National Oceanic and Atmospheric Administration
National Ocean Service
Geodetic Support System
006-48-01-15-02-3403-00-117-057
Operational Analysis
FY 2009

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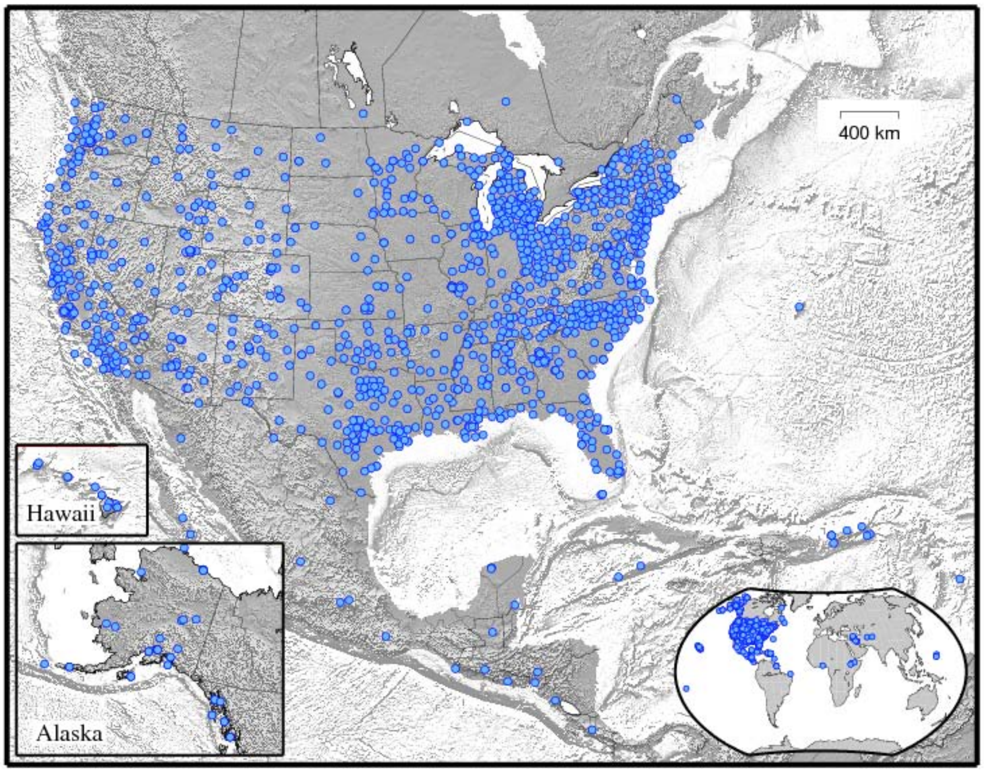
Executive Summary

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 1,370 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 primary goal of CORS 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 and at www.ngs.noaa.gov/CORS/.

CORS Coverage October 2009



This report focuses on the operational state of the program as of October 1, 2009 and is based on guidance developed by the Department of Commerce (DOC). The Geodetic Support System directly supports the DOC Objective for NOAA, "Support safe, efficient, and environmentally sound commercial navigation", as well as the Objectives "Protect, restore, and manage the use of coastal and ocean resources" and "Advance understanding of climate variability and change" under the broader DOC strategic goal "Promote environmental stewardship". The current program meets established cost, schedule, and performance parameters.

Each year, an operational analysis (OA) is performed for an in-depth review of the program's performance, and it is based on the following:

- Customer Results
- Strategic and Business Results
- Financial Performance
- Innovation

1.0 Customer Results

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

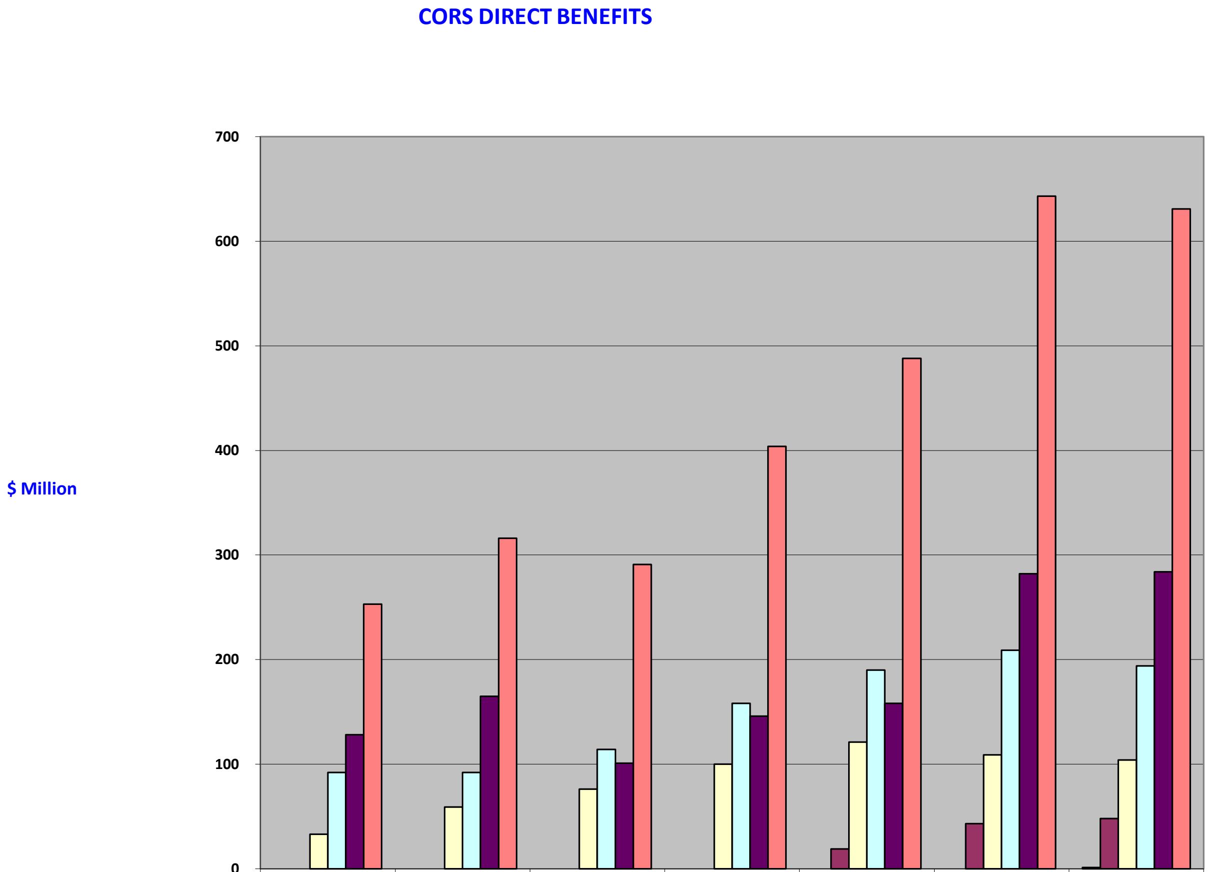
Additionally, CORS data are used by:

- Earth scientists to monitor crustal motion
- Meteorologists to monitor the distribution of moisture in the atmosphere
- 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, Geographic Information System (GIS) professionals, remote sensing 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. The OPUS utility enables a user to submit GPS data to NGS and obtain, via email, the positional coordinates for the location where the data were collected. OPUS accomplishes this task by processing the user-submitted GPS data with corresponding GPS data from three or more CORS sites. There are three types of OPUS currently in operation: OPUS-RS (rapid static), for processing GPS data sets spanning between 15 minutes and 2 hours; OPUS-S (static), for data sets spanning more than 2 hours; and OPUS-DB (data base), for processing data sets for users who would like NGS to archive the results so they may be shared with others. NOAA estimates that (1) each FTP download saves the customer $30 in the cost to obtain the information otherwise; (2) each UFCORS download saves the customer $200; (3) each OPUS-RS or OPUS-S solution saves the customer $600; and (4) each OPUS-DB solution saves the customer $1,000. The following graphic summarizes the direct financial benefits provided by the CORS program for each fiscal year from FY2003 to FY2009. Note that OPUS-RS became operational in January 2007, and OPUS-DB in September 2008.



	FY2003	FY2004	FY2005	FY2006	FY2007	FY2008	FY2009
OPUS-DB	0	0	0	0	0	0	1
OPUS-RS	0	0	0	0	19	43	48
OPUS-S	33	59	76	100	121	109	104
UFCORS	92	92	114	158	190	209	194
CORS FTP	128	165	101	146	158	282	284
TOTAL	253	316	291	404	488	643	631

As the above graphic reveals, FY2009 CORS direct benefits ($631 million) decreased by two percent, relative to the FY2008 CORS direct benefits ($643 million). The decrease is likely associated with the downturn in the U.S. economy during the past year, particularly in the construction sector where many CORS users are employed. The graphic also reveals that CORS direct benefits have grown at an average rate of 20 percent per year over the period from FY2003 to FY2009.

A recent socio-economic scoping study, performed by Leveson Consulting of Jackson, New Jersey, estimated the FY2008 annual benefits of CORS at $758 million. This estimate differs from the $643 million shown in the graphic, primarily because Leveson's estimate includes both direct and indirect CORS benefits, whereas the results of the graphic are in consideration of only the direct CORS benefits. Leveson's estimate also differs from this report, because it made different assumptions concerning the values of the various CORS services: FTP, UFCORS and OPUS. The full report for the Leveson study is available at:

http://www.ngs.noaa.gov/PUBS_LIB/Socio-EconomicBenefitsofCORSandGRAV-D.pdf .

1.2 Performance Measures

In FY 2009, NOAA used two performance measures to quantify the success of the Geodetic Support System: (1) the percent of U.S. counties 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.

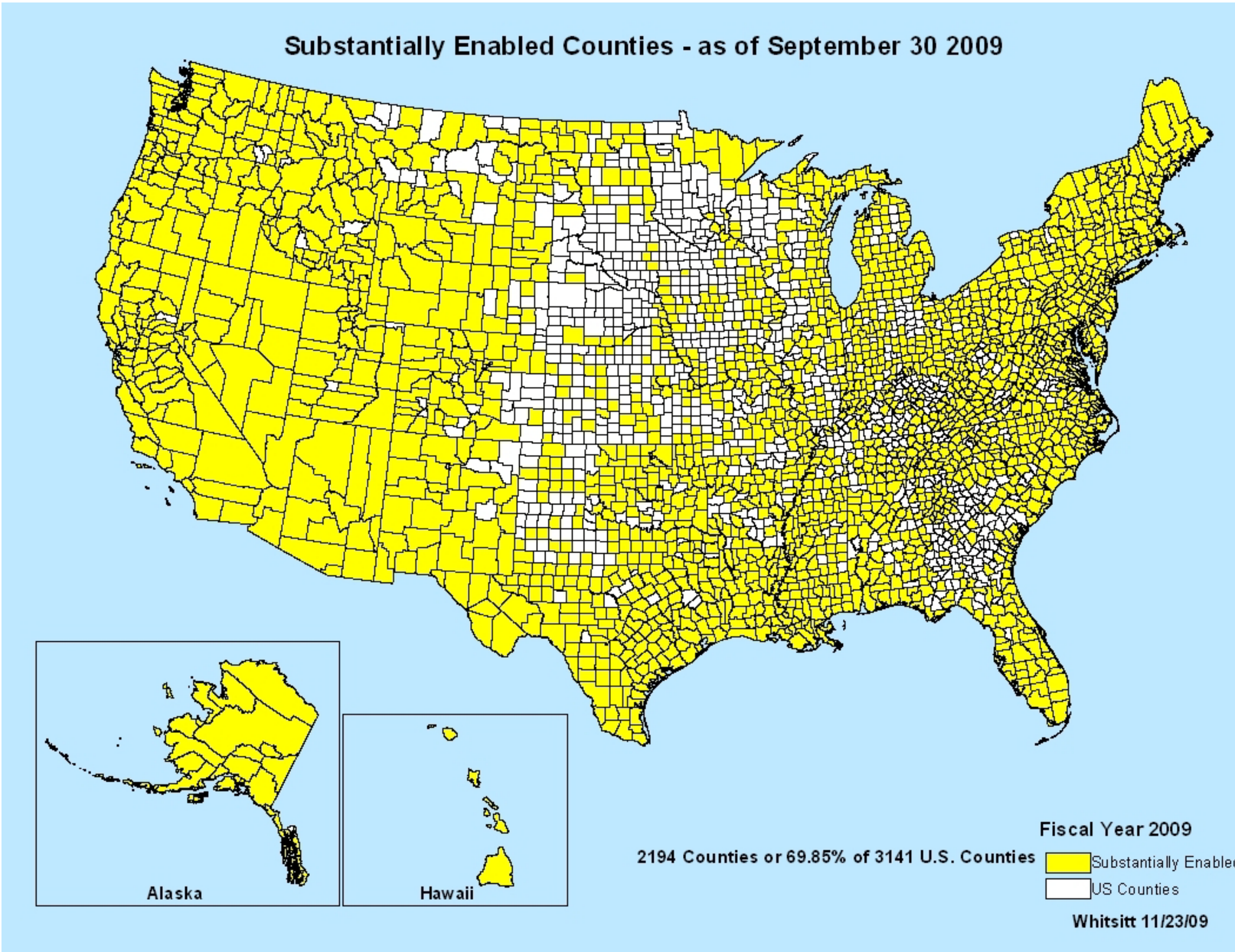
For a county to be considered substantially enabled in FY2009, users were required to have applied the OPUS utility a minimum of 25 times to accurately position points located within the county. To apply OPUS, a user would have collected a minimum of 15 minutes of GPS data and then submitted these data to NOAA via the Web (www.ngs.noaa.gov/OPUS). Once submitted to NOAA, the data were automatically processed with data from a minimum of three CORS sites in order to compute accurate positional coordinates for the location where the data were collected. NOAA subsequently emailed the resulting coordinates to the user, usually within minutes.

Users apply UFCORS to obtain CORS data and related information more conveniently than is currently possible using anonymous FTP. Anonymous FTP better serves users downloading large volumes of CORS data on a regular basis—users already familiar with the structures of the CORS online storage formats. UFCORS is easier for users downloading small volumes of CORS data on an infrequent basis; the only requirement being the completion of a simple 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.

The measures presented in Table 1 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	FY2005	FY2006	FY2007	FY2008	FY2009
Customer Requirements	Percentage of counties that are substantially enabled	32.2%	42.7%	50.75%	58.5%	69.85%
	Number of CORS data packages downloaded via UFCORS	583,261	797,165	958,964	1,042,733	977,390



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 controls are in place to ensure the program continues to meet its goals and objectives and to monitor the performance of the Geodetic Support System program.

2.1 Geodetic Support System Helps to Achieve Strategic Goals

The Geodetic Support System program directly supports the DOC Objective for NOAA, "Support safe, efficient, and environmentally sound commercial navigation", as well as the Objectives "Protect, restore, and manage the use of coastal and ocean resources" and "Advance understanding of climate variability and change" under the broader DOC strategic goal "Promote environmental stewardship".

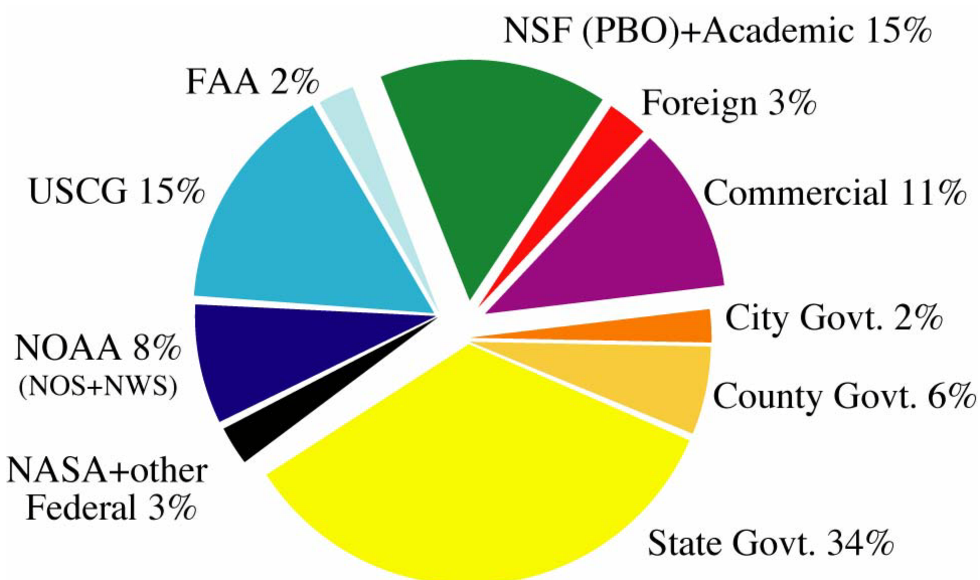
Program management controls are in place to ensure the Geodetic Support System program continues to meet its goals and objectives and to monitor how well the program is performing.

