IGS

SESSION 1

OVERVIEW OF THE IGS

State of the IGS by the End of 1998

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Abstract

In this article we briefly review the motivation of the IGS as viewed in the past and today (end of 1998) and we remind ourselves of the key products and the *routine achievements*, as represented by the IGS products. Then we address recent developments, in particular the creation of a number of IGS working groups addressing topics that clearly indicate the interdisciplinary impact of the IGS. In the final section *Epilogue and Outlook* we review the changes that took place by the end of 1998, in particular the change of the IGS chairmanship and the analysis coordinator, as well as the decision to create the position of an ITRF Coordinator within the IGS.

The IGS as a Service in 1998

Towards the end of the 1980s it became clear that for regional and global high accuracy applications of the Global Positioning System (GPS) in the fields of geodesy, geodynamics and fundamental astronomy, the orbit accuracy was the crucial factor limiting the accuracy. This statement is very well illustrated by Figure 1, which shows the repeatability estimates of the European 1000 km baseline from Graz to Onsala with 24 hour data spans acquired during 90 days in 1994, first using the broadcast orbits (left), then using the IGS precise orbits (right). The repeatability is about at the 0.1 ppm (parts per million) level for the broadcast and it is of the order of 1 cm, or below 0.01 ppm (in all three coordinates), when the IGS precise orbits are used. By the way, there is clear indication that the repeatability seen in Figure 1 (right) is no longer limited by the orbit accuracy, but by other error sources (e.g., tropospheric refraction estimates).

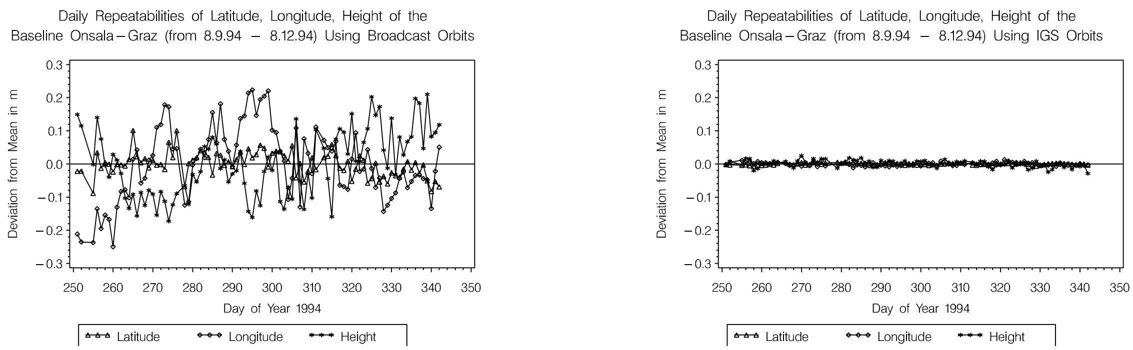

Figure 1: Repeatability of baseline Graz-Onsala using 24h observation intervals with broadcast (top) and IGS precise orbits (above) during 90 days in 1994.

When the IGS was created through a Call for Participation in 1991 (Mueller, 1992), participation was fostered in the following areas: (a) Network, (b) Data Centers, (c) (Associate) Analysis Centers, (d) Analysis Coordination, and (e) Central Bureau. Basically, this structure still is in place today. As *everybody* knows, there are seven IGS analysis centers (even eight for the IGS rapid products), three global data centers plus a number of regional data centers, and around 200 IGS stations.

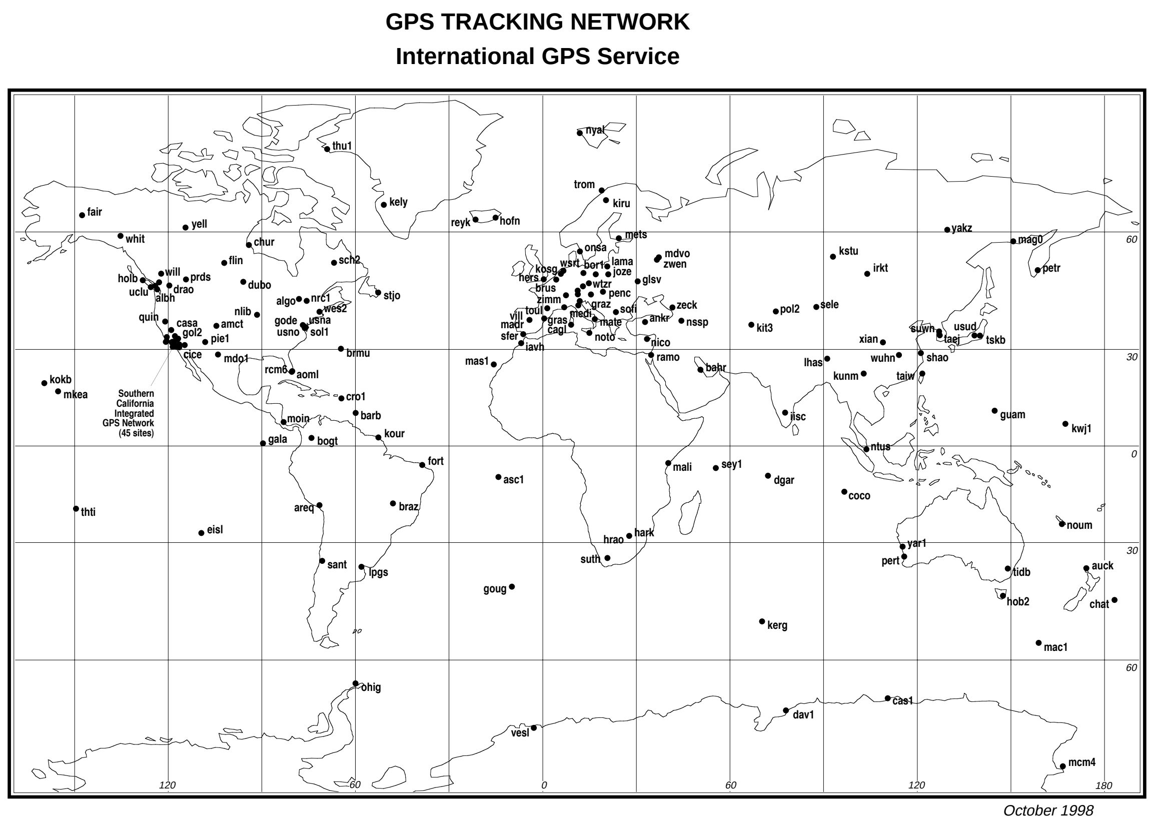

Figure 2: The IGS Station Network in October 1998.

Figure 2 gives an impression of the IGS station network as of October 1998. It is a fantastic achievement in itself that daily observation files from such a rich global GPS tracking network are readily available for each day over such a long time period.

Till the end of 1998 Natural Resource Canada (NRCan) was acting as the Analysis Coordinating Center for the IGS. The Jet Propulsion Laboratory (JPL) serves as Central Bureau since the creation of the IGS.

A vital element of the Central Bureau is the CBIS, the Central Bureau Information System. The current IGS structure, including all the changes made by the end of 1998, is very well documented in this Information System (accessible though the Internet: http://igscb.jpl.nasa.gov/). Here, a general description of all the IGS components, all participating agencies and the currently valid Terms of Reference, etc., may be found. Additional information concerning the development of the service is summarized, e.g., in (Beutler et al., 1996).

The results of the IGS Analysis Centers have been made available from the IGS data centers with decreasing delays, i.e., initially from about three months down to 11 days for the so-called final products, and with a current delay of less than one day for the so-called rapid products. This fact and Figure 1, which is based on the 1994 IGS products, indicates that the IGS has reached, rather rapidly, its primary goal, i.e., to be a scientific orbit determination service in support of geodynamics.

Analysis coordination proved to be a vital stimulus for IGS analysts and the ideal tool to strive for the highest accuracy, reliability, and compatibility of IGS products. The principles for the IGS Analysis Coordination were first presented in (Beutler et al., 1995), the latest review of the IGS analysis coordination activities may be found in (Kouba et al., 1999). In view of this rich documentary material, we may confine ourselves here to a brief summary of the essential elements of IGS analysis coordination.

The IGS orbit and clock combinations were already in place at the start of the approved IAG service on January 1, 1994. Since May 1995, the so-called rapid IGS combined Earth Rotation Parameter (ERP) series has been produced and made available by the coordinator with a delay of only one day. Since June 1996 the products of individual analysis centers account for sub-daily ERP and include polar motion rates (in addition to the polar motion estimates). Since then the IGS *final* products are made available with a delay of only 11 days and the rapid products with a delay of 22 hours. Moreover, since this date the IGS combined predicted orbits are also produced and made available in real time. Since June 1996 the official IGS ERP series accompany both the rapid and the final orbits. Since 1998, a combined IGS troposphere products containing the tropospheric zenith delay estimates, with a 2 hour time resolution, for the sites of the IGS global network, are generated by the IGS troposphere coordinator, Dr. Gerd Gendt of GFZ in Potsdam.

As mentioned earlier, this summary contains only the major events of the *coordination arena*. It proves, however, that the development was rapid, significant, and laborious. Figure 3 shows the time series of the weighted RMS errors of satellite positions as computed by the individual IGS analysis centers with respect to the IGS combined orbits. It illustrates that the development was not only laborious, but also highly successful, for more details see Kouba et al., (1999). Currently, the analysis centers are reaching, or approaching a 5-10 cm consistency level of satellite coordinate solutions. In 1991 nobody would have believed that this would be achievable. It is also encouraging to see in Figure 3 that the IGS Rapid Combinations (IGR), available within one day after the last observation, is on the same consistency level as the final products of the best IGS analysis centers.

