IGS

SESSION 7

NETWORK UPGRADE ISSUES

Strengthening the IGS Infrastructure

Yehuda Bock
Scripps Orbit and Permanent Array Center (SOPAC)
Scripps Institution of Oceanography
La Jolla, CA 92093-0225, USA

Introduction

The accomplishments of the IGS have been very impressive since its establishment in 1993. This is quite remarkable considering its “volunteer” nature and diverse international character, and is a tribute to the dedication and contributions of many individuals and organizations. It is clear that the IGS has become an important facility for worldwide geodetic and geodynamics research as well as a service for a growing number of civilian applications of the Global Positioning System.

The IGS has been a pioneer in the development of a robust international GPS infrastructure building on and consolidating earlier networks, including CIGNET and FLINN. It has wisely promoted a free and timely electronic distribution of GPS data which has improved the quality of its own data products, assuring their widespread usage. The development of the infrastructure (the “network”) has been rapid with the goal of increasing and densifying global coverage, which in most part (the glaring exception is the African continent) has been accomplished. In parallel with the growth of the IGS, regional continuous GPS arrays have proliferated and benefited from the IGS umbrella.

The rapid development of the IGS without its own identifiable source of income, except the collective resources of its participants, coupled with the rapid developments in GPS technology and regional GPS arrays has led to certain deficiencies in the IGS infrastructure and a certain level of ambiguity regarding its role and identity (for example, the fundamental question of “What is an IGS Station?”). The focus of this position paper is to provide a critical assessment of the current IGS infrastructure, to recommend needed upgrades, and to suggest a strategy for consolidation and sustainable development.

I will consider here the tracking stations, the raw data collected by these stations, and the unambiguous reporting and cataloguing of these data as they are transmitted into the IGS system and to IGS users. I will concentrate on how infrastructure impacts data (raw and products) in terms of quality (reliability, completeness), timeliness, and accuracy.

I bring several points of view to this exercise: as a user of IGS data and products, particularly for monitoring tectonic deformation, an operator of a global data center and global analysis center for the IGS and a large regional GPS network in southern California, and finally as a member of the IGS Governing Board (“GB”) and its Infrastructure Committee “IC.”

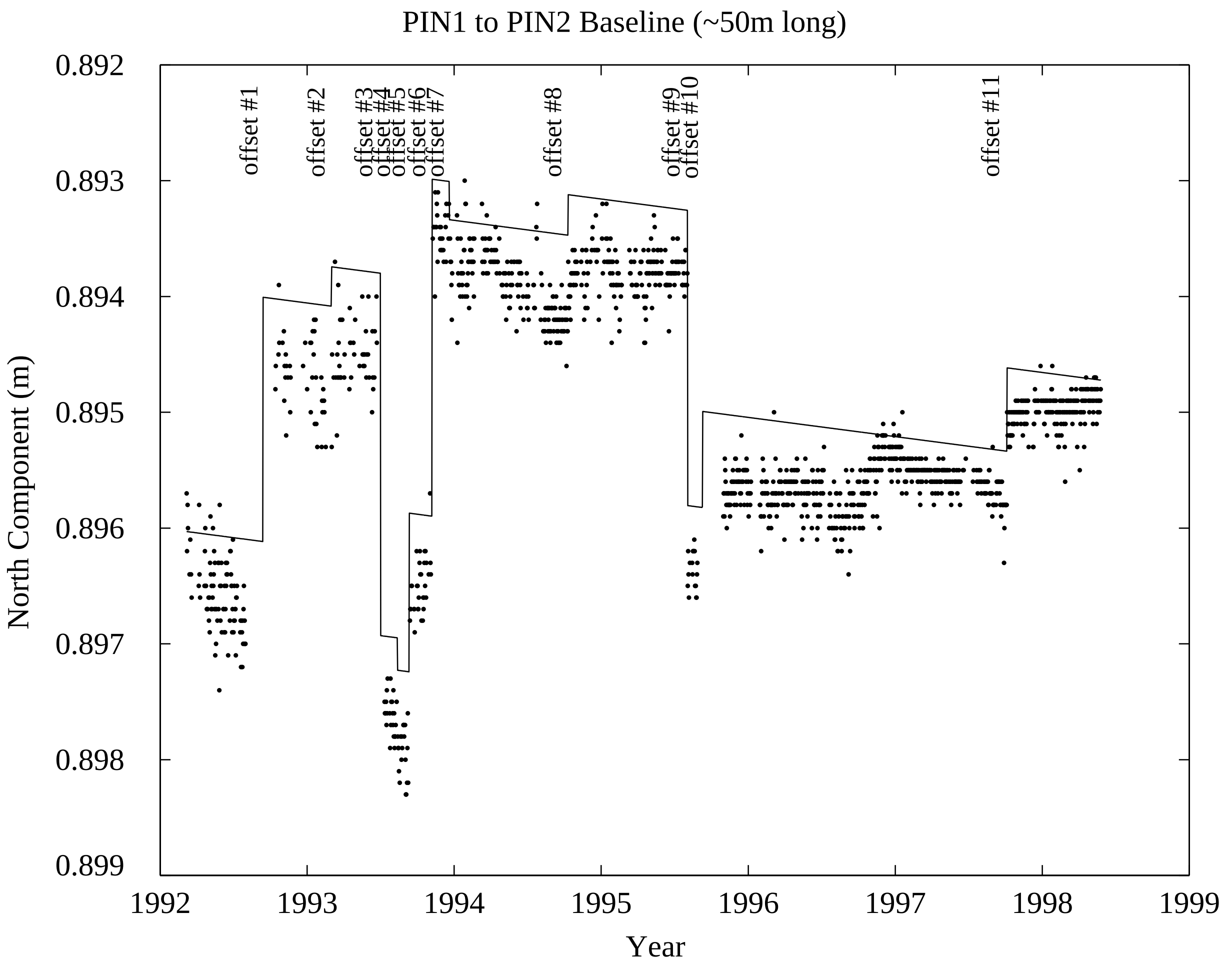
IGS Infrastructure: Impact on Data Quality, Timeliness and Accuracy

