IGS

Session 4: Network Issues

Session Description

Chairs: A. Moore, C. Bruyninx, R. Twilley

The IGS network is the foundation of all IGS activities. This session will review the current status and future directions of the network. In particular, we will address IGS network documentation, including site configuration information, station operation guiding documents,

and the network area of the IGS web. Further, this session will discuss the growth of the IGS network, conflicting goals of inclusiveness and simplicity, relationships to dense regional networks, and network planning in light of newly available information on station usage across IGS products and projects. We will also review progress since the 2001 Ottawa Workshop "Toward Real Time" and the goals set there. We invite posters on any topic illustrating usage of the network or participation in the network, including successes and recommendations for network improvement. product generation.

Session Summary

A. Moore, C. Bruyninx, R. Twilley

The Network Issues session featured a fine set of talks, looking at the IGS network from a variety of viewpoints.

Michael Schmidt of Natural Resources Canada's Pacific Geoscience Centre reviewed changes in the IGS network since the 2002 IGS Workshop in Ottawa, with a specific look at what progress has been made against the goals set at that meeting. This showed us the growth of the network, yielding data coverage in some previously sparse areas, but also what might be termed “thinning” of the network. The increasingly plentiful stations have widely varying sets of capabilities and instrumentation, and there are more stations in many areas than most ACs regularly process. This leads to a decrease in the number of independent analyses and therefore a dilution in the rigor of analysis of each site. Ignacio Romero of ESA's European Space Operations Centre treated us to a view of the network as seen by an IGS analysis center, which underscored that new IGS sites are not typically analyzed unless featuring a particularly attractive data set based on instrumentation or location. The position paper by the session co-chairs, among other topics, turned to how the IGS can assure appropriate “depth” in station capability by evaluating its policies on admitting new stations to the IGS network.

We heard positive news on network expansion as well, as we were exposed to the organizational and practical concerns in bringing stations to the remaining challenging areas. Bob Twilley of Geoscience Australia informed on the design and installation of the South Pacific Regional GPS Network, which provides a framework for spatial data in these island nations in addition to its climatology and sea level mission. Grigory Steblov of the Geophysical Survey, Russian Academy of Science described the Northeast Asia GPS Deformation Array, which has succeeded in bringing data to the IGS from an area which only a few years ago represented a significant hole in the IGS network. And Zuheir Altamimi of Institut Géographique National described the African Reference Frame project, which has sub-divided into five regional AFREF projects with the goal of establishing a continental reference frame for Africa.

The papers in the Workshop Proceedings will explore these topics fully, and we invite readers to enjoy them and communicate any further suggestions they raise to the session chairs and/or authors.

Network Issues

A. Moore
Jet Propulsion Laboratory, California Institute of Technology

C. Bruyninx
Royal Observatory of Belgium

R. Twilley
Geoscience Australia

1 Introduction

The IGS network today consists of 364 stations managed by about 100 different agencies worldwide. The RINEX observations are contributed (generally on a daily or hourly basis) to the IGS Data Centers, which permanently archive the data and make it freely available to all users. The primary customer of the data set is the IGS Analysis Centers, which acquire the data for generation of precise GPS products such as ephemerides, clocks, earth orientation parameters, and station positions and velocities. The IGS Network Coordinator (NC) at the Central Bureau acts as liaison between the station operators and the Analysis Centers, providing necessary station configuration metadata and ensuring the dataset meets the requirements of the analysis. Further details on the current makeup of the network are available in the "Update Since Ottawa Workshop" paper in the Network Issues session.

In this paper we examine several topics currently warranting attention, leading to recommendations for future directions. We have identified (1) classification of the now-plentiful IGS sites for the benefit of users (2) the multiple sources of IGS station configuration metadata available to and used by analysts, (3) the new suite of IGS station operation guidelines, (4) effective notification of station status within the IGS framework of electronic communication, and (5) how to properly introduce north and east eccentricities to IGS SINEX files.

2 Network growth and station classification

Current procedures for new station acceptance are not entirely well defined, thanks to the conflicting goals of inclusiveness and selectivity. Beginning in the past year or so, the NC requests that those submitting new stations state to what IGS product or project the station will make a significant global contribution. Also, it is gently suggested that regional networks submit only a globally relevant small subset to the IGS. However, in the end any station meeting the IGS requirements is accepted if the operator feels strongly that it should be designated an IGS station. This can create a situation where there are several similar sites in a small area, decreasing the number of independent analyses performed on each site. It has been stated that Analysis Centers (ACs) have difficulty keeping up with which site in an area is "best," and presentations by ACs at the Berne Workshop confirmed that new stations are usually not added to the ACs' analysis lists nowadays, except in the case of particularly attractive stations.

During 2002 and 2003, 81 sites were added to the IGS network. An analysis of current usage of these stations is presented in Table 1. Most are associated with either the IGLOS or TIGA projects, and all except a few of the rest are actively being utilized by ACs in product generation. These patterns will be helpful to keep in mind while thinking about the policies and procedures.

Table 1: Current usage of sites added to the IGS network during 2002 and 2003. Complete information on each site is available in the Tracking Network area of http://igscb.jpl.nasa.gov.

Current usage	sites (by 4-character ID)
global	alrt ban2 conz dwh1 glps ohi2 qaq1 reun sach scub thu3 yibl zamb
IGLOS	bogi cagz conz darr davr dlft drej dwh1 ffmj godz helj hert hueg irkj joz2 khaj kir0 kou1 leij lhaz mar6 mat1 mdvj metz mtbg mtka ohi3 reyz str2 sunm thu2 titz vis0 wroc wtzj yarr zamb zimj zimz
TIGA	ajac alrt antc? brst copo? hlfx mars nain
MASER	godz irkj khaj mat1 mdvj nnor opmt usn1
VLBI co-loc	svtl
Some AC usage	aspa daka eurk mizu morp nnor obet ous2 sutm tnml
Usage unclear	baie bake gmas guao kuuj mikl picl tukt vald

First let us ask what is the benefit of the inclusiveness value *in cases where there is no clear benefit to IGS products?* Presumably, to encourage the construction and operation of sites to IGS standards and offer recognition to agencies expending the effort to do so. Such recognition can even result in better funding for the agency within its own organization, a boon to global geodesy and other fields.

If there is agreement that this recognition is the primary reason for inclusiveness, then we can offer a solution that provides such recognition without crowding the IGS network with sites that do not add value to the IGS products (and in fact, dilute the rigor of analysis that IGS sites receive).

A category of Proposed IGS Stations could be the first stop for sites submitted to the IGS. The CB would verify metadata suitability, and collect information on the location of sample data and which products or projects might benefit from this site. This information would be entered in a table of Proposed IGS Stations on the CB web, and an email announcement from the CB/NC would indicate that initial checks find that station is operated to IGS standards and it could be added to the IGS Network on the request of an AC or Associate AC (AAC). At that point, the station operator would be able to point to that web page and announcement to demonstrate that the station has been proposed to the IGS and found to be nominally suitable.

However, a Proposed Station would not actually be added to the IGS network unless at least one IGS analysis expert (AC, ACC, Working Group or Pilot Project chair, or product coordinator) requests it for the benefit of an IGS product or project. After the initial CB checks, analysts would be notified by email of an update to the table and directed to reply if they request that site be added. If there is no such request from an analyst, the site would remain in the Proposed table, where analysts may from time to time review known Proposed sites and request addition of any site, should it later become beneficial to a product. If a site remains on the list for more than a year, the CB would re-verify the information at that point. A demonstration of what a Proposed IGS Station table might look like is presented at http://igscb.jpl.nasa.gov/network/proposed.html.

Experience has shown that sometimes new stations present a satisfactory sample set of metadata and sample RINEX, but operational status reveals a pattern of partial data files, etc. New sites coming out of the Proposed status could be termed a “Provisional IGS Site” for the first 90 days, after which it would become an ordinary IGS site only if stable operation had been demonstrated. Would ACs support the removal of a site if problems arose in the provisional phase?

Besides Proposed and Provisional site categories, another suggested by recent patterns is IGS Project sites. Naturally, stations participating in a sanctioned IGS Pilot Project should have their IGS participation properly acknowledged. However, it should be recognized that upon termination of the project, those stations may not necessarily benefit any IGS activity. This can be seen currently in the cases of TIGA and IGLOS, where the sites admirably participate in these activities, but if TIGA or IGLOS were to end without resulting in an ongoing IGS product, many sites would not actually be useful to any IGS product. Classifying sites as IGS Project sites for the duration of the project would appropriately acknowledge the effort without creating the expectation that they are undoubtedly IGS stations for all time. Upon termination of a Project, the associated sites could become Proposed sites, for review by analysts on which are of continuing benefit to the IGS.

One further obvious category is Inoperational sites. Sites (excepting the obvious TIGA Project sites) transmitting no data within 30 days would automatically be placed into a list of Inoperational sites and the operators notified by email.

These categories address controlling the future growth of the IGS Network, but do not entirely solve the issue of AC “confusion” over which site in a small area is preferred for processing. The IGS guidelines state that it is preferable to maintain one station as “best” (while avoiding unnecessary equipment changes and observing data overlaps when unavoidable), than to operate multiple receivers at a site and submit all to the IGS. It has been further suggested to actually enforce that station operators choose only one “site” per “site” to submit to the IGS. This would not be a complete solution since in some cases separate agencies install sites nearby, and there is no common management to make a choice.

As a further step, a set of approximately 200 sites will be identified, primarily from the rate of usage to generate official IGS products. These “product sites” should include the IGb00 Reference Frame sites, most co-locations with SLR and VLBI, sites with MASERS, and a good selection of hourly sites. Identifying these product sites will serve to communicate their importance to the IGS products, and could help indicate to ACs which sites “should” be analyzed in the absence of overriding reasons.