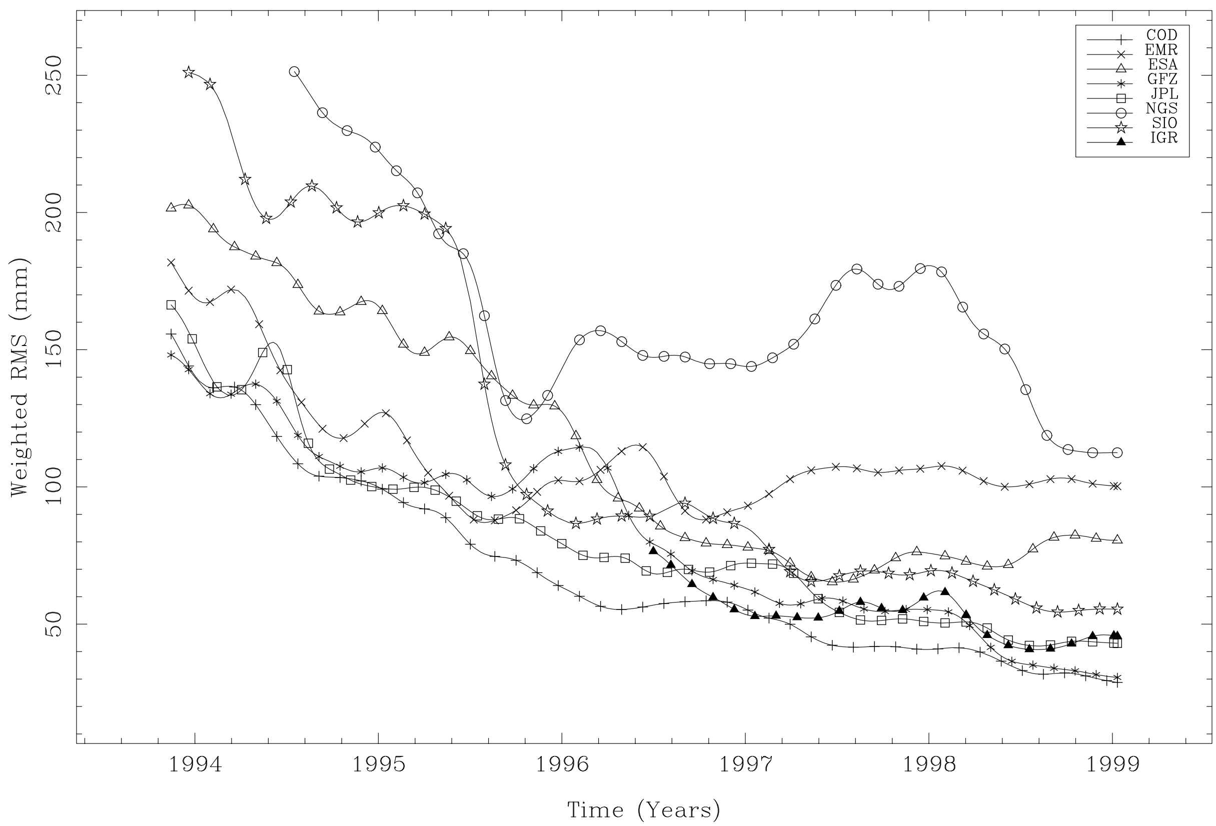

Figure 3: Weighted orbit RMS with respect to the IGS Final Orbits (starting November 14, 1993).

The realizations of the terrestrial reference frame, the Earth rotation parameters (ERP), and the orbits in principle have to be fully consistent. It is the IGS policy to use the most recent versions of the ITRF as the IGS reference frame. To be more precise, since March 1998 all the IGS products are based on the ITRF96 coordinates and velocities of 47 well selected IGS stations (Kouba et al., 1999). Since July 1998 all IGS Analysis Centers submit weekly sets of coordinates for their processed networks of IGS stations, with the above mentioned 47 stations loosely constrained to the ITRF96 positions and velocities. These network solutions are then combined by the three IGS Global Network Analysis Centers (GNAACs), namely by JPL, MIT (Massachusetts Institute of Technology) and NCL (University of Newcastle). These files in turn are cross-checked and combined by NRCan. The solutions resulting from this combination will be the basis for the future IGS realization of the ITRF. This latter product will be the essential GPS input for the future realizations of the ITRF. Together with the results of the other space techniques, it will be used by the IERS to generate new versions of the ITRF of unprecedented density, accuracy and reliability.

As all the IGS Analysis Centers, in essence, are now using the same terrestrial reference frame, their orbits and ERPs may be combined into IGS combined products (orbits, ERPs, and clocks) that refer to the same reference frame, namely the IGS realization of ITRF96. It is remarkable that the IGS gives access to the longest continuous ERP series (polar motion (PM) x, y and the length of day (LOD)) with one-day resolution. Since 1992 up to now, these time series are of highest value and they are unique because no other technique has covered the above time interval with comparable time resolution. Figure 4 shows the three components of atmospheric angular momentum as retrieved from the IERS Subbureau for Atmospheric Angular Momentum (AAM) (χ_1 and χ_2 top, χ_3 component bottom, left). Also shown here are the corresponding components computed from the IGS ERP and PM rate data for the time period of December 1997 – November 1998. The bottom right of Figure 4 shows the power spectrum of the χ_3 with periods up to 40 days. Here, the usual dimensionless representation in units of 10^{-7} is used. The high degree of correlation between the two time series is obvious. According to our opinion these IGS ERP time series are not yet fully exploited for geodynamics purposes. Further studies are possible and encouraged!

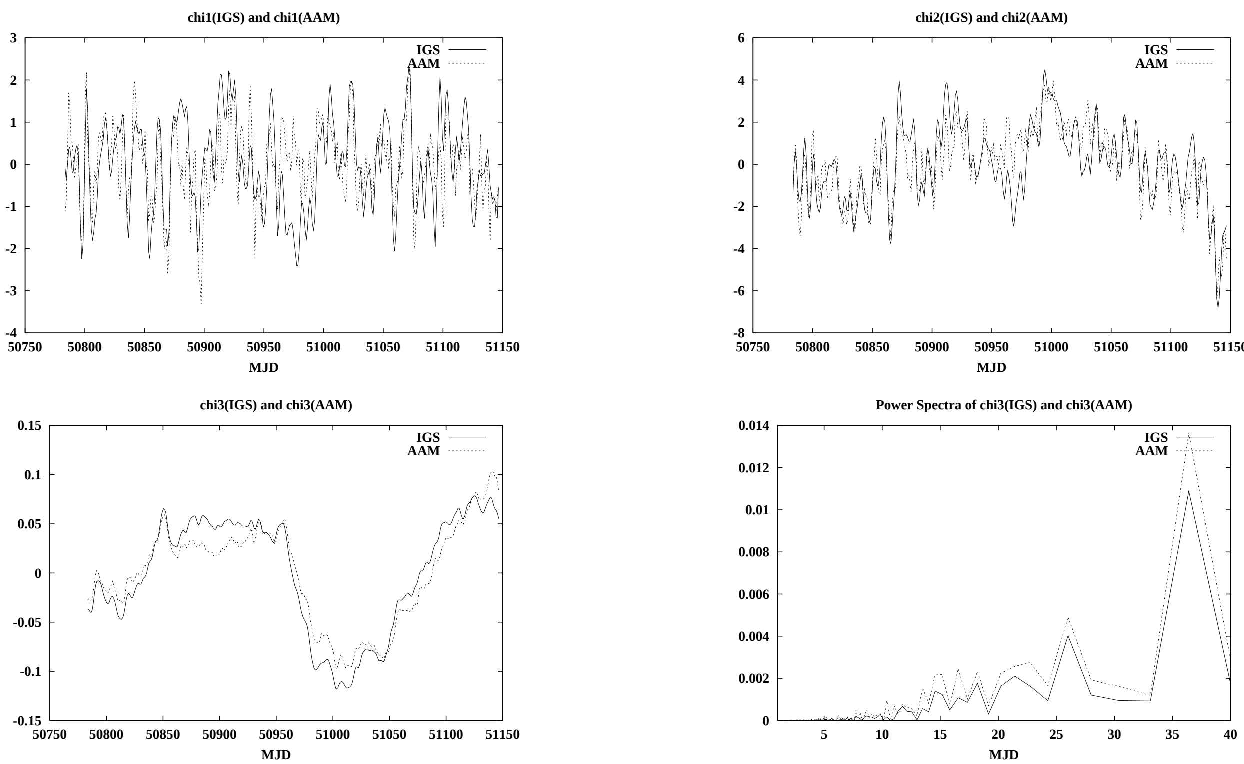

Figure 4: Angular momentum computed from IGS Earth Rotation Parameters (ERP) (and PM rates) compared to the Atmospheric Angular Momentum (AAM) (units of 10^{-7}).

In recent years the IGS and in particular its network have been *(ab)used* more and more for purposes which are no longer purely geodesy or geodynamics related. Let us briefly address in the subsequent sections the use of the IGS (network) for ionosphere monitoring, for troposphere calibration, for GLONASS orbit determination, and for time transfer. The activities related to these topics were set up, and organized in IGS working groups, or pilot projects. Some of them are joint working groups with other organizations such as BIPM (Bureau International des Poids et Mesures) or CSTG (IAG Commission VIII on the International Coordination of Space

Techniques for Geodesy and Geodynamics). It is thus fair to state that the IGS has already moved into the direction of an interdisciplinary service. We can only address a few highlights of these developments. For additional information we refer to (Beutler et al., 1999).

Earth Rotation: Advanced Aspects

It is mandatory within the IGS to estimate ERP (the x- and y-components of polar motion (PM), PM rates, and the length of day (LOD)), with the time resolution of one day. Apart from this tradition, there is no real reason for selecting such a *modest* time resolution. It is expected, that the IGS would also estimate ERPs with a time resolution of, let us say, 1-2 hours, if the IVS (International VLBI Service) would make operational the CORE project (Continuous Observation of the Rotation of the Earth), with comparable time resolution. For more information on the CORE project see Clark et al. (1997). Competition is always a stimulus!

The proof that it is possible to exploit the IGS network for monitoring of the Earth rotation with a much higher than daily resolution has already been delivered, e.g., by Rothacher et al. (1998). Here, a long time series (three years) with 2-hour resolution has been produced by the CODE analysis center of the IGS and analyzed, with the goal to determine subdaily ERP. The results are, at least, of comparable quality as those stemming from altimetry data, of course only for the ERP effects, not for the estimation of the sea surface topography and ocean tides. Figure 5, taken from Rothacher (1998), indicates that the ocean tides are very clearly visible in the LOD series with a time resolution of 2 hours. More details and results may be found in Beutler et al. (1998), or Rothacher et al. (1998).

