AN OVERVIEW OF GLOBAL POSITIONING SYSTEM CONTINUOUSLY OPERATING REFERENCE STATIONS

by William A. Stone New Mexico State Geodetic Advisor, National Geodetic Survey Albuquerque, New Mexico, USA

ABSTRACT

Most applications of Global Positioning System (GPS) technology in surveying, mapping, and related disciplines have accuracy requirements that necessitate the use of a relative positioning technique. Many organizations are establishing GPS continuously operating reference stations (CORS) in support of these activities. CORS facilities collect and record, in an automated manner, the GPS data at a known location that are required for relative positioning. The issues that must be considered in developing a CORS facility are discussed. These include the hardware components and configuration, site characteristics, and data handling. Examples of both national and global CORS networks are presented to illustrate some of the concepts.

I. INTRODUCTIO N

The 1994 version of the Federal Radionavigation Plan[(1)], promulgated by the United States Government, states that the Standard Positioning Service component of the Global Positioning System (GPS) supports autonomous positioning accuracies of 100 meters (2 drms) in the horizontal component and 156 meters (2 sigma) in the vertical component. For most GPS applications in surveying, mapping, and related disciplines, these accuracies are insufficient. In order to improve positional accuracies to the level of a few meters or better, a relative positioning technique is usually employed. Relative GPS positioning involves the collection of observables by a GPS reference station whose position is known. These data are then combined with data collected by other receivers whose positions are to be determined. This process may be performed either in real-time or in a post-processed mode. If performed in real-time for navigation purposes, the technique is generally known as differential GPS. Differential GPS involves the generation and transmission to users of reference station correction data. The equipment and procedures utilized in a relative GPS positioning technique determine the level of accuracy that is attainable.

In order to simplify the process of relative GPS positioning, many organizations are establishing automated reference station facilities. These unstaffed, permanently configured facilities continuously collect and record GPS data. The reference station data are then made available to users. In a very simple scenario, a user could collect data in the field with a single GPS receiver, later retrieve the data collected during the same time span by a nearby reference station, and combine the two datasets to perform single-handed, post-processed relative positioning. Such a procedure is well suited for mapping grade (few meter level accuracy) GPS work designed for applications such as geographic information system (GIS) data collection. Survey grade (few centimeter level accuracy) GPS work can also be supported by a reference station, but it usually involves more than one field receiver operating simultaneously to provide for redundancy and to enhance productivity.

In addition to supplying GPS observational data needed for relative positioning, a reference station may also, depending on its configuration, contribute to a variety of efforts such as the generation of precise satellite ephemerides and clock correction data, crustal motion monitoring, and atmospheric and earth rotation studies. While automated reference stations are referred to by a variety of names in the literature, such as base stations, active control stations, tracking stations, etc., I will use the term continuously operating reference station (CORS), which has been adopted by the National Geodetic Survey, an office of the United States Department of Commerce's National Oceanic and Atmospheric Administration. The National Geodetic Survey is embarking on an ambitious CORS program in support of its fundamental mission of providing an accurate and consistent national coordinate system, known as the National Spatial Reference System. Although a set of standards that define a CORS has not yet been formally adopted, I use the term to refer to a multipurpose, automated, permanently configured GPS reference station facility. A CORS system must also address issues such as the distribution, archiving, and quality control of the data that it collects.

The intent of this paper is to present general information regarding the development and design of CORS facilities. Aspects including hardware and site configurations as well as data archival and distribution are addressed. In order to illustrate these concepts, an example of CORS programs on both a national and a global level are discussed.

II. HARDWARE CONFIGURATION

Many government, private sector and academic organizations around the globe are involved in the development of CORS facilities. Although basic commonalities between these different programs exist, there are many variations on the CORS theme. The specific requirements that are motivating a CORS development effort will determine the details of the configuration.