The robustness and maintenance of network infrastructure has a direct impact on the quality, timeliness, and accuracy of IGS data and products, often in subtle ways. For example, a site on a relatively unstable geodetic mark will have no impact on the short-term accuracy of the IGS final orbit but may have a significant impact on the long-term accuracy of the global terrestrial reference frame, the interpretation of tectonic deformation, and sea level monitoring. On the other hand, unreliable communication links resulting in occasional loss of data and late reporting of antenna height changes or other significant site-specific changes could have a severe impact on short-term products such as real-time orbits and weather forecasting but no long-term impact on the global reference frame nor climate modeling. It is clear, however, that the IGS infrastructure needs to be able to support reliably both short-term and long-term applications in order to sustain a viable and useful scientific service. My view is that the IGS infrastructure needs to be as good or better than regional GPS infrastructures, which is rarely the case today.

The most stringent geodynamics applications will require determining the 3-D positions and velocities of geodetic markers to mm-accuracy and sub-mm/yr-accuracy, respectively, as well as non-secular changes in positions, relative to a well-defined regional or global reference frame. I will discuss a baseline time series between two well-monumented closely spaced points (PIN1 and PIN2) at the Piñon Flat Geophysical Observatory (PFO) to demonstrate the intrinsic accuracy of GPS geodetic positioning and to isolate some site-specific and hardware/firmware-specific issues. By focussing on a short baseline, we can ignore distance-specific and global errors. Figure 1 shows the north and vertical baseline components (the east component is similar and not shown) for about a 7 year period from 1992 to 1998. The daily baseline components were analyzed with the GAMIT software using L1 and L2 data as independent observations (an extrapolation to precision for typical LC mode processing should include a multiplicative factor of about 3). Figure 2 shows that after known site-specific changes (reflected as jumps in the time series) have been accounted for, intrinsic short-term horizontal position is about 0.1 mm and vertical position is about 3 time worse. The implications of Figure 1 to our focus on infrastructure will be become clear in the subsequent sections.

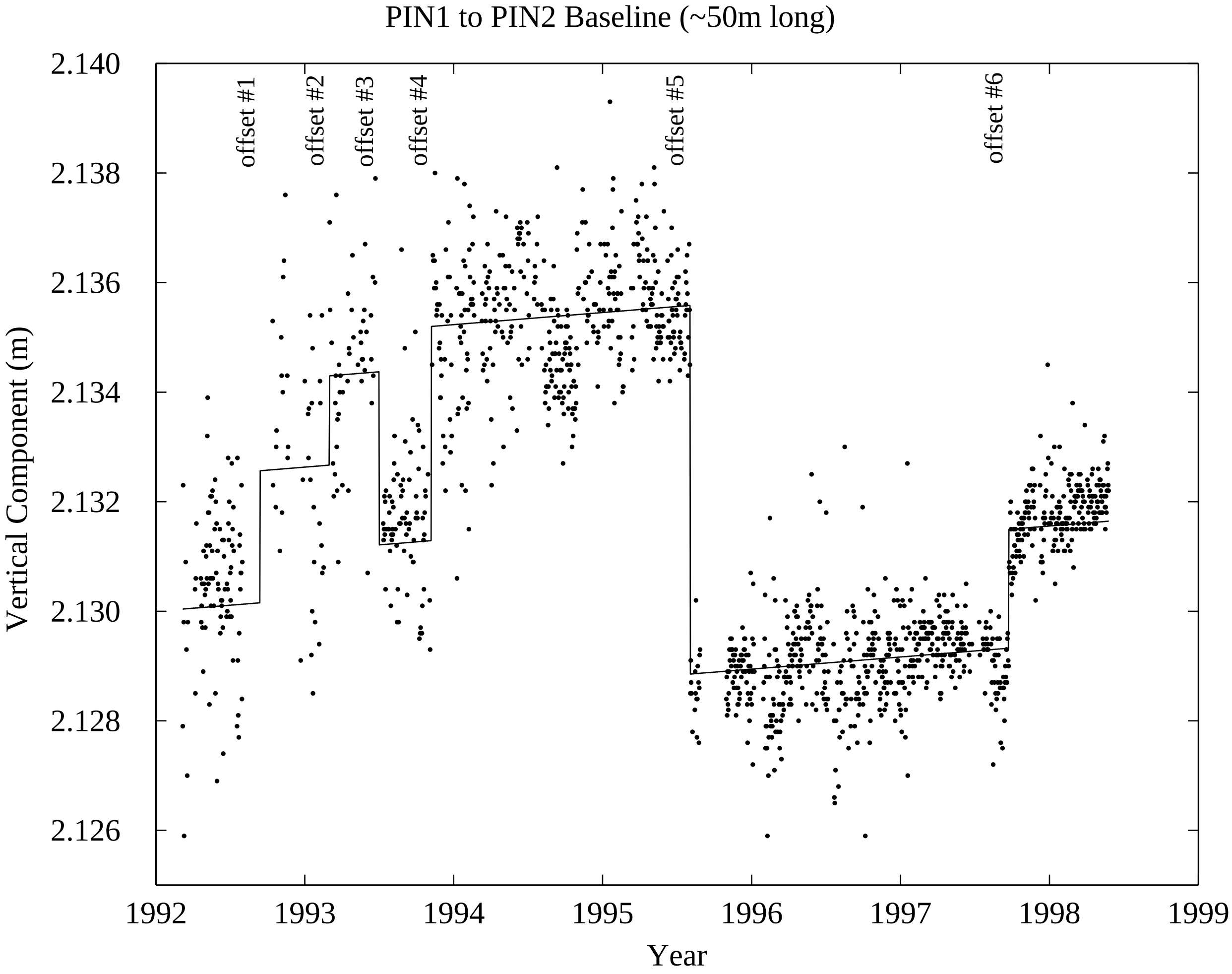
Site Stability and Monumentation

Geodetic monumentation is an important consideration in the long-term accuracy of GPS coordinate estimates and their derivatives, and hence in the long-term stability of the global terrestrial reference frame. Colored noise seen in GPS coordinate time series thought in part to be due to monument motion can reduce the accuracy of derived site velocities by at least a factor of 2- 3, compared to time series with strictly white noise properties [*Zhang et al.*, 1997].



