventually grow to about 900 installations. Many of these PBO sites have already been incorporated into the CORS network, with more to follow, as they are installed.

Several other institutions in the geophysical research community have established regional GPS networks to monitor crustal deformation-induced motions – efforts that are similar to PBO's undertaking, but on more localized scales.

Second, NOAA's Global Systems Division (GSD) has installed dozens of CORS sites. Many of these are collocated with meteorological monitoring instrumentation, and they participate in a nationwide network of nearly 400 sites, used to determine atmospheric moisture content.

Third, the United States Coast Guard and Department of Transportation are working cooperatively to expand the Coast Guard's existing real-time GPS maritime navigational beacon system to provide nationwide differential signal coverage, in support of safe and efficient terrestrial navigation. Stations in this Nationwide Differential GPS (NDGPS) network, now numbering nearly 100, will serve double-duty by also participating in the CORS network.

Fourth, the Federal Aviation Administration's (FAA) Wide Area Augmentation System (WAAS) is a satellite-based, real-time correction system, designed for aircraft navigation, but is frequently used in terrestrial-based applications as well. All of the ground reference stations of the WAAS infrastructure are also feeding data into the CORS system.

Fifth, the National Aeronautics and Space Administration (NASA) has been establishing permanent GPS installations for many years. Many of these sites, used for various space applications and research, have been incorporated into the CORS network.

Finally, many state governments, including Florida, Michigan, North Carolina, Ohio, Oklahoma, and Texas (each currently has about 20 or more sites), have established statewide or large-region GPS networks to support their own positioning applications, either post-processed or real-time. These statewide efforts are generally the work of the state's department of transportation (except for the North Carolina Geodetic Survey) and many also contribute to the CORS network. Several other states are currently in the planning stages of developing their own similar statewide GPS-based infrastructure.

In addition to providing coverage for the nation, the CORS network has spread to several foreign countries, furthering the unique collaborative nature of the program. Both Mexico's Instituto Nacional de Estadistica, Geografia e Informatica (INEGI) and Canada's Natural Resources Canada (NRCan) have established stations that have been incorporated into the CORS network. These sites contribute greatly to large-area, CORS-based modeling applications in the United States that might otherwise suffer from adverse "boundary condition" weakness, caused by proximity to an edge of the coverage area. Nearly a dozen nations in the Caribbean Sea region, Central America, and South America also participate in the program. NGS worked closely with the United States Army to establish a six-station network in Iraq to support that nation's ongoing reconstruction process.

B. Site Configurations

In order to provide the requisite high level of CORS data quality and consistency needed to support a broad spectrum of user applications, including the vital role that the network plays in the realization of the NSRS, NGS has rigorous site standards and installation criteria that must be met by potential collaborators, before a station can be included in the network. Reference [2] provides the latest set of site requirements and recommendations for the establishment and operation of a CORS site. These specifications were developed with the goals of providing an optimal GPS signal collection environment, the highest possible quality in computed station coordinates and velocities, and the required site documentation for users. As the document explains, site selection decisions are made on an individual basis and consider not only site quality details, but overall network issues, including regional station coverage, site infrastructure robustness, and other requirements. An NGS site selection team meets regularly to review and consider potential additions to the CORS network, submitted by interested organizations.

Because CORS sites are installed and operated by individual collaborators, they come in many different configurations, each tailored to meet the native application requirements established by the site owner. The fundamental site and installation criteria that must be satisfied to participate in the network can be summarized as follows (see the guidelines document for more details and the complete list):

- stable, well-anchored monument and antenna mount
- minimal visibility obstructions (none > 10 deg elevation)
- benign signal environment (no interference or multipath)
- L1/L2 GPS receiver tracking > 10 satellites
- L1/L2 NGS-calibrated GPS antenna
- L1 C/A- or P-code pseudorange observations
- L1 and L2 full wavelength carrier phase observations
- ≤30 second epoch interval
- data logging hourly, daily, or in real-time stream
- uninterruptible power supply capability

The CORS network is divided into two sub-networks – National CORS, which is by far the larger component, and Cooperative CORS. Each CORS is assigned to one of these network categories depending on how a user accesses the site's data, as described in the following section. Other than this distinction, there are few substantive differences between the two CORS varieties, and a detailed comparison is included in the guidelines document.

Fig. 2 is an example of a CORS installation.

C. Data

Researchers in various disciplines have developed many creative and significant applications of the CORS network during the dozen years the system has been evolving. However, the network's fundamental purpose, from the outset, has been to provide geospatial users with GPS observation data that can be incorporated into post-processed user positioning applications, primarily in surveying, mapping, and related disciplines. The CORS data augment users' GPS observation data by providing a direct connection to the highest accuracy realization of the NSRS and a corresponding direct link to precisely determined station coordinates.

Users access the GPS observation data collected at National CORS directly from NGS, via anonymous ftp (ftp://www.ngs.noaa.gov/cors/) or the World Wide Web (http://www.ngs.noaa.gov/CORS/). Whereas access to the Cooperative CORS network data is provided directly by the establishing organization, via a Web page (http://www.ngs.noaa.gov/CORS/Coop/), that provides links to Web sites of all the cooperating entities. A number of CORS installations fall into both categories and are referred to as "Combo CORS," to reflect the fact that data can be accessed from either NGS or the host organization.

CORS observation data files consist of GPS code and carrier phase observations, which are provided in the universally recognized Receiver Independent Exchange (RINEX) format. Users retrieving data via the World Wide Web interface have two different options for requesting data –

Fig. 2. CORS site P028, located in Chaco Canyon, NM, and established/owned by the Plate Boundary Observatory. Pictured are: satellite dish for data communications, solar panels, equipment housing boxes, and GPS antenna attached to anchored mount.

the user-friendly CORS (UFCORS) and the standard download interfaces. UFCORS provides the user with the ability to: request a data file covering a desired time period (including, for instance, a time block that spans multiple calendar days); have it populated at a specified epoch interval; have the observations packaged along with various site metadata and ancillary GPS information; and to have all of this information file-compressed, as desired. Although the same information, including the ancillary data, can be accessed via the standard download interface, this approach can involve multiple manual operations on the part of the user. UFCORS is extremely easy to use and has proven to be popular. UFCORS data requests currently average approximately 40,000-60,000 per month, with typical total data download volume of 30-50 gigabytes. This traffic represents an approximately ten-fold increase, compared with typical monthly activity in 2000.

Anonymous ftp is the most popular method, in terms of data volume, for accessing CORS data. Users who download large quantities of CORS, often for research applications, find this mechanism to be faster and easier to automate into their own data management and access processes. In March, 2006, nearly 750 gigabytes of CORS-related data were downloaded via ftp.

In addition to providing access to GPS observation data, the CORS Web site also allows a user to view or download a variety of metadata and related information about each site. This information includes the following:

- data availability plots

- station coordinates and velocities of both the L1 phase center and the antenna reference point referenced to the North American Datum of 1983 (NAD83) and the International Terrestrial Reference Frame (ITRF)
- site logfile with equipment and installation details
- NGS station datasheet
- local and regional maps and site satellite imagery
- site photographs
- notices about site operation, outage forecasts, etc.
- 60-day station coordinate time series plot
- long-term station coordinate time series plot
- precise GPS satellite ephemeris data

The CORS Web site provides a wealth of CORS-specific and more general GPS-related information, in addition to site-specific data and information. It includes a newsletter with updates about GPS and the CORS network; a list of frequently asked questions (and their answers); information for potential CORS collaborators; access to software; a list of related publications and presentations; links to other organizations and Web sites; a discussion of CORS coordinate issues; national and regional maps showing CORS site coverage; a list of forthcoming sites; and much more – including contact information for users to pose a question or provide a comment to CORS personnel.

A critical aspect of the CORS program is the computation, monitoring, and quality control of station positional coordinates and velocities. It is the combination of CORS GPS observations and corresponding station coordinates that give the system its full value, for most users.

To satisfy the needs of the wide range of CORS users, NGS computes and provides station coordinates and velocities in two reference systems – ITRF and NAD83. ITRF was developed by the International Earth Rotation Service (IERS) and is widely utilized in the global research community, whereas NAD83 was produced by NGS and is commonly used in surveying and mapping applications in the United States. A fundamental distinction between these two systems is that NAD83 is defined to be fixed with respect to the North American tectonic plate, while ITRF satisfies a global condition of zero net rotation of all of the plates. One result of this difference is the characteristic that, on most of the stable part of the North American plate (most of the United States, excluding portions or all of California, Oregon, Washington, Alaska, and Hawaii), NAD83 coordinates generally have zero, or negligible, velocities associated with them, and ITRF horizontal coordinates change at a rate of approximately 1-2 cm per year. Hence it is important to provide velocity estimates and specify an epoch date for coordinates.

CORS coordinates and velocities are provided for both ITRF and NAD83, in Earth-centered, Earth-fixed Cartesian coordinates (X, Y, Z) and geodetic coordinates (latitude, longitude, and ellipsoid height – relative to the Geodetic Reference System of 1980 (GRS80) ellipsoid). Every few years IERS computes a global network solution that integrates measurements from a number of different geodetic technologies to generate a revised realization of ITRF. NGS is currently utilizing the 2000 realization (ITRF2000) referred to an epoch date of January 1, 1997, and will adopt future ITRF realizations, as they are released by IERS. The global precise positioning community is currently anticipating a near-term release of the 2005 realization of this system – the ITRF2005.

CORS coordinates are published for both the L1 phase center and the antenna reference point (ARP) of each site's GPS antenna. The ARP is usually the physical bottom of the antenna and is commonly used as the reference height level in GPS data processing. There are, however, some users and applications that prefer to reference the L1 electrical phase center of the antenna, so NGS provides both sets of coordinates.

Part of the process of incorporating a new station into the CORS network is to compute the station coordinates that will be published and provided to users. This initial determination of the station position is based on the processing of a minimum of about two weeks (and more in some areas, due to problematic atmospheric conditions, etc.) of GPS observations. The native result of this effort is a set of ITRF station coordinates. The velocities associated with the station are modeled using the NGS Horizontal Time-Dependent Positioning (HTDP) software. The NAD83 station position and velocities are then computed from the ITRF values using a Helmert transformation. Eventually, after a number of years, and the station has realized sufficient history in the CORS network, the ITRF and NAD83 modeled velocities are replaced by GPS-measured values.

The accuracy and consistency of CORS site coordinates are continuously monitored by NGS – for both National and Cooperative CORS – through a daily solution of all stations and a rigorous least squares network adjustment. This adjustment is currently constrained to three well-determined CORS sites and two stations that are part of the cooperative network of the International Global Navigation Satellite System (GNSS) Service (IGS), thereby providing an important link between the CORS and a more global, research-focused GPS network. The recent behavior of each station's coordinates can be viewed in the 60-day time series plots, which show the differences between the daily ITRF solution, transformed in time back to the published position epoch date, and the published station coordinate values. The plotted values are the north, east, and up components, each characterized with an error bar and summarized by a statement of the 60-day mean (or bias) and RMS.