In developing a CORS, a variety of issues pertaining to the configuration of the hardware must be addressed. These issues include the characteristics of the GPS receiver: the antenna, model, and type; the selection of an on-site computer, if necessary; peripheral equipment such as an uninterruptable power supply, a weather station, an accurate timing reference, and miscellaneous sensors; and the mechanism for connecting the facility to the outside world, such as modem and telephone line or network connection. Issues of redundancy and reliability must be carefully considered as they will have a significant impact on many hardware-related decisions.

The GPS receiver is the heart of a CORS configuration. In order to support a wide realm of activities, the receiver must be a high quality geodetic unit capable of tracking and recording all components of the GPS signal. Ideally, a CORS receiver can collect both P-code and C/A-code pseudoranges as well as L1 and L2 carrier phases. In the presence of anti-spoofing, the encryption of the P-code, the receiver should be able to utilize one of the various codeless techniques, known as "Y-codeless," that have been developed by several receiver manufacturers in order to provide for the complete set of measurements.(2) With the United States Air Force's long awaited July 1995 announcement of Full Operational Capability, anti-spoofing is reportedly here to stay.

Many organizations doing GPS positioning in support of feature mapping for geographic information system (GIS) activities have developed reference stations to support these mapping efforts. Often these reference stations are capable of tracking and recording only the code range data of the GPS signal. They are not suited for the multipurpose applications, usually requiring carrier phase data, for which fully developed CORS facilities are intended.

Other receiver characteristics that should be considered include data collection rate, number of satellites tracked, real-time output capability, and ease of remote operation. Most geodetic receivers available today that would be candidates for incorporation into a CORS facility are capable of recording data as frequently as every second. This data rate should satisfy most applications of the CORS data. While some activities, such as aircraft positioning for aerial mapping work, might require data as frequently as every half second, the amount of data, if collected routinely, would become extremely cumbersome. This type of activity might be better supported on a special request basis where the CORS receiver collects at the high data rate only for the duration of a specific mission. With the full GPS satellite constellation that is available today, there are times when up to 10 satellites are visible from a given location. In order for a CORS to be capable of supporting a wide range of applications, its receiver should be able to collect data from all satellites in view. If a CORS is required to provide real-time differential positioning capability, the receiver should be capable of generating the necessary correction information and outputting it to be broadcast. Although this task can be performed by an attached computer, the process is usually simplified if it can be done directly by the receiver. Finally, if a custom CORS configuration is being developed, the ease with which a receiver can be remotely controlled should be considered. Some receivers are more amenable to being remotely controlled and interfaced with than others.

In addition to the GPS receiver, many CORS installations include a computer located at the site. These CORS-dedicated processors are frequently personal computers. The primary function of the CORS computer is usually to record the observation data. The computer may also be utilized to assist with the remote controlling and monitoring of the CORS. CORS facilities are generally designed to operate for a considerable length of time without the necessity of being visited by personnel. Ideally, a remote operator, perhaps located at the sponsoring organization's headquarters, should be able to monitor the operation of a CORS as well as have the ability of controlling functions of the GPS receiver as if working directly at the front panel of the receiver. The interface between the remote operator and the receiver is often provided by the on-site computer. Several GPS receiver manufacturers have produced receivers that do not require an on-site computer in order to operate in a CORS configuration.

For a CORS facility to provide a high level of reliability, it should be able to operate during periods of power outage. This functionality is usually provided by an uninterruptable power supply (UPS), which is always ready to provide power for the operation of a CORS through power outages up to a few minutes duration. Some CORS are capable of operating for a much longer period, but often in a standby mode in which some of the components, such as the on-site computer, are not operational. In the event that full CORS functionality during extended periods of power outage is required, an emergency generator could be engineered into the system design. Such capability would be required, for example, when safety of property and human lives might be dependent on the timely availability of CORS data. Another aspect of the reliability of a CORS configuration is the amount of equipment component redundancy that exists. Equipment failures do happen and if this presents an unacceptable situation because of production or safety concerns, then safeguards must be built into the system. Ultimately, the applications for which a CORS is designed will dictate the levels of reliability and redundancy that are required.

