Pilot Projects/Committees

GLONASS IGEX-98 Campaign
IGS 1997 Annual Report

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The GLONASS system is a Russian navigation satellite system, very similar in its principle to the GPS system. Even if the GLONASS constellation of satellite is not yet operational, this system may have some geodetic applications in geodesy and geophysics that need to be studied, specially combined use of GLONASS/GPS receivers.

At the 1997 IAG Scientific Assembly in Rio de Janeiro in Brazil, it was decided that the CSTG Subcommission for Precise Microwave Satellite System È should organize an international campaign of observation for the GLONASS satellites. This action was done jointly with the IGS as the IGS Directing Board also decided at its Rio de Janeiro meeting to organize such a campaign.

Several scientific goals were foreseen: precise GLONASS orbits using GLONASS data from a worldwide international tracking network, terrestrial reference frame issues, possible use of GLONASS and GPS data.

A Steering Committee was appointed in Rio de Janeiro to organize such a campaign, called IGEX-98 (International GLONASS Experiment): G. Beutler, W. Gurtner, G. Hein, R. Neilan, J. Slater, Pascal Willis (chair). This campaign was supported by several associations or services: the International Association of Geodesy (IAG), the International GPS Service (IGS), the International Earth Rotation Service (IERS) and the ION (US Institute of Navigation).

In order to organize such a campaign, the Steering Committee met at the AGU Fall Meeting in December 1997 and decided to send out in early 1998 an International Call for Participation for stations (combined GPS and GLONASS measurements), Data Centers, Data Analysis Groups for GLONASS and SLR data. A Web site has been created (http://lareg.ensg.ign.fr/IGEX) in order to give information to submit the proposal of participation.

Several institutions have answered positively to the International for Participation (the list is accessible at this Web site). The Steering Committee met in Marne-la-Vallee, France on June 29, in order to validate and analyse these answers. On June 26, 47 proposals were received, leading to a possible network of 30 to 50 GLONASS/GPS receivers collocated at existing IERS sites (mainly IGS sites).

An IGEX mail facility (equivalent to the IGS mail) has been started in order to regularly exchange information between the different participants. The campaign is planned for 3 months starting from September 20, 1998 to December 20, 1998.

More information can be found on the Web at the following address:

http://lareg.ensg.ign.fr

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IGS/BIPM Time Transfer Pilot Project

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1 Introduction

The "IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons using GPS Phase and Code Measurements" was authorized in December 1997 jointly by the International GPS Service for Geodynamics (IGS) and the Bureau International des Poids et Mesures (BIPM). A Call for Participation was issued shortly afterwards with responses received from about 35 groups. The respondents have formed a working group co-chaired by C. Thomas, BIPM, and J. Ray, U.S. Naval Observatory (USNO).

A number of groups have been working for several years to develop the capability of using geodetic GPS techniques for accurate time and frequency transfer. A variety of convincing demonstrations has already been performed showing the potential for determining clock differences at the level of a few hundred picoseconds. The current state of maturity of both the global tracking network and data analysis techniques now allows practical applications to be considered. The central goal of this Pilot Project is to investigate and develop operational strategies to exploit GPS measurements for improved availability of accurate time and frequency comparisons worldwide. This will become especially significant for maintaining the international UTC timescale as a new generation of frequency standards emerges with accuracies of 10^{-15} or better.

The Project is expected to run until January 2000. By that time, those aspects which are suitable for integration into the operational activities and official products of the IGS or BIPM should be underway. To the extent that some functions may not be suitable for the existing structure of the IGS, a new coordinator for this might be appropriate. The progress of the Project and other related information is maintained at the Web site *http://maia.usno.navy.mil/gpst.mil*.

2 Areas of Participation

2.1 Deployment of GPS Receivers

In addition to the GPS receivers already installed as part of the IGS global tracking network, other receivers at laboratories having accurate time standards are sought. These should be high-quality geodetic receivers capable of recording and rapidly transmitting dual-frequency pseudorange and carrier phase observations. The station configuration and data distribution should conform to IGS standards and appropriate documentation must be filed with the IGS Central Bureau. A log file should be completed and sent to the IGS Central Bureau for each IGS station. For this Project, due consideration should be given to electronic stability, environmental control, and other factors which might affect the timing results. Upgrading of existing tracking stations for better timing performance is also encouraged. Deployment of dual-frequency GLONASS receivers, especially collocated at IGS sites, would provide an additional data source of interest.

2.2 GPS Data Analysis

Strategies for analyzing GPS phase and pseudorange observations must be developed, consistent with other IGS products, to allow the routine, accurate characterization of time standards at a large number of independent GPS receiver sites and onboard the GPS satellites. This work will be done in close cooperation with the IGS Analysis Center Coordinator. It is expected that regular reports will be issued by participating analysis centers, analogous to those distributed by the IGS for other activities, and filed in the IGS Electronic Reports series.

The precise relationship between the analysis activities that are needed for this Pilot Project and those required for the official products of the IGS is not entirely clear at this point. Certainly, the Project should build and rely upon the existing IGS structure. There may, however, exist a need for clock analysis and related products beyond the charter of the IGS. Also, some changes in the current analysis procedures of the IGS may be advantageous for enhanced timing performance. For these reasons it is essential that the Analysis Coordinator be actively involved.

2.3 Analysis of Instrumental Delays

In order to relate clock estimates derived from GPS data analysis to external timing standards it is necessary to understand the instrumental electronic delays introduced by the associated hardware. Studies are sought to characterize the short-term and long-term sensitivities to environmental changes and to develop suitable calibration methods. Differences for the L1 and L2 frequencies must be considered. Studies of both GPS ground sites as well as the GPS satellites are sought.

2.4 Time Transfer Comparisons

Simultaneous, independent time and frequency comparison data are needed to compare with the GPS-derived estimates. Collaborations are sought with groups performing time transfer experiments using a variety of techniques. Close cooperation is expected with the Consultative Committee for Time and Frequency (CCTF) of the ComitJ International des Poids et Mesures (CIPM).

3 Objectives

To accomplish the overall goal of improved global accessibility to accurate time and frequency using GPS, several specific objectives can be set.

3.1 Accurate and Consistent Satellite Clocks

Satellite clock estimates are among the "core" products of the IGS (Kouba *et al.*, 1998). The IGS combined solutions for satellite clocks are distributed together with the IGS combined orbits in the sp3 product files. It is essential that the clock information be as accurate as possible and also that it be fully consistent with the other IGS products. Kouba *et al.* (1998) describe the importance of global consistency to ensure that the point positioning technique (Zumberge *et al.*, 1997) can be applied without degradation.

A type of point positioning likely to become increasingly important is for tracking low Earth-orbiting satellites equipped with onboard GPS receivers. For this application the 15-minute tabulation interval of the sp3 orbit files is not adequate because the SA corruption of the broadcast clocks does not allow accurate interpolation over intervals longer than about 30 s (Zumberge *et al.*, 1998a). For this and other applications, the IGS ACs have been asked to provide satellite clock products with 30-s sampling rates and the IGS will probably begin producing a corresponding combined product (Springer *et al.*, 1998). Methods for efficiently computing high-rate satellite clocks have been presented by Zumberge *et al.* (1998b) and Soehne *et al.* (1998). A new exchange format will be needed to permit easy distribution of the new high-rate results.