Offset	Size	Cause
1	2.1 mm	PIN1 equipment change: Rogue to Ashtech
2	0.3 mm	PIN1 and PIN2 antennas removed/replaced
3	-3.1 mm	PIN1 equipment change: Ashtech to Rogue
4	-0.3 mm	PIN1 and PIN2 antennas removed/replaced
5	1.4 mm	PIN1 and PIN2 antennas removed/replaced
6	2.9 mm	PIN1 equipment change: Rogue to Ashtech
7	-0.3 mm	PIN2 (only) antenna removed/replaced
8	0.3 mm	PIN1 and PIN2 antennas removed/replaced
9	-2.5 mm	PIN1 antenna change: L-12 to DM
10	0.8 mm	PIN1 and PIN2 antennas removed/replaced
11	0.7 mm	PIN2 antenna change: DM to DM

Figure 1a. Time series of the North component of the PIN1 to PIN2 baseline over a period of nearly 7 years. Note that the vertical axis spans 7 mm. Eleven distinct jumps can be detected in the series and correspond to known changes at one or both of the sites.



Offset	Size	Cause
1	2.4 mm	PIN1 equipment change: Rogue to Ashtech
2	1.6 mm	PIN1 and PIN2 antennas removed/replaced
3	-3.2 mm	PIN1 equipment change: Ashtech to Rogue
4	3.9 mm	PIN1 and PIN2 antennas removed/replaced
5	-6.7 mm	PIN1 antenna change: L-12 to DM
6	2.2 mm	PIN2 antenna change: DM to DM

Figure 1b. Time series of the Vertical component of the PIN1 to PIN2 baseline over a period of nearly 7 years. Note that the vertical axis spans 15 mm. Six distinct jumps can be detected in the series and correspond to known changes at one or both of the sites.

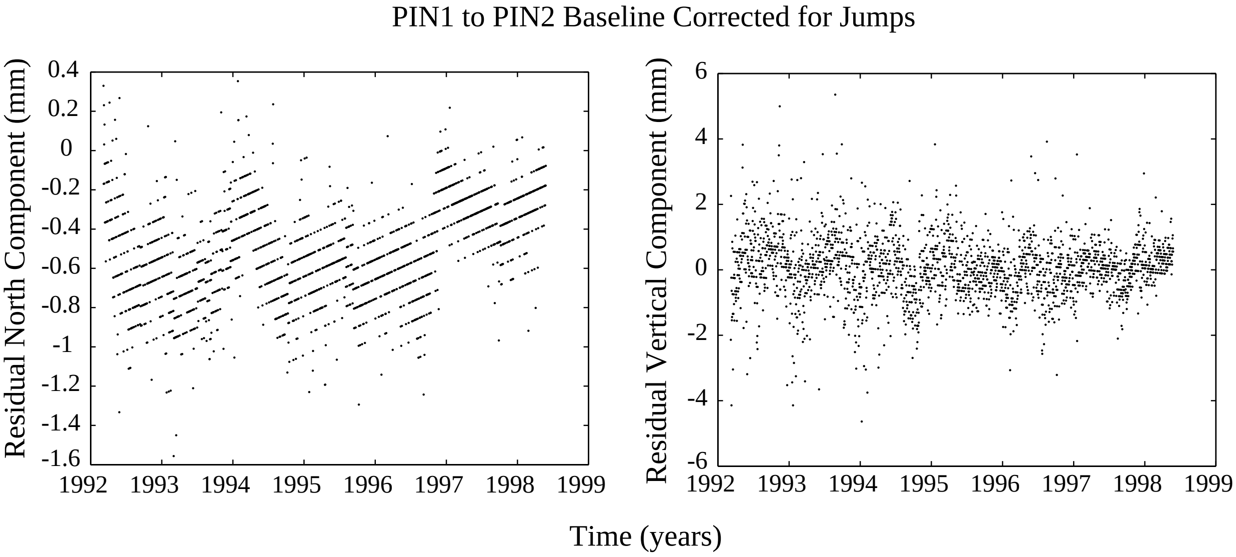


Figure 2. All statistically significant offsets shown in Figure 1 have been removed as well as the best-fitting linear trend. The quantization in the figure is at the 0.1 mm level. This is the limit to which baseline distances are printed from the GAMIT software used to analyze these data. The slope to the quantization is due to having removed a linear trend from the original data. Note that the vertical scale spans 2 mm for the north component (left panel) and 12 mm for the vertical component (right panel).

Many years of precise geodetic measurements in California indicate that ground monuments undergo random-walk like motions that can be minimized by constructing deeply-anchored marks [*Langbein et al.*, 1995; *Langbein and Johnson*, 1997]. Figure 3 shows a drawing of such a monument designed for the Southern California Integrated GPS Network (SCIGN). Sites PIN1 and PIN2, whose time series of relative components are depicted in Figures 1 and 2, both have monuments of this basic design. A spectral analysis of the PIN1 to PIN2 component time series does indicate a definitive random walk component but with an amplitude of only 0.3-0.4 $mm/yr^{1/2}$ [Hadley Johnson, personal communication], which is about an order of magnitude better than monuments with shallow anchoring (< 3 m). Monuments placed on buildings and other types of structures are known to be subject to unpredictable anomalous motions that can mimic significant secular (tectonic) deformation. An example of this is shown in Figure 4 for a baseline time series between sites SIO2 to SIO4 anchored to a hanging wall of the Scripps library. Even though the two marks are only 5 m apart, cumulative rainfall caused a torque of the library wall resulting is about a 10 mm relative secular motion between the two sites over a period of nearly 2 months.