In order to allow for the monitoring and controlling of a CORS, as well as to facilitate transfer of the GPS data collected, the CORS must be connected to the outside world. This connection frequently takes place through a high speed modem and telephone line. If the CORS is located in a facility with a direct connection to a computer network, such as the INTERNET or a local area network, the CORS should be directly connected into the network. Due to the large volume of data inherit in CORS work, a direct network connection is preferable to a modem connection. An alternative now being employed by the United States Coast Guard with their CORS network, is the X.25 packet switching data system that provides for high speed transfer of large amounts of data over special telephone lines.

High accuracy surveying applications of GPS often require information about meteorological conditions at the location where the GPS data were collected. This information allows for a refinement of tropospheric models in order to better determine the delay of the GPS signals. By configuring a CORS with an automated weather station, the necessary observations (temperature, pressure and relative humidity) can automatically be injected into the GPS observation data stream, or recorded in a separate file, for transmission to the data gathering facility.

In order to support a variety of research and development work, as well as for efforts such as precise satellite ephemerides and clock correction generation, an accurate time reference is desirable. Typically, the clocks provided in GPS receivers, even high quality geodetic units, are not very good when compared with the excellent atomic clocks in the GPS satellites. By utilizing a higher accuracy external timing standard, many of the problems associated with timing errors are mitigated.

III. SITE CONFIGURATION

The suitability of a site for a CORS installation is dependent on many factors. First of all, the site must be well positioned to support the intended applications. For example, if the CORS is designed primarily to support relative positioning activities, such as surveying or mapping, it will ideally be centrally located in the area in which these activities will be performed. If the CORS is one of a network of such facilities involved in precise satellite ephemerides or clock correction generation, it is more crucial that it be well located relative to other CORS facilities that are contributing to the same efforts.

Basic utilities such as electrical power and a telephone line or computer network connection are essential for CORS operation. Some temporary CORS facilities make use of batteries for power and cellular telephones for data transfer and remote controlling functions, but these are very specialized configurations. A CORS installation must include a structure to house the GPS receiver and peripheral equipment. This structure provides protection from the elements and security for the equipment. If possible, an existing building near the CORS GPS antenna and monument can be utilized. Alternatively, a small field structure specifically constructed to house the equipment might be required. In either case, there may need to be some type of climate control capability in order to provide for proper operating conditions for all of the hardware components. The structure must be sufficiently close to the location of the CORS monument and antenna to allow the antenna cable to reach from the receiver to the antenna. The maximum standard antenna cable length is usually 30 meters. Longer cables exist, but often require an amplification of the signal before it is sent from the antenna to the receiver.

Sky visibility from the CORS antenna location must be adequate to support the intended applications of the facility. Ideally there should be no obstructions above a few degrees above the horizon. In the real world, this a difficult criterion to comply with fully. The Jet Propulsion Laboratory recommends that for GPS stations contributing to networks involved in high accuracy applications, the antenna should have no obstructions greater than 5 degrees above the horizon.[(3)] A CORS designed primarily for more local area use can probably get by with a less stringent requirement. A CORS receiver antenna should be in an environment that is free of radio frequency interference. GPS users have documented problems when attempting to collect data in the presence of conflicting signals. Problematic signals might originate from facilities such as microwave broadcast antennae or, if located close enough, from transmission facilities utilizing other portions of the electromagnetic spectrum.

