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The Synergistic CORS Program Continues to Evolve

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BIOGRAPHY

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ABSTRACT

This document describes the current status of the CORS program and some anticipated enhancements. The document addresses (1) the various utilities for accessing CORS information, (2) how CORS positions and velocities are determined, (3) the web-based utility--called OPUS--for automatically computing accurate positional coordinates with CORS data, (4) the expected accuracy of positional coordinates derived with CORS data, and (5) specialized applications of CORS data to remote sensing and crustal motion monitoring.

INTRODUCTION

The tremendous diversity of GPS applications has motivated numerous organizations to establish several (essentially independent) networks comprised of ground-based stations that collect dual-frequency GPS data on a continuous basis. The National Geodetic Survey (NGS), an agency of the National Oceanic and Atmospheric Administration (NOAA), is collaborating with most of these organizations to make data from hundreds of such GPS base stations freely available to the public via the Internet. The term, CORS (Continuously Operating Reference Stations), is used to identify those stations participating in this integrated network. Regardless of the primary purpose of a CORS' existence, its data may find use in positioning, navigation, geophysics, and/or meteorology.

The National Aeronautics and Space Administration (NASA) established many of the early CORS to generate accurate trajectories for GPS satellites and GPS-equipped space vehicles. The geophysics community also established many of the earlier CORS to monitor tectonic plate motion, earthquake displacements, and other forms of crustal deformation. The Texas Department of Transportation was the first government agency to establish a regional CORS network to support requirements for land surveying and GIS development. Numerous national, state, and local agencies have since emulated this Texas initiative. The U.S. Coast Guard then created a CORS network whose sites feature the capability to broadcast radio signals containing local "correctors" to the GPS signal. Originally designed for maritime navigation, this special collection of CORS is now being expanded by the U.S. Department of Transportation into the Nationwide Differential GPS (NDGPS) network that also supports safe and efficient land navigation throughout the entire United States. In addition, the Federal Aviation Administration (FAA) has created a special CORS network that features the capability to have GPS data from all of its stations collectively integrated to generate regional correctors to the GPS signal. This FAA network forms the foundation for the Wide Area Augmentation System (WAAS) that supports safe and efficient air navigation. Furthermore, NOAA's Forecast Systems Laboratory (FSL) and the academic community have established several CORS, collocated with ground-based meteorological sensors, to monitor the spatial-temporal distribution of precipitable water vapor in the Earth's atmosphere. The U.S. Naval Observatory, moreover, has established CORS, collocated with atomic clocks, to support accurate time transfer. In total, more than 80 organizations currently participate in the CORS program, with each organization operating at least one CORS.

Stations may be part of the National CORS network, the Cooperative CORS network, or both (Fig. 1). The National CORS network is comprised of stations whose GPS data are