Coordinates and velocities of approximately 50 IGS ("core") sites are used for the realization of the ITRF by the IERS and by the IGS analysis centers to compute their products. Monuments at these critical sites, as well as other IGS tracking sites, are of highly variable quality and need to be upgraded in many cases. Otherwise, low frequency biases that are not readily apparent in the coordinate time series may impact future long-term IGS products. Proper monumentation is usually expensive and often presents logistical difficulties. Nevertheless:

Recommendation

A coordinated effort should be made to identify and upgrade those existing IGS global sites that require better monuments. The effort should be first addressed at IGS sites that are processed by several analysis centers and that are part of the GPS realization of the ITRF. IGS monumentation standards should be reviewed and adopted for new IGS sites.

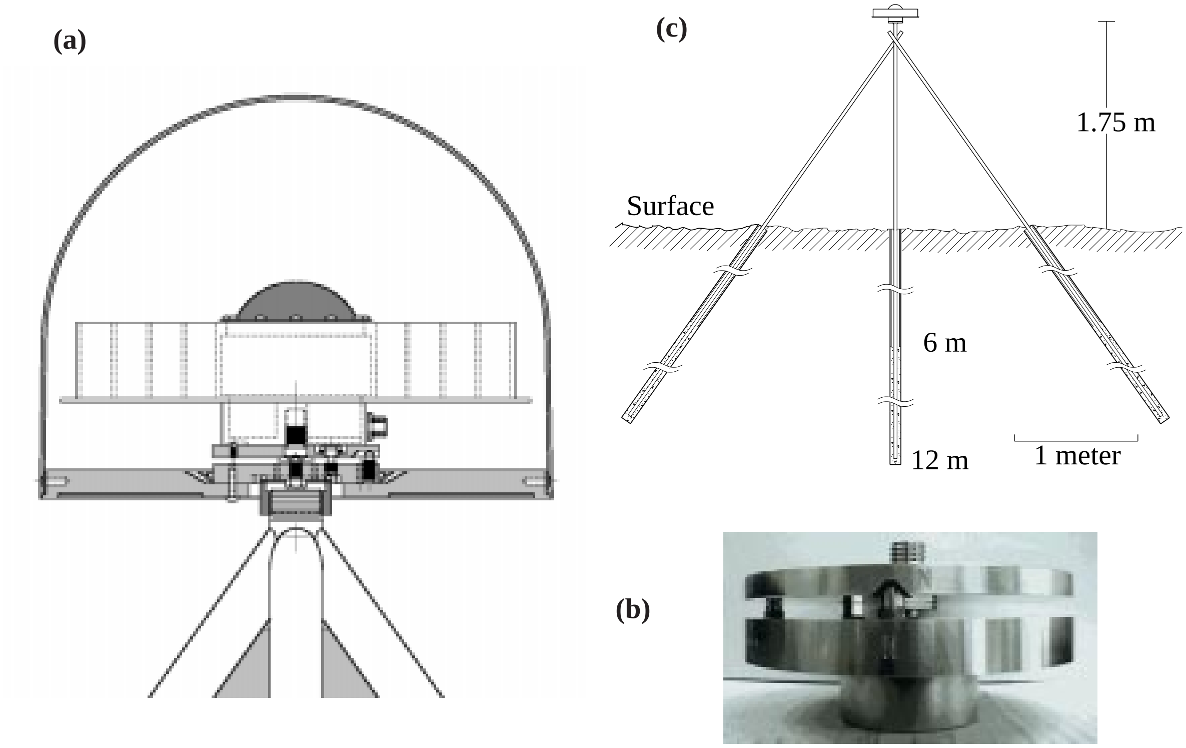


Figure 3. The SCIGN monument, adaptor and antenna dome are designed especially for use with the Dorne-Margolin antenna with choke rings. (a) As this drawing of the assembly shows, the components are designed to provide all necessary functions. The antenna can be readily adjusted to level, oriented to north, and then secured against tampering. Once enclosed by the dome, the antenna and adaptor are protected from the elements, yet the GPS signal distortion due to the dome is expected to cause less than 0.1 mm changes in apparent phase center position. (b) The SCIGN adaptor is designed to allow the antenna to be securely attached to the monument using a kinematic mount. Re-mounting of antennas is precisely repeatable. Antenna heights are constant, and the vertical and horizontal datum are the same point. Pressure points are rounded to minimize metal fatigue. (c) Schematic of the mounument designed for SCIGN. The deeply anchored "Wyatt" monument consists of four oblique rods and one vertical rod drilled to a depth of at least 10 meters and isolated from the soil in the upper 3 meters. This monument has been shown to have short-term accuracy of 0.1-0.2 mm horizontally and 0.4-0.5 mm vertically, and long-term accuracy of 0.3-0.4 mm/yr$^{1/2}$.

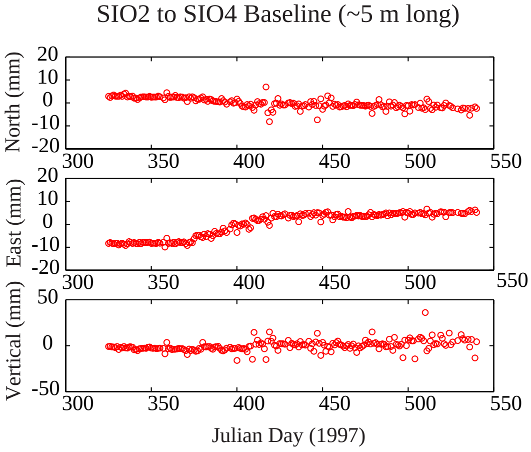


Figure 4. Component time series for the baseline SIO2 to SIO4 located on a hanging wall of the SIO library over a period of about 200 days. Note the strong linear trend in the East component over a 50 day period with a peak to peak amplitude of about 10 mm over this very short line. This feature is highly correlated with cumulative rainfall in La Jolla during these winter months and illustrates the danger of placing monuments on buildings.

