INTERACTION BETWEEN SCIENTIFIC RESEARCH AND SERVICES

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RESUMÉ - La dernière décennie a vu la création et le développement d'une nouvelle génération de services scientifiques internationaux pour la géodésie et la géodynamique caractérisés par une intense interaction, d'une part entre établissements de pays différents et, d'autre part, entre objectifs de recherche et travaux de service. Une réflexion sur leurs modes d'organisation et de fonctionnement peut donner des indications utiles dans la perspective de la création d'un nouveau service international destiné à la valorisation du système DORIS.

ABSTRACT - *In the last decade, the wide spread use of space techniques in all fields of geodesy and the development of powerful communication means have allowed a spectacular transformation of the traditional services activities into privileged forums for scientific discussions. The analysis of the organization and operation of these new generation scientific services may carry useful information when preparing for a new international service dedicated to the promotion of the DORIS system.*

1 - INTRODUCTION

Research in geodesy and geodynamics makes use of a variety of data that are collected in large scale observational programs managed by institutions or groups of institutions. These data may be used at various levels of elaboration by scientists, ranging from practically out of the observational device, e.g. GPS[1] RINEX data sets, to highly compact models, e.g. terrestrial reference frames including the time evolution of station positions in SINEX format, or tables of ocean loading coefficients. Geodesy, as well as geophysics and astronomy, has a long tradition of organizing some of these activities under international services based on voluntary contributions of national institutions. By this way, the operational and research groups benefit from the work and expertise of other groups that deal with validations, intercomparisons and combinations of data in a service mode. The services sponsored by IUGG, IAU or URSI are monitored by FAGS (Mueller 1998).

In the last decade, the wide spreading of space techniques in all fields of geodesy and the development of powerfull and easy-to-use communication means has allowed a spectacular transformation of this traditional activity into a priviledged field for scientific discussion, in a spirit of friendly but alert competition.

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[1] See meaning of acronyms in the References section

The life of the services is marked by intense electronic discussion that makes full profit of Bulletin Board facilities (IERS Gazette, IGS Mail, etc), as well as frequent and well-attended workshops focused on technical and scientific issues of the service work. The services also organize schools, they distribute tutorials and even software (models, analysis protocols, etc.).

With the development of international programs for observation and analysis that rely on geodetic techniques, the services are solicited to contribute with their technical expertise, scientific knowledge and organisational skills in various fields of geosciences. There are many examples of such cases: IERS for the monitoring of global geophysical fluids, IGS for troposphere and ionosphere monitoring, ILRS for multi-purpose orbitography, ICET for the GGP network of cryogenic gravimeters, PSMSL and IGS for intergovernmental sea level monitoring projects, etc. In parallel, the global products of the services are of daily use in the wide scientific community; to take only one example, crustal deformation studies in all countries make a heavy use of the IGS orbits of the GPS satellites and of the IERS/ITRF terrestrial references. The usage of the services products goes beyond the scientific world, to professional users - as is more and more the case for IGS in particular.

2 - A NEW GENERATION OF INTERNATIONAL SCIENTIFIC SERVICES

Following the transformation of the early services that were set up for monitoring the Earth’s rotation (ILS, IPMS and BIH) into the decentralized IERS in 1988, the space geodetic techniques developped multi-centres, multi-products services devoted to the use and valorization of worldwide networks. The next one was the International GPS Service (IGS) in 1994, followed by the International Laser Ranging Service (ILRS) in 1998, and the International VLBI Service for geodesy and astrometry (IVS) for Very Long Baseline radio Interferometry in 1999.

The major task of these new services are of two different natures. While the ‘technique oriented’ services IGS, ILRS, IVS have the mission to develop and promote the use of their technique in all possible operational and technical fields, the IERS main task is to provide dense, accurate and global references as well as detailed information on the dynamics of the Earth’srotation, also for both operational and scientific applications. It relies on the technique oriented services for the collection and first analysis of observational data and to obtain intermediate results, e .g. SINEX files. The set of missions and networks involved is in part complementary and in part redundant. Redundancy is necessary to insure the reliability of the whole system. One part may fail but overall the service will survive. It is also indispensible to insure the accuracy of the results through their permanent intercomparison.

