IGS Network Issues 2002-2004
Update Since Ottawa Workshop

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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.

	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)	

Table 1

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*

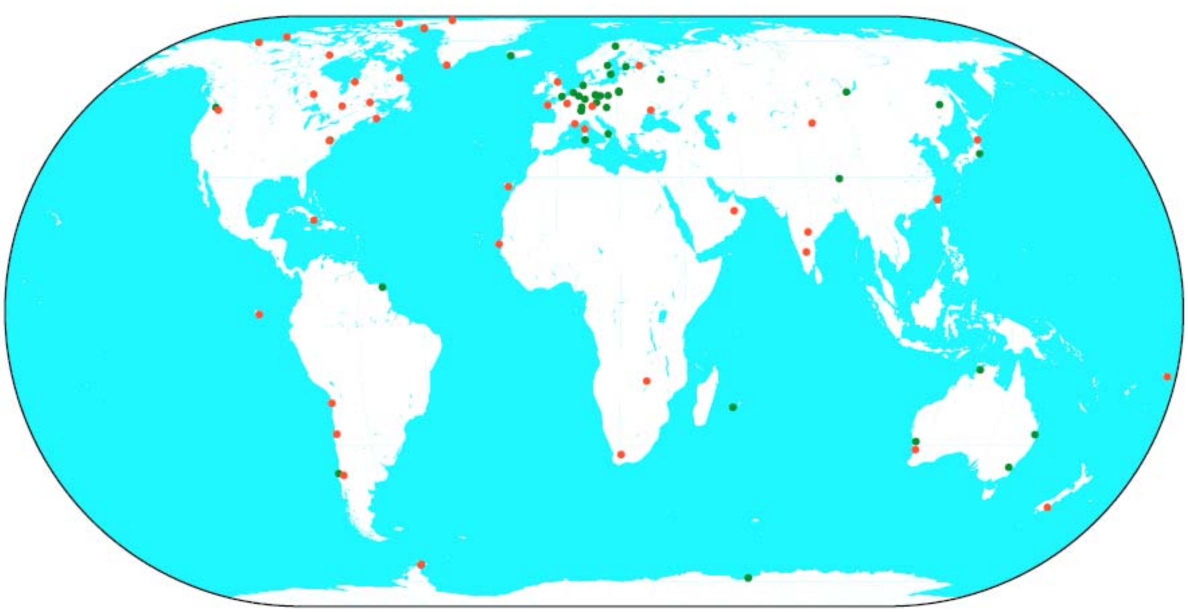