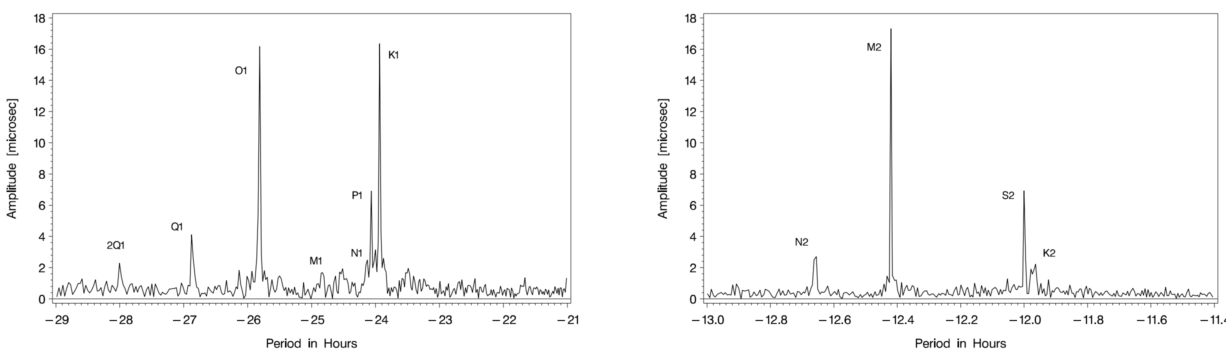

Figure 5: Spectra of diurnal and semidiurnal retrograde LOD variations (from Rothacher (1998)).

Let us address one more aspect: we routinely solve for LOD parameters in the IGS analyses. LOD may be viewed as a (simple) function of the first time derivative of the siderial time θ. Now, θ is just one of the three Eulerian angles that are used for the transformation between the celestial and the Earth fixed coordinate systems. The other two components are precession plus nutation ψ in (ecliptical) longitude and nutation ε in obliquity. If we can solve for LOD, then, from the mathematical point of view, there is no reason whatsoever NOT to solve for the drifts (i.e., the first time derivatives) of nutation in longitude and obliquity as well. Rothacher et al. (1999) have shown that the IGS network may even be used to establish some of the nutation terms. Because of correlation with orbital elements good results may be expected only for the short period terms. The *break even point* in accuracy, when compared with VLBI established series, currently is viewed to be at periods of 15-30 days.

Be this as it may: the current IGS network, accompanied by *slight* modifications of the processing schemes of the IGS analysis centers would allow to refine and improve Earth rotation monitoring within the IGS. This aspect is particularly important if in the near future, we want to study non-periodic ERP signals, or the time evolution of periodic ERP signals like, e.g., due to the ocean tides. In collaboration with VLBI, which clearly is indispensable for providing the long-term stability of the celestial reference frame, the IGS network provides a fantastic monitoring tool for these advanced aspects of Earth rotation. It would perhaps make sense to set up a working group *advanced aspects of Earth rotation using the IGS and the IVS networks* to address such topics.

The Ionosphere Working Group

As all receivers in the IGS network are dual-frequency band receivers, and as the ionosphere is a dispersive medium in the microwave frequency band of the electromagnetic wave spectrum, the IGS network, in principle, is of interest for a global monitoring of the total electron content.

The IGS Ionosphere working group was formally set up at the 9th IGS Governing Board Meeting on May 28, 1998 in Boston. Dr. Joachim Feltens was elected as the chairman of this working group. It was the first working group, which was set up according to the rules of the document IGS POLICY FOR THE ESTABLISHMENT of IGS PROJECTS and WORKING GROUPS. This document, together with the charter of the ionosphere working group, may be found in the IGS Central Bureau Information System (Internet address http://igscb.jpl.nasa.gov/).

The ionosphere group prior to the official creation of the working group has already performed a lot of work. It was, e.g., essential that the IONEX format be accepted as the format in which IGS Ionosphere Associate Analysis Centers (IAACs) would deliver maps of the ionosphere (Schaer et al. 1998). This was why the group was fairly rapidly ready to deliver ionosphere maps with a two hours time resolution. Figure 6 includes four of the original 24 global ionosphere maps generated by the JPL IAAC. Figure 6 shows the motion of the bulge of electrons over the globe on June 1, 1998.

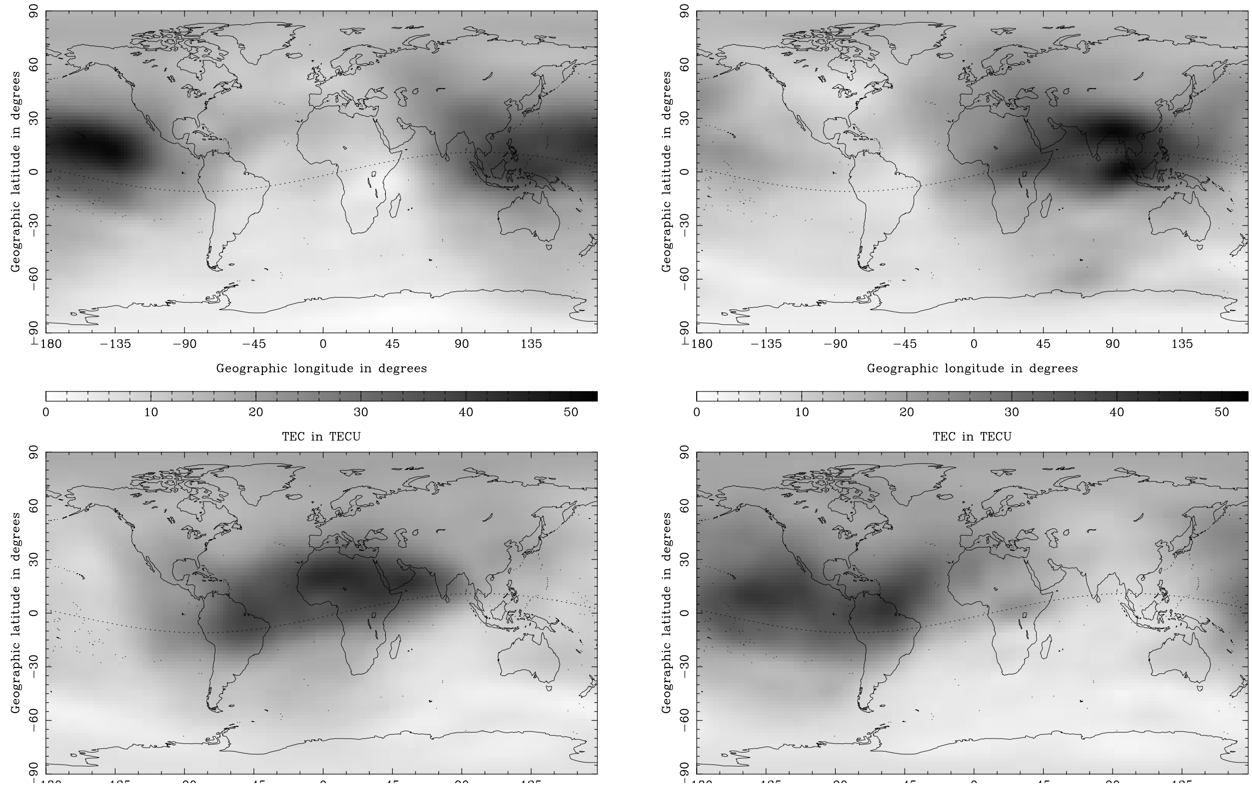

Figure 6: Ionosphere maps of the JPL IAAC referring to June 1 1998, 02:30 UT (top, left), 08:30 UT (top, right), 14:30 UT (bottom, left) and 20:30 UT (bottom, right).

Currently there are five IAACs (CODE (Center of Orbit Determination in Europe), NRCan (Natural Resources, Canada), ESA (European Space Operation Center (ESOC) of European Space Agency), JPL, and UPC (Polytechnical University of Catalonia, Spain)). Their products are delivered on a daily basis, and the ESA team compares them. It is planned in the future to come up with a combined ionospheric product.

It is important to note that, thanks to the height of the ionospheric layers above the Earth's surface, the IGS network is, in principle, well suited to monitor the atmosphere's total electron content. It is not necessary to mention that the IGS stations in the equatorial zone are of particular importance for this kind of work. It is of equal importance that these IGS stations are equipped with receivers that work properly, in particular during the upcoming period of high solar activity.

The Troposphere Working Group

After the *elimination* of the orbit errors through the IGS, tropospheric refraction was recognized to be the major accuracy-limiting factor for high accuracy applications of the GPS. Unfortunately, tropospheric refraction is NOT wavelength dependent in the microwave band. Moreover, due to a resonance with water molecules in the atmosphere, tropospheric refraction is highly variable in space and in time. For GPS analysts this means that the tropospheric zenith delay has to be modeled, either in a stochastic way, or by setting up, for each station, tropospheric zenith delay parameters with a high (e.g., two hour) time resolution.

Bevis et al. (1992) have first suggested making use of these, for GPS analysts nuisance solution parameters, for a GPS based meteorology. They have shown in particular that the integrated water vapour content can be perfectly monitored above a GPS station, provided excellent barometers and good thermometers are available at the sites for monitoring of the dry part of tropospheric refraction. The idea and the first results were very promising, even exciting.

Can we therefore conclude that, in analogy to the ionosphere, that the IGS network is perfectly suited for global troposphere monitoring? The answer clearly is NO, since each GPS station of the IGS network monitors only a very small part of the Earth's troposphere. Simple considerations done, e.g. by Beutler et al. (1998) show that a density of receivers, much higher than that of the IGS network would be required for this purpose and we are not even considering the oceans here.

Despite these negative aspects, GPS based meteorology will have a major impact on meteorology and climatology in the future, through specialized regional networks. What is the role of the IGS network in this context? IGS will be essential as a calibration tool: the tropospheric zenith path delays established in the IGS global analyses will be of the greatest value when processing data from such regional GPS meteorology networks. The IGS-validated troposphere estimates from the IGS global sites may be used, so to speak, as a ``ground truth" for the regional troposphere projects.