There is some level of circularity in this approach: usage in products helps determine usage in products. The introduction of new sites is a clear point of complication, since they will present no prior usage in product generation. Product coordinators must monitor the sites analyzed for their product(s), and communicate with the NC and ACs/AACs if they find an important site is being missed.

Introduction of the product site category is still not a complete solution, but will help get a handle on which sites receive regular and rigorous analysis, what sites need operational improvements, and so on. This is a first step and will likely be refined and revised.

In summary, we have discussed the following categorizations:

IGS Proposed Sites Sites proposed to the IGS and found to have suitable characteristics, but not yet requested by any IGS analyst.

IGS Provisional Sites Sites added to the IGS Network in the past 90 days, during which time they must demonstrate adequate operations.

IGS Project Sites Sites associated with a specific limited-duration IGS Project, which would not necessarily remain IGS Sites at the conclusion of the Project unless helping an IGS product.

IGS Product Sites Sites most often used in, and most valuable to, IGS products.

IGS Inoperational Sites Sites not transmitting data in the past 30 days, but which are expected to eventually return to service.

3 IGS Station Metadata

A brief poll of IGS Analysis Centers (AC's) and coordinators was undertaken to understand how they presently ingest station metadata into their analysis processes. The responses differed in details, but the following can be deduced from the collection:

- Many ACs have internal databases which are compared automatically to some metadata source at the CB, but an operator examines the results and decides on updates manually.
- The site logs, in addition to the SINEX template, are used directly and automatically. In fact, all of the following are used operationally in IGS analysis: site logs, igs.snx, logsum.txt, igs_01.pcv, NGS ant_003.pcv.
- The SINEX template is not used by all ACs and may have been not well advertised since the 1998 AC Workshop in Darmstadt. Additional factors are discussed below.
- The SINEX template has some shortcomings, notably A5 serial number field, absence of some types of information not associated with position/velocity products (such as frequency standards and met equipment), and absence of former sites (the latter easy to solve).
- Several ACs analyze IGS sites simultaneously with other sets of sites, such as a regional network (SCIGN, EUREF). It is an issue how to acquire and combine metadata for different site sets.
- Analyzing different site sets also makes it frustrating to figure out how to do phase center offsets & variations. If getting some from NGS and some from igs_01.pcv, there are differences since igs_01.pcv is not updated when new data is later taken. As a result, some ACs use igs_01.pcv to only a partial extent, and some ACs use no variations at all. The antenna and analysis communities should address this.

Other comments included:

- it would be nice to know what periods of time had no data from the site log or SINEX template.
- it would be useful if the SINEX template had ITRF positions & velocities.
- full automation is not really desired, because it is preferable to have critical parameters under management by humans.
- changed or new log files should be available ASAP for ultra rapid analysis.
- machine readable/tabulatable codes for monument type, geology, other equipment types would be nice.

How did we get here?

Between 1994 and 1998, various IGS Technical Reports and Workshop Proceedings have evidence of encouragement from the Analysis Coordinator for ACs to use a “SINEX header” or “SINEX template” from the CB as the authoritative source of station configuration information. This was not realized uniformly, however, due to (at minimum) delays in the production of such a file.

ACs, therefore, originally had to implement internal collections of station parameters. Nobody likes to undo long-standing functional software, so much of it is still left in place. In some cases, the SINEX template was partially implemented later to cover some instances where it makes some improvement over the other options.

What now?

The analysis community should decide what level of standardization among ACs is required. Additionally, the analysis community is requested to agree on a way forward such that the network element can work toward operational provision of metadata in only a few formats, to reduce complexity.

4 Guidelines

At the 22nd IGS Governing Board meeting, a thorough update of the IGS site guidelines was identified as a pressing priority for a number of reasons. The Network Coordinator formed a first draft based on many preceding documents, including "Standards for IGS Stations and Operational Centers," "Procedures for becoming an IGS Station," "Network Issues" (from the proceedings of the IGS 2002 Workshop in Ottawa), "ISGN Sites Criteria," documents from several IGS Pilot Projects, "Guidelines for IGEX98 Sites," EUREF Permanent Network Guidelines, and IGS Reference Frame Working Group discussions from early 2003. This draft was reviewed by G. Gendt (ACC), C. Bruyninx (EPN NC), R. Ferland (RF Coordinator), J. Ray (AC/RF expert), M. Schmidt (Site ops expert), W. Gurtner (Author of previous guidelines), and C. Noll (DCWG Chair). As appropriate, questions were also asked at an early stage of Z. Altamimi (ITRF expert), H. Drewes (Author ISGN guidelines), D. Stowers (Site ops expert), S. Schaer (AC expert), R. Weber (GLONASS coord), Y. Bar-Sever (Tropo chair), G. Mader (Antenna expert), and M. Rothacher (Antenna expert).

This serves as an example of how the NC can utilize the expertise of usual and additional groups of advisers to assist in network matters. After several rounds of revision with these reviewers, the document was made available for comment from the entire IGS community.

The Governing Board approved (provisionally, and later officially) the document and a program of continuous review and improvement. Update authority is delegated to the NC, with the under-standing that significant changes would be discussed with appropriate advisers beforehand (ACC, RF Coord, station ops, WG Chairs, as needed for the topic), and a list of changes made in the preceding period will be made available to the GB at its regular meetings.

Although public comment on the new set of IGS guidelines was solicited, received, and utilized, the workshop provided another opportunity to discuss the guidelines[1]. The following few example guide-lines were highlighted in various sessions at the Berne Workshop. The complete set of guidelines is permanently available at http://igscb.jpl.nasa.gov/network/site/guidelines/guidelines.html or http://igscb.jpl.nasa.gov/network/site/guidelines/guidelines.pdf

Local survey requirements

(required) 2.1.4 The eccentricities (easting, northing, height) from the primary marker to the antenna reference point (defined for the antenna type in ftp://igscb.jpl.nasa.gov/pub/station/general/antenna.gra) must be surveyed and reported in site logs and RINEX headers to ≤ 1mm accuracy.

[1] Since the Governing Board directed the Network Coordinator to maintain the document in a "continuous improvement" mode, comments are appropriate and welcome at any time.

(desired) 2.2.18 3-dimensional local ties between the GPS marker, collocated instrumentation (e.g. DORIS, SLR, VLBI, gravity, tide gauge) and other monuments should be re-surveyed regularly to an accuracy of 1mm and reported in ITRF.

- The marker-antenna reference point (ARP) eccentricities should be reverified during such a survey.
- Repeat the survey after known motion incidents such as earthquakes.

Radomes

(required) 2.1.6 Avoid using radomes unless required operationally, for instance due to weather conditions, antenna security, wildlife concerns, etc.

(required) 2.1.8 If a radome must be used, an entry for antenna+radome pair must be in the phase center variation file ftp://igscb.jpl.nasa.gov/pub/station/general/igs_01.pcv.

- Exceptions (for historical reasons) are listed in ftp://igscb.jpl.nasa.gov/pub/station/general/uncal_radome.txt
- To use an antenna+radome pair not found in either of these files, contact the CB. A calibration from an independent, recognized laboratory such as NGS (http://www.ngs.noaa.gov/ANTCAL) or Geo++ (http://www.geopp.com) will be required.

Data issues

(required) 2.1.17 Transmission of data to the DC must be verified to be uncorrupted.

(required) 2.1.13 The station operating agency must archive the raw (native binary) GPS data, or arrange for this at a suitable agency such as a partner agency, or an Operational Data Center.

Reference Frame site practices

3.3.1 3-dimensional local ties between the GPS marker, collocated instrumentation (e.g. DORIS, SLR, VLBI, gravity, tide gauge) and other monuments should be re-surveyed at least every two years to an accuracy of 1 mm and reported in ITRF.

3.3.2 Survey measurements, field notes, and reduced results should be preserved and be made publicly accessible

3.3.3 All survey data, but especially ties to other IERS and IGS markers, should be rigorously reduced in a geocentric frame related to ITRF (preferably ITRF itself) and the results be made available in SINEX format (defined at ftp://igscb.jpl.nasa.gov/pub/data/format/sinex.txt), including full variance-covariance information

3.3.4 Moving to another monument must be avoided except in extreme circumstances, requiring prior announcement and submission of overlapping data sets starting one year in advance. Analysis of the two sets is helpful; results should be documented in the site log and in an IGSStation message.

3.3.5 When antenna change is unavoidable, minimize position discontinuities by first operating the new antenna on an nearby ancillary monument, and announce to IGSStation how analysts may get the test data set.

Data completeness items

(desired) 2.2.1 Receiver support for “all-in-view” tracking

(desired) 2.2.2 The receiver tracking cutoff is ideally 3 degrees or less, especially for “all in view” receivers.

(desired) 2.2.7 Support for GLONASS observations is desirable. See Chapter 6, Guidelines for IGS sites with GPS/GLONASS receivers below for further guidance.

(desired) 2.2.21 Receivers should be set to record data from all satellites, including those newly launched or set “unhealthy”.

5 IGS Network Communication: splitting the IGSMail list

The suggestion to have separate mailing lists for major announcements and station advisories has been made from time to time over the past years, but now the frequency of receiving this request has reached the point of confirming a clear need in the community.

We envision that “announcements” means messages such as IGS Workshops, new IGS stations, product-related announcements, major DC announcements, sessions at conferences, enhancements to web pages or services, etc.

“Station advisories” includes station configuration notices and outage or repair notifications. Although new procedures for RINEX data replacement notification are under discussion in the Data Center Working Group, data replacement messages will also be sent in this mailing list until a new system is in place.

Four options identified for implementation were presented in the preliminary position paper disseminated prior to the workshop, and the scheme shown in Figure 1 was chosen.