Fig 1. New Sites 2002-2004

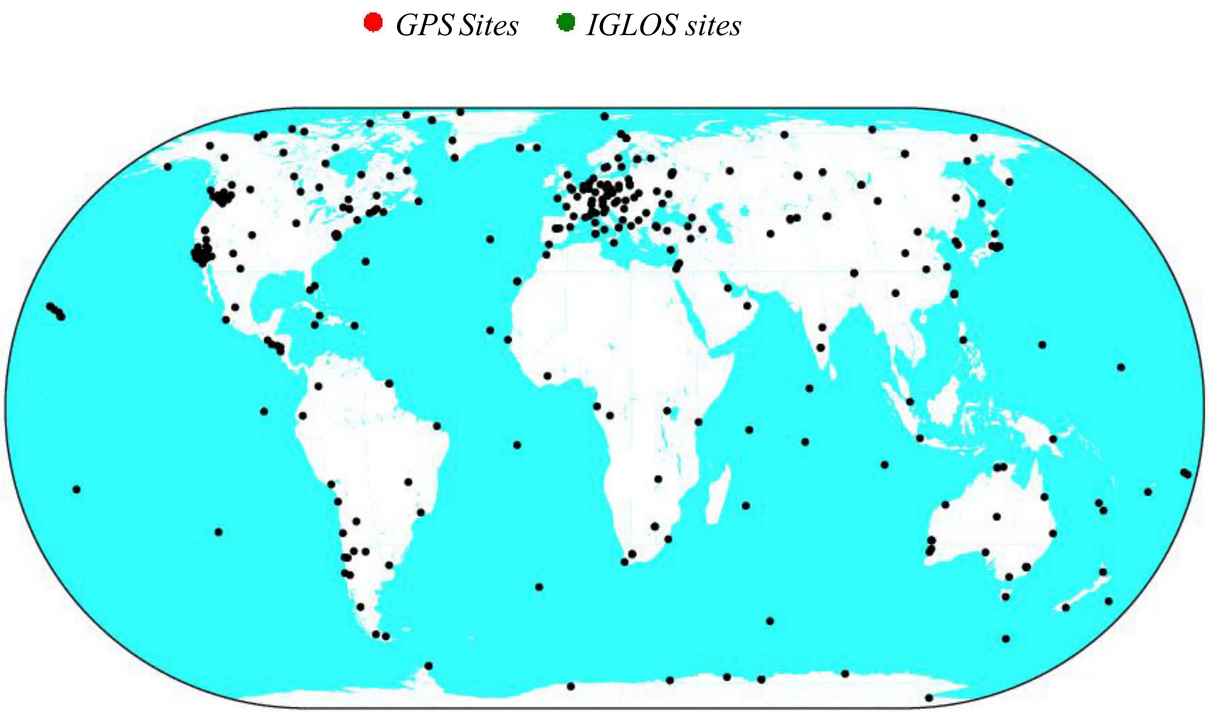


Fig. 2 IGS Network 2004

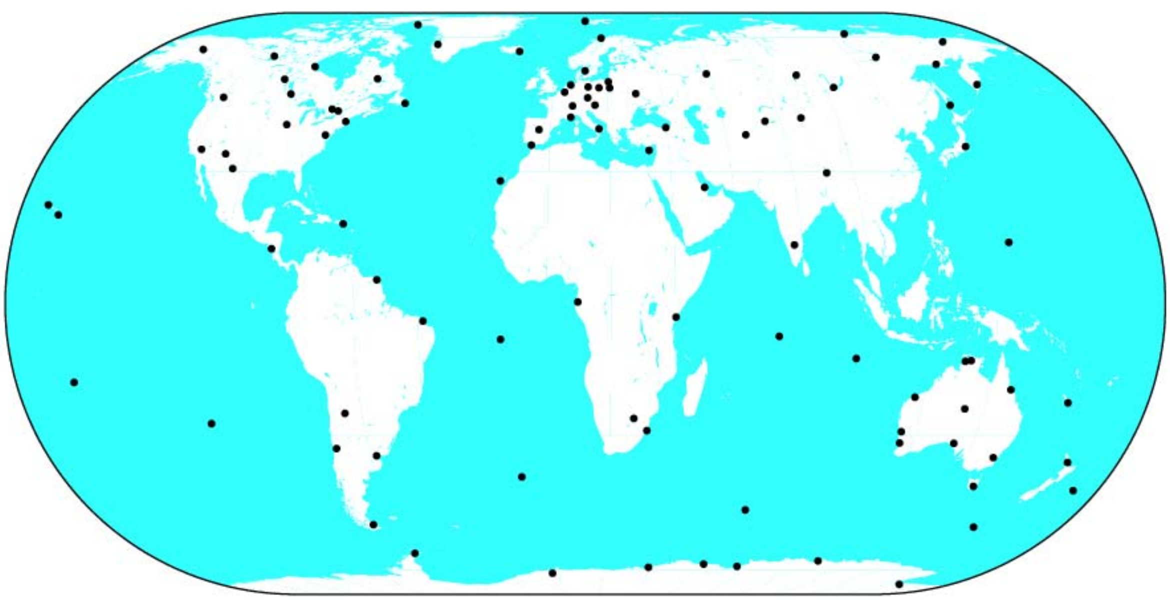


Fig 3 IGS Reference Frame Stations

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.

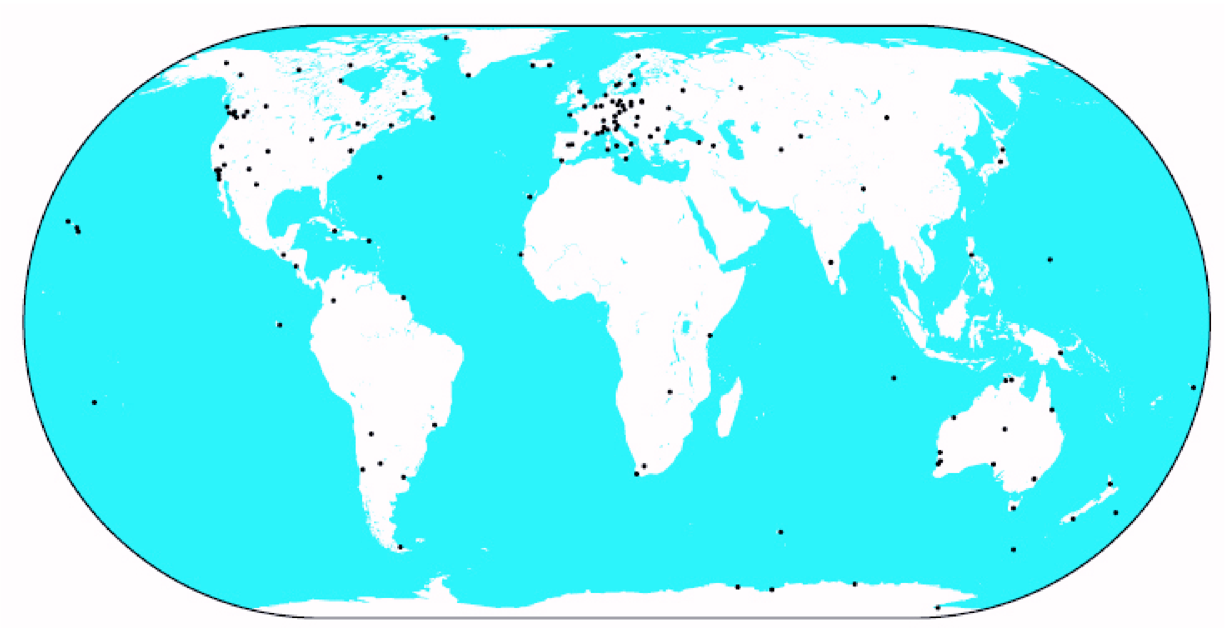


Fig 4 – IGS 1-hr Stations

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.