Approximately every year, NGS also computes a rigorous set of station coordinate values based on every third day of GPS observations over the history of every CORS. This allows the behavior of each site, over time, to be analyzed and the quality of its published position to be monitored. If the difference between a station's published coordinates and history of computed coordinates – based either on analysis of the 60-day plots or the multi-year solution – consistently exceeds 1 cm in either horizontal component or 2 cm in the vertical component, for ITRF, or 2 cm in either horizontal component or 4 cm in the vertical component, for NAD83, NGS will publish new coordinate values, and velocities, relative to the impacted reference frame(s). These coordinate republication criteria represent a compromise between maintaining coordinate consistency over time and providing the most accurate values possible. The coordinate behavior of each site, for its entire history, can be viewed in the long-term time series plots that are provided.

The ongoing monitoring and characterization of station behavior and the occasional republishing of CORS coordinates mean that users can be assured of a high degree of CORS coordinate quality. For this reason alone, a CORS is superior to a static ground control station, whose coordinates can become accuracy-degraded over time, relative to the requirements for some demanding applications. Even in areas that are prone to surface motions, due to tectonic, volcanic, fluid-withdrawal effects, etc., the CORS system provides station behavior characterization to support decisions about how best to utilize the station's coordinates. Some users of the CORS network exploit this coordinate behavior information through the computation of their own updated CORS coordinate values, based on statistics provided in the 60-day plots. They, in effect, use the recent observed history of the site to fine-tune its coordinates for use in their project.

D. Applications

The primary motivation behind NGS' effort in building the CORS network has been to provide the infrastructure to allow the geospatial user community to improve the accuracy of GPS measurements through relative positioning techniques, based on simultaneous data collected at CORS sites. These user techniques can include long-session static positioning for the establishment of geodetic control (centimeter accuracy), kinematic travel-path determination of moving platforms (few-decimeter accuracy), and feature mapping for GIS data collection (meter to sub-meter accuracy). In each of these application categories, the power of the CORS network is realized through its ability to provide GPS observations, collected at precisely known locations, which substantially improve the accuracy of the user's GPS measurements.

Paralleling the ongoing growth of the CORS network is an expansion in the range of applications supported by CORS and CORS-derived data. The high accuracy of CORS coordinates and velocities coupled with the reliability and availability of the associated GPS observation data have enabled a broad array of applications, many of which were not envisioned during the early days of the CORS system – now a decade ago. With the ability to support centimeter-level accuracies, the system is now involved in disciplines far beyond the original focus of surveying- and mapping-related applications.

NOAA's Global Systems Division (http://www.fsl.noaa.gov/) conducts research and development to provide the nation with environmental information and forecast capabilities. The agency's Ground-Based GPS Meteorology program relies on CORS data, from hundreds of sites, to determine atmospheric water vapor content, derived from tropospheric GPS signal delays. This precipitable water data is now being used operationally to enhance meteorological forecast capability and has proven very valuable to the meteorological community, and hence to the nation.

NOAA's Space Environment Center (http://www.sec.noaa.gov/) is responsible for monitoring and forecasting Earth's space environmental conditions. CORS observations are now contributing prominently to this effort by providing the ability to characterize the total electron content (TEC) in the ionosphere. By exploiting the dispersive nature of the ionosphere and the delay effect it has on the GPS signals, ionospheric TEC can be calculated. GPS-derived TEC maps for the continental United States are now provided online and are updated on a 15-minute cycle with just 30-minute latency. This data is valuable to researchers, satellite operators, utility companies, and others who are impacted by ionospheric conditions.

Tropospheric and ionospheric modeling efforts are being further exploited to enhance GPS surveying capabilities. The ability to quantify atmospheric GPS signal delay can greatly benefit the GPS data processing task of resolving integer ambiguities, thereby allowing for a decrease in required occupation times. Additionally, for users of single frequency GPS equipment, CORS-derived atmospheric condition data can allow greater project distances to be covered.

CORS data are frequently used to provide GPS base station data to differentially correct GPS observations used in aircraft to locate airborne imagery. This application benefits greatly from the CORS network because of the simplification in project logistics that is realized by tapping into the existing CORS infrastructure. Aerial imagery providers can enjoy considerable time and cost savings by incorporating CORS data into their process and reducing or eliminating the requirement to establish their own project-specific base stations. Recovery work in the United States Gulf Coast region following the devastating 2005 hurricane season was bolstered by the collection of aerial imagery by the NGS Remote Sensing Division. This comprehensive set of aerial photographs, all of which were positionally controlled by regional CORS sites, was made available to the recovery effort with rapid turnaround – thanks, in part, to the CORS network.

NGS and many other organizations use observation data from the CORS network, and other permanent GPS networks, for the determination of precise GPS satellite orbits. These orbits, in turn, contribute to high accuracy positioning capability because the accuracy of GPS-derived coordinates on the ground is partially dependent on the accuracy of the satellite positions used in processing the observations. The IGS, an international federation of 200 organizations – including NGS – involved in the production of a variety of GPS and GLONASS data products, coordinates the production of precise GPS satellite orbits which are derived from analysis performed by participating organizations located around the globe. The participation of the CORS network in a multi-national, worldwide effort of developing GPS-related data products provides an important bridge between the United States-centric CORS network and the global space-based positioning arena.

GPS has become one of the tools of choice for the research community interested in measuring motions of the earth's surface, which are the result of tectonic deformation, post-glacial rebound, groundwater withdrawal, or other natural or man-induced causes. The accuracy capabilities, in both the horizontal and vertical components, supported by the CORS network – and related continuous GPS networks – have made possible the monitoring of these motions and, in some cases, the determination of trends supporting some predictive capability. Many organizations and multi-organization cooperative endeavors are using permanent GPS networks to monitor motions. A few examples are: EarthScope/Plate Boundary Observatory (http://pboweb.unavco.org/), Pacific Northwest Geodetic Array (http://www.geodesy.cwu.edu/), Scripps Orbit and Permanent Array Center (http://sopac.ucsd.edu/), Bay Area Regional Deformation Network (http://www.ncedc.org/bard/), and Basin and Range Geodetic Network (http://cfa-www.harvard.edu/space_geodesy/ BARGN/). Many of the continuous GPS sites in these networks are also included in the CORS network, thereby furthering the cooperative, multi-use nature of these ambitious programs.

NGS is relying heavily on the CORS network in satisfying its federal requirement to provide the NSRS. CORS represents the highest accuracy component or tier of the NSRS. This importance of the CORS network is reflected in NGS' present effort to readjust the existing, GPS-observed ground control stations to produce a new realization of the NAD83 system. For this process, the published positions of all CORS sites will be held fixed and the monumented points, which have been observationally connected to the CORS system, will be adjusted to the CORS. The results of this readjustment will be an increase in the positional accuracy of the monumented points and a higher degree of consistency, than currently exists, between the coordinate values of the CORS and the monumented points.

E. Future CORS Plans

NGS is constantly trying to improve its products and services, including the CORS network. As previously mentioned, CORS personnel operationally monitor daily CORS solutions and long-term site behavior to track issues such as coordinate and velocity consistency and site stability. Reference [3] describes the ongoing effort of maintaining the most accurate coordinate set possible for the CORS network, and the authors emphasize that daily monitoring of coordinate variability is an essential part of providing a rigorous permanent network.

Reference [4] examines data from nearly 400 CORS sites to better understand signal multipath issues, and important conclusions were made regarding the impact of site issues such as monumentation, antenna configuration, and signal environment, and how they affect data quality. Ongoing research efforts, such as this, have contributed to the development of the aforementioned site guidelines document, which was developed to provide consistency and reliability throughout the CORS network. The guidelines will help to ensure that the system can support even the most accuracy-demanding of applications well into the future.

Due in part to the ongoing interest in the development of local and regional permanent GPS networks, the CORS system will continue to grow and NGS will accommodate this growth to the extent possible. One near term goal of the CORS program is to improve the spatial coverage throughout the United States. Presently, some areas are considerably better served than others, because of the cooperative nature of the network. A level of station redundancy is desirable because, at any given time, a small percentage of stations might be non-operational due to site maintenance activity or equipment failure.

NGS also hopes to reduce the latency of data provided by stations. Although many stations provide data to NGS hourly, or in real time, there are still a number of sites that, due to communications limitations, are restricted to providing the data daily. As new sites are being considered for inclusion in the network, the data latency is one of the site issues that are examined.

In recent years, NGS has solicited feedback and recommendations from the CORS user-community, often at venues such as national conferences presented by organizations, including the Institute of Navigation and the American Congress on Surveying and Mapping. In order to determine how best to evolve the CORS system, NGS needs to know what the user community requires in reference station infrastructure and ideas garnered through these forums – and other means – have helped guide this process.

One GPS issue that is of great interest, particularly in the surveying community, is the delivery of reference station data in real time, which is the foundation of the network real-time-kinematic (RTK) approach to precise positioning. With the profusion of real-time networks, such as many state and regional entities are presently developing, there has been a profound paradigm shift in the precise positioning arena. And, NGS is exploring fundamental support, through the CORS network, to this technology.

Testing is currently underway to determine how NGS can provide real-time delivery of CORS GPS observation data via the Internet. One method that is being examined and considered is a Radio Technical Commission for Maritime Services (RTCM) standard protocol, known as Network Transport of RTCM via Internet Protocol (NTRIP). By utilizing a technique such as NTRIP, NGS could provide a real-time stream of CORS GPS observation data over the Internet that would be accessible to end users or to real-time service providers, who would process the data and deliver a derived product. It is important to note that, at this time, there are no plans for NGS to provide a real-time derived product, such as a network RTK solution, nor would the anticipated Internet data stream from NGS be suitable for applications such as navigation. NGS' involvement in the real-time arena is still very much open to discussion, evaluation, and consideration

IGS is interested in supporting a global, real-time positioning infrastructure and the CORS network could be an important component of such an undertaking. Such a lofty goal would require the participation of an unprecedented number of collaborators, but the result would indeed be profound.

Estimates of the tangible value of the benefits provided to the positioning community by the CORS network are now in the range of tens of millions of dollars per month. For taxpayers in the United States alone, this represents a huge return on the relatively minimal cost incurred by the program. As the network grows and more users find new ways to take advantage of CORS data, the direct value of the system will undoubtedly continue to increase.

III. ONLINE POSITIONING USER SERVICE

A. Overview of the Utility

The CORS program underwent a profound functional advancement in 2001 when NGS began offering enhanced access to the system through a powerful Web-based utility – the Online Positioning User Service (OPUS). In developing OPUS, which is still substantially evolving, NGS' goal has been to provide the geospatial community with a simplified means of accurately accessing the NSRS through an automated process that provides consistent results with rapid turnaround.