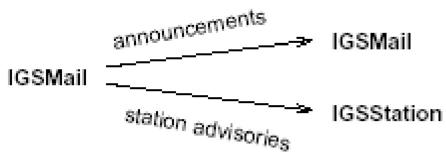

Figure 1: Creation of the IGSStation mailing list

In summary, the new list “IGSStation” will be created for station advisories, and announcements will stay on IGSMail. When IGSStation is created, IGSMail subscribers will be advised to subscribe to IGSStation if they wish to continue getting station advisories

6 A lingering question: North and East eccentricities

This is a tricky issue that needs a solution. Originally (pre-2002) the IGS site logs had no provision for collecting North and East eccentricities in a standardized way. Furthermore, the IGS SINEX template had been hard-coded to write zeroes in these fields, apparently since inception.

There are presently 3 IGS sites with nonzero N, E eccentricities: NYAL (N = -0.0010m, E = 0.0040m), OBET (N = 13.7960m, E = -5.2640m), and WUHN (N = -0.0022m, E = -0.0094m).

Obviously, suddenly changing these from zero to nonzero in the SINEX template could produce a confusing time series. ACs probably have differences in handling (or ignoring) nonzero N or E eccentricities in the SINEX template, site logs, and/or RINEX headers.

We prefer that the SINEX template and products reflect the "best" set of information known about a site, and therefore accurately reflect reported N, E eccentricities.

The community is invited to discuss and recommend a controlled plan for introducing the proper N, E eccentricities into the SINEX template with analysts, RF coordinators, and SINEX product users in mind. This should be done promptly while the number of sites with nonzero N, E eccentricities is small and before the IGS celebrates any more major anniversaries.

7 Recommendations

Five major recommendations were chosen for inclusion in the main Workshop recommendations:

1. New stations proposed to the IGS should be described on a web page and announced to the community by the CB, but added to the IGS network only on the request of an AC or Coordinator.
2. The "Global" station designation should be discontinued. The 99 IGb00 Reference Frame stations will be promoted on station lists and a letter will be written to agencies operating IGb00 stations, noting the significant effort and responsibility and requesting a reaction to the Reference Frame station guidelines.
3. The analysis community should develop a plan to handle North and East eccentricities.
4. The IGSMail list will be split into IGSMail (for messages such as IGS Workshops, new IGS stations, product-related announcements, major DC announcements, sessions at conferences, enhancements to web pages or services, etc.) and IGSStation (for station configuration notices, outage or repair notifications, and RINEX data replacement notification).
5. Monitoring and encouraging compliance to the data recording and transmission guidelines is encouraged.

In addition, the following action items are suggested by this paper:

1. IGS Provisional, Project, Product and Inoperational categories should be pursued as discussed.
2. The Network section of the Terms of Reference should be re-written to reflect the chosen policies on station classification.
3. The analysis community should identify the necessary level of standardization of metadata ingestion, and provide an agreed-upon direction to the NC for future development of metadata products.
4. Former IGS sites should be added to the IGS SINEX template.

8 Acknowledgment

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IGS Network Issues 2002-2004 - Update Since Ottawa Workshop

Michael Schmidt NRCan – GSC

Angelyn Moore JPL / Caltech

1.0 IGS Network Status 2004

In the 2002-2004 time period the IGS Network evolved to include more stations and new GNSS sensors (GLONASS), as well as seeing previously sparse areas of the world represented by new reference stations. Table 1 summarizes the evolution in the past two years since the Ottawa workshop.

Table 1

	2004	2002
Total No. of Stations	364	293
Global Stations	127	117
1-Hr Stations	158 (70 are Global Stations)	117
High Rate (1Hz) Stations	44	35
IGLOS (GPS/GLONASS)	42 (4 are Global Stations)	

Global Station:

- *IGS Stations which are analyzed by at least three IGS Analysis Centers for the purpose of orbit generation*
- *At least one of the Analysis Centers lies on a different continent than the station considered*

Fig 1: New Sites 2002-2004

● *GPS Sites* ● *IGLOS sites*

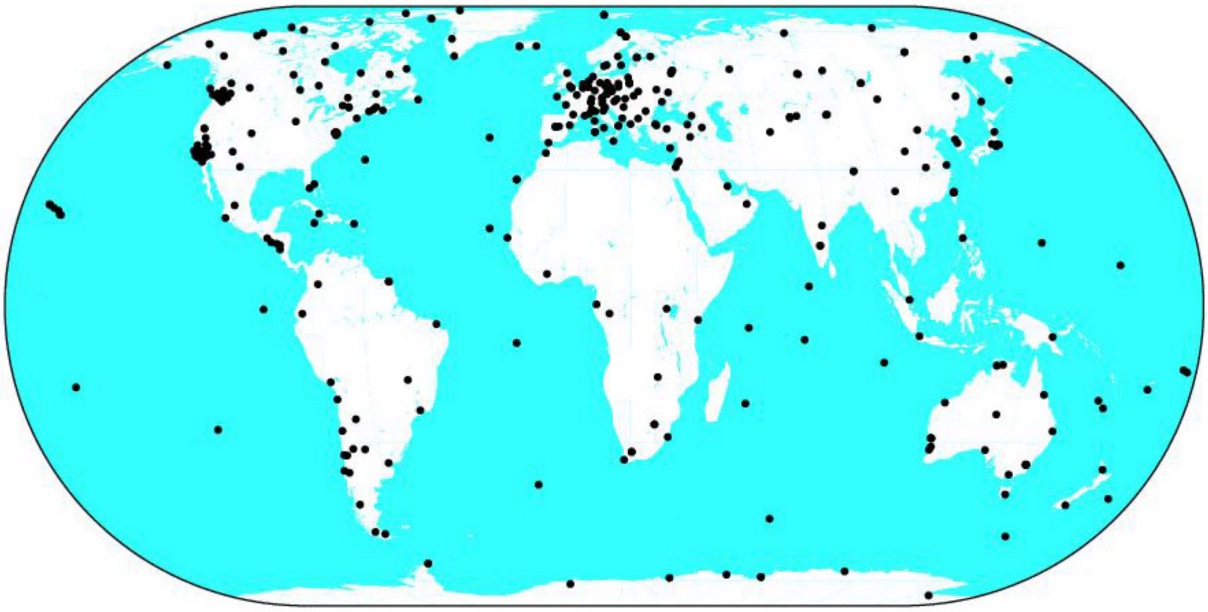


Fig 2: IGS Network 2004

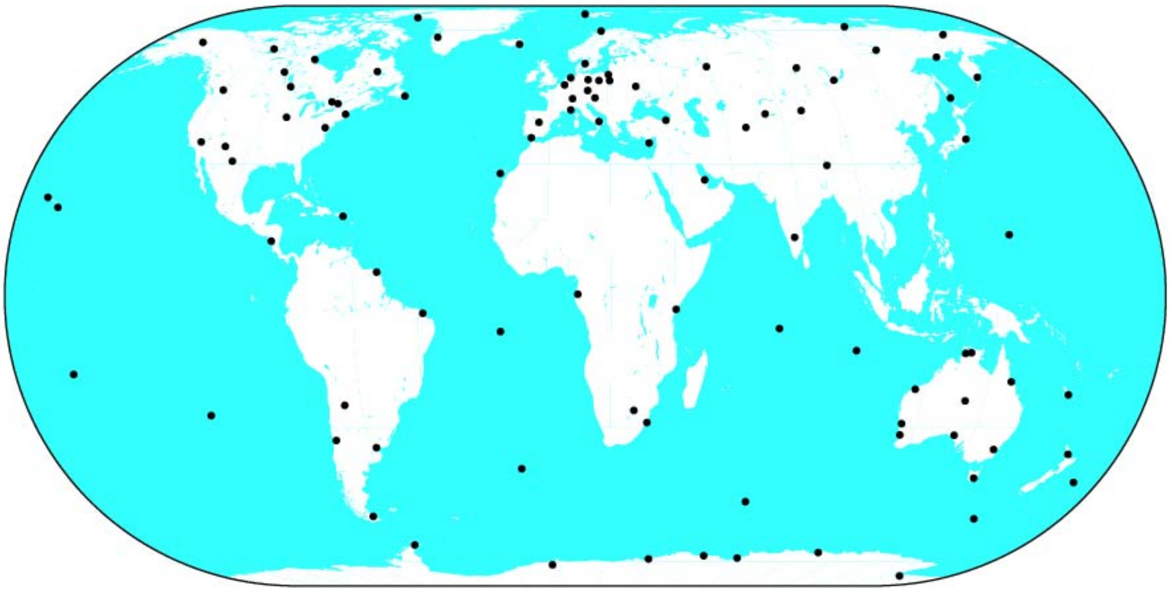


Fig 3: IGS Reference Frame Stations

Despite the growing number of stations within the IGS Network, it is clear from both figures 3 and 4 that certain parts of the world lack coverage. Similarly, it should be noted (see fig. 4) that the stations contributing 1 hour data are clustered in Europe and western North America while the global distribution is sparse.