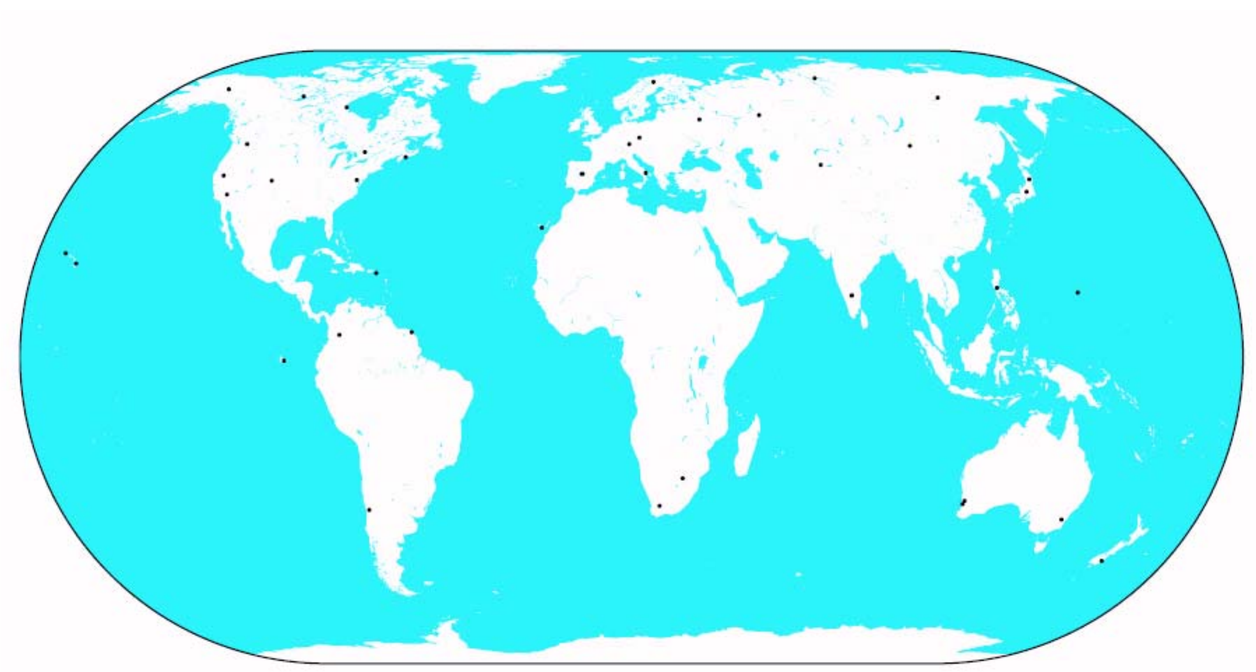


Fig 5 - IGS 1Hz (LEO) Sites

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

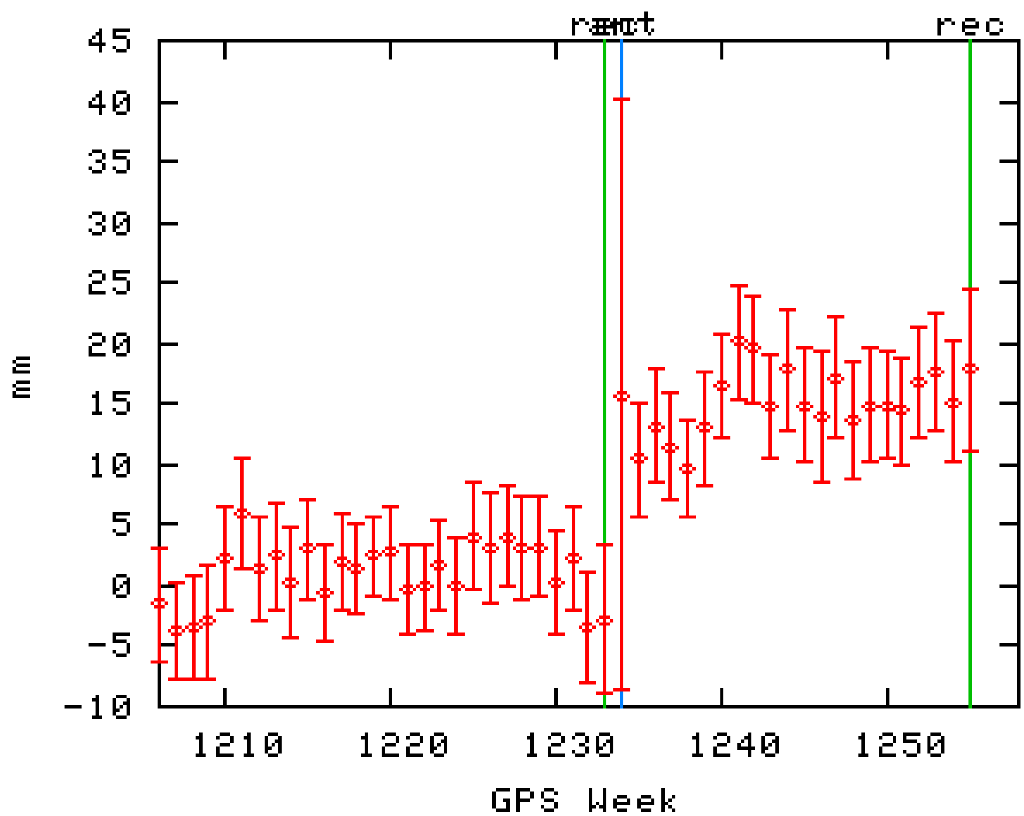
AC residuals (height) weekly solution with respect to the IGS weekly for weeks 1230-1237 is shown in the table 1 below.