Selection of a CORS installation site often involves a tradeoff between security and access. Although a CORS ideally requires only infrequent visitation by personnel, there will be times when the site needs to be accessed for maintenance or inspection. The site should be reached with a minimum of bureaucratic and logistical complications. However, the site should be protected from casual visitation by the public. Even well intentioned visitors to the site could cause problems with data collection simply by standing too near to a CORS antenna. Certainly, the site should be as protected from vandalism as practical. It is much easier to monitor a CORS installation if the staff of the hosting facility is stationed in the area on a regular basis. In addition to providing a monitor function, they can also be utilized by the organization operating the CORS to help with quick troubleshooting or simple hardware reconfiguration tasks.

Two related issues that are handled in a variety of manners by different CORS systems are those of monumentation and antenna installation. However it is configured, the GPS antenna must be securely attached to an anchoring structure. Examples of antenna installations are: a bracket, located on the roof of a building, that is rigidly connected to an integral part of the building's structure; a monolithic pedestal or monument anchored directly and securely to the ground; or a tower structure of sufficient stability to effectively eliminate antenna motion. The choice of antenna installation technique is often determined by the intended uses of the CORS data. The more demanding the CORS applications are, in terms of antenna positional stability, the more rigorous the mounting technique should be. An important issue pertaining to antenna site selection is the signal multipath environment. Multipath is caused by the presence of reflective surfaces in close proximity to the antenna which results in the combining of directly transmitted GPS signals with reflected signals. By avoiding reflective surfaces near the antenna, problems due to multipath should be minimized.

From a data standpoint, the physical location, or reference point, of a CORS that is generally of most interest is that of the L1 and L2 phase center of the antenna. Ultimately, this is the position that will be utilized by software involved in relative positioning computations or involved in precise satellite ephemerides or clock correction calculations. When a position for a CORS is computed or published, it may be expressed either directly for the antenna phase center or for a nearby monumented point and an offset from that monumented point (for example, this information might be given by the position for a mark located directly beneath the antenna and the height of the antenna above the mark). Although the position of the antenna itself is usually of most interest, a permanently and stably monumented point of reference should always be established and the offset to the antenna determined. In the event that the antenna set up is disturbed or is purposefully modified, the monumented point can serve as a reference to relate the different configurations.

One final, and very important, aspect of CORS site considerations is that of the coordinate system in which the reference position of the CORS should be expressed. Most surveying and mapping activities require that positions be expressed relative to the commonly used reference datum in the region of interest. For instance, in North America most surveys are performed relative to the North American Datum of 1983 (NAD 83). For these activities, the NAD 83 position for the CORS antenna, or monumented reference point and offset to the antenna, must be computed and made available to users. For research activities or applications that are global in nature, a global reference system, such as the International Earth Rotation Service's (IERS) International Terrestrial Reference Frame (ITRF), should be utilized. Regardless of the reference system used by a CORS, adequate GPS connections must be made between the CORS and previously established points whose positions are known relative to the desired reference system. The accuracy of the CORS position will be only as good as the accuracies of the established points to which it is connected and the connections themselves. Since the results obtained by users of the CORS data are directly dependent, in part, on how well the position of the CORS is determined, this issue is worthy of careful attention.

IV. DATA HANDLING

Under normal operating conditions, CORS facilities are collecting and recording GPS observation data all the time. A P-code dual frequency receiver collecting data at a 5-second collection rate for a 24-hour period, will generate about 5 megabytes of data, even in a compressed format.[(4)] For organizations involved in the operation of a network of several CORS facilities, the problem of data management can quickly become formidable. Fortunately, with the processing and data storage capabilities of today's computers, the task is more easily handled now that just a few years ago.

Managers of CORS programs must make a variety of decisions regarding the handling of data. Issues including data format, distribution, and archival, as well as quality control, must all be addressed. Ultimately, it is the data itself that is of most interest to users of CORS facilities, so this aspect of developing a CORS must be carefully considered.