Considerations of this kind led to the establishment of the IGS troposphere coordination center at GeoForschungsZentrum (GFZ) in Potsdam, Germany, with Dr. Gerd Gendt as the coordinator. The corresponding IGS working group was set up only at the 10th IGS Governing Board Meeting held in December 1998 in San Francisco.

Figure 7 illustrates the usefulness of GPS for troposphere monitoring. Here we see the time series of the tropospheric zenith delay (TZD) of the IGS sites Kourou (equatorial site), Zimmerwald (mid-latitude site), and McMurdo (Antarctic site). All the delays were reduced to the sea level. The TZD offsets between these stations are therefore almost entirely caused by the water vapor above the station. The seasonal signal is clearly seen at the mid-latitude site together with the high temporal variation, which is, however, decreasing with latitude. These may also be attributed to atmospheric water vapour effects.

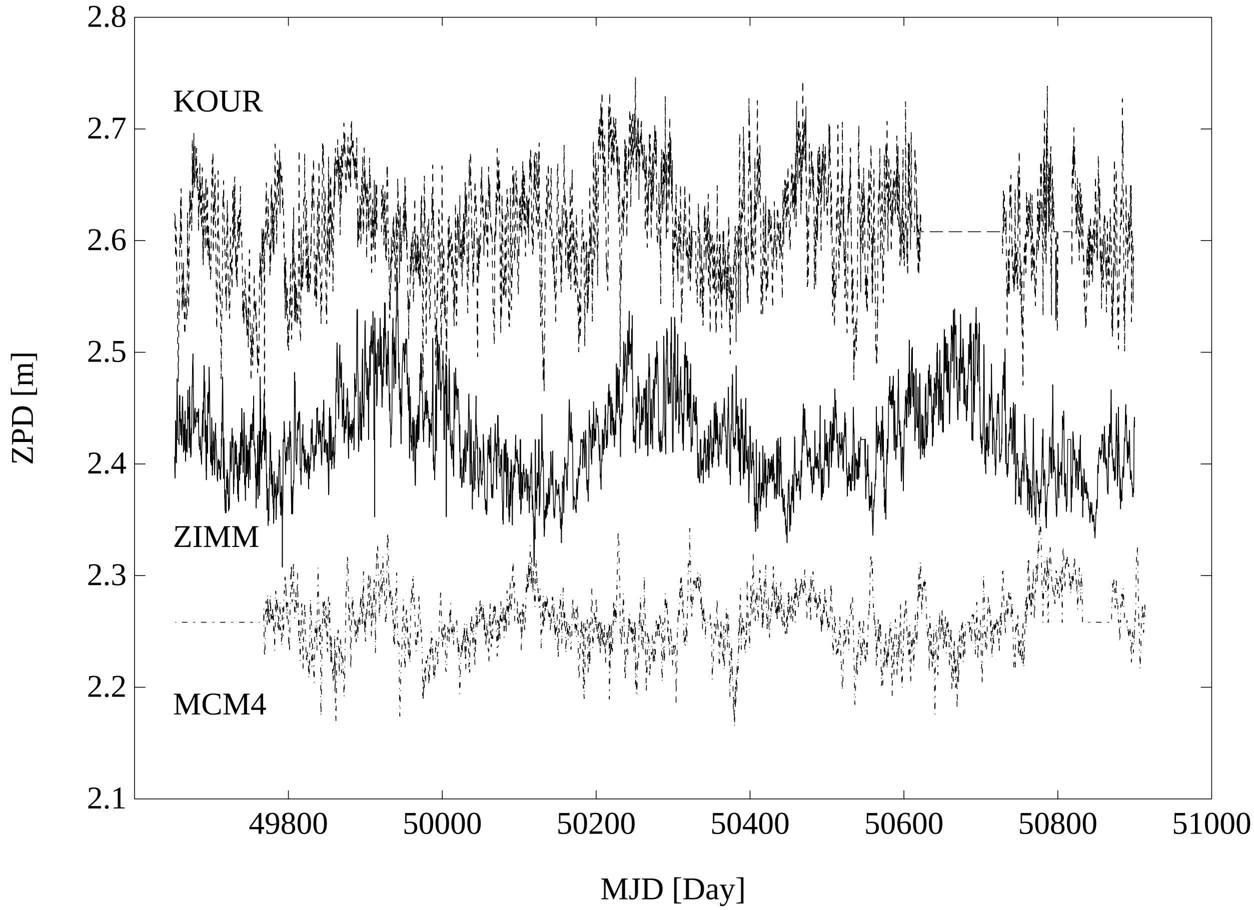

Figure 7: Time Series of troposphere zenith delay (reduced to the sea level) at the IGS stations McMurdo (Antarctica), Zimmerwald (Europe), and Kourou (Equatorial zone).

The IGEX-98

IGEX-98, the International GLONASS Experiment 1998, started on October 18, 1998. It is organized by a joint working group of CSTG (chair Pascal Willis), IGS, and ION (Institute of Navigation). It is also sponsored by the IERS. It was scheduled to last for three months, but subsequently it was extended till April 17, 1999. This extension was justified by the launch of three new GLONASS satellites at the end of December 1998 and by a slow, but steady and significant growth of the IGEX network. IGEX-98 is a typical project for CSTG. It involves microwave tracking of GLONASS and GPS satellites, and it allows for SLR support as well (all GLONASS satellites have SLR retroreflectors). It also involves coordination with other organizations, in this case the IGS, the ION, and the IERS. IGEX-98 very much relies on the IGS; (a) through the collocation of sites, (b) by utilizing the GPS orbits as known from the IGS global analyses. It must be said that without these two *loans* from the IGS the IGEX-98 could not have succeeded.

Figure 8 indeed shows that the experiment has been rather successful. It shows, for the first two months of the campaign, the differences of the SLR distances, as measured by the SLR stations in the ILRS (International Laser Ranging Service) network, and the corresponding distances computed from the GLONASS orbits. The broadcast GLONASS orbits are shown on the left and the IGEX precise orbits (as computed by the CODE Analysis Center) are shown on the right. One may conclude that GLONASS orbits with an accuracy of a few decimeters are now available in the same reference frame as the orbits of the GPS satellites, i.e., the IGS realization of the ITRF. One of the goals of the campaign obviously has already been achieved!

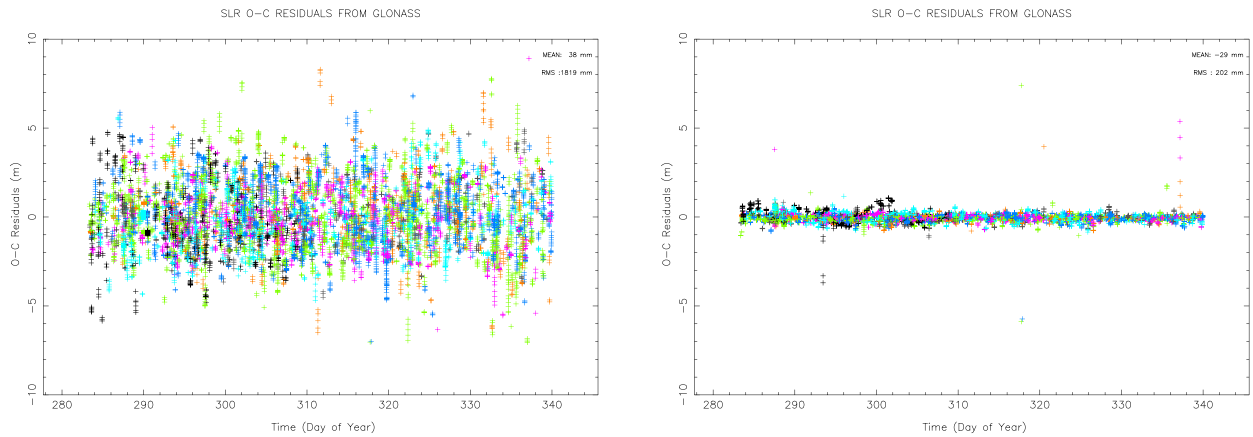

Figure 8: Residuals of SLR observations with respect to the broadcast (left) and IGEX precise (right) GLONASS orbits.

The IGS/BIPM Time and Frequency Transfer Project

The IGS/BIPM Project to Study Accurate Time and Frequency Comparisons was set up in December 1997 at the 8th IGS Governing Board Meeting under the leadership of Drs. Jim Ray (US Naval Observatory USNO) and Claudine Thomas (Bureau International des Poids et Mesures BIPM). The project goal is to fully exploit the potential of the GPS and the potential of the IGS network and the analysis centers by using the precise orbit, position and clock solutions of the IGS and by operating suitable geodetic-type GPS receivers at timing laboratories. This in turn should introduce the best available time standards into the IGS processing and products.

It is expected that a highly operational and very accurate time transfers, well below the nanosecond level (ideally at a few tens of picoseconds), will be achieved, and that frequency transfer will essentially only be limited by the noise of the phase observable! It is also an important aspect that the *timing network* is properly incorporated into the IGS network.

Meanwhile the project is in full progress and encouraging results are being presented. Figure 9 shows Allen deviations as computed by one of the analysis centers in this project for a number of sites of the IGS/BIPM project. It illustrates the potential of the approach.