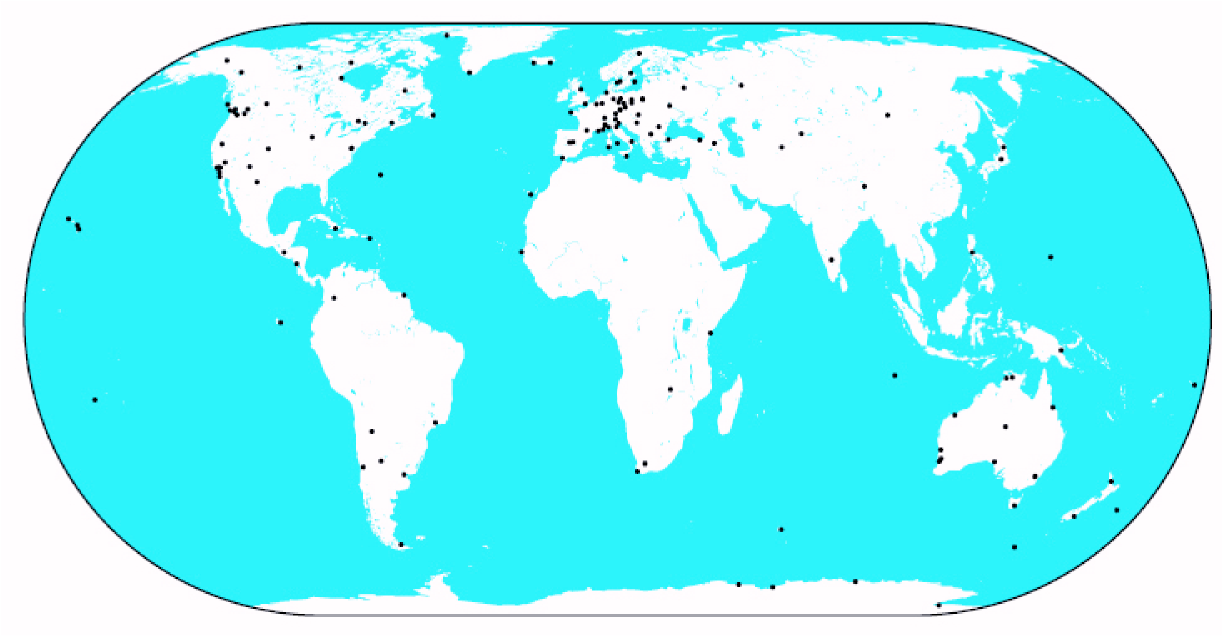


Fig 4: IGS 1-hr Stations

It should also be noted that the distribution of stations providing 1 HZ data in 15 minute files, not real time, is also limited geographically, see fig. 5.

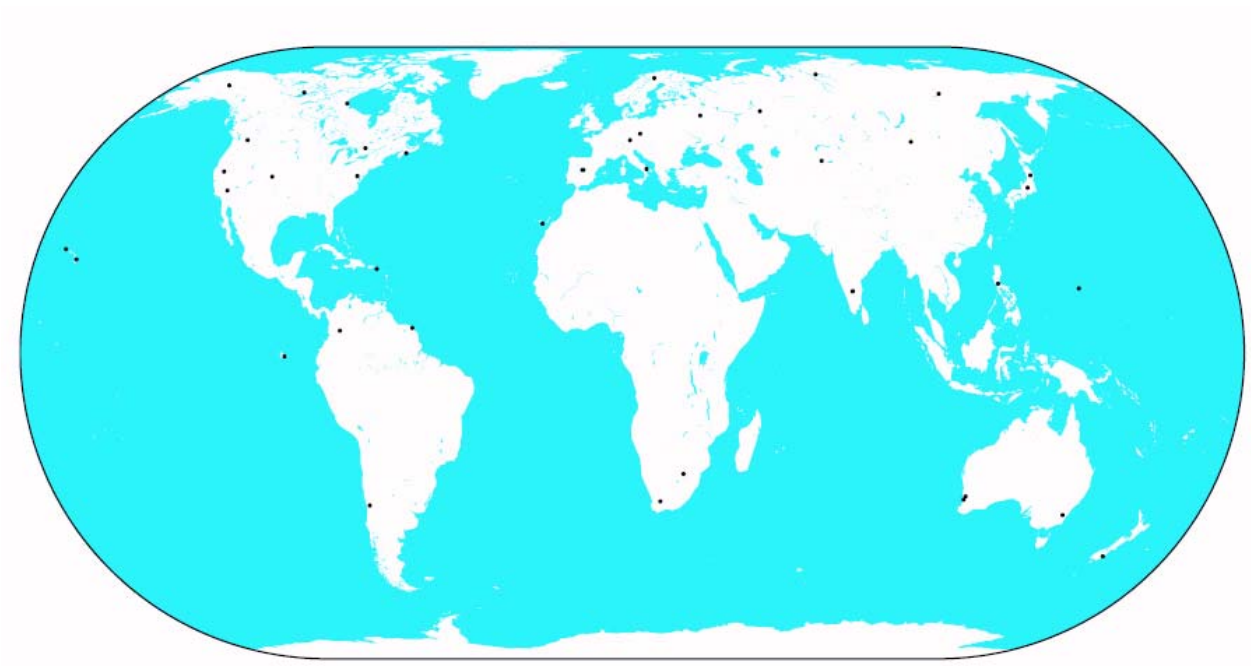


Fig 5: IGS 1Hz (LEO) Sites

1.1 Network Status Summary

While the overall number of stations as well as the types of data sets have increased, there are still some issues the IGS must address in the coming year:

- Geographic Coverage. As is evident from the maps, there are a number of areas in the world where it would be desirable to increase the station density either by establishing new sites or by obtaining data from existing sites which are not currently part of the IGS.
- 1-Hr Sites: How many are reference frame sites – how many are used in the derivation of IGS Products? Do we need to actively pursue / convince other station operators to provide 1hr files?
- 1-Hz (15 min files – LEO) – coverage adequate?
- RT Sites – where are they currently?

In the past 10 years, the IGS Network has evolved based primarily on the needs of individual member agencies. In order to meet the objectives as outlined in the IGS Strategic Plan, it is clear that the IGS must define its combined requirements in terms of station distribution and density, station sensor(s) (GPS, GLONASS, modernized GPS, Galileo), and capacity for producing data with low latency or in real-time.

2.0 GPS Modernization

The modernization of the GPS constellation has not proceeded as timely as anticipated at the Ottawa workshop. The current status of GPS modernization as well the launch of new space based signals is somewhat tentative but can be summarized as follows:

- First Block IIR-M (L2C) launch date 2004-2005
- First Block IIF (L2C + L5) launch date as 2010 timeframe
- Full L2C / L5 Capability TBD
- Galileo first launch 2006(?) – operational 2008 (??)
- GLONASS-M (second civil signal) 2003-2013
- GLONASS-K (third civil signal) 2006-2022

It is evident that these dates are not firm and that further changes / delays can be expected. The civil L2 signal (L2C), a stronger GLONASS constellation and the new Galileo signal appear to provide the strongest near-term challenges for the IGS in terms of providing global coverage of stations capable of tracking the new signals. In order to maintain its role as a truly international organization, the IGS must be pro-active in monitoring the evolution and implementation of the new signals. Network evolution will be required for:

- IGS 'Global Stations'
- 24-hr sites
- Near-real time sites (1-hr data)
- Near-real time sites (15min files, 1 Hz data)
- Real time sites

In addition, the products provided by the IGS will evolve both in the near term and in the long term, thus providing challenges not only to station operators but also to the analysis centers. Upgrades and improvements will also be required on the methods and tools used in data handling and analysis systems – for example, changes to the RINEX standard, data validation software (e.g. TEQC, etc.) as well as the analysis software (e.g. Bernese, GIPSY, GAMIT, etc.).

As noted in Ottawa, the mandates of member agencies may drive the upgrade of IGS sites to provide the modernized signals. However, this may not necessarily meet the standards and requirements for a robust global modernized IGS network. The IGS must therefore prepare for the modernized era and, from a global network perspective, ensure that the coverage is available to transition to a GNSS Service.

3.0 Associate Regional Networks

The evolution of the IGS Network stations has been accomplished through a remarkable effort by numerous member organizations worldwide. Inclusion in the IGS has been promoted on a station-by-station basis. This has resulted in the robust network we see in 2004. There are, however, areas of the world which are oversubscribed and as noted in Sect. 1, areas where additional sites are required.

In 2002 it was recommended that the IGS should consider the concept of Associate Regional Networks (ARN) for those areas where:

- agencies operate stations that meet the IGS criteria
- station density is greater than that required by the IGS

It was envisioned that the data from ARN stations that are required globally would continue to be submitted to IGS Global data centers. However, those data sets and associated metadata which were more regional in nature would be held at Regional data centers and made available to the international community via FTP distribution and, with time, through seamless data distribution.

The issues leading to this recommendation centered on:

- The current distribution of IGS stations (GPS and GLONASS) – is this distribution sufficient to meet requirements for reference frame, final, rapid and ultra-rapid products, etc.?
- The “Optimal Station distribution” - What is the optimal distribution of IGS stations required to meet IGS Product Stream and by extension how many of these have to be IGS ‘Global Stations’?

It is recognized that a certain amount of redundancy is desirable (indeed, essential) to ensure a robust network and thus a complete set of IGS products. However, it is also recognized that adding new stations to the IGS Network in areas of the world with dense station coverage may be confusing and redundant.

It is essential that the IGS balances the conflicting goal of inclusivity with that of providing a globally relevant and high quality data / product set. The IGS values its inclusive and voluntary nature – this is, in fact, a cornerstone of the success of the IGS. During its first ten years, the IGS has accepted any proposed station meeting the technical requirements. This is of mutual benefit to both the host agencies and the IGS.

To deal with the proliferation of GPS/GNSS reference stations worldwide, both within and outside of the IGS Network, it was proposed that Associate Regional Networks would provide a way to extend the inclusive nature of the IGS at a network as well as at a station level. This would thus clearly identify the IGS global network of stations required by the IGS to produce internationally-recognized products of the highest caliber, yet at the same time facilitate access to and use of GNSS data from an extended network of regional stations operated to international (IGS) standards.