	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		

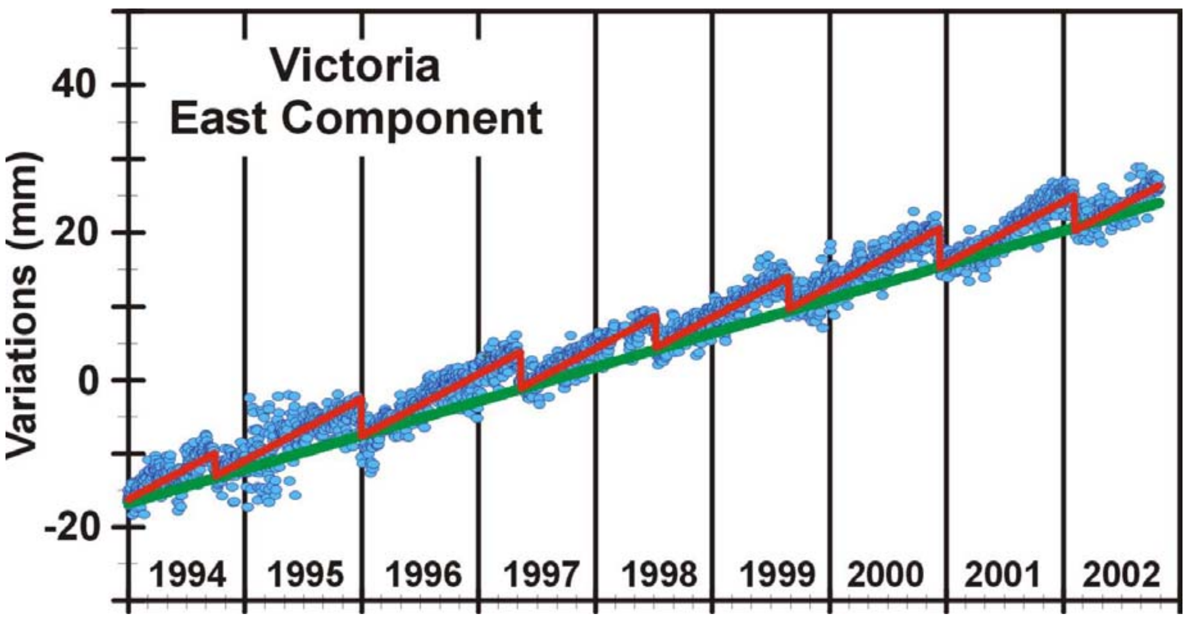
Table 1

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

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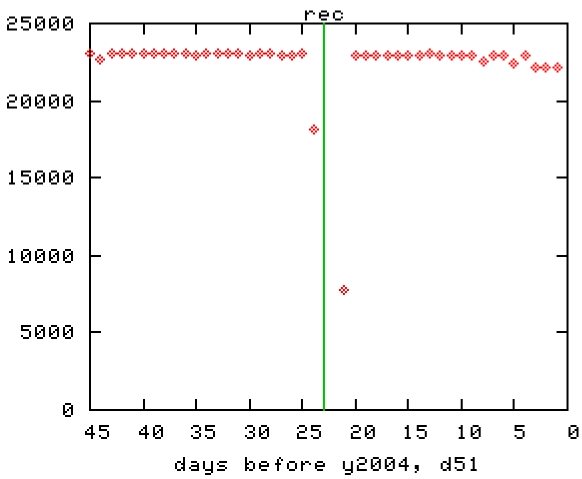
