IGS

IGS 10TH ANNIVERSARY SYMPOSIUM

The Accomplishments of the IGS and their Implications on the Future of Geodesy

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Abstract. The following report is in essence based on the author's previous reports about the IGS and its development between 1991 and 2004. The initial development of the IGS consisted of a planning phase between 1989 and 1991. It was initiated and conducted by Ivan Mueller. The second phase was devoted to the proof of concept for this scientific service in 1992 with the *1992 IGS Test Campaign* and the densification experiment *Epoch'92*. Data collection and analysis continued after the official end of the 1992 campaign in the form of the so-called IGS Pilot Service, which was eventually succeeded by the official service starting on January 1994.

Initially, the IGS was designed as an orbit determination service. In the second half of the 1990s it developed, however, into an *interdisciplinary service in support of Earth sciences and fundamental astronomy,* including the determination of the ITRF and of Earth rotation parameters, of global ionosphere maps and of tropospheric refraction above the IGS tracking sites. Accurate time and frequency transfer between the timing laboratories was another topic covered within the IGS. Lately, the IGS extended its activities towards a general GNSS service by including the GLONASS orbits (of all active GLONASS satellites) into its regular products. The IGS had considerable impact on the development of geodesy and (associated with it) with the restructuring process of IAG. The new role of the IGS within geodesy and IAG are addressed in conclusion of this article.

1. The IGS Planning Committee 1989-1991

According to Mueller (1993) the primary motivation in planning the IGS was the recognition in 1989 that the most demanding users of the GPS satellites, the geophysical community, were purchasing receivers in exceedingly large numbers and using them as more or less black boxes, using software packages which they did not completely understand, mainly for relative positioning. The observations as well as the subsequent data analyses were not based on common standards; thus the geodynamic interpretation of the results could not be trusted. The other motivation was the generation of precise ephemerides for the satellites together with by-products such as earth orientation parameters and GPS clock information.

These ideas were first discussed in 1989 at the IAG General Meeting in Edinburgh by Neilan, Melbourne and Mader (1990) and led soon thereafter to a Working Group, later re-designated as the *IAG Planning Committee for the IGS*, with Ivan I. Mueller, then President of the IAG, as chairman. After several meetings the *Call for Participation* was issued on February 1, 1991. More than 100 scientific organizations and governmental survey institutions announced their participation either as an observatory (part of the IGS network), as an analysis center, or as a data center. The Jet Propulsion Laboratory (JPL) volunteered to serve as the Central Bureau, and the Ohio State University as the Analysis Center Coordinator. At the 20th General Assembly of the IUGG in Vienna, August 1991 the IAG Planning Committee was restructured and renamed as *IGS Campaign Oversight Committee*. The author of these lines was asked to chair the committee and accepted to serve. The committee started organizing the 1992 events, namely the *1992 IGS Test Campaign* and *Epoch'92*. Two IGS Workshops (the first at the Goddard Space Flight Center in October 1991, the second in Columbus, Ohio in March 1992) were necessary to organize the 1992 activities. The essential events of this first phase of the IGS development are summarized in Table 1.

Date	Event
August 1989	IAG Scientific Assembly in Edinburgh. Plans by Mueller, Mader, Melbourne, Minster, and Neilan
March 1990	IAG Executive Committee Meeting in Paris decides to establish a Working Group to explore the feasibility of an IGS under IAG auspices. I.I. Mueller was elected as chairman.
April 1990	The Working Group is redesignated as *IAG Planning Committee for the IGS* in Paris
September 1990	Planning Committee Meeting in Ottawa. Preparation of the *Call for Participati*on
February 1991	CFP mailed. Letters of Intent due 1 April 1991
April 1991	CFP Attachments mailed to those whose letters of intent were received
May 1991	Proposals due
June 1991	Proposals evaluated and accepted in Columbus, Ohio
August 1991	Planning Committee reorganized and renamed as *IGS Campaign Oversight Committee* at the 20th IUGG General Assembly in Vienna
October 1991	First IGS Campaign Oversight Committee Meeting in Greenbelt

Table 1: Chronicle of Events 1989-1991

2. The I992 IGS Test Campaign, Epoch'92, the IGS Pilot Service, and the 1993 IGS Workshop in Bern

The *1992 IGS Test Campaign*, scheduled to last from 21 June to 23 September 1992, focused on the *routine determination* of high accuracy orbits and Earth Rotation Parameters (ERPs); it was to serve as the *proof of concept* for the future IGS.

Epoch'92 on the other hand was scheduled as a two-week campaign in the middle of the three-month IGS Campaign for the purpose of serving as a first extension of the relatively sparse *IGS Core Network* analyzed on a daily basis by the IGS Analysis Centers. More background information about this early phase of IGS may be found in Mueller (1993) and Mueller and Beutler (1992).

Two events prior to the 1992 IGS Test Campaign were crucial for the success of the 1992 IGS test campaign:

- the communications test, organized by Peter Morgan, Australia, demonstrated that data transmission using the scientific Internet facility had sufficient capacity for the daily data transfer from the IGS stations to the Regional, Operational and Global Data Centers then to the Analysis Centers.
- The establishment of the *IGS Mailbox* and the *IGS Report series* based on e-mail proved to be very important as information resources and as a tool to insure a close cooperation between the IGS participants. This e-mail service, initially located at the University of Bern, was transferred to the Central Bureau (JPL) by January 1, 1994.

The 1992 IGS Campaign started as scheduled on June 21, 1992. About two weeks later the first results of the IGS Analysis Centers started to flow into the IGS Global Data Centers, which in turn made these results available to the user community. The ERP series were regularly analyzed by the IERS Central Bureau and by the IERS Rapid Service Sub-bureau, (as it was called at that time).

Toward the end of the 1992 IGS test campaign it became apparent that the campaign was a full success and that it would be most harmful to stop or interrupt the data collection and the analysis activities. Therefore, data collection and transmission as well as data analysis continued on a *best effort basis* after the official end of the 1992 IGS Test Campaign on 23 September, 1992.

At the third IGS Campaign Oversight Committee meeting on October 15, 1992 at Goddard Space Flight Center (Table 2) it was decided to formally establish the IGS Pilot Service to bridge the gap between the 1992 IGS Test Campaign and the start of the official service. Since November 1, 1992 the orbits of the individual processing centers were regularly compared by the IGS Analysis Center Coordinator. An overview of the 1992 IGS events may also be found in the proceedings of the 1993 IGS Workshop, Brockmann and Beutler (1993). At the 1993 IGS Workshop in Bern, officially dealing with the evaluation of the 1992 IGS Test Campaign and of Epoch'92, "everybody" was confident that the IGS community was ready to start with the official service in the near future. Table 3, showing the root mean square errors of Helmert transformations between pairs of solutions (tabular satellite positions at 15 minutes intervals of all active GPS satellites), and Figure 1, showing polar motion as established by the Scripps Institution of Oceanography, indicate that the community was not only confident, but also very optimistic in 1993. When looking at the 1993 results with a smile from today's perspective, one should, on the other hand also be aware of the fact that the generation of the global products was based on a rather sparse global network in 1993 (see Figure 2) and on rather recent software developments (the "analysis noise" was considerable in 1993).

Date	**Event**
March 1992	2nd IGS OSC Meeting at OSU, Columbus, Ohio
May 1992	Communication test
May 1992	Establishment of IGS Mailbox at University of Bern
June 21, 1992	Start of IGS Test Campaign 1992
July 1992	First results!
July 27, 1992	Start of Epoch'92 campaign, lasting for two weeks
September 23, 1992	Official end of the campaign, continuation on best effort basis
November 1992	Start of IGS Pilot Service
March 1993	1st IGS Workshop in Bern, IGS Terms of Reference drafted
May 1993	Meeting of the OSC in Baltimore
August 1993	IAG Approval for IGS at IAG Scientific Meeting in Beijing
October 1993	IGS Analysis Center Workshop
October 1993	IGS Network Operations Workshop and First Governing Board Meeting
December 1993	2nd Governing Board Meeting in San Francisco

Table 2: Chronicle of Events 1991-1993

	COD	**SIO**	**JPL**	**EMR**	**ESA**
COD	--	43	46	38	87
SIO		--	48	39	81
JPL			--	33	75
EMR					70

Table 3: Mean values of rms errors in cm of 7-parameter Helmert transformations between pairs of orbital ephemerides as produced by the IGS analysis centers between 1 Nov 1992 and 15 Nov 93 (from Beutler, 1993)

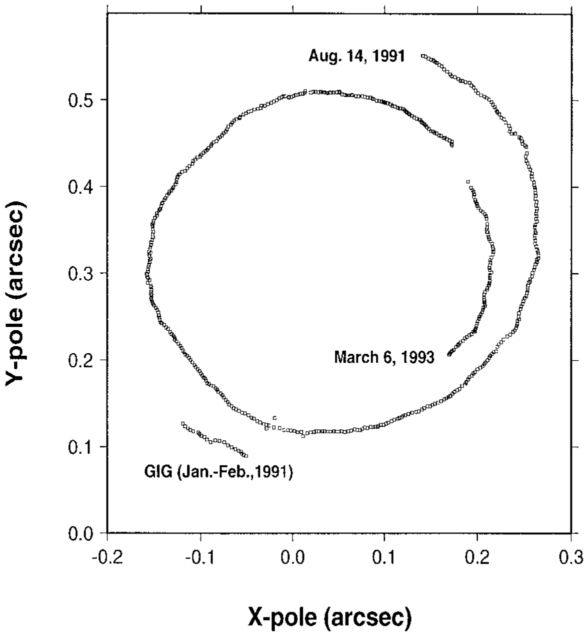

Figure 1: Polar Motion as established by the Scripps Institution of Oceanography 1991-1993

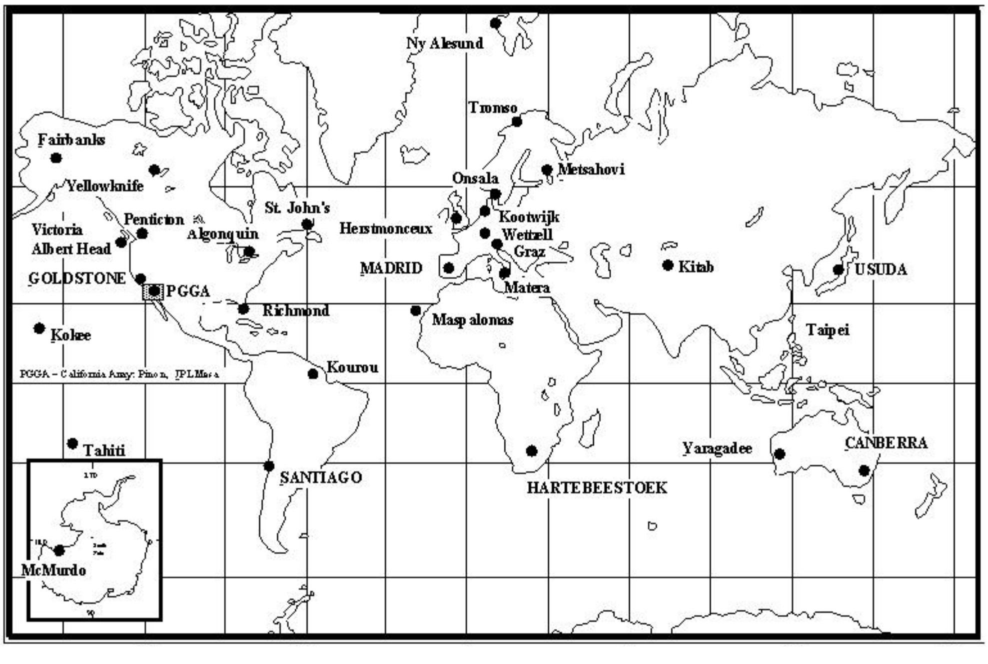

Figure 2: The IGS Global Tracking Network in 1993

Two Workshops, the Analysis Center Workshop in Ottawa (Kouba, 1993) and the Network Operations Workshop in Silver Spring, MD, and the first Governing Board (GB) Meeting (also in Silver Spring) took place in October 1993. One important outcome of IGS meetings in October 1993 was the decision to produce an official IGS orbit. This responsibility was given to the IGS Analysis Center Coordinator, who, according to the IGS Terms of Reference must be an analysis centers' representative. The author of this report was elected by the IGS Governing Board as its first Chairman and accepted to assume this new responsibility.

3. The International GPS Service 1994-present

The IGS started its operations as an official IAG Service on January 1, 1994. Obviously, the operational aspects had to be watched very carefully from now on. The official IGS products, orbits, ERPs, and later on also the satellite clock corrections, were based on the contributions of the individual IGS Analysis Centers. So called final and rapid products were defined and delivered. From the technical point of view the IGS Analysis Center Coordinator was responsible for regularly generating the IGS products in a timely manner. The IGS can be very proud of the fact that since January 1, 1994 (as a matter of fact already since June 21, 2004) this task was always performed without any failure. This was of course only possible because

- the steadily growing IGS network of geodetic GPS receivers was reliable,
- the data transmission, based on the Internet, was always available,
- the IGS concept of hierarchical data centers worked perfectly,
- the IGS Analysis centers performed their analyses in a timely fashion, and
- the orbit, ERP, and satellite clock comparison and combination strategies according to Beutler, Kouba, and Springer (1995) proved to be reliable and robust.

It is absolutely essential that the user community has available reliable, robust and unique IGS products of highest quality within the promised time limits *in addition to* the products of the individual analysis centers. The consistency of combined products is much more difficult to establish for a combination of analyses, which are based (at least partly) on the same observations, which estimate a common subset of parameters in addition to center-specific parameters, than the consistency of an individual analysis. In the latter case the consistency is, so to speak, guaranteed by the fact that all parameters are estimated in one and the same parameter estimation procedure. The IGS was very fortunate that its Analysis Center Coordinators

- Clyde Goad (IGS Test Campaign and Pilot Service 1992-1993)
- Jan Kouba (1994-1997)
- Tim Springer (1998-1999)
- Robert Weber (2000-2001) and
- Gerd Gendt (2002-present)

were and are extremely capable analysts. Figure 3 documents the development of the consistency of the individual solutions of IGS Analysis Centers (mean error per satellite coordinate) since 1993. The figure documents that today the consistency level of the IGS final products is of the order of 1-3 cm, only. Compared to the consistency achieved in 1993 as documented in Table 3, more than a factor of ten was gained. The picture was taken from the current Analysis Center Coordinator’s home page.