Station Environment and Calibration

The station environment and changes in the station environment over time are important factors in the selection of GPS site locations and in the subsequent accuracy of geodetic estimates. Environmental factors include multipath [e.g., *Counselman and Gourevitch*, 1981; *Georgiadou and Kleusberg,* 1988; *Genrich and Bock*, 1992], signal scattering [*Elósegui et al.*, 1995], precipitation [*Jaldehag et al*., 1996], horizon obstructions, and radio interference. Errors due to these factors are also correlated in a complex manner with antenna phase center errors [e.g., *Schupler et al.*, 1994], all of which are sensitive to the elevation of the satellite above the horizon as viewed from the GPS station. The analysis of space geodetic data has shown that there are high correlation between estimates of zenith atmospheric delays and heights of geodetic sites due to errors in the atmospheric mapping functions [*Davis et al.*, 1985; *Herring*, 1986; *Niell*, 1996]. Likewise, elevation dependent errors in GPS phase measurements introduce correlation among the estimated parameters. The rate at which height error is traded off with zenith delay error is modulated by the distribution of the GPS data with respect to elevation angle, and this correlation is particularly sensitive to the amount of data collected at low elevation angles [*Santerre*, 1991; *Fang et al.*, 1998].

As long as the station environment and the observation scenario (e.g., elevation angle cutoff) is static some fraction of the errors such as multipath can be calibrated at the analysis stage [e.g., *Genrich and Bock*, 1992] because of the nominal 12 hour periods of the GPS satellites. Most often, however, the station environment is subject to changes at various time scales. For example, trees growing near the antenna may cause a gradual increase in horizon obstructions and snow cover may increase signal scattering for certain types of geodetic monuments [*Jaldehag et al.*, 1996].

There has been considerable progress in site calibration methods. For example, a consortium of research groups is studying site calibration for the University NAVSTAR Consortium (UNAVCO). Analysis of one-way phase residual plots is revealing sites with significant environmental problems (e.g., see Tom Herring's Web page http://www-gpsg.mit.edu/~tah/cont98g/cont98.html for sites in southern California and central Asia).

Recommendation

A coordinated effort should be made to calibrate the global sites to identify those sites that have environmental problems. This can often be accomplished by examination of geodetic time series and phase residual plots and during routine site maintenance. IGS site specifications should be reviewed and adopted for new sites. Reports of significant environmental changes at sites should be added to station log files and forwarded to the CB for dissemination to IGS analysis centers and users.

GPS Hardware

The GPS hardware components (receiver, antenna, cables, preamplifiers, etc.) are, of course, the heart of an IGS tracking station. It is clear that the IGS has had an impact on the GPS marketplace. In particular, the Dorne Margolin antenna with choke rings ("Dorne Margolin T") that is part of the TurboRogue equipment package is now the standard for all manufacturers of high-precision geodetic GPS receivers, as well as the reference antenna for the IGS antenna phase center models [*Schupler et al.*, 1994; *Rothacher et al.*, 1995; *Mader and MacKay*, 1997; *Meertens et al.*, 1997] that are being adopted throughout the GPS community.

The situation with GPS receivers is more complicated as manufacturers come up with new innovations and features, for example improved tracking algorithms (important for low elevation angle tracking and tropospheric delay estimation), pseudorange multipath suppression (important for wide-lane ambiguity resolution), and higher sampling rates (important for ionosphere and LEO tracking). For example, a recent study by *Fang et al.* [1998] on systematic errors in GPS estimates of zenith delay shows larger elevation angle cutoff sensitivity at stations with Trimble GPS equipment than it does at stations with TurboRogue GPS equipment. This cutoff sensitivity is due to the fact that TurboRogue receivers, in general, are recording much less usable data below 15° than are the Trimble receivers (Figure 5). Most Trimble receivers are collecting some data below 10° and a significant amount below 15°. This is probably due to a limitation in TurboRogue receiver firmware version 3.2 and not to any limitation in the antenna.

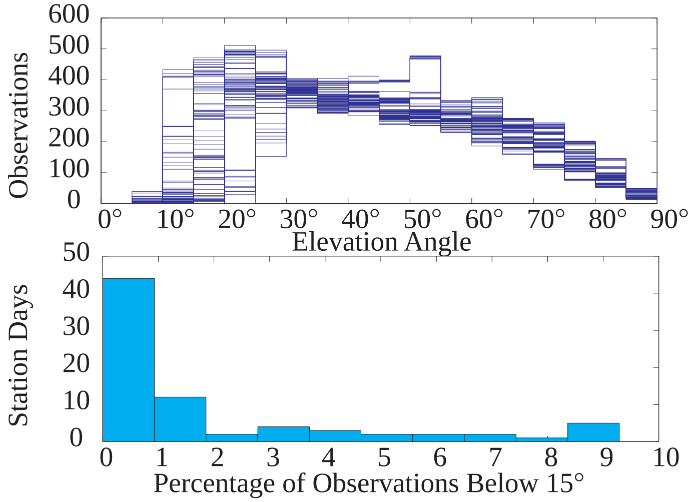
Other important questions include interchangeability of like hardware components. For example, SCIGN compared short baseline repeatability for like antennae and found that the no significant differences between the old milled Ashtech Dorne Margolin with choke ring antenna and the new cast/coated antenna [Note: the cast/coated antennae were later recalled by Ashtech because of excessive porosity and replaced by newly designed watertight milled antennae]. The precision (repeatability) of either type of antenna is about 0.1-0.2 mm in the horizontal and 0.5 mm in the vertical. The relative phase-center accuracy of the SCIGN antennae, based on a sample of 34 antennae tested at SIO, is about 0.5 mm in the horizontal and 1.7 mm in the vertical. Taking into account a small number of outliers, the relative accuracy may even be better (about 0.3 mm in the horizontal, 1.0 mm in the vertical). The differences among antennae probably reflects the mechanical limitations of the Dorne-Margolin antenna manufacturing process. See http://www.scign.org/AntennaTest for more details on these tests.