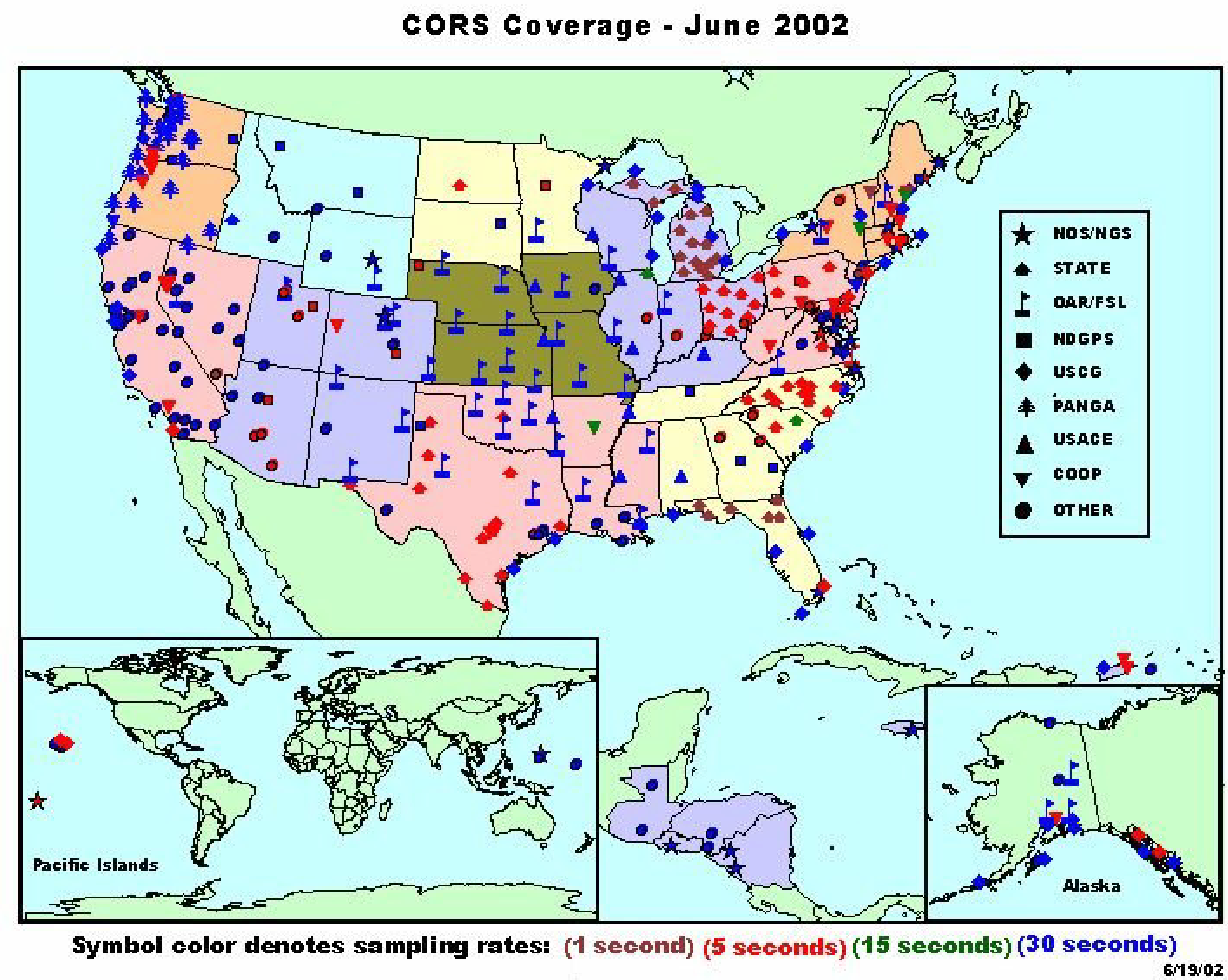

Figure 1. The National and Cooperative CORS network.

available directly from NGS via anonymous ftp (file . transfer protocol) at

ftp://www.ngs.noaa.gov/cors/

and via the World Wide Web at

http://www.ngs.noaa.gov/CORS/ .

The Cooperative CORS network is comprised of stations, each of whose GPS data are available directly from the organization that operates the station. The Web site

http://www.ngs.noaa.gov/CORS/Coop/

contains links to the websites of the various cooperating organizations. These organization include the California Spatial Reference Center (CSRC), which provides data from more than 250 CORS in California. See

http://csrc.ucsd.edu/ .

The term "Combo CORS" designates a station whose GPS data is distributed both by NGS and a cooperating organization. Such accessibility to CORS data is highly desirable, because more and more people are coming to rely on these data. Organizations that publicly distribute GPS data for selected Combo CORS include CSRC, the International GPS Service (IGS), the Pacific Northwest Geodetic Array (PANGA), and State agencies in Florida, Ohio, Michigan, North Carolina, Pennsylvania, South Carolina, Texas, and Vermont.

Currently (September 2002), the CORS network contains more than 600 stations in the United States and its territories, plus several stations in Central America and the Caribbean. Of these stations, 316 are contained in the National CORS network, which is currently growing at a rate of about six new stations per month. As of February 2002, the total land area in 49 states, plus much of Alaska, is located within 400 km of at least one National CORS, and more than half the land area of these 49 states is located within 100 km of at least one National CORS.

APPLICATIONS

To obtain 3-D positional coordinates for a point with an accuracy of a few centimeters, at least two GPS receivers are necessary, one located at a point whose positional coordinates are already known and the other located at the point whose positional coordinates are to be determined. Because positional coordinates for the CORS have been well determined, CORS data enable GPS users to deploy only one GPS receiver for accurately positioning points of interest to them. Consequently, surveyors, GIS professionals, engineers, scientists, and others can apply CORS data to accurately and economically interrelate the locations of navigational aids, utility lines, important boundaries, and other map-worthy features.

Photogrammetrists, remote-sensing professionals, and others can apply CORS data to determine the travel path of a moving platform with an accuracy of a few decimeters, provided this platform is GPS-equipped. Such platforms include aircraft, watercraft, and land vehicles. This capability was applied with LIDAR instrumentation aboard an aircraft to produce 3-dimensional maps of Manhattan within 24 hours of flight time to assist recovery operations after the terrorist attack on the World Trade Center in September 2001.

Earth scientists can apply several years of CORS data to determine the crustal velocities of these stations with an accuracy of a few millimeters per year. CORS data have been so used to study plate tectonic motion, earthquake-related deformation, volcanic activity, land subsidence, glacial isostatic adjustment, tidal loading, and atmospheric loading.

Meteorologists can apply CORS data to monitor the spatial-temporal distribution of water vapor in the Earth's atmosphere. Indeed, FSL has developed techniques to combine CORS data with other observations of the lower atmosphere that improve short-term (0-6 hour) moisture and precipitation forecast accuracy. Knowledge of the water-vapor distribution is critical for forecasting such severe weather as tornados, hurricanes, thunderstorms, and snow storms. In addition, continuous global monitoring of water vapor using CORS and other observing systems such as satellites will improve our understanding and predictability of the Earth's climate because of the relationships between water vapor variability, the El Niño-Southern Oscillation, and cloud formation. Many additional CORS are needed to translate NOAA's current research activities into a truly operational system for monitoring the national and global distribution of water vapor.

Atmospheric scientists studying "space-weather" can apply CORS data to monitor the spatial-temporal distribution of free electrons in the ionosphere, a region of the upper atmosphere between 50 and 1,000 km that is affected by solar and geomagnetic storms. The distribution of these free electrons is highly correlated with the location of the Sun relative to the Earth, as well as with solar and geomagnetic activity. Rapid changes in the ionosphere affect satellites, aircraft, certain radio communications, and even the power distribution grids on Earth. NOAA, in collaboration with the Department of Defense, FAA, and NASA, is using CORS data to monitor and predict the state of the ionosphere with high temporal resolution.