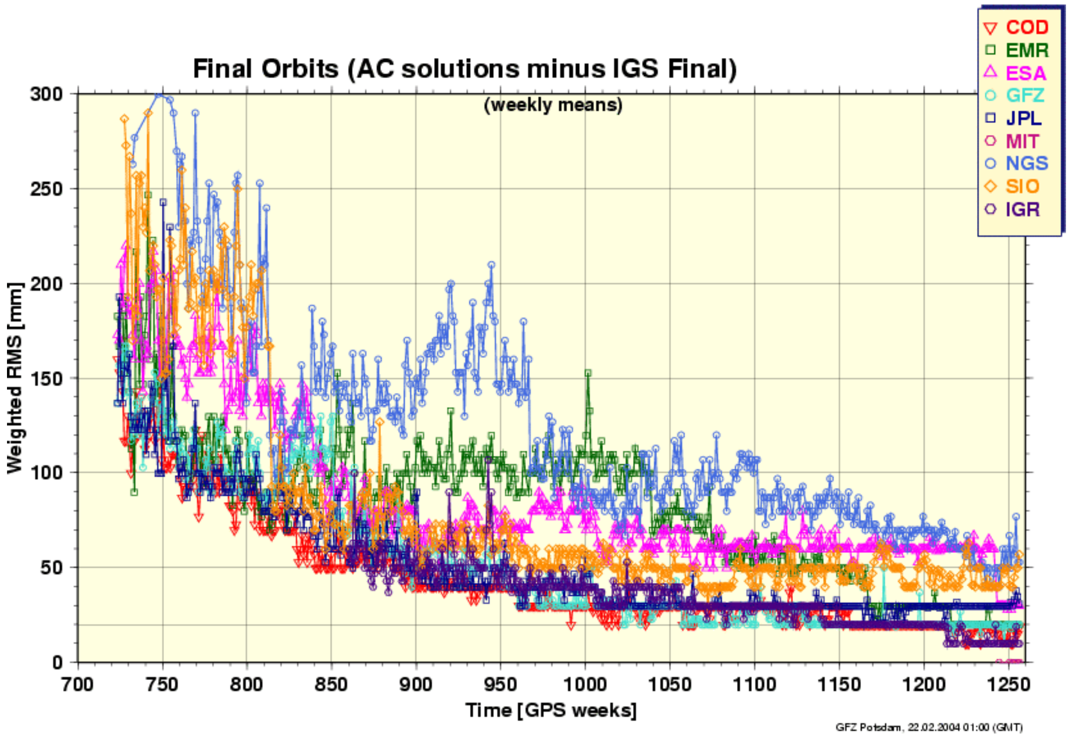

Figure 3: Development of Orbit consistency since 1993 (RMS per satellite coordinate of individual AC solutions w.r.t. IGS final orbit)

This astonishing achievement was, of course, only possible thanks to a continuous refinement of the analysis methods *and* thanks to the continuous growth of the IGS Global Network, which consists today of well over 200 sites (see Figure 4).

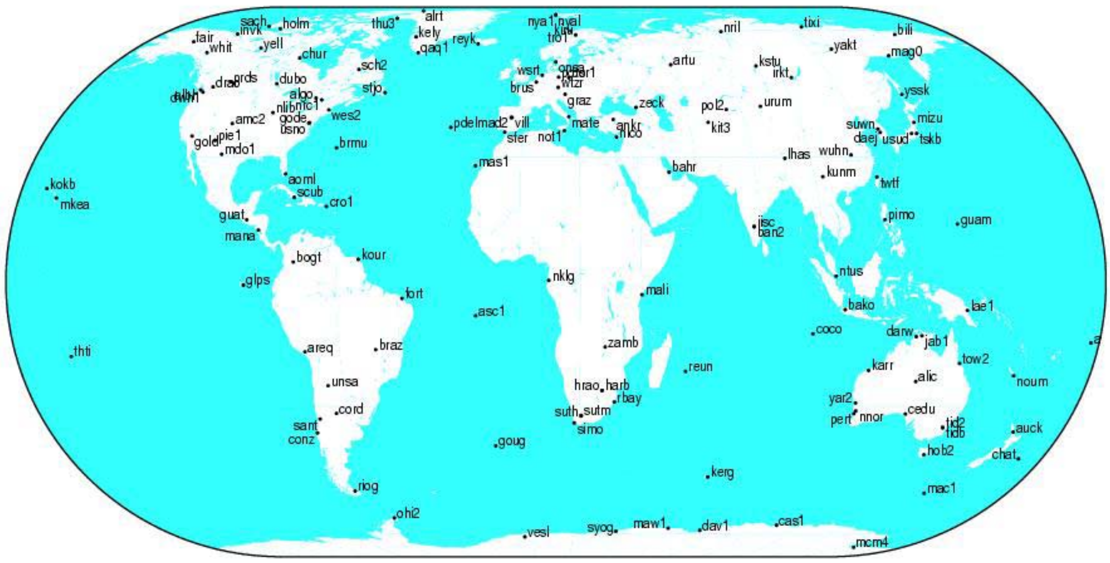

Figure 4: The IGS Network of tracking sites in 2004

The IGS network is, of course of paramount importance for geodynamics purpose. It is undoubtedly the densest and most accurate realization of the ITRS, the International Terrestrial Reference System, as defined by our sister service, the IERS, the International Earth Rotation and Reference Systems Service. The ITRF, the International Terrestrial Reference Frame, is produced by the IERS using the results of all space geodetic techniques. Similar statements can be made about the IGS ERPs: With their sub-mas accuracy and their (at least) daily resolution of polar motion, the IGS significantly contributes to the monitoring of the ERPs. Based on satellite geodetic techniques, the IGS cannot contribute to other ERPs like UT1 or the parameters defining precession and nutation *in an absolute sense.* The IGS analyses may only detect the time derivatives of those parameters during the time interval covered by an individual parameter estimation procedure (usually one to several days in the case of the IGS analyses).

What was said so far about the development of the IGS could be characterized by the famous olympic logo "*altius, citius, fortius*". When reading these lines one might thus get the impression that in 2004 the IGS does exactly the same things as in 1994, but in a much better way. This is of course true, in a way – and this was of course the main motivation for IAG to establish the service in 1993: The long-term perspective is a key element in geodesy. We refer to the various services to monitor Earth rotation, which have their roots in the late 19^{th} century, when the ILS, the International Latitude Service, was created by the predecessor of IAG.

The IGS development had, however, yet another component: The IGS developed into a multi-disciplinary "service" (it should better be called an "institution" in this context) by adapting the attitude of extracting the maximum information from the permanent tracking activities performed within the IGS. Today, the IGS should be called an *Interdisciplinary Service in support of Earth Sciences*. This aspect was in particular considered by Beutler et al. (1999). The IGS workshops, taking place at a rate of 1-2 per year, were extremely important in this respect. They may be found (together with other important IGS events) in Table 4.

Let us deal with the interdisciplinary aspects in more detail, where – in view of the limited space available – we will focus on a few aspects rather than on complete series of events and the sequence of their implementation within the IGS.

Date	**Event**
January 1994	Start of official service on January 1
November 1994	Workshop on the *Densification of the ITRF* at JPL, Pasadena
May 1995	IGS Workshop on *Special Topics and New Directions* at GFZ in Potsdam
March 1996	IGS Analysis Center Workshop in Silver Spring, USA
March 1997	IGS Analysis Center Workshop at JPL in Pasadena
December 1997	IGS Retreat in San Francisco
February 1998	IGS Analysis Center Workshop at ESOC in Darmstadt
December 1998	Prof. Christopher Reigber elected as IGS Chairman 1999-2002
March 1999	LEO Workshop, Potsdam, Germany
June 1999	Analysis Center Workshop, La Jolla, California
March 2000	IGS Tutorials in South Africa
May 2, 2000	Selective Availability removed!!
July 2000	IGS Network Workshop
July 15, 2000	CHAMP Launch
September 2000	IGS Analysis Center Workshop at USNO

December 2000	IGS Strategic Planning Meeting
February 2001	LEO Workshop
March 2001	Glonass Service Pilot Project
March 2001	TIGA Project established
April 2002	Ottawa Workshop: Towards Real-time
July 2002	UN Regional GNSS Workshop
December 2002	Prof. John Dow elected as IGS Chairman 2003-2006
April 2003	Ionosphere maps (IONEX) etc. official IGS product
May 2003	First operational combined GPS/GLONASS analysis products
August 2003	Essential improvement of "near-real-time" orbits
March 2004	IGS Analysis Center Workshop and 10 Years Symposium

Table 4: Some important IGS events 1994-present

Whenever a new aspect was studied within the IGS, a so-called working group was created. The chairpersons of the working groups became members of the IGS Governing Board. The charter of these working groups went (at least in some cases) far beyond the original charter of the IGS, which focused on the core products GPS orbits, clock corrections, ERPs, station coordinates and velocities. The IGS extended its activities in particular into the following domains:

- Atmospheric research,
- determination of LEO orbits,
- time and frequency transfer using the GPS code and phase observable,
- exploitation of the Russian GLONASS,
- tide gauge projects, and
- development into the direction of a GNSS service

The extension of the IGS to *Atmosphere Sciences* and to *Low Earth Orbiting Satellites (LEOs)* carrying GPS receivers was first discussed at the 1995 IGS Workshop in Potsdam, then at the 1996 and 1997 workshops. Eventually, *IGS LEO Working Group* was created and the *IGS Troposphere Combination Center* was established at GFZ (GeoForschungsZentrum in Potsdam) in 1997. The *IGS Ionosphere Working Group* was established in 1998. Moreover, at the 8th IGS Governing Board Meeting in December 1997 the *IGS/BIPM Project to Study Accurate Time and Frequency Comparisons* was created, where the IGS network is exploited (after previous suitable extension) for the purpose of high accuracy time and frequency transfer.

Most of the new areas of IGS activities mentioned above are covered at this one-day symposium. The aspect of monitoring the ionosphere using the two frequencies L_1 and L_2 of the GPS signal is an exception. Let us therefore illustrate the interdisciplinarity of the IGS with an example stemming from fall 2003, when there was exceptionally high solar activity. Figure 5 shows a picture of the Sun taken by the SOHO spacecraft on October 29, 2003. The extended sunspot groups indicate that the Sun was rather active end of October and early November 2003. This level of solar activities induced in turn a very high level of ionization in the Earth's ionosphere, which was recorded by the IGS network. At the Code homepage one may find a "movie" of the maps of an exceptionally high ionosphere content in the same timeframe. Figure 6 shows the maximum electron content observed in October 2003.

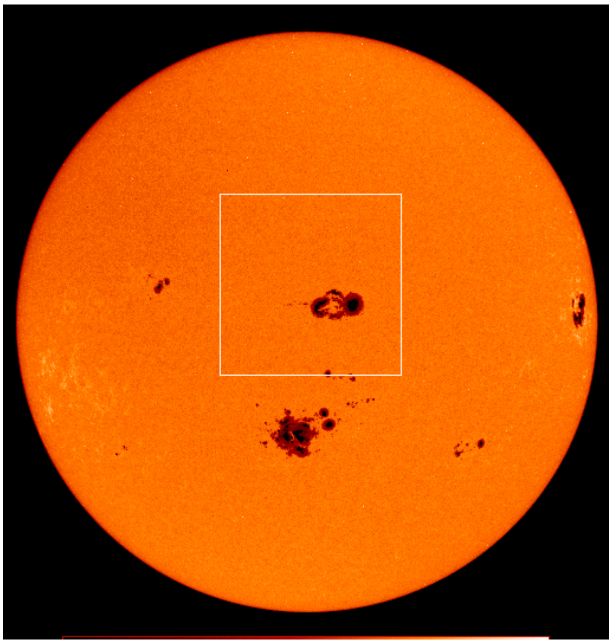

Figure 5: Sun observed by SOHO on October 29, 2003 (from SOHO homepage)

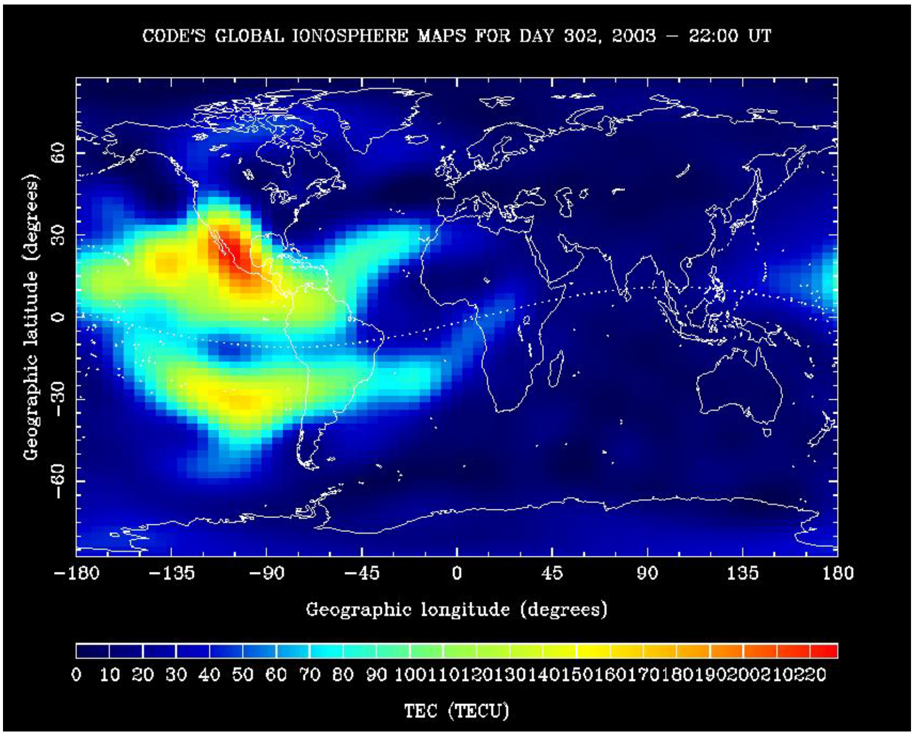

Figure 6: Maximum ionosphere content observed on October 29, 2003 by the IGS Network (from CODE homepage)

Key Elements of the IGS

The IGS was based on user requirements. Without the IGS each geodynamics group wishing to exploit the GPS for scientific purposes or each national mapping agency wishing to use the GPS to produce its first-order survey would have to generate its own GPS satellite orbits. A real chaos of local, regional, continental, etc. geodetic datums, but no unique global terrestrial reference frame like the ITRF would be the result.

Thanks to the comparison and combination procedures established by the IGS for its key products at a very early stage of its development, IGS products are easy to use and understand for a very broad class of users. Datum problems could be minimized.

There is a fair amount of redundancy in all but one components of the IGS:

- The number of sites in the network is such that occasional receiver or data transmission failures are not (too much) endangering the quality of the regular analyses of the IGS analysis centers.
- The hierarchical/regional structure of the IGS data centers, and the maintenance of three global data centers make it comparatively easy to retrieve data with a minimum delay from anywhere on the globe. Loss of data could be avoided, so far.
- The data transmission based on the internet proved to be extremely reliable. Ten years earlier, data transmission would have been based on magnetic tapes – a real nightmare for a service-like environment.
- The number of IGS analysis centers allows it to detect and safely remove blunders from the IGS key products and to greatly reduce the effects of smaller inconsistencies in the official IGS products.
- There is *no* redundancy for the IGS Central Bureau. This automatically means that the Central Bureau is a, if not the, crucial component of the IGS.

The regular comparison of analysis results and the implicit quality assessment of individual products led to an intense, but stimulating and friendly competition between IGS analysis centers. If the IGS would have only one or two analysis centers, the key products would never have the quality and consistency achieved today.

The IGS is based on voluntary contributions of its participants, which implies in particular that there is no central funding. This is a clear disadvantage in some cases. With a central funding it would be much easier to create an even much more homogeneous network (receivers, meteorological equipment, site selection, monumentation, etc.).

Today the IGS is an *interdisciplinary service in support of Earth sciences* and fundamental astronomy. With the regular exploitation of the GLONASS signals and with setting up links with the upcoming European Galileo system, the IGS develops into a *general GNSS service*.

Thanks to its performance in the past ten years and thanks to the level of acceptance reached in the user community, the IGS has a good chance to become the leading authority concerning the scientific exploitation of global navigation satellite systems for science. This is a very important aspect, because such systems will be the dominating tools at least for the next twenty to thirty years.

Ten years of "routine" service operations cannot consist of highlights, only. Problem areas must have shown up, as well. In the author's opinion the following aspects are problematic and might possibly even endanger the existence the IGS in its present form. Let us address a few of these aspects:

Funding is getting more and more a problem in science – not only in areas related to the IGS. On top of these general problems, which are mostly due to the current economic situation, one must be concerned that quite a few of the IGS components are currently still funded by sources related to *research and development.* It is in particular getting more and more difficult for university-type and pure research-institutions to raise the necessary funds to maintain their level of activities within the IGS. For participants of this kind the expansion of IGS activities was a *must*, not a luxury.