All these services organize and coordinate a broad spectrum of activities performed by governmental or private institutions. Their administrative organization is very similar, with the association of clearcut responsibilities ascribed to network centres, data centres, analysis centres, working groups, pilot projects, etc, with centralised responsibility for the global running of the service (central bureau or coordinating centre) and the quality of the products (analysis coordinator). The services are managed by a directing/governing board where all major elements of the service are represented by individuals that are elected under well-defined terms of reference. This decentralised organisation was first implemented in the IAU/IUGG MERIT Project (1978-1987) which led to the creation of the IERS in 1988. The initial IERS organisation was the first tentative in this style of management. The IGS one came next, with improvement towards more flexibility. It was taken as a model in the setting up of the ILRS and the IVS, then it inspired a reorganisation of the IERS. This style in governing an international scientific service is well suited to the current life style of the research and operational institutions and individuals.

In the following, we briefly analyse the operation and organisation of these services and try to point out the characteristics that explain their success. Our description of the goals and structure of the services extensively uses the rich World Wide Web sites that each of them has developped.

2.1 - International GPS Service, IGS

The creation of the IGS resulted from a series of networks organizations and campaigns held in the early 1990s under the auspices of US organisations (e.g. CASA Uno led by JPL, CIGNET led by NGS), the IERS (GIG,91) and the IAG. A highly successful test campaign initiated in mid-1992 evolved into a permanent service that started official operation in 1994 (Beutler et al. 1999).

The primary objective of the IGS is to provide a service to support, through GPS data and data products, geodetic and geophysical research activities. One of the first goals of IGS is to provide to scientific users precise orbits of GPS satellites for use in a post-processing mode. The service also develops the necessary standards and specifications and encourages international adherence to its conventions.

IGS collects archives and distributes GPS observation data sets of sufficient accuracy to satisfy the objectives of a wide range of applications and experimentation. These data sets are used by the service to generate the following IGS products:

- High accuracy GPS satellite ephemerides,
- Earth rotation parameters,
- Coordinates and velocities of the IGS tracking stations,
- GPS satellite and tracking station clock information,
- Ionospheric information,
- Tropospheric information.

The accuracies of these products are sufficient to support current scientific objectives including:

- Realization of global accessibility to and the improvement of the ITRF,
- Monitoring deformations of the solid Earth,
- Monitoring Earth rotation,
- Monitoring variations in the hydrosphere (sea level, ice-sheets, etc.),
- Scientific Low Earth Orbiting (LEO) satellites orbit determinations,
- Ionosphere monitoring,
- Climatological research, eventually weather prediction.

This list of products is in no way a closed list one. Taking advantage of new opportunities, new products are elaborated in ad-hoc working groups. When validated they become new IGS products.

Under the pressure of technical and field users, a persistent effort in all operational aspects has led the IGS general timeliness from weekly products with a two-weeks delay in 1994 to hourly products and delaysand even predictions in 2000, in a general context of ever increasing precision and reliability.

2.2 - International Laser Ranging Service, ILRS

The ILRS started operation in 1998. Its primary objective is to provide a service to support, through Satellite and Lunar Laser Ranging data and related products, geodetic and geophysical research activities as well as IERS products important to the maintenance of an accurate ITRF.

The service also develops the necessary standards/specifications and encourages international adherence to its conventions.

The ILRS collects, merges, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation datasets of high accuracy. These data sets are used by the ILRS to generate a number of scientific and operational data products including but not limited to:

- Earth orientation parameters (polar motion and length of day),
- Three-dimensional coordinates and velocities of the ILRS tracking stations,
- Time-varying geocenter coordinates,
- Static and time-varying coefficients of the Earth's gravity field,
- Centimeter accuracy satellite ephemerides,
- Fundamental physical constants,
- Lunar ephemerides and librations,
- Lunar orientation parameters .