Degradation of hardware components (for example, frayed cables, corrosion of antenna elements, etc) over time is also an important consideration and can affect the long-term quality of raw data and the accuracy of geodetic estimates. As part of this effort to ensure network consistency, improve data quality, and reduce equipment failures SCIGN has re-evaluated its station designs and identified three areas that needed improvement: the receiver enclosure including power backups, the antenna adaptor and antenna cover (dome). The new adaptor design allows one to replace an antenna on a monument with high precision (see Figure 1 for jumps in the baseline time series induced solely by removing and replacing the same antenna, in this example, without any dome). The antenna at each site is protected from vandalism and the elements by a hemispherical dome. The dome material necessarily causes a slight delay in the GPS signal, so it is important that this delay be uniform over the dome and consistent from site to site. After careful evaluation and testing of the materials and fabrication techniques, SCIGN designed a high precision dome that will be deployed throughout its 250-site network (http://www-socal.wr.usgs.gov/scign/group/dome). The new SCIGN dome design (Figure 3a) and the manufacturing process have resulted in a dome that has less than 10% loss of incident intensity, and have less than 0.1 mm of apparent phase center variations due to non-uniformity of the wall thickness. Field tests have indicated no significant horizontal offset and 1-2 mm vertical offset in apparent site position after deploying a new dome. This development has been followed closely by commercial GPS equipment manufacturers and other scientists.

Recommendation

The IGS should consider standardizing and upgrading GPS hardware currently operating within the network to assure short-term and long-term data quality and reliability.

(a) 11 TurboRogue Stations, 77 Station-Days



(b) 10 Trimble Stations, 66 Station-Days

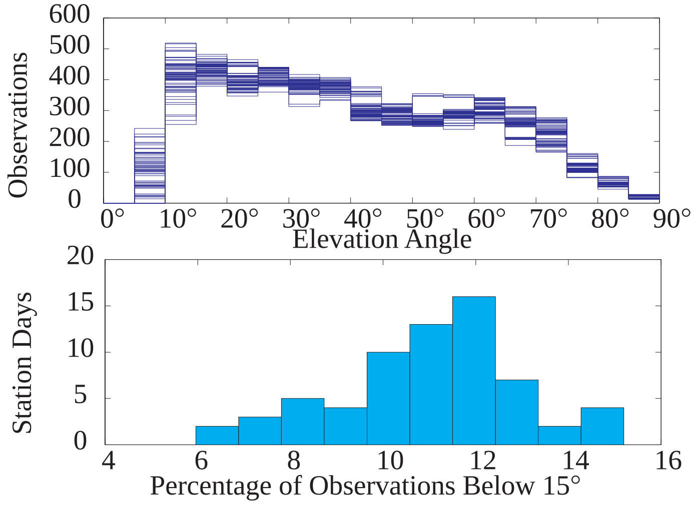


Figure 5. Stacked histograms showing distribution of elevation angles (above 7° cutoff) in 5° bins (upper graph) and histogram of percentage of usable double-difference observations below 15° to which a site contributed (lower graph) over a one week period in 1995 for (a) IGS TurboRogue stations, and (b) NOAA CORS Trimble stations (adapted from Fang et al., 1998).

Other Hardware

Radio signals from the GPS satellites are perturbed as they pass through the Earth's atmosphere, first by the charged atmosphere (ionosphere) and then the neutral atmosphere (troposphere). Well positioned continuous GPS networks can be used to estimate integrated atmospheric water vapor content and its variations with a temporal resolution of 30 minutes or less to an accuracy of 1 mm [e.g., *Duan et al.*, 1996]. Water vapor plays a crucial role in a variety of atmospheric processes from global climate to micrometeorology. Improved monitoring of atmospheric water vapor will lead to more accurate forecasts of precipitation, and to a better understanding of climate and climate change.

Recommendation

The IGS should consider surface meteorological packages to be an essential component of an IGS station. Efforts should be made to deploy met packages at existing stations.

Reporting of Station Information

Accurate, unambiguous, and timely reporting of station information for existing and new sites and its dissemination within the IGS and to the outside IGS user community has been recognized by the Governing Board as a perennial and difficult problem (which is not unique to the IGS). This problem must be solved and procedures implemented to minimize future problems, irrespective of any improvements in the IGS infrastructure discussed above. Assigning unique site names (4-character codes) is a related difficult problem and is treated in another position paper.

A particularly onerous problem is the unambiguous identification of the antenna reference point and its relationship to the geodetic reference mark. For example, the analysis centers compute a consistent 3 cm difference between their estimates and the adopted ITRF96 position of the Fairbanks (FAIR) site (http://www.igscb.jpl.nasa.gov) which is most likely due to this incorrect identification.

It is clear that the site log is the definitive source of information that must propagate throughout the IGS system and be available to all users of IGS data and products. A comprehensive examination of current and historical RINEX headers at the SOPAC archive indicates, however, pervasive and serious discrepancies with information recorded in the corresponding site logs.