Extension of activities. When compared to the original purpose of the IGS, the activities were greatly expanded in the past decade. This growth, witnessed by the number of IGS working groups and pilot projects, had a significant impact on the workload of some of the key components, in particular on the

IGS Analysis Coordinator and on the IGS Central Bureau. Whereas this aspect is explicitly reviewed at four-year intervals for analysis coordination, on the occasion of the rotation of the IGS analysis coordinating center, it was so far always implicitly assumed that the Central Bureau would be able to cope with this growth. This is not necessarily true, however.

Commercial Aspects. The IGS does not have a business unit, allowing it to sign contracts with other organizations. This problem is known for a long time, but so far it could not be resolved in a satisfactory way.

The role of the IGS in IAG. The IGS took over many responsibilities within geodesy, within the International Association of Geodesy (IAG) in particular. This is of course fully justified by the impact of the GPS on the entire field of geodesy. This impact is in general very positive and will be briefly reviewed in the next section. There are, however, also potential problem areas.

- Where is the borderline between service-like activities and pure research?
- How shall the interfaces be set up between the IGS on one side and the IAG Commissions, Study Groups, etc., on the other side?
- How can the IGS stimulate scientific work, related to IGS activities, outside the IGS?

4. Implications on the New IAG Structure and on the future of geodesy

The IGS was the pioneer over the last decade of the 20th century concerning the applications of the most advanced positioning and navigation tools in geodesy and in Earth sciences. The IGS is today providing most valuable products to a large user community. The IGS, through its GPS orbits, satellite clock corrections, Earth rotation parameters, offers the day-to-day access to the international terrestrial reference system to a large and still growing user community. It is expected that the IGS will continue playing this role in future, as well.

The IGS, together with the IERS pioneered the development of modern services in IAG, probably even in Earth sciences. Their example was in essence followed by the IVS (International VLBI Service for Geodesy and Astrometry) and the ILRS (International Laser Ranging Service). These space-geodetic services, together with other IAG services (related, e.g., to the determination of the Earth's gravity field) are of fundamental importance in modern geodesy and in the wider field of Earth sciences. They are *part of* a very precious global geodetic infrastructure.

This pioneer role of the IGS and the IERS, and the excellent record of their activities and achievements, had a deep impact on the creation of the new structure of the IAG in the 1999-2003 time frame, between the Birmingham and Sapporo General Assemblies of IUGG and IAG in 1999 and 2003, respectively. It became clear at a very early stage of the restructuring process that these services, in a way standing for the positive image of geodesy towards the end of the 20th century, had to play an important role in the new IAG structure.

It is therefore not amazing that the four new IAG Commissions, in a certain sense the successors of the five IAG sections, *and* the IAG services are elements on the same level of the IAG in the new structure. Whether or not this hybrid construction, the *cohabitation* of commissions and services, will be a success uniquely depends on whether a sound cooperation between services and commissions and a healthy partition of work can be realized. In order to facilitate the development of this interface, three service representatives were elected as members of the IAG Executive Committee. For the time period 2003-2007 Ruth Neilan, Markus Rothacher and Harald Schuh were elected as service representatives into the IAG Executive Committee. Note that two of them are also members of the IGS Governing Board.

It was mentioned previously, that the IGS, together with the other space-geodetic services IVS and ILRS, and the IERS, are part of our very precious global geodetic infrastructure. This infrastructure contains even more elements. The network of gravity sites, space geodetic missions (like Lageos, CHAMP, GRACE, GOCE) , and the network of analysis centers are part of this global infrastructure as well. This global infrastructure is not safe. We have, e.g., seen major problems (related to national funding) in the ILRS. This SLR/LLR-related problem is, unfortunately, neither an exception nor a singularity. Problems of the same kind may occur in all the mentioned branches of geodesy – at least in those parts, which have to rely on an expensive infrastructure. The IGS certainly is no exception in this respect. These considerations were the basis to create the GGOS project in the new IAG structure.

GGOS stands for *Global Geodetic Observing System*. *System* should be understood as the basis on which the future advances in geosciences can be built. By considering the Earth system as a whole (including solid Earth, atmosphere, ocean, hydrosphere, ice, liquid core, etc.), monitoring it by geodetic techniques and by studying it from the geodetic point of view, the geodetic community does provide the global geosciences community with a powerful tool consisting mainly of high quality services, standards and references, and theoretical and observational innovations.

GGOS is based on the existing IAG Services. GGOS wants to provide a framework for existing or future services and ensure their long-term stability. New entities will be established only if there is a stringent requirement.

GGOS must be recognized by partners outside IAG, e.g., by UNESCO, ICSU (International Council of Science), IGOS (the United Nations' Integrated Global Observing Strategy), governments, inter-government organizations, WCRP (World Climate Research Program), IGBP (International Geosphere Biosphere Program), etc., as geodesy's most important contribution to Earth sciences. For this purpose contacts have to be established to these organizations.

GGOS must promote its master product(s) and the related sub-products. GGOS must promote research in geodesy, provide standards and enforce quality management (validation, calibration, ensure the one-ppb level) either by a new GGOS entity or by delegating this task to one or several of the existing services. The initial structure to be established for the GGOS definition phase is simple and compatible with the existing IAG services. The key elements of the initial GGOS structure, are:

- The GGOS Project board as the central oversight entity,
- few well defined working groups,
- an GGOS Science Council representing the geodetic community.

In its final form GGOS wants to provide

- geometric products (e.g., the global terrestrial reference frame),
- gravity products (e.g., the Earth's stationary and time varying gravity field), and
- and the transformation between the "Earth-fixed" (the Earth rotation parameters) and inertial reference frame

in one and the same consistent reference system. The consistency of the geometrical and gravitational GGOS products on the 1 ppb or better level are of central importance.

Needless to point out that the IGS is of key crucial importance in this context. In the decade of gravity field determination the Earth's gravity field is determined with dedicated satellites, which are equipped with spaceborne GPS-receivers, accelerometers, and possibly gradiometry instrumentation. The technique relies, in one way or another, on the reconstruction of the gravity probe's (the satellite's) trajectory on the one-cm level. The IGS, its network observations, and its products, are indispensable prerequisites to reconstruct the Earth's gravity field. The IGS will be instrumental in this new era of geodesy, as well. For the same reason the IGS must play an extremely important role when setting up the GGOS.

Prof. Christopher Reigber from GFZ, Potsdam is chairing the GGOS in its definition phase. For more information we refer to Beutler et al. (2004).

5. Summary

The creation and the operation of the IGS over the time interval 1989-2004 were reviewed. The creation of the IGS was based on user requirements. The IGS started as an orbit determination service, focusing on the day-to-day determination of

- satellite ephemerides,
- satellite clock corrections,
- Earth rotation parameters, in particular polar motion and length of day, and
- site coordinates.

The third and the fourth product mentioned are of great importance for the IERS, which uses them for the establishment of the ITRF and the Earth rotation parameters together with the corresponding results of the other space geodetic services. The density of the terrestrial network and the time resolution of the IGS products are unparalleled.

The following phases have to be distinguished in the IGS:

- Planning phase 1989-1991,
- proof of concept phase 1992,
- pilot service 1992-1993, and
- official IAG service since January 1, 1994.

In the years 1994-1998 the IGS developed into an interdisciplinary service in Earth sciences and fundamental astronomy by adding the following fields to its activities:

- Global ionosphere mapping,
- Troposphere mapping over the IGS sites (determination of water vapor content),
- Time and frequency transfer between timing laboratories, and
- Kinematic and deterministic determination of LEO orbits based on the IGS products.

By conducting dedicated GLONASS observation (and analysis campaigns) in the late 1990s and by eventually implementing the GLONASS ephemerides into the official IGS products, the IGS made the first steps into the direction of a general GNSS (Global Navigation Satellite Systems) service. This development will shall be pursued systematically by implementing at the earliest possible stage the Galileo system into the IGS scheme. The IGS is (hopefully) on its way to become the authority concerning the scientific exploitation of all GNSS systems.

The IGS scheme of operation was successfully adapted to the other space geodetic techniques SLR/LLR and VLBI by setting up the IVS and the ILRS.

The space geodetic services, together with the gravity-related services and the IERS are the main building blocks of the GGOS project of IAG. They are part of the global geodetic infrastructure inherited from the 20th century. It is our duty to secure this infrastructure and to make the best possible use of it to monitor the Earth, including plate motion, tidal (and other) deformation, Earth rotation, and atmospheric behavior.

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The IGS Strategic Plan and Future

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Abstract

An overview is given of the IGS Strategic Plan 2002-2007 [1], which together with the IGS Terms of Reference, provides the necessary strategic and organisational framework for the multitude of activities carried out by the various components of the International GPS Service. The paper also summarises the status of its implementation as reflected in the work of some key elements, and the outlook for the coming years.

1. Introduction

After four years of operation as an official service of the International Association of Geodesy, the IGS Governing Board held a two day retreat from 12 to 14 December 1997 to review the state of the service. A number of issues were highlighted and discussed in depth. The recommendations and action items arising from the discussions were summarised by Ivan Mueller in a paper published in the Proceedings of the IGS 1998 Analysis Centre Workshop, which was held shortly afterwards in Darmstadt in February 1998 [2].

Some two years later, the Board began preparations for a second systematic review of the service and its future priorities. At the Governing Board Business Meeting in May 2000, a Strategic Planning Committee consisting of Ch. Reigber (Chair), G. Beutler (Former Chair), J. Manning, R. Neilan, J. Ray, R. Serafin, A. Moore, N. Beck, B. Melbourne and I. Mueller was set up. H. Bazoian later joined this group as consultant and facilitator. The Committee met in Frankfurt in September 2000 to evaluate the results of a questionnaire which had been sent to GB members and to many active contributors to the service, and to prepare for a retreat of the Board in Napa Valley, California following the Board's meeting at the AGU Fall Meeting in San Francisco. The retreat took place on 12-13 December 2000.

By the time of the next Board meeting in Nice, April 2001, a draft Plan was available.

Long-term goals and objectives and three strategic axes were derived from a mission statement, which was finally formulated as follows [1]:

"The International GPS Service is committed to providing the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multi-disciplinary applications and education. These activities aim to advance the understanding of the Earth system components and their interactions, as well as to facilitate other applications benefiting society."

2. Long and Medium Term Goals

A number of high level, long-term goals and objectives were derived from the mission statement. These are:

- To provide the highest quality, reliable GNSS data and products, openly and readily available to all user communities.
- To promote universal acceptance of IGS products and conventions as the world standard.
- To continually innovate by attracting leading-edge expertise and pursuing challenging projects and ideas.
- To seek and implement new growth opportunities while responding to changing user needs.
- To sustain and nurture the IGS culture of collegiality, openness, inclusiveness and cooperation.
- To maintain a voluntary organisation with effective leadership, governance and management

3. Three Key Strategies

In order to achieve the agreed objectives, three key strategies were identified:

Strategy 1: Ensure delivery of "world standard" GPS (and other GNSS) data and products, providing the standards and specifications globally.
Strategy 2: Pursue new opportunities for growth to improve the services and serve a broader range of users.
Strategy 3: Continuously improve the effectiveness of the IGS organisation.

3.1 Strategy 1

Ensure delivery of "world standard" GPS (and other GNSS) data and products, providing the standards and specifications globally.

IGS products quickly reached the level of a world standard, during and subsequent to the initial campaign of 1992, and the quality of its products has been improving ever since: in particular, the core IGS products orbit, clock corrections (satellite and ground) and ground positions (ITRF coordinates) should be mentioned. Formats developed, or further developed, by IGS, including RINEX for GNSS data, SP3 (in various flavours) for orbits, SINEX for exchange of solution data (containing sufficient standardised information about the solution to enable easy and meaningful combination with other solutions, even based on different measurement techniques) are important examples, which established themselves as global standards during the early and mid 1990's. Later developments are IONEX (for exchange of ionosphere maps) and Antenna Phase Centre Value (PVC) Tables.

An essential element of this strategy relates to user outreach and education, and understanding of user needs and identification of new user groups, supported by an open data policy.

Expanding the participation in the core elements of the IGS system (stations, data centres, analysis centres, projects); attracting fresh talent through new, challenging projects consistent with the overall aims of the IGS; and diversifying the Governing Board by including members of other communities are all ways of contributing to implement this strategy. Publicising the work of the IGS, both within and outside of the agencies directly involved is another essential aspect. This can consist of participation in conferences and workshops, as well as through publications of Annual Reports and Workshop Proceedings, in addition to direct contacts.

3.2 Strategy 2

Pursue new opportunities for growth to improve the services and serve a broader range of users.

Two areas were highlighted here as necessary for the growth if the IGS:

- Develop and pursue plans in support of LEO satellite missions. In addition to providing standards and formats for mission-independent information, two directions were foreseen, viz. creation of new IGS LEO Precise Orbit Determination (POD) Products, and evaluation of the impact of LEO data on IGS global products.

- Develop and pursue plans related to real-time (RT) and near-real-time (NRT) applications, with the aim of providing standards and formats for RT operations, forming liaisons with existing regional communities and broadcasting IGS products for RT users.

Both of these are key fields of research and development in GNSS, and are natural areas of activity for the IGS. Several of the agencies active in the IGS (NASA, GFZ, ESA, CNES) are engaged in missions involving use of high-precision GNSS receivers on board of LEO spacecraft. Several such spacecraft are already in orbit (CHAMP, the two GRACE spacecraft, Jason-1, ICESat) and several others will be launched in the next few years (MetOp-1, GOCE, Jason-2, COSMIC, NPOESS).

3.3 Strategy 3

The third major area of the Strategic Plan concerns the continuous improvement of the effectiveness of the IGS organisation.

First of all, it is essential both to re-enforce the continuity of support provided by those organisations which have been involved since the early days of the IGS, by seeking an appropriate recommitment from those organisations. New alliances with organisations which may be motivated to contribute to IGS activities are also being explored.

4.   Where are we now?

It is useful to survey briefly the current status of several core elements of the IGS and of Working Groups (WG) or Pilot Projects which are particularly central to furthering aims of the Strategic Plan. More information on all of these can be obtained from the Proceedings of this Symposium/Workshop.

4.1 Analysis Centres (AC) and AC Coordination

A major asset is the continuity of the AC participation. All of the original AC’s are still actively participating on a daily basis to the work of the service. (The same applies to the Global Data Centres and to the Central Bureau.) Several new contributors have joined the service more recently, including two which were officially admitted at the Governing Board meeting in December 2003. In view of the continuously increasing load on the AC’s, this is a welcome development. A well-coordinated handover of AC Coordination took place over the first half of last year: the tradition of strong and highly competent AC Coordination is continuing, as is the concept of passing this responsibility from one AC to another in a 4 year cycle.

4.2 Data Centres

Three Global Data Centres (two in USA, one in Europe) guarantee availability of data products to AC's and end users, with appropriate redundancy between them. A proposal from Korea to establish a fourth one is expected to be realised in 2004, and additional possibilities for new centres are being investigated.

4.3 Timing Products

Timing is central to the operation and exploitation of GNSS. The successful Time Transfer WG activity established jointly by IGS and BIPM has been superceded by a Timing Products WG, chaired by a Timing Products Coordinator. IGS timescales (rapid and final) are being generated daily and weekly, providing better stability with respect to UTC/TAI than is possible using only the satellites themselves, taking advantage of the existence of very stable hydrogen masers in the IGS ground segment.

4.4 GNSS/Galileo WG, IGLOS

IGS has already played a major role as an important reference in the development of the Galileo Mission System, in particular through the Galileo System Test Bed GSTB V1. An active GNSS WG is focussing attention on aspects such as requirements for proper calibration of satellite and ground antennas; radiation pressure models; integration of new signal measurements (both GPS and Galileo) into the IGS processes; and early participation in signal and receiver validation. Appropriate interactions with GNSS system operators and developers at programme office and technical levels are essential to further these objectives.