2.2 Business Results

2.2.1 Program Management and Controls

The CORS program is a highly leveraged system that benefits from the voluntary contributions of over 200 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 92 percent of the CORS network stations; NOAA currently sponsors and/or operates 8 percent of the stations. The following pie chart summarizes the composition of the CORS partners.

Percentage of CORS Stations by Type of Partner



NOAA has not entered into formal agreements with other 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 over 200 partner organizations through its CORS website (www.ngs.noaa.gov/CORS/) which features the electronic CORS Newsletter and other pertinent information. The CORS Newsletter is immediately updated whenever a news-worthy event occurs. Each Monday, NGS emails the latest CORS Newsletter to several hundred addresses; however, the most current edition may be downloaded from the CORS website at any time.

On a daily basis, NGS checks incoming GPS data provided by CORS partners and contacts a partner directly (by phone or email) if a station is underperforming (see www.ngs.noaa.gov/CORS/Establish_Operate_CORS.html for performance criteria).

NOAA operates two parallel CORS Data Management and Online Storage Facilities: one, (CORS-East), is located in Silver Spring, Maryland and is hosted by NGS, and the other, (CORS-West), is located in Boulder, Colorado and 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 from FY 2004 through FY 2009.

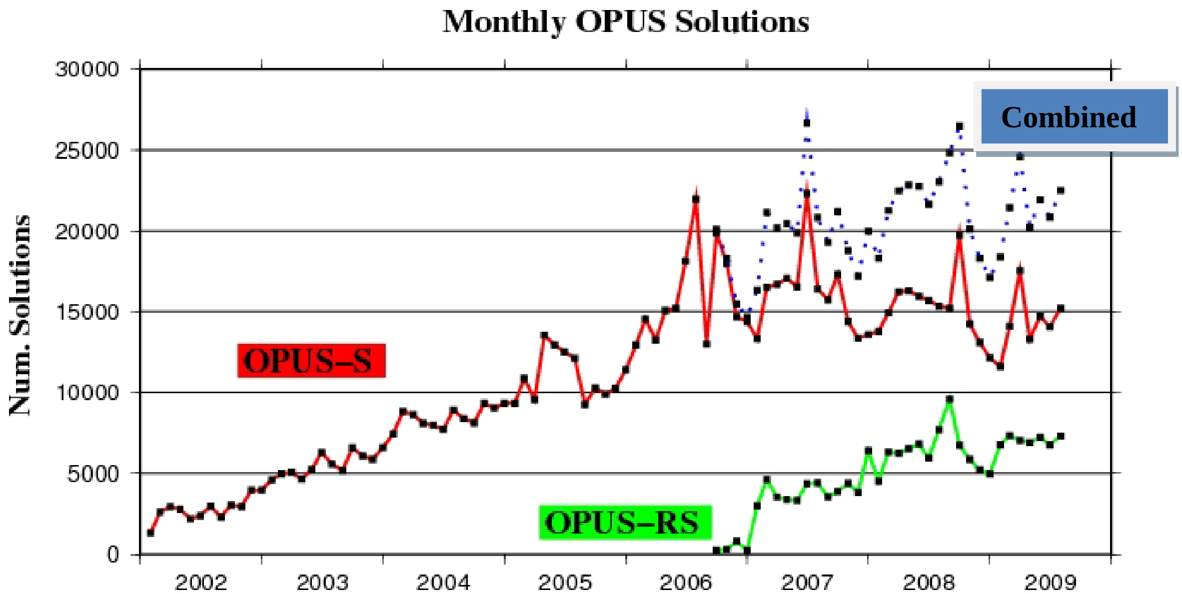
The overall CORS program is managed within NGS, primarily through a Program Manager and several informal teams, including the CORS Site Management Team, CORS Data Management Team, CORS West Team, CORS Data Analysis Team, CORS Systems Development Team, CORS Technical Innovation Team, and CORS Outreach Team. Members from all the teams attend a joint meeting once a month to coordinate activities. Numerous other meetings occur regularly among various team representatives to address specific issues. In addition, the CORS Program is represented by the Chief of NGS' Spatial Reference System Division at a weekly meeting of the NGS Director's staff and at 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 FY2009 milestones were met, and these milestones are documented in the next section of this report.

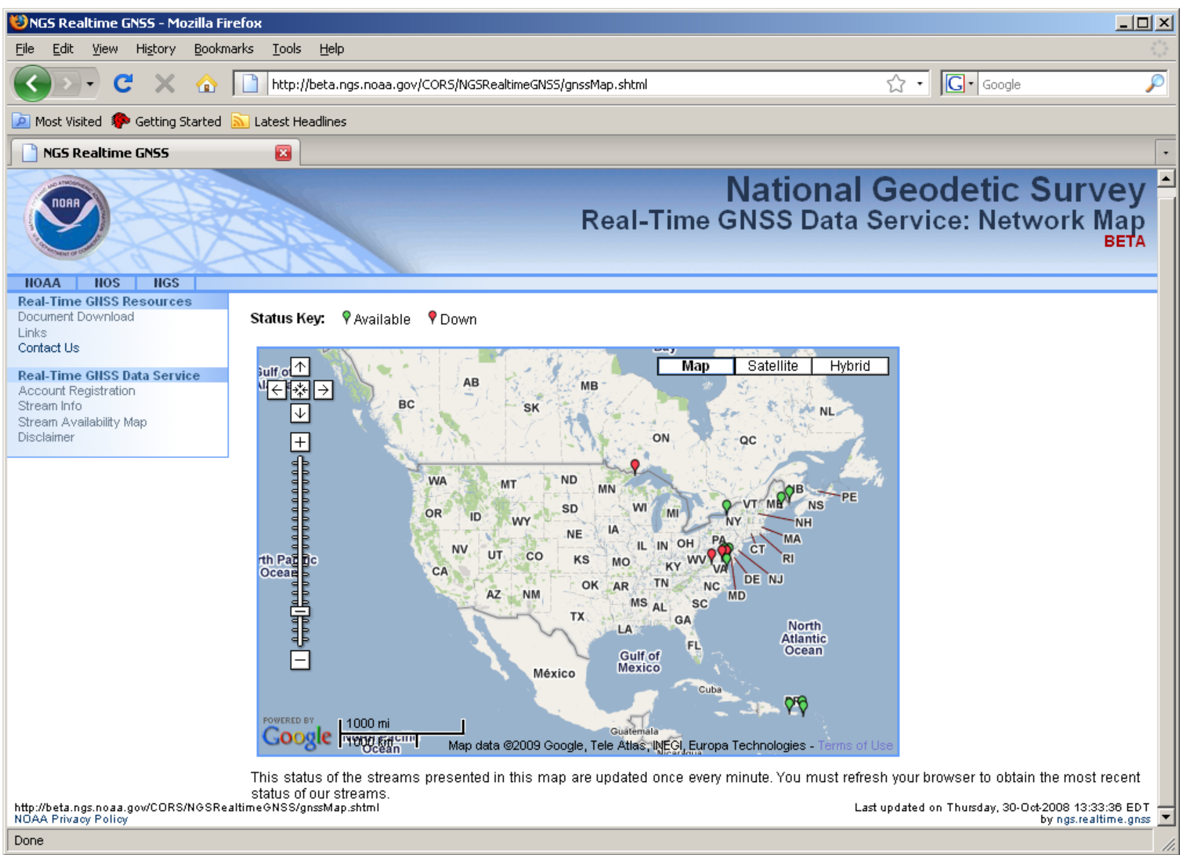
Performance – On a monthly basis, NGS monitors (1) the percentage of counties substantially enabled to perform positioning activities relative to the National Spatial Reference System, (2) the number and distribution of operational CORS sites, (3) the volume of CORS data being downloaded by CORS users, and (4) the number of times CORS-related tools, such as UFCORS and OPUS, are used. The first item is reported to NOAA as a Government Performance and Results Act (GPRA) measure. The latter three items are reported publicly in the CORS Newsletter. The following graph displays the number of files processed each month by OPUS-S and OPUS-RS since 2002. It should be noted that in October 2006, 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. Also, The Department of Commerce awarded Gold Medals to Dr. Gerald Mader and Dr. Neil Weston in December 2007 for their roles in developing the OPUS utility.



The following text describes CORS-related milestones achieved by NGS in FY2009:

- NGS contributed to a new realization of the International Terrestrial Reference System by using the latest technology to reprocess GPS data that were collected since 1997 from a worldwide collection of satellite tracking stations.
- Leveson Consulting successfully completed a scoping study of the socio-economic benefits of CORS and other NGS activities. According to the study, the CORS program currently provides benefits estimated at $758 million per year. NGS organized a Congressional rollout of the study report in June 2009. The benefit measurements examined in the study will set the stage for a full analysis and validation of benefits and will contribute to other studies, including a planned multi-agency study of geodetic infrastructure by the National Academy of Sciences.
- NGS and NOAA's National Geophysical Data Center have installed OPUS-S and OPUS-RS on a server located in Boulder, Colorado, allowing OPUS users to submit their GPS data to either to the OPUS server located in Silver Spring, Maryland or the new OPUS server located in Boulder. Having two OPUS servers, each located in a different part of the country, helps assure reliable service to our OPUS users, because each server is able to operate independently, even when the other server is down for repairs or malfunctions.
- Giovanni Sella has drafted a document describing the Foundation CORS Network and presenting a plan for its implementation.
- NGS personnel conducted CORS/OPUS presentations at more than 25 various events in FY2009.
- Mark Schenewerk, Steve Hilla, and Neil Weston encoded software to compute GLONASS orbits.
- Bill Henning has organized a team of more than 60 people to generate guidelines for the administration and use of real-time GNSS networks. A draft of these guidelines is expected to be ready for public review in early 2010.
- Jake Griffiths and Jim Ray published the paper "On the Precision and Accuracy of IGS Orbits" in the *Journal of Geodesy*.

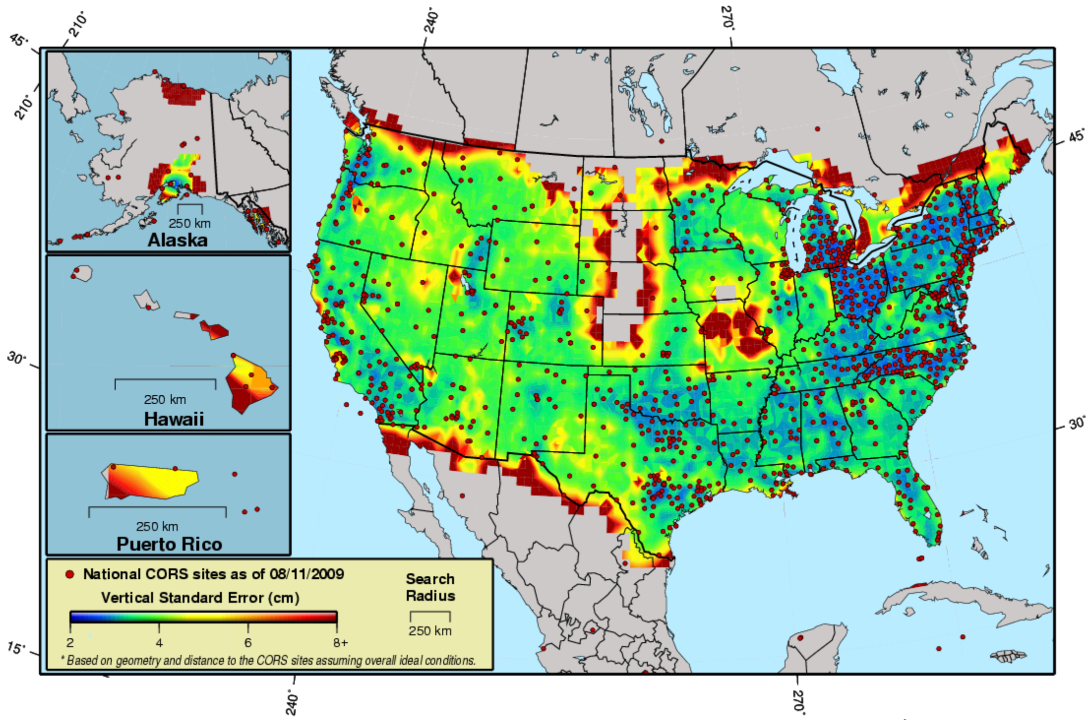
- Neil Weston, Tomás Soler, and Gerald Mader published a paper “Rover Station Positional Accuracies from OPUS as a Function of Reference Station Spacing and Rover Station Occupation Time” in the Proceedings of the International Federation of Surveyors meeting in Eilat, Israel in May 2009.
- Charles Schwarz, Richard Snay, and Tomás Soler published a paper “Accuracy Assessment of the National Geodetic Survey’s OPUS-RS Utility” in *GPS Solutions*.
- The paper “HTDP 3.0: Software for Coping with the Coordinate Changes Associated with Crustal Motion” has been accepted for publication in the *Journal of Surveying Engineering*. The authors are Chris Pearson, Robert McCaffrey, Julie Elliott, and Richard Snay.
- NGS has added two stations in Afghanistan to the CORS network. The stations were installed by the U.S. National Geospatial-Intelligence Agency in cooperation with the Afghanistan Federal Government.
- NGS has added six stations in Benin to the CORS network. The stations were installed with funding from the U.S. Department of State.
- NGS installed a CORS near the tide gauge located at Battery Park in New York City.
- NGS enhanced Google maps to improve the way users obtain CORS information via the NGS webpage.
- NGS is now streaming real-time GNSS data via the Internet from 16 stations as an operational prototype.



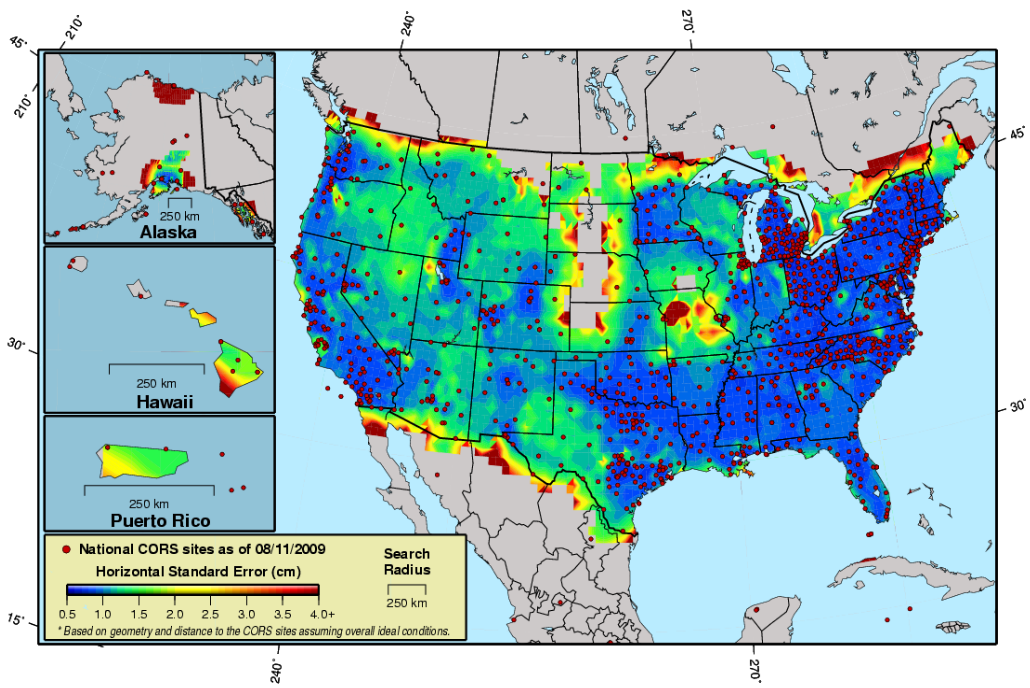
- During FY2009, GPS users successfully submitted for archiving an average of more than 64 datasets per month to OPUS-DB.

