International Earth Rotation and Reference Systems Service (IERS)
Service International de la Rotation de la Terre
et des Systèmes de Référence

IERS
Annual Report
2005

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IERS Annual Report 2005

Edited by Wolfgang R. Dick and Bernd Richter

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1 Foreword

The IERS Annual Report for 2005 shows how the Service is continuing its active role according to its charter to provide the terrestrial and celestial reference frames and Earth orientation parameters for the astronomical, geodetic and geophysical communities. These IERS products lay the foundation for Earth and astronomical observations as well as practical applications.

Several activities during 2005 were aimed at improvement of key products and consideration of future development. The most prominent was work towards the next ITRF based on rigorous combination of time series at two levels, first within each Technique Centre from the input of their respective Analysis Centres and then combining all the Technique Centre time series by the ITRS Combination Centres. The task was a new level of integration among the IERS components but was not completed as planned in 2005. The IERS Workshop on the Combination Pilot Project considered how the combination process could be extended to other IERS products. Many technical and organizational questions must be resolved. The IERS established a Working Group on Prediction to study how to improve predictions of EOP, which are required for important practical applications. Underlying all IERS products are the IERS Conventions. The Conventions Centre activated its Advisory Board to draw upon the expertise of various communities to address specific modeling issues affecting IERS products.

I take this opportunity writing my first foreword as Chair of the IERS Directing Board to say that the coming years will undoubtedly be a time of change and challenges for the IERS. The IAG has established the Global Geodetic Observing System (GGOS) based on the existing IAG Services to be the integrating entity and advocate for geodesy in its three facets, geometry, rotation and gravity. The IERS is central to two facets and plans to take an active role in GGOS. The space geodetic networks that provide the raw data for the Technique Centres are in decline in some places but elsewhere there is work to advance the techniques and to strengthen the geometry. The future fundamental network will have the various techniques co-located to a high degree and a more uniform geographic distribution. The IERS must be able to withstand and take advantage of these developments. As new methods for generating the IERS products based on greater integration of data and analysis are developed and validated, the relationships between the IERS components and between the IERS and other IAG Services and GGOS may need review. To achieve steady progress and the best outcomes for our communities will require considerable work, attention and good will.

Chopo Ma
Chair, IERS Directing Board

2 The IERS
2.1 Structure

From 2005 to 2007, the IERS had the following components. For their functions see the Terms of Reference (Appendix 1), for addresses and electronic access see Appendices 3 and 4. Dates are given for changes in 2005 to 2007.

Analysis Coordinator

Markus Rothacher

Central Bureau

Director: Bernd Richter

Technique Centres

International GNSS Service (IGS)
IGS Representatives to the IERS Directing Board:
Gerd Gendt, Angelyn W. Moore (since 1 January 2005)
IERS Representative to the IGS Governing Board: Claude Boucher

International Laser Ranging Service (ILRS)
ILRS Representatives to the IERS Directing Board:
Ron Noomen (until 18 October 2006),
Peter J. Shelus (until 18 October 2006),
Jürgen Müller (since 19 October 2006),
Erricos C. Pavlis (since 19 October 2006)
IERS Representative to the ILRS Directing Board: Bob E. Schutz

International VLBI Service (IVS)
IVS Representatives to the IERS Directing Board:
Chopo Ma, Axel Nothnagel
IERS Representative to the IVS Directing Board: Chopo Ma

International DORIS Service (IDS)
IDS representatives to the IERS:
Hervé Fagard, Martine Feissel-Vernier (until 31 October 2005),
Frank G. Lemoine (since February 2006)
IERS Representative to the IDS Governing Board:
Ron Noomen (since 23 September 2005)

Product Centres

Earth Orientation Centre
Primary scientist and representative to the IERS Directing Board:
Daniel Gambis

Rapid Service/Prediction Centre
Primary scientist and representative to the IERS Directing Board: William Wooden