The International GLONASS Pilot Service IGLOS, which developed out of the International GLONASS Experiment IGEX in 1998, has provided a very successful demonstration of the capability of the IGS to successfully integrate another GNSS into its operations.

4.5 LEO WG

The Low Earth Orbiter (LEO) Working Group was restructured in 2001. With the availability of data from several orbiting LEO's since that time, processing campaigns have been carried out with the participation of a considerable number of Associate Analysis Centres. These have helped a lot to clarify some of the issues involved in processing data from orbiting receivers. Some progress has also been made with the other central aim of the WG, which relates to the utility of using LEO data within the generation of the core IGS products.

4.6 Real Time WG

The IGS Workshop held in Ottawa in February 2002 took as its unifying theme "Towards Real Time" [3]. The development of real time data flows from a sub-set of IGS stations has been proceeding since then, and currently 4-5 networks are contributing data on an experimental basis. With the availability of increasing communication capacities, real time data and derived products will play a much more important role in the future, complementing the reference role of the IGS in providing the highest accuracy products a posteriori.

4.7 Reference Frame WG

During the years of its existence, the IGS has played an ever-increasing role in the maintenance of the International Terrestrial Reference Frame (ITRF). Using the weekly contributions of the Analysis Centres, the IGS Reference Frame Coordinator, supported by a WG, has responsibility for the IGS reference frame, which underlies the IGS products and is a very close realisation of the ITRF and a major contributor to each ITRF update. Like the timing coordination, this is a core function in the IGS structure.

4.8 IGS Global Network

The IGS network is the foundation on which IGS products, in particular for reference frame purposes, are built. A major concern of the IGS during the year 2003, and a continuing concern, has been the maintenance and improvement of the network. (The same concern was expressed in the 1997 retreat, see [2].) A standards document for stations of the network [4] was developed by the Network Coordinator with the support and contributions of a specially appointed group. The resulting document was approved by the Governing Board at its 23rd Meeting in San Francisco in December 2003. The Network Coordinator will maintain this document and report back regularly to the GB on progress. A better understanding by station and network operators of the requirements on IGS stations and better and faster feedback from the Network Coordinator, AC's and ACC to them are key elements to improving the quality of the global network.

4.9 IGS as an IAG Service, GGOS

The new structure adopted by the IAG in July 2003 impacts the IGS, as it does the other IAG services [5]. New relations with the IGS Commissions, in particular with Commission 1 (Reference Frames) and Commission 4 (Positioning) are being developed by the IGS to facilitate this, as documented in a paper adopted by the IGS GB at its 24th Meeting as a working basis [6]. The IGS, working closely with its sister services including IERS, ILRS, IVS and IDS, is prepared to play an appropriate (major) role in the first project of the new IAG, viz. the Global Geodetic Observing System (GGOS) [7].

4.10 Central Bureau (CB)

The IGS is fortunate to have been served by a single highly competent CB since its beginnings. Unfortunately the considerably more demanding task which the CB is now asked to handle (including for example outreach to users and potential users, and participation in relevant international fora) have not been matched by increased funding of its activities, on the contrary, the CB has been struggling to continue with less resources than were available to it some years ago. This has been recognised as a central problem of the IGS for several years and has reached the point where some significant core requirements are becoming more and more difficult to satisfy. The Board, in close collaboration with the CB, is actively looking at possible solutions.

5. Outlook

The Strategic Plan 2002-2007 of the IGS, developed by the Governing Board and approved in December 2001, remains a valid basis for the work of the service, and many of its objectives are being successfully implemented. Several agencies which have been making major contributions to the IGS over the past decade are facing the challenge of finding new sources of funding, and in the future new ways of operating and of supporting the major undertaking represented by the combined efforts of the 200 agencies involved will be needed. Despite this, the very extensive use of IGS products in a wide range of applications and the continuous improvements reflected in these products, demonstrate very clearly that the IGS is thriving and can look forward with confidence to the next decade. The Strategic Plan is likely to need periodic revision, and it seems appropriate to envisage a further review of it during the next year, extending its validity beyond 2007. All active participants in the IGS are strongly encouraged to familiarise themselves with the current version of the plan and to contribute to the process of ensuring its continuing validity.

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Industry Perspectives on IGS Collaboration, Impact and Influence – Past, Present and Future

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1. Abstract

This paper focuses upon the influence the IGS has had on industry over the past 10-year period and the next 10 years. It felt odd to be asked to contribute to such a knowledgeable and able group but also quite a challenge to try and envisage what the future may appear like. By reviewing and examining the various achievements the future is considered. The future, that is, of the IGS, as seen by an observer from Industry. In the ever-changing world it is impossible to clearly predict the situation in 10 years time, but it is fun to put some ideas and concepts forward. The views in this paper are those of a relative outsider, to the community that the IGS represents, and so the perspectives offered are not necessarily going to be accepted in the same way, but of course everybody has their own life history and experiences that create, for them, an individual model of their world. The intention of this paper is to raise the awareness of various components that make the world of the IGS so interesting and challenging.

2. Introduction

The announcement that the IGS was to celebrate its 10th anniversary in March 2004 came as a surprise as it seems only recently that the strategic review was being undertaken. Having been associated with GPS and satellite positioning for over 17 years, it seams that the IGS has been around since the early days of GPS. How easy it is to forget having to contact VLBI and SLR sites around the globe to gain access to zero order control for our ambitious real time Differential GPS plans. Time has passed really quickly and it's amazing to consider what the IGS has achieved in its first ten years. My perspective is very much that of a professional surveyor who both uses the products and data from the IGS but is also involved in the delivery of a commercial DGPS service within the Offshore and Marine Survey Industry sector. In this context this paper must therefore not be a technical one.

It is relatively straightforward to review the past and offer a brief series of examples that provide an impression of how the period has enabled Industry and Academic communities to work and develop successful programmes. It is only fair to also consider if perhaps there are aspects to the activity that have not generated success, at least on a relative basis. Many events occur, not due to planning and effort, but due to external factors and these, I believe, have created a huge impact on how the IGS has managed to influence and work with Industry.

The current situation is one that should need little explanation although the Industry perspective offered here may differ from the viewpoint of a more "internal" IGS observer. How we see ourselves and how others see us is one of the great themes explored by many great philosophers and minds over the centuries. Indeed the term "exploring" is quite apt as there is no real absolute, but many variations, of the perspective each of us develops from our experiences and interpretation of events. The final element of this short paper considers the future and how the interaction of the IGS with Industry may continue. The prediction of future events is not too easy so I make no apologies for a personal and perhaps quite narrow focus on the activities and how these could play out over the next 10 years.

3. The Past

The initial effort by the IGS to deliver a word wide tracking capability developed very quickly and was conceived with a quite brilliant federated approach. As time has passed by the multiple agencies and organisations involved have remained in a competitive and dynamic state to ensure the fabric of the IGS remains intact if not entirely secure in terms of it's financing. Industry appears to have largely ignored the calls and requests generated by the IGS and set about it's own programme of geodetic campaigns and networks without a clear statement of intent and therefore opportunity for collaboration with the IGS. On the face of it this was commercial sensitivity however there was also a general lack of awareness of what the IGS stood for and could contribute to the process. Many experiences of Industry considered that the individual mapping and geodetic institutes offered the real geodetic answers and resources. The IGS was something that initially lacked an identity and applied the data in another direction for later access if required.

The 1990's saw various technological advances and four in particular, I believe, enabled the IGS and Industry to move forward. Although in 1989, the IAG meeting in Edinburgh announced for the first time, at least for some of the Industry people, that the concept of long range, international geodetic campaigns could be carried out with fiducial sites acting as control for a homogenous framework. The significance use of dual frequency GPS observations would become apparent thereafter. A key enabling capability for the DGPS service providers in the marine Industry and latterly for the high accuracy services.

The development of the Internet is one of the key components to the success of many of today's ventures. Without the access to vast quantities of data using desk top, everyday technology, the GPS infrastructure, we have often come to rely on, could have remained in a very virtual and specialised world of IT and data analysis.

The 1990's also experienced one of the more significant changes in policy for the US control of GPS and as a result in 2000, President Bill Clinton approved the removal of the man-made Selective Availability (SA) thus releasing lots of developers to explore new ways of generating positioning and RF solutions. As a consequence the acceptance that real time high accuracy solutions for land as well as offshore users could be provided and the general awareness of the capability of GPS was further promoted.

The final technical advance that should be given credit is the European GNSS Galileo adventure. Although not here yet, and may arguably not represent a huge technical advance for many users, Galileo has created a hugely competitive atmosphere between many groups.

It appears obvious with hindsight that the IGS did not target Industry, but chose to concentrate upon the GPS activities within academia and governmental bodies. This was the right approach as it enabled the IGS to develop and create standard technical parameters for the various products and services. As a consequence however, Industry established only a small demand for the supply data and products. This use, when needed, would not have sustained the IGS even if the sales and marketing departments had established what the potential cost saving was. As an example take a geodetic campaign, visiting several VLBI and SLR sites in Europe. In each case we had to contact and agree dates and visiting rights with the owners, establish the correct co-ordinate reference frames for the individual specific marker we set up over and supply all the equipment, personnel and travelling and accommodation costs in order to obtain our 4 or 5 days of data. Thus the process could cost an estimated $6-10000 per site visit.

The impact of the IGS and the associated developments mentioned above have resulted in huge progress by Industry, not simply in alternative sources for cheaper data sets, but in providing positioning, navigation and location based solutions and services. Of significance for Industry was the ability to develop regional augmentation systems on the basis of precise international reference frameworks. The IGS created a market for high precision products and the reliance upon such products and the service associated with it increased.

Various sectors of Industry achieved many things with the use of GPS. In particular the timing provided the telecommunications Industry with new capability, transport and navigation was revolutionised and the meteorological community came to adopt GPS observations for their own uses. The overall impression is that a series of data products and services became useful to Industry through their specific technical needs and academic interest. At best a few interactions took place, more commonly Industry simply used what was available but really any true collaboration was rare. The IGS created for itself a market primarily within the academic community and as the general outreach made possible by technology continued so Industry accessed and used various elements. Despite the complete lack of commercial input form Industry the IGS survived and this is a tribute to the Board and very dedicated personnel who managed to maintain the momentum of the early years. The IGS demonstrated that the deliverables being produced were sustainable and this is what impacted most on Industry.

The success of these initiatives is such that local mapping agencies and other groups are now trying to offer a similar local service. For Industry the opportunities to develop new hardware products and systems and the increase in the acceptance of high accuracy solutions owe a debt to the IGS.

4. The Present

To review the current situation the approach in this paper is examine what current activities and initiatives of Industry are significant and dependant upon the existence of the IGS. This is not so easy as it could be argued that the influence or impact of the IGS on various Industry activities may not be significant. Nevertheless from a relatively narrow perspective a number of elements emerge. Other elements can be developed through considering a wider picture.

The current offshore and marine positioning market is developing Real Time High Accuracy solutions using Global Error Modelling (Wide Area) techniques. Whilst satellite based delivery of Differential corrections has been around for over 13 years the adoption of a truly global Wide Area system has only recently been adopted and introduced to commercial service. The delivery of Real Time services is a growth Industry at present.

Associated with the greater expectation of high accuracy and ever decreasing residuals and errors, a number of Clients have recognised the importance of the IGS and it’s members. Consequently Industry often has to deal with specifications that require such processing packages as Bernese or similar. This increased acceptance and reliance upon what are essentially ingredients of the IGS and it’s members creating an interesting situation where the traditional academic remit to serve science comes directly into contact with the need of Industry to serve Clients and, of course generate revenue. In the end to serve the academic institutions some funding needs to be identified. Whether the benefits are direct sponsorship or income or more indirect research grants and donations may not in the end be too critical.

Currently there are few true bilateral agreements in place between IGS members and Industry. Whilst these may actually be common for some of the larger organisations with government funds what is becoming significant is that the desire for the agreement is increasingly due to the elements identified with the association of the IGS. With agreements to supply and offer solutions based upon a collaboration of academic and Industry, the IGS member is thus managing to derive benefit, either from direct revenue, professional research programmes or papers. It also brings much needed stability to the funding situation. One such example of this is the real time offshore platform subsidence monitoring. In this example the Academic group do not wish to carry extensive insurance and liability for data processing nor be held to operational requirements for going offshore. The Industry partner however does not have the latest GPS knowledge nor does it wish to if available elsewhere. Consequently a firm "win win" is created to deliver the latest technology to a Client.

It's worth at this stage to review the current expectations and requirements that Industry now expects when GPS and GNSS are involved. In the business sector of the Offshore Survey Industry a number of companies use GPS as the basis for their undersea engineering and route surveys as well as for hazard avoidance and safe navigation. The requirements for such groups can very enormously from project to project however currently the emphasis is on the following:

Deep Sea Survey Requirements for AUV's

- **Rapid Initialisation and re-acquisition for alignment, attitude as well as 3D/4D position.**
- **Repeatable accuracy annually of 1-5mm over 5-10+ years**
- **Availability – E.g. when an underwater vehicle such as an AUV surfaces (see figure).**
- **Relevant Integrity, Reliability and Continuity of Service parameters – Through QC.**
- **A full Customer Service and Support facility, globally.**
- **Dual installation and/or a Secondary (with redundancy) Svstem.**

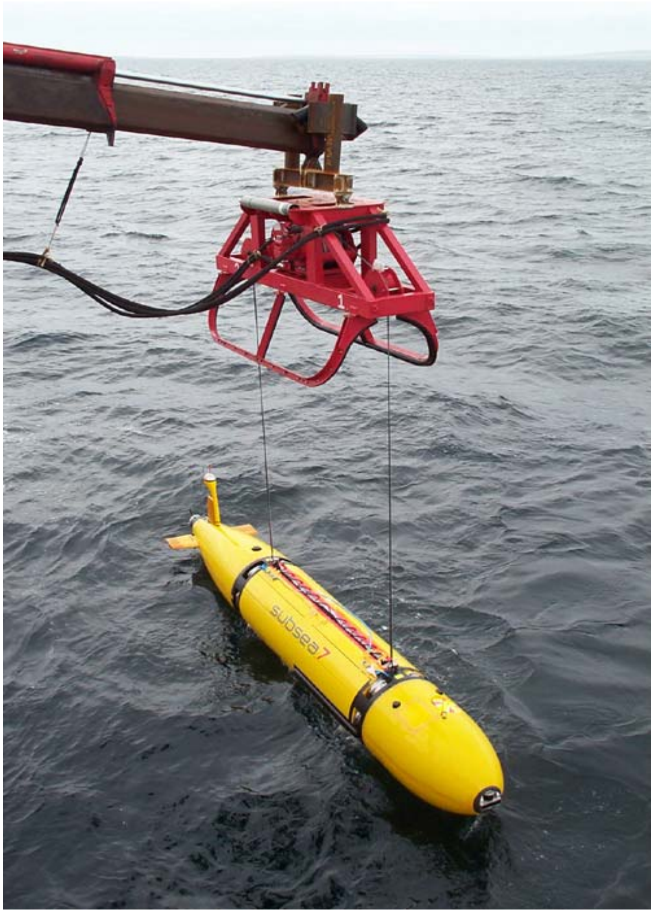

Figure 1. During the AUV deployment the GPS is often used for the initialisation of It's 3D position and precise attitude. (Picture courtesy of Subsea 7).

Overall the level of real collaboration and co-operation between Industry and the IGS members is relatively small. It is increasing slowly, but is an area of limited opportunity due, in part, to the need for specialised knowledge and specialised requirements by Industry that often limit mass appeal. From the Industry perspective there are many ways to analyse and interpret what the IGS has achieved and how it may be viewed.

In Figure 2 the concept of a value chain has been introduced to show where Industry considers the IGS lie in the overall matrix of GPS data products and services. Note that this is a very simplified assessment and a whole new paper could be written on the methods and analysis of such value chains as well as their content discussed.