With OPUS, users can submit their own GPS observations through a simple Web interface, requiring only minimal user input, and within minutes they will receive an email reporting the coordinates of their data collection site, computed via rigorous GPS vector connections to three CORS. This process is performed using NGS software and computers and is provided free of charge.

B. User Interface

The OPUS submittal Web page (www.ngs.noaa.gov/ OPUS/) can be link-accessed from several locations around the NGS Web site – principally the NGS homepage, the main CORS homepage, and the Geodetic Toolkit. This submittal page asks the user to enter the following basic information through a straightforward interface:

- email address to receive the results
- observation file(s) in RINEX or most receiver raw formats, optionally compressed
- vertical antenna height, in meters, from mark to ARP
- antenna type, chosen from dropdown menu

and the following information, which is optional:

- forced State Plane Coordinate System zone
- up to 3 specific CORS to include in the solution, which may include Cooperative CORS
- specific CORS to exclude from the solution
- whether extended output information is desired
- whether to capture user configuration in a profile

Once this information is compiled and uploaded to OPUS, the user simply waits for an email containing the results that will normally (depending on the current processing load) arrive within minutes.

Some guidelines/requirements governing user submissions are:

- static GPS observations
- dual-frequency (L1/L2) GPS observations
- minimum 2-hour span of data recommended
- epoch rate an integer divisor of 30 seconds

C. The Process

Final OPUS-derived coordinates reported back to the submitter are the average of separate single-baseline solutions connecting the user's GPS measurements to simultaneous measurements made at each of three CORS. These ionospheric-free solutions are generated by NGS' GPS processing software package, PAGES (Program for the Adjustment of GPS Ephemerides), utilizing double-differenced, carrier-phase measurements to compute ITRF-referenced baseline vectors.

Prior to processing the baselines, OPUS must first determine the CORS sites that PAGES will use. This is an iterative procedure involving a number of tests that examine the availability and quality of data collected at candidate stations, beginning with the optional user-specified sites, which may include Cooperative CORS, and the National CORS sites which are closest to the user's data collection location. Data quality issues that are investigated include signal multipath and cycle slips, the presence of which can degrade the results' accuracy. If the GPS data of the user-selected CORS or the closest CORS are deemed insufficient – in quality or quantity – the search is then expanded outward and other potential CORS data files are examined, until three sites with suitable data are identified.

Typically, the result of the CORS selection process is that the three closest CORS are picked, but there are exceptions to this generalization. One such situation could occur if a user performs an OPUS submittal with very little delay following the end of the observing session. Because some CORS sites transmit data to NGS only daily, data from some nearby CORS might not yet be available for the required time period, and OPUS would then expand its search to more distant sites in order to find adequate data coverage.

It is important to note, however, that users are allowed to submit their data as soon as desired after it is collected. Because many CORS sites do provide data to NGS on an hourly or real-time basis, there will normally be a sufficient number of CORS with valid data to allow OPUS to work, even with very little time delay following the end of the user's session. The CORS utilized in such a situation, however, might be much more distant than they would be if the user were to wait a number of hours before submitting.

Although OPUS computes the inter-site vectors in the ITRF system, it produces final coordinate values referenced to both ITRF and NAD83. To derive the ITRF results, OPUS retrieves the published ITRF positions for the selected CORS from the NGS Integrated Database. These coordinates are then transformed to the epoch represented by the mid-point of the time span of the user's data file, to accommodate the motion-induced changes (e.g. approximately 1-2.5 cm annually on the North American tectonic plate) of ITRF coordinate values. The time-transformed coordinates are then used in the three distinct PAGES solutions that are ultimately averaged to determine the final ITRF coordinates.

Corresponding NAD83 coordinates (for the date of observation) are obtained by transforming the derived ITRF coordinates via the 14-parameter Helmert equations adopted for this purpose. These NAD83 coordinates are then projected to a standard epoch date of January 1, 2002, using the NAD83 velocity predicted by the HTDP software.

It is important to note that, for both ITRF and NAD83, the three distinct solutions, each based on a connection to one of the three CORS, are not completely independent of each other. This is due to the fact that all three solutions incorporate the same set of user-submitted observations and are all subject to the same potential biases at the user's data collection site. Possible biases include signal multipath caused by the site environment and an error in determining the horizontal and/or vertical relationship between the user's GPS antenna and the ground monument, resulting, respectively, in centering or antenna height errors. The ultimate effect of such biases would not be averaged out or mitigated through a combination of the three distinct solutions and would likely go undetected.

D. Output

The OPUS output page contains a concise, yet thorough, summary of the results of the automated processing of the submitted observation file. In addition to echoing back all of the user's input information, the output includes the following:

- GPS satellite ephemeris used
- start/end time of observation file
- number of observations used/present and % used
- number of ambiguities fixed/total and % fixed
- overall RMS of vector processing

- NAD83 and ITRF coordinates in (X, Y, Z) and latitude, longitude, ellipsoid height
- NAVD orthometric height based on Geoid03 model
- peak-to-peak error for all coordinate components
- UTM and SPCS metric planar coordinates, convergence, and scale factors
- U.S. National Grid designator
- name, position, and distance for each of the 3 CORS
- nearest published NGS control point.

And if the user requests the optional extended output, the following information is included in the email:

- for each CORS, summary of derivation of time- transformed ITRF coordinates
- for user's location, summary of derivation of time- transformed starting coordinates
- for each baseline, summary of derivation of user's coordinates
- G-file vector records for use in NGS Adjust software
- Post-fit RMS satellite vs. baseline results
- summary of number of observations for each satellite vs. baseline
- covariance matrix elements for inclusion in network adjustment software
- estimate of horizontal and vertical network accuracies
- summary of derivation of NAD83 vector components
- SPCS planar coordinates in feet, if a specific state- specified foot conversion exists

E. Results

The quality of the computed coordinate components is characterized in the OPUS output by comparing the results of the three individual solutions and computing the peak-to-peak errors of the X, Y, and Z geocentric values and the latitude, longitude, ellipsoid height, and orthometric height (NAD83 solution only) values. Peak-to-peak errors are simply the difference between the maximum and minimum value for each coordinate component.

The peak-to-peak error statements included in the output provide a more meaningful characterization of the quality of results compared with the formal errors derived from GPS vector processing, which are known to be unrealistically optimistic. In addition to providing more realistic estimates of the precision of the solutions, the peak-to-peak errors have the added advantage that they also reflect any error in the CORS coordinate values used in the solutions.

The achievement of quality OPUS results is, in part, dependent on freedom from any systematic error in the process. Most typical user-caused potential errors are related to the GPS antenna – errors in measuring or inputting the mark-to-antenna (measured at the ARP, in meters) vertical offset, centering the antenna over the mark, or selecting the antenna type on the OPUS submittal page. The use of an incorrect antenna type alone, which would cause OPUS (and PAGES) to use the wrong antenna electrical phase center model during processing, could lead to an error in height as great as 10 cm, or more. Systematic errors such as these would neither be detected by OPUS nor would they be reflected in the peak-to-peak error statements.

The following list provides a guideline set of minimum OPUS output criteria that will help the user identify when an OPUS run has been successful:

- > 90% of submitted observations used
- > 50% of integer ambiguities fixed
- < 3 cm overall RMS

- < 5 cm peak-to-peak errors, in each component
- confirm correct antenna type and height were input.

For OPUS users desiring to better their results, the routine advice to be given is quite simple: collect more data. Reference [5] presents an investigation to determine the relationship between the duration of observing session and coordinate accuracy achieved by OPUS. By utilizing 30 days of CORS data, subdivided into sessions of 1, 2, 3, and 4 hours and submitting these test datasets to OPUS, the authors compared the results with the published positions of the CORS sites, which were the sources of the test data. For sessions of 2 hours, the RMS results of 0.8 cm, 2.1 cm and 3.4 cm in the north, east, and vertical components, respectively, corroborated the OPUS guidelines suggesting 2 hours as the minimum time needed to typically provide sufficient accuracy for many surveying-related tasks. Applications that are more demanding, in terms of accuracy, will require longer datasets. The results for the 3- and 4-hour sessions show substantial improvement compared with the 2-hour sessions. Furthermore, the study shows that a reduction of session length to 1 hour greatly deteriorates the accuracy, due primarily to the inability of the software to adequately determine the integer ambiguities.

Another NGS study, by OPUS personnel, involved the submission to OPUS of over 200 2-hour test datasets, again collected at CORS sites, to examine the accuracy achieved with the recommended session length. The results – RMS values of 0.8 cm, 1.4 cm, and 1.9 cm in the north, east, and vertical components – were slightly better, particularly in the vertical component, than the results of [5].

Other studies, such as [6], have shown that for static GPS processing, there is little relationship between coordinate accuracy achieved and GPS vector length, assuming that there is adequate observation data to fix the integer ambiguities and to correctly estimate the tropospheric delay.

The impact of the results of these aforementioned studies is that OPUS users can expect to achieve good results as long as they have collected and submitted a sufficient (sufficiency being determined by the user's specific application of the results) quantity of data from a quality collection site, even if OPUS uses CORS sites in the solution that are a great distance from the user's site.

In addition to session length, another issue that can impact OPUS results is the GPS satellite orbits that are used in the processing. The orbits come in three different varieties, all available from IGS, and they are listed here in increasing order of accuracy, along with their typical availability delays:

- IGS ultra-rapid orbits (no delay)
- IGS rapid orbits (1 day)
- IGS precise orbits (10-14 days)

OPUS will always use the best available orbit file for processing. If an OPUS submission is made within a few hours after the end of the user's observing session, for example, OPUS will use the ultra-rapid orbit file because that is the only version that is available. If, however, there is a delay of a few days before the submission, the rapid orbits will then be available and will be used. The OPUS output will report which orbit file was used.

For most users, the resulting coordinate accuracy improvement realized in going from a solution based on the ultra-rapid orbits, which are partially predicted, to the rapid orbits, which are based fully on observations, warrants the effort of waiting a day or so and resubmitting the file to OPUS for reprocessing with the improved orbits. The effective improvement for most users (working with baselines up to several hundred kilometers in length), however, in going from a solution based on the rapid orbits to one utilizing the final precise orbits is so minimal that resubmission is typically not warranted.

OPUS processing utilizes 30-second epoch rates and, although users often collect data at a faster rate, there is no advantage (nor is any harm done, assuming the epoch rate in the submitted file is an integer divisor of 30) to submitting higher-rate data.