- Bill Stone and Mike Aslaksen travelled to Mongolia to assist the Mongolian government in developing a CORS network and to help with other geospatial capabilities.
- NGS reprocessed all IGS and CORS data observed since 1994. The results will provide rigorous estimates of three-dimensional positional coordinates and velocities for all IGS & CORS reference stations.
- NGS merged the National CORS network and the Cooperative CORS network into a single network, allowing users to obtain data from the former Cooperative CORS sites in the same way they obtain data from National CORS sites, that is, from either of the two parallel CORS data facilities—Silver Spring, Maryland and Boulder, Colorado
- In 2009, users successfully downloaded 9,457,160 CORS datasets via anonymous file transfer protocol (FTP), representing a one percent increase compared to FY2008.
- Richard Snay and Tomás Soler published the scientific paper "Continuously Operating Reference Stations (CORS): History, Applications, and Future Enhancements" in the *Journal of Surveying Engineering*. The paper is reproduced as Annex A of this document.
- Charlie Schwarz published the paper "Heuristic Weighting of Data Conditioning in the National Geodetic Survey Rapid Static GPS Program" in the *Journal of Surveying Engineering.*
- Bill Kass, Bob Dulaney, Jake Griffiths, Steve Hilla, Jim Ray, and Jim Rohde published a paper "Global GPS Data Analysis at the National Geodetic Survey" in the *Journal of Geodesy*.
- NGS conducted numerous tests to document the accuracy achievable when a user submits 15 minutes of GPS data to OPUS-RS (rapid static) and found that the accuracy at a given location is dependent on the local geographic distribution of the CORS stations. The following maps illustrate the vertical (ellipsoid height) and horizontal standard errors achievable as a function of the location where the GPS data were collected.

Predicted OPUS–RS Vertical Standard Error *



Predicted OPUS–RS Horizontal Standard Error *



2.3 Reviews

The NOAA IT Review Board reviewed the Geodetic Support System on September 11, 2007.

2.4 Security

The CORS program is accredited under requirements documented 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 June 2007. Management, operational, and technical security controls are adequate to ensure the confidentiality, integrity, and availability of information. System security is reviewed annually as part of the NOS Continuous Monitoring program. The Geodetic Support System is scheduled to undergo the full Certification and Accreditation (C&A) cycle in FY2010.

2.5 Performance Measures

The performance measures in Table 2 indicate the Geodetic Support System's performance regarding 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	FY2005	FY2006	FY2007	FY2008	FY2009
Strategic and Business Results	Number of CORS/OPUS workshops presented	6	7	12	20	25
	Number of new stations added to the CORS network	221	189	210	263	180

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 seven years, the Forum has been an integral part of the Civil GPS Service Interface Committee's annual meeting 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 9th Annual CORS Users Forum held in Savannah, Georgia in September 2009.

3.0 Financial Performance

3.1 Current Performance vs. Baseline

The Geodetic Support System had a modest budget of $1,815K in FY2009. Expenses include the salaries (and benefits) of five Government FTE's ($540K), support services ($635K), a contract with NOAA's National Geophysical Data Center to operate the Parallel CORS Data Management Facility in Boulder, Colorado ($275K), telecommunications ($80K), the procurement of IT equipment ($255K), common services ($25K), and training ($5K). The budget remains relatively constant from year to year, once it is normalized for the influence of inflation.

3.2 Performance Measures

Considering the small budget—one dominated by salaries—no financial performance measures have been established for the Geodetic Support System. Nevertheless, the CORS network continues to grow by approximately 200 stations per year. In FY2009, the CORS network increased by 180 stations, bringing the total number of active CORS to 1,370 on September 30, 2009. This continuing growth may require the number of people on the CORS staff to be increased in the near future.

3.3 Cost Benefit Analysis

As reported in Section 1.1 of this report, the total direct benefits provided by the CORS program in FY 2009 amounted to $631M. The FY2009 cost to NGS for managing the CORS program (of which the Geodetic Support System constitutes the IT component) was $3.2M, yielding a benefit-to-cost ratio of 197-to-1. The primary reason NGS has been able to achieve this impressive benefit-to-cost ratio is that 92 percent of the CORS network stations 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 approximately 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 enable after-the-fact positioning activities. Also, the National Science Foundation is sponsoring a network to maintain more than 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 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 in attendance. A detailed review of work and priorities is undertaken if cost is significantly above baseline values. Any necessary corrective actions are identified and implemented.

4.0 Innovations to Meet Future Customer Needs

During the next few years, NGS will

- adopt an XML (extensible markup language) format for reporting OPUS results,
- implement OPUS-Projects,
- provide to the public those GLONASS data collected at CORS sites,
- enable OPUS to process GLONASS data, as well as GPS data, and
- continue promoting the use of the CORS system to support real-time GNSS positioning.

Additionally, the number of stations in the National CORS network is expected to continue growing for a few more years, because many organizations are installing eligible stations in the process of establishing several GNSS Real-Time Networks (RTN) across the United States and its territories.

4.1 Number and Types of Users

More than 100,000 people have used CORS data for precise positioning, and it is possible that millions of people have benefited from the use of CORS data to monitor weather and/or space weather.

NGS records reveal that more than 60,000 unique users have used the OPUS utility since its introduction in March 2001. It is estimated that at least an additional 40,000 have used other CORS services (the CORS anonymous FTP server or UFCORS) for precise positioning. These 100,000 users include land surveyors, GIS professionals, construction engineers, remote sensing professionals, environmentalists, educators, and hydrologists.

In addition, CORS data are used by:

- earth scientists to monitor crustal motion,
- meteorologists to monitor the distribution of moisture in the atmosphere (for weather), and
- atmospheric scientists to monitor the distribution of free electrons in the ionosphere (for space weather).

The fact that annual CORS benefits have grown an average rate of 20 percent per year between FY2003 and FY2009 suggests the CORS user base has been expanding.

4.2 Providing OPUS Results in XML Format

When a user submits a GPS data set to NGS for OPUS processing, the user automatically receives an email with an ASCII file containing the computed coordinates for the location where the GPS observations were performed, together with appropriate metadata. Currently, NGS is testing a new feature to be added to OPUS to allow software users to also elect to receive the OPUS output file in XML format. Software may be more easily developed to read the XML format as compared to the ASCII format. The software could then instruct the user's computer to perform an action based on the information in the CORS report, without requiring human interaction. That is, the XML format would facilitate machine-to-machine conversation between the computer executing OPUS and a user's computer.

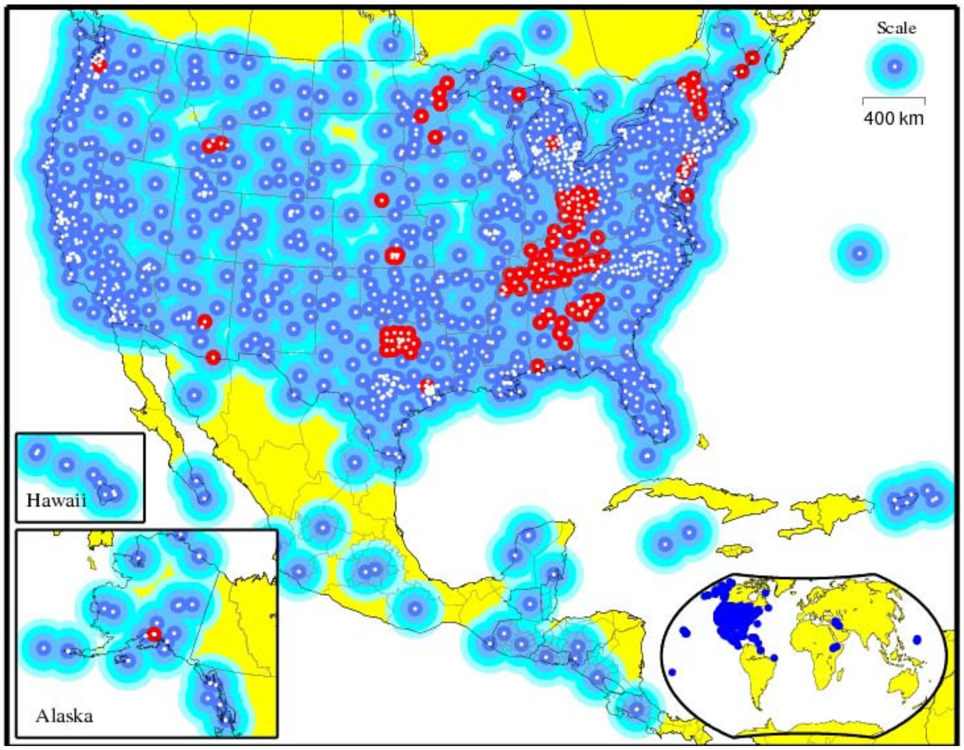
4.3 Implementing OPUS-Projects

NGS has developed a working OPUS-Projects utility prototype and is testing it on a FEMA-sponsored $3M surveying project to upgrade the National Spatial Reference System in the Gulf states. The project will assist area reconstruction efforts to remediate the devastation caused by Hurricanes Katrina and Rita in 2005. OPUS-Projects differs from the standard OPUS utility, enabling 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 in a manner consistent with all submitted data. Recall that the standard OPUS utility computes positional coordinates for one location only, using data from one observation session only. NGS expects to declare the OPUS-Projects utility to be "initially" operational in FY2010.

4.4 Providing GLONASS Data

Other countries are currently developing various Global Navigation Satellite Systems (GNSS) to emulate the U.S.-sponsored Global Positioning System (GPS). Russia is developing GLONASS, the European Union is developing Galileo, and China is developing Compass. Of these three, GLONASS has progressed the farthest, and the Russians hope to have GLONASS fully operational by 2010. Currently, the GLONASS constellation includes approximately 19 operational satellites, whereas no operational satellites have been launched for either the Galileo constellation or for the global component of the Compass constellation. Together, GPS and GLONASS will provide more than 50 satellites, enabling users to obtain positional coordinates more accurately and more reliably.

In December 2006, in Key West, Florida, NGS installed its first GPS+GLONASS receiver to establish a CORS site collocated with a tide gauge station. NGS will install several additional GPS+GLONASS receivers in the future and will encourage CORS partners to do the same. The following figure identifies stations in the CORS network currently collecting both GPS and GLONASS data. Starting in FY2010, NGS plans to distribute GLONASS data, as well as GPS data, from such stations.



Red circles identify CORS that collect both GPS and GLONASS data.

4.5 Processing GLONASS data

NGS has begun to develop software for processing GLONASS data as needed for differential positioning between GLONASS receivers. Eventually, this software will be embedded into the various versions of OPUS so that users may submit GPS and/or GLONASS data, obtaining coordinates for locations where the observations were collected. Also, NGS will develop software to compute the path of the GLONASS satellites as they orbit the Earth.

It will take a couple of years to develop and implement GLONASS data-processing software, because there are significant differences between GLONASS data and GPS data; the dominant difference being that each GLONASS satellite broadcasts data on a different radio frequency from the other GLONASS satellites. As a result, the widely used GPS data-processing technique of differencing data between two satellites cannot be readily used for processing GLONASS data. NGS is planning to build two separate GLONASS processing engines, although there will be many similarities between them. One engine would be used for GLONASS data sets spanning several hours; the other for those spanning shorter time periods. The former would be similar to the GPS data-processing engine contained in OPUS-S, and the latter would be more similar to the one contained in OPUS-RS. It is anticipated that the upgraded OPUS-RS utility will be capable of computing centimeter-level positions using only five minutes of GPS+GLONASS data, because the combined GPS+GLONASS constellation will contain more than 50 satellites.

4.6 Supporting Real-Time GNSS Positioning

Several organizations are establishing GNSS Real-Time Networks (RTN) in various regions of the United States. These organizations include state and local government agencies, as well as commercial institutions. Approximately 80 RTN's currently exist in the United States. CORS and RTN's are similar in that they both enable centimeter-level positioning accuracies. They are different in that CORS has traditionally addressed post-processing applications, whereas RTN's address real-time applications. They are similar in that both rely on ground-based GNSS tracking stations. They are different in that CORS is a highly coordinated nationwide effort, whereas the existing RTN's are comprised of a somewhat disjointed collection of regional and local networks. In some instances, two or more RTN's may even compete for the same customer base. Some coordination, however, exists among those RTN's that share the use of their GNSS tracking stations with each other.

To better coordinate the growth of RTN's across the United States, NGS adopted the following policy statement in FY2008:

NGS Policy Statement: Supporting Real-Time GNSS Positioning

Rationale:
NOAA's National Geodetic Survey (NGS) endorses the development of Global Navigation Satellite Systems (GNSS) technology to provide accurate and reliable real-time positioning services consistent with the U.S. National Spatial Reference System (NSRS).

Goals:
NGS will support real-time GNSS positioning by implementing an action plan to:

1) Provide low-latency access to GNSS data from selected CORS via the Internet. All streaming data from these CORS will be provided free of charge, without correctors, in current Radio Technical Commission for Maritime Services (RTCM) formats.
2) Develop standards, specifications, and guidelines to help users obtain optimal results from real-time GNSS positioning technologies, including specific documents for users of single-base technology, as well as for users of GNSS real-time networks (RTN).
3) Develop standards, specifications, and guidelines for administrating RTN. This may include:
   a. Reference station siting and construction considerations
   b. Policy to promote the use of open source, generic data formats such as RTCM, through the use of the most current Networked Transport of RTCM via Internet Protocol (NTRIP) programs
   c. Policy to encourage the RTN to support as many different GNSS hardware and firmware packages as possible
   d. Guidelines to enable RTN results to be consistent within the NSRS. This may include methods to archive and quality check RTN data.
   e. Guidelines to determine accurate positional coordinates and velocities for RTN reference stations
4) Provide a service to RTN administrators and users to verify the positional coordinates obtained from their RTN are consistent with the NSRS.
5) Maintain a strong participatory presence and seek leadership roles at various conferences, meetings, and venues where real time positioning is addressed.

6) Participate in education and outreach to both disseminate relevant information, as well as to acquire feedback regarding the suitability of guidelines promoted by NGS.
7) Research phenomena affecting accurate positioning, including but not limited to: satellite orbits, refraction, multipath, antenna calibration, and crustal motion.

4.7 Funding Levels

NGS expects to serve many more customers in the near future, by offering several new products and services as documented in this report. NGS proposes meeting the challenges associated with the new level of service with a modest 20 percent increase to its base budget by 2011.

Project to Address Challenge: Customer Support

As a result of the introduction of several new CORS-related products and services, NGS expects that its day-to-day customer base will grow, perhaps by a factor of 10, over the next few years. It will be a challenge to provide quality customer support to a community this large.

Project to Address Challenge: Technical Expertise

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

Annex A

Continuously Operating Reference Station (CORS): History, Applications, and Future Enhancements

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Abstract: The National Oceanic and Atmospheric Administration's National Geodetic Survey (NGS) manages the National Continuously Operating Reference Station (CORS) system that comprises a network of over 1,350 sites, each containing a geodetic quality Global Navigation Satellite System receiver. This network is currently growing at a rate of about 15 sites per month. NGS collects, processes, and distributes data from these sites in support of high-accuracy three-dimensional positioning activities throughout the United States, its territories, and a few foreign countries. CORS data are also used by geophysicists, meteorologists, atmospheric and ionospheric scientists, and others in support of a wide variety of applications. This paper addresses the history of the CORS network, some of its applications, and plans for enhancing it within the next few years.

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Historical Introduction

The history of the Continuously Operating Reference Stations (CORS) system is intimately connected to the National Oceanic and Atmospheric Administration's (NOAA's) National Geodetic Survey (NGS) and this agency's mission to define, maintain, and provide access to the U.S. National Spatial Reference System (NSRS). The NSRS constitutes the official system of the civilian government for enabling a user to determine geodetic latitude, longitude and height, plus orthometric height, geopotential, acceleration of gravity, and deflection of the vertical at any point within the United States and its territories. The NSRS contains information about its orientation and scale relative to international reference frames, as well as the precise orbits of all satellites used in defining or accessing the NSRS. Last, the NSRS also contains all necessary information to describe how all of these quantities change over time. The NSRS is crucial for meeting our nation's economic, social, and environmental needs.