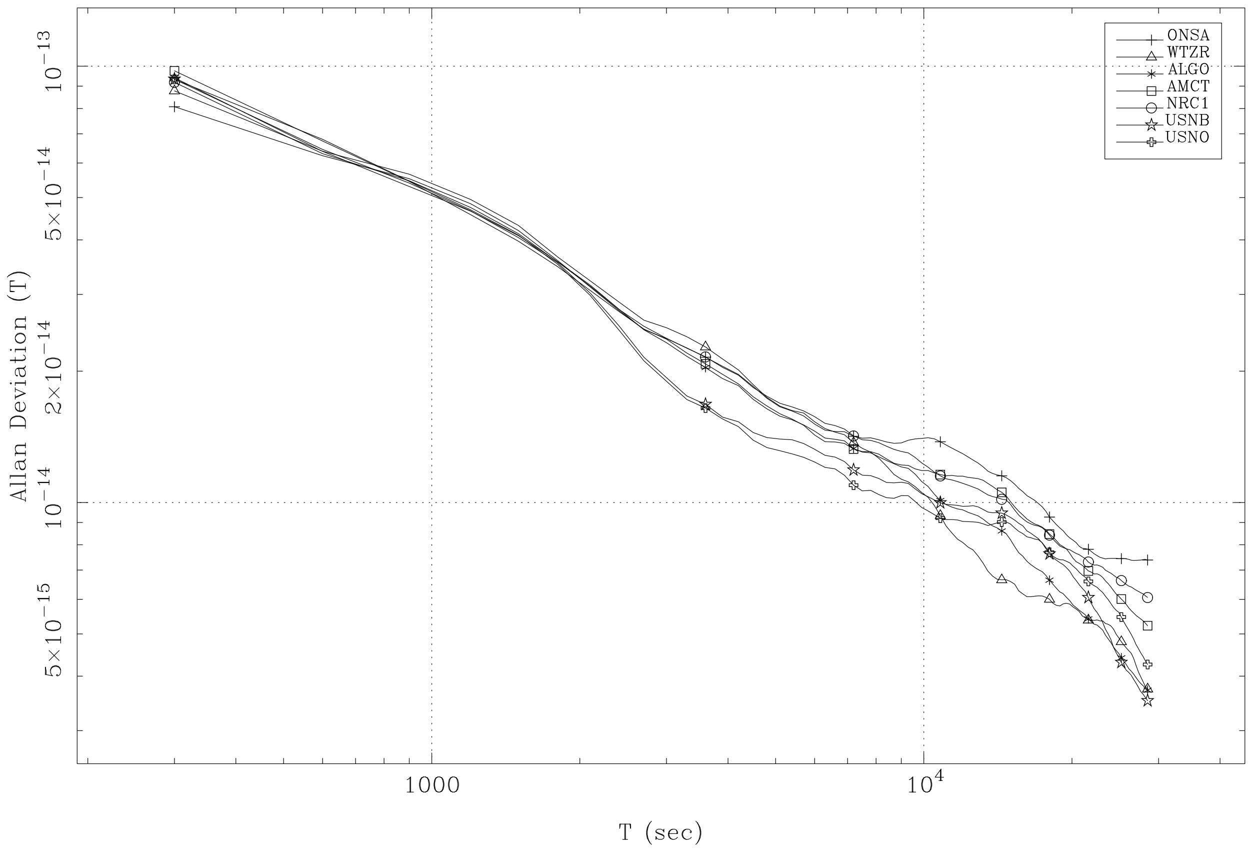

Figure 9: Allan deviations for a subset of clocks in the *time and frequency network* as computed by the CODE Analysis Center of the IGS.

It is highly desired that the time and frequency network, as established by the IGS/BIPM pilot project, becomes a permanent part of the IGS network. In analogy to the stations used for ITRF, this time and frequency station network would facilitate the IGS realization of the UTC (time scale), which would ensure that IGS solution would confirm to the international time and frequency standards. For more information concerning the IGS/BIPM Project we refer to Ray (1999).

Epilogue and Outlook

The year 1998 was a very busy year from the IGS Governing Board point of view. Two Governing Board meetings were held, No. 9 in May in Boston and No. 10 in December in San Francisco. Two business meetings of the Board took place, one in February in Darmstadt, Germany (attached to the 1998 IGS Analysis Center Workshop) and one in October 1998, prior to the October IAG Section II Symposium held in Munich, Germany.

Amongst the more important issues, there were; the complete revision of the Terms of Reference (giving, e.g., the working groups a more important role), the decision to set up the ionosphere and troposphere working groups, the decision to formally terminate the IGS project on the densification of the ITRF and instead to create the position of the IGS/ITRF Reference Frame Coordination center at NRCan with Remi Ferland as the coordinator. The charter for this working group is currently being set up. It is expected that the group may be created at the next IGS Governing Board meeting.

Last but not least, Prof. Christoph Reigber was elected as the new Chairman of the IGS Governing Board at the 10th IGS Governing Board Meeting on December 6, 1998. This change in chairmanship, which has become effective on January 1, 1999, will undoubtedly influence the future direction of the IGS. It seems clear that space borne applications of the GPS will play a major role within the IGS. The upcoming IGS/LEO workshop in Potsdam in March 1999 underlines this development.

At the same meeting it was confirmed that Tim A. Springer from the CODE Analysis Center would succeed Jan Kouba as the Analysis Center Coordinator on January 1, 1999. His term will last till the end of the year 2002.

For the authors of this paper the IGS chairmanship, respective by the responsibility for the IGS Analysis Coordination, were a challenge, a burden, an honor, but, last but not least, also a pleasure. We enjoyed the fruitful collaboration with the IGS Governing Board, the IGS Central Bureau, the IGS Analysis Centers, and the entire IGS Community.

We wish the new Chairman, the new Analysis Center Coordinator and all the IGS Components, and in particular its network, which is the basis for all the IGS activities, all the best for the future.

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Current Performance of the IGS Network

J. Zumberge, W. Gurtner, J. Kouba, T. Springer

Abstract

IGS stations now provide near complete coverage of the Earth's surface. Some gaps remain when one considers only the best performing sites, or only sites used regularly by IGS Analysis Centers, or only sites used by IGS for reference-frame realization. A number of metrics are in place for regular and largely automatic assessment of station performance, each with their own strengths and weaknesses.

The complexities of station configuration control were not fully appreciated during the initial designs of IGS site documentation and file-naming conventions. Inconsistencies have hindered the ability of the IGS to produce an official combined station product. Clear and well documented guidelines to ensure consistent and up-to-date station data information are needed at all levels of IGS operation. Additionally effective means and measures are needed to ensure that such guidelines are followed and maintained.

Set and Subsets of IGS Sites

The growth of the IGS network in the 1990s has been remarkable. The map in Figure 1 indicates IGS sites as of October 15, 1998, according to `ftp://igscb.jpl.nasa.gov/igscb/station/general/logsum.txt`. Only three terrestrial regions exist - two in the Pacific Ocean, and one in Africa - which are not within 3000 km of an IGS station. The expanding network has arguably been the single most important factor that has contributed to the improved quality of the IGS combined orbit over the years.

Figures 2-4 show the following subsets of the IGS network:

- the best performing sites, with IGSnet entries in at least 10 of the 13 weeks during July-September of 1998, and with an average quality during that period of 9 or more;

- IGS -global" sites, or sites most used by IGS Analysis Centers (ACs) in their regular analyses;

- those sites which are used in IGS for International Terrestrial Reference Frame (ITRF) realization;

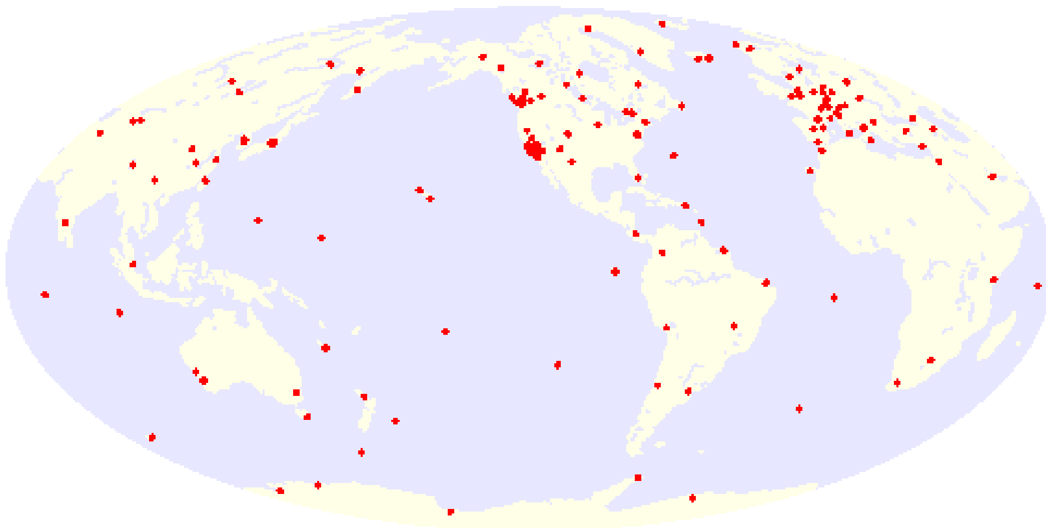

Figure 1: The IGS network as of Oct 15, 1998, according to `ftp://igscb.jpl.nasa.gov/igscb/station/general/logsum.txt`.

Compared with Figure 1, all of these subsets indicate a need for expanded/duplicate coverage and/or improved performance at existing sites in the oceanic regions, Africa, and Asia. Such an expansion will benefit global IGS products (the combined orbit, for example) and ITRF realization. The general robustness of the IGS network will also be improved by adding more stations in these areas. Because failures - especially at remote sites - can and will continue to occur, we should strive to build a network where coverage is everywhere sufficiently dense that no single failure leaves a large gap.

For completeness we show in Figure 5 the subset that is being proposed as a set of “fiducials" for future IGS realization of universal time (see below).

IGSnet Metrics

The IGSnet system was described in the 1996 IGS Annual Report. On-line documentation is available at http://igscb.jpl.nasa.gov/igscb/data/network/igsnet.doc.

Briefly, the IGSnet system computes latency by looking at the time stamps of files at each of the three IGS global Data Centers (DCs), and comparing the earliest with the data in the file. (Currently the system looks at cddis.gsfc.nasa.gov instead of cddisa.gsfc.nasa.gov for CDDIS latency; this should be remedied.) Quantity and quality are computed as soon as JPL's rapid precise transmitter parameters are available with precise point positioning. Daily metrics are published three days after the end of the day in `ftp://igscb.jpl.nasa.gov/igscb/mail/igsnet/daily`. Weekly reports are computed every Wednesday for the GPS week that ended the previous Saturday. These are e-mailed to a wide distribution, and saved in ftp://igscb.jpl.nasa.gov/igscb/mail/igsnet/weekly.

The IGSnet system has advantages of nearly complete automation and well-defined site-specific metrics based on precision analyses. Some examples of its disadvantages are shown on Figure 6.