UFCORS

In November 1998, NGS introduced the "user-friendly" CORS (UFCORS) information server that enables users to request and receive CORS GPS data and associated metadata (satellite ephemerides, CORS positions and velocities, station-specific descriptive information, and CORS meteorological data) via the World Wide Web. UFCORS supplements anonymous ftp and the Web-based "standard" CORS information server in providing such CORS information. Anonymous ftp and the standard CORS information server allow users to select each type of information individually, somewhat like ordering food "a la carte". Alternatively, UFCORS allows people to select a comprehensive package of information for a particular station and a particular time interval, somewhat like ordering a complete meal (from soup to nuts) at a restaurant. Anonymous ftp and the standard CORS information server provide the information only in the format that it is stored at NGS, while UFCORS can repackage the information into any of several different formats. For example, with anonymous ftp and the standard CORS information server, users can obtain GPS data only for individual hours and/or individual (universal-time) days. With UFCORS they can obtain a file of GPS data for a time interval spanning any number ($\leq$ 24) of hours. Moreover, UFCORS–unlike the other two information servers–enables people to request and receive CORS GPS data that has been interpolated or decimated to certain popular sampling rates, ranging from 1 second to 60 seconds. Also, UFCORS allows users to select how the requested data files should be compressed.

Anonymous ftp remains the most popular CORS information server in terms of data volume. More than 150 gigabytes of CORS data were distributed via anonymous ftp in July 2002, whereas UFCORS distributed about 21 gigabytes in July 2002. Anonymous ftp is the server of choice among users that download GPS data from many CORS on a regular basis. Users who want CORS data only occasionally or only from a few stations prefer to use UFCORS. The usage of UFCORS, however, has been growing impressively over the years. UFCORS responded to 1,800 requests in July 1999; 4,800 requests in July 2000; 20,300 in July 2001; and 31,500 requests in July 2002. The information distributed by UFCORS contains more than 2 hours worth of GPS data on average, plus orbits for the GPS satellites, and various types of descriptive information. Assuming that it would cost a person about $200 to travel about 50 miles to a site, collect 2 hours of GPS data, and return (labor, GPS equipment rental, transportation, etc.); the cumulative value for the 31,500 data sets distributed by UFCORS in July 2002 exceeds $6 million. The monthly benefit of the CORS program also includes the value of the CORS information distributed via anonymous ftp and the standard CORS information server, plus the value of the utilities supported by CORS, such as the Online Positioning User Service (OPUS) which is descibed later.

NGS is currently developing yet another CORS information server, "computer-friendly CORS" (CFCORS). CFCORS will help automate the process of requesting and receiving large volumes of customized CORS information over the Internet. Users and third parties will be able to develop software that interact with CFCORS. With such software, a user might be able to submit several UFCORS-type requests upon the specification of a few parameters, such as a time interval and an approximate geographic location. Such software may also repackage the acquired CORS information into a user-specified format. The user will also not have to wait by the computer to respond to prompts when the data is ready to be downloaded, as is the case with UFCORS.

In addition to the previously mentioned methods for accessing CORS data, NGS is willing to work with selected users to provide CORS information in pre-arranged formats. These cases include organizations that regularly download large volumes of data for a well-defined group of stations, such as FSL which applies CORS data for forecasting weather.

CORSAGE

In January 2000, NGS introduced a new interface to the CORS Web site. This interface, known as the "CORS Amiable Geographic Environment" (CORSAGE), enables users to access CORS data and metadata through a series of geographic maps. The CORS homepage itself features an index map (Fig. 1) in which the total area of CORS coverage has been partitioned into color-coded regions, each usually involving a few states. By clicking the mouse on one of these regions, the user obtains a window displaying a more detailed map of that region (Fig. 2). Each regional map locates the CORS contained in that region, relative to state and international boundaries and major bodies of water. The area of each regional map is color coded according to the distance from the nearest CORS in increments of 100 km.

On a regional map, a user can select a map symbol representing a particular CORS to obtain a window containing a local map that pinpoints the station'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 the user to view/download particular information about this station. For example, the user can view/download a file containing the station's positional coordinates and its velocity. Another item on the menu enables the user to view a calendar displaying the time intervals–with a 10-minute resolution–when GPS data are available for this station. By inspecting such calendars beforehand, users can avoid downloading and processing files that contain unwanted data gaps. Other menu items provide access to the station's GPS data and to files containing certain descriptive information about the station (type of GPS equipment, responsible institution, contact person, history of station modifications, etc.) Recently, menu items were added that enable the user to view photographs of the station as well as time-series plots of the positions that are estimated daily using a 24-hour span of data.

POSITIONAL COORDINATES AND VELOCITIES

In order to meet the needs of the varied groups that use CORS data, CORS positional coordinates and velocities are expressed in two different reference frames. One of these reference frames, the International Terrestrial Reference Frame (ITRF), was instituted by the International Earth Rotation Service (IERS). The other reference frame is the North American Datum of 1983 (NAD 83). For each of these reference frames, CORS files present positions in both Earth-centered, Earth-fixed (ECEF) cartesian coordinates (X,Y,Z) and in geodetic coordinates (latitude, longitude, ellipsoid height) for the ellipsoid of the Geodetic Reference System of 1980 (GRS80). Also for each reference frame, the files present velocities in ECEF cartesian coordinates (Vx,Vy,Vz) and in local horizon coordinates (northward velocity, eastward velocity, upward velocity) where the vertical dimension is locally oriented normal to the GRS80 ellipsoid. NAD 83 positions given in these files are identical to those contained in the NGS Integrated Data Base.