Conventions Centre
Primary scientists: Dennis D. McCarthy (until 11 July 2005), Brian J. Luzum (since 12 July 2005), Gérard Petit
Representative to the IERS Directing Board: Gérard Petit

ICRS Centre
Primary scientists: Ralph A. Gaume, Jean Souchay
Current representative to the IERS Directing Board: Ralph A. Gaume (since 1 January 2005)

ITRS Centre
Primary scientist and representative to the IERS Directing Board: Zuheir Altamimi (since 1 January 2005)

Global Geophysical Fluids Centre
Head and representative to the IERS Directing Board: Tonie van Dam (since 1 January 2005)

Special Bureau for the Atmosphere
Chair: David A. Salstein

Special Bureau for the Oceans
Chair: Richard S. Gross

Special Bureau for Tides
Chair: Richard D. Ray

Special Bureau for Hydrology
Chair: Clark R. Wilson (until April 2005), Jianli Chen (since May 2005)

Special Bureau for the Mantle
Chair: Benjamin F. Chao (until January 2006), Erik R. Ivins (since 29 June 2006)

Special Bureau for the Core
Chair: Tim van Hoolst

Special Bureau for Gravity/Geocenter
Chair: Michael M. Watkins

Special Bureau for Loading
Chair: Hans-Peter Plag (since 1 January 2005),
Vice-chair: Tonie van Dam (since 1 January 2005)

Combination Centres

ITRS Combination Centres

Deutsches Geodätisches Forschungsinstitut (DGFI)
Primary scientist: Hermann Drewes

Institut Géographique National (IGN)
Primary scientist: Zuheir Altamimi

Natural Resources Canada (NRCan)
Primary scientist: Remi Ferland

Combination Research Centres

CRC representative to the IERS Directing Board:
Sheng Yuan Zhu (until 31 August 2005)

Agenzia Spaziale Italiana/Centro di Geodesia Spaziale (CGS)
Primary scientist: Giuseppe Bianco

Astronomical Institute, Academy of Sciences of the Czech Republic, and Department of Geodesy, Czech Technical University, Prague
Primary scientist: Jan Vondrák

Deutsches Geodätisches Forschungsinstitut (DGFI)
Primary scientist: Detlef Angermann

Forschungseinrichtung Satellitengeodäsie, Technical University Munich (FESG)
Primary scientist: Markus Rothacher (until 31 December 2005)

Forsvarets forskningsinstitutt (FFI, Norwegian Defence Research Establishment)
Primary scientist: Per Helge Andersen

GeoForschungsZentrum Potsdam (GFZ)
Primary scientist: Sheng Yuan Zhu (until 31 August 2005), Markus Rothacher (since 1 September 2005)

Geodetic Institute of the University of Bonn (GIUB)
Primary scientist: Axel Nothnagel

Groupe de Recherches de Géodésie Spatiale (GRGS)
Primary scientist: Richard Biancale

Institute of Applied Astronomy, St. Petersburg (IAA)
Primary scientist: Zinovy M. Malkin (until July 2006)