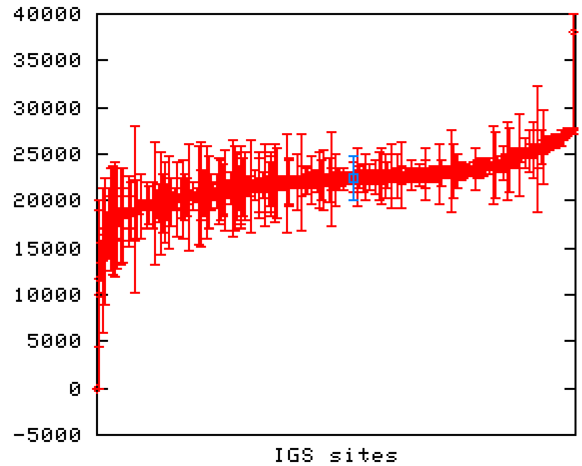
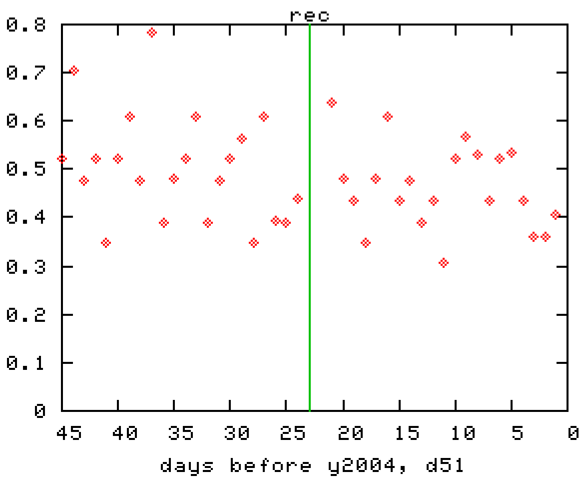
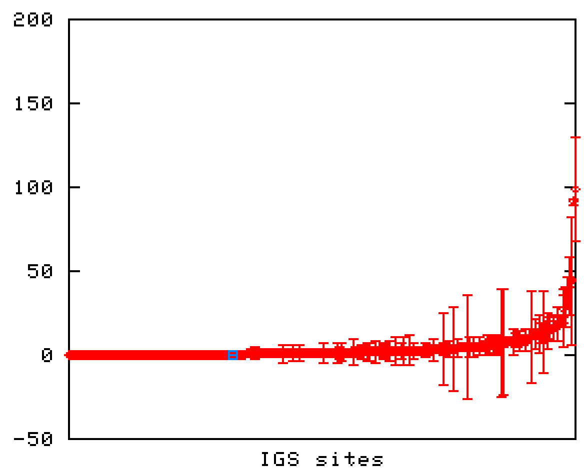
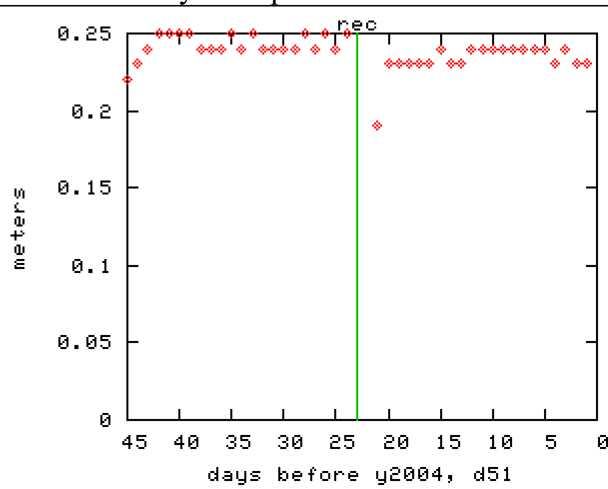
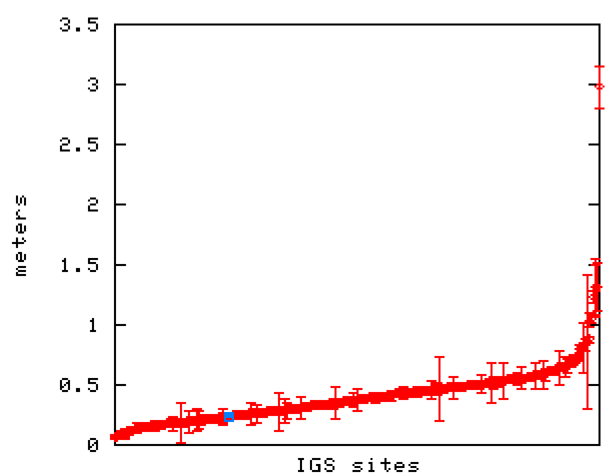
SITE in Blue all Other IGS Sites in Red</th></tr>
<tr><td>