IERS publishes revised ITRF positions and velocities every few years for a worldwide network of geodetic stations. Each IERS solution for these positions and velocities uses observations obtained from various geodetic techniques including GPS, very long baseline interferometry, and satellite laser ranging. New solutions not only incorporate

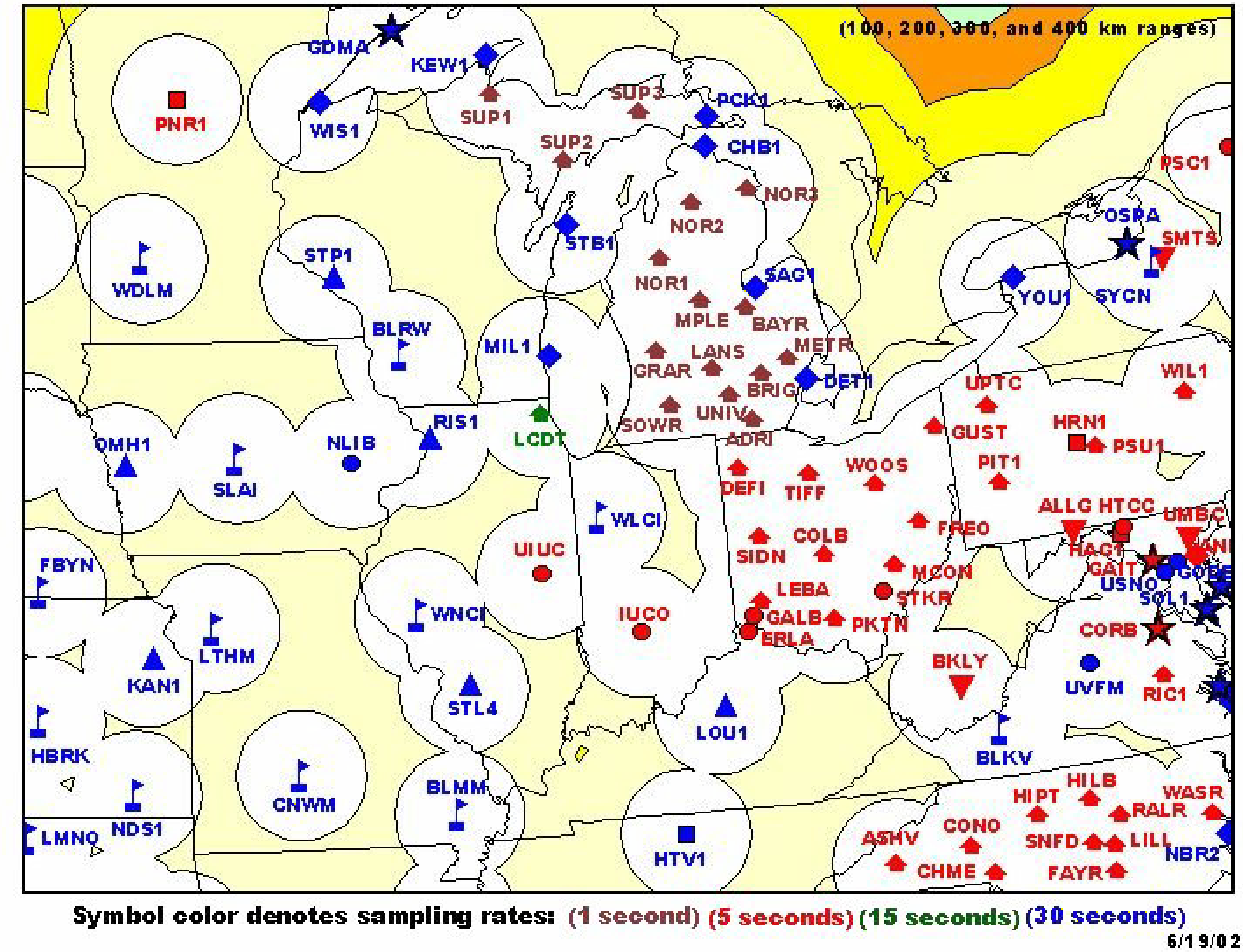

Figure 2. Regional CORS coverage for the midwest. Background colors identify the distance to the nearest CORS in 100-km intervals.

at least an additional year of data, but also the most current understanding of the Earth's dynamics.

For the CORS network, NGS currently uses ITRF positions and velocities that are consistent with the IERS's solution referred to as ITRF2000 or more simply as ITRF00 [Altamimi et al., 2002] with an epoch date of 1997.0 (1 January 1997). The epoch date denotes the date for which estimated positions correspond. An appropriate velocity must be applied to estimate positions for another date. A site's velocity characterizes various forms of crustal motion including the motion associated with plate tectonics, land subsidence, and crustal loading/unloading. Relative to ITRF00, even points located on the rigid part of the North American tectonic plate move continuously at rates ranging from 9 to 22 mm/yr.