NGS recognized the potential contributions of the Global Positioning System (GPS) for enhancing the NSRS in the early stages of GPS development. Hence, in the late 1980s, this agency embarked on applying GPS instrumentation and field techniques to improve the NSRS. NGS quickly converted its traditional horizontal field operations (which applied line-of-sight instruments) to three-dimensional (3D) field operations using GPS instrumentation. Snay (1989) reported that traditional line-of-sight techniques provided positional coordinates with relative accuracies of approximately 1:250,000 among the primary horizontal reference stations in the NSRS. GPS, on the other hand, easily yields relative accuracies exceeding 1:1,000,000. In addition, because of the line-of-sight requirement, many of the older reference stations had been installed in locations, like mountain tops, which are difficult to access.

NGS first applied GPS to determine positional coordinates for the brass disks and other monuments that served as traditional reference stations. Starting with Tennessee in 1987, NGS collaborated with various state and federal agencies and others to establish a high accuracy reference network (HARN)—also called a high precision geodetic network—in each of the 50 states. For each HARN survey, many new reference marks were positioned so that, as compared to the preexisting reference marks, the new ones would be located in more accessible places (e.g., near public roads) and/or they would provide a relatively less obstructed view of the sky. These statewide HARNs were embedded into a more accurate sparse nationwide network whose points were also positioned using GPS techniques, first in 1987 and again in 1990 (Soler et al. 1992). Once a HARN survey was completed in a particular state, NGS performed a statewide readjustment of the HARN data, together with all archived classical geodetic surveys and local GPS projects performed in that state, to compute consistent positional coordinates for the associated ground marks.

Anticipating the need to perform accurate HARN surveys, NGS introduced, in the fall of 1986, the Cooperative International GPS Network (CIGNET) (Chin et al. 1987), the forerunner of the CORS network. Each CIGNET site was equipped with a high quality dual frequency GPS receiver that continuously recorded signals from GPS satellites. The primary intention was to make dependable tracking data available from a network of ground stations to compute precise ephemeredes (orbits) for the GPS satellites. In 1989, CIGNET contained three stations in the United States (MOJA in Mojave, Calif.; RICH in Richmond, Fla.; and WEST in Westford, Mass.). These early CORS were equipped with Mini-Mac 2816-AT dual-frequency codeless receivers (Aero Service Division, Western Geophysical Company of America, Houston). In 1990, CIGNET expanded into the southern hemisphere. By the end of 1991, CIGNET comprised a total of 21 sites spanning all continents except Antarctica. As is now the case, all tracking data were collected by several partners and made freely available to GPS investigators through NGS archives (Schenewerk et al. 1990). Gradually, NGS augmented the CIGNET network, generating the core of the first public global GPS network that, unknowingly at the time, evolved into the current International Global Navigation Satellite System (GNSS) Service (IGS) network under the auspices of the International Association of Geodesy.

The concept of covering the entire United States with a network of CORS to enhance the NSRS was first postulated by Strange (1994). Soon after, Strange and Weston (1995) published a preliminary description of the CORS system. Around this same time, several other federal agencies were also starting to establish networks of continuously operating GPS base stations, but for different reasons. The U.S. Coast Guard (USCG) wished to supplement its LORAN radionavigation service by offering the differential GPS (DGPS) service to support safe marine navigation in U.S. coastal waters. Similarly, the U.S. Army Corps of Engineers (USACE) sought a cost efficient navigation system to support their inland waterway operations (dredging, hydrographic surveys, etc.). They collaborated with the USCG to extend the DGPS service inland along several of the major rivers. Finally, the Federal Aviation Administration (FAA) wanted to use some type of CORS to support safe air navigation. The FAA developed their Wide Area Augmentation System (WAAS). Other federal agencies like NASA's Jet Propulsion Laboratory (JPL) and the U.S. Geological Survey were already heavily invested in using CORS sites to determine satellite orbits and study crustal motion. Because of the similarities between these projects, the U.S. General Accounting Office directed these agencies to work together and to coordinate activities and equipment procurements to reduce the expense to the federal government and the U.S. taxpayer. NGS found itself in an advisory role helping to define the GPS equipment specifications needed to support the missions of all these agencies (Spofford and Weston 1998).

Since the late 1980s, data from both CIGNET and JPL sites were used to support global GPS orbit computations (Schutz et al. 1990). In 1994, NGS officially began building the CORS network by installing a GPS receiver on the campus of the National Institutes of Standards and Technology, formerly called the National Bureau of Standards, in Gaithersburg, Md. Six months later, NGS installed a GPS receiver near Boulder, Colo. and with time incorporated into the CORS network a number of continuously operating GPS fiducial stations that originally were part of CIGNET. Data from all these sites were made available via the Internet and, progressively, NGS added selected U.S. permanent GPS base stations to the CORS network.

The USCG and USACE began installing their DGPS sites and FAA their WAAS sites in 1995. NGS worked with these agencies to incorporate both the DGPS and WAAS sites into the CORS network. The initial phase of the USCG network was largely completed by January 1996, although more sites have since been added. Other federal, state, and locally sponsored continuously operating receivers were identified and gradually included into the CORS network from 1995 onwards. By 1995 NGS obtained access to more than 50 geodetic quality GPS receivers, most of them deployed by USCG and other participating agencies without the need by NGS to install, maintain, or operate any of the sites. The Texas Department of Transportation was the first state agency to join the CORS system with the inclusion of their ten-station Regional Reference Point network that provided significant coverage in Texas. By 1996 the number of CORS sites had increased to 85. By making contact with interested agencies and arranging to exchange data, NGS expanded the network to 108 sites by December 1997. The 200-site milestone was surpassed in 2000, and since then the CORS network has grown to its current size of approximately 1,350 sites, and it continues to grow in importance as the primary way for the geodetic-surveying community to access the NSRS. At present, the CORS network contains stations in the United States, Canada, Mexico, Central and South America, the Caribbean, and Iraq. More than 200 organizations participate in the program. Recently some sites of EarthScope's Plate Boundary Observatory (PBO), established in the western part of the North American continent to detect crustal motions, have been incorporated into the CORS network.

Although the number of CORS sites is currently growing at a rate of about 15 sites per month, the total number of permanent GPS tracking stations in the United States is probably growing perhaps twice as fast. An ongoing project, that may take several years to complete, is to determine an accurate orthometric height for each CORS site. Determining the orthometric height of a CORS site may require special methodology (Greenfeld and Sens 2003) depending on the location and the type of antenna mounting.

The latest international installation by NGS of a CORS antenna was done near Fortaleza, Brazil, where the local tie between the new and the old reference points was remeasured to about 1 mm accuracy. The receiver at this site is connected to an external atomic hydrogen-maser clock. According to Ray et al. (2007), the performance of this clock is among the best of any H-maser station in the combined CORS-IGS network.

The National CORS system is rapidly becoming the preferred method for accurate 3D positioning in the United States and abroad. The advantage to GPS practitioners is that they only need to deploy one GPS receiver and download corresponding CORS data via the Internet to process these data in differential mode. The Web-based utility, UFCORS (see the following), has made such downloads easy. As part of the CORS project, NGS is working with scientists around the world to develop digital models and techniques that will enable GPS users to determine accurate positions economically and in a timely manner. Fig. 1 shows the geographic distribution of CORS sites as of May 2008. The primary access for CORS information is via the Web (http://www.ngs.noaa.gov/CORS/). See also the articles by Snay et al. (2002b) and Stone (2006).

The CORS network continues to evolve as we speak. It is expected to increase by ~200 stations in 2008 due to the large number of organizations establishing real-time positioning networks and the project to build EarthScope's PBO for monitoring crustal motion. This rate of growth will result in a CORS network with average intersite distances on the order of 100 km in the contiguous United States. In light of this growth, NGS has recently updated its guidelines for establishing CORS sites (NGS 2006), improved its tracking of metadata, upgraded its GPS analysis software (called PAGES), and is planning a complete reanalysis of all IGS plus CORS data observed since 1994. The latter activity will be performed in collaboration with several other IGS Analysis Centers, and it is expected to be completed within the year 2010.

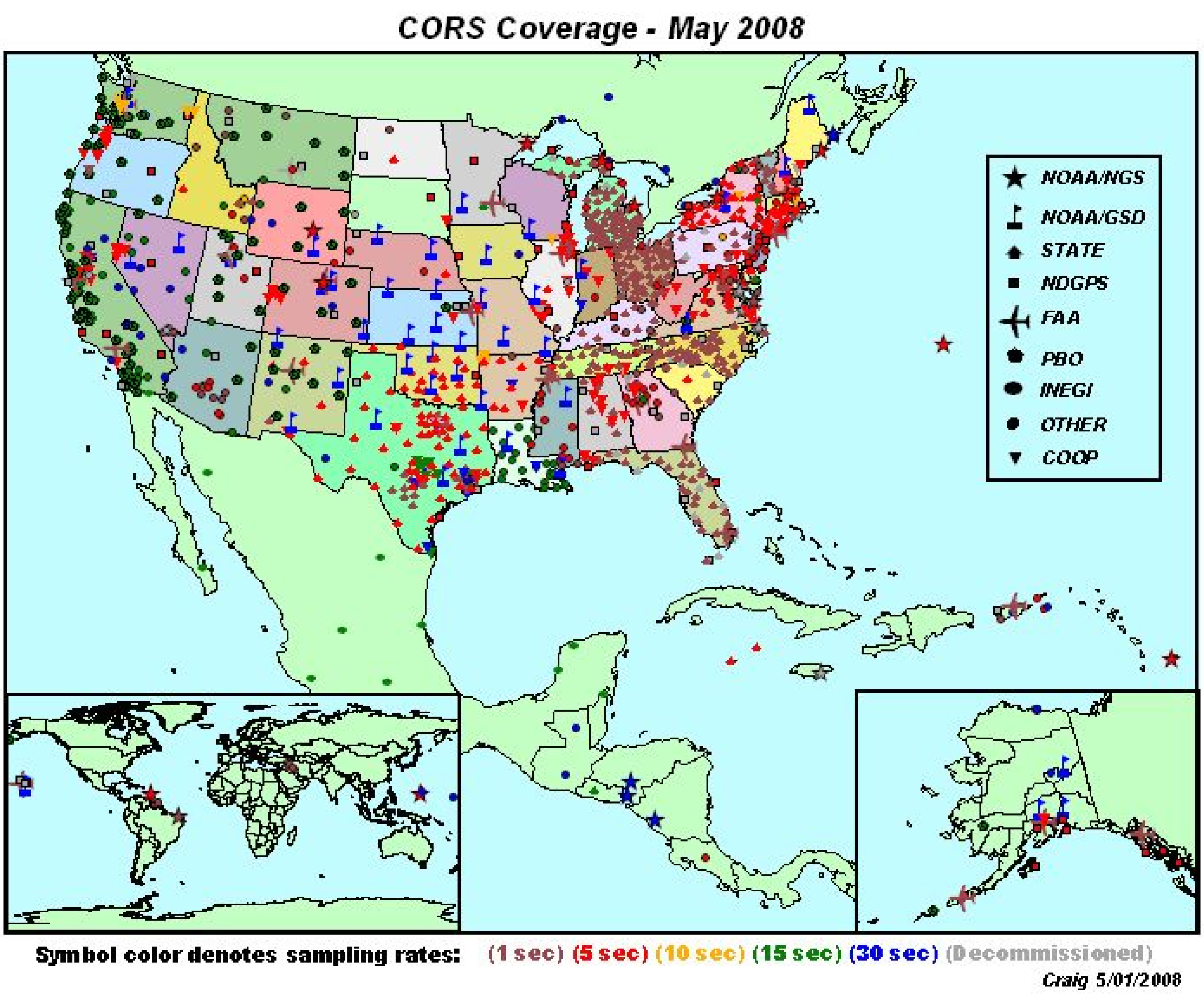


Fig. 1. Operational CORS sites as of May 2008

CORS and the Definition of the NSRS

NGS derived the original realization of the North American Datum of 1983 (NAD 83) in 1986 by performing a rigorous adjustment of most of the classical geodetic observations in its archives together with Doppler observations and a few very long baseline interferometry (VLBI) baselines (Schwarz 1989). This original realization is called NAD 83 (1986). With improvements in our knowledge of terrestrial reference frames, NGS has introduced several newer realizations of NAD 83, refining at each step the adopted coordinates. In 1998 NGS introduced the current realization, called NAD 83 (CORS96), which is based on the CORS network by defining a transformation from the International Terrestrial Reference Frame of 1996 (ITRF96) to NAD 83 (Craymer et al. 2000). In both reference systems, ITRF and NAD 83 (CORS96), the 3D positional coordinates of each CORS is complemented by a 3D velocity to account for crustal motion. A more recent ITRF realization is known as the ITRF2000. ITRF2000 coordinates and velocities may be transformed to corresponding NAD 83 (CORS96) values using equations and parameters described by Soler and Snay (2004). The NAD 83 (CORS96) positional coordinates are published for an epoch date of 2002.0, except in Alaska and California where epoch dates of 2003.0 and 2004.0, respectively, have been adopted because of recent earthquakes. One must apply the adopted velocities to compute positional coordinates for any other epoch date. At this writing, the coordinates and velocities of the CORS sites form the foundation of the NSRS and the recently completed NAD 83 (NSRS2007) readjustment (Vorhauer 2007).

It is important to note that CORS sites located in Hawaii and other Pacific islands have been used to define the NAD 83 (PACP00) reference frame for points located on the Pacific tectonic plate. Similarly CORS sites located in Guam have been used to define the NAD83 (MARP00) reference frame for points located on the Mariana tectonic plate. More information about the procedures used to define these two reference frames is available in Snay (2003). CORS sites have been also employed to establish accurate geodetic control in other countries such as Mexico (Soler and Hernández-Navarro 2006a) and Jamaica (Newsome and Harvey 2003).

When a CORS site first comes on line, NGS uses at least ten 24-h GPS data sets to compute this station's ITRF2000 positional coordinates relative to other stations in the global IGS network. Also, NGS uses the horizontal time-dependent positioning (HTDP) software (Snay 1999) to predict the station's ITRF2000 velocity. NGS then transforms the ITRF2000 positional coordinates and velocity for this CORS site into their corresponding NAD 83 (CORS96) values via the adopted 14-parameter similarity transformation (Soler and Snay 2004).

Every few years, NGS reprocesses all CORS data collected since 1994 to compute provisional positions and velocities for all CORS relative to the current ITRF realization: call it ITRFxx. If, for any station, these provisional ITRFxx positional coordinates differ from the currently adopted ITRFxx positional coordinates by more than 1 cm in the north-south or east-west component or by more than 2 cm in the vertical component, then NGS adopts the provisional position and velocity to supersede the previously adopted ITRFxx position and velocity.

In addition to this validation process, NGS performs a solution for each day to monitor the quality of adopted CORS positional coordinates. Each solution includes all CORS data collected during the 24-h period spanning that day. As a by-product, NGS compiles plots showing differences between the published ITRF2000 coordinates and the values obtained from the daily solutions, corrected for crustal motion, for the latest 60 days. The results are plotted relative to a local horizon (north-east-up) coordinate frame and are made available to the general public through the CORS Web page (ftp://www.ngs.noaa.gov/cors/Plots/xxxx.pdf; where xxxx denotes the site's four-character identification). The movement or replacement of the antenna or an unexpected natural phenomenon may displace the position of the CORS reference point. Geophysical processes (earthquakes, volcanic activity, etc.) may also produce significant station displacements that should be documented. This information is critical to CORS users if they want to use CORS data to determine accurate positional coordinates for points of interest to them. When the trend of the 60-day series of daily estimates differ from this station's adopted positional coordinates by more than the tolerances described in the preceding paragraph (1 cm horizontal; 2 cm vertical), then NGS carefully analyzes the available data to determine whether or not this station's published positional coordinates and velocities should be updated. Similar analysis is done with respect to the adopted NAD 83 (CORS96) coordinates. When the daily provisional transformed coordinates referred to the NAD 83 frame differ by more than 2 cm in the north-south or east-west component or by more than 4 cm in the vertical component, then NGS adopts the provisional NAD 83 positional coordinates and velocity to supersede the previously adopted NAD 83 values. As a result of these less stringent tolerances, adopted NAD 83 (CORS96) positional coordinates and velocities are less likely to be updated than their ITRF counterparts. However, this NGS policy, established in 1999 is currently being discussed at NGS for possible revision to lower tolerances in response to both internal and external requests.