F. Future OPUS Plans

The popularity of OPUS has been increasing substantially with time and usage is now typically in the range of 10,000 to 15,000 files processed per month, with a range of 2,000 to 3,000 users per month. Fig. 3 shows the history of the number of files processed by OPUS per month for the past 4 years. Usage has become more widespread, both geographically and in the variety of applications for which it is being employed. This growth is at least partially a result of the expansion of the CORS network, but is also due to the fact that as more people

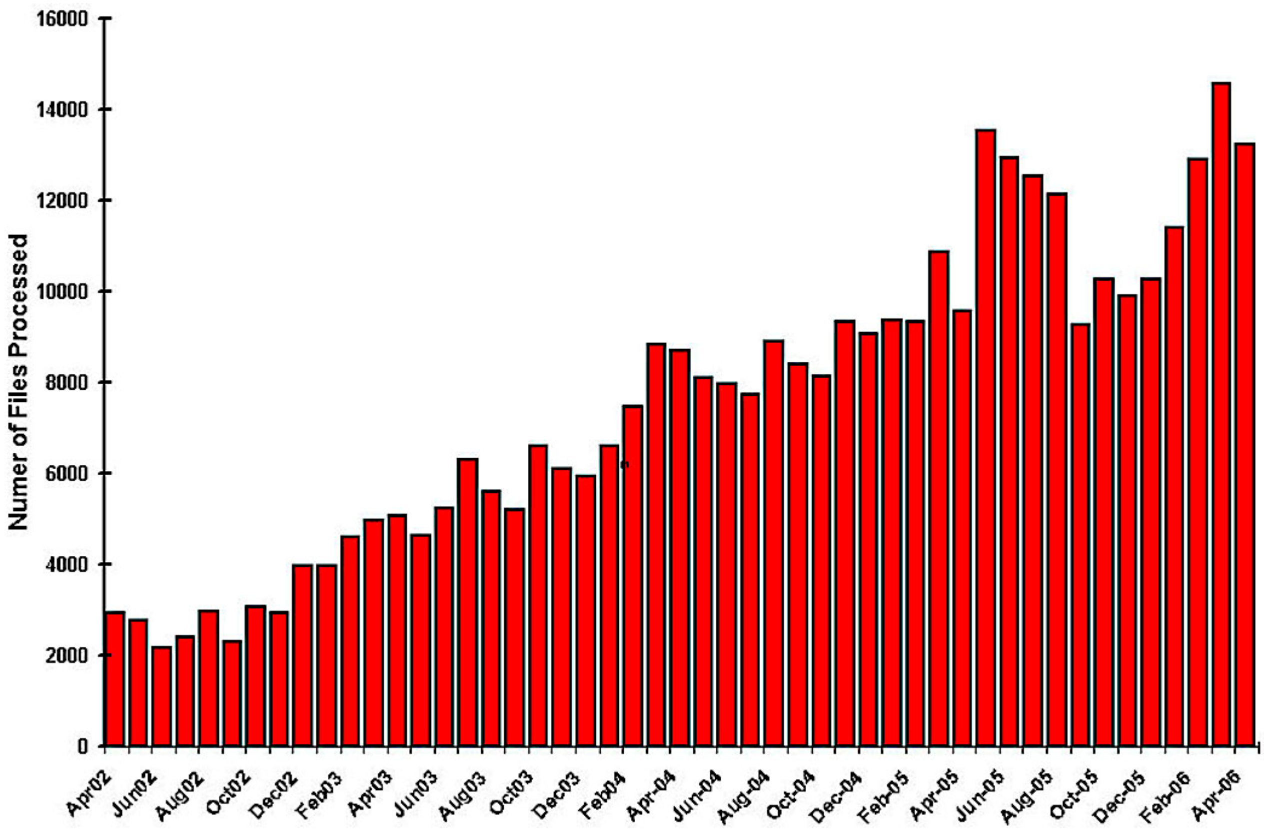


Fig. 3. Chart of number of monthly OPUS files processed for April, 2002 through April, 2006.

learn about the utility and how it can be used, they are putting it to work. Reference [7] is a good overview of the utility that provides exposure to the general surveying community, the largest single group of OPUS users. Additionally, [8] presents the utility to an audience that is more likely to be focused on defense and intelligence applications of positioning technologies. As an example of the recognized importance of OPUS, it was selected as the March, 2004, "Internet Resource of the Month" by *GEO World* magazine.

Most OPUS users employ the utility simply to statically establish their own geodetic control for various surveying-related project applications. OPUS is extremely powerful in its support of this kind of work. Some users are going a step further in how they use OPUS by doing things such as integrating the utility into their own RTK GPS work. In this approach, surveyors can set up an RTK base station anywhere, perform the RTK survey based on an approximate, autonomous position for the base station, and after returning to the office, submit the base station data to OPUS to determine the base coordinates. The RTK rover data can then be reprocessed utilizing the new, OPUS-derived base station coordinates to correct the rover data for the entire project.

NGS presently has tentative plans for several future versions of OPUS that will greatly improve its usefulness and flexibility. In its present configuration, OPUS requires the use of dual-frequency, survey-grade GPS receivers, at least two hours of GPS observations, and it delivers the results to the submitter only and not to any database. In the proposed forthcoming enhanced OPUS versions, each of these characteristics will be modified. It is important to note that the following proposed OPUS versions, their capabilities, and names are all subject to change. Implementation of any of these changes to OPUS will depend on NGS policies which have not yet been established.

With "OPUS-Database," qualified submitters will be able to register in order to have their OPUS results captured into the NGS database for others to access. Database entries will be restricted to OPUS submission results that meet specific quality criteria. The "OPUS-Database" results can complement geodetic control data pertaining to stations already existing in the NGS database or they can be used to establish new points not previously contained in the database. An example of how "OPUS-Database" might be used to improve data on an existing point would the OPUS-positioning of a vertical control point, whose existing horizontal position of record was derived by scaling from a topographic map. By capturing the OPUS results into the database, the recorded horizontal position of the point would be upgraded from the approximate, scaled coordinates to the more accurate OPUS values. Furthermore, the OPUS-derived ellipsoid height would also be captured, thereby providing an observed determination of the station's geoid height (the difference between the existing orthometric height and the newly established ellipsoid height) – an important contributor to future geoid models. "OPUS-Database" represents a vastly simplified procedure for capturing geodetic control into the NGS database, compared with the existing process that is required of all submitted projects.

"OPUS-Rapid Static" is being designed to provide precise positioning capabilities with occupation times around 15 minutes, instead of the currently recommended 2 hours. This capability will come from the use of a different processing engine, instead of PAGES, that will utilize the P1 and P2 pseudorange measurements in addition to the L1 and L2 carrier phase observations.

"OPUS-Projects" will allow users to submit simultaneous observations collected by their multiple receivers and the utility will process the connections between these multiple receivers as well as the connections to the CORS sites.   A user's multiple observation sessions can be accumulated, thereby allowing for the establishment of a geodetic network approach to establishing control stations, including rigorous network adjustment analysis.

"OPUS-GIS" will be of most interest to the mapping and GIS communities. It will involve the use of short, approximately 1 minute, occupation times with code data from mapping-grade GPS equipment to achieve anticipated positional accuracy of a meter or better.

Each of these potential new varieties of OPUS will have specific applications for which it is best suited. The commonality for all of them is that they provide fast, easy, and reliable access to the NSRS and ultimately accurate geographic positions.

IV. CONCLUSIONS

GPS technology has revolutionized the positioning and navigation arenas. The CORS network provides the infrastructure that supports even the most accuracy-demanding of location-based applications. Furthermore, OPUS gives users a fast and easy way to access the NSRS, via the CORS network. As the CORS network continues to evolve, and as applications of the CORS system expand, NGS will endeavor to provide enhanced user access to a consistent and reliable national positioning framework for years to come.

ACKNOWLEDGMENT

I thank NGS employees Cindy Craig, Ruth Osborne, Dr. Dru Smith, Dr. Richard Snay, and Neil Weston for their assistance. I appreciatively recognize Bill Strange, retired NGS chief geodesist, for long ago having the insightful vision of a nationwide CORS network, which has indeed come to pass.

REFERENCES

[1] R.A. Snay, G. Adams, M. Chin, S. Frakes, T. Soler, and N.D. Weston, "The synergistic CORS program continues to evolve," *Proc., ION GPS 2002* (CD-ROM), Institute of Navigation, Alexandria, VA, pp. 2630-2639, 2002.

[2] "Guidelines for new and existing Continuously Operating Reference Stations (CORS)," National Geodetic Survey, 33 pp., February, 2006 (http://www.ngs.noaa.gov/CORS/Establish_Operate_CORS.html).

[3] T. Soler, R.A. Snay, R.H. Foote, and M.W. Cline, "Maintaining accurate coordinates for the National CORS network," *Proc. FIG Working Week*, Paris, France, 8 pp., April 13-17, 2003.

[4] S. Hilla and M. Cline, "Evaluating pseudorange multipath effects at stations in the National CORS Network," *GPS Solutions*, 7(4), pp. 253-267, 2004.

[5] T. Soler, P. Michalak, N.D. Weston, R.A. Snay, and R.H. Foote, "Accuracy of OPUS solutions for 1- to 4-h observing sessions," *GPS Solutions*, 10(1), pp. 45-55, 2006.

[6] M.C. Eckl, R. Snay, T. Soler, M.W. Cline, and G.L. Mader, "Accuracy of GPS-derived relative positions as a function of interstation distance and observing-session duration," *Journal of Geodesy*, 75(12), pp. 633-640, 2001.

[7] G.L. Mader, N.D. Weston, M.L. Morrison, and D.G. Milbert, "The On-line Positioning User Service (OPUS)," *Professional Surveyor Magazine*, pp. 26-30, May, 2003.

[8] G.L. Mader and N.D. Weston, "NGS' Online Positioning User Service," *GeoIntelligence*, pp. 16-19, January-February, 2006.

ANNEX B

CORS West Project Plan:

Parallel Operation of Essential Continuously Operating Reference Station Activities in Boulder, Colorado

FY04 – FY06

CORS Program Background:

The Continuously Operating Reference Station (CORS) program comprises a nationwide network of permanently operating Global Positioning System (GPS) receivers. NOAA's National Geodetic Survey (NGS) provides access to GPS data from this network free of charge via the Internet. The program's primary objective is to enable GPS users to determine precise positional coordinates relative to the National Spatial Reference System. Users can achieve centimeter- or decimeter-level accuracy by post-processing several hours or minutes, respectively, of their GPS data with data from the CORS network. Users can also determine the travel path of a moving platform–like an aircraft, a boat, or a land vehicle–with decimeter-level accuracy by post-processing GPS data from a receiver mounted on this platform with data from the CORS network. Other users of CORS data include:

- Earth cientists to monitor crustal motion,
- Meteorologists to monitor the distribution of moisture in the atmosphere, and
- Atmospheric scientists to monitor the distribution of free electrons in the ionosphere.

The CORS network currently (May 2004) contains more than 800 stations and is growing at a rate of about seven stations per month. These stations are operated by a collection of more than 110 organizations representing various federal, state, and local government agencies, as well as various academic and commercial institutions.