3.2 Accurate and Consistent Station Clocks

Presently, the IGS does not produce clock information for the GPS ground stations although doing so is mentioned in the IGS Terms of Reference. There is a clear interest in the user community for this information. Apart from time transfer uses, it could be used to characterize and monitor the performance of station frequency standards. Clock solutions from stations equipped with very stable frequency standards (especially H-masers) are needed to apply the method of Zumberge *et al.* (1998a) to estimate high-rate satellite clocks. For this purpose, station clock determinations at intervals of about 5 minutes can be accurately interpolated to the 30-s intervals needed to solve for the satellite clocks provided that the ground stations are referenced to stable clocks.

For time transfer applications, such as envisioned for this Pilot Project, accurate analysis results for the station clocks are mandatory. As with high-rate satellite clocks, a suitable exchange format must be developed. Regular summary reports to describe the analysis results characterizing satellite and station clocks will be encouraged. These should be publicly distributed in the IGS Electronic Reports series. Some IGS ACs, particularly JPL and EMR, already include valuable clock information in the weekly analysis summary reports that accompany their Final product submissions.

From geodetic analyses of the GPS data, the effective "clock" of each station is determined for the ionosphere-corrected L3 phase center of the antenna displaced by the electronic delay to the point in the receiver where the time tags are assigned to the phase measurements. These clock determinations are relative measurements in the sense that usually a single station is chosen as a time reference and not adjusted. From the viewpoint of geodetic applications, the precise reference point of the analysis clocks is irrelevant. As a result, manufacturers of geodetic receivers have generally not taken care to provide easy or accurate access to the time reference points. However, for timing applications, such as time transfer comparisons with other techniques, the precise location of the clock reference and accurate access to it are essential. Consequently, the investigation of instrumental path delays and access points is critical to the success of the Pilot Project.

Even if one imagines a shift in the timing paradigm so that the GPS receivers are eventually regarded as a part of the outer ``electronics package'' of stable frequency standards, it is nonetheless vital to establish accurate access to the clock reference points. The effects of environmental influences will be even more important in that case and must be minimized. Doing so will require new approaches for isolating GPS receiver equipment, such as efforts by Overney *et al.* (1997).

3.3 Accurate and Stable Reference Timescale

Ultimately, it is necessary that all clock information, for satellites and stations, be referenced to a common, consistent timescale. Individual sets of results from different ACs generally refer to different reference clocks. Thus, in the IGS combination process, the AC submissions must be realigned. This is currently done by choosing one submission as a reference solution, realigning its satellite clock estimates to GPS time based on the broadcast clocks for all the satellites (using only daily offset and rate terms), and then realigning all the other AC submissions to the reference solution (Springer *et al.*, 1998). Corrections are applied to each solution set to account for radial orbit differences compared to the IGS combined orbits. The IGS combined satellite clock estimates are then formed from the weighted average of the realigned, corrected submissions.

It has been suggested that the clock realignment and combination process would be improved if a common set of "fiducial" station clocks were used in all analyses and included in the IGS submissions (Springer *et al.*, 1998). Naturally, only stations equipped with very stable frequency standards (preferably geometrically well distributed) should be considered as candidate fiducials. Recommendations for this station set will likely be made during 1998.

Likewise, it is questionable whether GPS time is an appropriate choice for the underlying IGS timescale. The ideal choice should be accurate, accessible, and stable over all relevant time intervals (namely, 30 s and longer). GPS time is readily accessible but not with an accuracy comparable to other IGS products due to SA effects. Nor is GPS time particularly stable. The clocks of the GPS constellation are monitored from USNO and this information is provided to GPS operations with the goal of maintaining GPS time within 28 ns (RMS) of UTC(USNO), allowing for accumulated leap second differences. In practice, the two timescales have been kept within about 6.5 ns (modulo 1 s) over the last two years (for 24-hour averages). However, the GPS time steering algorithm has a ``bang-bang" character resulting in a saw-tooth variation with a typical cycle of about 25 days. This is equivalent to a frequency error greater than 10^{-14} over days to weeks, which changes periodically in an abrupt, nearly step-like fashion.

Almost certainly, an internal ensemble of the frequency standards used in the IGS network can be formed which would possess better stability than GPS time (Young *et al.*, 1996). There are currently about 27 IGS stations using H-masers, and about 40 with Cesium or Rubidium standards. Addition of new IGS sites located at primary timing laboratories would only improve this situation. A purely internal IGS timescale would probably not be stable against long-term drifts so some linkage to external laboratory timescales is required. Indeed, tracability to UTC(BIPM) is most desirable. In principle, this could be accomplished using the instrumental calibration data mentioned above, especially for the fiducial clock sites. It will be technically difficult, however, to achieve comparable accuracies for the calibration measurements to the few hundred picosecond level possible for the data analysis clocks. This will be one of the greatest challenges for this Pilot Project.

An alternative approach to provide external linkage that can be readily implemented uses monitor data for the GPS constellation that are collected and compared at the timing labs. USNO collects such data using pseudorange timing observations and makes the results publicly available. Using the observed offsets of GPS time relative to UTC(USNO), the corresponding IGS clock estimates can be related to UTC(USNO). Because of the effects of SA such comparisons would only be useful to remove long-term differences. This is probably sufficient, at least for an initial realization. Other timing laboratories would be encouraged to provide similar monitor data for a more robust tie to UTC(BIPM). A potential problem with this approach is possible biases between the effective clocks transmitted by the satellites as measured from the pseudorange and carrier phase observables.

Apart from the issues discussed above concerning calibration and external referencing for an IGS timescale, there are other practical questions that must be resolved. In particular, it may be difficult to form and maintain a timescale within the IGS product delivery schedule. This is likely to be especially true for the Rapid products even though that is probably also where the greatest user interest lies. Fundamentally, this does not seem overwhelming although it will require entirely new and highly automated IGS processes. Other practical concerns are minimizing discontinuities at day boundaries, dealing with clock discontinuities and drop-outs in the ensembling process, and finding an appropriate robust ensembling algorithm. These subjects, together with those mentioned above, should be studied during this Pilot Project.

4 References

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IGS Combination of Tropospheric Estimates -- The Pilot Experiment

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1 Introduction

The existing global and regional networks of permanent GPS receivers installed for geodetic and navigational applications can be used with marginal additional cost for determination of atmospheric water vapor with high temporal and spatial resolution. In different countries projects are under way in which the impact of GPS derived water vapor on the improvement of weather forecast are studied. Within the IGS a network of more than 100 globally distributed sites is analyzed on a daily basis. The zenith path delay (ZPD) values obtained should be converted into precipitable water vapor (PWV) and should be made available to the scientific community.

This IGS product could meet the demands for climatological studies. Here a time resolution of 2 hours (this is what IGS will provide) is sufficient, because long-term characteristics are of interest only, and a time delay of a few weeks for product delivery is acceptable.

Since the beginning of the Pilot Experiment six of the global IGS Analysis Centers (ACs) have regularly contributed (Table 1). Different mapping functions and elevation cutoff angles of 10, 15 or 20 degrees are implemented. The number of sites per AC varies from 30 to 85, and their were 100 sites in total. The product from the combination is a weekly file for each site containing the ZPD estimates and precipitable water vapor if conversion is possible. Additionally, a combination report will summarize some statistics on the differences to the IGS Mean (bias, standard deviation), for the global mean of each AC and separately for all sites.