Value Chain Elements	DATA	PRODUCTS	COMMS	REAL TIME	HARDWARE	CUSTOMER SUPPORT
% Gross Revenue Target?	15 %	70 %	13 %	25 %	30 %	25%
Description of the elements of the Value Chain	"RAW" material for all products. Uses tracking stns	IGS sets formats and Stds. Tools made by Members Allow best use.	Static Stn links. Relies on Internet. Limited access to Users.	No Real Time service with commitment to Users. May not use Internet.	No Longer Involved in hardware units	Need High level of Customer Service plus good QC.
Key Factors on each element	• Distributed Stations • Permanent • Dual Freq. & Met. Obs.	IGS maintain standard PE format and provide most reliable	Good static Stn lines. Need various links for Users. The critical element.	A Real Time service must have ease of access and uniformity of service.	Smaller OEM's & greater functionality aimed at mass market consumer	Need support team for Users. Quality Control & good service levels vital.
Position of the IGS	No. 1	No. 1	No. 3	(No.4)	---	No. 3
Competitors & Players Positioning	IGS Market Leader		No Guarantees	No User Viz	No Capability	Ltd Exposure
	Local Mapping Bureau & Agencies				Various OEM Manufacturers	Fugro, JDeere
	Fugro, J Deere (C&CT, Navcom), Local Systems, Veripos				No direct IGS Competition	

Figure 2. A Value Chain for the IGS.

In Figure 2 the Value Chain illustrates the various products and services of the IGS and how these may be interpreted in their overall context of a commercial and local government populated sector. On the top row is a series of arrows showing the progress made by the "raw" material in this case dual frequency GPS data. As each step is taken, in theory, some value is added to the element. So when step two is reached the data has been processed and formed into Precise Ephemeris or Orbit files thus adding value.

On the second row is the estimated revenue or margin an operator might wish to try and achieve with the activity in the column. Note: accurate figures for such activities are closely protected by companies and so these are example figures and do NOT reflect any current systems. Many factors can influence these numbers such as User numbers, timescales, asset liabilities, processing costs and complexity. Given that for the data and products there is no real commercial equivalent the revenue is just for completeness.

The 3rd row describes the key elements to that step and the 4th row outlines the positive components. In row 5, the position that the IGS is regarded as having in that particular activity is shown. So for data and products the IGS stands first but lacks real time infrastructure and customer interface to archive top marks in the later steps. Remember this is the perspective of Industry and not that of an IGS Member!
The remaining rows offer some comments on competitors and other service providers in the sector of providing real time positioning solutions.

How should the IGS view such a table and what does it offer in terms of forward progress for the IGS? The original title of the paper was very much one that seemed to balance the past, present and future but it's often more interesting and not easy to be proven wrong, at least initially, to speculate on the future. However, before contemplating the future, it is worth re-iterating that the current success of the IGS is due to it's excellent reputation gained through an uncompromising approach to delivering data and products that are the de facto standards within the Geosciences community. Not only is the IGS very successful, at the areas in which it has concentrated its efforts, but it has also proven to many during these 10 years that the process is sustainable.

At present a tremendous amount has been achieved and yet much of how the IGS obtains it's funding and financing remains precarious. It is certainly not an open demonstration of sustainable investment. Over the years the Bureau has developed and maintained a huge following and this despite annual threats on their income and an increasing demand for global representation and visibility. Today the IGS is a very strong community of federated organisations that generally compliment each other and provide great support to the efforts of the Central Bureau. Was it otherwise, I wonder if the IGS would have lasted this long?

The subject of funding cannot be answered in the present time, as there appears to be a continuing stationary situation between the organisations with funds, the IGS in the middle and the end Users. Some organisations are on both sides of the funding equation; others are not and so may lose out. After 10 years the situation is not ideal and must be addressed going forward for the future. From the Industry perspective it appears quite fragile and yet the situation probably has many parameters causing ebbs and flows in the balance. A different sort of earth tide really, where the effects are always present but only severe if you don't take account of them.

The long-term future of the IGS and its survival will depend upon stable funding and concentration on a set of the elements included in the Value Chain.

5. The Future

In setting out to look into the future and feel a way through possible scenarios, it is necessary to also take account of the experiences to date. History, we are told, is a window on the past, but it also often helps us to understand and develop in the future. Certainly the current trend of Users wishing to adopt real time solutions will vastly reduce, if not completely replace the need for certain categories of data and product uses. In reality a complete withdrawal of such services is unlikely to occur as the naturally conservative surveying and Geosciences Users are unlikely to let go of their traditional and time-honoured methods, at least not without encouragement. Will the IGS provide that encouragement and influence and if so in what form? Use of the data and products will also be reduced due to a more critical User demanding ever more QC parameters within files and independent QC. This coupled with the growth in the real time systems could threaten the IGS, as alternative sources of products will appear, either from local departments, government mapping agencies or commercial organisations. This competitive trend of multiple sources will be dependant upon whether the IGS, currently hugely influential, adopts primarily a Scientific role or a Commercial role. Can it fill both roles?

Let us review what history can show us with a couple of Case Studies.

Case Study 1: Reference Station Selection Criteria. In the late 1990's the Ionosphere was causing many Users difficulty. In particular areas close to the geo-magnetic equator would often experience scintillation effects causing loss of GPS tracking. Industry tackled this by adding more augmentation systems, using dual frequency receivers and adding GLONASS to the mix. However the "hot Spots" often were in remote areas and not well served with tracking stations. Since the left hand map from 1998, the IGS has almost doubled the tracking stations but not the coverage in the affected areas. With time coming for the solar maximum again what exactly is the IGS strategy for introducing more Tracking Sites? All potential sites must be assessed and reviewed in order to ensure a cost effective infrastructure for the data and products being generated in the future.

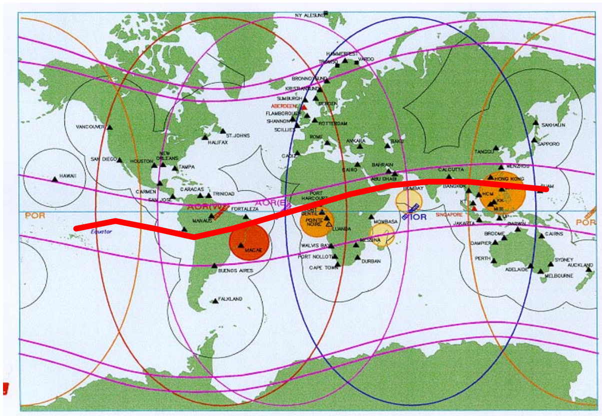

Fig. 3: 1998

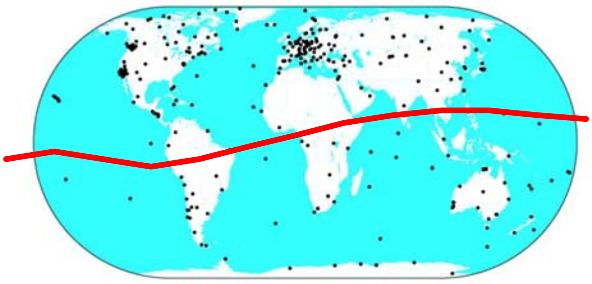

Fig.3: 2003

Figure 3. The 1998 map on the left shows "hot spots" of Ionospheric interference and scintillation. The 2003 IGS map of Tracking Stations although now numbering many more appears to still have large areas within the geo-magnetic region still to be adequately covered.

Do the benefits of such an enormous infrastructure outweigh the costs and can the IGS sustain such a system? It is vital to preserve the quality and reliability but the Tropics need more sites and then what will be the influence of Galileo on sites the require equipment upgrades? This is not the first time that a new GNSS has been introduced to the IGS.

Case Study 2: GLONASS. The introduction of GLONASS observations was interesting and offered some opportunity to expand satellite based positioning activity, especially near the poles. The IGS very much helped to get GLONASS recognised and included on various campaigns causing groups to expand their interests and accept additional observation sets. However for Industry, GLONASS often represented a complication both with Time and Geodesy and other on very specific projects the value of its inclusion was not understood or realised.

What can we take from these two case studies? Firstly that Industry has a need and if the IGS has other priorities in developing it's Tracking Sites then a possible collaboration between both parties could offer a "win win" situation. More sites and better coverage for all. Collaboration with Industry should not be seen as a great betrayal of Scientific honour but a pragmatic acceptance that both can and must co-exist for future survival. As Industry develops new and more accurate, Real-Time, long-range decimetre accurate systems, coupled with general data capacity capability, the demand for real time services will increase. The price that the Customer is prepared to pay will not rise. Good Customer Service levels must also be provided and for the IGS to compete in this area, investment will be required but perhaps a greater price to be paid will be the need to hold formal contracts. Without that crucial element, many Industry Customers will avoid depending upon the IGS and opt for an alternative because of the liabilities and commitment.

6. Conclusion

The IGS has a clear role to continue to monitor & update the reference co-ordinates and to aid research on the atmosphere. To avoid the arrival of a competitor for it's various data sets and products it should look at two possible sources of security. Firstly it must review and again consider it's ownership and how it reports into the rest of the world. As a United Nations organisation it could be adversely affected by administration. Better to feed up into an umbrella organisation such as the World Meteorological Organisation, or another with direct UN authority.

The introduction of the new Galileo system will impact the IGS by creating a possible competitor, especially in the Real Time activities and if the IGS continues without a clear strategy and an ability to hold formal service level contracts. By collaboration with Industry, some duplication could be avoided, new reference Sites could get supported and the core academic research could continue. Of course Galileo would also have to be a collaborator.

The IGS is a supplier of robust data products and is respected globally. The above potential threats and opportunities can be mitigated by careful planning and management and, with some limited developments, the IGS can remove most of the pressure to compete. A clear area that the IGS can enhance it's influence and authority is in Training. The User community needs a "one stop shop" for all manners of GPS, geodetic, satellite and related information. The IGS can provide this by developing a single point of contact for the Geosciences User community.

The IGS and the Education of the Next Generation of Users

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Education/to educate:
"… the imparting and acquiring of knowledge through teaching and learning …"

"… systematic instruction or training for a particular calling, practice, etc. …"

"… the development of knowledge, skill, ability, or character by training, study or experience …"

1. Introduction

Education is an issue that concerns every one of us. That may sound trite coming from a professor at a university. But no, I mean it. All sorts of organisations are focussing on this issue: major businesses, associations (including voluntary ones), and even NGOs. Scientific and professional associations have also increasingly been concerned with "education" (and its closely-related cousin: "outreach"). This paper will focus on the situation within one of the services of the International Association of Geodesy (IAG): the International GPS Service (IGS).

It wasn't so long ago that scientific associations, and especially ones with an international membership or focus as in the case of the IAG/IGS, were concerned only with the *generation* of knowledge, and *"reporting"* (some believe that this is a form of "education") of the most recent scientific results at prestigious (exclusive? narrowly-themed?) conferences, and in high-impact ("high brow"? esoteric? obscure?) peer-reviewed publications. So what has changed? Such associations in the past were never concerned with the education of "peers" by their peer. *Perhaps there is a recognition that the audience, or the "consumers" of the products and services of scientific and professional associations has changed (or should change)?*

Whatever the formal definition of "education" may be, I believe it is an activity that is directed to (and for the benefit of) *the next generation of researchers, the wider community of users, and even society in general*.

Although professional organisations such as Institutes/Associations of engineers, navigators, geographers, etc., have long had programs of education, or "professional development" as it is often referred to, more recently the broader goals of "education" have also become incorporated into their business strategies or mission statements. But as education has traditionally been the role of "educators" (taken to mean principally those *researchers* working within tertiary *education* institutions such as universities), this does raise some issues. For example, where does "advanced training" fit? Who educates the critical users on how best to apply the latest knowledge in their field? In the context of the IGS, the users need to "apply" the methodologies of GPS Geodesy, through the correct use of high precision IGS products.

Another example is explicit "K-12" education. Is it truly education in the classical sense, or "outreach", or "marketing", or even just a grab for attention of the next generation of users, researchers, and (most importantly) politicians/community leaders? It seems that "education" is sometimes viewed as a tool for gaining "market share". But which "market"? Maybe it is the finite attention span of prospective students and critical constituencies? We want people to make the right "choice" (that is, to choose our expertise, our products/services, our scientific discipline, our university programme, etc.), therefore we must first "educate" the consumers. And the younger we start the better!

So, the questions need to be asked. How broad is our view of "education"? What are the objectives of discipline/association-specific education? What are the delivery modes for such education? Who is the "educator"? How central is the "education function" vis-à-vis the primary mission of a scientific/professional association?

In this paper I do not propose to explore such broader themes, but rather look at the IGS, its mission/vision, and strategies to achieve its goals; past educational activities (or lack of them); and explore some options for future educational and outreach activities. However, it is difficult to avoid not placing IGS-relevant education in the wider context.

2. GPS Geodesy, the IGS and Education: "The Good Old Days"

The beginning of the 1980s saw the first civilian innovations and applications of the Global Positioning System (GPS) technology -- in the form of the development of carrier phase-based techniques first for the establishment of geodetic networks and later, as the precision and reliability of GPS improved, the addition of GPS to the space geodesist's toolkit. The 1980s were therefore the dawn of "GPS Geodesy", and by the end of the decade GPS had revolutionised the *operations* of geodetic surveying and *geoscience* of regional geodynamics. It was in this heady era of GPS Geodesy that we saw the first proposals for the establishment of permanent, continuously operating GPS reference stations which ultimately led to the setting up in 1994, by the International Association of Geodesy, of the International GPS Service (Beutler, 2004).

It is worth noting that the original acronym for the IGS was the "International GPS Service for Geodynamics", identifying clearly the first intended users of such a service. In fact, according to Ibid (2004) *"the primary motivation in planning the IGS was the recognition in 1989 that the most demanding users of the GPS satellites, the geophysical community, were purchasing receivers in exceedingly large numbers and using them as more or less black boxes, using software packages which they did not completely understand…. The other motivation was the generation of precise ephemerides for the satellites together with by-products such as Earth orientation parameters and GPS clock information.".* It is also clear from this quote that the IGS was intended to service the most demanding of civilian GPS users at the time, the geoscientists. They did this (and continue to do so very successfully) by generating *products* that would support their precise positioning application.

However, that was only part of the story. The IGS (through its component parts) also developed a body of "GPS Geodesy" *methodology*. Furthermore, in addition to servicing the researchers within the geosciences, the IGS (through its provision of a set of high quality products) played an invaluable role supporting national geodetic agencies in their tasks to establish modern, geocentric reference frames for surveying and mapping. The IGS infrastructure of permanent GPS tracking stations, the precise ephemerides and tracking station coordinates, and the "recipes" for the correct operation of sophisticated "scientific GPS software", all have contributed in making GPS now the premier space geodesy technique for almost all operational and fundamental geodetic research applications.

Hence from the beginning the IGS was addressing the needs of two classes of users: the operational geodetic surveyors and the geoscientists. *So how were these users "educated" in the correct use of IGS products?* Although a generalisation, it is fair to say that the majority of geoscientists became GPS Geodesy experts as a by-product of university-based research. During the 1990s a large number of graduate students gained their PhDs by "doing GPS Geodesy" projects. That is, it was essentially a *self-education process*, where graduate students and their supervisors "learned by doing". Data gathering campaigns were organised, and such data were the ingredients of this graduate-level/expert user "education". Yes, their experiences (and knowledge) were shared with others through publications and conference presentations. Also at this time many national geodetic agencies (especially from developing countries) sent selected officers to universities around the world, where they too gained a "GPS Geodesy education" as PhD students.

