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)

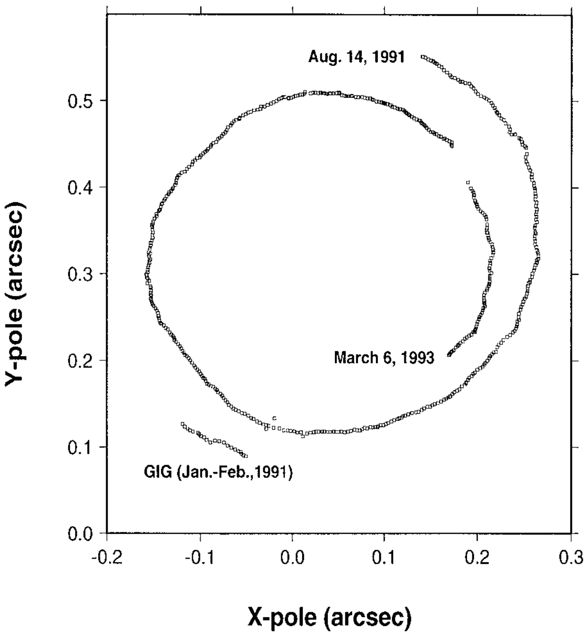

Figure 1: Polar Motion as established by the Scripps Institution of Oceanography 1991-1993

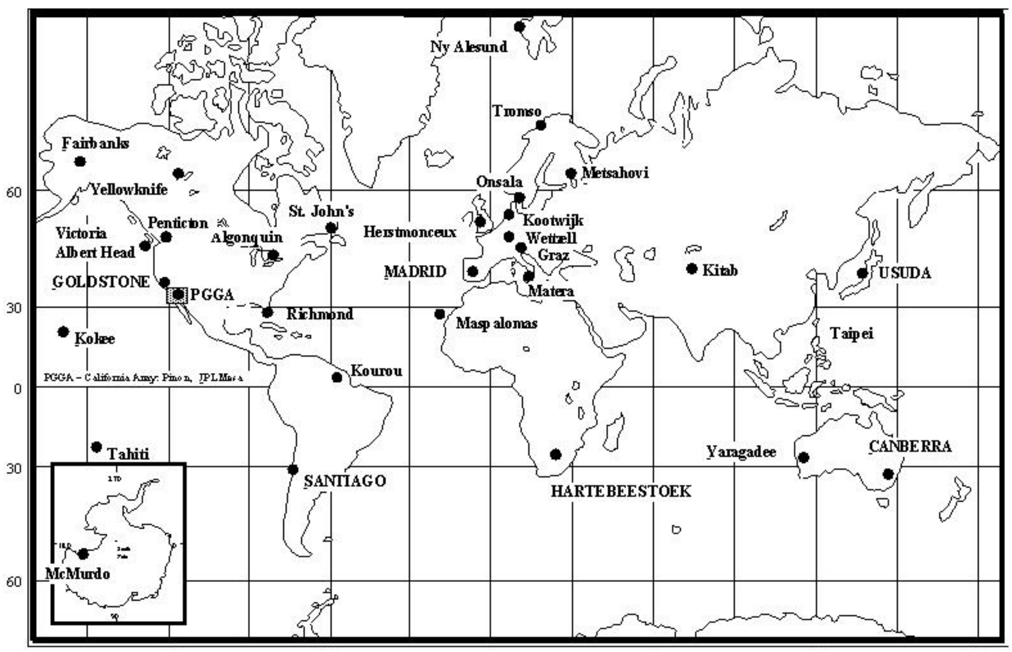

Figure 2: The IGS Global Tracking Network in 1993

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.