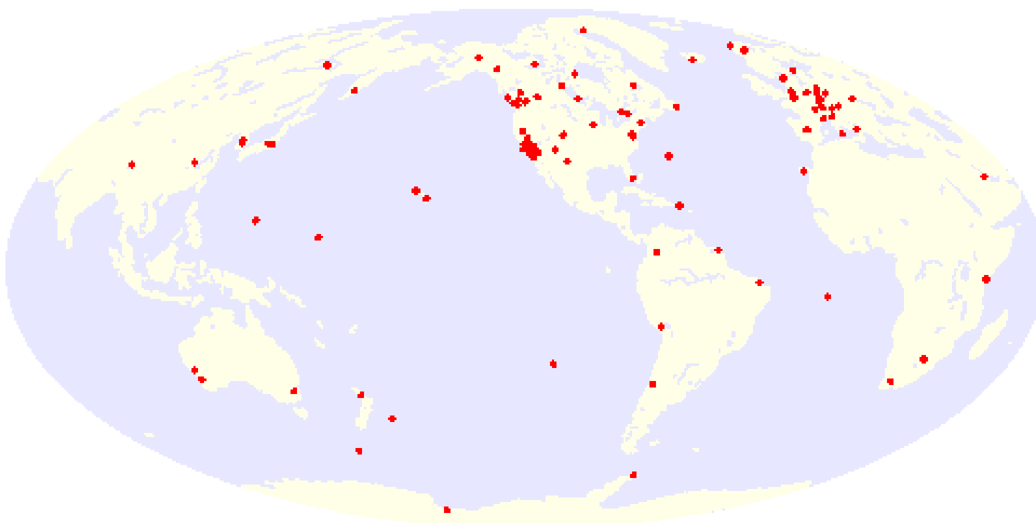

Figure 2: Those sites with IGSnet entries in at least 10 of the 13 weeks during Jul-Sep, 1998 and with an average IGSnet quality of 9 or more.

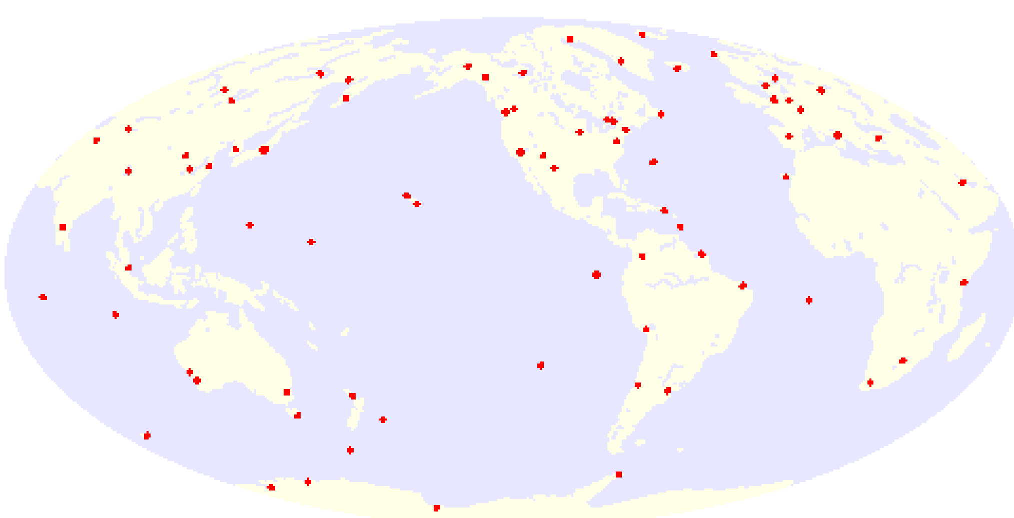

Figure 3: IGS "global" sites, according to the Oct 20, 1998 version of http://igscb.jpl.nasa.gov/dev/network/list.html.

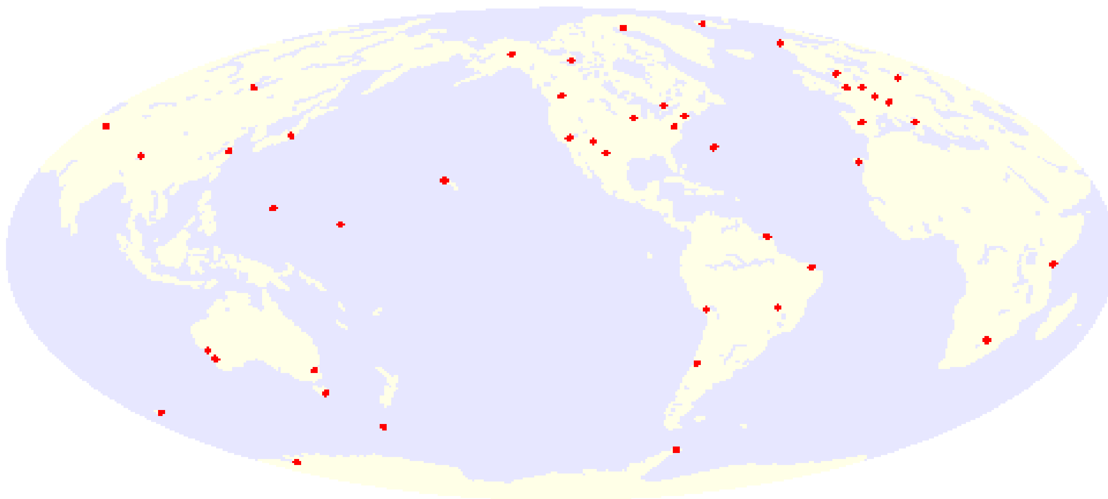

Figure 4: IGS sites used for ITRF realization: ALGO, AREQ, BRAZ, BRMU, DAV1, DRAO, FAIR, FORT, GODE, GOL2, GRAZ, GUAM, HARK, HOB2, IRKT, KERG, KIT3, KOKB, KOSG, KOUR, KWJ1, LHAS, MAC1, MADR, MALI, MAS1, MATE, MDO1, NLIB, NYAL, OHIG, ONSA, PERT, PIE1, POTS, SANT, SHAO, THU1, TID2, TROM, TSKB, VILL, WES2, WTZR, YAR1, YELL, ZWEN.

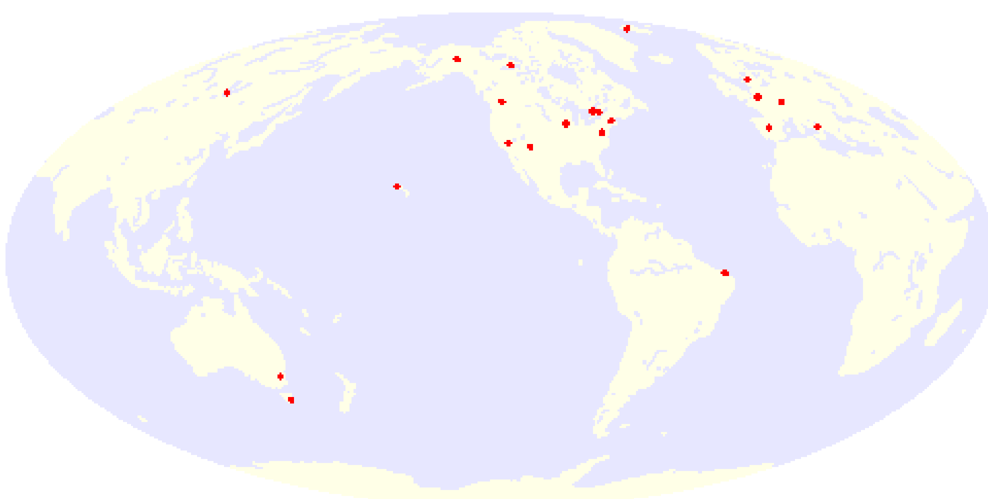

Figure 5: IGS sites proposed for use in a potential combined IGS clock product: ALGO, BRUS, DRAO, FAIR, FORT, GODE, GOL2, HOB2, IRKT, KOKB, MAD2, MATE, NLIB, NRC1, NYAL, ONSA, PIE1, TID2, USNO, WES2, WTZR, YELL.

```
Station Report for 1998-10-22
(generated 1998-10-26 01:40)
...
site   overall     quantity  quality  latency    agency       location
-----------------------------------------------------------------------
algo       10          10        10       10     NRCan/GSD    Canada
...
irkt        .           .         .        9     DUT          Russia
...
cas1        .           .         .        2     AUSLIG       Antarctica
...
sey1        .           .         .        0     JPL-IDA      Seychelles
...
```

Figure 6: Excerpt from file 1998-10-22 in directory `ftp://igscb.jpl.nasa.gov/igscb/mail/igsnet/daily`. The entry for `algo` is an example of a normal IGSnet record. The one for `irkt` occurs when JPL is too slow in retrieving the data, and no quantity or quality metric can be computed. The entry for `cas1` suggests that the data weren't available in time to be included in the report. The entry for `sey1` indicates a non-operational site.

Files at the IGS Central Bureau

For over a year an automated system at the CB computes the following files, all in [ftp://igscb.jpl.nasa.gov/igscb/station/general:](ftp://igscb.jpl.nasa.gov/igscb/station/general)

- `igs.snx` - General site log information in SINEX format (`ftp://igscb.jpl.nasa.gov/igscb/data/format/sinex.txt`).
  Phase center offsets are a function of antenna type, using as reference `Igs_01.pcv`.

- `igs.snx.diff` - Changes to `igs.snx` from previous day (standard UNIX diff).

- `igs.snx.err` - Error flags from process that produces `igs.snx`. Lists one record per error (omission, incomplete, or unrecognizable fields in site log information files), with a location and brief description.

- `loghist.txt` - Historical antenna and receiver information, one record per configuration per log. A change to either antenna or receiver adds an additional record.

- `logsum.txt` - General log info, one record per log (IGS Mail 1698).

- `rinex.err` - Compares `logsum.txt` and “yyddd.status” (ddd = current day - 7) RINEX summary from CDDIS. Lists one record per discrepancy, comparing monument name, receiver, antenna and antenna height.