Institut Géographique National (IGN)
Primary scientist: Zuheir Altamimi

Jet Propulsion Laboratory (JPL)
Primary scientist: Richard S. Gross

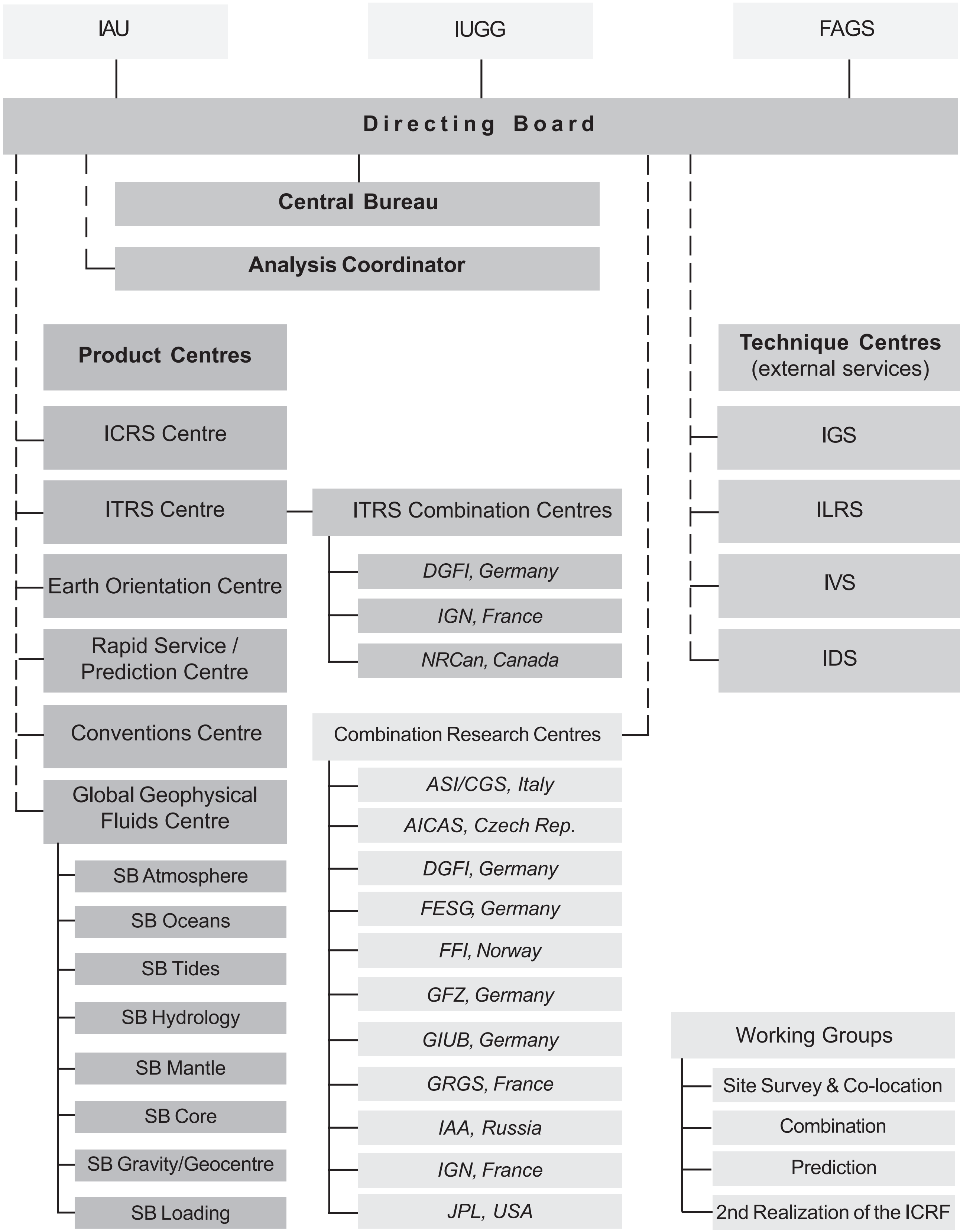
Working Groups

Working Group on Site Survey and Co-location
Chair: John Dawson (until December 2005),
Gary Johnston (since January 2006)

Working Group on Combination
Chair: Markus Rothacher

Working Group on Prediction
(established in December 2005)
Chair: William Wooden

IERS/IVS Working Group on the Second Realization of the ICRF
(established in January 2007)
Chair: Chopo Ma