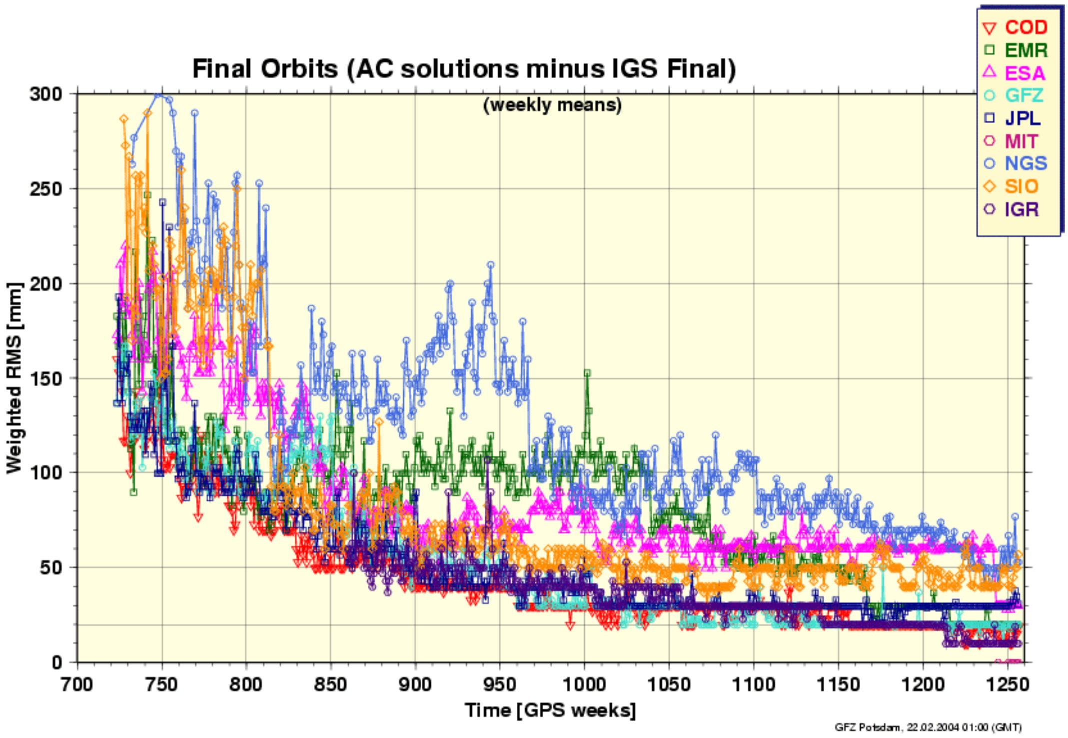

Figure 3: Development of Orbit consistency since 1993 (RMS per satellite coordinate of individual AC solutions w.r.t. IGS final orbit)

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).

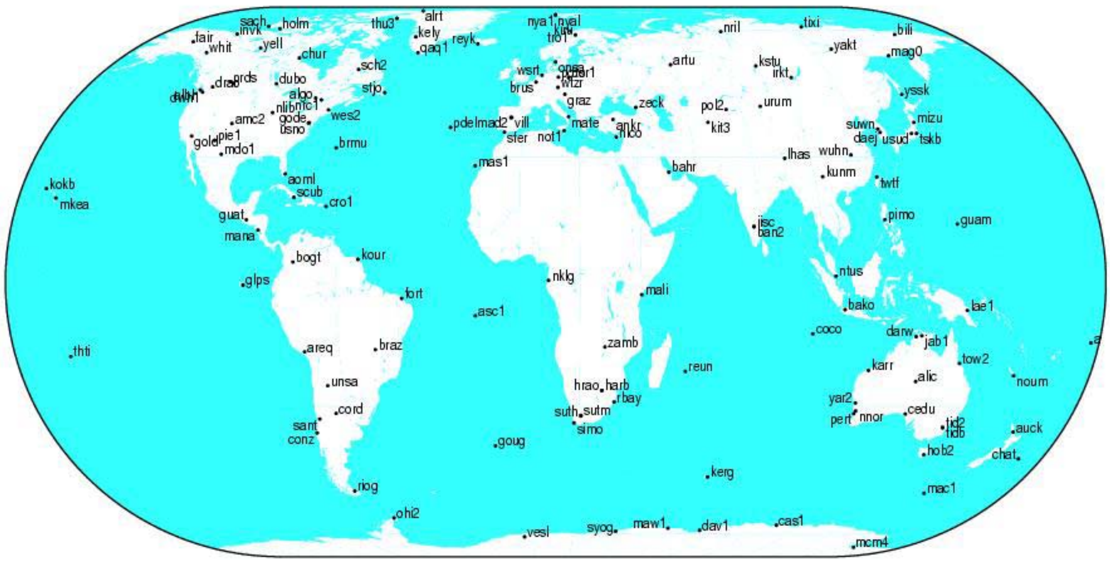

Figure 4: The IGS Network of tracking sites in 2004

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 19th 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 multidisciplinary "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.