Many users of CORS data prefer to position themselves relative to the NAD 83 reference frame that is used widely throughout North America for surveying and mapping activities. The NAD 83 reference frame is defined so that the North American tectonic plate does not move as a whole relative to it. Thus, users can generally treat NAD 83 positions as unchanging over time, except where regional or local crustal motion occurs (California, Oregon, Washington, and Alaska) or at locations on a different tectonic plate (Hawaii).

When a CORS first comes online, NGS uses at least ten 24-hour GPS data sets to compute this station's ITRF00 positional coordinates relative to other stations in the CORS network. Also, NGS uses the Horizontal Time-Dependent Positioning (HTDP) software [Snay, 1999] to predict this station's ITRF00 velocity. NGS then transforms the ITRF00 positional coordinates and velocity for this CORS into NAD 83 values via an adopted 14-parameter Helmert (similarity) transformation [Soler and Snay, 2002].

Approximately every year, NGS uses every third day of CORS data in its archives to compute provisional positions and velocities for all CORS relative to the then 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 dimension or by more than 1 cm in the east-west dimension or by more than 2 cm in the vertical dimension, then NGS adopts the provisional position and velocity to supercede the previously adopted ITRFxx position and velocity.

In addition to this annual validation of CORS positions and velocities, NGS computes ITRFxx positional coordinates for each CORS on a daily basis using the 24-hour data set collected two days previously. If, for any CORS, the time series of daily estimates differ "systematically" from this station's adopted ITRFxx positional coordinates by more than the tolerances given in the preceding paragraph, then NGS carefully analyzes the available data to determine whether or not this station's adopted ITRFxx position and velocity should be updated.

Whenever NGS adopts a new ITRFxx position and velocity for a station, it transforms these ITRFxx values into provisional NAD 83 values via an adopted Helmert transformation. If the provisional NAD 83 positional coordinates differ from the currently adopted NAD 83 positional coordinates by more than 2 cm in the north-south dimension or by more than 2 cm in the east-west dimension or by more than 4 cm in the vertical dimension, then NGS adopts the provisional NAD 83 position and velocity to supercede the previously adopted NAD 83 position and velocity. As a result of these less stringent tolerances, adopted NAD 83 positions and velocities are less likely to be updated than their ITRF counterparts. Because of these daily and annual validation processes, users can rely on the accuracy of CORS positions and velocities.

OPUS

In March 2001, NGS introduced a new Web-based utility, known as OPUS, which will quickly and automatically calculate an accurate 3-D position for a location corresponding to a user-supplied file of appropriate GPS data. Currently, OPUS requires the user to supply a file in the receiver-independent-exchange (RINEX) format. This file must contain at least a 2-hour span of dual-frequency, carrier-phase observations at a single location. OPUS then automatically retrieves pertinent GPS data for three suitable CORS for use in calculating the positional coordinates associated with the user-supplied data. OPUS then emails the calculated coordinates to a user-specified email address. These computed coordinates are provided for in two different spatial reference frames: NAD 83 and the pertinent ITRF realization. Moreover, OPUS-derived coordinates are expressed in as many as four different manners: (1) latitude, longitude, ellipsoid height, (2) X,Y,Z Earth-centered, Earth-fixed coordinates, (3) Universal Transverse Mercator planar coordinates, and (4) if appropriate, state plane coordinates. Also if appropriate, OPUS refers the point's location to the U.S. National Grid [Federal Geographic Data Committee, 2001].

NGS recently upgraded OPUS to process GPS data within an hour after these data are observed, provided sufficient CORS data are available. Previously, OPUS waited until after universal-time (UT) midnight before processing GPS data that had been submitted on the day of observation. While users can obtain OPUS-derived positional coordinates within a hour after observing their data, much more accurate coordinates can be obtained by submitting the GPS data to OPUS at least two days after the end of their observational session. By waiting two days, OPUS will have access to the corresponding IGS "rapid" orbit, which has been postfitted to GPS data from more than 50 satellite tracking stations. When processing data submitted before this "rapid" orbit is available, OPUS uses the IGS "ultra-rapid" orbit. Being a predicted orbit, the "ultra-rapid" orbit is less accurate and less reliable than the corresponding "rapid" orbit. Also, by waiting at least until UT midnight, OPUS will have access to the GPS data from about 50 percent more stations. That is, NGS currently receives GPS data only once per day from about 100 of the 316 stations in the National CORS network. NGS receives data from the remaining CORS either hourly or instantaneously.

NGS is now upgrading OPUS to enable a user to select one or more of the three CORS to be used in the calculations. Future versions of OPUS will also accept RINEX files that have been compressed by certain popular algorithms, eg., GZIP and UNIX compress.