GPS receivers generally produce observation data in a proprietary format developed by the receiver manufacturer. This format of data works well for users that are combining data from receivers that are all of the same type and who are utilizing the processing software provided by the manufacturer. Some software packages, such as the National Geodetic Survey's program OMNI, are even capable of combining and processing data from different receiver manufacturers. However, in order to facilitate the processing of mixed types of receivers, most CORS systems are utilizing the receiver independent exchange (RINEX) format for their data distribution. RINEX is simply a well-defined universal format for GPS observation data that is independent of the brand of GPS receiver used to collect the data. Since CORS GPS receivers are made by a variety of manufacturers and since users of CORS data are often working with different brands of receivers, users will typically be dealing with a mixture of receivers. RINEX is currently the best way to deal with this situation. Although most receiver manufacturers met RINEX with some resistance at first, they now seem to be accepting it and are making available software to perform the conversion between their proprietary formats and RINEX.

Most CORS systems are configured so that GPS data are transferred in the proprietary receiver data format from the CORS site to a central facility. The data may be transferred, on an occasional basis, in files that contain data collected during time spans ranging from one hour to a full day, depending on the system design. Alternatively, the data may be sent in a near continuous stream for subsequent file formation at the central facility. However the data are transferred to the central facility, once the observation files are available, they can be automatically processed through the appropriate RINEX conversion utility to generate corresponding RINEX files that are then available for distribution, archival, or further processing.

Although most users of CORS data will usually retrieve the data they are interested in within a matter of hours or a few days after it is collected, a system allowing for permanent archival of the data should be considered. For various reasons, there will be instances where a user will need to access data that is weeks or many months old. Other uses for the data may be found well after the data are collected. With future generations of software, atmospheric modeling, etc., a considerable improvement in previous results might be realized by reprocessing old data. Also, questions of liability may present themselves in the future in which an organization will be required to produce some old data. Due to the large quantity of data that they must deal with, organizations involved in multi-station CORS networks are often using optical disk or CD-ROM technology for archival of observation data. Although there are some relatively small CORS programs that simply utilize floppy disks for archival, this would obviously be an unsatisfactory solution for any kind of full capability CORS network. The amount of data generated is simply too great.

The data distribution mechanism being utilized by most CORS programs is some kind of on-line system. Either an electronic bulletin board, accessed by telephone and modem, or INTERNET network connection are the two most common ways of dealing with this issue. At the other end of the spectrum, some systems distribute data on floppy disk, but this approach should certainly be avoided if at all possible. Since most users access the CORS data soon after it is collected, distribution systems usually make data easily available for a period of several days up to a few weeks. Usually, after that time period is over, the old data are taken off-line and archived by whatever means is being utilized. These off-line data can usually be accessed by users but a special request to the system operator is required. If the data are being archived on CD-ROM, copies of the pertinent CD-ROM can be distributed to users interested in old data that has been taken off-line.

A final issue of data handling that should be addressed by an organization developing a CORS capability is that of quality control. In order to insure that high quality data are being produced, several organizations have developed processing routines to analyze observation data in order to identify problems such as antenna multi-path situations, severe receiver noise or cycle slip occurrences, etc. Also, by performing repeated inter-station baseline calculations for a network of CORS stations, it is possible to monitor antenna positional stability in order to identify problems or changes with the antenna installation. Automated procedures can be established in order to perform these various checks on a routine basis.

V. EXAMPLES OF CORS ACTIVITIES

Individual CORS facilities and networks of many CORS stations have been developed by a number government, private sector, and academic organizations. Examples of CORS efforts include: local government agencies interested in supporting relative GPS positioning for a limited geographic area, such as a city; regional transportation departments required to support a variety of surveying and mapping efforts throughout an entire state or region; federal geodetic agencies involved in supporting relative positioning and the generation of GPS-related data products for an entire country; global, interagency services designed to support a wide realm of GPS activities around the world; and private sector companies involved in providing differential correction information to paying customers on a subscription basis.

For purposes of illustrating the CORS concept, I briefly discuss two examples of CORS networks: one that involves coverage for the entire United States and one that encompasses the entire globe.