Several groups are working hard to improve the current situation. For example, SOPAC, as a Global Data Center for the IGS and the data archive for SCIGN, is working on several related projects to streamline and improve station reporting. One project is the development of a Web-based automatic site information manager that can be used to easily record, archive, and disseminate site information for GPS tracking stations, as well as for GPS field occupations. Appendix A includes a proposed revised station log template indicating the required and optional information that needs to be recorded for each site. Required information is information that could have a direct impact on analysis of the data, IGS products, or users of raw IGS data. Of course, it is critical that site logs be updated immediately in the event that a change has occurred at a site. A Web-based upgrade template would make it much easier to record these changes and post the changes on-line so that the information is available to the analysis centers and IGS data users.

A second challenging project involves reconciliation of historical and current data in the SOPAC archive. This painstaking process which is more difficult for older data will ensure that site log files and RINEX headers agree. The reconciliation requires, for example, a definitive list of GPS receiver and antenna types with unambiguous descriptions. Such a list has been compiled by the

IC and the CB. Of course, a standard list linked to the automatic site information manager would ensure unique receiver and antenna identifiers (e.g., in SINEX files).

A third project is the development of a relational data base management system (RDBMS) to organize, integrate, and automate all data collection, archiving, analysis, and dissemination operations. The schematic in Figure 6 symbolizes the concept of this integrated approach. The RDBMS is the core with a direct interface to the SOPAC archive where the data reside. However, it also has a link to other archives and data bases so that a user can transparently obtain data from any available source through a Web-based or ftp-based query. This is the concept of the "seamless archive" being pursued by UNAVCO. Ultimately, the RDBMS will also be linked to a GIS to facilitate user queries and to overlay other types of spatial information (e.g., SAR images) on the GPS reference backbone.

Station reporting also includes quality control of the raw tracking data, the accurate and complete generation of RINEX files, and the timely flow of the data into the IGS system. This topic is treated in another position paper.

Recommendation

Accurate, complete, timely and automated station reporting should be a high priority for the IGS community. This effort should be spearheaded by the CB with assistance of the IC, the Analysis Coordinator, the Global Data Centers and the Global Analysis Centers. The IGS should adopt an integrated approach to data .

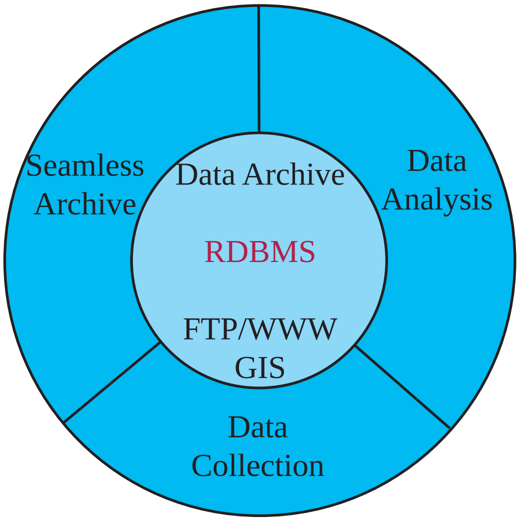


Figure 6. SOPAC is implementing a relational database management system (RDBMS) to organize, integrate, and automate its data collections, archiving, analysis, and postprocessing operations, to maintain site metadata, and to serve as a hub in the "seamless archive" under the UNAVCO umbrella. The RDBMS will be queried via ftp and the World Wide Web and will be interfaced with a GIS. By integrating and automating these operations we hope to minimize data discrepancies. Accurate and complete site information is critical for this implementation to be successful. This is our motivation for developed a Web-based automatic site information manager.

Summary

I would like to end by outlining a concise strategy for strengthening the IGS infrastructure and supporting mm-accuracy applications (ITRF, geodynamics, LEO's, ionosphere, troposphere, etc.), to the extent possible.

Consolidation: Identify those global stations (>100) that are "IGS stations." This should be done in consultation with operators of regional GPS arrays and individual site operators. This may imply removing the IGS label from certain stations and adding the label to other stations. Information about these sites needs to be accurate and complete.

Standardization: Upgrade and standardize to the extent possible a uniform global "core" subnetwork of 50-100 IGS stations to the quality of the very best regional arrays, including GPS hardware, site calibration, stable monumentation, and real-time communications. Consider redundant monuments and receivers at each site to facilitate site calibration and to enable long-term positioning accuracy at the mm-level (Figures 1 and 2 provide the rationale for this recommendation). Consider higher sampling rate scenarios. A global communications solution for the IGS network data paths should be investigated, planned, and implemented. Co-locate other instruments, in particular meteorological packages, to support GPS meteorology.

Expansion: Limit expansion to areas that fill gaps in the global coverage (e.g., Africa). Be more selective in adding new sites to the network, with regards to both quality and quantity. Focus, rather, on consolidation and co-location.

Cooperation: Strengthen relationships with existing regional arrays (e.g., Western U.S., EUREF) and promote new arrays that will fill in the global polyhedron (e.g., Asia-Pacific, Middle East). Improve cooperation with related global networks (e.g., seismic, magnetic) and space programs (e.g., CHAMP, ECHO-ELSIE).

Coordination: Strengthen coordination within the IGS to accomplish these tasks. Develop a long-term strategies for sustainable growth and development to guarantee the standardization, data quality and longevity of the IGS infrastructure. The focus of the IGS should be shifted from an R&D (i.e., volunteer) organization to that of an operational service.