Table 1. Contributing Analysis Centers with some relevant parameters

	ZPD[min]	Cutoff[deg]	No.Sites	Mapping Function
CODE	120	20, 10(wk 926)	85	Saastmoinen; Niell (week 926)
EMR	60	15	30	Lanyi
ESA	120	20	50	Saastmoinen
GFZ	60	20	55	Saastmoinen; Niell (week 929)
JPL	5	15	37	Lanyi; Niell (week 920)
NGS	120	15	55	Niell

2 Comparisons, Results

For comparisons the differences between individual AC estimates and the IGS can be used. More than 60 sites are used by at least three ACs, so that sufficient statistical information about the quality of the tropospheric estimates can be gained. For most sites and ACs the stddev is ±6 mm ZPD (which corresponds to ±1 mm PWV) and it approaches in many cases the ±3 mm level. The magnitude of the stddev is of course highly correlated with the magnitude in the repeatability of the estimated station coordinates. Looking into the geographical distribution of the magnitude for the stddev the largest stddevs can be found in the equatorial region. The bias for most sites is below ±3 mm. Even for sites with a larger bias its repeatability is very high.

The global mean stddev (mean over all sites) of the best ACs is at the 4 mm level (Figure1). Only a small global bias at the 1 mm ZPD level can be stated. However, significant effects of ±1-2mm from AC to AC exist. ACs having changed their parameters (cmp. Table 1) show larger jumps correlated with those changes.

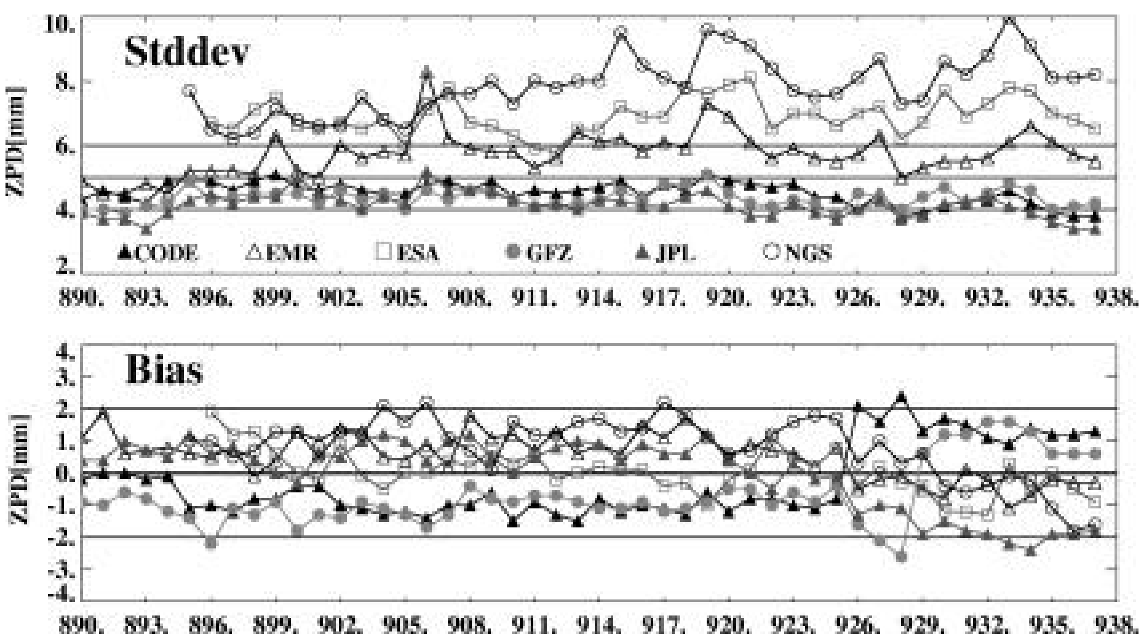

Fig. 1. Difference between AC ZPD and IGS Combined ZPD. Mean values (mean over all sites) per week and Analysis Center

The biases for fiducial (or other well determined) sites are very small, and the repeatability is at the 2 mm ZPD level. However, larger systematic effects can be found for some sites too, especially in the equatorial region. Here systematic effects of about ±6 mm exist with single peak to peak differences in the weekly biases of 20 mm. The bias differences could be reduced by taking into account the well-known correlation between the station height and the ZPD estimates. This works rather well for some sites, but not for all. However, such a procedure will not be recommended because any corrections to the estimates are dangerous. It is better to reduce the scattering in the determined station heights. One step in this direction will be the enlarged set of 52 fiducials, which will be constrained to a certain extent by all the ACs. The introduction of a smaller elevation cutoff angle may also help to reduce the bias.

3 Conversion into Precipitable Water Vapor

For the conversion meteorological surface measurements are needed. At the moment 19 sites report regularly their met data to the global data centers. Ten further sites have announced the installation of met packages, but the data are not yet available. The met data must be of high precision (1 mbar corresponds to 0.35 mm in PWV) and reliability (continuous time series). For some sites too many missing days or larger gaps must be stated. In those cases no meaningful series of PWV could be produced. Unfortunately, only 10 to 15 reliable sites with met sensors exist at the moment (a small percentage of all analyzed sites).

The GPS derived PWV estimates can be compared with WVR measurements to get a measure for the absolute accuracy. Only at POTS measurements of a collocated WVR were available. A WVR-1100 of Radiometrics Corporation is operated by Meteorological Observatory Potsdam of the German Weather Service, and is located 400m apart from the GPS receiver. The agreement of the GPS results (both CODE and GFZ) with the WVR is at the 1 mm level (Figure 2). The stddev of the difference approaches ±0.5 mm, the bias has a level of ±1 mm and shows some long-periodic behavior for both GPS results. The difference between the two GPS solutions is smaller than their differences to the WVR measurements.

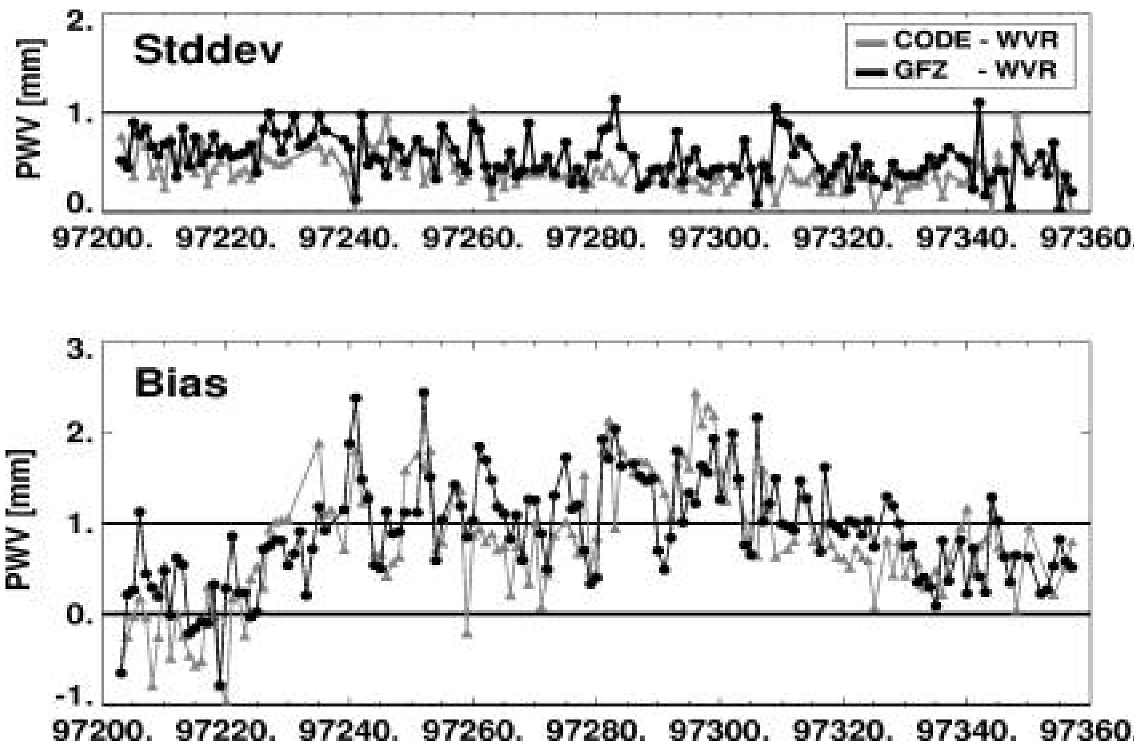

Fig. 2. Comparison of PWV estimates from GPS and WVR at POTS. WVR data are from Meteorological Observatory Potsdam, 400 apart from GPS receiver.