Station Configuration – Overview

From the beginning, IGS has attempted to set standards for the establishment of new IGS stations, as well as the documentation of changes at existing IGS stations. However, the effort has been only partially successful. The IGS station code names and the corresponding data file naming conventions for site log information and RINEX files have allowed easy reference and information retrieval. Later on, at the solution level, the SINEX format information blocks were designed to accommodate a complete record of station configuration history.

The IGS designers could not foresee the complexity and the numerous perturbations of hardware and offset changes. For example, no provisions were made to allow several receivers to be operated at a single IGS site, be it from the same or different monument markers. The problem of trouble-free and reliable hardware changes at an IGS site, in order to maintain the solution continuity and history, has been fully appreciated only recently. Solution sensitivity to such mundane effects as adding protective antenna dome, or slight changes in the antenna environment was not foreseen. Furthermore, no formal mechanism was set up for conforming, and more importantly, enforcing the timely compliance and update reporting. Also, no standards and rejection criteria currently exist for marginal or unacceptable data quality.

Clearly, all these issues need to be addressed in a systematic way. Appropriate measures, with clear and widely publicized and available guidelines, need to be instituted at all levels - stations, DCs, and ACs - of IGS operations. Conflicts and inconsistencies in the station and file naming, incorrect or incomplete station information, and bad data quality, have all hindered use and progress, even for the internal users of IGS. A good example is the ITRF Densification Pilot Project, where such persisting conflicts (see Appendix) have caused much delays and significant problems for SINEX station combinations. Perhaps this is the most significant factor why today, even after several years of the Pilot Project operation, there is no official IGS (combined) station product!

A set of AC guidelines was discussed amongst all ACs and they are summarized in the next section. Such AC guidelines, along with the similar ones for station operators and Data Centers should be formulated, and should be made visible and widely available by the IGS CB. At the same time the IGSCB should be the cognizant and responsible (and enforcing) central agency for such guidelines.

Analysis Center Processing Guidelines

The AC guidelines listed below were compiled from the preliminary version (dated Oct. 1997) and from numerous discussions amongst all ACs during 1997 and 1998.

1. ACs should *not* report solutions for the stations that have no DOMES number, or no site log information files at the IGSCB archives, or the corresponding RINEX data files are not available from at least one DC (Global and/or Regional). Note a DOMES number can be requested from the ITRF Section of IERS (`http://lareg.ensg.ign.fr/ITRF/domesreq.html`). ACs are free to analyze all data, but they should not include such stations in their SINEX files and other reports submitted to IGS.

Likewise, the Global Network Associate Analysis Centers (GNAACs) and Regional Network Associate Analysis Centers (RNAACs) should not include such station solutions, since there is no way to resolve conflicts in the absence of a DOMES number and/or a reliable log.

2. All ACs, GNAACs, and RNAACs must make certain that their processing and the SINEX file information blocks are consistent with the current `igs.snx` master template as maintained at the IGS CB. IGS CB should ensure that the information in this template file is always up to date and consistent with the station log files and the corresponding RINEX headers. The `igs.snx` should include all the historical changes as well.

3. There should be an initial "shake-down" period when SINEX/station log and RINEX headers errors are reported directly to the offending ACs and/or operation centers/stations, rather than only including them in the AC/DC reports. There could be, for example, one-month period, when *all* errors are reported to *all* ACs so that everybody is given a chance to fix their problems (and to debate them if they disagree). After that, results/stations should be excluded if they continue to have errors/conflicts.

4. Assignments of sequential four-character names codes (SITE/ID) (e.g. WXY1, WXY2,) are not recommended and should, if possible, be avoided. Instead, the official IGS site code (e.g. WXYZ) should be used. Specific monuments at the site area are uniquely distinguished with different DOMES number. Also, a SITE/ID + PT is local and in SINEX equivalent to DOMES number, e.g. WXYZ A; WXYZ B, etc. ACs thus should be free to assign the PT pointer, but not the official IGS (SITE/ID) four-character code identifier. In this way, each monument is uniquely identified by DOMES number, and all the monuments (at one IGS site), by the IGS SITE/ID code name. This also means that any solution combinations (e.g. by GNAACs) must then rely only on DOMES number for a unique monument identification.

5. The third station ID parameter in SINEX, i.e. SOLN should be used by ACs to differentiate solutions, (but only when it is warranted and significant) e.g.

   - before and after a significant earthquake (no DOMES change!)
   - before and after removing an antenna radome (if they are not distinguished and accounted for by a new antenna name with a new antenna offset information)
   - before and after mounting/removing a VLBI antenna, fence, tree, etc.

   Note that, except for the second case above, there is currently no place or mechanism to enter the above events in the station log information files.

6. By mutual consensus amongst ACs, the AC Coordinator recommends to IGS CB which station data, with persisting data quality problems, should be removed from the official IGS data archives at all DCs.

Suggestions for Station and Data Center Guidelines

Consistent and unique station naming is very important for all IGS data and product users, consistent and official names should be maintained, starting at the station operator level, including the Data Centers (DC) as well as the Analysis Centers. Using sequential (four character) code names, such as GOLD, GOL1, GOL2 has not worked satisfactorily up to now, and has created considerable confusion even for the IGS internal users. Additionally, inconsistent or incomplete site hardware and offset information could make IGS data unusable. In fact, for these reasons there is no official IGS combined station product yet. Clear guidelines at the official IGS level are needed. To help mitigate these persisting problems and to provide means to enforce standards and good quality data, the following suggestions for station and DC guidelines are offered:

1. It is recommended that only officially accepted (four character) IGS site names (i.e. approved by IGSCB) are used and maintained for the current and future IGS site occupations, specific monuments at an IGS site are then uniquely identified by specific DOMES Numbers. This ensures less confusion for IGS users as well as it ensures the continuity for long series observations at an IGS site. The same (four character) IGS site name should be used for the corresponding log info and RINEX file names. (For more detailed discussions and specific suggestions for consistent naming site log info and RINEX files, as well as SINEX station solutions, refer to the position paper on *Physical Site Specifications* by W. Gurtner et al.)

2. That no duplicate, low quality data, or data with inconsistent or incomplete site information (the missing DOMES Number in particular!) are made available through the official IGS DC channels. This ensures that no more than one set of good quality data would be available to all IGS users at each official IGS site. The duplicate data sets (be it at the same antenna, or a different monument at the IGS site), or the data with inconsistent or incomplete information, or with persisting data quality problems should be put on special `not.recommended` directories at DCs. Such data directories should not be generally visible to IGS users.

3. A set of specific instructions needs to be developed for any future hardware and station offset changes, in order to minimize possible step functions in the long station solution series. Such hardware/station changes should involve several overlapping observation and solution intervals over extended periods, in order to check the magnitude and the stability of the possible offsets in station position solutions .

Considerations for Implementations

Implementing the above suggestions, such as changing IGS code names (e.g. for GOLD, MADR, TROM), using different station offsets could be potently quite dangerous and disruptive for IGS processing if not approached carefully. However, this could be made relatively safe if it is done carefully.

For example, if there is an overlapping (grace) period allowed, when the original file names are left in DC (e.g. for TRO1). ACs then could be asked to implement the new naming convention (i.e. TROM) during a grace period (e.g. the month of November, 1998). The original (old Rogue - TROM) data would be moved to the `not.recommended` directories at all DCs so the new station name (TROM) when looked up by ACs would not be found.

However, at the end of the grace period, (e.g. on December 1, 1998), the TRO1 files would become the TROM files and the change should be seamless, provided ACs had implemented the TROM station search during the grace period. So, after the grace period there will be only one, i.e. TROM, data file available at the official IGS data directories.

A similar grace period could be provided for IGS sites with persisting low quality data or with persisting site information inconsistencies, after which the site data would be moved to the special directories and would not be generally available to IGS users. This way, after the grace period, and if it is maintained so by a central authority, only good quality data, with consistent and unique information for each official IGS site would be available to IGS users. For example, the station MADR has had persistent data quality problems for a long time and thus should be moved to such `not.recommended` directories.

The current situation and problems with station naming and other inconsistency problems can be seen in the Appendix, which includes the pertinent portion of a recent G-SINEX comparison report performed and distributed by Dave Hutchison of NRCan.

Fiducial Stations for ITRF and Timing

During 1997, ACs have identified a set of 47 good quality stations (Figure 4). Subsequently the set was adopted at the February 98 AC workshop held in Darmstadt, Germany. This new, much larger set of 47 stations has replaced the aging and diminishing set of the 13 ITRF stations (ALGO, FAIR, KOKB, KOSG, GOLD, HART, MADR, SANT, TIDB, TROM, WTZR, YAR1, and YELL) used for IGS ITRF realizations until March 1, 1998. For selection of this 47-station set, a number of criteria were used, such as data and (ITRF96) solution quality, long station occupancies, latency, multi-technique collocations, station geometry, and so on. This makes all these stations rather special and very important, and thus station operators, in particular in regards to hardware configuration updates should give them a special consideration. The ITRF station selection should be reviewed periodically, and new stations that qualify (in particular those in the remote areas) should be added to the list.

Similarly, a smaller set of 22 primary clock fiducial stations with hydrogen maser frequency standards have been identified recently (Jim Ray, private communication). ACs will use this set for station clock solution submissions to IGS, to be combined into a new IGS station clock product. These stations will become equally important as they, in fact (analogously to the above ITRF stations), can provide means for the IGS realization of UTC. Thus, any receiver clock interruptions/resets as well antenna cables subjected to extreme temperature variations, should be avoided. Specific IGS guidelines for establishments of a clock fiducial stations, operation and maintenance should also be developed in cooperation with timing laboratories and then they should also be enforced by IGS.

The suggested list of clock reference stations is given in the caption of Figure 5.

Note that both sets of stations include the station at Madrid, which has had problematic data quality and which should be excluded from both station sets, or at least these data should be put on `not.recommended` directories to discourage their use within and outside IGS.