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

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

Recent cycle slips X1000/observations</td><td>

Cycle slips X1000/observations</td></tr>
<tr><td>

Recent RMS MP1 (L1 Multipath)</td><td>

RMS MP1 (L1 Multipath)</td></tr>
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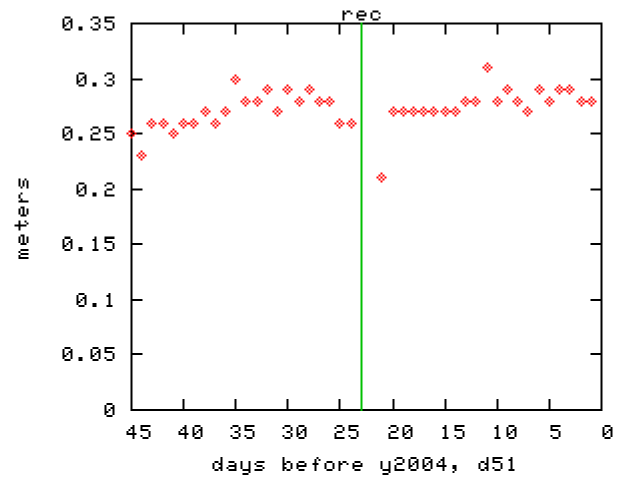
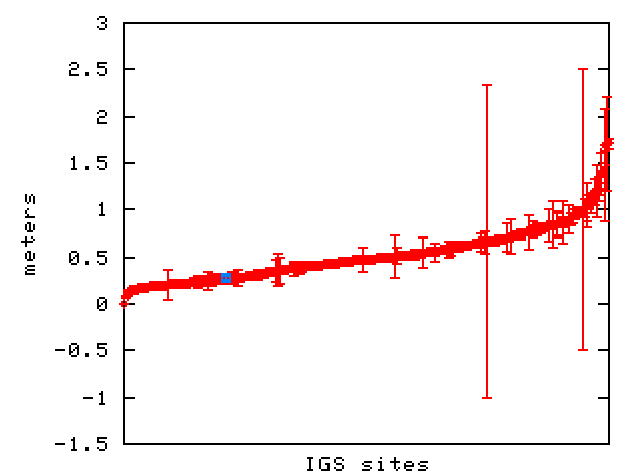
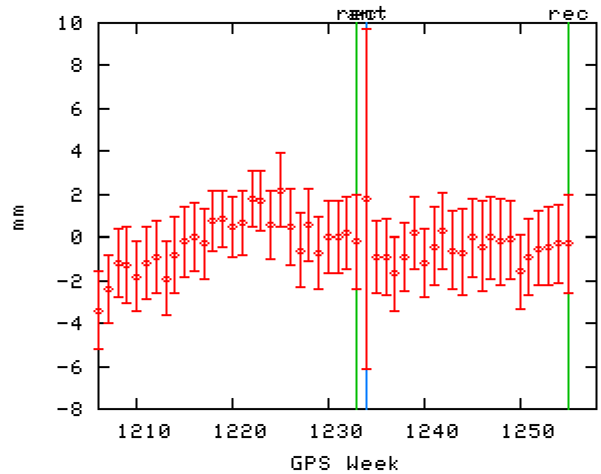
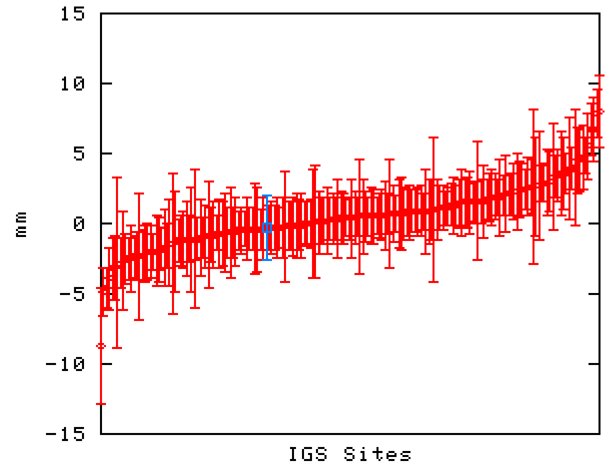
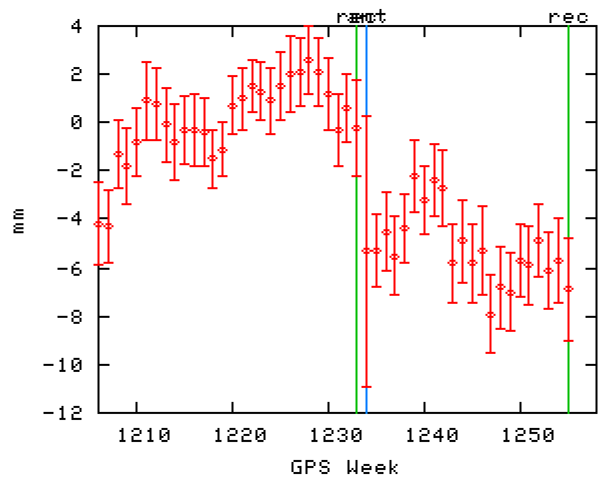
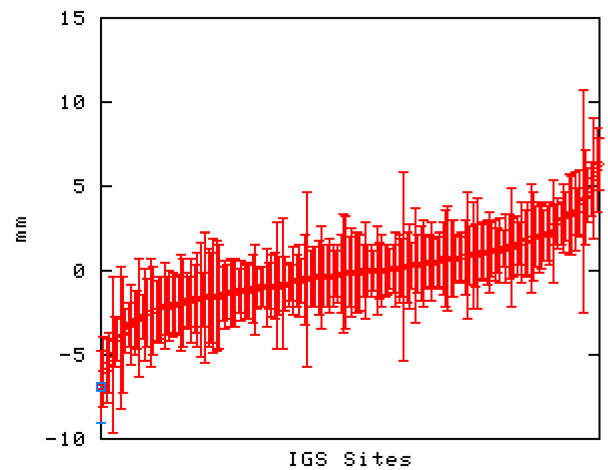
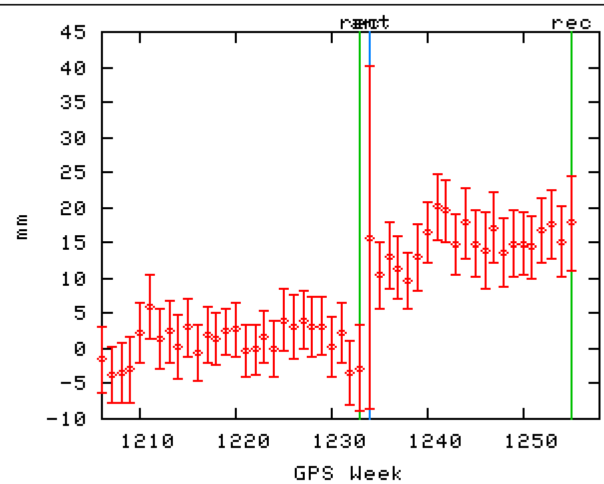
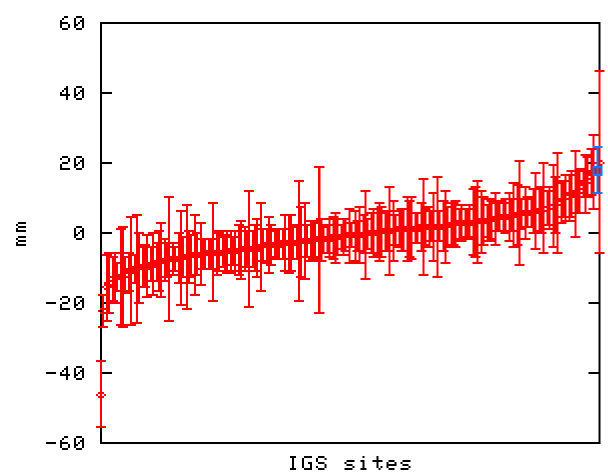