4 Summary

During the one year experiment all components involved in the combination have performed well and timely. The ZPD estimates have a high quality for all the weeks. The consistency is at the 4 to 5 mm level both for the bias and for the stddev.

The importance of the IGS contribution to climate research will not only depend on the quality of the ZPD estimates but also on the number of sites which could be equipped with met packages. The number of instruments available now is not sufficient.

To get a better insight into the behavior of the bias more collocated WVR should be made available, either at existing IGS sites or at non-IGS sites which then should be analyzed by all IGS ACs for some test periods.

The pilot phase for the IGS Combined Tropospheric Product is finished and the combined zenith path delay (ZPD) estimates are an official product now. The conversion into precipitable water vapor will be postponed until a sufficient number of surface met packages is available. At the moment it is to the customer to convert the ZPD by relying both on the existing RINEX met files as well as on interpolation within global or regional meteorological fields. The product will be archived at the global Data Centers.

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1997 IGS Activities in the Area of the Ionosphere

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A subsession was dedicated to the ionosphere at the IGS workshop in Potsdam in May 1995 and again at the IGS workshop held in Silver Spring in March 1996. In preparation for the latter, an intercomparison of ionosphere TEC maps and satellite differential code biases was initiated. Five Analysis Centers (ACs) contributed to this intercomparison, for which TEC data over a time span of five weeks had been used. The intent of this intercomparison was to get an idea of the accuracies that can be achieved. Additionally it could be identified which ACs were interested in contributing to an IGS ionosphere product.

However in 1996, most of the ACs were still in a development stage with their modeling and software, and at this time they were not in a position to produce ionosphere products for the IGS on routine basis. During the year 1997, the ionosphere activities at the ACs were thus concentrated in the background rather than in the foreground, and some of the ACs modeling capabilities were significantly improved during that time. These improvements include the successful prediction of ionosphere model parameters as well as first attempts to model the ionosphere's electron content 3-dimensionally.

Another important thing that was achieved in 1997 was the development of the so-called IONosphere Map EXchange Format (IONEX) (Schaer et al., 1997), defining for the first time which and how ionosphere products should be exchanged. The IONEX became in the meantime the mandatory ionosphere format within the IGS.

At the Darmstadt IGS workshop in February 1998 it was then decided to start a coordinated routine processing and a combination of IGS ionosphere products. Based on a Position Paper (Feltens and Schaer, 1998) and a Terms of Reference (Schaer and Feltens, 1998) an IGS Ionosphere Working Group has been established at 28 May 1998, which started immediately with its pilot phase in June 1998.

The importance of an IGS engagement within the area of ionosphere science is obvious, and representatives of the ionosphere community have indicated a great interest in a continuous series of global IGS ionosphere models. Since mid 1996 we are approaching the next solar maximum. Therefore good and rapidly available information about the ionosphere's actual state becomes increasingly important. Users of satellite navigation systems need accurate corrections to remove signal degradation caused by the ionosphere, information on the ionosphere's behavior is of great importance for radio signal propagation applications, and scientists will benefit from up-to-date and long-term ionosphere information.

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IGS Infrastructure Committee Report

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1 Introduction

The IGS Infrastructure Committee was established by the IGS Governing Board at its meeting in Rio de Janeiro in September, 1997. The primary motivations for the formation of this committee was to assist the IGS Central Bureau in:

1. eliminating existing discrepancies that impact the accuracy, reliability, and timeliness of IGS products (e.g., incorrect or ambiguous antenna heights, incorrect or ambiguous RINEX data file headers),

2. identifying weaknesses in station infrastructure and recommending actions (e.g., replacing aging and obsolete equipment, evaluation of monumentation and long-term site stability, evaluation of data flow), and

3. re-evaluating and promoting adherence to IGS standards within the IGS organization (e.g., site standards, station reporting, data quality and reliability, data archiving and dissemination).

The committee identified several actions that could improve the IGS infrastructure:

1. Development of guidelines for IGS tracking stations and operational centers
2. Promotion of improved communications between operation centers
3. Recommendation of courses of action to the Governing Board and Central Bureau
4. Preparation of an automated site log preparation scheme to solve the persistent problem of contradicting or missing information about sites
5. Preparation of a network "road map" to chart data collection and data flow
6. Preparation of a station performance table

2 Progress

The committee in consultation with the IGS Central Bureau prepared two documents (initially drafted by Werner Gurtner) which were adopted as IGS policy by the Governing Board at its meeting in Boston in May, 1998:

1. Joining the IGS
2. Guidelines for IGS Stations and Operational Centers

The first document describes the procedures to be followed when establishing a new IGS station. The second document gives guidelines for operating IGS tracking stations and Operational Centers.

The documents can be found in Appendices A and B. The latest version of these documents is being maintained by the IGS Central Bureau (//http://igscb.jpl.nasa.gov/)

Committee members have been active in planning for the IGS Network Workshop planned for November, 1998 in Annapolis, Maryland. An organizational meeting of the network planning committee was held at Scripps Institution of Oceanography in August, 1998. At the meeting the following actions were adopted in preparation of the November workshop and to meet the objectives of the infrastructure committee:

1. Preparation of a network “road map” to chart data collection and data flow (led by the Central Bureau).
2. Preparation of an automated site log preparation scheme to solve the persistent problem of contradicting or missing information about sites (led by Scripps Orbit and Permanent Array Center).

APPENDIX A: Joining the IGS

Version 1.1 ((reformatted for IGS Report, August 31, 1998))
(prepared by IGS Infrastructure Committee and Central Bureau)
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A.1 Introduction: Procedures for Becoming an IGS Station

This document describes the procedures to be followed when establishing a new IGS station. It is applicable to stations of global and regional interest, and includes detailed steps to be taken by the responsible agency, in consultation with the IGS Central Bureau (CB). Also described in this document are maintenance of the public station log files and procedures related to data flow, archiving, and analysis.

> *Note: The IGS recommends that these procedures also be applied to stations of local interest, as well. However, the IGS does not take any responsibility for completeness, correctness, nor for data processing and data archiving for "Local" stations.*

For more detailed descriptions of station requirements with respect to monumentation, receiver, antenna, data handling, documentation, and data formats please refer to "Guidelines for IGS Stations and Operational Centers."

All electronic messages, unless otherwise specified, should be sent to the CB at igscb@igscb.jpl.nasa.gov.