For those agencies whose sites are included in the CORS network, NGS computes highly accurate 3D positional coordinates and velocities in the NSRS for their site antennas, provides an international data distribution mechanism, monitors the positions of the antennas on a daily basis, and notifies the agencies when movements of the antennas are detected. In exchange, the agencies notify NGS when they change equipment or software so that NGS can keep CORS users abreast of the status of the CORS sites. Scientific users who monitor very small movements of the Earth's crust are especially interested in any antenna changes so that they can account for those effects when they undertake long-term analyses of site locations. When antenna changes are detected and corrections made, NGS immediately publicizes this information through the CORS Newsletter (http://www.ngs.noaa.gov/CORS/newsletter1/).

In March 2001, efficient access to the NSRS through GPS was introduced with the release of the On-line Positioning User Service (OPUS) utility. OPUS is an automatic service that requires the user to input only a minimal amount of information; its instructions are self-explanatory and its Web page contains enough details to be followed easily (http://www.ngs.noaa.gov/OPUS/). However, OPUS has a few restrictions users should be aware of: first, and most importantly, OPUS provides a differential GPS static solution. Second, a minimum of 2 h of GPS observations are recommended to obtain surveying-geodetic accuracies (Soler et al. 2006b). Third, a maximum of 48 h of GPS data is permitted (the GPS data can cross midnight only once). Fourth, the submitted data file must contain dual-frequency (L1/L2) carrier phase observables. Finally, GLONASS observations cannot be processed at this time, although in the future they will be accepted along with Galileo data, as the constellation of this European navigational system becomes available. Strictly based on Internet access, OPUS provides the geospatial community with positioning referred to both the ITRF2000 and the NAD 83 (CORS96) reference frames. OPUS routinely achieves accuracies (reported as "peak-to-peak" values) better than 2 cm in the horizontal dimensions and 5 cm in the vertical dimension by using corresponding data from three nearby CORS sites. Readers interested in knowing the statistical meaning of the peak-to-peak values reported by OPUS should read Schwarz (2006). More detailed information about OPUS may be obtained in a number of references, e.g., Mader et al. (2003); Stone (2006); Soler et al. (2006c); and Weston et al. (2007). The infrastructure of OPUS is the GPS data and the fiducial control available from the CORS sites. The original idea of creating CORS to support GPS surveying activities reached a new level of efficiency with the introduction of OPUS. The geodetic, surveying, mapping, and GIS communities have embraced OPUS with great enthusiasm. The progress of this Internet-based utility has been nothing less than spectacular since its inception in 2001. Fig. 2 depicts OPUS usage by county during the 12-month period from May 2007 to April 2008. As Fig. 2 shows, during this period a total of 171,573 OPUS solutions were successfully processed. For completeness, it should be reported that during the same 1-year period OPUS processed a total of 23,502 data sets observed outside the United States. The number of OPUS users is expected to increase significantly now that NGS is broadening the functionality of OPUS. On January 31, 2007, the first variation of OPUS, called OPUS-RS (rapid static), was declared "initially" operational. Like the original implementation of OPUS, OPUS-RS computes positions in differential mode for dual-frequency data collected by a GPS receiver. What's new about OPUS-RS is a new processing engine (Schwarz 2008), allowing as little as 15 min of data, while (generally) maintaining the accuracy of the original OPUS. The user can send GPS data to OPUS-RS by accessing: http://www.ngs.noaa.gov/OPUS/. For a brief introduction to OPUS-RS, see Martin (2007); Meade (2007). A practical example of how OPUS-RS can be applied to day-to-day work in surveying engineering is described in Lazio (2007). Another variation of OPUS will be OPUS-DB (database) that will require a minimum of 4 h of observations but will give surveyors, geodetic engineers, and others the option of archiving the resulting positional coordinates in an NGS database for public accessibility. Finally, OPUS-Mapper is being developed to process L1 code data to determine positional coordinates accurate enough for mapping and GIS applications. Although each of these functionalities are being developed in phases, they will ultimately all be part of an integrated "OPUS" utility.

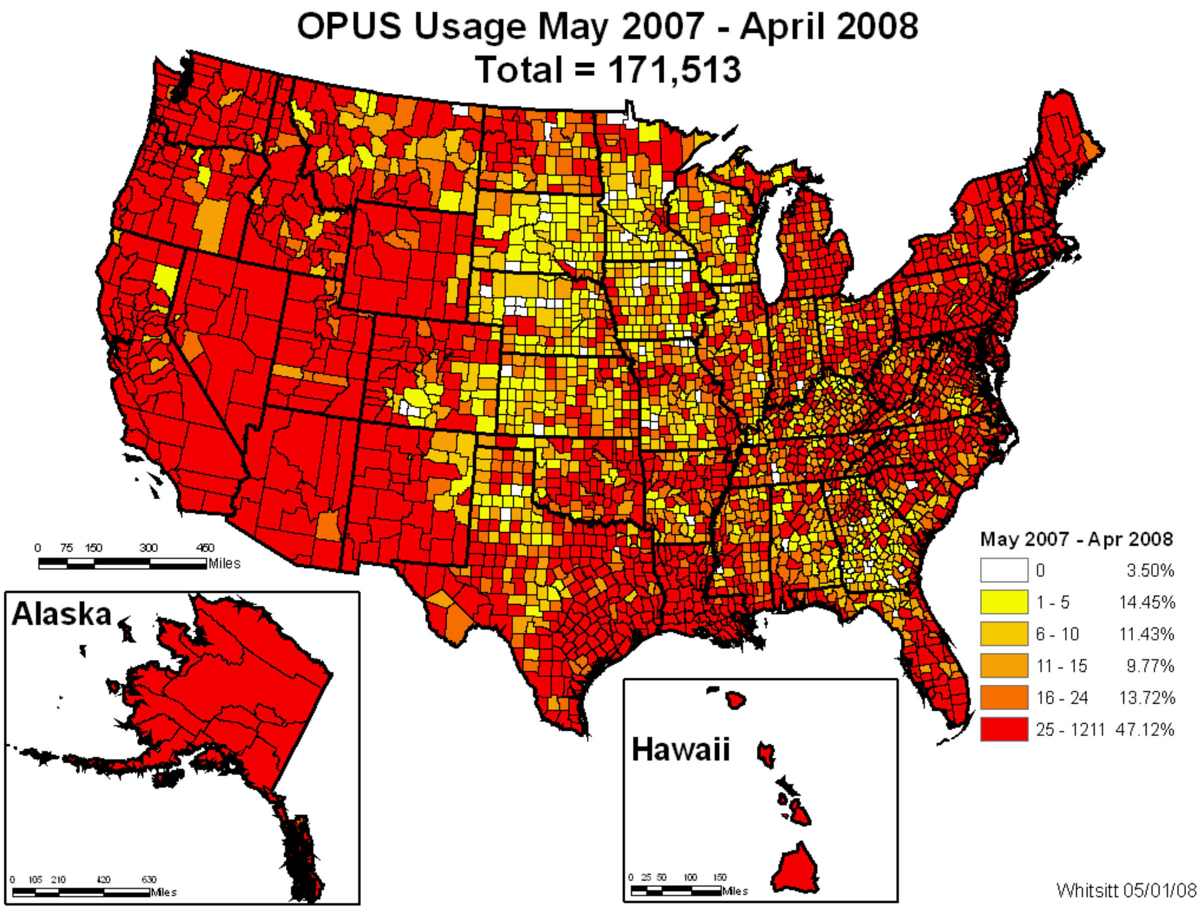


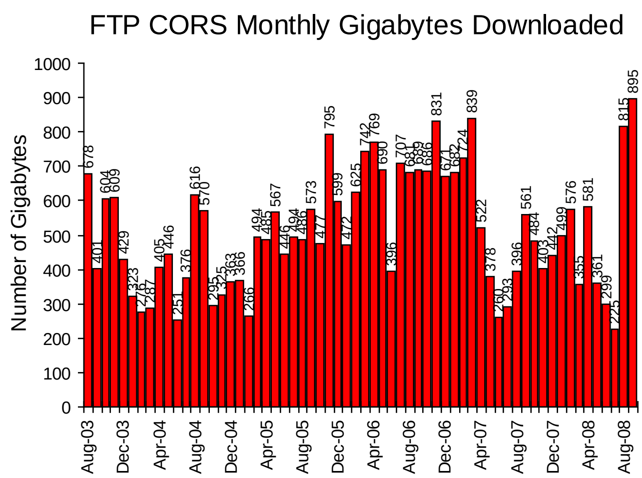
Fig. 2. OPUS usage by county from May 2007 to April 2008

Data Archives

All CORS data are collected at two facilities, one located in Silver Spring, Md. and the other in Boulder, Colo. At each facility, the GPS data are organized into various types of formatted files (RINEX, Hatanaka, etc.) for public distribution. People may freely access these data files and related metadata either via anonymous file transfer protocol (ftp://www.ngs.noaa.gov/cors/) or via the World Wide Web (http://www.ngs.noaa.gov/CORS/). In January 2000, NGS introduced a new interface to the CORS web site. This new interface is known as CORSAGE (CORS Amiable Geographic Environment) because it enables people to access CORS data and metadata through a series of geographic maps. The CORS homepage itself features an index map in which the total area of CORS coverage has been partitioned into several color-coded regions, each usually involving a few states. On a regional map, a user can click his/her mouse on the map symbol representing a particular CORS site to obtain a window containing a local map that pinpoints this site's location relative to nearby population centers, major roads, and other geographic features. A menu appears to the left of the local map which enables users to view/download particular information about this site, for example, a file containing the site's positional coordinates and velocity. Another item on this menu enables users to view a calendar displaying—with 10-min resolution—the time span when CORS data are available for this site. Inspecting such calendars can save users from downloading and processing files that contain undesirable data gaps. Other menu items provide access to the site's GPS data and to files containing certain descriptive information about this site (type of GPS equipment, responsible institution, contact person, history of receiver and antenna replacements, etc.). Access to CORS information using a geographic Google interface has recently been added.

UFCORS

In November 1998, NGS introduced the “user-friendly” CORS (UFCORS) information server that enables users to request and receive GPS data and associated metadata (satellite ephemeris and station-specific descriptive information) for stations in the CORS network via the World Wide Web. UFCORS provides a convenient alternative to both the anonymous FTP information server and the Web-based “standard” CORS information server for retrieving CORS information. UFCORS allows a user to select a comprehensive package of information for a particular station and a particular time interval. Anonymous FTP and the standard CORS information server provide the information only in the format that is stored at NGS, whereas UFCORS can repackage the information into any of several different formats. For example, with UFCORS a person can download GPS data files for any discretionary number of hours ($\leq$24). Also UFCORS allows users to select how the requested data files should be compressed. UFCORS also can interpolate GPS data to sampling rates, other than the standard 30-s rate. Finally, UFCORS can decimate archived CORS data of one sampling rate to a user specified sampling rate of greater value. Anonymous FTP remains the most popular CORS information server in terms of data volume. More than 581 gigabytes of CORS data were distributed via anonymous FTP in April 2008 (Fig. 3(a)), whereas UFCORS distributed about 66 Gbytes in April 2008 (Fig. 3(b)). Anonymous FTP is the server of choice among users that download GPS data from many CORS sites on a regular basis. Users who download CORS data only occasionally or only from a few stations prefer to use UFCORS.



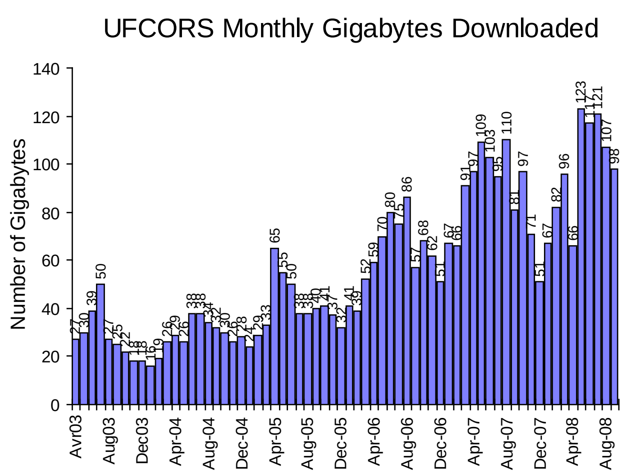


Figure 3. Monthly volumes of CORS data downloaded (a) using FTP; (b) using UFCORS

CORS Applications

In addition to the primary application of CORS, to enable accurate positioning relative to the NSRS, CORS has been pivotal in advancing other, well documented, multidisciplinary investigations. The scientific literature is flooded with articles citing CORS as the basis for their experiments and/or research projects. The realm of applications is diverse and multifaceted and it is expected that this trend will continue in the future. CORS has already made an impact on solid Earth science and is on the fringe of significantly impacting atmospheric science. In the following sections, we describe a few areas where the use of CORS data was significant in advancing scientific knowledge.

Upgrading the NSRS

NGS recently completed an adjustment involving GPS data observed at ~70,000 geodetic marks during the past 20 years. This adjustment termed NAD 83 (NSRS2007) held fixed the published NAD 83 (CORS96) 3D positional coordinates of the CORS sites, to obtain a solution whose coordinates are consistent with the NAD 83 (CORS96) frame. Once more, the CORS network fulfills its primary mission of implementing the NSRS. Thus, because of the procedure followed Vorhauer 2007) these ~70,000 geodetic marks now have positional coordinates that are compatible with the NAD 83 (CORS96) reference frame.

Assessing GPS Observational Accuracies

The availability of continuous GPS data from stations well distributed throughout the United States makes it possible to design experiments aimed to answer many questions related to GPS methodologies now in vogue and to expand our understanding of scientific phenomena. Eckl et al. (2001) and Snay et al. (2002a) studied the accuracy of GPS-derived relative positions as a function of interstation distance and observing-session duration using data from 19 CORS sites. Eleven baselines connecting pairs of these 19 sites were formed with lengths ranging from 26 to 300 km. GPS data for each baseline was partitioned into 10 nonoverlapping 24-h sessions. These same data were also subdivided into 20 nonoverlapping 12-h sessions, 30 nonoverlapping 8-h sessions, 40 nonoverlapping 6-h sessions and, finally, 60 nonoverlapping 4-h sessions. The results of this investigation empirically demonstrated that the dependence of accuracy on baseline length is negligibly small, whereas the dependence on the duration time of the observing session obeys the following simple mnemonic rule when the observing time spans 4 h or longer:

$$RMSE = k / \sqrt{T} \qquad (1)$$

where k = 1.0 in each horizontal dimension (north and east) and k = 3.7in the vertical dimension.

In Eq. (1), the root mean square error (RMSE) is given in centimeters when T denotes the duration of the observation session in hours and k is a constant (cm√h). Soler et al. (2006b) reached similar conclusions for data sets having durations of 2, 3, and 4 h. Experiments involving 1-h data sets suffered from an inability to reliably determine the integer values of the carrier phase ambiguities caused by the nonaveraging atmospheric conditions at the control stations. Preliminary results, however, demonstrate that OPUS-RS can produce accurate positional coordinates for observing sessions as short as 15 min in duration by interpolating atmospheric conditions measured at CORS sites to the location where the OPUS-RS user collected his/her GPS data.

Multipath Studies

For GPS antennas, multipath errors are caused by the interference of signals that have reached the receiver antenna by two or more different paths, usually caused by one path being bounced or reflected from the ground or nearby surfaces (buildings, fences, etc.). The understanding of multipath effects is important to decipher the systematic errors associated with a particular station and antenna and the possibility to correct for them. Hilla and Cline (2004) conducted an investigation to evaluate the amount of multipath occurring at each of 390+ sites contained in the National CORS network. This study identified the most and least affected sites in the network, compared different receiver/antenna combinations, and investigated closely those sites that appeared to be severely affected by multipath. Dual-frequency carrier phase and pseudorange measurements were used to estimate the amount of L1 and L2 pseudorange multipath at each site over a one-year period. A similar study (Park et al. 2004) combining CORS and IGS sites also found that the postfit phase residuals were highly dependent on the GPS antenna type. This investigation concluded that antenna types with choke rings are very effective in suppressing multipath and that multipath is highly dependent on the unique environment at each site.