At NGS' request, NOAA's National Geophysical Data Center (NGDC) is to undertake the following:

- Host and co-manage a parallel CORS data site at NGDC's facilities in Boulder, CO. This data site is to collect, process, store, and distribute CORS data in parallel with the primary CORS data site located at NGS' facilities in Silver Spring, MD. This parallel data site is to sustain uninterrupted operation of essential CORS activities whether the primary data site is destroyed or whether it goes down for only a relatively short period—such as in the case of a power outage or a computer failure. This parallel data site, in addition, is to share the work of distributing CORS data with the primary data site when both sites are fully operational.
- Review CORS data management procedures.
  Review data collection, data processing, data storage, and data distribution procedures and, if some procedures are deemed relatively ineffective, suggest appropriate modifications to these procedures. It is fully expected that new product development will be accomplished jointly by NGS and NGDC.

- Enable those NOAA offices located in Boulder (National Weather Service, Environmental Systems Research Laboratory, etc.) which have a requirement for CORS data to obtain these data more directly and expediently than they can using only the primary CORS data site located in Silver Spring.
- Host and help maintain a replication of the NGS Integrated Database (NGSIDB) in Boulder, CO.
  Replication in Boulder means the contents of the NGSIDB will be readily available in the event that the primary NGSIDB server – located in Silver Spring, Maryland – is lost. The NGSIDB contains information pertinent to the CORS program and all other major NGS activities.

Program Objectives:

To accomplish the following Program Objectives, NGS will provide funding for the FY04-FY06.

Fiscal Year	2004	2005	2006
FTE	0.5	0.5	0.7
Contract	0.5	1.0	1.3
Funding	$136K	$187K	$240K

Tasks / Milestones

Below are the major Tasks and Milestones (in order of priority) required to sustain CORS capability:

Tasks

Provide network and system administration support for the CORS computers and Cisco network equipment located in Boulder.

Collect, process, store, and distribute CORS data in parallel with the primary CORS data site.

Sustain uninterrupted operation of essential CORS activities.
Share the work of distributing CORS data.
Review data collection, data processing, data storage, and data distribution procedures.

In conjunction with NGS, develop, operate, maintain, and manage the archival functions for CORS data.

Enable NOAA Boulder offices that have a requirement for CORS data to obtain these data more directly and expediently.

Host and help maintain a replication of the NGS Integrated Database (NGSIDB) in Boulder.

Milestones

1. Establish methods to monitor and manage the CORS data collection activities at the Boulder site.
2. Make the FTP server operational in Boulder and begin distributing data collected there.
3. Fully populate the storage array and make operational via the Boulder FTP server.
4. With NGS support, get the NGSIDB and TESTIDB2 databases and Sybase replication server operational in Boulder.
5. Provide programming support for CORS data collection, analysis, archiving, and distribution.
6. Define and design a data archive system and procedure for handling all National CORS data.
7. Implement a data archive system and procedure for handling all National CORS data.

Provisions:

1. Any activities undertaken by the parties pursuant to this Document are subject to the availability of appropriate funds and proper authorization.
2. Modifications to this agreement may be proposed at anytime during the period of performance by either party, and shall become effective upon approval by both parties.
3. Nothing herein is intended to conflict with current directives of any participating agency. If the terms of this Document are inconsistent with existing directives of any of the parties entering into this agreement, then those portions of the agreement which are determined to be inconsistent shall be invalid. The remaining terms and conditions that are not affected by inconsistency shall remain in full force and effect. At the first opportunity for the review of the agreement, such changes as deemed necessary will be

accomplished by either an amendment to this agreement or by entering into a new agreement, whichever is deemed expedient and in the interest of all parties.

Project Tasks and Funding by FY (note: * indicates Federal Employee)

FY04	**1 full-time**	Provide network and sysadmin support, monitor and manage data collection, get public ftp server operational, work on database replication.		
		%	**Total Cost**	
	Joynt	50%	$64,000	System Administration
	Buhmann*	30%	$42,969	Operations and system oversight
	Edwards*	5%	$8,258	Data archive Manager
	McLean*	5%	$8,573	Program Manager
	Cooke*	10%	$7,172	Archive data technician
	Travel		$2,500	NGS Silver Spring
	Supplies		$3,000	Archive Tapes etc.
	Total		**$136,471**	
FY05	**1.5 full-time**	Expand network and sysadmin support, monitor and manage data collection, expand archive, programming support for data collection and distribution.		
		% FTE	**Total Cost**	
	Joynt	50%	$67,200	System Administration
	Buhmann*	30%	$44,688	Operations and system oversight
	TBD	50%	$40,200	Software engineer
	Edwards*	5%	$8,670	Data archive Manager
	McLean*	5%	$8,916	Program Manager
	Cooke*	15%	$11,301	Archive data technician
	Travel		$2,500	
	Supplies		$3,000	Archive Tapes etc.
	Total		**$186,475**	
FY06	**2.0 full-time**	Network and sysadmin support, monitor and manage data collection, ftp, and archive; programming support for data collection, analysis, and distribution. Review / improve NGSIDB and TESTIDB2 databases with database replication.		
		% FTE	**Total Cost**	
	Joynt	60%	$71,266	Hardware & communications
	Buhmann*	45%	$69,713	Program manager and system oversight
	TBD	75%	$62,712	Programmer / Data Technician
	Edwards*	5%	$9,104	Data archive Manager
	McLean*	5%	$9,273	Overall Program Manager
	Cooke*	15%	$11,753	Archive data technician
	Travel		$2,500	
	Supplies		$3,000	Tapes etc.
	Total		**$239,320**	

Approved

Mr. Charles W. Challstrom
Director, NGS

Date: ______________________________

Dr. Christopher G. Fox
Director, NGDC

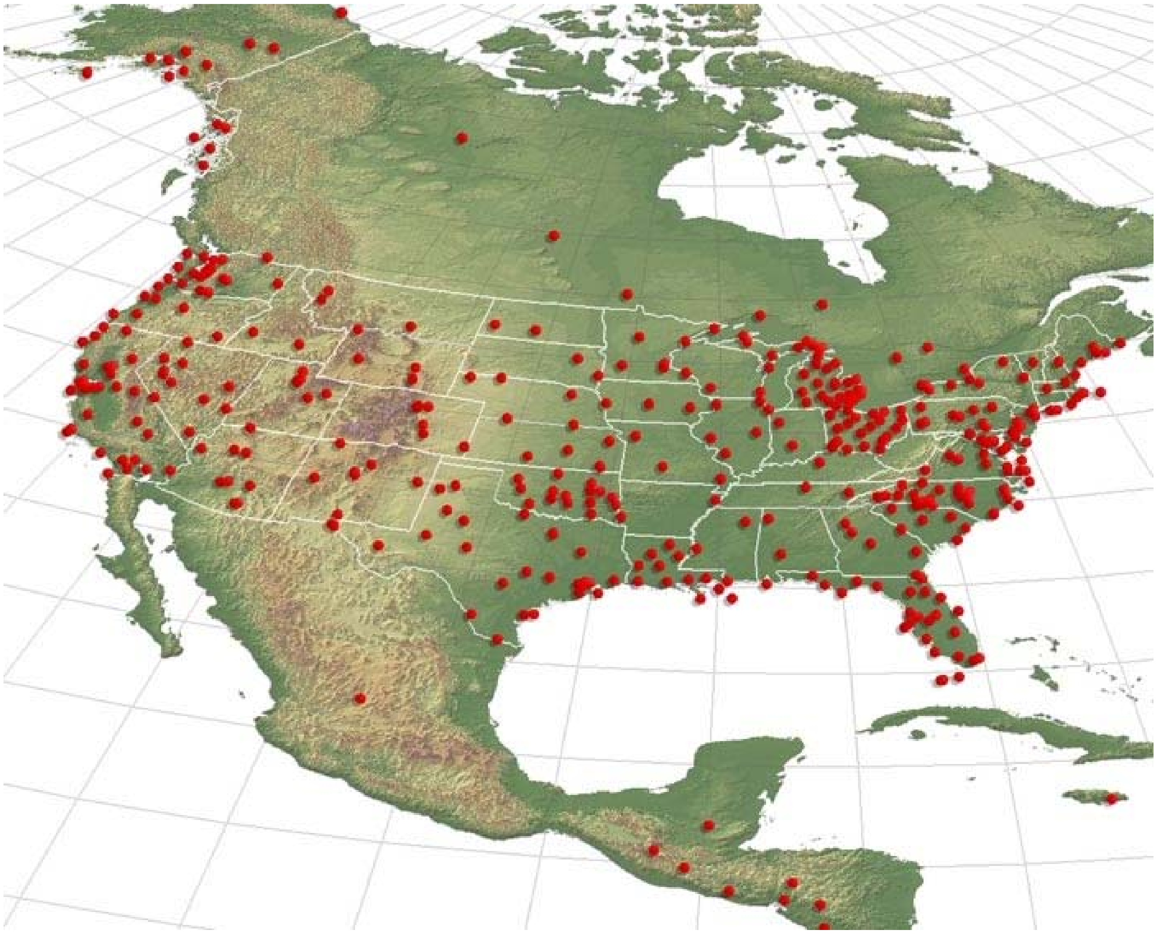
Date: ______________________________

ANNEX C

Final Report
6th Annual CORS Users Forum
Fort Worth, Texas
September 26th, 2006

NOAA's National Geodetic Survey (NGS)--in cooperation with the U.S. Department of Transportation and the U.S. Coast Guard—organized a CORS (Continuously Operating Reference Station) Users Forum on 26 September 2006. This Forum was an integral part of the Civil GPS Service Interface Committee (CGSIC) meeting, 25-26 September 2006, at the Renaissance Worthington Hotel in Fort Worth, TX. The Institute of Navigation's GNSS Conference convened 26-29 September 2006 in the Fort Worth Convention Center.

The National and Cooperative CORS networks are comprised of numerous subnetworks operated by more than 180 organizations. Collectively, these networks include more than 970 sites—each containing a geodetic quality, dual-frequency GPS receiver—and these networks are growing at a rate of about 15 sites per month. NGS and its partners collect, process, and distribute data from the CORS sites on a continuous basis in support of numerous activities including land surveying, navigation, GIS/LIS development, remote sensing, weather forecasting, satellite tracking, geophysics, and time transfer.



AGENDA

1:30 Welcome and Opening Presentation

CORS/OPUS: Overview and Status

Richard Snay, NOAA's National Geodetic Survey

1:45 **On-GRID: An Initiative to Promote Regional Real-Time GNSS Networks**
Gavin Schrock, City of Seattle, WA

2:05 **OPUS-DB and Other OPUS-Related Innovations**
Rick Foote & Joe Evjen, NOAA's National Geodetic Survey

2:25 **The Texas Spatial Reference Center**
Gary Jeffress, Texas A&M Univ., Corpus Christi, TX

2:45 **NGS Support for Regional Real-Time GNSS Networks**
Neil Weston, NOAA's National Geodetic Survey

3:05 **EarthScope's Plate Boundary Observatory: Status Update**
Greg Anderson, UNAVCO, Inc.