Acknowledgments

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Appendix A. Revised Template for IGS Station Log (Proposed)

* indicates optional information

0. Form
    - Prepared by
    - Date/Time prepared
    - Report Type [NEW/UPDATE]
    - Prepared Using
1. Site Identification
    - Four Character ID
    - *Name
    - IERS DOMES # (“N/A” if not available)
    - Mark Description (e.g., divot in SCIGN D-3 adaptor)
    - *Monument Description (e.g. Wyatt/SCIGN)
    - Monument Inscription
    - Monument Installation Date
    - *Date/Time Installed
    - *Geologic Characteristic
        - *Bedrock Type
        - *Bedrock Condition
        - *Fracture Spacing
        - *Geologic Notes
    - *Additional Information
2. Site Location
    - City/Town
    - *State or Province
    - Country
    - *Tectonic Plate
    - Approximate Position (either Cartesian or Geodetic Coordinates)
        - X-coord
        - Y-coord
        - Z-coord
        - Geodetic Latitude
        - Geodetic Longitude
        - Ellipsoidal Height
    - * Additional Information
3. Receiver Information
    - Type (off Master List — see Appendix B)
    - *Model Number
    - Firmware
    - Date/Time Installed
    - * Date/Time Removed
    - Serial Number
    - * Additional Information

4. Antenna/Dome Information
    - Antenna Type (off Master List — see Appendix B)
    - Dome Type (“NONE” for no radome) (off Master List — see Appendix B)
    - *Antenna Model Number
    - *Dome Model Number
    - Antenna/Dome Date/Time Installed
    - *Antenna/Dome Date/Time Removed
    - Antenna Serial Number
    - Antenna Reference Point
    - Antenna Height
    - * Additional Information

5. Local Site Ties (need at least of one of following 3 items)
    - Four Character ID (“N/A” if not available)
    - Name (“N/A” if not available)
    - IERS DOMES # (“N/A” if not available)
    - *Mark Description (e.g., divot in SCIGN D-3 adaptor)
    - Local Site Tie dx from GPS Mark to Site Reference (ITRF)
    - Local Site Tie dy from GPS Mark to Site Reference (ITRF)
    - Local Site Tie dz from GPS Mark to Site Reference (ITRF)
    - Local Site Tie Accuracy dx
    - Local Site Tie Accuracy dy
    - Local Site Tie Accuracy dz
    - Local Site Tie Date Measured
    - * Additional Information

6. Frequency Standard
    - Type
    - *Frequency
    - Begin Date
    - *End Date (*new*)
    - *Frequency
    - *Additional Information

*7. Collocation Information
    - Instrumentation Type
    - Status
    - Begin Date
    - *End Date
    - * Additional Information

8. Other Instrumentation
    - Type of Sensor (e.g., Pressure, Temperature, Humidity, WVR)
        - Manufacturer
        - Model Number
        - *Serial Number
        - *Data Frequency
        - Accuracy
        - Begin Date
        - *End Date
        - * Additional Information

9. Point of Contact Agency Information
    - Agency Name
    - Mailing Address
    - Primary Contact
        - Name
        - Phone (primary)
        - *Phone (secondary)
        - Fax
        - E-mail
    - *Secondary Contact
        - Name
        - Phone (primary)
        - *Phone (secondary)
        - Fax
        - E-mail
    - *Additional Information
10. Responsible Agency
    - Agency Name
    - Mailing Address
    - Primary Contact
        - Name
        - Phone (primary)
        - *Phone (secondary)
        - Fax
        - E-mail
    - *Secondary Contact
        - Name
        - Phone (primary)
        - *Phone (secondary)
        - Fax
        - E-mail
    - *Additional Information

*11. URL for More Information

12. Local Environment and Other Information
(e.g., earthquakes, horizon mask changes, multipath, weather)
Date : (dd-MMM-yyyy hh:mm UT)
Event : (multiple lines)

Calibrations for GPS Sites

J. L. Davis
Smithsonian Astrophysical Observatory
Cambridge, MA USA

“Calibrations” are those features of the observation model that are generally obtained as determinations from some previous measurements and simply “applied” as corrections. Uncorrected, these features represent errors in our modeling of the GPS phase observables. Thus, the term “site calibrations” covers a wide number of effects including signal propagation effects (multipath, scattering and diffraction, refraction), and antenna- and receiver-specific contributions to the phase observable. I will not include “monument wander” in the “calibrations” category, since this is a real motion of the site and is hence a position-modeling problem, or atmospheric effects, which are generally estimated from the data themselves.

A great deal of effort has been made recently simply to understand the sources of site-dependent GPS calibration errors. Antennas used for GPS have been shown to have perceptible variations of phase with direction and significant below-horizon admittance of signals [Schupler et. al., 1994]. The directionality implies a dependence of the position solution on the aggregate satellite distribution [Santerre, 1991]. The admittance of signals from low and negative elevation-angles leads to sensitivity to multipath and scattering, the effects of which are also dependent on the aggregate satellite distribution [Georgiadou and Kleusberg, 1988; Elósegui et. al., 1995]. The sensitivity to scattering implies that the mount for the GPS antenna is an important feature [Elósegui et. al., 1995]. Recent zero-baseline tests reveal elevation-angle dependent differences in phase-observable statistics among different receivers [Johansson, 1998].

Antenna phase-calibration models have been developed, but have not been conclusively tested. Calibrations that are based on antenna-range measurements [e.g., Schupler et. al., 1994] neglect the change in the phase patterns attendant to mounting the antenna in the field, which usually involves the introduction of objects made of metal or concrete (or both) within the near field of the antenna. Calibrations based on the adoption of a “reference antenna,” such as those used by the IGS [e.g., Mader and MacKay, 1997], appear to have a significant beneficial effect when used on a continental-wide network [Fang et. al., 1998], and look to be quite useful. Such calibrations should be less useful on a global scale, though, since the calibrations simply “map” the errors of one antenna to those of another, and such errors, do not cancel over global scales. One possibility would be to map the errors to a “perfect” antenna; this ideal is the basis for the “Multipath Calibration System” (really an antenna plus multipath in situ calibration) being developed cooperatively at SAO, Haystack Observatory, MIT, UNAVCO, and GSFC.

Regarding GPS receiver calibration, there is no substitute for understanding in detail the manner in which the observable is extracted. Since GPS receiver design is generally proprietary, it may be difficult to obtain the required information. Nevertheless, we should continue to make efforts as a community to work with the vendors to obtain the information we need for accurate receiver calibrations.

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