Crustal Motion

Crustal motion monitoring is perhaps one of the most obvious of all CORS applications. If CORS data are rigorously processed and analyzed during a period of several years, then the motion of the Earth's crust can be determined wherever the CORS network provides sufficient coverage.

Gan and Prescott (2001) analyzed GPS data observed between 1996 and 2000 for 62 CORS sites distributed throughout the central and eastern United States. Their results suggest that no significant horizontal crustal motion occurred during this time period in this part of the country, except possibly in the lower Mississippi River Valley. This particular area appears to be moving southward relative to the rest of the continent at an average rate of 1.7$\pm$0.9 mm/ year. Although this rate is not statistically significant at the 95% confidence level, the fact that the motion occurs near New Madrid, Mo.—where earthquake risk is thought to be high—argues that the motion may be real.

Sella et al. (2002) applied GPS data from the CORS network, together with data from a worldwide distribution of stations, to produce a global "recent velocity" (REVEL) model that quantifies the motions of 19 tectonic plates and continental blocks during the 1993–2000 time interval.

Park et al. (2002) used data from 60 CORS sites to estimate the upper and lower mantle viscosity by comparing radial site velocities with velocities inferred from glacial isostatic adjustment (GIA) models. In addition, their GPS-derived velocities are consistent with previous estimates obtained using different methods and data over different time spans.

Recently, the deformation occurring within the North American plate interior was estimated using 10 years of GPS data from the CORS network processed using both the GIPSY and GAMIT software packages (Calais et al. 2006). These authors analyzed data from about 300 CORS stations covering the central and eastern United States. The investigation indicates that the velocity field is described within uncertainties by a simple rigid plate rotation that is distorted in some areas by a deformation pattern consistent with GIA. Similarly, using CORS sites and episodic GPS data in Canada and the United States, Sella et al. (2007) show that the strongest signal within the nominally stable interior of the North American plate is the effect of GIA due to mass unloading during deglaciation. On a more local scale, Dokka et al. (2006) used GPS data from CORS sites to infer that southeast Louisiana, including New Orleans and the larger Mississippi Delta, are both subsiding vertically and moving southward with respect to the interior of the North American plate.

Sea Level Changes

The variations of vertical crustal velocities at CORS sites near tide gauge stations may be used to determine the "absolute" sea level change with respect to the International Terrestrial Reference Frame. This type of analysis was impossible to conduct before the proliferation of CORS in coastal areas. Recently, a study by Snay et al. (2007) involving 37 tide gauge stations, distributed along the U.S. and Canadian coasts, such that each is located within 40 km of a CORS site, determined rigorously the crustal velocity near tide gauge stations from GPS observations spanning between 3 and 11 years. After calibrating historical tidal data with these derived crustal velocities, the results show that the mean rate of absolute sea level change equals 1.80$\pm$0.18 mm/ year for the 1900–1999 interval. The same investigation determined the absolute rate of sea level change equals −1.19$\pm$0.70 mm/ year along the southern Alaskan coastline. This lowering of absolute sea level near southern Alaska is probably due to ongoing melting of mountain glaciers and ice masses. With time, more CORS data will become available near tide gauges to conduct investigations able to accurately estimate vertical crustal velocities and thereby absolute sea level rates with greater certainty.

Tropospheric Studies

The delay of GPS signals, which is caused by the refractivity of the troposphere or electrically neutral atmosphere, is associated with temperature, pressure, and the distribution of water vapor up to a height of about 16 km. If the atmospheric pressure is known with reasonable accuracy at the elevation of the GPS antenna, then the total "wet" and "dry" delay at the site can be effectively separated with little error. Mapping the resulting wet signal delay into the integrated (total column) precipitable water vapor (IPW) is accomplished in a straightforward manner if the mean vapor-weighted temperature of the atmosphere is known. Water vapor is one of the most important constituents of the Earth's atmosphere. It is the source of clouds and precipitation, and an ingredient in most major weather events. IPW varies greatly over the planet: ~5 mm near the poles and ~50 mm near the equator. Most (~95%) of the water in the atmosphere resides below 5 km (or essentially below the 500 hPa pressure surface). Significant changes in the vertical and horizontal distribution of water vapor can occur rapidly _minutes to hours_ during active weather.

NOAA's Earth Systems Research Laboratory (ESRL), formerly called NOAA's Forecast Systems Laboratory, has developed the capability to estimate the spatial and temporal variation of tropospheric delay within the contiguous United States (CONUS) (Gutman et al. 2004). Their prediction process is based on modeling the delay using GPS observations from the CORS network in combination with other meteorological data. They update their model every hour. It is possible to use CORS sites to estimate the tropospheric signal delay at each station with high accuracy because of stringent instrument requirements for high accuracy GPS positioning. Data from a network of approximately 385 CORS sites are assimilated hourly into the operational version of the rapid update cycle (RUC) numerical weather prediction model which refers the results to a two-dimensional (2D) horizontal grid having a 13-km nodal spacing.

The Global Systems Division of NOAA's ESRL has developed NOAATrop, a new way to improve GPS positioning, navigation and timing accuracy using real-time weather data at CORS sites (Gutman et al. 2004). NOAATrop is available for download at ftp://aftp.fsl.noaa.gov/gpsmet/zwdgrids/. This information provides zenith wet delay and ALT (a proxy for zenith hydrostatic delay) for a 2D grid with 13-km resolution over the CONUS. NOAATrop is based on RUC, an operational model that is updated hourly. The root mean square accuracy of the modeled delays is currently ~2 cm in cold seasons and ~4 cm in warm seasons.

Ionospheric Studies

Wide area ionospheric models have been developed to model and mitigate local ionospheric effects. Such models are based on dual frequency observations from a subset of the CORS network. The ionosphere is a dispersive medium located in the region of the upper atmosphere that begins at an altitude of around 50 km and extends upwards several hundred kilometers. The radiation from the Sun and particles precipitating from the magnetosphere produces free electrons and ions that cause phase advances and group delays in radio waves. The state of the ionosphere is a function of the intensity of solar and magnetic activity, position on the Earth, local time and other factors. As GPS signals traverse the ionosphere, they are delayed by an amount proportional to the total electron content (TEC) within the ionosphere at a given time. Daily maps showing the estimation of TEC over the CONUS based on CORS data from about 180 stations have been produced at NGS and distributed through the Internet since 1997 (Musman et al. 1997).

Recently NOAA's Space Weather Prediction Center (SWPC) began modeling TEC in 3D for CONUS using CORS data (Fuller-Rowell et al. 2006). This model is updated every 15 min with a latency of 30 min (http://www.swpc.noaa.gov/ustec/). This product is designed to quantify TEC over CONUS in near real time and has evolved through collaboration between the SWPC, NGS, ESRL, and NOAA's National Geophysical Data Center.

Data from the CORS network have been used in studies of large-scale ionospheric disturbances caused by geomagnetic storms on a continental scale (Tsugawa et al. 2003). Investigations to correct for ionospheric effects in local CORS networks (e.g., Ohio State) established for real-time kinematics (RTK) applications have proliferated lately with the deployment of state-operated CORS networks (Wielgoz et al. 2005a,b; Grejner-Brzezinska et al. 2007). GPS data from CORS sites have been used to test ionospheric models aimed to improve long baseline differential GPS positioning of rovers using only L1 data (Mohino et al. 2007). Finally, Smith (2004) experimentally introduced an interesting alternative approach to compute absolute (unambiguous) TEC values relying only on dual frequency ambiguous carrier phase data from the CORS network, though the approach was only a research prototype.

Geolocation of Aerial Moving Platforms

Data available from CORS sites has been used in many remote sensing applications. The accurate positioning of aircrafts employed in aerial mapping is crucial to improve the reliability of photogrammetric restitution primarily for large-scale aerial survey applications over remote or inaccessible terrain. The same concepts implemented for geolocating landmarks from the air with digital cameras has been extended to a broad array of mapping terrain applications using cutting edge technologies such as scanning radar, light detection and ranging (LiDAR), inertial systems, interferometric synthetic aperture radar, and/or sonar. The use of CORS data in airborne mapping processes has proven to provide a significant alternative (Mostafa 2005). The utility of CORS sites in differential GPS aircraft positioning was investigated by Booth and Lunde (2003) showing that very accurate carrier phase differential results can be obtained using much longer baselines than originally thought. The aerial mapping community will certainly benefit from the growing number of CORS sites. Perhaps, the decisive factor in all these applications is the accessibility to GPS data at a 1-s sampling rate instead of the standard of 30-s sampling rate. NGS has cooperated with federal, state, and private institutions to schedule ahead of time changes at specified CORS sites to the 1-s sampling rate. This facilitates the postprocessing of airborne GPS data to accurately estimate the position of a plethora of aerial moving platforms. For example, NGS's Remote Sensing Division obtains aerial imagery to assess hurricane damage. These missions are well served by CORS data, collected at a 1-s sampling rate, to accurately determine the travel path of the aircraft being used to collect aerial imagery. NGS personnel worked closely with their CORS partners to temporarily increase data sampling rates after the hurricanes of 2005. The imagery of areas affected by individual hurricanes is available at www.ngs.noaa.gov.

On the CORS Horizon

In December 2006, NGS installed a new CORS near the tide gauge station located in Key West, Fla. This CORS will help relate local sea level change at Key West to the globally consistent, rigorously defined International Terrestrial Reference Frame. Indeed, NGS plans to install a CORS at each of several additional tide gauge stations contained in the U.S. National Water Level Observation Network (NWLON). Established in 1913, the Key West tide gauge station is one of the longest continually operational stations contained in the NWLON.

The new CORS at Key West is also significant because it is the first CORS, installed by NGS, which collects both GPS and GLONASS data. A number of CORS partners have begun upgrading stations to collect both GPS and GLONASS data, and NGS will soon begin distributing such GNSS data to CORS users.

Additionally, several CORS are streaming GPS data in real time to NGS headquarters in Silver Spring, Md. NGS will broadcast these data to the public in real time to support the growth of regional GNSS networks that enable real-time positioning in the United States. In response to user demands, more than 40 organizations, both public and private, are now establishing such regional GNSS networks. Also, many more of these regional real-time positioning networks are expected to be established in the near future. NGS needs to support these networks by developing appropriate standards and guidelines so that:

• Promulgated positional coordinates and velocities for the corresponding GNSS base stations are compatible with the NSRS;
• User equipment can operate with services from different real-time GNSS networks to the greatest extent possible; and
• Stations contained in each real-time network meet prescribed criteria in terms of stability and data quality.

Accordingly, NGS is considering the possibility of streaming GNSS data from about 200 federally funded CORS so that this agency may understand the intricacies involved in operating a real-time GNSS network to the extent necessary to develop appropriate standards and guidelines.

NGS encourages the institutions, who are providing real-time positioning services, to use the NGS-provided data in their operations so as to (1) supplement the data from other GNSS base stations, and (2) use the positional coordinates and velocities of the GNSS stations contained in the NGS real-time network as fiducial values for determining positional coordinates and velocities of other real-time GNSS stations.

Also, NGS is planning to stream these data because U.S. citizens should have real-time access to data from federally funded stations in the CORS network whenever it is economically and technically feasible to do so. It is important to emphasize that NGS intends to stream only the GNSS observables and *not* "correctors" to these observables. Also, NGS does not intend to stream GNSS data that are already being streamed by another organization. In all likelihood, NGS will use NTRIP (networked transport of RTCM standard via internet protocol) to broadcast the stream of GNSS observables over the Internet.

Conclusions

The intent of this paper was to summarize the history, applications, and future prospects of the CORS network by describing the more important contributions of the CORS system to the scientific community. Many surveying engineers, geodesists, mapping specialists, as well as scientists from different backgrounds, are using CORS on a daily basis by downloading GPS data through UFCORS and anonymous FTP, and then postprocessing these data for a variety of applications. The CORS network has contributed significantly to geodetic positioning by providing easy and accurate access to the NSRS. The CORS network should also be recognized for supporting the research of numerous scientific investigators. Finally, the CORS network serves as the primary data source for all types of OPUS solutions.

Acknowledgments

This paper is dedicated to Bill Strange, the "Father of CORS." Bill's vision and impetus when he served as NGS's Chief Geodesist provided the inspiration that shaped the early days of the CORS program. Although initially designed to support geodetic activities, the CORS program has contributed to several additional scientific applications. Other important contributors from NGS include, in alphabetical order: Gordon Adams, Donna Amoroso, Nancy Brantner, Hong Chen, Miranda Chin, Michael Cline, Cindy Craig, Dave Crump,William Dillinger, Dave Doyle, Nancy Doyle, Jim Drosdak, Robert Dulaney, Mark Eckl, Joseph Evjen, Richard Foote, Steve Frakes, Don Haw, Steve Hilla, Michelle Ho, Toni Hollingsworth, Ying Jin, William Kass, Gerald Mader, Richard Male, Ernie Marion, Frank Mowry, Linda Nussear, Julie Prusky, Jim Ray, Jim Rohde, Bruce Sailer, Donna Sailer, Mark Schenewerk, Charles Schwarz, Giovanni Sella, Dru Smith, Paul Spofford, Lijuan Sun, Vicki Veilleux, and Neil Weston. Their continuous striving for perfection has been exemplary. Finally, the success of the CORS program is due to contributions from more than 200 organizations, with each organization operating at least one CORS. For a current list of these organizations, please see the CORS Newsletter at www.ngs.noaa.gov/CORS/. Comments on the draft made by John Hamilton and two anonymous reviewers are greatly appreciated.

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ANNEX B

CORS West Project Plan:

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

FY2004—FY2009

1. CORS Program Background

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

1.2. The CORS network currently (September 2008) consists of approximately 1,250 stations and is growing at a rate of about 200 stations per year. These stations are operated by a collection of more than 200 organizations representing various foreign, federal, state, and local government agencies, as well as various academic and commercial institutions.

1.3. The primary CORS operations facility is maintained by and located within NGS in Silver Spring, Maryland. At NGS's request, NOAA's National Geophysical Data Center (NGDC) hosts a parallel CORS operations facility in Boulder, Colorado. This facility is co-managed by NGS and NGDC. The Boulder CORS facility is referred to herein as CORS-West. The existence of a parallel CORS operation facility, located several hundred miles from the primary CORS operation facility, is a fundamental element of NOAA's continuity of operation plan (COOP) for the CORS program.

2. CORS-West Program Objectives

2.1. The following are the CORS-West program objectives to be addressed by NGDC:

a. Host and co-manage the CORS-West facility including the collection, processing, storage and distribution of CORS data in parallel with the primary CORS data facility. Provide uninterrupted operations of essential CORS capabilities during brief or sustained periods when the primary CORS facility is unavailable. Share the work of distributing CORS data with the primary facility when both locations are fully operational,
b. Review CORS data management procedures,
c. Review data collection, processing, storage and distribution procedures for CORS functions. Suggest updates and modifications to these procedures as deemed appropriate. Develop strategies to create, operate, maintain and manage the archival functions for CORS data. Jointly pursue with NGS new product developments as needed,

d. Enable those NOAA offices located in Boulder (NOAA's Space Weather Prediction Center (SWPC), NOAA's Environmental Systems Research Laboratory (ESRL), etc.) which have stringent requirements for CORS data to obtain these data locally, (per the current MOU among NGS, ESRL, SWPC and NGDC)
e. Host and help maintain a replication of the NGS Integrated Database (NGSIDB) in Boulder. 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, is lost. The NGSIDB contains information pertinent to the CORS program and all other major NGS activities.
f. Provide NGS with an annual report on the status of CORS West.

3. CORS-West Major Activities

3.1 The following are the major activities needed to sustain CORS-West capabilities. These activities are prioritized from most essential to less essential:

a. Provide network and system administration support for the CORS computers and Cisco network equipment located in Boulder,
b. Collect, process, store and distribute CORS data in parallel with the primary CORS data facility,
c. Sustain operation of essential CORS activities for NGS COOP requirements,
d. Share the work of distributing CORS data,
e. Review CORS data collection, processing, storage and distribution procedures,
f. In conjunction with NGS, develop, operate, maintain and manage the archival functions for CORS data,
g. Enable NOAA offices that have a requirement for timely CORS data to obtain these data locally,
h. Host and help maintain a replication of the NGS Integrated Database (NGSIDB) in Boulder.