3:25 Question & Answer Session with Panel of the Speakers

3:45 Break

4:00 Interactive Sessions within Small Discussion Groups
Group A: Real-Time Positioning
Facilitators: Neil Weston, Bill Henning and Richard Snay, NGS
Group B: OPUS
Facilitators: Joe Evjen & Rick Foote, NGS
Group C: Texas Spatial Reference Center
Facilitators: Cliff Middleton & Casey Brennan, NGS
Group D: Ionospheric Modeling
Facilitator: Joe Kunches, NOAA's Space Environment Center
Group E: Tropospheric Modeling
Facilitator: Seth Gutman, NOAA's Earth Systems Research Laboratory

5:00 End of Forum

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The PowerPoint files for each of the six formal presentations may be viewed and/or downloaded at http://www.ngs.noaa.gov/CORS/ . Click on "General Information" and then on "Presentations".

CORS/OPUS: Overview & Status
Richard Snay, NOAA's National Geodetic Survey

Richard Snay provided an overview of the session. He stated that 985 CORS stations were operational at last count; 817 National CORS and 168 Cooperative CORS. The network is currently growing at about 15 sites per month. Most of these sites are operated by more than 180 partners, rather than by NGS.

CORS are mainly used for post-mission static positioning, although they are also used for post-mission kinematic positioning, geophysics, meteorology, and space weather.

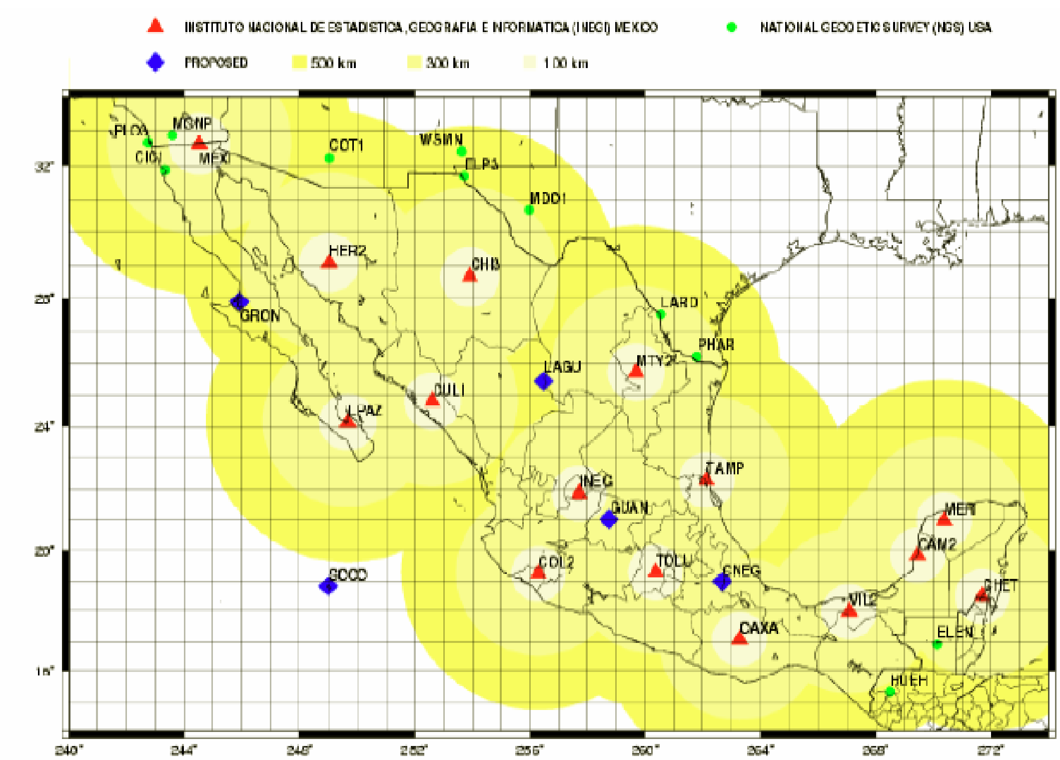


Figure 1. National Active Geodetic Network RGNA

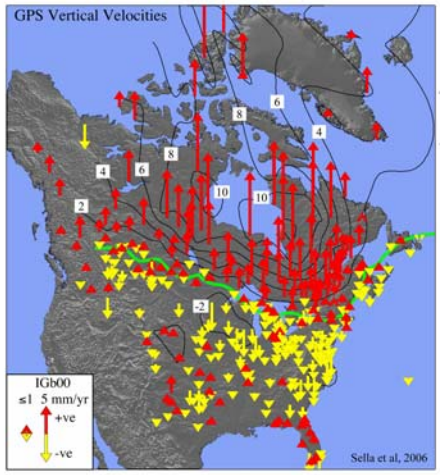
During the past year the Mexican CORS network merged with the U.S. CORS network, expanding upon previous agreements with Canada and many Cenral American and Caribbean countries. As a result CORS data are freely available throughout North America and its immediate surroundings.

In December 2006, NGS adopted the new CORS guidelines developed by Giovanni Sella.

Other FY 2006 accomplishments:

- 180 new CORS sites, most of which came from the Plate Boundary Observatory (PBO) and regional real-time networks.
- The Online Positioning User Service (OPUS) performed 166,000 solutions in 12 months.
- The User Friendly CORS (UFCORS) delivered 792,000 GPS data packages in 12 months.
- Bill Stone (the NM State Advisor) published an article on CORS and OPUS.
- CORS websites now features Google Maps and includes satellite photos of individual CORS sites.

- CORS data now contribute to measure post glacial rebound.
- CORS data are also serving to monitor the distribution of free electrons in the ionosphere.



On the CORS horizon:

- ITRF 2005 positional coordinates and velocities will be computed for all CORS.
- NGS procured 11 new GPS+GLONASS receivers to deploy as part of the CORS network.
- NOAA will install at least 4 new CORS sites at U.S. tide gauges.
- NOAA will publish article on using CORS data to calibrate tide gauge stations, which will help measure global sea level rise.

On-GRID: Resources and Support for High-Precision Real-Time GNSS Networks

Gavin Schrock, City of Seattle

On-Grid Goals and Objectives: Help acquire the Resources, Expertise, Policy Assistance and Cooperative efforts to establish regional real-time GNSS networks.

What it is NOT: Rules, big funding, public sector only, proprietary solutions

Gavin stated that the goals of On-Grid program are high precision real-time positioning applications, such as surveying, monitoring the deformation of critical structures, construction and science (in the 5 cm or less range). This program will establish lots of reference stations and you won't need a high end rover to use this network.

There are already about 200 real-time GNSS networks (RTN's) in various places around the world. Japan has a number of them. Germany is completely covered. Ohio is already covered with 51 stations. The state of Washington is about 2/3 of the way there.

The NTRIP protocol is being used promoted for transporting GPS data via the Internet.

The users segment is growing. People are finding out that network RTK offers several advantages as compared to single-base RTK:

- improved accuracy,
- increased range from base stations, and
- users do not need to operate/maintain their own base stations.

Real-Time GNSS Networks will introduce thousands of new CORS. This will lead to additions to National CORS, better modeling, more rovers being sold.

On-Grid early objectives: Support the real-time initiatives across the nation. Support public safety and commerce.

Starting in 2006 On-Grid hit the road. We attended several meetings: ACSM, NSPS, RTN administrators, local and state industry associations and the 2006 NGS CORS Forum.

Current issues:

- Little local expertise
- With higher precision, there are new considerations
- Migration from legacy reference systems

Expertise and Education:

- Few publications
- No risk assessments have been undertaken
- Infrastructure developed without considering RTN utility
- Little outreach
- Few applicable guidelines and standards

Cost Benefit Analysis:

- Few case studies have been done
- Few business model examples
- Big ticket public works projects often don't consider using RTN

Policy:

- Security is often misinterpreted
- High precision is not often discussed at higher levels

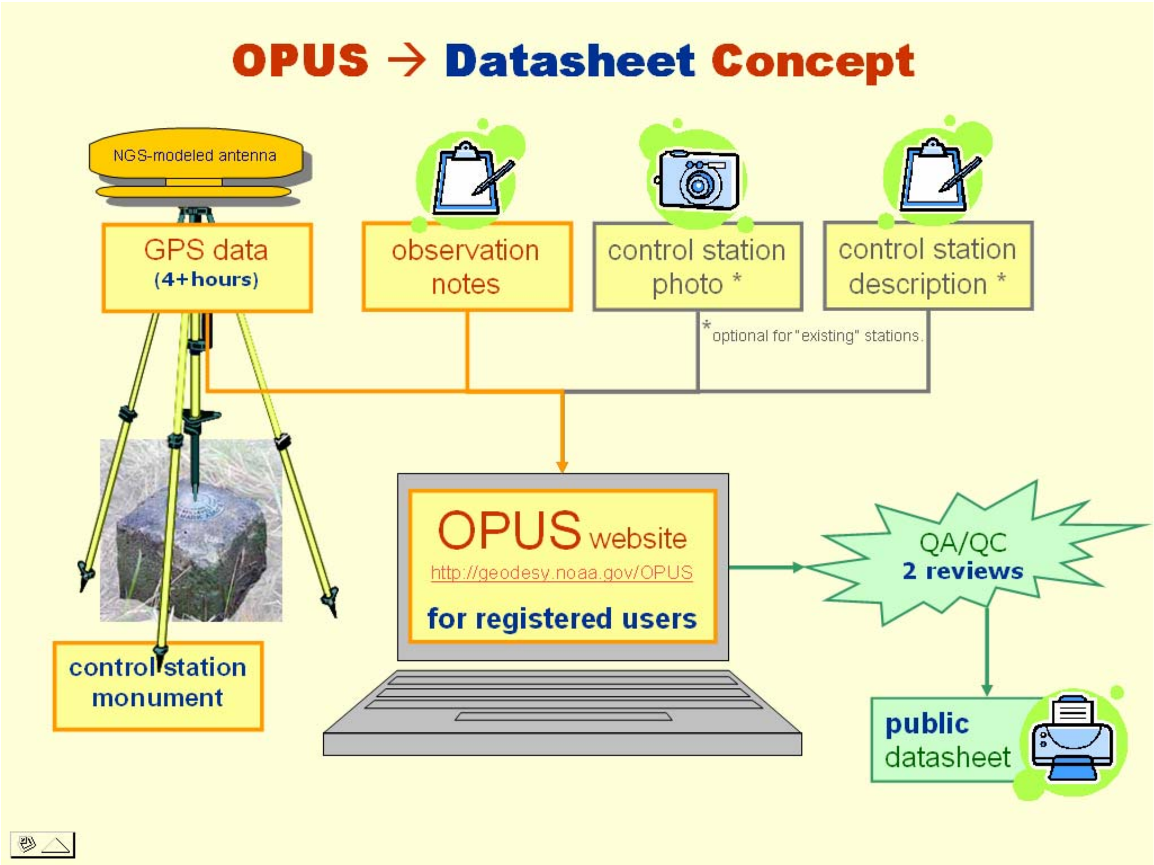
Proposed actions:

- Support NGS role by including RTN's into the National Spatial Reference System.
- Guidelines and standards
- Publications
- Academic studies
- Security issue position papers are needed
- Application case studies
- Raw data stream sharing from existing publicly funded reference stations
- Identify public works projects that would benefit from RTN infrastructure
- Conduct cost-benefit studies and business model examples
- Make cooperative agreement boilerplates
- Outline other PNT (position-navigation-timing) benefits
- Support/Develop outreach
- Support NDGPS
- Seek interface with PNT

The future: On-Grid will continue as a grass roots effort.