A.2 Initial Steps

Contact the CB concerning the intent to install the station(s). Include a statement of desire for the station to be considered as part of the IGS network. Clearly identify the schedule for implementation, the responsible installation agency, the responsible operational agency once the site is established, and the funding agency (including prospects for long-term funding support).

A proposed four character station identifier should also be included for confirmation by the CB. The CB will assist in the designation of the identifier to prevent duplication.

The CB will announce the new station on its schedule of future or proposed stations.

A.3 Site Installation

IGS standards need to be followed when installing the station. (see "Guidelines for IGS Stations and Operational Centers").

Once the station is installed and operational, a communication should be addressed to the CB indicating the data availability.

A.4 Station Log

If the new station is part of an existing network, the responsible Operational Center has to update the center description form (download /igscb/center/oper/'center'.ocn from igscb.jpl.nasa.gov, modify, and send an electronic notification to the CB).

If the station is part of a new network, the new Operational Center has to create a center description form (download /igscb/center/oper/BLNKFORM.OCN from igscb.jpl.nasa.gov, modify, and send electronic notification to the CB).

A station log must be prepared (download /igscb/station/general/BLNKFORM.LOG from igscb.jpl.nasa.gov); many examples are available in /igscb/station/log.

Forward the station log to the IERS with a request for a DOMES number; this is the numbering system that is used by the International Earth Rotation Service (IERS) to keep track of all space geodetic stations. Instructions on obtaining a DOMES number is available from the Laboratoire de Recherche en Géodésie (LAREG) (http://lareg.ensg.ign.fr/ITRF/domesreq.html). The IERS will assign a DOMES number for the station and any other monument or reference marker located at the same site location.

Forward completed station log (updated with DOMES number) to the CB to be included into the Central Bureau Information System (CBIS). E-mail files to the CB.

Mandatory items include: Station name, 4-character site code, DOMES number, approximate coordinates (X/Y/Z and/or lat/lon/elev), antenna height and description, receiver and antenna types, antenna diagram (see files rcvr_ant.gra, antenna.gra available at ftp://igscb.jpl.nasa.gov/igscb/station/general for correct names), eccentricity elements (if any) to nearby geodetic markers at the same site location, contact addresses.

Important Note: Station log files with missing or incorrectly entered information will not be accepted by the CB.

When all the information is available on the CBIS an announcement should be prepared by the implementing agency for distribution through IGSMail. (It is not necessary to distribute the log file itself through IGSMail).

A.5 Station Log Updates

Whenever there is an update or change to the information contained in the station log file, the current log file should be downloaded from the CBIS (/igscb/station/log) and modified by adding the new information and the modification date. This file should be sent back to the CB and an announcement of the modification should be made through an IGSMail message. This procedure ensures that modifications of the station log done by the CB will be preserved.

Important Note: Any changes at the site must be relayed promptly (preferably in advance) to the CB and posted via IGS Mail. In particular, these include but are not limited to changes in monument, GPS equipment, and antenna height.

A.6 Data Format

It is the responsibility of the Operational Agency to provide GPS data to the IGS in Receiver Independent Exchange (RINEX) format. The RINEX files must be prepared following the guidelines for IGS stations and Operational Centers (“Guidelines for IGS Stations and Operational Centers”, “rinex2.txt”).

To ensure compatibility, send an extract of a sample daily RINEX file (header, first and last few epochs of data records, ASCII) per e-mail to the CB.

A.7 Data Flow and Archive

The long-term archiving of the data falls within the responsibility of the Operational Center.

If the station is part of a local, regional or special network (e.g. SCIGN, EUREF, CIGNET, JPL FLINN) the daily data files have to be sent to the respective data centers from where they will be forwarded, if appropriate, to other IGS Data Centers.

The operational agency needs to inform the CB to which IGS Data Center it is planning to send its data.

The data from regional networks that will not be processed by more than one IGS Analysis Center can be kept in the Regional Data Center and not forwarded to an IGS Global Data Center.

The data of sites of local networks not to be processed by an IGS Analysis Center should be kept in their respective Local Data Center, or forwarded to a Regional Data Center.

Important Notes:

Daily data may not be accepted by the IGS Data Centers if station log files are missing or incomplete, if the RINEX data files are not correctly formatted or incomplete, or if the station log files and RINEX file headers are inconsistent.

Individual data files may not be accepted by the IGS Data Centers if the files contain less than 10 percent of the nominal amount of data.

A.8 Data Analysis

“Global sites” are those sites of global interest that are processed by at least three Analysis Centers located on more than one continent. That is, data from these sites contribute significantly to the production of IGS global products (e.g., satellite orbits, EOP). New sites which contribute significantly to regional densification of the IGS polyhedron are classified as “Regional sites.” Otherwise, a site is classified as a “Local site.” Analysis of Local sites will be performed by a local analysis center and will not be the responsibility of the IGS.

For densification purposes the results (especially coordinates and velocities) may be forwarded as SINEX files to Associate Analysis Centers to be included into combined solutions (SINEX: see ftp://igscb.jpl.nasa.gov/igscb/data/format/sinex.txt).

Important Note: IGS Analysis and Associate Analysis Centers may not process data and submit results to the IGS of those sites not meeting all of the requirements outlined in this document.

APPENDIX B: Guidelines for IGS Stations and Operational Centers
Version 1.2 (reformatted for IGS Report, August 31, 1998)
(prepared by IGS Infrastructure Committee and Central Bureau)
****

B.1 Introduction

This document gives guidelines for operating IGS tracking stations and Operational Centers. For potential or new IGS participants, please refer to the document "Joining the IGS" (Appendix A).

B.1.1 Organization of the IGS Data Flow

En route to Analysis Centers and other users, the tracking data collected by permanent GPS receivers flow through the following components of the IGS network:

- Tracking Stations (TS): They set up and operate the permanent GPS tracking receivers and antennae on suitable geodetic markers.

- Operational Centers (OC): They perform data validation, conversion of raw data to Receiver Independent Exchange Format (RINEX), data compression, and data upload to a data center through the Internet. For some sites the OC is identical with the institution responsible for the respective site (i.e., the OC is identical with the TS).

- Local Data Center (LDC): They collect the data of all stations of a local network and distribute them to the (local) users. One or more of these stations are part of the IGS network. For many of the local networks the LDC will be identical with their Operational Center.

  The LDC will forward the data (of a selection) of the local sites to the Regional Data Center.
  If there is not a LDC for particular data, data will flow directly from the OC to the designated Regional Data Center.

  Note: These guidelines do not pertain to local networks which are not part of the IGS network, nor to any actions of Local Data Centers related to non-IGS stations.

- Regional Data Centers (RDC): They collect all the data of a certain region (e.g., Europe) or special network (e.g., JPL) and make it available to the users, especially to those of the respective region. They forward the data of the sites of global interest to one of the three Global Data Centers.

- Global Data Center (GDC): They collect the data of global interest from the Regional Data Centers. They equalize their data holdings among themselves and make the data available through anonymous ftp to the users, especially to the IGS Analysis Centers.

B.1.2. Requirements for Permanent Stations

Because the user of the network will be mainly interested in the data and the necessary auxiliary information about the tracking sites, we do not make a clear distinction between the activities and responsibilities of the Tracking Stations and the Operational Centers.

Very strict rules are inconsistent with the nature of the IGS. However for a station to be included in the IGS Network, the following guidelines will be used to judge the merits of a candidate station. Please consult also the check list of how to become an IGS station.