4. CORS-West Previous FY Milestones

4.1. The following is a list of CORS-West previous FY milestones with current status:

a. Establish methods to monitor and manage the CORS data collection activities at the Boulder site. **Completed**,
b. Make the FTP server operational in Boulder and begin distributing data collected there. **Completed**,
c. Fully populate the storage array and make operational via the Boulder FTP server. **Completed**,
d. Provide programming support for CORS data collection, analysis, online storage, and distribution. **Completed**,
e. Implement at CORS-West the collection of GNSS data for active CORS on an hourly or daily basis and in a manner that is identical of the operations of CORS-East. **Completed**,
f. Ensured that the CORS-West staff has the ability to fully run all data management scripts and can identify basic problems with data collection. **Completed**.

5. CORS-West FY09 Milestones

5.1. This section includes the list of FY09 milestones for CORS-West. Achieving these milestones requires a collaboration between personnel at CORS-East and CORS-West. Successful completion of a milestone is at the discretion of the CORS program manager. The following is the list of new FY09 milestones for CORS-West:

a. Complete development of the new CORS data collection software referred to as the Internet Collector,
b. Validate the new Internet Collector at CORS-West.
c. Create a web-server at CORS-West to facilitate the implementation of the following web utilities at CORS-West: the "user-friendly" CORS (UFCORS) , the Online Positioning User Service-Static (OPUS-S), and the OPUS-RS (Rapid Static),
d. Assist NGS in implementing UFCORS, OPUS-S and OPUS-RS at CORS-West,
e. Assist NGS to replicate the NGS Integrated database (NGSIDB) and TESTIDB2 at CORS-West; i.e. complete Submission Agreement.
f. Define and design a data archive system and procedure for handling all National CORS data; i.e. execute Submission Agreement.
g. Implement a data archive system and procedure for handling all National CORS data.

6. Provisions/Limitations:

6.1. Any activities undertaken by the parties pursuant to this Document are subject to the availability of appropriate funds and proper authorization.

6.2. 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.

6.3. 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.

7. CORS-West Project Funding for FY09 with Outyear Estimates

7.1. To accomplish the CORS-West program objectives (Section 2), CORS-West Major Activities (Section 3) and CORS-West FY09 Milestones (Section 5), NGS will provide to NGDC funding in the amount of $275,000 in FY09.

7.2. A detailed fiscal/manpower breakout for FY09 is provided in the following table:

		FTE	**Total Cost ($)**	
	Joynt	.50	$95,605	Systems administrator
	Coloma	1.00	$73,750	CORS-West data manager
	Denig*	.14	$37,768	CORS-West program manager
	Prentice	.30	$43,415	Software engineer
	Travel		2,462	Approved travel
	NGDC Other (8%)		22,000	Budget, secretary, metadata
	Total		**275,000**	

7.3. The following table provides a fiscal overview for the CORS-West program, FY04-2011. The funding and manpower loading for FY04-08 are the actuals. The FY09 amount is the planned execution budget for the current year. The FY10-11 costs are estimates provided for planning purposes only:

Fiscal Year	2004	2005	2006	2007	2008	2009	2010	2011
Federal FTE	*0.5*	*0.5*	*0.70*	*.35*	*0.15*	*0.15*	*1.15*	*1.15*
Other FTE	*0.5*	*1.0*	*1.30*	*1.65*	*1.80*	*2.00*	*1.00*	*1.00*
Funding	*$136 K*	*$187 K*	*$240 K*	*$250 K*	*$265 K*	*$275 K*	*$286 K*	*$298 K*

Approved:

Mr. David Zilkoski
Director, NGS

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Date: ____________________________

Dr. Christopher G. Fox
Director, NGDC

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Date: ____________________________

ANNEX C

Report on the

9th Annual CORS User Forum

Savannah, Georgia
September 22, 2009

NOAA's National Geodetic Survey (NGS)—in cooperation with the U.S. Department of Transportation and the U.S. Coast Guard—convened the 9th annual Continuously Operating Reference Station (CORS) Users Forum on September 22, 2009 in Savannah, Georgia. The Forum was an integral part of the Civil GPS Service Interface Committee (CGSIC) meeting, September 21-22, 2009. Additionally, the Institute of Navigation's Global Navigation Satellite System (GNSS) Conference convened from September 22-25, 2009 in Savannah.

The CORS network is comprised of numerous subnetworks operated by about 200 organizations. Collectively, these networks include approximately 1,370 sites—each containing a geodetic quality, dual-frequency GPS receiver. The CORS network is growing at a rate of about 200 sites per year – many with updated GNSS capabilities, such as receiving GLONASS observables. 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 development, remote sensing, weather forecasting, satellite tracking and geophysics.

The Forum is designed to provide users with the latest information about CORS, its partners, its tools, and its support for real-time positioning, while hearing from these users about their experiences and what NGS can do to improve its products and services.

This year's Forum featured a panel of speakers discussing the guidelines being prepared to help real-time GNSS network (RTN) operators, as well as those using RTN positioning services. A team of more than 60 people are involved in developing these guidelines, including current RTN administrators (both public and private), representatives from several GNSS manufacturers, and NGS employees. NGS plans to provide a draft of these guidelines for public review in early 2010.

Agenda

1:30 **Welcome –** Richard Snay, NOAA's National Geodetic Survey

1:35 **CORS/OPUS: Overview and Status –** Giovanni Sella, NOAA's National Geodetic Survey

1:50 **PANEL SESSION**: **Guidelines for Real-Time GNSS Networks (RTN)**

A. **Site Considerations** - Dan Martin, NOAA's National Geodetic Survey
B. **Planning & Design** - Gavin Schrock, Washington State Reference Network
C. **Administration -** Gary Thompson, North Carolina Geodetic Survey
D. **Best Methods for Users -** Bill Henning, NOAA's National Geodetic Survey

3:05 **Question & Answer Session with Speakers**

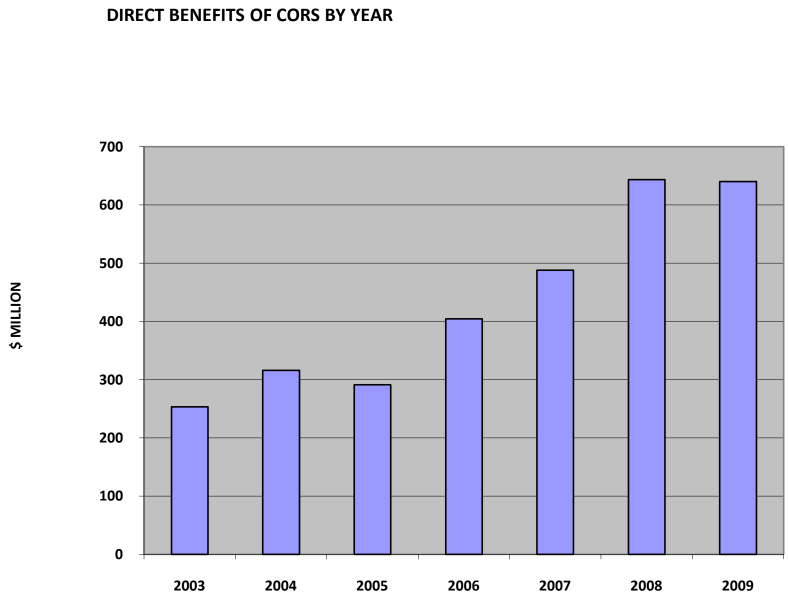
3:50 **Interactive Sessions within Small Discussion Groups**

Group 1. CORS/OPUS
Group 2. RTN Site Considerations and RTN Planning & Design
Group 3. RTN Administration and RTN Best Practices for Users

5:00 **End of Forum**

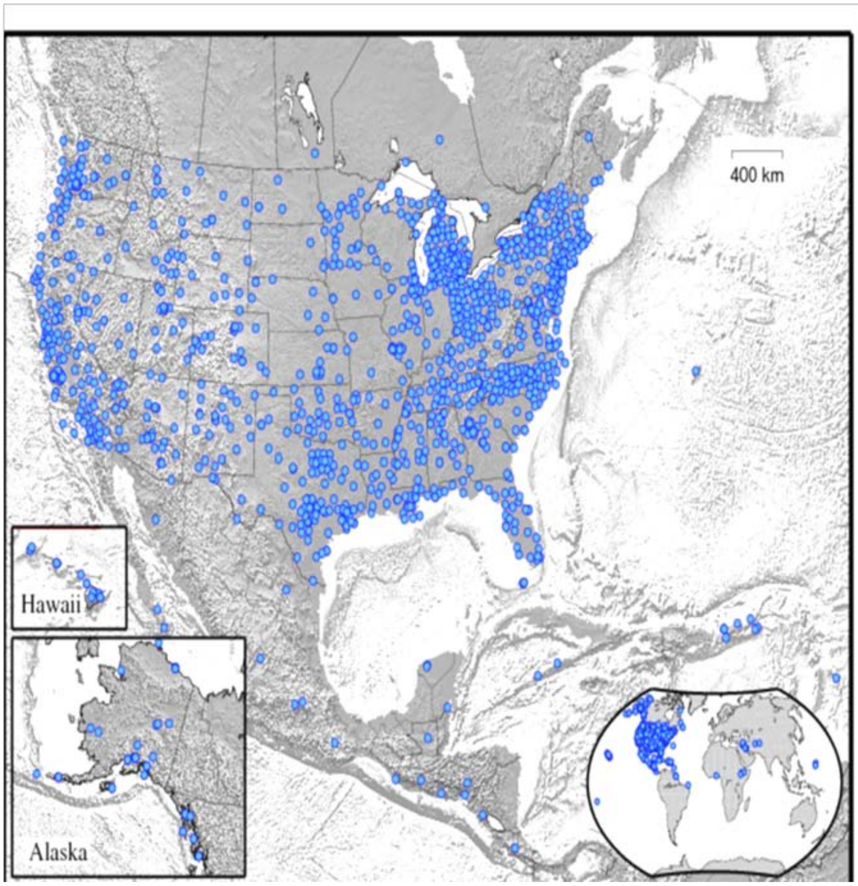
PowerPoint files for the formal presentations may be viewed and/or downloaded at: http://www.ngs.noaa.gov/CORS/CorsPP/PPT.html

Richard Snay of NGS presented the following graph during his welcoming remarks:



Snay also described a recent study to estimate the socio-economic benefits of both the CORS program and the Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project. According to this study, conducted by Leveson Consulting of Jackson, New Jersey, the annual benefits (both direct and indirect benefits) of the CORS program equals $758 million. Details of the study are available at www.ngs.noaa.gov.

Giovanni Sella (NGS), the CORS Program Manager, reported that NGS added 180 new stations to the CORS network during the past year, including new sites in Iraq, Afghanistan and Benin. NGS also merged the National CORS network and the Cooperative CORS network into a single network in 2009. As a result of the merger, users may now obtain data from former Cooperative CORS sites in the same manner they obtain data from National CORS sites from either of the two parallel CORS data facilities—one located in Silver Spring, Maryland and the other in Boulder, Colorado. NGS, moreover, recently enhanced the OPUS utility so that its users now have the option to archive their OPUS-generated coordinates at NGS—together with such other information as a photo and a description of where the corresponding observations were collected. Thus, OPUS now allows its users to share their survey results with others. During 2010, NGS will publish positional coordinates and velocities for all CORS in the soon-to-be-released International Terrestrial Reference Frame of 2008 (ITRF2008), as well as in a new realization of the North American Datum of 1983 (NAD 83). NGS also plans to begin distributing GLONASS data from selected CORS and to start generating precise orbits for the GLONASS satellites within the next 12 months. NGS, moreover, is developing the OPUS-Projects utility that will rigorously process and adjust GPS data collected at multiple locations, using one or more receivers, and during one or more observing sessions.

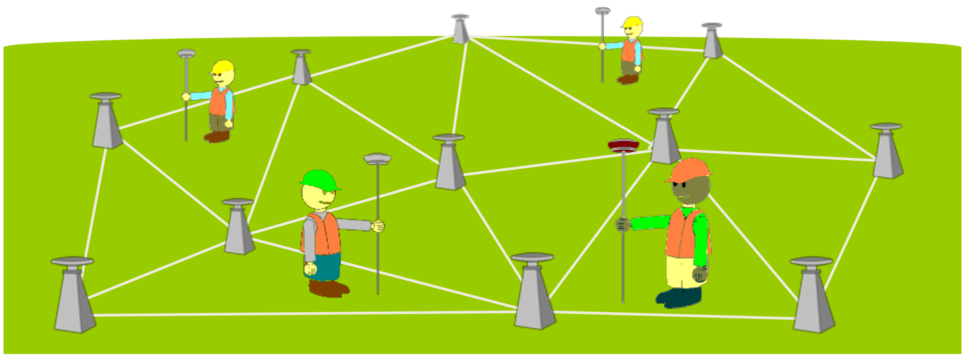


Dan Martin of NGS discussed various topics relating to the construction of RTN sites, including different options for mounting the GPS antenna. The following photo shows an antenna mounted on the corner of a building.

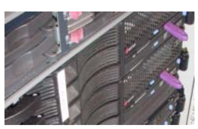
Gavin Schrock, administrator of the Washington State Reference Network, discussed various considerations involved in planning and designing a RTN.

Planning & Design

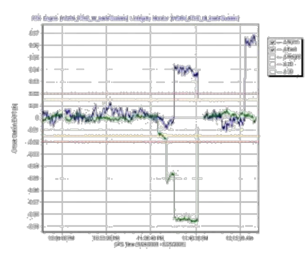
- Pre-Planning
- Spacing
- Processing Center



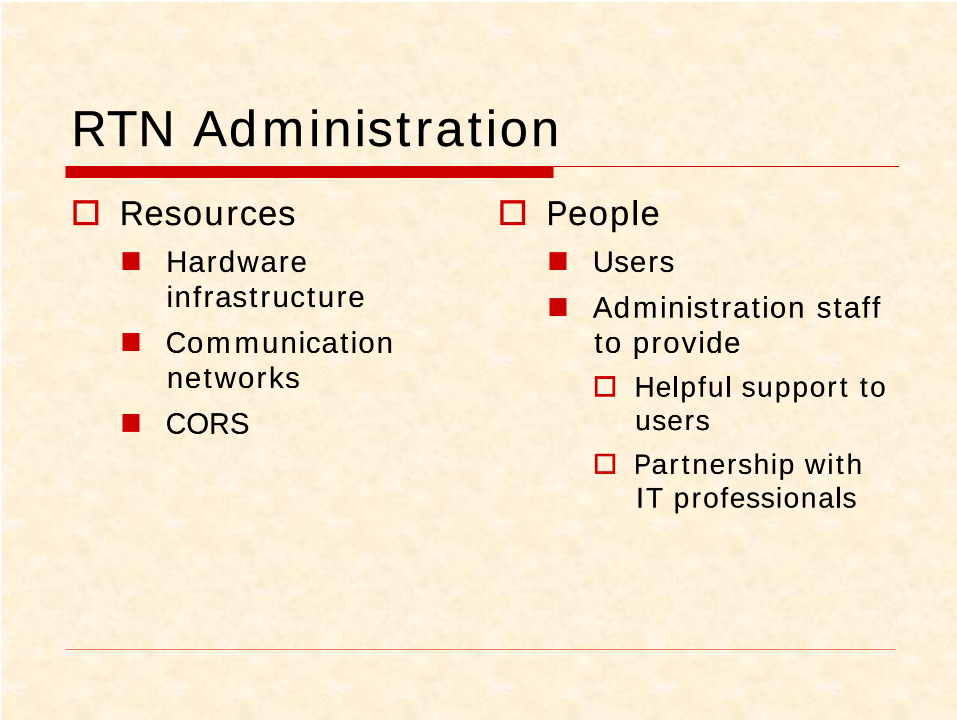
Processing Center

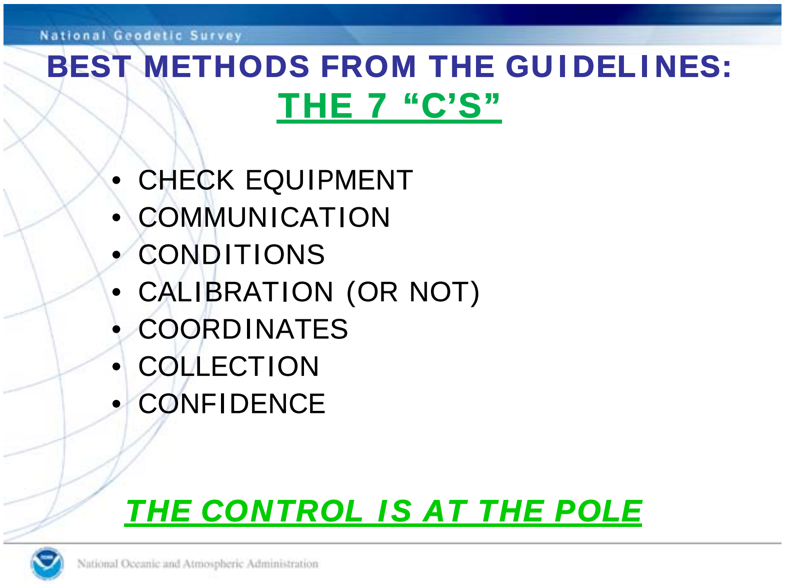
- Central Processing Center (CPC)
  - Host and Host Site
  - Servers and Arrays
  - Power & Environment
  - Archiving
- Communications
  - CORS to CPC
  - CPC to End-User
  - Redundancy
- Design for Operational Levels
  - Minimal (Tool Style)
  - Full (Utility Style)
- Maintenance and Support
- Network Integrity Monitoring



Gary Thompson, Director of the North Carolina Geodetic Survey, discussed the issues involved in the administration of an RTN.