OPUS: The Online Positioning Users Service

Rick Foote and Joe Evjen, NOAA's National Geodetic Survey



User need submit only four pieces of information to OPUS: an e-mail address, a RINEX file, the type of antenna used and the height of that antenna.

The Future of OPUS:

- OPUS-DB (data base)
- OPUS-Projects
- OPUS-RS (rapid static)
- OPUS-GIS

OPUS-DB: Enables users to share the positional coordinates derived from their GPS data. User's data is submitted to NGS, processed, and the results are returned via e-mail. To share your data, you need to occupy a survey monument that is stable and permanent. You need to submit a minimum of 4 hours of dual-frequency, carrier-phase GPS data, photos of the monument, information about the GPS antenna and any other notes that might be useful. With the users' consent, the resulting coordinates will be archived in the NGS Integrated Database and these coordinates will be publicly disseminated in the traditional NGS datasheet format. Contributors will need to register with NGS and leave contact information so that other people who would use the resulting positional coordinates will be able to contact them.

Limitations:

- GPS only
- PAGES software only
- No tie to local survey monuments
- No redundancy
- Reduced oversight

Other flavors of OPUS:

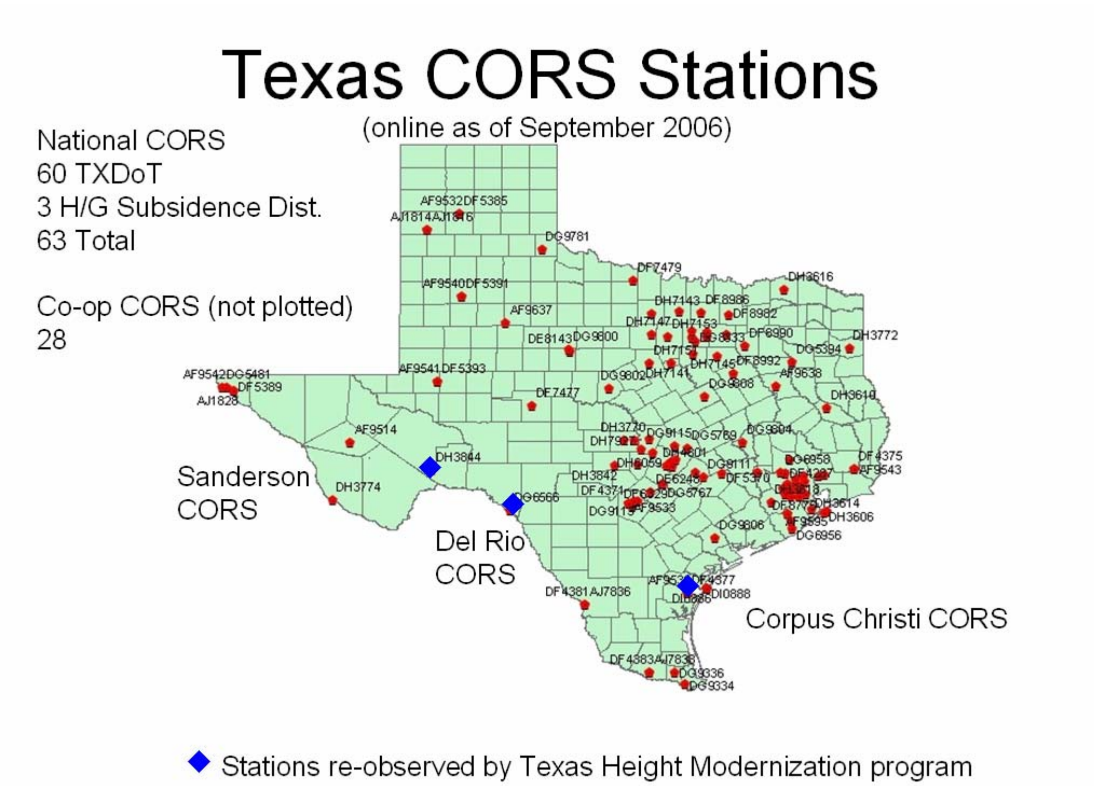
OPUS Projects: Will process dual-frequency, carrier-phase data for a GPS survey involving multiple sites and multiple observing sessions such that the resulting positional coordinates will best fit the combined set of observations in a least squares sense.

OPUS-RS (Rapid Static): The observer will be able to submit dual-frequency, carrier-phase GPS data for an observing session as short as 15 minutes. OPUS-RS may use more than 3 CORS for control to better estimate tropospheric and ionospheric refraction delays.

OPUS-GIS: Will process single-frequency pseudorange GPS data.

The Texas Spatial Reference Center

Gary Jeffress, Texas A&M Univ., Corpus Christi



The Texas Spatial Reference Center (TSRC) has been proposed and will require an act of the TX state legislature. The Governor of TX has signed a letter supporting the center.

The current challenge is determining NAVD 88 heights for the antenna reference points associated with CORS stations. There are 63 National CORS stations in TX and more are coming. Many of these are in the Houston-Galveston Subsidence District, which has major subsidence issues.

The central facility of the TSRC is located in Corpus Christi and features a CORS station. We recently ran levels to that station to help obtain a good NAVD 88 height for it. Don Mulcare, the TX State Geodetic Advisor, was in charge of this project.

We also verified that GPS can be used with a good geoid model to determine elevations.

Other work:

- Selected 100 benchmarks that will be observed with GPS to provide good data for improving the geoid model
- Developed software for handheld PDAs
- Produced elevation profiles for hurricane evacuation routes using the Applanix Pos-LV system
- Will establish a CORS at the NOS tide gauge station located on the Galveston Pleasure Pier

On November 15-16,2006, we will convene a Height Mod forum in Austin TX.

NGS Support for Regional Real-Time GNSS Networks

Neil Weston, NOAA's National Geodetic Survey

Modify selected CORS sites to enable real-time of their GNSS data.

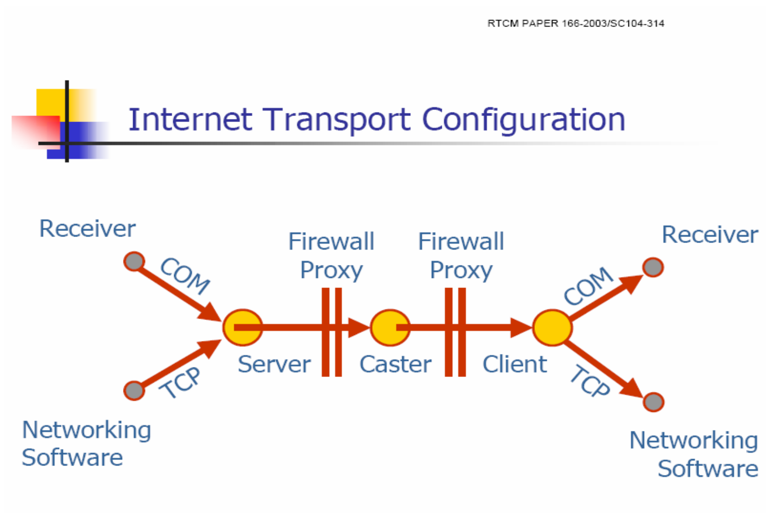
NGS would identify 200 CORS stations and then stream their GNSS data, not GNSS correctors, via NTRIP and TCP/IP over the Internet.

The site modifications:

- Receiver modifications
- Communications/network changes
- Software changes

Network design issue:

- what format
- which stations
- what software
- what distances
- what data rate
- what latency



Data Distribution Formats

Data Collection Formats

Communications:

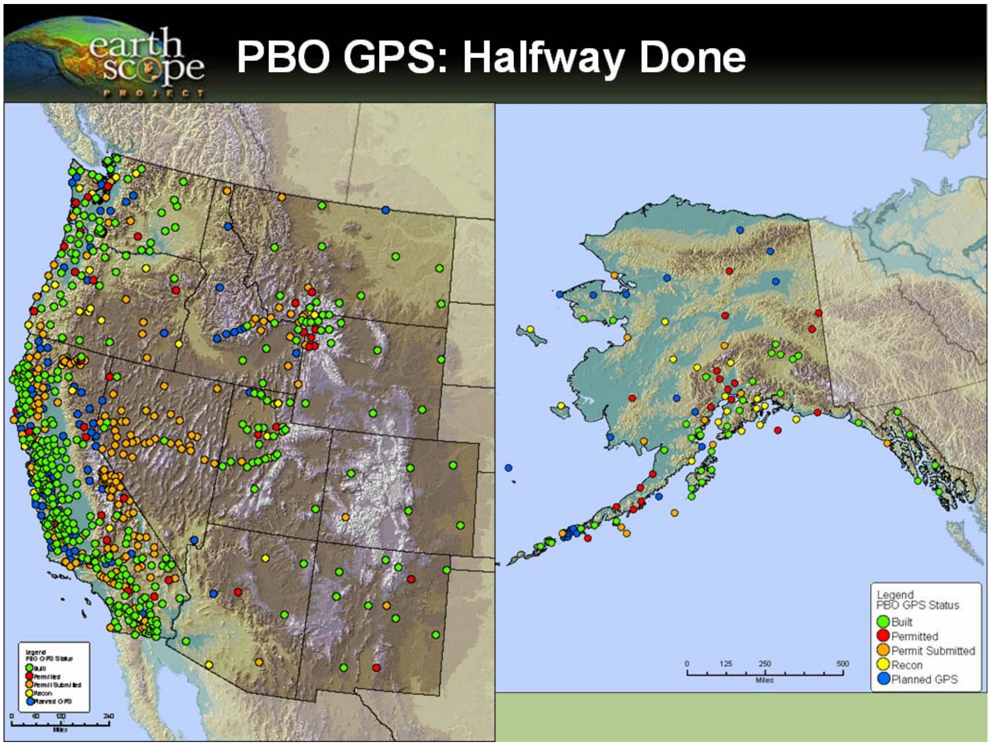
- Frame relay
- Internet
- Satellite/modem
- NTRIP

Real Time Applications:

- Structural monitoring
- GIS
- Rapid response
- Meteorology
- Space weather

EarthScope's Plate Boundary Observatory: Status Update

Greg Anderson, UNAVCO, Inc.