IAU
IUGG
FAGS
Directing Board
Central Bureau
Analysis Coordinator
Product Centres
ICRS Centre
ITRS Centre
Earth Orientation Centre
Rapid Service / Prediction Centre
Conventions Centre
Global Geophysical Fluids Centre
SB Atmosphere
SB Oceans
SB Tides
SB Hydrology
SB Mantle
SB Core
SB Gravity/Geocentre
SB Loading
ITRS Combination Centres
DGFI, Germany
IGN, France
NRCan, Canada
Combination Research Centres
ASI/CGS, Italy
AICAS, Czech Rep.
DGFI, Germany
FESG, Germany
FFI, Norway
GFZ, Germany
GIUB, Germany
GRGS, France
IAA, Russia
IGN, France
JPL, USA
Technique Centres (external services)
IGS
ILRS
IVS
IDS
Working Groups
Site Survey & Co-location
Combination
Prediction
2nd Realization of the ICRF

2.2 Directing Board

In 2005 to 2007, the IERS Directing Board had the following members (for addresses see Appendix 2):

Chair	Chopo Ma
Analysis Coordinator	Markus Rothacher
Product Centres Representatives	
Earth Orientation Centre	Daniel Gambis
Rapid Service/Prediction Centre	William Wooden
Conventions Centre	Gérard Petit (until 31 December 2006) Brian J. Luzum (since 1 January 2007)
ICRS Centre	Ralph A. Gaume
ITRS Centre	Zuheir Altamimi
Global Geophysical Fluids Centre	Tonie van Dam
Central Bureau	Bernd Richter
Combination Research Centres	Sheng Yuan Zhu (until 31 August 2005)
Technique Centers Representatives	
IGS	Gerd Gendt Angelyn W. Moore
ILRS	Ron Noomen (until 18 October 2006) Peter J. Shelus (until 18 October 2006) Jürgen Müller (since 19 October 2006) Erricos C. Pavlis (since 19 October 2006)
IVS	Chopo Ma Axel Nothnagel
IDS	Hervé Fagard Martine Feissel-Vernier (until 31 October 2005) Frank Lemoine (since February 2006)
Union Representatives	
IAU	Nicole Capitaine
IAG / IUGG	Clark R. Wilson
FAGS	Nicole Capitaine

2.3 Associate Members

Andersen, Ole Baltazar
Andersen, Per Helge
Angermann, Detlef
Arias, Elisa Felicitas
Behrend, Dirk
Biancale, Richard
Bianco, Giuseppe
Boucher, Claude
Bruyninx, Carine
Carter, William E.
Chao, Benjamin F.
Chen, Jianli
Dow, John M.
Drewes, Hermann
Feissel-Vernier, Martine
Ferland, Remi
Gross, Richard S.
Gurtner, Werner
Herring, Thomas
Ivins, Erik R.
Johnston, Gary
Kolaczek, Barbara
Kostelecký, Jan
McCarthy, Dennis D.
Melbourne, William G.
Neilan, Ruth E.
Noomen, Ron
Pearlman, Michael R.
Petit, Gérard
Plag, Hans-Peter
Pugh, David
Ray, Jim
Ray, Richard D.
Reigber, Christoph
Salstein, David
Schuh, Harald
Schutz, Bob E.
Shelus, Peter J.
Souchay, Jean
Tavernier, Gilles
Van Hoolst, Tim
Veillet, Christian
Vondrák, Jan
Watkins, Michael M.
Weber, Robert
Willis, Pascal
Yatskiv, Yaroslav S.
Yokoyama, Koichi
Zhu, Sheng Yuan

Ex officio Associate Members:
IAG General Secretary: Carl Christian Tscherning
IAU General Secretary: Karel A. van der Hucht
IUGG General Secretary: Jo Ann Joselyn
President of FAGS: Nicole Capitaine
President of IAG Commission 1: Hermann Drewes
President of IAG Subcommission 1.1: Markus Rothacher
President of IAG Subcommission 1.2: Claude Boucher
President of IAG Subcommission 1.4: Harald Schuh
President of IAG Commission 3: Véronique Dehant
President of IAG Subcommission 3.1: Gerhard Jentzsch
President of IAG Subcommission 3.2: Markku Poutanen
President of IAG Subcommission 3.3: Richard Gross
President of IAU Commission 8: Imants Platais
President of IAU Commission 19: Véronique Dehant
President of IAU Commission 31: Demetrios Matsakis
Head of IAU Division I: Toshio Fukushima

(*Status as of June 2007*)

3 Reports of IERS components
3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of the year 2005. Summaries of these meetings are given below.