In 1994, the United States National Geodetic Survey adopted an updated statement of its mission, vision, and goals.[(5)] The fundamental mission of the National Geodetic Survey is "to apply state-of-the-art methods of precise positioning and advanced geodetic, photogrammetric, and remote sensing techniques to establish and maintain a consistent national coordinate system and to support mapping, charting, navigation, boundary determination, property delineation, infrastructure development, resource evaluation surveys, and scientific applications." In support of this mission, 15 goals were identified that address various issues including the establishment and maintenance of, as well as educating the user community about, the National Spatial Reference System; the coordination of federal geodetic activities; research to improve geodetic and positioning techniques, including the use of GPS to obtain orthometric heights; the performance of specialty surveying and mapping of coastal areas and airports; and improvement in the production of GPS satellite ephemerides. An additional goal, that is a high priority item, is the coordination of efforts with various organizations to establish, maintain, and monitor a national CORS network. By developing such a network, the National Geodetic Survey hopes to provide the mechanism that will allow users to directly position their own permanent and temporary GPS reference stations relative to the National Spatial Reference System. A national CORS network will permit ongoing maintenance of this national coordinate system at the centimeter level. In addition, activities such as the monitoring of crustal motion and other specialized GPS applications will be supported by a CORS network. This effort to develop a national CORS system is now well underway with a prototype network of stations currently in operation.

The primary agencies cooperating with the National Geodetic Survey in this activity are the United States Coast Guard, Federal Aviation Administration, and Army Corps of Engineers. Such a multi-agency GPS-related activity is in accord with the recommendations of a recent report of the United States General Accounting Office that addressed concerns of duplication of effort between federal agencies involved in the use of GPS technology.[(6)] By agreeing to configure their CORS installations in a manner that supports multiple uses, the cooperating agencies are contributing to a multitude of applications in addition to those mandated by their various missions.

The Coast Guard is developing a national network of about 50 CORS facilities in coastal areas to support real-time marine navigation. This network is currently being installed and should be complete by early 1996. Each CORS configuration in this network will include GPS receivers for both the provision of differential correction data as well as for monitoring the integrity of the system. A marine radiobeacon will provide the differential data correction link to properly outfitted users navigating the waters of coastal areas. A staffed control station facility will perform centralized control and monitoring of the system. Communication between CORS sites and the control station, allowing for remote monitor and control capabilities, will utilize a federal government high speed telecommunications packet service, called X.25, that makes use of specialized telephone lines. This same communication service will also be used to transfer GPS data to National Geodetic Survey headquarters.

With the safety of mariners and vessels being dependent on the accuracy and availability of data provided by the Coast Guard CORS system, considerable reliability and component redundancy have been engineered into the system. Four GPS receivers and antennae at each site will provide significant redundancy in both differential correction and integrity monitoring tasks. System integrity software will support both the monitoring of the differential data being broadcast as well as communicating alarms and various status information to the control station.

The Army Corps of Engineers CORS stations will be configured essentially the same as those of the Coast Guard. When completed in the next three years, this network will consist of 10 stations designed to support real-time navigation along major riverways in the United States interior. Data from these stations will also contribute to the National Geodetic Survey's national CORS program.

In order to support en route aviation navigation, the Federal Aviation Administration is developing a national GPS capability, called the Wide Area Augmentation System. This system will consist of about 30 CORS stations, monitor and control facilities, and integrity monitors. Geostationary satellites will be used to broadcast the real-time differential GPS corrections to both commercial and private aircraft that are properly outfitted to utilize the information. A contract for the implementation of this system was just recently awarded and work should begin in the near future with completion probably by 1998.