Instrument

The GPS receivers should

- track both codes and phases on both frequencies under non-AS- (anti spoofing) as well as AS-conditions
- track at least 8 satellites, simultaneously
- track at least with 30 seconds sampling rate. If the sampling rate is faster, the data should be decimated to 30 seconds prior to upload to the Regional Data Center
- synchronize the actual instant of observation with true GPS time within +- 1 millisecond of the full second
- be protected from power failures wherever feasible. If the data are downloaded in real time to an external PC without being stored in the receiver for a certain time, the same protection should include the PC as well

Antenna

- The antenna should include a Dorne-Margolin element and a choke ring
- The antenna should be oriented in the manner proposed by the manufacturer.
- The antenna should be protected against a heavy snow load, other meteorological factors, and vandalism by use of an antenna cover (“radome”). The effect of the radome on the antenna phase center should be determined. Various radome designs are available from the IGS Central Bureau.

Marker

The marker should fulfill standard requirements for a first order geodetic monument with respect to stability, durability, long-term maintenance, documentation, and access. The marker description should be fully documented in the IGS site log file (see *Documentation* below).

Obstruction should be minimal above 15 degrees elevation, but visibility to lower elevations is encouraged whenever possible.

Signal reception quality has to be verified, especially with respect to interference of external signal sources like radars, and with respect to multipath.

The antenna height corresponds to the vertical distance of the agreed-upon physical reference point (see antenna diagrams) on the antenna above the marker.

Local ties to other markers on the sites should be determined in the ITRF coordinate system to guarantee 1-mm precision in all three dimensions. Offsets are given in delta-X, delta-Y, delta-Z, X,Y,Z being the geocentric Cartesian coordinates (ITRF).

Documentation

A standard IGS site description file (log file) should be filled out and sent to the IGS Central Bureau at e-mail:

igscb@igscb.jpl.nasa.gov

Blank forms are available through anonymous ftp at the IGS Central Bureau Information System (CBIS):

ftp://igscb.jpl.nasa.gov/igscb/station/general/blank.log

Consistency in both format and content is strongly encouraged. Additional site descriptions (photos, maps, etc) should be sent to the Central Bureau.

B.1.3 Operational Centers

Responsibilities

The Operational Centers control the sites of a particular (local) network from the operational point of view.

They form a link between the sites and the Data Center. The Data Center then makes available the data to the Analysis Centers, other Data Centers, and individual users.

The Operational Centers are responsible for

- the download of the raw data from the receivers of the local network
- the archiving of the raw data
- the reformatting of the data into the agreed-upon exchange format (RINEX)
- the quality check of the data on a station by station basis

- the generation of status messages (abnormal conditions)

- the alert/engagement of on-site personnel (abnormal conditions)

- the upload of the data to the Data Center at agreed-upon times

Within the International GPS Service for Geodynamics there are many independent tracking sites (e.g. Zimmerwald, Herstmonceux) that are not part of a local or special network. As such they are not connected to an actual Operational Center. In this case the organization operating the site also performs the tasks outlined above.

Data Download From the Stations

The downloading from the receiver to the Operational Center's computer system can either be done directly or indirectly through a small on-site computer, e.g. a PC:

```
+-----------+       +------------+
| receiver |--------| on-site PC |-----+
+-----------+       +------------+     |
                                  |    +--------------------+
                                  +-----| Operational Center |
                                  |    +--------------------+
+-----------+                          |
| receiver |----------------------------+
+-----------+
```

The PC could download the data from the receiver continually, using e.g. some manufacturer-provided download software.

The communication between the Operational Center and the stations can be achieved through any one of several means, including dialup modem, Internet, special-purpose data links, Inmarsat, etc. Station communication configuration information should be included in documentation provided to the CB.

Data Archive

As the exchange data format does not conserve all information found in the raw data it should not be used for the primary data archiving. The Operational Center is responsible for the long-term data archiving unless this task has been delegated to the Tracking Stations. The original raw data files or compressed (e.g. zipped) raw data files are usually archived.

The IGS Data Centers archive the RINEX files for the general benefit of the IGS.

Data Format

The data are to be prepared in daily (24 hours) RINEX files, both for observations and broadcast navigation messages. This is the current standard. For emerging applications (e.g., atmospheric sensing, Low-Earth-Orbiters -- LEO’s) more frequent data collection and preparation may be considered by the IGS.

The daily observation files contain the observations collected between 00:00:00 and 23:59:59 GPS time. The sampling rate (observation interval) must be the adopted standard, currently 30 sec. In case of a higher original observation rate a decimation of the data to the adopted standard is mandatory.

The header information, especially the station name, receiver and antenna information, and antenna height, must be up-to-date and has to strictly follow the agreed-upon conventions (see blank log forms for the stations). Consistency in both format and content is strongly encouraged.

The navigation message file contains all messages with TOC/TOE (time of clock, time of ephemeris) between 00:00 and 23:59 GPS time of the respective day.

It is recommended to generate a combined daily RINEX navigation file containing non-redundantly all navigation messages collected by all sites of a local network. The filename (part "ssss", see below) should then contain a 4-character code of the Operational Center.

The RINEX navigation files are prepared in a compressed form using the standard UNIX compress program. The RINEX observation files are additionally compressed using the Hatanaka compression scheme. Compress and decompress programs for other platforms (PC/DOS, VAX and Alpha VMS) are available at the IGS CBIS:

ftp://igscb.jpl.nasa.gov/igscb/software/compress (for the UNIX Compression)
ftp://igscb.jpl.nasa.gov/igscb/software/rnxcmp (for the Hatanaka Compression)

File Type	**ASCII File**	**Compressed Files**		
	UNIX	UNIX	VMS	DOS
Observation	ssssdddf.yyO	ssssdddf.yyD.Z	ssssdddf.yyD_Z	ssssdddf.yyE
Navigation	ssssdddf.yyN	ssssdddf.yyN.Z	ssssdddf.yyN_Z	ssssdddf.yyN
Meteorological	ssssdddf.yyM	ssssdddf.yyM.Z	ssssdddf.yyM_Z	ssssdddf.yyM

ssss: 4-character station code
ddd : day of the year of the first record
f : file sequence number within the day
0: containing all data of the day
yy : year

The extension yyD (or yyE in DOS) indicates Hatanaka-compressed files. More information about the Hatanaka compression can be found in

ftp://igscb.jpl.nasa.gov/igscb/software/rnxcmp/docs/README

Files sent to another host must be named on the target system in accordance with the target operating system:

Example: Put a file from a UNIX to a VMS system:

```
binary
put zimm1230.94D.Z ZIMM1230.94D_Z
```

Data Validation

Data should be checked before being sent to a Data Center. A minimum verification should consist of a check of

- the total number of observations
- the total number of observed satellites
- the date of the first observation record in the file

· the station name, receiver/antenna types, antenna height

The use of a true quality check program is highly recommended, e.g. UNAVCO's QC program (available through the IGS Central Bureau Information System, directory /igscb/software/qc).

Files which do not meet the minimum verification should not be sent to a Data Center.

Data Handling

It is highly recommended that all steps in the data handling -- download from the receiver, reformatting, data validations, generation of statistics, data archiving and transmissions -- be fully automated. Data failing to pass the validation step should be kept back for manual treatment and then posted.

Data Upload

The data must be sent daily to a designated IGS Data Center, via a Local Data Center if appropriate.