4.0 Instrumentation and Site Changes

There has been a natural evolution of best practices at GPS Reference stations over the past 10 years. However, it is also clear that in order to preserve the standards of IGS products and ensure orderly and robust improvements in the future, new updated guidelines based on current ‘best practices’ and experience to-date must be developed. These guidelines have been completed through a consultative process involving several experts within the IGS and are now available on-line. It should be noted that this is a ‘living document’ and will be updated as required. A new site log format was also implemented, to improve the meta-data and thus the recording of site changes. An on-line link to IGS member site construction / monumentation information has also been made available.

- ► New Guidelines
  - New set of station Guidelines (Sept. 2003) are available at: http://igscb.jpl.nasa.gov/network/guidelines/guidelines.html
  - Spearheaded by NC, reviewed by experts within the IGS
  - Approved by Governing Board
  - Living Document (see also Bern Networks PP)
    - ► *http://igscb.jpl.nasa.gov/network/guidelines/guidelines.html*

      1. Introduction and how to use this document
      2. For all IGS sites
      3 .IGS Reference Frame Sites
      4. IGS sites submitting hourly data
      5. IGS sites submitting meteorological data
      6. IGS sites with GPS/GLONASS receivers
      7. IGS sites submitting LEO Pilot Project (LEO-PP) (15min/1Hz) data
      8. IGS sites participating in the Tide Gauge Benchmark Monitoring Project (TIGA-PP)
      9. IGS sites participating in IGS timing activities

- ► New Log File Format
  - Implemented

    ftp://igscb.jpl.nasa.gov/igscb/station/general/sitelog_instr.txt

- ► On-Line monumentation info
  - *http://igscb.jpl.nasa.gov/network/monumentation.html*

This deals with instrumentation changes / replacements and recording of these. The determination and recording of change in site coordinates due to instrument changes, seismic activity or other factors is equally important and more challenging; since change in coordinates is analysis dependent, publication of an "absolute value" may be difficult. The following recommendations from the Ottawa meeting are to be resolved:

- Develop a system of feedback from IGS analysis to site operators
- Discontinuities as determined by IGS AC could be published on IGS web site in collaboration with site operator and NC
  - ► To be Resolved (see proposals in Bern Reference Frame PP)

Communicating Change in Site Coordinates

The following example for station ALBH illustrates the challenge of detecting changes in station coordinates as a result of site instrumentation changes. During weeks 1233-1235 several changes were made in order to eliminate a problem, the cause of which was determined through a process of step-by-step component replacements:

- 2003-08-26: Receiver changed 1233-2
- 2003-08-28: Receiver disconnected from Maser; on internal clock; 1233-4
- 2003-09-03: RG-214 cable replaced by Andrews FSJ-2-50 cable; 1234-3
- 2003-09-05: Antenna replaced; dome replaced, RF screen removed; 1234-5
- 2003-09-08: New RF screen added; 1235-1
- 2003-09-10: Receiver connected to Maser; 1235-3

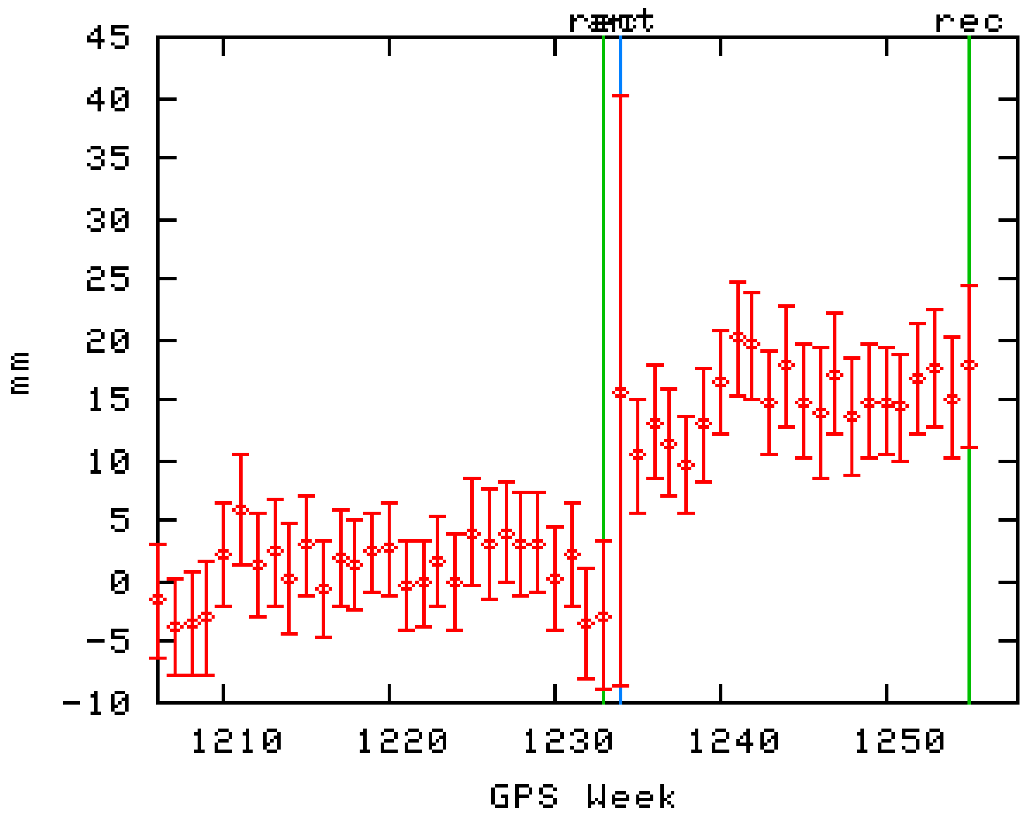
AC residuals (height) weekly solution with respect to the IGS weekly for weeks 1230-1237 is shown in the table 1 below.

Table 1

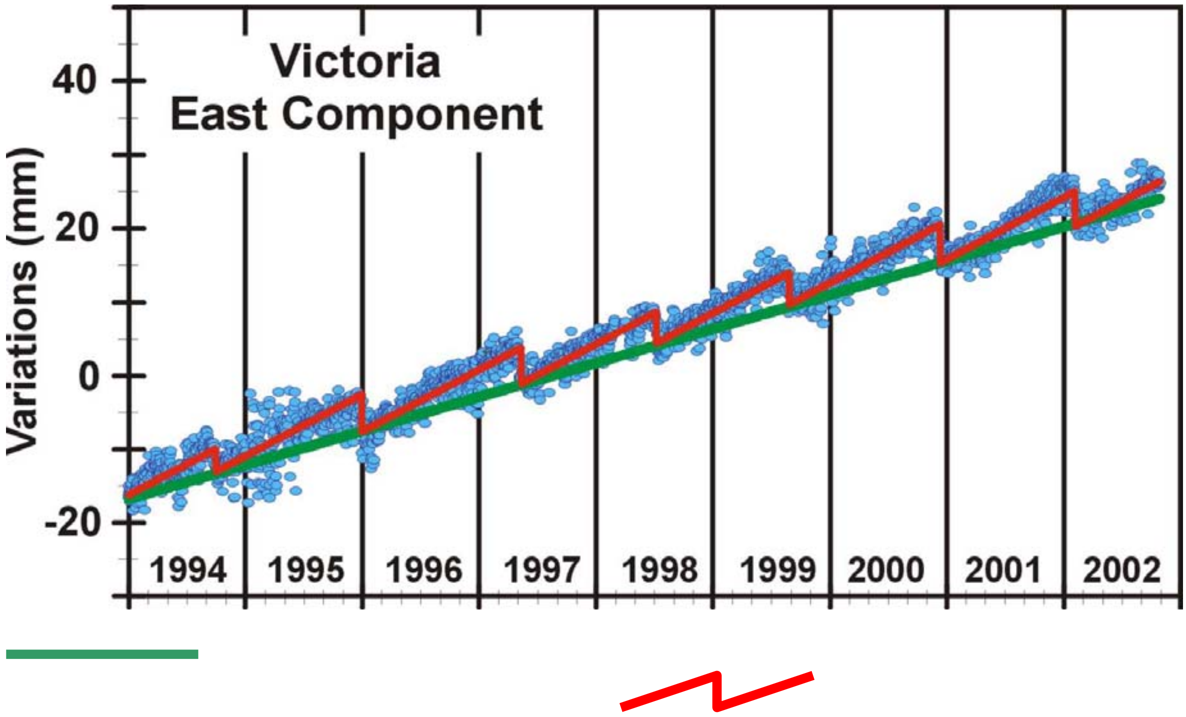
	COD		ESA		GFZ		JPL		SIO	
Wk	**H**	**sH**	**H**	**sH**	**H**	**sH**	**H**	**sH**	**H**	**sH**
1230	-3.9	8.0			0.7	7.3			-1.5	4.5
1231	-2.8	7.9	-6.0	17.5	2.2	7.0			-3.1	4.7
1232	-3.0	7.9			2.2	7.1			-3.8	5.1
1233	0.7	11.0			4.0	9.3			-5.3	6.3
1234					-1.8	19.0				
1235	3.6	9.2	-1.4	17.7	1.7	7.7	10.4	15.5	-4.2	5.3
1236	4.9	8.6	-11.1	24.7	3.4	8.1	7.5	15.7	-5.1	5.3
1237	6.2	8.3	-6.5	12.7	1.3	8.2	-3.2	15.3		

The COD AC shows a clear discontinuity at week 1234. GFZ hints at a problem with week 1234; however, there is no clear discontinuity when comparing the weeks leading up to the change with the weeks following week 1234. There is a positive trend. SIO has not processed week 1234 and shows a negative trend. ESA and JPL are inconclusive. Clearly from these figures one cannot determine an "absolute" calibration of the offset induced by changing the antenna dome and RF skirt.

The offset is clearly noted in the Fig. 6 below obtained from the IGSCB web site (see Sect. 6). The plots of the height residuals represent the position residuals for ALBH, between the weekly solution and the cumulative solution. Error bars are the standard deviation for this station, based on the weekly solution covariance information (*http://igscb.jpl.nasa.gov/network/residualsplots.html*).