In the beginning the IGS did not explicitly mention the word "education" in its mission statement. The primary mission of the IGS is (IGSCB, 2004): *"to provide a service to support, through GPS data products, geodetic and geophysical research activities. Cognizant of the immense growth in GPS applications the secondary objective of the IGS is to support a broad spectrum of operational activities performed by governmental or selected commercial organizations. The service also develops the necessary standards/specifications and encourages international adherence to its conventions."* But, as hinted above, there was an education process, and many of the people who were identified with the IGS (leading academics and researchers) did contribute to educational initiatives.

The primary educational initiatives were specially organised workshops intended to impart some knowledge of the precise "GPS Geodesy" techniques that were applicable for a particular scenario. Hence there were workshops on geodetic network establishment, on how to use GPS for geodynamics, for long-range precise GPS positioning, and so on. And some that tried to address all geodetic applications. It is not possible for me to do justice to all the "GPS Geodesy" educational initiatives that were undertaken, but I will refer to two in order to contrast these with the current *lack* of similar activity.

The 1st International School "GPS for Geodesy", was held 26 March-1 April 1995, in Delft, The Netherlands. A veritable "who's who" of geodesists gave lectures that distilled the collective knowledge of "GPS Geodesy", and indirectly drew attention to the important work of the IGS. The 2nd International School was held 2-8 March 1997. Since then nothing! The concrete outcome of these workshops were the collection of lectures published as Teunissen & Kleusberg (1998), a textbook for "GPS Geodesy". The tragedy is that this book is no longer available from the online bookstore Amazon.Com! Is there a more recent text or reference book? As far as I am aware, there is none. All of the recent GPS books emphasise applications such as surveying and navigation, and although have the obligatory chapter dealing with the International Terrestrial Reference System (ITRS) and datums, and mention the IGS, none builds on the network-centric techniques first described in Ibid (1998), and since refined even further by the IGS community.

The second example of an educational initiative firmly focussed on "GPS Geodesy" is one in which I played a part as co-organiser and lecturer: the "Tropical School of Geodesy", the first of which was held 18-29 October 1993 in Bandung, Indonesia. This workshop covered all geodesy topics, including GPS, and was intended for geodetic surveying practitioners in developing countries. The lecturers intended that the workshop would promote the use of modern geodetic techniques. The second School was held 4-16 November 1996, also in Bandung. No further Schools have been held. What happened? Did we just tire of the task? Did we not get as many "kicks" from teaching as before? Or did we believe that it was no longer necessary, that the user was educated enough? Speaking for myself, I favour the last explanation. What if this is a universal attitude? Have the early educators of the 1980s and 1990s just scaled back such initiatives? Does a new generation need to step forward?

It is more complex than just passing the education role to a new generation of academics and researchers. The target user community has also changed, and the stakes in *not* investing effort into education are now as high (or perhaps higher) than they were in the past. *So perhaps the IGS has to (finally) take a more central role in education*.

According to the new mission statement (IGS, 2002), *"The IGS is committed to providing the highest quality data and products as the standard for GNSS in support of Earth science research, multidisciplinary applications, and education. These activities aim to advance scientific understanding of the Earth system components and their interactions, as well as to facilitate other applications benefiting society."* The word "education" has now appeared!

3. Should the IGS Be Concerned About Education?

The development of the IGS Strategic Plan 2002-2007 (IGS, 2002) was the catalyst for the change of the Mission Statement. Three of the six identified long-term goals and objectives of the IGS are relevant to this discussion:

1. *Promote universal acceptance of IGS products & conventions as the world standard.*
2. *Continuously innovate by attracting leading-edge expertise & pursuing challenging projects & ideas.*
3. *Seek and implement new growth opportunities while responding to new user needs.*

The first goal clearly would involve the "education" of all users that might benefit from IGS products. Such users are now clearly a wider community than the geodesists/geoscientists of the 1980s and 1990s. The second goal involves more "outreach" than education, however we need not make such a distinction here as the aim is to reach out to the non-traditional user and to engage them in new projects and ideas. Finally, the third goal refers to "new user needs". In summary, these updated IGS goals and objectives relate, explicitly or implicitly, to a future "new" user community. By implication, a community that is not currently aware of the IGS and its products/services, and hence a user group (or groups) that is (are) outside the traditional "GPS Geodesy" community.

If we follow this "educating the new user" theme further, we note in the IGS Strategic Plan (Ibid, 2002) that the first strategy is to: *Ensure delivery of "world-standard" GPS (& other GNSS) data & products, providing the standards & specifications globally.* Three methods to fulfill this strategy were identified -- they speak for themselves:

1. Maintain & improve accurate, robust and reliable GPS/GNSS data, products, …
2. Promote IGS data, methods & products to current & potential users as a "world" standard, and broaden the IGS user community into other areas.
    - *Develop broader outreach & education.*
    - *Devote attention to user needs & interfaces…*
    - *Build partnerships – interdisciplinary, suppliers, commercial, intergovernmental, & sponsorships.*
    - *Expand participation.*
3. Attract leading-edge talent for continuous innovation.
    - *Embrace new & innovative project proposals.*
    - *Publicize IGS involvement in novel science, pilot projects, working groups, & other challenging activities.*

While it may be possible to differentiate user "education", "outreach" and "engagement", let me not split-hairs. Each of these warrants attention (energy, money, commitment, etc.) that is in addition to that focussed on the primary mission of the IGS, the generation of high quality products and services.

Can the IGS take on such new activities? Who is the target community? What is at stake if it is not done? There are no obvious and/or simple answers, and that is one of the stark lessons to be learned. However, the following *personal* observations can be made:

- There has been little IGS "badging" of education activities in the past.
- Traditional IGS user communities (geodesists and geoscientists), although they are in the best position to adopt new products and services, still need "GPS Geodesy" education.
- New user communities (navigation, engineering, telematics, non-positioning, etc.) is largely ignorant of the IGS, and needs "educating" (in the widest sense).
- There are a variety of ways to address training/education needs, through short courses, symposia, books, etc.
- If the IGS does not embrace new users (through "education" or "outreach"), new products and services may be developed with formal IGS involvement.
- A Global Navigation Satellite System (GNSS) such as GPS is but an enabling technology, and many users do not have an appreciation of the fundamentals of reference frames, etc., nor of the performance constraints due to biases and errors.
- There are other (rival?) organisations apart from the IGS working on developing "standards & specifications" related to GPS products.
- There are many professional or scientific associations, agencies, and even commercial organisations, that have initiated educational activities associated with GPS technology and applications.
- The IAG has recently established an Outreach Branch (IAG, 2004), which has as one of its objectives "education" and "outreach".
- There are many sister organisations or forums by which the IGS can reach new and old user communities, e.g. through Institute of Navigation, the F.I.G., the U.N. agencies, the C.G.S.I.C., and so on.
- There is (so far) a disturbing lack of interest in raising the profile of the IGS through greater levels of advocacy (even for its traditional user communities) at forums to influence the signal definition for next generation GNSSs, such as Galileo and GPS-III.

Is the IGS ready?

4. What Could Be Done? Some Final Remarks

If the IGS is to take "education" seriously then it should convene a workshop or Working Group to explore strategies and options for "user education", in an analogous procedure followed when a new IGS product or service is proposed. Education should therefore be taken seriously, and not attempted in a half-hearted fashion.

Here are some actions to consider. An educational initiative that is the least risky is to resurrect the "GPS for Geodesy" workshops. Admittedly these address only the IGS's traditional user communities, but they have been neglected during the last half decade or so. Updated materials are required. Of course what has to be determined are the operational issues of running workshops, the "who, where, when, etc.". However, such workshops are surely within the means and expertise of the IGS.

Experience gained in organising and running such workshops would be invaluable if/when the IGS chooses to expand its educational activities beyond this traditional user market.

What about the other user communities? One option would be to partner other organisations that already are active in such communities. For example, team with the F.I.G. to address the education needs of surveyors and engineers for new GNSS techniques, network-RTK, CORS networks, 3D and 4D reference frames, etc. Another example is partnerships with Institutes of Navigation, to educate professional navigators in the use of mixed GPS/GNSS, real-time carrier phase-based positioning, WADGPS, SBAS/GBAS, and so on. Or with the IEEE to educate telematics system developers on reference frames, GNSS trends, CORS and A-GPS techniques, multi-sensor systems, etc.

I would like to conclude this paper with one final comment, if the IGS decides that "education" *is* an important function, *on par* with research activities and geodetic operations, *should there be an appropriate "IGS component" established?*

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Kinematics of deformation in the Tibetan Plateau and its margins constrained by GPS measurements

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Abstract

As the most prominent example of large-scale continental deformation, Tibetan Plateau offers an ideal natural laboratory for quantifying such deformation and understanding the relevant dynamic processes. GPS provides a powerful means to directly measure the kinematics of present-day deformation. Our synthesis of GPS velocities from 553 stations in Tibetan Plateau and its margins quantitatively show that most of the relative India/Eurasia motion has been accommodated primarily by crustal shortening along the margins, strike-slip and normal faulting in the plateau interior, and clockwise rotation around the eastern end of Himalaya. The eastward extrusion of Tibetan Plateau out of India's northward pass is carried out by roughly eastward flow of crustal material rather than by rigid block rotation. To the east, the eastward flow of crustal material causes shortening across the eastern margin of the plateau and clockwise rotations where resistance to such flow may be weak. The present-day tectonics in the Tibetan Plateau is best described as deformation of a continuous medium, at least when averaged over distances of ~100 km.

Introduction

The Tibetan Plateau, the world's largest and highest plateau, has been growing and evolving since the collision and subsequent penetration of the India with Eurasia 50 million years ago (Molnar and Tapponnier, 1975; Rowley, 1996). How the Tibetan Plateau deforms in response to the collision, however, remains enigmatic and subject to debate, with rigid plates or blocks, continuous deformation of the entire lithosphere, and flow in the lower crust providing keys to its understanding (Tapponnier et al., 1982, 2001; England and Houseman, 1986; Molnar et al., 1993; England and Molnar, 1997; Royden et al., 1997; Holt et al., 2000; Flesch et al., 2001). Unfortunately, much of the region is remote, and a complete kinematic description of deformation over the entire Tibetan Plateau has not been available until recently. Dynamic models intended to explain deformation of the Tibetan Plateau need to be tested in terms of kinematics. Global Positioning System (GPS), developed in last decade with the successful operation of International GPS Service (IGS), provides a powerful means to directly measure the kinematic pattern of present-day crustal deformation in remote and large-scaled region like the Tibet (Chen et al., 2001; Wang et al., 2001; Chen et al., 2003; Calais et al., 2003; Zhang et al., 2004). We, in this paper, synthesis GPS studies in the Tibetan Plateau and its margins (Paul et al., 2001; Wang et al., 2001; Banerjee and Burgmann, 2002) to show in which ways the collision between India and Eurasia is accommodated and to shed new insights into the dynamics of its contemporary tectonic deformation. We designate this paper to the decadal anniversary of IGS for its excellent service to the researches of geodynamics.

Data and data process

Significant advancement for the monitoring of crustal deformation in the Tibet Plateau was accomplished in 1998 when the Crustal Motion Observation Network of China (CMONOC) was established. The principal data used for this study come from the CMONOC collected during 1998 and 2002, including 25 continuous stations, 56 annually observed stations with an occupation of at least 7 days (~168 hours' data collection) in each survey, and 961 regional stations observed in 1999 and 2001 with an occupation of at least 3 days (~72 hours' data collection) in each survey.

The data were processed in four steps (Shen et al., 2000, 2001). First, we put the observation data together to solve for the daily loosely-constrained station coordinates and satellite orbits using the

GAMIT software (King and Bock, 1995). Second, we combined the regional daily solution with the loosely constrained global solutions of ~80 IGS tracking stations produced at the Scripps Orbital and Position Analysis Center (Bock et al., 1997) using the GLOBK software (Herring, 1995). The merged daily solution includes the loosely constrained station coordinates, polar motion and satellite orbit parameters, and the variance-covariances matrix. Third, we estimated station positions and velocities in the ITRF2000 reference frame using the QOCA software (Dong et al., 1998). The QOCA modeling of the data was done through sequential Kalman filtering, allowing adjustment for global translation and rotation of each daily solution. In the last step, we transformed the velocity solution to a Eurasia-fixed reference frame using the angular velocity of Eurasia with respect to the ITRF deduced from 11 IGS stations (NYAL, ONSA, HERS, WSRT, KOSG, WTZR, VILL, GLSV, IRKT, TIXI) in the stable Eurasia plate [Shen et al., 2000; 2001].

Besides the CMONOC data, we collected three additional data sets of station velocities from Paul et al. [2001], Wang et al. [2001], and Banerjee and Burgmann (2002) to increase the coverage and station density of the India, Himalayan and central Tibetan regions. Paul et al. (2001)' s velocity data (13 stations in India and the Himalaya) are in an India-fixed reference frame, whereas Wang et al. (2001)'s velocity data (41 stations distributed in India, the Himalaya, and central Tibet) and Banerjee and Burgmann' (2002)'s (24 stations in the western Himalaya) are in a Eurasia-fixed reference frame, which differs slightly from the above Eurasia-fixed reference frame we employed. As each of the additional velocity data sets has some common stations with the CMONOC data set, we chose common stations for the three data sets, to transform them to the Eurasia-fixed reference frame of the CMONOC data set, by minimizing the velocity differences of the common stations in the corresponding reference frames. After the transformation, the maximum difference of the velocities for each common station in different data sets is less than 2.9 mm/yr and 2.6 mm/yr for the east and north components, respectively, which are within the 2 standard deviations of the velocity components. Thus, we calculated the weighted average of the velocity components for the common stations and estimated their standard deviations. We finally obtain velocities for 553 stations in the Tibetan Plateau and its margins, that provide adequate coverage to interpret the magnitude and style of deformation despite of void areas in northwestern corner of the plateau (Fig. 1).

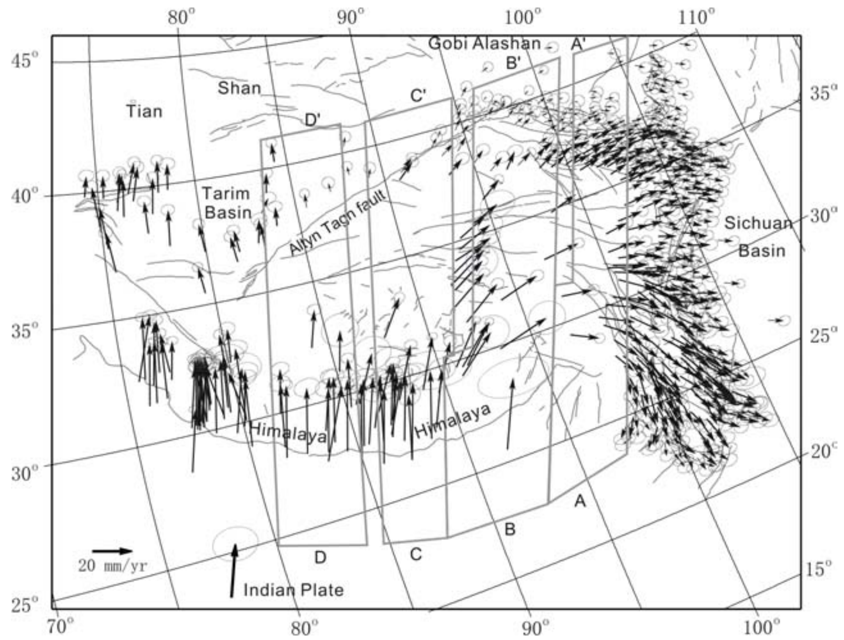

Figure 1. GPS velocity vectors (mm/yr) in the Tibetan Plateau and its margin with respect to the stable Eurasia, The ellipses denote the region of 1-sigma error. The polygons show locations of the profiles, and GPS stations covered by each profile.