The IGS Data Center to be used is assigned by the Central Bureau. Alternate and back-up routing will also be assigned in case of emergency and should be fully tested.

Timeliness of the Data Transfer

In order to allow for rapid analysis of the data and to avoid the times of heavy network traffic on the international data lines the data should arrive at the Regional Data Center not later than 2 hours after midnight Universal Time, to be forwarded to one of the Global Data Centers not later than 03:00 UT.

Documentation

The IGS Central Bureau Information System makes available a blank form for an Operational Center description file (blankform.ocn in /igscb/center/oper). This form should be filled out by the Operational Center or by the agency operating an independent permanent GPS station and sent to the Central Bureau.

B.1.4 Local Data Centers

General

Depending on the policy of the respective agencies, the tracking data and the auxiliary station information of the local network can be made available through computer networks or bulletin boards etc. This task would be the responsibility of a Local Data Center.

Stations not part of a local network send their data directly to the designated IGS Data Center.

Data Access

It is recommended to allow access to (all or part of) the data through Internet's anonymous ftp, currently being the most effective and easy to use access method, especially for automated data download. Another access procedure on Internet is through World Wide Web (WWW) servers with easy to use browsers such as Mosaic or Lynx.

Available Information

It is recommended to make available at least the following information:

- Station information (site log files, requested)
- Data Center Information (blank forms and examples can be found in the IGS CBIS (ftp://igscb.jpl.nasa.gov/igscb/center/data).
- Other network information: Data flow, Operational Center description, reference and access to other networks (EUREF, IGS, ...)
- Daily tracking data (RINEX files), including results of quality checks
- Data holding information (i.e. a machine-readable summary of the available tracking data). Examples can be found in directory ftp://igscb.jpl.nasa.gov/igscb/data/holding. A program to generate such a data holding file can be obtained through the IGS Central Bureau.
- Status information about the network and GPS in general and cross-references to other information systems

Sites for which there is incomplete, incorrect, or contradictory documentation will be identified automatically at the Central Bureau. A notification will be made to users by the CBIS. Users of data may use this information as they see fit. However, the expectation is for these discrepancies to be eliminated.

Data Organization

It is recommended to organize at least the tracking data in a hierarchical directory structure. From the user's point of view it is usually preferable to combine all the data of one day (or one week) into one directory than to have station-dependent directories. Examples of directory organizations can be found in the IGS Data Center description files (ftp://igscb.jpl.nasa.gov/igscb/center/data).

All the other information can be made available either through ASCII files in a directory tree or through more advanced means like data bases of hypertext documents or, preferably, through both.

The Local Data Center description file and the daily updated data holding file should be made available to the IGS Central Bureau Information System.

Data Transfer to the Regional Data Center

The tracking data of stations that are also part of an upper level network (EUREF, IGS) have to be forwarded through Internet to the respective Regional Data Center by anonymous ftp, or other reliable electronic means. It is recommended that a binary (image) "put" be used.

B.1.5 Data Analysis

- Although the IGS Analysis Centers are free regarding which sites to process they should not report results (such as coordinates and velocities) for sites for which there are no correctly filled out log files available at the IGS CBIS. In principle the corresponding RINEX data files should also be available at least one IGS Regional Data Center. Data available only from Local Data Centers should be used by special arrangement only.

- The Analysis Centers are requested to use the primary site information (DOMES numbers, receiver and antenna names, antenna heights, antenna phase center information) provided in master files available at the CBIS.

- The Analysis Centers and Associate Analysis Centers are requested to ensure that their SINEX files are consistent with the site information provided in master files available at the CBIS.

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Continuous GPS Positioning of Tide Gauges: Some Preliminary Considerations

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1 Introduction

The IGS is working with the oceanographic community to begin implementation of the long-considered step of adding continuous GPS (CGPS) stations to tens of tide gauges around the world so as to reference sea level at this set of points to the ITRF. A technical committee formed under the auspices of the IGS and the PSMSL was established at the 1997 JPL Workshop in order to write a set of standards for groups constructing these CGPS stations. During its discussions the committee has come to realize that the oceanographic community is pursuing several different agendas, and that these efforts have distinct accuracy requirements and are impacted in different ways by various geotechnical considerations and local environmental factors. There are two main agendas:

(i) The ‘centimeter’ agenda. The idea is to establish the absolute vertical position of the tide gauge and its benchmarks (and ultimately the local sea level history) with an accuracy of 2 - 3 cm, for the purpose of calibrating and/or validating modern satellite altimeter measurements (e.g. TOPEX). The oceanographers engaged in this activity typically place little importance on providing tectonic corrections for historical sea level data obtained at their calibration stations.

(ii) The ‘millimeter’ agenda. Tide gauge measurements reflect vertical motions of both the land (to which the gauge is attached) and the sea surface. The intra-annual, annual and even decadal fluctuations recorded by a tide gauge are usually totally dominated by absolute sea level changes. But when averaged over much longer periods of time (~100 years) the rates of vertical motion of the land and the sea surface are often similar in magnitude (~ 1 mm/yr). In order to obtain an absolute sea level history from a long historical record of relative sea level change, it is necessary to estimate the rate of vertical motion of the land or structure supporting the tide gauge. The goal is to use CGPS to measure the vertical velocities of tide gauge stations with an accuracy of better than 1 mm/year within ten years, and with considerably better velocity accuracy over longer periods of time. This more ambitious agenda was the main focus of the well-known Carter reports.

The second agenda is much more challenging and will lead to quite severe requirements for the selection of 'suitable' tide gauge sites, the CGPS installations and data analysis. Tide gauges that can be instrumented with CGPS for the purposes of the centimeter agenda may often be unsuitable for pursuing the millimeter agenda. As such the technical committee is now working on separate sets of recommendations for these distinct 'end case' applications. A key realization is that these recommendations need to be considered as tide gauges are being selected, and not just during the implementation stage.

2 The Impact of Geodetic Requirements on Site Selection

Some requirements are common to any positioning agenda and would apply to any tide gauge. For example, one should always 'tie', by precise leveling, the GPS antenna to the system of tide gauge benchmarks (TGBMs) as well as to a reference point on the tide gauge itself. This is especially important when one is working at a tide gauge with a long history and this history is a major focus of the effort. This is because over many decades the tide gauge is likely to have been modified, moved and even replaced on several and perhaps many occasions. It is the TGBMs and the associated program of precise leveling measurements that provide the temporal continuity of the vertical datum at such stations. In this sense one could argue that when the focus is on a very long sea level time series, the system of TGBMs is even more important than the specific tide gauge that is operating today. Nevertheless, the need to tie the GPS antenna to the TGBMs as well as to the tide gauge is clear no matter what application we are pursuing or where we are working. Not all requirements are this straightforward, however.

The technical requirements for geodetic positioning of tide gauges need to be considered during the selection of gauges for GPS augmentation, and not just subsequently. Only a small fraction of all available tide gauges will be retrofitted with a CGPS station. It would be short-sighted to base the selection of these tide gauges purely on oceanographic criteria, without regard to the relative geodetic suitability of the candidate tide gauges. The ease with which a given tide gauge can be positioned geodetically depends both on the positioning accuracy required and the local environmental conditions. Consider the standard issue of sky view, for example. It is unlikely that one could ever obtain subcentimeter vertical accuracy by making GPS measurements at a tide gauge located at the base of a 200 meter cliff. This raises the question of how far the CGPS station can be removed from the tide gauge. In many cases the existence of walls or buildings besides the tide gauge will require the GPS antenna to be moved at least several meters from the gauge itself. This will rarely matter as long as the GPS antenna mount is connected to the same structure as the gauge, making significant relative motion of the tide gauge and GPS antenna impossible. But could it ever be acceptable to install a CGPS station hundreds of meters or even kilometers away from the tide gauge in order to optimize conditions for the GPS measurements (e.g. an improved sky view) or for other purposes such as security of the GPS equipment?