POSITIONING PRECISION WITH CORS

A fundamental CORS application is to determine the positional coordinates of a specific point by collecting GPS data at this point and then processing these data together with GPS data from one or more CORS. For the case of using a single CORS, Eckl et al. [2001] studied how the error of the determined coordinates depends on the distance to this CORS and on the duration of the observational session. For their study, they processed 10 days of dual-frequency, carrier-phase observations for each of 11 baselines formed by pairs of sites in the National CORS network. These 11 baselines range in length from 26 km to 300 km, and they are widely distributed throughout the coterminous United States. The data for each baseline

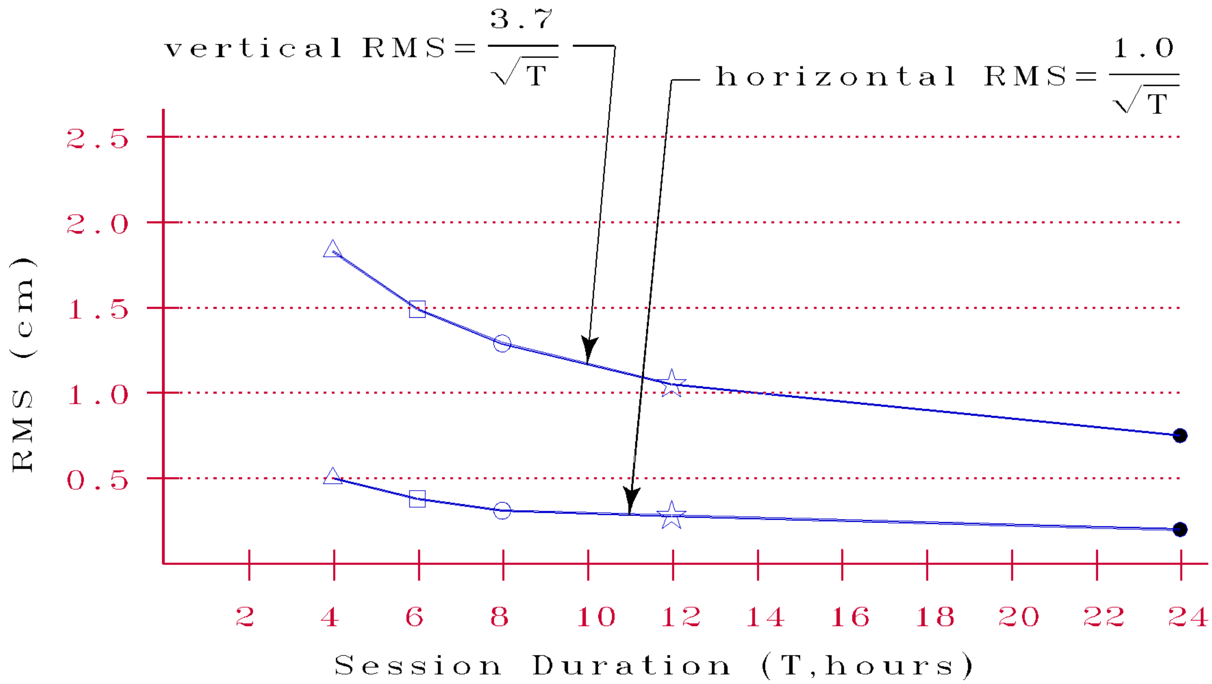

Figure 3. RMS error as a function of the observational session duration.

comprises 10 non-overlapping 24-hour sessions that were further subdivided into 20 non-overlapping 12-hour sessions, 30 non-overlapping 8-hour sessions, 40 non-overlapping 6-hour sessions, and finally, 60 non-overlapping 4-hour sessions. Moreover, the data for each baseline and each session were processed independently from the data of other baselines and other sessions.

In addition to the length of the baseline and the duration of the observational session, positioning error will depend on several other factors, including the methodology and the software used for processing the GPS data. Eckl et al. [2001] used the "static-mode, ionosphere-free, double-difference-carrier-phase" option as encoded in the PAGES (Program for the Adjustment of GPS Ephemerides) software developed by NGS
http://www.ngs.noaa.gov/GRD/GPS/DOC/pages/pages.html .
Also, they used the IGS 'final' satellite orbits from
http://igscb.jpl.nasa.gov/ ,
and they fixed phase ambiguities to integer values whenever these investigators were sufficiently confident in these values.

Eckl et al. [2001] found that the repeatability among the solutions for a given duration does not change significantly as a function of baseline length. In particular, these investigators found that the "best fitting" lines that quantify the standard errors of selected GPS solutions as a function of baseline length have slopes of 0.4 $\pm$ 1.8 parts-per-billion (ppb) in the north-south dimension, 3.0 $\pm$ 1.7 ppb in the east-west dimension, and 14.0 $\pm$ 7.8 ppb in the vertical dimension, where given uncertainties correspond to standard errors. They attribute this result to the use of the IGS orbits which provide satellite positions that have a standard error smaller than 10 cm. The fact that relative positioning error is essentially independent of baseline length also indicates that meteorological effects on the accuracy associated with relative GPS positioning are statistically the same for baselines lengths ranging between 26 and 300 km. This is probably not the case for baselines shorter than 26 km. That is, as baselines become much shorter than 26 km, the relative meteorological effects should approach zero and the corresponding error in relative GPS positioning should decrease.

While distance doesn't matter under the conditions of their experiment, Eckl et al. [2001] found that the duration of the observational session does. The repeatability among GPS solutions for a longer observational session are smaller than that for a shorter observational session. They empirically fit the root-mean-square (RMS) error to an equation of the form

$$RMS\ error = k / (T)^{0.5}$$

where T denotes the duration expressed in hours and k is a free parameter in units $cm \cdot hr^{0.5}$. In these units, k has a value of 1.0 for each horizontal component (north and east) and 3.7 for the vertical component. The curves in Figure 3 illustrate these predicted RMS errors.