Shortenings across the Tibetan Plateau and its margins

The Tibetan Plateau and its margins, including the Himalaya, the Altyn Tagh and the Qilian Shan, undergo substantial shortening. We draw four profiles (A-A', B-B', C-C' and D-D') across the plateau along the N20°E direction, the inferred India-Eurasia convergence direction (Sella et al., 2002), to calculate the shortening across different parts of the plateau. The total shortenings between India and Tarim in this direction are 28±2.5, 33±2.0, and 34±3.0 mm/yr along profiles D-D', C-C' and B-B' respectively (Fig. 2). The shortening seems to be slightly larger than 34±4.0 mm/yr, if the Shilong Hill is regarded as part of the Himalaya, between the India and Gobi Alashan along profile A-A' (Figs. 1&2). Taking 36-40 mm/yr as total relative motion between India and Eurasia, the eastern Tibetan Plateau and its margins (Profiles A-A' and B-B') accommodates 85-94% of the total motion, whereas western Tibet (Profiles C-C' and D-D') absorbs 70-91% of total convergence and the rests are taken up by shortening across the Tianshan in the north (Abdrakhmatov et al. 1996; Reigber et al., 2001).

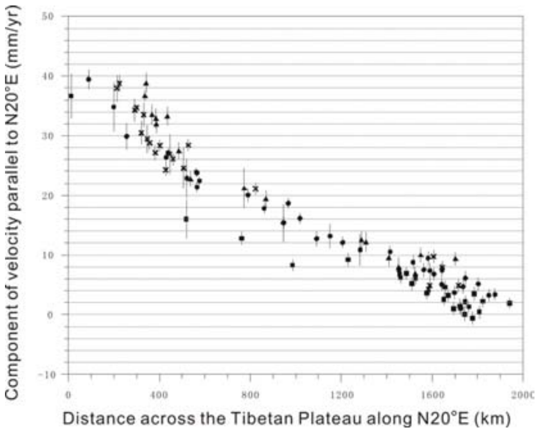

Figure 2. Velocity components parallel to N20ºE vs. distance in km along each of 4 profiles in Fig. 1. Squares, diamonds, crosses and triangles show profile A-A', B-B', C-C' and D-D' respectively.

Partitions of the shortenings in the Himalaya, the northern margin, and the plateau interior

The N20ºE convergence across the western Himalaya is 16±2.5 mm/yr along profile D-D' (80°-84°E), slightly less but approximating previous geological (Lavé and Avouac, 2001) and geodetic (Bilham et al., 1996; Larson et al., 1999; Paul et al., 2001; Banerjee and Bürgmann, 2002) findings. To the east, the shortening rates across the Himalaya are 15±3.0 and 14±3.0 mm/yr along profiles C-C' and B-B' respectively (Fig. 2). The shortening along profile A-A' is not well constrained because of the poor station coverage and the influence by rotation of crustal material around the eastern Himalaya syntaxis (Fig. 1). We estimate 15-20 mm/yr shortening rate across the Himalaya along profile A-A'.

The northern margin of Tibet absorbs only slow convergence: 5.3 ± 1.0 and 6.2 ± 1.5 mm/yr parallel to N20°E on profiles C-C' and B-B' (Figs. 2 and 3), which includes left-lateral strike slip at 5.6 ± 1.6 and 5.0 ± 2.0 mm/yr parallel to the Altyn Tagh fault and 2.9 ± 1.8 and 3.2 ± 1.5 mm/yr of convergence perpendicular to the margin of Tibet (Fig. 3). These strike-slip and convergence rates along the eastern third of the northern plateau margin (profiles B-B' and C-C') are consistent with geological (Working Group on the Altyn Tagh fault, 1993) and other geodetic (Bendick et al., 2000; Wang et al., 2001; Shen et al., 2001) results. Shortening occurs at 6.0 ± 1.5 and 5.5 ± 1.8 mm/yr across the northeastern edge of the Tibetan Plateau perpendicular to the western and eastern Qilian Shan respectively (Fig. 3).

The amounts of shortening must be accommodated by the plateau interior are 11.3±5.0, 14±3.0, 12.7±3.0, and 10±3.0 mm/yr along profile A-A', B-B', C-C', and D-D' respectively (Figs. 2and 3). These velocity profiles show general feature of linear gradients except profile A-A' that may be significantly affected by rotations around the eastern Himalaya syntaxis (Figs. 1 & 3). However, views on how the shortening in the plateau interior is accommodated are still diverse, with the rigid block extrusion (Armijo et al., 1989; Avouac and Tapponnier, 1993), eastward transfer of crustal material (Le Dain et al., 1984; Molnar and Lyon-cean, 1989; Royden et al., 1997); localized deformation (Tapponnier et al., 2001), broadly distributed shortening (Houseman and England, 1993; Wang et al., 2001), and others. The apparent linear gradients of velocity profiles (Fig. 2) preclude the rigid block extrusion because the gradients imply internal deformation of the plateau interior. The linear gradients neither support the localized deformation for otherwise there would be significant deviations from the linear trends. Although broadly distributed shortening may cause linear velocity gradient (Wang et al., 2001), the absences of active thrust faults (Armijo et al., 1989; Kidd and Molnar, 1988) and thrust-faulting earthquakes (Molnar and Lyon-cean, 1989) within the plateau interior nevertheless attest that uniform shortening is not on going process. Our GPS data suggest that eastward transfer of crustal material accommodates the convergence in the plateau interior.

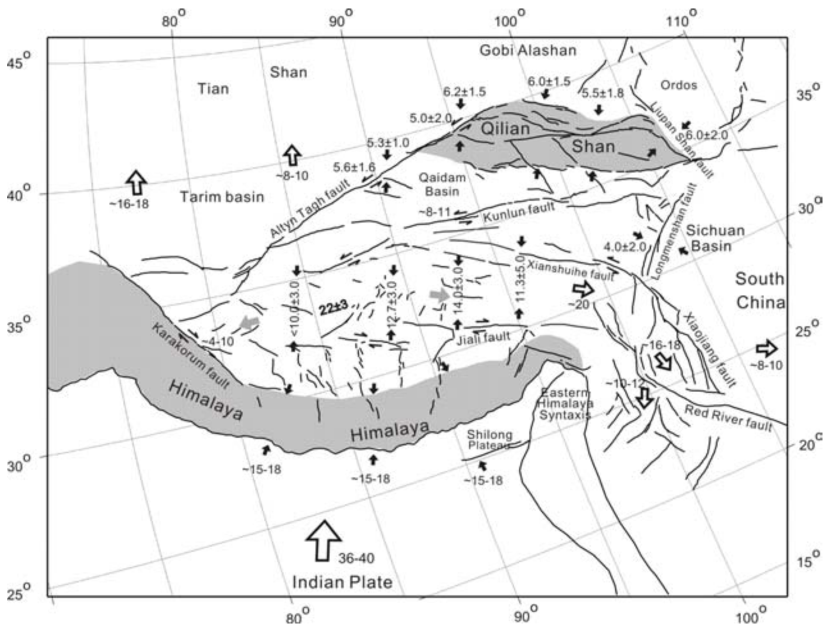

Figure 3 Kinematic pattern of present-day deformation from GPS data. Black thick lines are active faults. Solid black arrows are crustal shortening, nearby numbers are their shortening rates. Double arrows on opposite sides of faults indicate strike-slip faults, numbers nearby are slip rates. Gray arrows inside Tibetan Plateau denote extension in the plateau interior, number between them is rate of extension. Hollow arrows indicate relative motions relative to stale part of Eurasian plate, numbers nearby are velocities.

Strike-slip, extension, and eastward flow of crustal material in the plateau interior

The NNE-SSW shortening of the plateau interior is accommodated by conjugate strike-slip faulting and orthogonal normal faulting, which do not require that crustal thickening or thrust faulting occur. Neither field investigations (Kidd and Molnar, 1988; Armijo et al., 1989) nor fault plane solutions of earthquakes (Molnar and Lyon-caen, 1988) reveals evidence for active thrust faulting. Instead, they, like recent field evidence (Taylor et al., 2003), show ESE-WNW extension, which occurs by both normal faulting and conjugate strike-slip faulting. A sum of seismic moment tensors for earthquakes within northern and central Tibet suggests that ESE-WNW extensional straining dominates deformation of the plateau interior, with approximately half of that straining accommodated by strike-slip faulting (NE-trending left-lateral and NW-trending right-lateral) and half by normal faulting (Molnar and Lyon-caen, 1988). Our GPS data concur with this pattern of strain partitioning. Components of velocity parallel to N110ºE at stations in the interior of the plateau increase eastward to yield eastward stretching of 21.6 ± 2.5 mm/yr between longitudes 79°E and 93°E (Fig. 3), which is roughly twice the N20ºE convergence rate across the plateau interior of 10-14 mm/yr (Zhang et al., 2004). Simple calculations of strain rate using the velocities of 17 stations located within the plateau interior indicate that the average N20ºE contraction strain rates range from (-1.3 ± 0.4) x 10^{-8} to (-1.8 ± 0.4) x 10^{-8} yr^{-1}, and the average orthogonal extensional strain rate is (2.1 ± 0.3) x 10^{-8} yr^{-1}.

The straining associated with the eastward transfer of crustal material can be illustrated by lateral movements orthogonal to the inferred India/Eurasia motion (Fig. 4). Lateral motions along profile A-A' and B-B' in the eastern Tibet increase steadily northward from the Himalayan across the breadth of southern Tibet and then decrease further north across the broad northeastern Tibetan Plateau into the stable Gobi Alashan region (Fig. 4). The fastest east-southeastward motion occurs at latitudes of 31°N -33°N and 33°N-35°N along profiles A-A' and B-B' respectively. The core of rapid eastward flow of crustal material in the central plateau is bounded by two shear zones, several hundred kilometers wide: right-lateral in the southern Tibetan plateau and left-lateral in central and northern Tibetan Plateau (Fig. 4). In profile A-A', the right-lateral shear clearly exists, but is difficult to calculate due to lack of stations. The left-lateral shear is 7.3±1.5 mm/yr in the northern plateau interior. In profile B-B', the right-lateral shear is 13±2.0 mm/yr and the left-lateral shear is 10±1.5 mm/yr. These right-lateral and left-lateral shears are accommodated by distributed faults with right-lateral strike-slip in the southern plateau (Armijo et al., 1989; Institute of Geology, 1993) and with left-lateral slip in the northern plateau respectively (Kidd and Molnar, 1988; Institute of Geology, 1993).

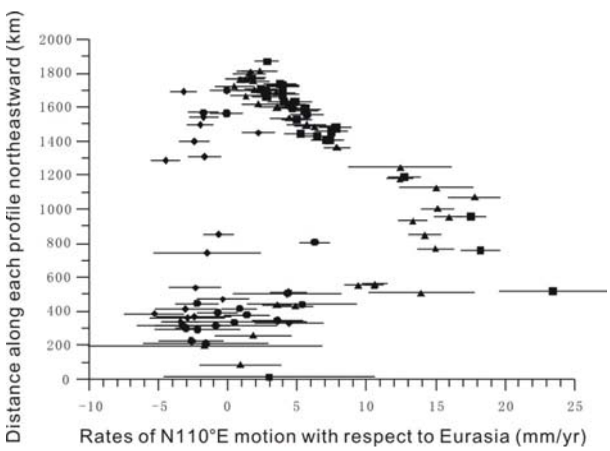

Figure 4. Velocity components normal to N20°E, the inferred India/Eurasia relative motion. Squares, triangles, dots and diamonds show profile A-A', B-B', C-C' and D-D' respectively.

The flow of Tibetan crustal material rotates around the eastern Himalaya syntaxis, causing southeastward to southward and even southwestward velocities observed in southern and western Yunnan province of China (Fig. 1). In addition to the rotation around the Eastern Himalayan Syntaxis reported previously (Le Dain et al., 1984; Molnar and Lyon-Caen, 1989; Holt et al., 1995; King et al., 1997; Royden et al., 1997; Wang et al., 2001), our data show that clockwise rotation involves the entire eastern part of the Tibetan Plateau. This kind rotation fundamentally differs from the rigid block rotation successfully describing plate motion, because for rigid-body movement, rates increase away form the rotation axis, and this seems opposite from velocity field in Fig. 1. Instead it probably relates to the eastward flow of crustal material away from internal parts of the plateau in response to the northward movement of India and southern Tibet with respect to southeastern China (Le Dain et al., 1984; Molnar and Lyon-Caen, 1989; King et al., 1997; Royden et al., 1997; Wang et al., 2001).

Eastward shortening in the eastern margin

Eastward transfer of crustal material from the plateau interior also implies roughly eastward shortening along its eastern margin (Fig. 3). The northern segment of the eastern margin is the

N15°W-trending Liupan Shan that also forms the eastern end of the northeastern margin of the plateau, where folding and thrust faulting take place (Zhang et al., 1991). A velocity profile perpendicular to the Liupan Shan indicates 7±2 mm/yr shortening in the direction of N75°E (Zhang et al., 2004). The central segment, the Longmen Shan with a sharp geomorphic expression of the plateau margin, trends N32°E. King et al. (1997) and Chen et al. (2001) show absence of convergence across it. Wang et al. (2001) find 5 to 11 mm/yr velocity difference across the Longmen Shan, but interpret it has being accommodated by clockwise rotation around the eastern Himalaya syntaxis. Our velocity profile orthogonal to the Longmen Shan gives a 4±2 mm/yr velocity difference in N122°E direction which we think has been absorbed by shortening along the margin itself (Zhang et al., 2004). The southern segment of eastern margin of the plateau is the Sichuan-Yunnan region where the Tibetan Plateau gradually grades into South China without obvious topographic boundary (Zhang et al., 2004). We draw an east-west profile across this segment. The velocity profile shows 7.5±3.0 mm/yr east-west shortening (Zhang et al., 2004). It seems that the shortening across the eastern margin of Tibetan Plateau and clockwise rotation together absorb the eastward flow of crustal material from the plateau interior.

Westward motion in the western margin

The N20°E shortening ranges from 19 to 23 mm/yr or 21±4.0 mm/yr across the western margin of the Tibetan Plateau (Fig. 1). Most of the shortening, however is taken up by the western Himalaya, whereas the interior of Tibetan Plateau only absorbs 4±1 mm/yr. The lateral motions orthogonal to the inferred India/Eurasia motion also show steady increases northward across the Himalaya to the Tarim, but the direction of motion is westward as noted by Banerjee and Burgmann (2002) rather than eastward in the eastern Tibetan Plateau.

The Karakoum fault contributes to westward motion of the western margin of Tibetan Plateau. But the right-lateral slip rate on the fault is not well constrained with 32±8 mm/yr (Avouac and Tapponnier, 1993), 11±4 mm/yr (Banerjee and Burgmann, 2001), ~10 mm/yr (England and Molnar, 1997; Holt et al., 2000), ~6 mm/yr (Murphy et al., 2000), and 4±1 mm/y (Brown et al., 2002). Our GPS measurements indicate that the velocity difference parallel to the fault is only ~4mm/yr across the northern segment. This rate agrees well with geological study by Brown et al. (2002). Further to the south, we estimate 4 to 8 mm/yr or 6±2 mm/yr right-lateral slip rate across the southern segment of karakorum fault. Together with recent determined lower slip rate along the Altyn Tagh (Bendick et al., 2000; Shen et al., 2001; Wang et al., 2001) and lower speed of westward motion of the western Tibetan Plateau, we think our rates on the Karakorum fault fit well in the kinematic system of present day deformation in the Tibetan Plateau and its margins.

Rigid-block like versus viscous-fluid like deformation

How the Tibetan Plateau deforms in response to the collision is subject to debate, with two end-member views of rigid plate-like (Tapponnier et al., 2001) and viscous fluid-like (Houseman and England, 1993) deformation of the lithosphere offering keys to its understanding. The GPS constraints on the kinematics of the Tibetan Plateau described above offer tests of plate-like and fluid-like descriptions of the kinematics (Fig. 4). As predicted by the fluid-like model (e.g. England and Houseman, 1986; Houseman and England, 1993; Holt et al., 2000), the N20°E convergence across the Tibetan Plateau and its edges absorbs a large fraction (70-94%) of India's northward penetration.