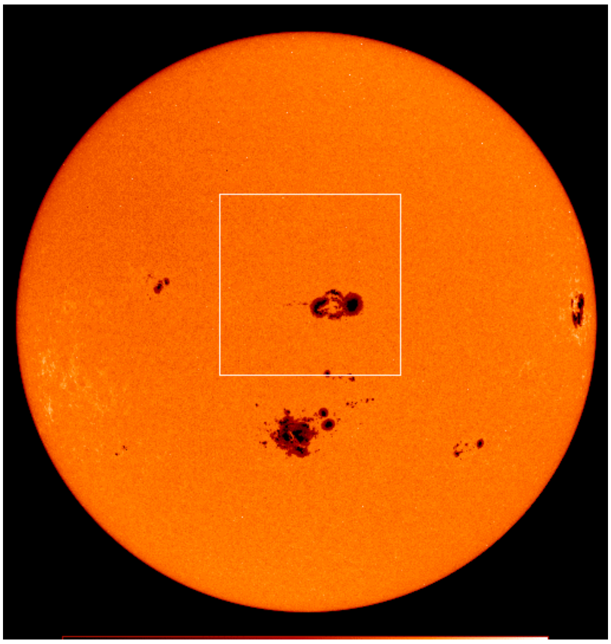

Figure 5: Sun observed by SOHO on October 29, 2003 (from SOHO homepage)

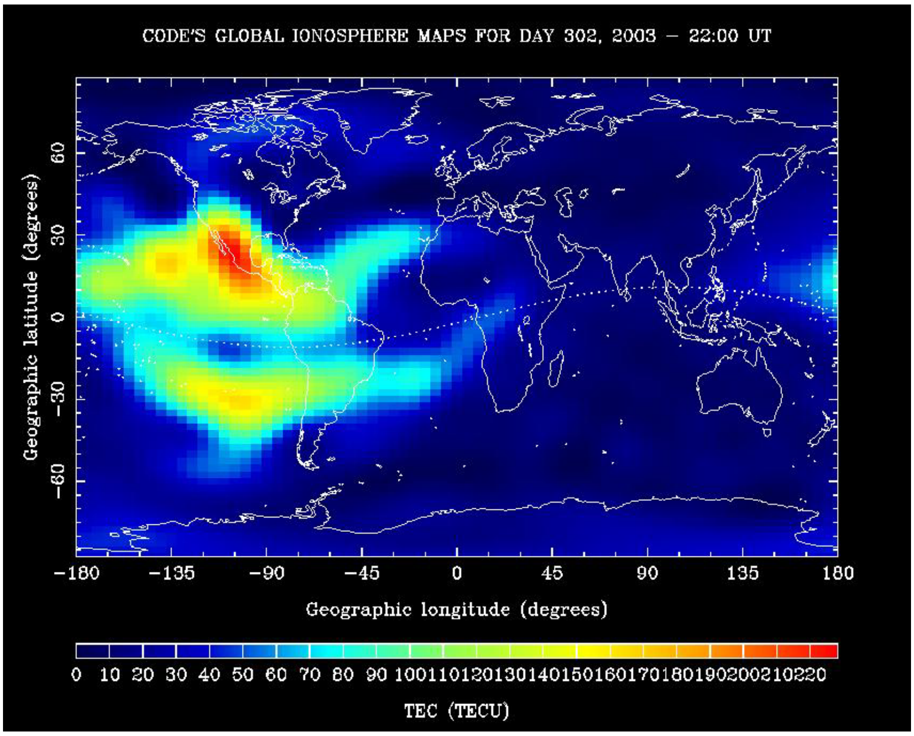

Figure 6: Maximum ionosphere content observed on October 29, 2003 by the IGS Network (from CODE homepage)

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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