Recent RMS MP2 (L2 Multipath)



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

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SITE in Blue all Other IGS Sites in Red</th></tr>
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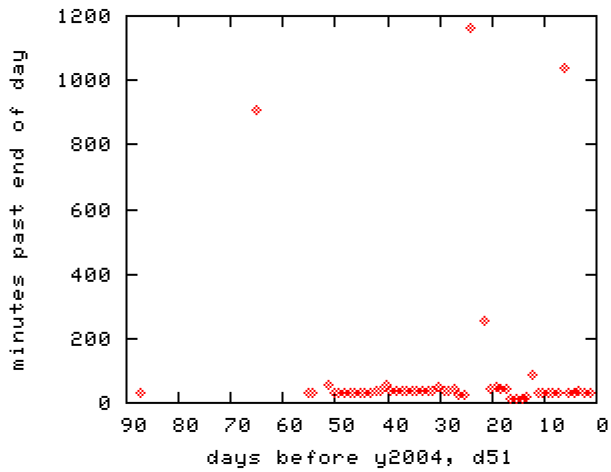

24 hr File Latency
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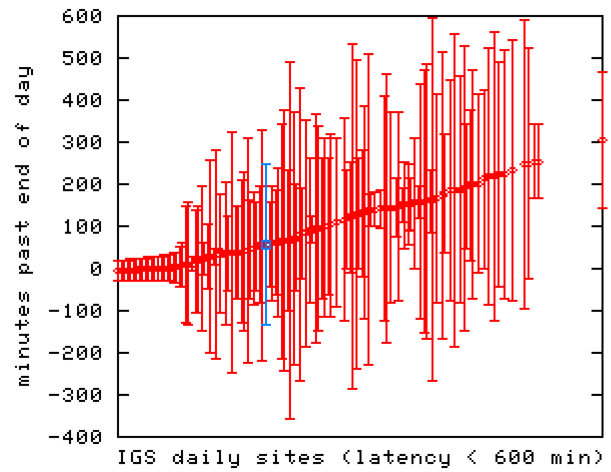

24 hr File Latency
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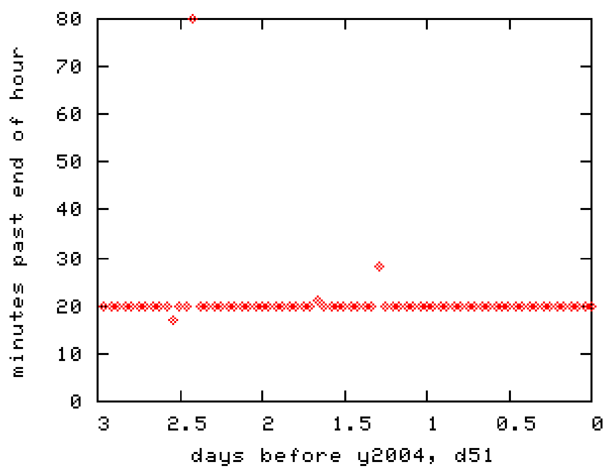