Surface velocities across boundaries between rigid blocks should vary discontinuously compared with smooth variations in both rates and directions, if large rigid bodies are absent. If dimensions of blocks are as large as 300-500 km (or more), as some argue for Asia and given fault locking depths of 10-20 km, GPS measurements at control points spaced at distances of tens of kilometers can test whether such blocks exist or not. The 10-12 mm/yr of left-lateral shear are distributed over a ~400-km-wide zone spanning the Kunlun fault, a rate consistent with geologically inferred slip rates on that fault (Kidd and Molnar, 1988). Either interseismic locking to a large depth of > 25 km or a very low-viscosity lower crust (Zhang et al., 2004) would be required to assign all of this broadly distributed deformation to elastic strain associated with slip on the Kunlun fault alone. Moreover, other active faults have been mapped within the 400-km-wide deformation zone that might accommodate some of the measured deformation. In any case, because of the ESE-WNW extension in the region between the shear zones, they cannot bound two rigid blocks, but rather seem to mark zones of more concentrated shear than elsewhere along profiles A-A' and B-B'. Crustal shortening across the Qilain Shan distributes in a zone of about 300~350 km width (Zhang et al., 2004). Across Liupan Shan, the northeastern margin, velocities gradually decrease across about 300 km wide zone (Zhang et al., 2004). In the eastern margin across the Longmen Shan, the about 4 mm/yr shortening forms approximate 200 km belt (Zhang et al., 2004). All of these cannot be matched by slips along a particular fault giving a reasonable locking depth and viscosity at depth, and therefore reject the model of rigid block extrusion.

Conclusion

The kinematics of contemporary deformation of the Tibetan Plateau in response to India/Eurasia collision involves crustal shortening along the margins, normal and strike-slip faulting in the interior and clockwise rotation of crustal material in the eastern part of Himalaya. To the west, the westward motion of the western margin of the plateau is observed with only 4 mm/yr slip rate. To the east, the eastward flow of crustal material causes shortening across the eastern margin of the plateau and clockwise rotations where resistance to such flow may be weak. The present-day tectonics in the Tibetan Plateau is best described as deformation of a continuous medium, at least when averaged over distances of ~100 km.

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Summary of the IGS Symposium and Panel Discussion – 'Visions for the Future'

Bern Switzerland March 3, 2004

Over the past decade, the IGS has convened many technical workshops organized to generate recommendations that drive the evolution of the IGS. At this 10^{th} anniversary celebration, it was decided to include a symposium day devoted to broader influences of the IGS. The agenda for this day included key people critical to defining science, policy, and programmatic directions for GNSS as complimentary to the in-depth technical discussions throughout the rest of the week. This venue was also an opportunity for these people to have a better understanding of what the IGS is and 'who' comprises IGS, the many impressive people from hundreds of organizations that contribute to the IGS for the greater benefit of all. The theme for the IGS symposium had three focus areas:

Celebrate the history, development and accomplishments of the IGS over the last decade and how this has benefited Earth and Space Science, and multi-disciplinary applications.
Provide a view of the evolution and future of Global Navigation Satellite Systems (GNSS) over the next 10-20 years.
Explore the future of international cooperation, the envisioned uses of GNSS and the role of IGS.

The meeting hall at University of Bern was at full capacity when Prof. John Dow, current Chair of the IGS Governing Board, welcomed the audience and introduced the first speaker, Prof. Gerhard Beutler who has been active in IGS for many years. He chaired the IGS Oversight Committee from 1991- 1993, and then was elected the first Chair of the IGS Governing Board from 1994 through 1998. In 1994, Beutler was elected President of the International Association of Geodesy (IAG). His paper included in this section provides an excellent summary of the IGS and future directions. He is also the head of the Astronomical Institute of the University of Bern, the organization hosting the $IGS10^{th}$ anniversary meeting.

Prof. John Dow (ESA/ESOC) addressed the IGS Strategic Plan in the second talk, reviewing the aspects of the plan outlined in the document, *'IGS Strategic Plan 2002-2007'*[1], available from the Central Bureau. Dow's term as Chair began in 2003 and he has been assessing the progress of the IGS compared to the strategic plan. He is intent on updating the plan during his term and ensuring that the organization is achieving stated goals and objectives. His paper outlines the status to date and future plans.

Bjorn Engen (Norwegian Mapping Authority) gave an interesting and timely presentation on the relation between the IGS and national mapping agencies. It was co-authored by Norman Beck of the Natural Resources of Canada and touches on the global infrastructure afforded by the IGS and the increasing necessity of understanding policies and national priorities to sustain or expand geodetic activities, a topic that is generally challenging with many groups facing diminishing resources.

The next four presentations focused on how the IGS and GNSS has fostered and supported scientific research and applications. Dr. Andrea Donnellan (JPL) represented Dr. Ghassem Asrar, head of NASA Earth Science. Her presentation, included on the CD accompanying this proceedings, was visually stunning and summarized many points contained in NASA's Solid Earth Science Working Group report *"Living on a Restless Planet*[2]*."* Next, Dr. Robert Serafin (UCAR/NCAR) gave an excellent overview on

[1] *IGS Strategic Plan 2002-2007*, IGS Central Bureau, http://igscb.jpl.nasa.gov, see publications
[2] *Living on a Restless Planet*, NASA Solid Earth Science Working Group (SESWG) Report, October 2003, http://solidearth.jpl.nasa.gov/seswg.html

the use of GPS for atmospheric science and weather forecasting. He addressed space based occulation missions, which carry a GPS receiver on board the satellite, such as GPSMet, COSMIC, CHAMP; and observations for weather forecasting derived from ground based GPS stations such as demonstrated by NOAA's Forecast Systems Laboratory. Prof. Christoph Reigber's presentation on gravity and space missions, such as CHAMP and GRACE, provided a remarkable overview on what GPS has enabled for low Earth orbiter science missions[3]. Dr. Kosuke Heki (Director of Mizusawa Astrogeodynamics Observatory, Japan) provided a unique presentation on earthquakes and deformation that included humorous animations to portray the scientific aspects[4].[5]

The IGS is keenly interested in the developments of Global Navigation Satellite Systems (GNSS) and the next set of invited speakers were experts on the future developments, policies and plans for GPS, GLONASS and the future Galileo. Dave Turner, head of the secretariat office of the US Inter-Agency GPS Executive Board (IGEB) gave a very complete and detailed briefing on where GPS is headed. Jörn Tjaden, head of the Technical Division, Galileo Joint Undertaking described the process and policies of the new EU Galileo system, the new GNSS intended to be fully interoperable and compatible with GPS. He was followed by Steen Houg from ESA, France who represented Rene Osterlink, head of the ESA Navigation Department. Houg addressed technical aspects of the Galileo system and schedule. Sergey Revinivykh from Russian Mission Control described the plans for GLONASS, and recognized the IGS' incorporation of GLONASS observations and the pilot service within the IGS that produces the suite of classic products for GLONASS alongside GPS products (see Session 8 of these proceedings).

The day concluded with a session on international cooperation, education and outreach. Ken Hodgkins (US Department of State), who co-chairs the GNSS Action Team of the United Nations Office of Outer Space Affairs (UN-OOSA), gave an overview of the recent negotiations between the US and EU and prospects for reaching an agreement. He also summarized the progress of the GNSS Action Team highlighting its recent final report[6] and expressing thanks for the participation of the IGS/IAG in the working meetings. Gordon Johnston (private consultant) presented a compelling presentation on IGS relationship to industry. It is interesting to note that at one of the first IGS workshops, the *'1995 Special Topics and New Directions'*, he presented a paper on using IGS information[7]. His latest paper is included here and worthy of reflection. Prof. Chris Rizos (UNSW, Australia), one of the newest members of the IGS Governing Board, provided a unique perspective on IGS and education. He questioned if the IGS is ready to fully address the needs of education, the cultivation of user communities, and the next generation of geodesists and geoscientists. Dr. Peizhen Zhang (Institute of Geology, China Seismological Bureau) presented GPS activities in China and how this related to deformation studies in the Tibetan plateau. He showed the GPS infrastructure in China, a 25-station permanent, continuous, state-of-the-art network, the Crustal Motion Observation Network of China (CMONOC) and how the global IGS enables geodynamics research of this accuracy level. The final

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[3] *Christoph Reigber, Hermann Luehr, Peter Schwintzer and Jens Wickert (eds), Earth Observation with CHAMP - Results from Three Years in Orbit, Springer-Verlag Berlin Heidelberg New York, 628 pp., 2005. ISBN 3-540-22804-7*

[4] Heki, K., Dense GPS array as a new sensor of seasonal changes of surface loads, in "The State of the Planet", edited by S. Sparks, Geophys. Monograph, American Geophysical Union, in press.

[5] Heki, K., Secular, transient and seasonal crustal movements in Japan from a dense GPS array: implication for plate dynamics in convergent boundaries, in "Seismogenic Zone Volume of SEIZE Theoretical Institute", edited by T. Dixon, Columbia University Press, in press.

[6] United Nations Office of Outer Space Affairs Final Report of the Action Team on Global Navigations Satellite Systems, A/AC.105/C.1/L.274, Vienna, Austria, December 2003

[7] *Special Topics and New Directions, Workshop Proceedings, Potsdam Germany, May 1995*, available from the IGS Central Bureau, http://igscb.jpl.nasa.gov, see publications

speaker was Dr. Thomas Stansell who presented plans for the improved L1 signal and sought IGS feedback on this issue.

Panel Discussion Summary – 'Visions for the Future'

The final session of the day was an hour-long panel discussion moderated by Dr. Robert Serafin. He posed the following questions:

> *What is your vision for the future of GNSS and the breadth of its uses?*
> *How should IGS evolve in order to meet the operational and scientific challenges of the future?*

Panel members:

- Prof. Gerhard Beutler, University of Bern
- Prof. Geoff Blewitt, University of Nevada – Reno
- Prof. Dorota Brzezinska, Ohio Sate University
- Dr. Hans-Juergen Euler, Leica Geosystems AG, Switzerland
- Dr. John LaBrecque, NASA Solid Earth and Natural Hazards Program Manager
- Prof. Markus Rothacher, Technical University of Munich
- Dr. Hans Van der Marel, Delft University of Technology

Rothacher summarized his considerations noting that in a few years 80+ satellites will be available realizing a robust GNSS infrastructure of which the IGS is integral. The IGS as part of this global effort should strive to work at the level of the UN, i.e., recognized as an international entity. He expressed the vision that the Earth is a moving, breathing system that can be monitored with the 10,000+ sites located around the world. This speaks to needing real-time communications and data which will enable the detection of new signals, such as high density observations for tomography. He observed that to understand Earth's processes, one must encompass and integrate other techniques such as GNSS, VLBI, SLR, DORIS, altimetry, INSAR, gravity missions, and this will be most challenging in the coming years.

Van der Marel considered that GNSS will be broadly based in the future, data products will become very common and students will learn more about concepts than purely focusing on the techniques. Climate and weather will benefit from the dense networks and radiosondes will likely be replaced. Students do need to know how to discriminate however, and need to have a fundamental understanding of the observations and how they are generated. Galileo will be both difficult and exciting, and perhaps the IGS can assist in utilizing Galileo and extending the IGS standards.

Brzezinska felt that is was important to emphasize the desire for overlap between GPS and Galileo at L2. User equipment of the future will be a box that can simultaneously observe all GNSS satellites in view. She noted that the average user is not aware of the IGS or the excellent products. The IGS should evolve into a 'one-stop' shop, perhaps for even more than the global products.

Euler provided the view of industry for the panel stating that multi-system applications will be common with receivers observing multi-satellite GNSS simultaneously and with increasing complexity of receivers, algorithms, and analysis. These advances, combined with the availability of the internet everywhere, will spawn numerous applications. People want real-time accuracy at the mm level, demanding calibration and monitoring of the reference system with implied maintenance of standards. He sees the IGS quickly moving towards the provision of real-time services.

Blewitt noted that the evolution of the IGS to meet scientific needs of the future is key. IGS should ask itself, “What can we do differently to serve science?” Rather than just improving products from each, it will be critical to integrate all components of the GNSS constellations and to produce even better products from the integrated observations. How IGS evolves organizationally is also important, and noted that IGS is a very natural fit in the organizational concept of the Global Geodetic Observing System (GGOS)[8]. IGS should move towards integrating physical characteristics of different geophysical processes, such as sea level, solid Earth deformation and gravity.

LaBrecque commended the IGS on tremendous success and sees an IGS-like entity helpful and necessary in unifying space geodesy: GNSS/ VLBI/SLR/INSAR. The precision and balance of techniques will continue to improve and will be driven by the pressure of friendly competition. He noted that collocation of the techniques at a subset of fiducial sites is important so that all can refer to the same geodetic ‘benchmarks’. He expressed concern about the ability of IGS to sustain its activities since most tasks and organizations depend on under funded research programs in order to contribute to the IGS. The whole is clearly much more than the sum of its parts and each contribution is critically important. He also questioned how to sustain real-time operations in this environment and noted that integrity monitoring is clearly important now and in the future as GNSS evolves.

Beutler summarized key reasons for the success of IGS, and noted that the robustness stems from redundancy of all components, with the exception of the Central Bureau. IGS *really* understands its business, which leads to new users and applications. The IGS really exploits GNSS which further leads IGS into multi-disciplinary science. To date he notes that the IGS has not established a business entity, and thinks that IGS should perhaps attach itself to another established international organization, e.g., the UN Office of Outer Space Affairs. IGS must incorporate the new GNSS and he thought that the next ten years will be difficult; in the past, IGS activities have been integral to the research of various IGS contributors but there is now an increasing focus on applications and projects. He notes that it will be challenging to manage all of the technical aspects of integrating the new GNSS into IGS while also retaining the strong research focus of the groups.

Open discussion

Tom Stansell addressed the panel asking what is the advantage of additional GNSS signals; Beutler stated that combinations of multiple sources invariably improve products.

Dave Turner asked how closer ties to the UN would work and if this was a good approach? He also asked whether the IGS could assume the role of providing integrity monitoring for other communities. Ruth Neilan noted that IGS should not look to the UN as a funding source, but as an alliance in promoting the importance and visibility of GNSS and geodesy in applications benefiting society. Van der Marel responded that IGS could certainly perform integrity monitoring with the sub-network of real-time stations. LaBrecque pointed out that IGS is composed of members who are self-funded and that getting the resources to make the real-time data available must be addressed, the flow of funding must be stable so that members can sustain their activities. Serafin said that there are certain difficulties in structuring operational services, but believes that IGS should attempt to facilitate such operations by brokering links between its members and operational users. Blewitt responded to the UN question by stating that such links also enable locating stations in difficult locations by developing key connections. Reigber emphasized that the point here is funding, and the IGS does not have a coordinated effort for seeking and obtaining resources, he asserted that this is what is really needed.

[8] Global Geodetic Observing System (GGOS)

Serafin noted that in numerical weather predictions and climate monitoring the IGS has already proven its value. There are other exciting atmospheric and earth science applications such as understanding the global water cycle, and measuring snowpack. Atmospheric science prediction and simulations seem to ahead of similar activities in the solid earth science but believes that numerical prediction of solid earth processes is soon to come and that the assimilation of IGS data into numerical models will be central to these advances.

Serafin closed by thanking the panel and the audience for a stimulating ending to the Symposium, and thanked the local organizers again for all their work which was met with loud and enthusiastic applause by all.

Note: Session 8, convened on March 4, was planned as a follow-on to the symposium sessions, presenting more technical details of the GPS modernization, use of GPS in international time transfer, architecture of the Galileo system, and progress of the IGS working group on GNSS.