The accuracy of SLR/LLR data products is sufficient to support a variety of scientific and operational applications including:

- Realization of global accessibility to and the improvement of the ITRF,
- Monitoring three dimensional deformations of the solid Earth,
- Monitoring Earth rotation and polar motion,
- Support the monitoring of variations in the topography and volume of the liquid, Earth (ocean circulation, mean sea level, ice sheet thickness, wave heights, etc.),
- Tidally generated variations in atmospheric mass distribution,
- Calibration of microwave tracking techniques,
- Picosecond global time transfer experiments,
- Astrometric observations including determination of the dynamic equinox, obliquity of the ecliptic, and the precession constant,
- Gravitational and general relativistic studies including Einstein's Equivalence Principle, the Robertson-Walker b parameter, and time rate of change of the gravitational constant G,
- Lunar physics including the dissipation of rotational energy, shape of the core-mantle boundary (Love Number k2), and free librations and stimulating mechanisms,
- Solar System ties to the International Celestial Reference Frame (ICRF).

Scientific Earth observing space missions like those dedicated to the Earth'sgravity field or to oceanography are closely related to, and heavily rely on the ILRS.

2.3 - International VLBI Service for geodesy and astrometry, IVS

The IVS started operation in 1999. Its objectives are to provide a service to support geodetic, geophysical, and astrometric research and operational activities; to promote research and development for VLBI; and to interact with users of VLBI products.

IVS provides data and products for the scientific community. Some of the products are:

- A terrestrial reference frame (TRF),
- The international celestial reference frame (ICRF), and
- Earth orientation parameters (EOP).

These results are the foundation of many scientific and practical applications requiring the use of an accurate inertial reference frame, such as high-precision navigation and positioning. IVS provides, through the collaborative efforts of its components, a variety of significant VLBI data products with differing applications, timeliness, detail, and temporal resolution, such as:

- All components of Earth orientation parameters at regular intervals,
- Terrestrial reference frame,
- VLBI data and results in appropriate formats,
- Local site ties to reference points,
- High-accuracy station timing data,
- Surface meteorology, tropospheric and ionospheric measurements.

The monitoring of the Earth orientation with respect to an inertial reference frame, i.e. universal time, precession and nutation is a unique capability of VLBI among the space geodetic techniques. All satellite geodetic techniques are using these VLBI products as input in their own computations.

2.4 - International Earth Rotation Service, IERS

The IERS started operation in 1988. Its primary objectives are to serve the astronomical, geodetic and geophysical communities by providing the following:

- The International Celestial Reference System (ICRS) and its realization, the International Celestial Reference Frame (ICRF),
- The International Terrestrial Reference System (ITRS) and its realization, the International Terrestrial Reference Frame (ITRF),
- Earth orientation parameters required to study earth orientation variations and to transform between the ICRF and the ITRF,
- Geophysical data to interpret time/space variations in the ICRF, ITRF or earth orientation parameters, and model such variations,
- Standards, constants and models (i.e., conventions) encouraging international adherence.

The monitoring of the reference frames and of the Earth's orientation is based on observations and analyses from a variety of techniques, including astronomical techniques like VLBI and LLR, and satellite geodetic techniques like GPS, SLR and DORIS for which they rely on, and interact with, the corresponding services.

IERS collects, archives and distributes products to satisfy the objectives of a wide range of applications, research and experimentation. These products include the following:

- International Celestial Reference Frame,
- International Terrestrial Reference Frame,
- Monthly Earth orientation data,
- Daily rapid service estimates of near real-time earth orientation data and their predictions,
- Announcements of the differences between astronomical and civil time for time distribution by radio stations,
- Leap second announcements,
- Products related to global geophysical fluids such as mass and angular momentum distribution,
- Annual report and technical notes on conventions and other topics,
- Long term earth orientation information.

The accuracies of these products are sufficient to support current scientific and technical objectives including the following:

- Fundamental astronomical and geodetic reference systems.
- Monitoring and modeling earth rotation/orientation.
- Monitoring and modeling deformations of the solid earth.
- Monitoring mass variations in the geophysical fluids, including the atmosphere and the hydrosphere.
- Artificial satellites orbit determination.
- Geophysical and atmospheric research, studies of dynamical interactions between geophysical fluids and the solid Earth.
- Space navigation.