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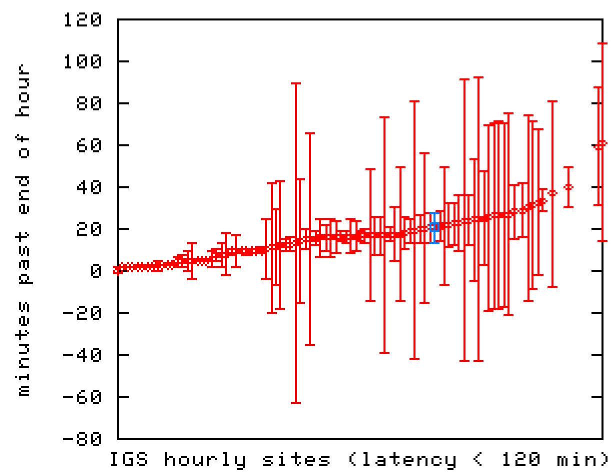
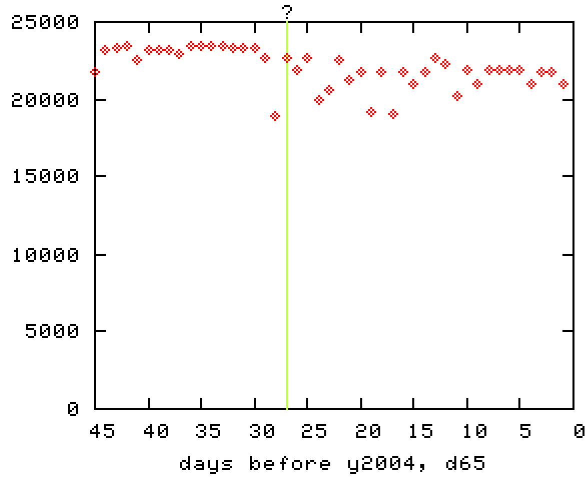
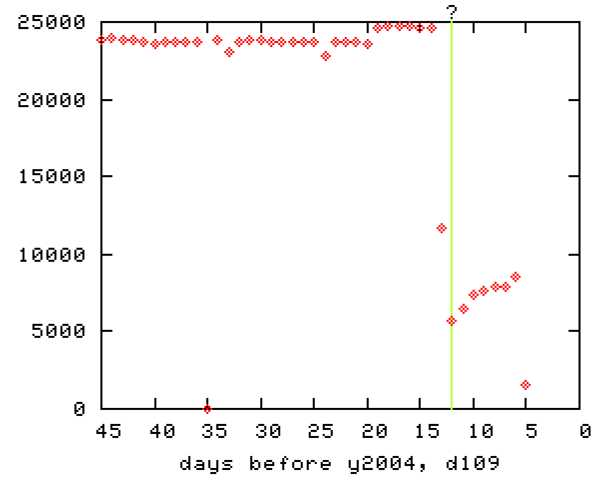
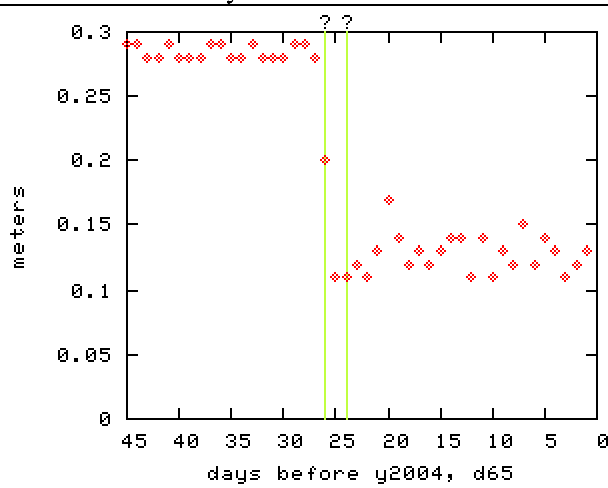
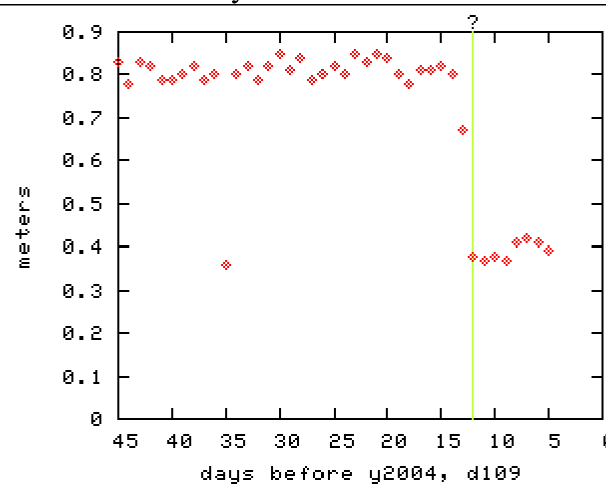
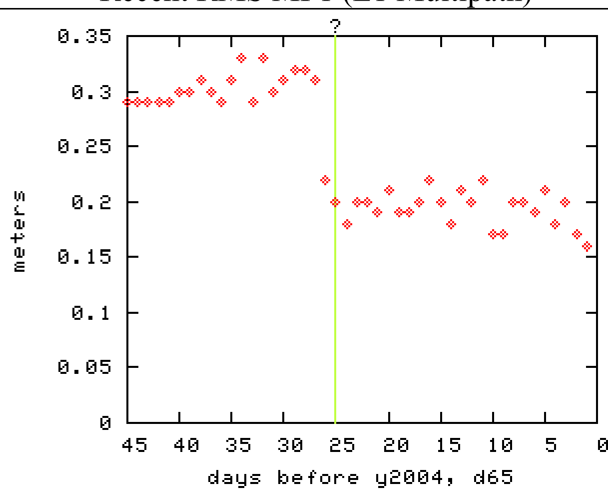
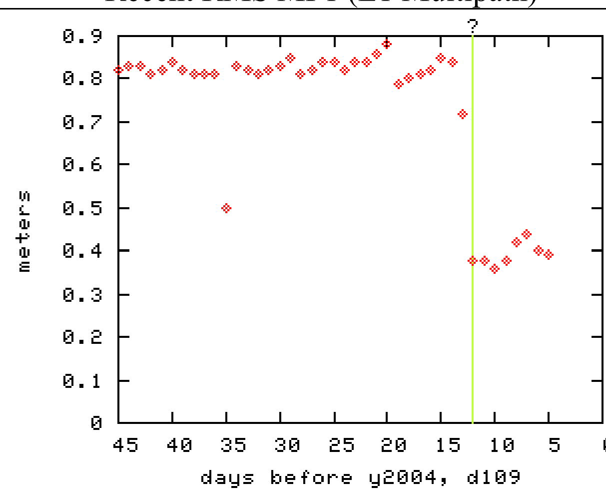


1 hr File Latency
</td></tr>
</table>

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)

6.0 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.

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