There are a number of factors that must be addressed before one can answer this question. What positioning agenda are we pursuing? How often would the GPS antenna be referenced to the tide gauge using precise leveling? What is the nature of the ground beneath and between the tide gauge and the GPS antenna? I do not have space to discuss here all the relevant issues in a comprehensive manner, but the following points may illustrate the nature of the problems and trade-offs involved.

Some tide gauges are attached to seawalls or piers that were constructed on sediments or, worse still, engineering fill. The well-known tide gauge at Valparaiso (Chile) is an example of the latter situation. These structures typically subside as the underlying material compacts. Oceanographers have long been aware that tide gauges may be subject to purely local vertical motions of this kind, and this is one of the reasons why they have referenced their tide gauges to TGBMs. Some oceanographers have concluded that a CGPS station serves a similar role to a TGBM, and so there is no particular need to place the CGPS station very close to the tide gauge. However, a CGPS station is being positioned in a global reference frame on a daily basis. If a somewhat remote CGPS station is moving by an unknown amount relative to its tide gauge, then the absolute position of the tide gauge is being determined only as frequently as the levelling tie is being made. This may be just once a year. This represents a massive dilution of the positioning power of CGPS.

The negative impact of losing the temporal continuity of CGPS measurements is further illustrated by the following example. Some tide gauges are tied to large standing structures such as piers that may be undergoing thermoelastic displacements with amplitudes of millimeters and sometimes even centimeters. Suppose one such tide gauge is being tied by precise leveling to a CGPS station built on a rock outcrop 1 km away. If the leveling survey happens roughly annually and always takes place around the same time of year, even large annual thermoelastic motions of the gauge might never be observed at all!

If a tide gauge and a non-colocated CGPS station are not constructed on a coherent outcrop of solid rock, the possibility of subsurface displacements changing the relative level of the tide gauge and the GPS antenna is present even when near-surface ‘engineering’ instability of a pier or a harbor wall can be ruled out. An analysis of all releveling data obtained in the USA prior to 1980 showed that most of the largest vertical displacements occurred in and near cities built on sediments such as those underlying the coastal planes of the Atlantic and Gulf Coasts. Most of these signals manifest differential subsidence associated with water withdrawal. Many tide gauges are based in this kind of setting.

One also needs to keep in mind that in many parts of the world precise leveling surveys do not take place at reasonable intervals (except on paper). In this case there will be no strong constraints on possible relative motions of the tide gauge and the GPS antenna.

If one is pursuing the centimeter agenda it will usually be acceptable to offset the GPS station from the tide gauge by distances as great as 1 km, provided that frequent first-order leveling ties are performed. In some settings the leveling ties should be performed several times during the first year to ensure that annual cycles of deformation affecting any large structures supporting the gauge (or the GPS antenna) are not going undetected or being misunderstood due to aliasing. Additionally these surveys should be performed throughout the lifetime of the observation program to ensure that slower (but not necessarily steady) secular movements will be adequately characterized. The larger the separation of the GPS station and the tide gauge, the more difficult and expensive the leveling program will be, and the more likely it will not be executed properly throughout the lifetime of the program. The inconvenience of frequent leveling should be contemplated very carefully before one abandons the idea of putting the GPS station very close to the tide gauge.

It will rarely be acceptable to separate the tide gauge and the GPS antenna by more than a few meters when one is pursuing the millimeter agenda. The only exception to this would be when both the tide gauge and the GPS station were being installed in a single massive outcrop of competent and locally rigid rock. Under these circumstances one could separate the tide gauge and the GPS antenna by a few tens of meters.

Suppose the oceanographic agenda in a given region could be satisfied by adding a CGPS station either to tide gauge A or tide gauge B. Suppose gauge A is built on a solid rock outcrop in an area with minimal human impact, and it will be possible to build a monument that couples the GPS antenna to the rock substrate just a few meters from the tide gauge. Suppose that tide gauge B is located on a harbor wall at the base of a large building. The nearest place with a good sky view is over a kilometer away and this place, the tide gauge, and the road between them overlie a sedimentary basin, which includes a heavily pumped aquifer. It would be unreasonable to select B over A even if the location of B made it slightly preferable for purely oceanographic reasons.

The selection of tide gauges for GPS augmentation must involve some sort of compromise between oceanographic and geodetic requirements. The higher the positioning accuracy required, the more weight must be placed on the environmental and geodetic suitability of the site. We must be very careful when we determine whether we are pursuing the centimeter or the millimeter agenda at a given site. If the geodesists hear one or two oceanographers say that their primary interest is the centimeter agenda then it is naturally tempting to settle on that goal, since it makes it much more likely that the proposed site can be considered suitable, and because the standards for installation will be more lax and therefore easier to achieve. However, in many cases, stations built to this standard will not be suitable for pursuing the millimeter agenda. So if the oceanographers change their minds about the precision levels they seek to attain, then much of early work on CGPS positioning of tide gauges will subsequently be viewed as substandard. This prospect is particularly worrying given the history of upwards creeping accuracy requirements in almost every application of GPS geodesy.

3 The Writing of Standards for CGPS Installations at Tide Gauges

The above discussion should make clear that the writing of standards for CGPS installations at tide gauges is more involved than most members of our technical committee first realized. Nevertheless we are working on a document which is based both on multidisciplinary discussions, and on experience gained during past installations.

The University of Hawaii is one of several groups working in this area. Our effort is a collaboration between the Pacific GPS Facility led by the author, and by the UH Sea Level Center led by Mark Merrifield, another member of the technical committee. Our first project, begun last year, was the installation of a CGPS station at the Honolulu Tide Gauge. This dataset is freely available on a daily basis. We are presently engaged in selecting another six tide gauges for GPS augmentation. Early site selection studies indicate that almost every station will be a special case! We will be documenting each project as it occurs, and will make this information available on the web. We hope that other groups will be doing this too. Hopefully we will be able to refer to these websites in the IGS/PSMSL standards document, so that specific cases can be made to serve as illustrations of the general requirements associated with CGPS positioning of tide gauges.

4 Data Processing and the Role of the IGS

By the beginning of the year 2000 we expect that 15 - 25 tide gauges around the world will have been retrofitted with CGPS stations. These data will be made available to the IGS via one or more data centers. The IGS needs to consider now what mechanisms need to be established to ensure that these data are processed in an optimum manner. We must keep in mind that, initially at least, most of these stations will not be reporting within a few days of real-time. Thus the processing streams associated with IGS orbit production are not relevant to this agenda. Additionally, because many tide gauges are built on relatively unstable structures, these new CGPS stations may not be of much interest to geodetic groups already engaged in ITRF densification efforts if their primary motivation is crustal motion research. Who is going to be responsible for this new processing effort? And who is going to pay for it?

5 Getting Involved

Anyone wishing to join the IGS/PSMSL technical committee on CGPS positioning of tide gauges, and/or participate in our email discussions, should send an email message to bevis@soest.hawaii.edu.

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