Temporal variation in Reference Station coordinates are also an issue that must be dealt with, within the IGS. The issues are similar to above: identification and recording of coordinate changes. The source of temporal variations is varied and includes seasonal changes, seismically induced movements, etc. As an example the station ALBH is used once again, illustrating both long term deformation induced by the station's location within a subduction zone as well as episodic changes due to change in long term rates induced by "ETS" or Episodic Tremor and Slip (Rogers/Dragert 2003).



Long-term linear trend (gradual eastward motion)

Segment trend with steps (accelerated eastward motion followed by brief reversal)

Clearly these types of coordinate shifts can bias IGS products.

As noted above, the issue of identifying and logging changes in stations coordinates (whether due to instrumentation, seismic, seasonal or other events) should be a priority for the IGS. Amongst other things this includes a requirement for better communication between the various levels of analysis centers and station operators and users of the data and data products. As the detection of and determination of magnitudes are analysis method dependent, it is essential as a first step to record not only station instrumentation changes but also changes in the local environment and external events such as illustrated above. The communication of these in a timely fashion is equally essential, (see Bern Network PP).

5.0 Data Exchange Format and Industrial Relations

At the IGS Workshop in Ottawa it was recommended that the IGS should establish a joint Task Force with GPS manufacturers. The primary mandate would be to:

- coordinate the evolution and international acceptance of the RINEX format
- encourage standardization of meta-data nomenclature
- coordinate any future data exchange formats

The preliminary steps have been taken and currently there are several initiatives under way to seek input from members (e.g. the changes to RINEX to accept new signals). However, there is still further work required in order to form this working group with on-going responsibilities. The role of the IGS within the real time environment and possible liaison with other international bodies; for example, the RTCM real time standards should also be considered.

6.0 Station Metrics

The final recommendation to come out of the 2002 Ottawa Workshop pertains to station performance / station metrics. Specifically, it was recommended that the IGS should examine the current station performance metrics and determine required changes.

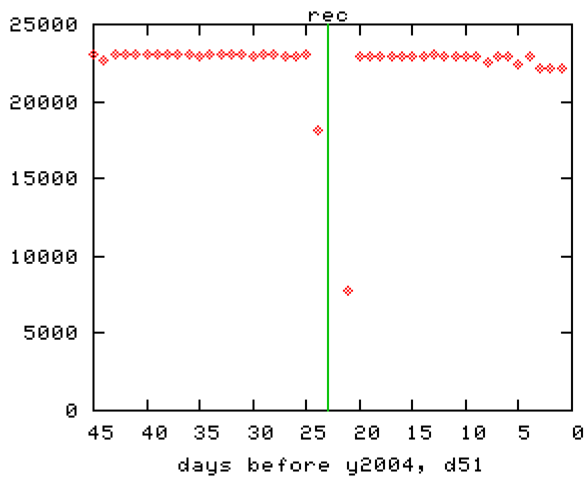
In addition the IGS should consider efficient methods of compiling and communicating station events or periods which may challenge present and future users' analysis; this is very much related to section 4.0 above. It remains unresolved. It should be noted that this is also analysis dependent as with Sect. 4. There are some important and related issues in the IGS Bern Reference Frame PP.

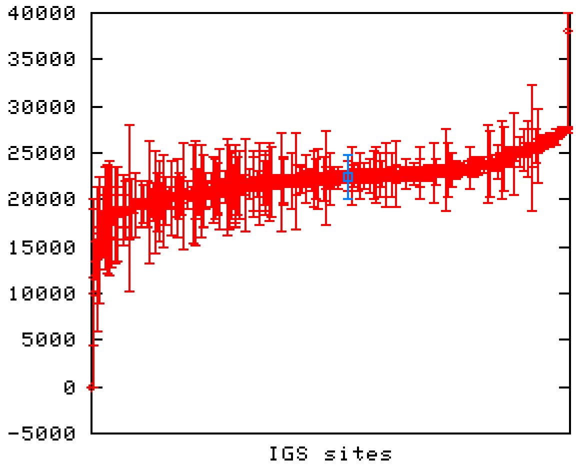
The third recommendation proposed that the IGS determine ways to improve any deficiencies in communicating station quality issues between AC's, the Coordinators (ACC, Ref. Fm. Coordinator, and NC), station operators, and outside users. This is a continuing effort, but considerable progress has been made in providing online information which can identify questionable recent station performance.

6.1 On-Line Station Metrics

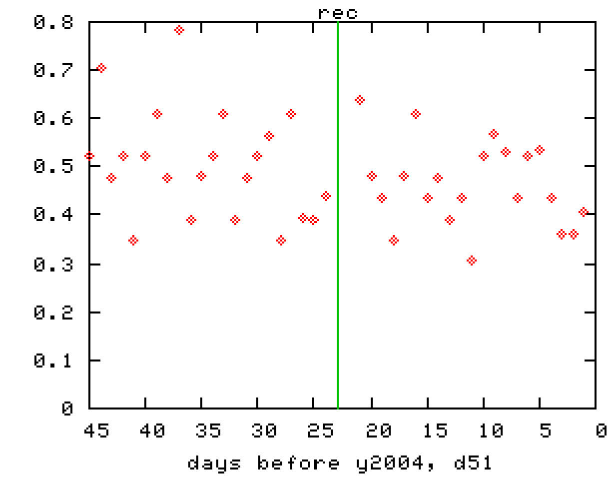
A new on-line set of station metrics are now available at the IGSCB web site via the links to individual IGS stations (*http://igscb.jpl.nasa.gov/network/list.html*). Three sections are available:

- Station Quality Plots *http://igscb.jpl.nasa.gov/network/dataplots.html*
- Station Position Residuals *http://igscb.jpl.nasa.gov/network/residualsplots.html*
- Station Latency Performance *http://igscb.jpl.nasa.gov/network/latencyplots.html*
- Station Usage in Products *http://igscb.jpl.nasa.gov/network/produsage.html*

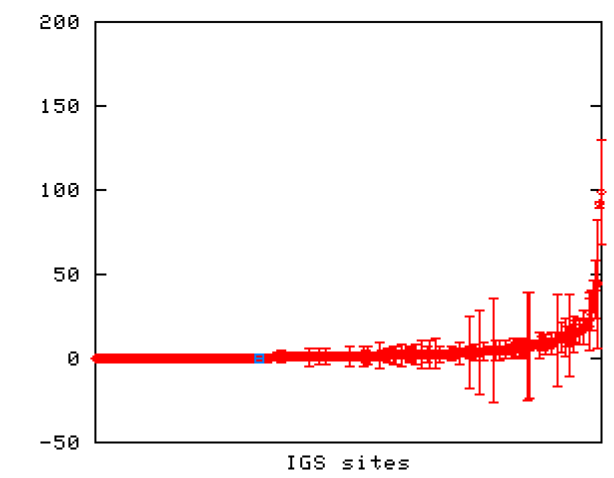
<table>
<tr><td>Station Quality Plots</td><td>IGS 45 Day Network Averages
SITE in Blue all Other IGS Sites in Red</td></tr>
<tr><td>

Recent daily number of observations</td><td>

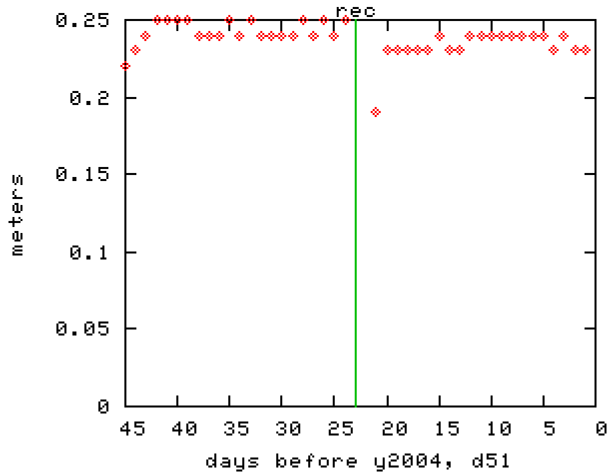
Daily number of observations</td></tr>
</table>



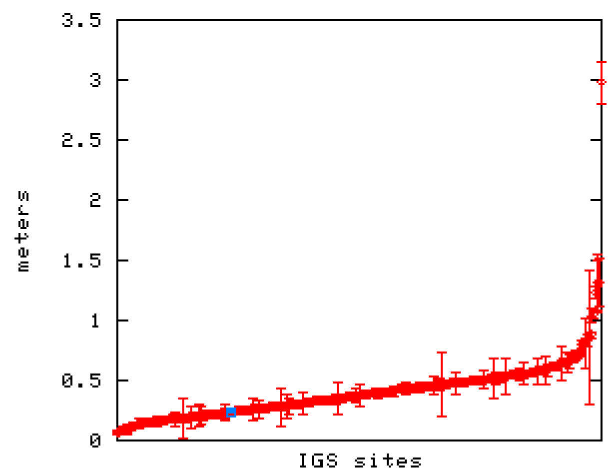
Recent cycle slips X1000/observations



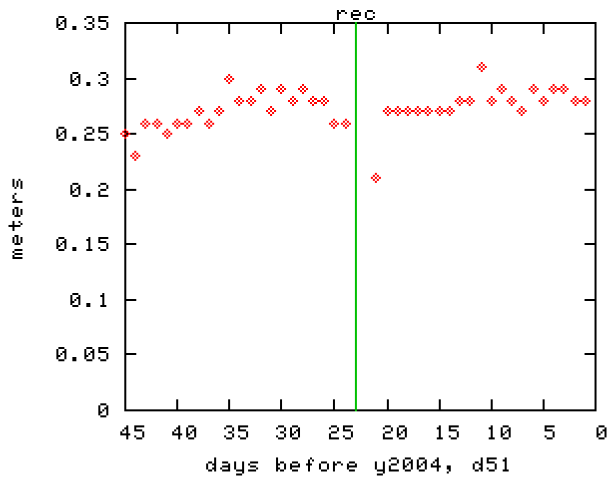
Cycle slips X1000/observations



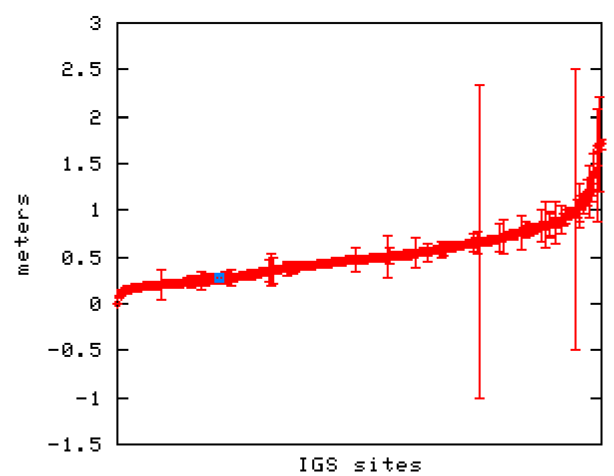
Recent RMS MP1 (L1 Multipath)