After ten years of operation which provided continuous improvements in the quality and time resolution of user products and in the accessibility of those products for research and applications, the IERS Directing Board decided in 1998 to reorganize the current operation and to come up with new Terms of Reference, satisfying current and near future requirements and taking into account new organizational structures of the space-observing techniques. The new organization is planned to start in 2000.

3 - INTERACTION WITH THE SCIENTIFIC COMMUNITY

There are many examples of the new generation services taking iniatives or participating in worldwide projects that benefit directly or indirectly the international community in many fields of science and its applications, such as solid Earth physics, atmospheric sciences, oceanography, or telecommunications. We give hereafter a few significant examples. More details can be found in the literature, e.g. Beutler et al. (2000), Kouba et al. (2000).

As one of the results of the general service review it conducted in 1996, IERS decided to extend its successful efforts to coordinate the monitoring of the Atmospheric Angular Momentum (AAM) into the organization of the permanent monitoring of global geophysical fluids (Dehant and Wilson, 1997).

IGS developped atmospheric parameters monitoring concerning both the ionosphere and the troposphere (Beutler et al. 1999). Maps of the total electronic content of the ionosphere at 6-hour intervals and time series of tropospheric zenith delays with a 2-hour resolution are produced routinely.

IGS, ILRS and IERS participated with BIPM, IAG and ION in the IGEX-98 international GLONASS experiment that addressed interoperability issues between GLONASS and GPS. This is an important step towards seamless use of future global navigation satellite systems (Slater et al. 1999).

PSMSL and IGS are organizing with the intergovernmental IOC/GLOSS program the geodetic monitoring of tide gauges benchmark, a key element in understanding the global sea level changes (Woodworth 2000).

4 - LEARNING FROM THE FIRST DECADE OF OPERATION OF NEW SERVICES

The first experiment in testing new generation services, i.e. that include many institutions and make specialists of all aspects of the running of the service work together in a structured organisation, was the IERS, based originally on VLBI, LLR and SLR.

In its first version (1988-2000), groups in charge of the coordination of the observing techniques, of the analysis of astronomical, geodetic and atmospheric data, and of the derivation of the global references (ICRF, ITRF, EOP) were associated in the management of the service. This collective management implied a good deal of internal competition, between techniques as well as between scientific views, in a context where all participants, although they could disagree on some aspects of the management, were responsible *together* for the performance of the service. This situation naturally created an opening to the outside, both on the observing side (e.g. the call for GPS participation issued as early as 1989) and on the scientific side (e.g. the active participation in the progress of IERS conventions and standards). The IERS could face with no particular difficulty the major event of the introduction of GPS results in its analyses, and later on of the DORIS ones. It was also able to reorganize without interruption of the service, in order to better interact with the new technique-oriented services and to refocus on the progress of its main objectives.

The second experiment was the IGS (1992-1994 and on), which introduced more duplication in the implementation of the key tasks and increased the role of the participating groups in the management of the service. The dramatic progress in station performance and the possibility of a worldwide observing network connected through the Internet - that one could called a *worldwired* network - as well as the technical efforts of many institutions allowed to rapidly create an open data base of observations that could be accessed by many analysts. The IGS then benefitted from the enthusiasm and the skills of scientists using highly developed satellite geodesy analysis software available in a number of laboratories. Another existing set of tools at the time when IGS started was the already well established IERS global products based on VLBI and SLR, that served both as a reference and as a challenge to the new service. The analysts entered into an open competition which resulted in the rapid increase of individual and collective performances. The intense internal competition maintained at a high level the spirit of enterprise. In the same time as the main products (the GPS constellation orbits and the terrestrial reference frame) became better and better, the capability of IGS analysts to master additional parameters for deriving new products was developing. This motion is still going on, with new projects regularly proposed.