Eckl et al. [2001] considered only the error associated with measuring the relative position between two GPS antennas. The total error involved in positioning a new point also depends on:

* the accuracy of the vertical offset measurement that relates the point's position to the position of the GPS antenna placed above it, and

* the accuracy of the positional coordinates of the CORS.

The use of a fixed-height pole will help to obtain a reliable offset measurement. To help mitigate errors associated with CORS coordinates, the new point may be positioned relative to each of two or more CORS, and the different results may be statistically averaged. As previously mentioned, OPUS positions points relative to three CORS.

CORS FOR REMOTE SENSING

Another fundamental CORS application is to compute the path of a GPS receiver that has been mounted on a moving platform, such as an aircraft involved in aerial mapping or other remote sensing operations. Mostafa and Hutton [2001], Bruton et al. [2001], and Mostafa et al. [2002] discuss two experiments that these investigators performed to determine how accurately the trajectory of an aircraft can be computed using GPS data from stations in the CORS network. One experiment was performed near San Jose, CA in June 2000 and the other near Dallas, TX in January 2001. For each experiment, these investigators computed a reference trajectory using data from one or two dedicated GPS base stations that either existed or had been temporarily established near the respective flight path. For each experiment, the resulting reference trajectory is considered to have an absolute accuracy of 10 cm, as determined by comparing corresponding aircraft positions to those derived from a set of photogrammetric data using aerial triangulation. In addition, these investigators computed 14 test trajectories (eight for the CA flight and six for the TX flight). Each of these 14 test trajectories used GPS data from only one CORS. Distances from the centroid of the flight path to the associated CORS ranged between 40 km and 417 km. The GPS carrier phase data were interpolated from a 30-second sampling rate to a 1-second rate for 10 CORS and from a 5-second sampling rate to a 1-second rate for four CORS.

The error associated with each test trajectory was estimated by computing the 3-D RMS positional difference between this trajectory and the corresponding reference trajectory over the duration of the flight (approximately 4 hours in each case). Figure 4 presents a plot of the derived RMS error for each trajectory to exhibit how this error depends on the distance from the centroid of the corresponding flight path to the associated CORS. Using a linear approximation, we found an intercept of 15.7 $\pm$ 5.2 cm and a slope of 0.57 $\pm$ 0.22 parts per million, where given uncertainties correspond to standard errors. Thus, at a distance of 100 km, the predicted 3D-RMS error is 21.4 (= 15.7 + 5.7) cm.

We detected no statistical difference between the results obtained with interpolated 5-second GPS data and those obtained with interpolated 30-second GPS data. Mostafa et al. [2002] present results supporting our conclusion.

In addition to computing a test trajectory for each of 14 CORS, these investigators computed three test trajectories, each using GPS data from several CORS in combination. Each of these three test trajectories resulted in a lower RMS error than the average of the RMS errors for the test trajectories that were derived from one of the CORS in the combination. The combination of GPS data from multiple CORS seemingly has enabled the investigators to edit out data problems that were specific one to of the CORS, for example, multipath and/or local obstructions. Similar results are documented by MacDonald [2002] for three comparable experiments involving multiple CORS.

The results of the various experiments indicate that using CORS data can save on the cost of establishing temporary GPS base stations for those remote sensing projects that allow for more than a 30-cm error in the 3-D position of the aircraft. These results also indicate that CORS data can supplement the data from a temporary GPS base station as a safeguard against the loss of some of the base station's data due to multipath, local obstructions, equipment failure, and/or human error. In general, using GPS data from several GPS base stations (including CORS) will provide a more reliable trajectory for an aircraft than the trajectory derived with data from a single GPS base station.

CRUSTAL MOTION

Gan and Prescott [2001] analyzed GPS data observed between 1996 and 2000 for 62 CORS distributed throughout the central and eastern United States. Their results suggest that no significant horizontal crustal motion occurs in this part of the country, except possibly in the region encompassing that part of the Mississippi River which is located south of Illinois. Here, points appear to be moving southward relative to the rest of the continent at an average rate of 1.7 mm/yr, with a standard error of 0.9