Data Latency

One of the recommendations of the Darmstadt AC workshop was to speed up the Rapid solutions submission deadline by 5 hours from the current 21:00 h to 16:00 h UT. This only makes sense when station data are arriving sufficiently early at the IGS DCs. T.J.Martin-Mur of ESA has recently reanalyzed selective station data latencies at the CDDIS DC, categorized by six main geographical regions in order to take into account the station geometry considerations. The regions that have been selected are:

- AS: Central and Eastern Asia
- EU: Europe, Near East and North Africa
- IN: Indian Ocean rim and islands
- NA: North America and Greenland
- PA: South Pacific, Micronesia and Polynesia
- SA: Caribbean, South America and South Atlantic

Only stations with site logs and data available at CDDIS within 2, 5, 12, and 48 hours after the end of tracking day were checked.

The number of stations available at CDDIS for the period from January 11 to February 9, 1998, are shown in Table 1. The three values that are shown are the minimum, the mean, and the maximum number of stations that were available within the specified time. Table 2 shows the same statistics for the period between August 14 and October 13, 1998.

As one see from the above tables, a significant progress has been made in recent months in fast data delivery. Each day, significantly more stations are now available at CDDIS by 05:00 UT than was the case at the beginning of 1998. This is encouraging, and it indicates that the proposed move to the new 16:00 UT Rapid submission deadline (by the end of November, 1998) should be now feasible.

Region	<	2	h	<	5	h	<	12	h	<	48	h
NA	0	9	17	10	25	38	18	33	46	25	40	50
EU	1	5	11	4	10	13	9	14	17	4	19	23
IN	0	1	3	1	4	8	3	7	10	4	8	11
AS	0	2	4	1	3	5	1	4	6	3	6	9
SA	0	1	3	0	3	8	1	5	11	3	9	13
PA	0	0	2	0	3	8	0	6	11	2	8	12
All	7	19	31	28	48	73	37	68	91	56	89	114

Table 1: Number of stations available at CDDIS for DOY 1 to 40 of 1998; delay after 00:00 UTC.

Region	<	2	h	<	5	h	<	12	h	<	48	h
NA	0	12	14	19	40	41	25	46	51	47	50	53
EU	0	1	2	3	11	17	8	17	22	18	25	30
IN	0	2	3	1	5	7	4	9	13	7	11	13
AS	0	1	1	2	4	5	3	5	7	5	8	10
SA	0	3	4	2	7	9	2	8	12	8	11	14
PA	0	5	6	2	9	10	4	11	13	9	12	14
All	0	23	27	35	76	88	66	104	118	101	127	140

Table 2: Number of stations available at CDDIS for DOY 226 to 286 of 1998; delay after 00:00 UTC.

Recommendations

Summarized here are our recommendations.

1. To improve the robustness of the IGS network, additional stations in Asia, Africa, and oceanic regions would be valuable.

2. Operators of sites used by IGS for ITRF realization should take special care in maximizing uptime, minimizing changes, and notifying IGS about unusual circumstances.

3. Using existing metrics, the Central Bureau should be responsible for communicating with station operators regarding poor performance and/or problems in documentation of site configuration. Priority should be given to global sites and ITRF sites.

4. To prevent confusion and use of low quality and unacceptable data, it is recommended that DCs set up a special data directories for low quality and/or problematic, data, and/or stations with missing or inconsistent information. Such special directories should not be generally accessible to IGS users.

5. To prevent possible confusion and propagation of incomplete and inaccurate site information it is recommended that the IGS sites with incomplete (in particular with no DOMES Number) and inconsistent site, or name information not be included in the public DC directories and to be excluded from all the AC and IGS combined products submitted to, or archived by IGS.

6. To prevent confusion and different name propagation, it is recommended that, except in special circumstances, only one official (four character) IGS name code be used and maintained for each current and future IGS sites. Different monument occupations within a specific site are to be distinguished only by unique DOMES Numbers that are assigned by the ITRF Section of IERS. (See the position paper by W. Gurtner et al. *Physical Site Specifications* for more detailed discussions and specific suggestions, including the possible treatment of exceptions.)

7. It is recommended that detail and careful guidelines for unavoidable hardware and/or station offset changes are developed and made available to all IGS participants in order to mitigate or eliminate possible discontinuities in long station solution series. Such unwanted steps in solutions could greatly diminish values of long term occupancy and analyses at such IGS sites.

Appendix: Conflicts From the Week 0975 G-SNX Comparisons

```
REMARKS:
 STATION NAME/POINT CODES CHANGED IN ncl0975g.snx
 ENFORCED FROM TEMPLATE FILE igs.snx at cddis.gsfc.nasa.gov.

    Old      New       IERS
Code/Pt Code/Pt  DOMES NO
------- -------  --------
YAKZ  A YAKA  A 12353M001

      1 Change  in all.

 STATION NAME/POINT CODES CHANGED IN mit0975g.snx
 ENFORCED FROM TEMPLATE FILE igs.snx at cddis.gsfc.nasa.gov.

    Old      New       IERS
Code/Pt Code/Pt  DOMES NO
------- -------  --------
YAKZ  A YAKA  A 12353M001
TROM  B TRO1  A 10302M006
NYAL  B NYA1  A 10317M003

      3 Changes in all.

 STATION NAME/POINT CODES CHANGED IN jpl0975g.snx
 ENFORCED FROM TEMPLATE FILE igs.snx at cddis.gsfc.nasa.gov.

    Old      New       IERS
Code/Pt Code/Pt  DOMES NO
------- -------  --------
YAKZ  A YAKA  A 12353M001

      1 Change  in all.


THE FOLLOWING ITRF96 FIDUCIAL STATIONS ARE MISSING FROM jpl0975g.snx :
   Stations: BRAZ
```

```
THE FOLLOWING ITRF96 FIDUCIAL STATIONS ARE MISSING FROM mit0975g.snx :
   Stations: BRAZ

THE FOLLOWING ITRF96 FIDUCIAL STATIONS ARE MISSING FROM ncl0975g.snx :
   Stations: BRAZ HART MAD2


SITE/ID BLOCK IERS DOMES NOS. VS STATION CODE/PT FIELDS IN COMPARED GNAAC
FILES:
(ENTRIES APPEAR ONLY WHERE GNAACS DIFFER.)

IERS DOMES NO    JPL    MIT    NCL
============= ====== ====== ======
    42202M005 AREQ A AREQ A AREQ A
              ARE1 A
    42005M001 GALA A GALA A GALA A
              GAL1 A GALA B
    40405S031 GOL2 A GOLD A GOL2 A
              GOLD A GOL2 A GOLD A
              GOL1 A
    30302M007 HARK A HARK A HARK A
              HART A HART B
              HAR1 A
    22306M002 IISC A IISC A IISC A
              IIS1 A IISC B
    13407S012 MAD2 A MAD2 A
              MADR A MADR A
    31303M002 MAS1 A        MAS1 A
              MASP A
    31303M001        MAS1 A
    12309M002 MDVO A        MDVO A
              MDV1 A
    12309M001        MDVO A
    10317M003 NYA1 A NYAL B
    40499S020 RCM6 A RICH A RCM6 A
              RICH A RCM6 A
    50103M108 TID2 A TIDB A TID2 A
              TIDB A TID2 A TIDB A
    10302M006 TRO1 A TROM B
```

```
    50107M004 YAR1 A YAR1 A YAR1 A
              YAR2 A

MISSING IERS DOMES NOS AT JPL:
-----------------------------
  ALIC A  BAKO A  BISH A  ELAT A  GILB A  KABR A  KARR A  KATZ A  MAW1 A  RAMO
A
  RIOG A  TELA A  TOW2 A  URUM A

MISSING IERS DOMES NOS AT MIT:
-----------------------------
  BAKO A  KATZ A  GILB A  KABR A  ELAT A  TELA A  RAMO A

SITE/ID BLOCK IERS DOMES NOS. VS STATION CODE/PT FIELDS IN ABBREVIATED .ssc
FILES:
 cod09757.ssc at cddis.gsfc.nasa.gov or cddisa.gsfc.nasa.gov
 emr09757.ssc at cddis.gsfc.nasa.gov or cddisa.gsfc.nasa.gov
 esa09757.ssc at cddis.gsfc.nasa.gov or cddisa.gsfc.nasa.gov
 gfz09757.ssc at cddis.gsfc.nasa.gov or cddisa.gsfc.nasa.gov
 jpl09757.ssc at cddis.gsfc.nasa.gov or cddisa.gsfc.nasa.gov
 ngs09757.ssc at cddis.gsfc.nasa.gov or cddisa.gsfc.nasa.gov
 sio09757.ssc at cddis.gsfc.nasa.gov or cddisa.gsfc.nasa.gov
(ENTRIES APPEAR ONLY WHERE ACS DIFFER.)
```

IERS DOMES NO	COD	NRCan	ESA	GFZ	JPL	NGS	SIO
22306M002	IISC A		IISC B	IISC A	IISC A	IISC B	IISC A
50107M004	YAR1 A	YAR1 A	YAR1 A	YAR2 A	YAR1 A	YAR1 A	YAR1 A
31303M002	MASP A	MASP B	MASP B	MAS1 A	MAS1 A	MASP B	MAS1 A
12309M002	MDVO A		MDVO B		MDVO A		MDVO A
40405S031	GOLD A	GOLD A	GOLD A	GOL2 A	GOL2 A	GOLD B	GOL2 A
40499S020	RICH A			RCM6 A		RCM6 A	RCM6 A
42202M005	AREQ A	AREQ B	AREQ B	AREQ A	AREQ A	AREQ B	AREQ A
50103M108	TIDB A	TIDB A	TIDB A	TID2 A	TID2 A	TIDB A	TID2 A
42005M001	GALA A			GALA A	GALA A	GALA B	GALA A
30302M007	HART A	HART B	HART B	HARK A	HARK A	HART B	HARK A
10302M006	TROM A			TRO1 A			
22601M001		NTUS A	NTUS A	NTUS A	NTUS A		NTUS A
22601M002						NTUS A	
13407S012			MADR A		MAD2 A	MADR A	MAD2 A

```
MISSING IERS DOMES NOS AT GFZ:
-----------------------------
  BISH A  URUM A  RIOG A

MISSING IERS DOMES NOS AT SIO:
-----------------------------
  BAKO A  KATZ A  GILB A  KABR A  ELAT A  TELA A  RAMO A
```