RMS MP1 (L1 Multipath)

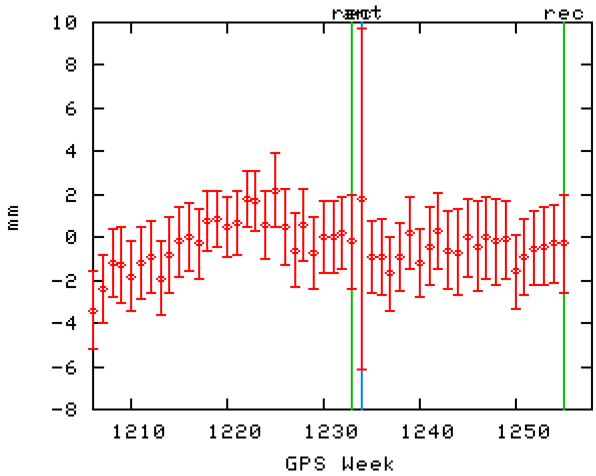


Recent RMS MP2 (L2 Multipath)

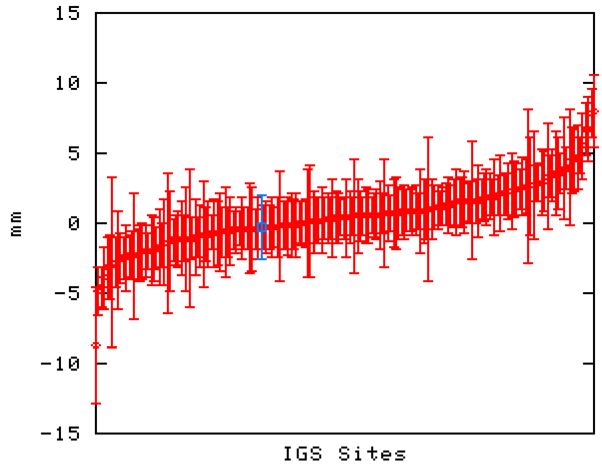


RMS MP2 (L2 Multipath)

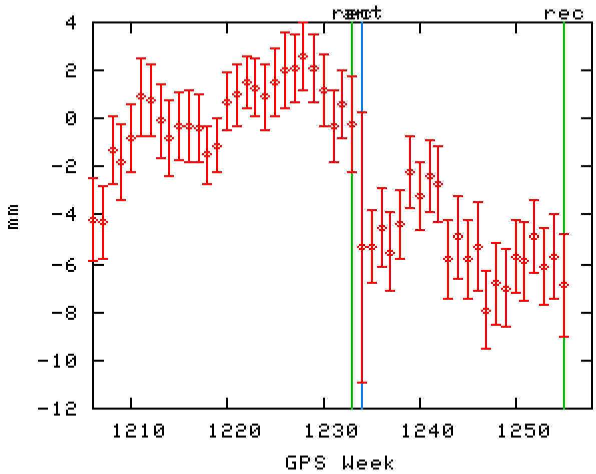
Position Residuals (Cumulative Minus Weekly) *for the Past Year*	*Most Recent Week* *SITE in Blue all Other IGS Sites in Red*



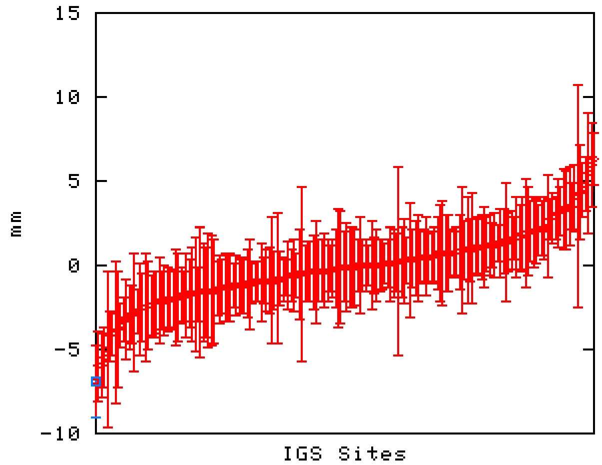
North Residuals



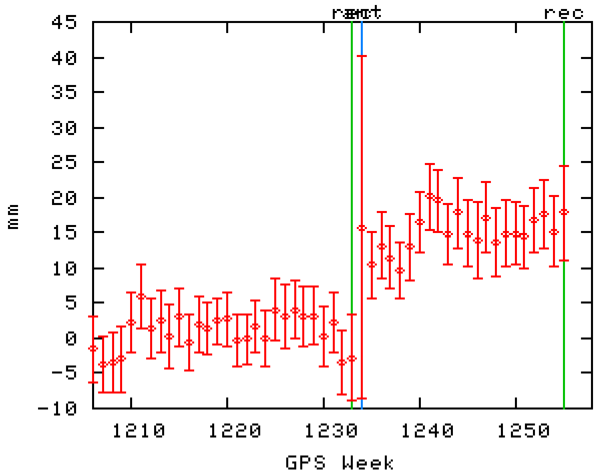
North Residuals



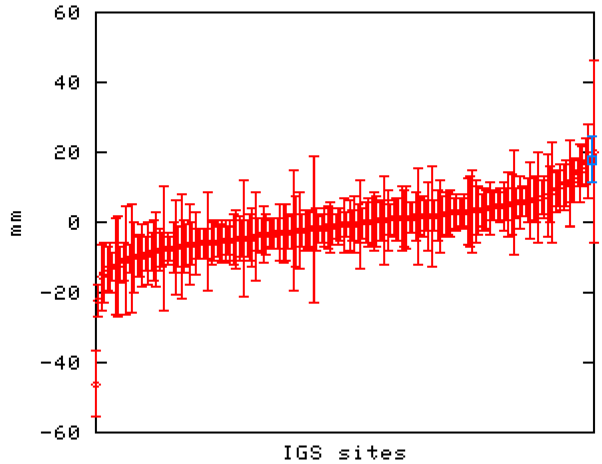
East Residuals



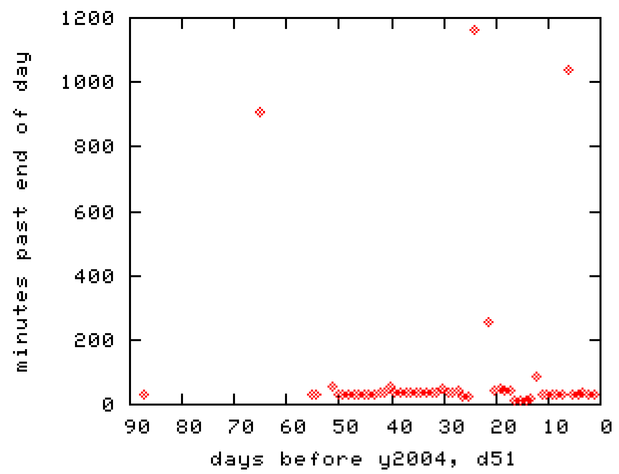
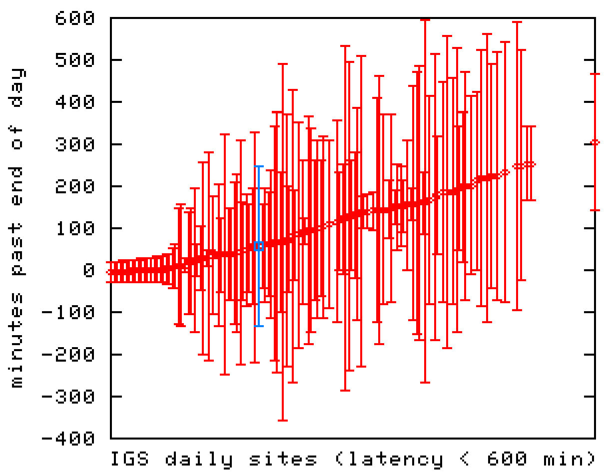
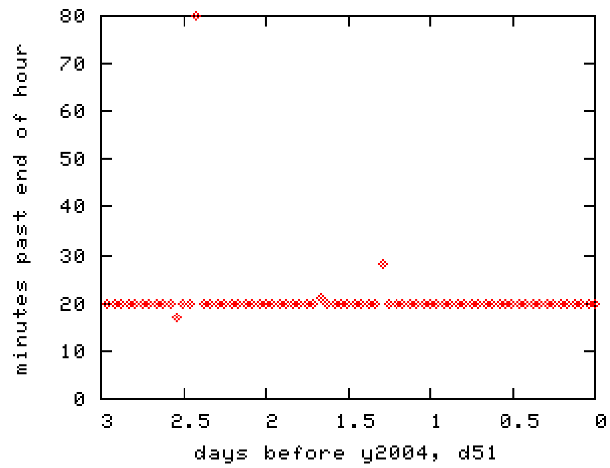
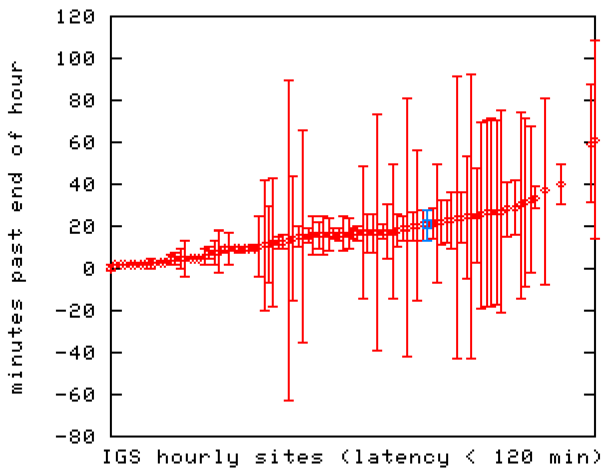
East Residuals