The National Geodetic Survey's primary role in its national CORS network is to assemble GPS observation data collected at the various CORS facilities, archive it, and provide the mechanism for users to access these data. In addition, the National Geodetic Survey is working to determine horizontal positions and ellipsoidal and orthometric heights of all monumented reference points that are associated with these CORS antenna installations. The positions of the CORS antennae will be determined by GPS connection between the antennae and the nearby monumented reference points. These positions, both for the antennae and the monumented points, will be rigorously determined relative to the National Spatial Reference System, allowing users of CORS data to directly compute their positions relative to this national coordinate system. By repeatedly computing the baselines between various sets of CORS, the National Geodetic Survey will be able to monitor the stability of the antennae and to provide for integrity monitoring of system positions.

Although the three agencies' CORS programs mentioned above will be the primary contributors to this national network, other government CORS activities will be included into the network whenever desirable from the standpoint of geographic distribution. The national CORS network will eventually comprise about 100 to 200 individual stations and should be complete by about 1998. Data collected at contributing CORS facilities will be transmitted to the National Geodetic Survey by either INTERNET connection or high speed telephone line link. Once the data are received, various automated functions will be performed. These include converting the data to RINEX format, placing the data in hourly or daily files, executing quality control activity, and posting the data for access through INTERNET. Data will also be permanently archived on CD-ROM, which will be the mechanism for data access once the data is more than three weeks old. Eventually, the data collection rate for all observations contributing to this network will be five seconds, thereby supporting a very wide range of post-processed GPS activities. The proposed configuration of the central processing facility at the National Geodetic Survey includes separate parallel communication and processing systems that will provide for thorough redundancy in those components of the system.

Established by the International Association of Geodesy in 1993, the International GPS Service for Geodynamics (IGS) is an international effort designed to support a wide range of geodetic and geophysical research activities by providing several GPS data products. The technical foundation of the IGS is a global network of GPS data collection sites. About 40 of these installations, designated as core stations, are in permanent CORS configurations. During specific observational campaigns, this network of permanent stations is augmented by an additional 150 to 200 fiducial stations that are a mixture of CORS facilities and temporary GPS receiver configurations. Other important components of this system are data centers which are responsible for tasks such as the reformatting, compression, and archival of observation data collected from the contributing observation sites. Due to the large volume of data involved, the data centers are configured in a three tiered organizational structure. Together, they work to prepare the data for analysis centers, which are responsible for producing various derived products. IGS also includes a governing board and management organization that are responsible for general oversight and operation of the entire system.[(7)]

The products that the IGS derives from the GPS observations include high accuracy satellite ephemerides and clock information, earth rotation parameters, positions and rates of movement of the stations contributing to the network, and ionospheric information. These products, considered to be of high accuracy, are suitable to support a variety of activities including the monitoring of earth rotation characteristics, deformation of the solid earth, and variations in sea level and ice sheets. They are also used for efforts pertaining to the realization and improvement of the International Terrestrial Reference Frame (ITRF), monitoring the ionosphere, and scientific satellite orbit determination.

Although the primary function of the IGS is to provide derived data products, the GPS observations, in RINEX format, can also be accessed and utilized for relative positioning. By including observation data from an IGS station in a post-processed survey session, the survey is directly connected to a well defined global reference system.

IGS has rigorous requirements regarding GPS hardware, site characteristics, monumentation, etc. for organizations wishing to contribute data to the program. The core network stations are generally co-located with some type of facility involved in space-oriented research, such as very long baseline interferometry. By choosing such sites, relationships between various reference systems are more easily determined. In addition, such sites are often well configured for CORS installations. IGS is an excellent example of a successful multi-agency, international cooperative effort.

VI. CONCLUSION

GPS continuously operating reference stations are an important enhancement to a wide range of GPS surveying, mapping, and positioning activities. They can improve the efficiency and accuracy of the activities they support and may result in a host of derived data products that in turn make possible additional GPS applications. By configuring a CORS facility in an appropriate fashion, a sponsoring organization can contribute to an effort far greater in scope than that encompassed by its own mandate. As GPS technology continues to evolve, CORS facilities will play an increasingly more important role.

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