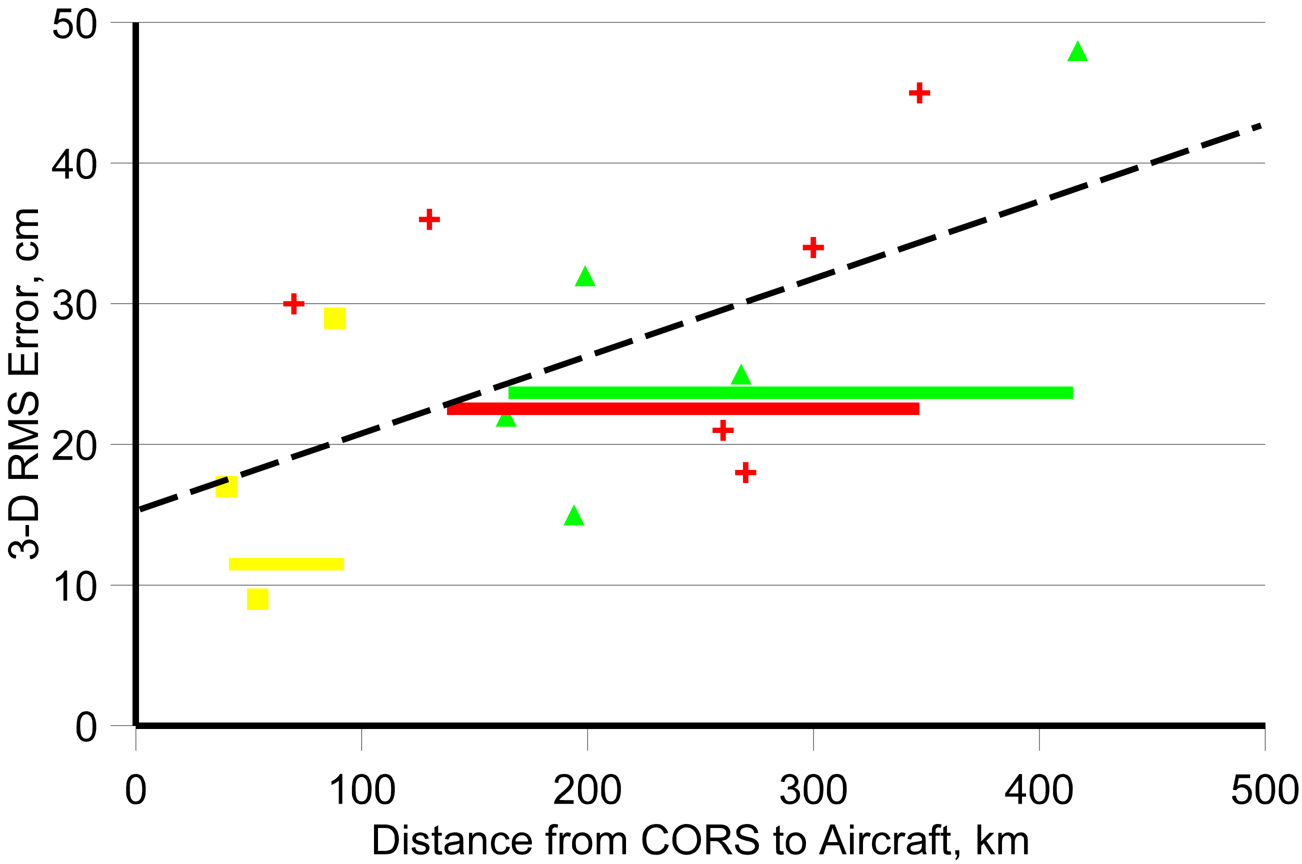

Figure 4. Error in aircraft trajectory derived from CORS data. Squares and triangles represent results from individual CORS for CA flight. Crosses represent results from individual CORS for TX flight. The dashed line represents a linear approximation to the results from individual CORS. Solid horizontal lines represent results from multiple CORS. The horizontal extent of each solid line corresponds to the range in distances from the aircraft to the involved CORS.

mm/yr. While 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], moreover, have applied GPS data from the National CORS network, together with space-based geodetic data from a worldwide distribution of stations, to produce the new "recent velocity" (REVEL) model that quantifies the motions of several tectonic plates during the 1993 - 2000 time interval.

NEW CORS DESIGN

The University Navstar Consortium (UNAVCO), the U.S. Coast Guard, and NGS collaborated to install two CORS, each featuring a highly stable monument, at the NDGPS site in Pueblo, CO. NDGPS sites are operated by the Coast Guard to broadcast "correctors" to the GPS signal, enabling real-time positioning at the 1- to 3-meter level. The design of these two CORS incorporates modifications to a previous NGS design [Hoar et al., 2000] to improve aspects of security and accuracy. The modifications include a choke-ring antenna--to help mitigate multipath effects--as well as an antenna mount and radome developed for GPS reference stations in the Southern California Integrated GPS Network and other networks.

Each of these two CORS includes a poured concrete monument to provide mechanical stability. Each monument has a 2-ft diameter below-ground base to a depth of 12 feet and a 12-inch diameter above-ground pillar to a height of 5 feet. A 2-inch diameter stainless steel antenna mast is placed into the top of the concrete monument such that its threads are 8 inches above this top. The top of the concrete monument is beveled to shed water. Additional details are given at http://www.unavco.ucar.edu/tech_highlights/pueblo/pueblo.html . The Pueblo installation has ushered in a new level of cooperation between the Federal government and the academic community in building a multi-purpose, nationwide GPS reference station network.

SUMMARY

The CORS program continues to evolve in many respects. The CORS network is currently growing at a rate of about six new stations per month. The NGS staff is developing new utilities, like CFCORS, to make CORS data more accessible. The NGS staff is also enhancing the Web-based OPUS utility so that people may more easily use CORS data to obtain accurate positional coordinates. Recent studies reveal how accurately new points can be positioned using several hours of CORS data, as well as how accurately the flight path of an aircraft can be determined using CORS data. Recent studies also demonstrate the value of CORS data for monitoring crustal motion.

ACKNOWLEDGMENTS

The success of the CORS program is due to contributions by people from more than 80 organizations, with each organization operating at least one CORS. For a current list of these organizations, please see the CORS Newsletter at http://www.ngs.noaa.gov/CORS/ . The authors thank Michael Aslaksen, Nikki Case, David Doyle, Seth Gutman, Dennis Milbert, and Dru Smith for suggestions that have improved the presentation of this paper.

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