William (Bill) Henning of NGS discussed best methods for RTN users. These methods build upon the guidelines for single-base RTK (real-time kinematic) users. These guidelines may be viewed and/or downloaded at:
http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.0.4.pdf



Question & Answer Session

The following notes were taken during the Question and Answer session.

Question [Irving Leveson, Leveson Consulting, New Jersey]: What happens after the Real-Time Network Guidelines come out? Will there be a push for mass education?

> William "Bill" Henning, NGS: There is no formal plan. Once the RTN guidelines are posted, we will invite public comment. NGS will be at venues such as the American Congress on Surveying and Mapping (ACSM), International Federation of Surveyors (FIG), and the Federal Geographic Data Committee's (FGDC) Federal Geodetic Control Subcommittee (FGCS) and will announce/receive questions regarding the RTN guidelines at these venues.

Question [Irv Leveson]: Will the RTN guideline have a dedicated help desk?

> Bill Henning: No, we do not have the resources. Any questions may be directed to the existing help desk.
>
> Richard Snay, NGS: NGS is investigating the possibility of hiring a person to assist Bill Henning.

Question [Lonnie Sears from eGPS Solutions, Georgia]: At the 2008 CORS User Forum, there was a discussion about "Interpolative Dilution of Precision" (IDOP). Has there been progress on this?

> Richard Snay: IDOP measures the geometric strength of the CORS network in a pre-specified neighborhood of a point. Charles Schwartz, Tomás Soler, and I published a scientific paper "Accuracy Assessment of the National Geodetic Survey's OPUS-RS Utility" in a recent issue of *GPS Solutions*. In the paper, we define IDOP and describe how to compute its value at a geographic location.

Question [Lonnie Sears]: Does the IDOP concept apply to RTN geometry?

> Richard Snay: Yes, the IDOP concept can be used to measure the geometric strength of the stations forming an RTN, to the extent correctors are computed via two-dimensional linear interpolation on the Earth's surface.

Question [Jim Richardson, Nebraska State Advisor]: I'm trying to convince my colleagues to install reference stations for submission and inclusion in the CORS network. I would like to be able to examine the 60-day plots for "good" sites and then search station log files for metadata, such as antenna cable lengths, antenna model, monumentation, etc., with the plan to build new, similar sites matching the target time series.

> Giovanni Sella, NGS: One challenge is that the site logs may not be complete, because data providers do not submit information. <*Note:* recall that the CORS network is 98% volunteer>. A great number of stations do not have the data you mentioned (antenna cable length, etc.). You are not alone in wanting this, but we cannot provide data if we don't receive it from the provider.
>
> Richard Snay: <To reiterate the question> you are trying to use the 60-day plots as an indicator of how well a site is performing? You would like to know what metadata evidences a good site, versus a bad site setup?

Question [Jim Richardson]: As the site requirements become more stringent, I'd like to know what setups have the best results.

> Richard Snay: So you would like to have someone perform a study on what makes a good site.
>
> Jim Richardson: Or a tool, say a "metadata monument tool."

Sidebar by Richard Snay: One controversial issue regarding site setups is that NGS CORS requirements prohibit installation of sites on any building with a metal roof. We realize many users have access only to facilities with metal roofs.

Question [James Stowell, Canary Inc., New Hampshire]: As a comment to Jim Richardson's request, wasn't there a study on the RMS scatter of 40-50 sites, where the sites were investigated as to how well they would track back to the "0-point" over a period of time?

Giovanni Sella: You are probably referring to the publication by Steve Hilla and Mike Cline, but that study quantified the multipath occurring at each site, not RMS scatter of daily solutions.

Richard Snay: Regarding repeatability, NGS is currently reprocessing GPS data collected as far back as 1994 for **all** CORS; a plot of the time series of weekly coordinates will be created for each CORS. It may be good to study the quality and repeatability (once the reprocessing is completed).

Question [Jim Richardson]: At this point, does NGS have vector processing software to validate the OPUS solutions—aside from using coordinates/vectors derived from other positioning services offered by other facilities (US and/or other countries)—for example, in the case of someone challenging the results output by OPUS? Will you then process the user-submitted data to a similar package, such as Bernese, Gipsy, etc., to compare with PAGES (the NGS processing software used by OPUS-S), to prove that the OPUS results are accurate?

Giovanni Sella: We are already doing that. Since NGS is an International GNSS Service (IGS) Analysis Center, we do separate processing for:

1. Rapid orbits
2. Final orbits

These are **separate** software packages. Also, during the transition of NGS becoming the IGS Analysis Center Coordinator, any issues discovered in the PAGES software were addressed at that time. In addition, NGS was the only IGS analysis center that correctly used the calibrations for GPS antennas covered by radomes. So, in answer to your question, we've compared the NGS software with Bernese, GFZ's processing software, Gipsy, GAMIT, etc., and we have addressed any discrepancies.

There are numerous online GPS processing services: JPL has "Auto-Gipsy"[1], the Australian government has "AUSPOS", the Canadian Geodetic Service has "CSRS-PPP", and SOPAC has "SCOUT."

Dan Martin, NGS: We can also compare the results using OPUS-S vs. OPUS-RS, as they are two completely separate software packages—OPUS-S uses PAGES, and OPUS-RS uses RSGPS. The metadata used are the same for both.

Richard Snay: We continuously compare PAGES results against other software.

Giovanni Sella: There may be discrepancies if the two software packages being compared do not use the same metadata file [i.e. station log data].

Question [Lonnie Sears,]: Will the new datum include the vertical?

Giovanni Sella: The new datum will be for the three-dimensional geometric reference system where the vertical component is represented by ellipsoid height. The orthometric height update will be under NGS' Gravity for the Redefinition of the American Vertical Datum GRAV-D program.

Question [Lonnie Sears]: When will Geoid '09 be released?

Giovanni Sella: The NGS Products & Services Committee (PSC) met last Thursday (9/17/09), and Geoid '09 should be available very soon.

David Doyle, NGS: The model should be available next week (week of 9/28/09).

Author's note: GEOID09 has been released for public use.

[1] note: Auto-Gipsy has been replaced on Aug 15, 2009 by "Automatic Precise Positioning Service (APPS)"

Question [Gavin Schrock, State of Washington Reference Network]: What is the status of modernizing NAD_83 (i.e. the modernization of the 3-D geometric reference system)?

Giovanni Sella: We are moving towards a geocentric 3-D geometric reference system. The current version of NAD_83 is ~2 meters off from geocenter. With WGS84, there was a transition to the geocentric. Some people will be happy with the transition to geocentric; others will not be happy. We must agree on a compromise. [What to call the new reference system is a problem because] the term "NAD_83" is prevalent in numerous legal documents and in various published government policy. Any decisions regarding the new reference system must be made with your [the GNSS community] input.

David Doyle: This transition is documented in the NGS 10-Year Plan. We are aware that moving to the new datum is a difficult and complex process. We will be soliciting input at venues held with FGDC, ACSM, and other working groups. The NGS state geodetic advisors will be assisting in education and outreach. As expected, the transition will not be painless. There will be a new datum, but the time frame for it is undetermined.

Question [Ross McKay, Kentucky State Advisor]: This is a follow-up question to the release of the RTN guidelines. What happens after the guidelines are published?

Bill Henning: NGS will develop and present new workshops to explain the new RTN guidelines.

Richard Snay: In May of this year (2009), NGS presented three webinars[2] via our Corbin Training Center. The webinars were successful and were remotely attended by approximately 200 participants. Webinars are a beneficial tool for educating those who cannot travel out of state.

Question [Eric Gakstatter, GPS World Magazine]: Is "OPUS-International" still an active project?

Giovanni Sella: Yes, the project is still active, but we have run into issues with the accuracy of the metadata at several reference stations located in other parts of the world. OPUS-International will have requirements similar to OPUS-S, but it will be globally accessible. The user data set must span a minimum of two hours, and the computed coordinates will only be expressed relative to the International Terrestrial Reference System; that is, coordinates will not be given in any local reference frame. Precision and accuracy of certain areas, such as the high north latitudes, low south latitudes, or mid-African continent, will be problematic.

CORS/OPUS Interactive Session

The following discussion was held among the participants in the interactive session on "CORS/OPUS." The participants included:

- Gerald "Gerry" Mader, NGS Geosciences Research Division
- Giovanni Sella, NGS CORS Program Manager
- Kevin Choi, NGS Spatial Reference System Division
- Irving Leveson, Leveson Consulting, New Jersey
- Dmitry Kolosov, Director of Software Division, Topcon Positioning Systems

[2] http://www.ngs.noaa.gov/corbin/calendar.shtml

- DeLane Meier, North Dakota Department of Transportation
- Francine Coloma, CIRES/University of Colorado (NGS CORS-West facility data manager)

Gerry Mader is the Chief of the Geosciences Research Division at NGS. Gerry provided an update on the forthcoming Web-based utility, OPUS-Projects.
Gerry Mader: We have Mark Schenewerk making good progress on OPUS-Projects. This tool is nearing completion, and it will be capable of generating plots. OPUS-Projects has a project-scheduling engine that allows users to create a schedule and assign values, such as personnel and equipment—similar to matching a person with a particular GPS receiver/antenna to go to a site. This tool can be updated to accommodate scheduling changes, and it also has the ability to pre-populate certain fields in the metadata page. Still in the discussion phase for OPUS-Projects is how to accommodate orthometric heights. There are several internal policy issues that need to be addressed, as well.

Question [Giovanni Sella to Dmitry Kolosov]: I have noticed that Topcon regularly retrieves large quantities of CORS data. Do you (Dmitry) know for which application Topcon is using this quantity of CORS data?
Dmitry Kolosov: I do not know about the usage you mentioned. I use CORS for comparison against my solutions from the Tennessee office.

Question [Dmitry Kolosov]: How is CORS to be used for real-time network (i.e. streaming)?
Giovanni Sella: NGS is currently streaming GPS data from eight NGS-owned sites. We have 30 sites capable of streaming data, but we are limited to the eight due to communications issues. Streaming in the RTCM 2.3 and 3.x formats is being tested, because they are commonly used formats, rather than in a vendor-specific format. We are aware other organizations are interested in having NGS stream their data, but we have a policy that we will not stream data from non-federal organizations. Also, NGS will not provide correctors, only the GNSS observables.
Dmitry Kolosov: Yes, I am aware that groups, such as Japan, stream in a vendor-specific format.

Question [Gerry Mader to Dmitry Kolosov]: Dmitry, how did your comparison between your (Topcon) software and OPUS turn out?
Dmitry Kolosov: About the same. I used 6 baselines, 50 - 110 km spacing, 10 days worth of data in 3-hr increments (80 pieces of data), for 80 independent processing solutions. I held three points fixed. I saw vertical RMS differences at 16 mm, while the maximum vertical difference is 18 mm.
Question [Gerry Mader to Dmitry Kolosov]: Do you have a tropospheric adjustment?
Dmitry Kolosov: Yes
Gerry Mader: For OPUS, we want only raw data, without adjustments for troposheric refraction, in order for it to process "clean." The biggest source of error in OPUS are the CORS positions themselves, so we use IGS as a fiducial network and compare it to CORS. CORS and IGS coordinates are both accurate for an epoch date of 1997.0; however, CORS coordinates becomes progressively worse for later epoch dates because CORS velocities are not known as accurately as IGS velocities. During comparison between the use of IGS and CORS coordinates, we select the three nearest CORS versus the three nearest IGS.
Dmitry Kolosov: It's possible that, by combining CORS with RTN and running an engine for precise orbits, you may have byproducts such as an ionospheric map or tropospheric model that may work well with RTK.

Giovanni Sella: Yes, groups like NOAA's Space Weather Prediction Center (SWPC) and NOAA's Earth Science Research Laboratory (ESRL) may provide some benefits to RTN services, if they would provide ionospheric and tropospheric models sooner. SWPC produces the US-Total Electron Content product every 15 minutes, while ESRL produces its GPS-Met model every 30 minutes. Internally to NOAA, both SWPC and ESRL receive low-latency data from certain sites in the CORS network. If SWPC or ESRL would like to add other streams, they themselves would need to subscribe to those particular streams. NGS is aware of, and is sensitive to, the concerns regarding our streaming of GPS data, by commercial vendors or the private sector that charge for such service.
Dmitry Kolosov: Many RTK networks, such as the one in Tennessee, could provide you with their data stream.
Giovanni Sella: <regarding Tennessee CORS sites> It would be good to receive hourly files from Tennessee; however, we were informed it was not possible.
Dmitry Kolosov: I wrote the software, and the Tennessee network should have the capability to produce hourly files; there may be a reason this network is not set up for distributing hourly files.
Giovanni Sella: I will inquire with Jim Waters [Tennessee Dept. of Transportation Design Division] concerning whether we can receive those hourly files.
Giovanni Sella: NOAA's GPS-Met project led by Seth Gutman produces the GPS-Met product with a 30-minute latency, and this product may be useful for RTK users.
Dmitry Kolosov: During the Forum's Question and Answer session, a participant thought that, by evaluating the stability of a site's 60-day plot, a search of the stable site's station log would be beneficial for establishing the same setup at new sites. I do not think this goal is feasible in the suggested process.
Giovanni Sella: I agree, the site logs are not easily searchable.
Dmitry Kolosov: We ourselves would like to extract this information for metadata.
Giovanni Sella: Yes, but the older site logs have serious problems. Since 2006, the site logs have had valid IGS antenna and receiver names. At NGS, we have attempted to enter checks due to mismatches in equipment, but we abandoned the idea, because site operators were having difficulty inputting those values into their receivers. As a result, those records may or may not abide by the IGS naming convention.
Giovanni Sella: A substantial amount of software is required to manage a network. <For example> for firmware versions in late 2007, our software leaves whatever value the site operators input and will only overwrite the file if it is left blank. <For example> UNAVCO sets aside all data with equipment mismatches and reprocesses them later. For NGS, our automated software does not reprocess after three days.
Gerry Mader: Regarding antenna calibration, NGS' absolute antenna calibration facility is now up and running! We have a considerable backlog of antennas to be calibrated, so we will continue to do relative calibrations for overlap. In our timeline, by December 1, 2009, we will provide absolute antenna calibrations to the National Geospatial-Intelligence Agency (NGA).
Dmitry Kolosov: Topcon plans to:

1. Use NGS' antenna calibration tables. For those antennas not calibrated by NGS, we will use internal Topcon calibration values,

2. Use absolute calibration values.