What is the Plate Boundary Observatory (PBO): A project for studying continental scale problems related to earthquake and magmatic activities in North America. The PBO project will establish 852 new GPS base stations, and at the end of the project there will be over 1100 such stations. As of August 2006, UNAVCO has installed half of the proposed new GPS base stations. On any given day, 90% of the sites are up and running.

The GPS data flows to two archiving facilities for backup reasons, and all the data are available through the PBO website. There are a variety of GPS data products available.

To access data and see what has been built or is going to be built, which stations are running and which ones are not, more information about a particular stations (including images of the station) go to the status map on our website. (pboweb.unaco.org)

To obtain data go to the website:

http://pboweb.unaco.org/gps_data

Special data requests:

http://pboweb.unaco.org/data_request

There are 40 some stations with RTK capabilities, mainly for the land owners. If you want to get involved with RTK issues with PBO sites, please call Greg Anderson. (303- 381-7555) or anderson@unavco.org

Question and Answer Session:

Q: (for Greg Anderson) Are there plans to expand the PBO sites into the eastern United States?

A: There are some small networks out there already. But I am not aware of any plans to build a "PBO East", but we have talked with folks about incorporating existing stations into the network.

Q: (For Gary Jeffress) What benchmarks were selected for the TX program?

A: We selected sites to cover as much of the state as possible and give work to as many surveyors as possible. The idea is that the HtMod will be the branch of NGS in the state, and that the surveyors will be doing most of the work, but doing it to NGS standards. We have been running workshops to show how to meet these standards. We are trying to get the surveyors to support height mod.

Q: (For Greg Anderson) What is the highest data rate available from PBO?
A: 15 seconds.
Q: What is the highest you can deliver?
A: We could go as high as 1 second.

Q: After 30 days data is removed from NGS site… Can you improve it; can you supply the data after 30 days? At COOP CORS sites?

A: For COOP CORS sites, we only keep the data for 30 days.

A: (Giovanni Sella) We only keep the 1 second data for 30 days. If there are requests to keep it longer we can talk about it. Also, if you know you need high rate data for a handful of sites, make that request to us

Q: (for Rick Foote and Joe Evjen) Can you talk about when other flavors of OPUS will be available:

A: Some of the other flavors are out in a testing mode right now. We don't have a formal date planned for a release of the other products. OPUS-RS is probably being used more than any of the others. Contact us at (ngs.opus@noaa.gov).

Q: (for Niel Weston) What is the communication media for real time processing between user and server? 2: Real time services are based on single stations, are you planning on using network systems and if not, why?

A: The communications mode is through the Internet, so users will have access to GPS data streams. (Q: Can you use a cellular phone?) A: People can use cellular phones to access the data. If you are in the field and have a cellular connection to the Internet, you can access the GPS data through the Internet.

2A: NGS will provide real-time GPS data via the Internet, but NGS will not provide GPS correctors. We are looking to provide data to organizations that provide positioning services, rather than provide the services ourselves. We provide the data to people to supplement their their networks so that they can provide positioning services. NGS is just making the data available; we will not be providing a real-time positioning service.

Discussion Group A: Real-Time Positioning
Facilitators: Bill Henning, Neil Weston, and Richard Snay

Participants:

Georg Weber, German Federal Agency for Cartography and Geodesy
Dmitry Kolosa, TopCon
Dave Newcomer, Trimble
Chuang Shi, Wuhan Univ.
Greg Anderson, UNAVCO Inc.
Karen Van Dyke, US DOT/Research & Innovative Technology Administration
Christa Von Hildebrandt, University of Puerto Rico
Sumio Usui, Mitsubishi Elec., Taiwan
Ryan Keenan, Leica
James Stowell, Leica
Eric Gakstatter, GPS World Magazine
Ken Bays, Oregon DOT
Marc Cheves, The American Surveyor Magazine.

Real-Time GNSS Network (RTN) discussion take-away:

- ✓ NOAA's National Geodetic Survey (NGS) should be proactive in supporting the development of regional RTN's across the USA.
- ✓ Regional RTNs should have a direct link to the National Spatial Reference System through the CORS network
- ✓ One or more sites in each RTN (a "representative sampling") should be included in the National and/or Cooperative CORS networks.
- ✓ Attendees were receptive to the idea of regularly validating positional coordinates for RTN reference stations. OPUS provides a good way to uniformly monitor these positional coordinates.
- ✓ Since the CORS network is expected to continue growing rapidly—approaching 3000 sites in the near future, mainly due to the establishment of new RTN reference stations—there should be automated procedures to check positional coordinates and error messages (daily? weekly?). Software procedures should be certified, e.g. who will receive error messages.
- ✓ NGS guidelines and standards should be developed for establishing and maintaining an RTN. By adhering to these criteria the RTN becomes "sanctioned" by the NGS and becomes more readily accepted by the users.
- ✓ A representative of one GPS vendor expressed the concern that NGS may stream GNSS data from more than 200 sites, because adding more than 200 stations may take away from other organizations installing new stations through vendors. There seemed to be no concern about NGS streaming data from only 200 or so stations, however. It should be noted that the number of Plate Boundary Observatory (PBO) stations will reach approximately 1200 and thus blanket much of the western USA, presenting a dense network for possible RT streams and causing concern among vendors in at least that area.

Others may contend that GPS base stations established and maintained through public funds (such as those in the PBO network) should have their data accessible to the public in current formats, which would include RT. According to Greg Anderson, a few organizations have already contacted UNAVCO about incorporating PBO sites into their regional RTNs.

- ✓ As RTCM 3.1 becomes available, consider a switch to a "world view" of GNSS by using ITRF coordinates as opposed to NAD 83 coordinates. Autonomous positioning done in the near future can show differences between NAD_83 and ITRF/WGS_84 as accuracy increases.
- ✓ As there is real user concern over the future of the NDGPS network, it is thought that RT data could be streamed from some of these stations via the Internet, and thus provide greater support for funding the development of the NDGPS network.
- ✓ Data latency should be closely considered through all the communication links.
- ✓ Consider installing more CORS near tide gauge stations.
- ✓ The NGS should be proactive in outreach and education in all of these areas.

Discussion Group B: OPUS

Facilitators: Joe Evjen and Rick Foote, NGS

Participants:

Delaine Meyer	ND DOT
Pierre Tetrault	Geodetic Survey Division, Canada
Alan Ip	Applanix
Jim Rumberg	Boeing

General Comments:

Thanks for outreach and accessibility to OPUS personnel, putting faces with names.

Add southern Canadian Active Control Stations to National CORS network to increase coverage for states contained in the northern tier of the U.S.

OPUS has successfully replaced traditional network; ND-DOT is skipping monuments, uses OPUS info on project control instead of datasheet info.

What version of OPUS most interest you? DB, RS, Projects, GIS?

Desire any support for RTK.
General interest in all flavors.

What OPUS functionality would you like to add?

The standard output should provide linear coordinates in units of feet.

OPUS-DB is currently proposed to update our database for scaled positions (lat/long or elev.) or for new marks. Should other updates be made?

General agreement with NGS proposal; replace inferior positions when applicable.

ACTION: Send OPUS-DB link to Delaine Meyer

OPUS output - XML? Web?

Applanix is interested in building applications which use OPUS.

Discussion Group C: Texas Spatial Reference Center
Facilitators: Cliff Middleton and Casey Brennan, NGS

Participants:

Steve Schmidt, TxDOT
Dr. Gary Jeffress, Texas A&M University, Corpus Christi
Dr. Stacy Lyle, Texas A&M University, Corpus Christi
Randy Hurtt, MAGELLAN/Thales

Also, several representatives from TxDOT met separately with Giovanni Sella during this time frame.

The question to kick off the session was: What can the TxSRC do to meet the needs of the GPS/NAV community? The following were suggested:

1. Support for RTK surveying.
2. Allow use of TxDOT VRS to public (currently only TxDOT contractors are allowed use outside of TxDOT. The point was raised that since private companies were offering such a service on a fee basis in some areas, that there may be conflicts. The data stream vs Network Solution Correctors was discussed.
3. Promote a unified Vertical Datum
4. Improve the GEOID model
5. Perform outreach and training to improve understanding of Heights/GPS/GEOID.
6. Provide easy to understand standards and specifications for contractors.

Follow up discussion:

What would you like to see at the TX Spatial Reference Center?

(Answer from a TX surveyor) I would like to see the real time capability of TxDOT, and the end users ability to tie into RT surveys, and see a proliferation of real time networks.

TxDOT is still looking into this. It is in the development stage.

There are a few private RTK networks out there. Dallas and the Dallas-FortWorth area have one. They are spread out all over the place.

(from a TX surveyor) I am interested in being able to freely tie into these rather than have to pay for it.

You run into problems because government can do it for free, or should we let private businesses do it for a fee? Private business gets upset when government starts doing stuff they get paid for.

Height mod work is more about getting better heights, than getting RTK systems. NGS is currently looking to get more gravity data for the US to improve the geoid model.

Q: What is happening to the geoid model in an area of subsidence? Do they move?

A: Well as the earth sinks, gravity should change too. But the short answer is that you will have to remeasure gravity every so often as the Earth changes.

Q: Do you think there would be local geoid models that get updated more often than the entire geoid model?

A: Well they do some of that, but what they really do is just make their own correction and just ignore the geoid. They know how far off it is and then they just make their own correction.

Q: What steps are NGS or TXDOT doing to educate the public on this stuff?

A: Well, we have been talking with politicians about this stuff and telling them it needs to be done. There are a few articles that explain this too. We also hold height mod forums, and have talks and conferences.

DISCUSSION GROUP D. IONOSPHERIC MODELING
Facilitator: Joseph Kunches, NOAA's Space Environment Center

Participants:

Marc Cheves, Editor, The American Surveyor Magazine

There's great interest in moving RTK techniques forward in the future. One of the most significant error sources for RTK—or a factor requiring a long time on-station—is the behavior of the ionosphere. NOAA's Space Environment Center (SEC) is now providing a specification in near real-time in the USTEC product, using CORS data as the primary input. In the future, SEC hopes to actually predict the behavior of the ionosphere, using solar wind data measured upstream of Earth, and then incorporate those predictions into USTEC. If this prediction technique proves to be successful, it will enable greater efficiency for future RTK applications.

Discussion Group E: Tropospheric Modeling

Facilitator: Seth Gutman, NOAA's Earth Systems Research Laboratory

The Tropospheric Modeling Breakout Section met to discuss issues involving the practical implementation of a weather model-based tropospheric signal delay correctors. The session was attended by representatives of only one GPS receiver manufacturer. They suggested that rather than transmit the entire CONUS grid to all users that provisions be made for users to specify a region of interest and only that subset of the entire model be transmitted and updated to the user. Some high level technical options to accomplish this were explored.