Height Residuals

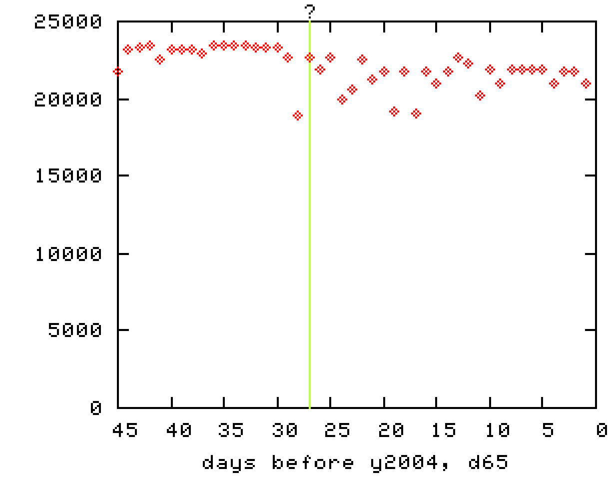
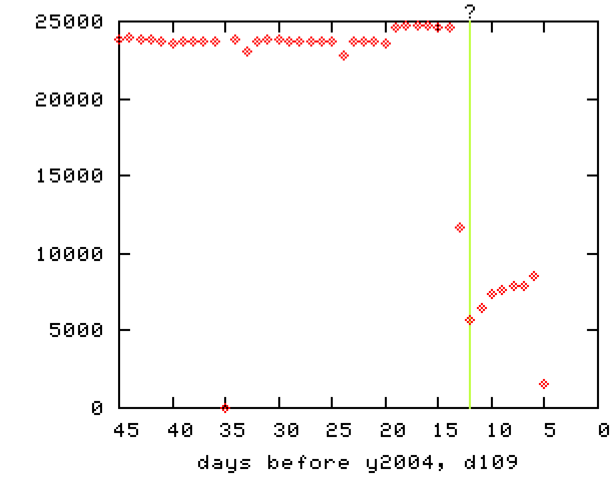
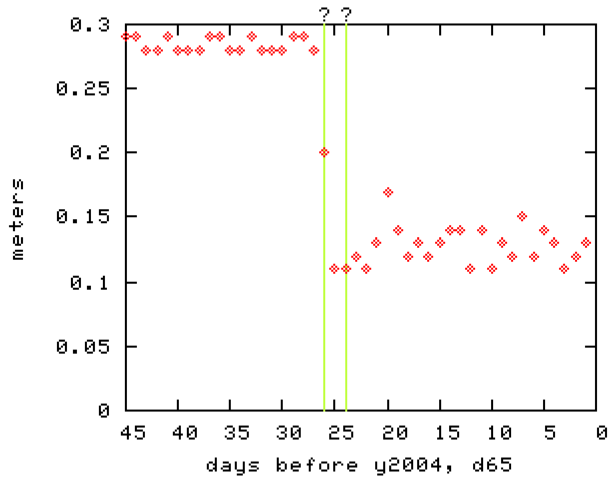
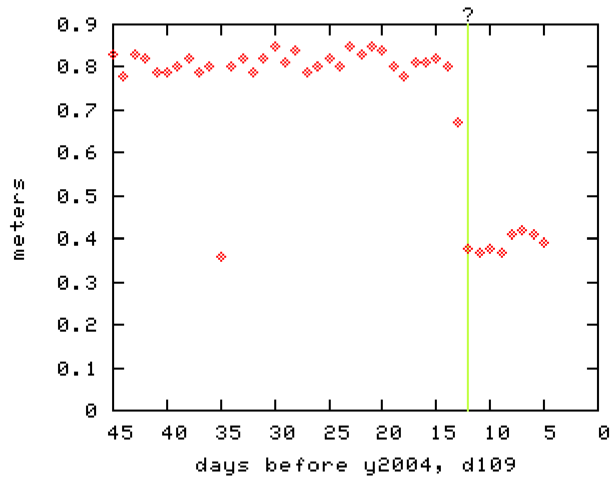
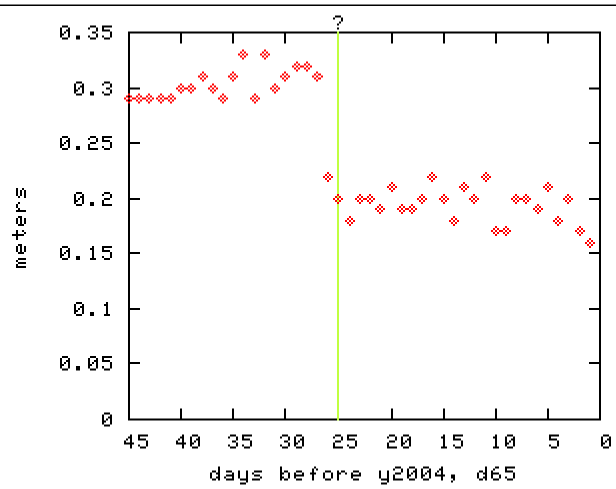
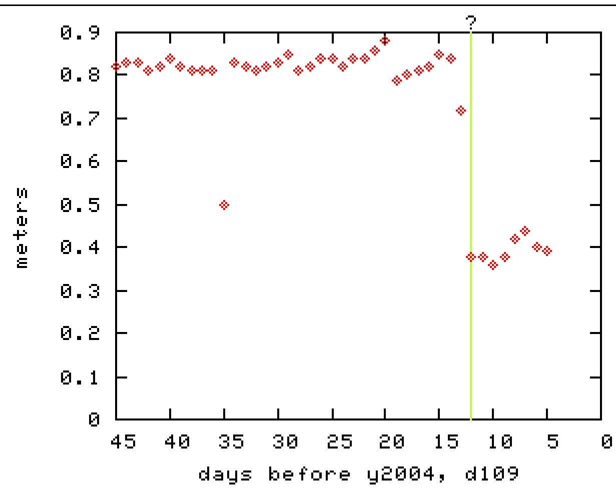


Height Residuals

File submission Latency: SITE	*Latency IGS* *SITE in Blue all Other IGS Sites in Red*
 *24 hr File Latency*	 *24 hr File Latency*
 *1 hr File Latency*	 *1 hr File Latency*

Changes in site instrumentation as reported in the site log are shown in the Station Quality and Station Residual plots by vertical lines and an annotation at the top of the graph. For example, in the graphs above, both antenna and receiver changes are indicated.

The time series of each of the four station quality parameters is passed through a change point analysis algorithm to identify likely changes in the parameters' behavior, which can indicate a change having taking place at the station. These detected change points are flagged with cautionary green vertical bars and a question mark. No attempt to is made to define the cause of the change. Examples from two sites are given below.

BRMU	SEY1
	
Recent daily number of observations	*Recent daily number of observations*
	
Recent RMS MP1 (L1 Multipath)	*Recent RMS MP1 (L1 Multipath)*
	
Recent RMS MP2 (L2 Multipath)	*Recent RMS MP2 (L2 Multipath)*

7.0 SUMMARY

In the past two years the number of IGS stations has increased, as has the number of stations providing lower latency data files to the Global Data Centers. The required station density and spatial distribution must yet be resolved, specifically the required station density for the different raw data streams produced by the IGS (24-hr, 1-hr, 1Hz 15min, Real Time). Furthermore, the IGS must also examine station density / global distribution with respect to data latency and data rates required to produce the expanding range of present and future IGS Products, to ensure that the IGS maintains its capability to produce reliable high quality data / products.

As seen from the examples above and from on-line resources, it is encouraging to see significant progress in the areas of station metrics, the approval / implementation of new IGS Guidelines, and the implementation of a new Station Log format. Monumentation Information has been placed on-line.

As would be expected (given the evolutionary nature of the IGS Network), there are still some issues to address (see also Bern Network PP). The key is to continue addressing these issues as they arise. Perhaps the most challenging issue is the emerging new satellite navigation systems (Galileo, GLONASS) and the new signal structure(s) of the GPS constellation. It is clear that the IGS must take a proactive role in ensuring global distribution of reference stations capable of providing a robust, high rate data stream of all emerging satellite signals, in order that the IGS maintains its recognized role as the international standard for GNSS data and product delivery.

Acknowledgements

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References

Rogers, Garry; Dragert, Herb; Episodic Tremor and Slip on the Cascadia Subduction Zone: The Chatter of Silent Slip; Science Express 8 May 2003