The success stories of IERS and IGS convinced the Laser Ranging and VLBI specialists that this new method of managing well focused services as a close cooperation-competition between many types of contributors and users provided a good organization model. These two communities organized themselves in a similar way. Although the ILRS and the IVS are still very recent, the first benefits of their reorganisation are already visible, with the development of intensive discussion between specialists for the improvement of the performance of the technique, hence of the service to the scientific and operational users.

The wide recognition of these services is a well deserved reward to the development of new approaches to their work. Keeping the basic constraints of precision, accuracy, reliability and open availability of results, the new generation of services include in their normal activity scientific research in the domains connected to the responsibilities of the service, upstream with basic geodesy and methodology, downstream with geophysical interpretation of their own results. Being under the permanent pressure of scientific competition, the groups in charge increase permanently the quality of the products to keep track of the state of the art.

The quality of their products stays very close to that of research results. Conversely, a large part of the progress in geodesy and Earth sciences takes place in, or in connection with, the services.

5 - RECOMMENDATIONS FOR A FUTURE DORIS ORIENTED SERVICE

DORIS groups are currently working on creating an international service, starting with an International DORIS Experiment. Similarly to the other ones, this technique on the one hand provide products that compete with others, and on the other hand has its unique capabilities. One lesson of the events of the last decade is that both can be enhanced by setting up an operational scheme with the maximum openness of observations and analyses. We enumerate hereafter a few recommendations that could be helpful in the setting up of a future International DORIS Service.

- Define missions encompassing the provision of focused products as well as scientific and operational applications.
- Describe and distribute responsibilities and tasks based on a clearly structured data flow, from observations to final analysis products.
- Whenever possible, organize duplication of key tasks in order to insure the reliablity of the whole service.
- Insure proper representation of the participating groups in the management of the service.
- Provide for easy information exchange among the participating groups and individuals (data centres, workshops, working groups, web site, bulletin board facility, etc.) and generally stimulate a spirit of cooperative competition.

6 - REFERENCES

6.1 - Printed documents

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P. Woodworth, 2000: «PSMSL Annual report for 1999», Proudman Oceanographic Laboratory, UK.

6.2 - World Wide Web access to the mentioned services

BGI	http://bgi.cnes.fr:8110
ICET	http://www.oma.be/KSB-ORB/ICET
IERS	http://hpiers.obspm.fr
IGS	http://igscb.jpl.nasa.gov
IGeS	http://ipmtf14.topo.polimi.it/~iges
ILRS	http://ilrs. gsfc.nasa.gov
IVS	http://ivscc. gsfc.nasa.gov
PSMSL	http://www.pol.ac.uk/psmsl.info.html

6.3 - Acronyms

BGI	Bureau Gravimétrique International
BIH	Bureau International de l'Heure
BIPM	Bureau International des Poids et Mesures
CASA Uno	Central America South America 1
CIGNET	Civil GPS Network
EOP	Earth Orientation Parameters
FAGS	Federation of Astrnomical and Geophysical data analysis Services
GGP	Global Geodynamics Project
GIG'91	GPS International Global campaign 1991
GLONASS	Global Navigation Satellite System (Russian system)
GLOSS	Global Sea Level Observing System
GPS	Global Positioning System
IAG	International Association of Geodesy
IAU	Internatiional Astronomical Union
ICET	International Centre for Earth Tides
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
IERS	International Earth Rotation Service
IGS	International GPS Service
IGeS	International Geoid Service
IGEX	International GLONASS Experiment
ILRS	International Laser Ranging Service
ILS	International Latitude Service
IOC	Intergovernmental Oceanographic Commission
ION	U.S. Institute of Navigation
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IPMS	International Polar Motion Service
IUGG	International Union of Geodesy and Geophysics
IVS	International Vlbi Service for geodesy and astrometry
JPL	Jet Propulsion Laboratory
LEO	Low Earth Orbiting satellites
LLR	Lunar Laser Ranging
MERIT	Monitoring Earth Rotation and Intercomparing Techniques
NGS	US National Geodetic Survey
PSMSL	Permanent Mean Sea Level Service
RINEX	Receiver Independent Exchange format
SINEX	Software Independent Exchange format
SLR	Satellitee Laser Ranging
URSI	Union Radio Scientifique Internationale