Meeting No. 40

April 28, 2005, Technical University Vienna, Vienna, Austria

C. Ma welcomed the participants of the meeting and reported about the following activity since the last Directing Board (DB) meeting: The letters of some institutions confirming that they are still supporting their work within the IERS arrived with a delay. IGN informed the IERS that Z. Altamimi is taking over the position as head of the ITRS Centre from C. Boucher. There have been also other changes within the DB since the last meeting: C. Ma was elected as Chair of the IERS DB; T. van Dam replaced B. Chao as Head of GGFC; A. Moore has been approved by the IGS Governing Board as the second representative of IGS within the IERS DB.

A certificate was given to J. Vondrak to accomplish his work as the chair of the IERS DB. Certificates of honour will also be mailed to the former DB members C. Boucher, D. McCarthy and J. Souchay.

Reports of the Unions (IAU, IAG/IUGG)

N. Capitaine reported about planned activities for the IAU:
1. The 26th IAU General Assembly is in preparation. It will be held in Prague (Czech Rep.) from 14 to 25 August 2006. Three proposals for scientific meetings during this 2006 GA were supported by Division I (Fundamental Astronomy): two Joint Discussions and one Symposium; those approved by the IAU Executive Committee during its joint meeting with the Division Presidents (April 2005 in Rome) have been the following:
i. Joint Discussion on „Nomenclature, precession and new models in fundamental astronomy; Applications and scientific contribution to astronomy“ (Chairs of the SOC: N. Capitaine, J. Vondrak and J. Hilton; Organized by Division 1 and Commission 19 (Rotation of the Earth); Supports: Division X (Radio Astronomy) and Commissions 4 (Ephemerides), 5 (Documentation and astronomical data), 7 (Celestial Mechanics and Dynamical Astronomy), 8 (Astrometry), 31 (Time), 40 (Radio Astronomy));
ii. Symposium on „Near Earth Objects, our celestial neighbours: opportunity and risk“ (Chairs of the SOC: B. Valeschi and A. Milani; Organized by Divisions: I and III (Planetary System Sciences) and Commissions 7 and 20 (Position of minor planets, comets and satellites).
2. According to the revision of the scientific organization of the IAU, the new IAU Working Rules have been adopted by the IAU EC and are now available on the IAU web page at <http://www.iau.org/IAU/

Organization/admdoc/workrulee.html>. These rules explain how the Divisions, Commissions and Working Groups are intended to work. The main point is that the Commissions are no more permanent but are intended to evolve in agreement with the evolution of the scientific matter so that their activity should be reviewed every other GA, beginning on 2006.

3. The special Committee, chaired by T. Fukushima, that is in charge of proposing the new Division 1 organization within the newly adopted IAU rules has not yet reached any conclusion, although this will be very important for identifying to which Commission the IERS will have to report in the future. For some information regarding alternative possibilities, see the summary of the discussion at the Journées 2004 in Paris at <http://syrte.obspm.fr/journees2004> (see Programme, Discussion 1, Summary). It will be important to prepare in advance proposals for new Division I WG to be established at the 2006 GA, as for example a new WG devoted to ICRS/ICRF issues.

4. The current IAU Division I Working Groups are circulating draft reports which contain a few recommendation proposals for the next GA, regarding nomenclature (see the web page of the IAU WG on Nomenclature in Fundamental Astronomy (NFA) at http://syrte.obspm.fr/iauWGnfa/ , Chair: N. Capitaine) and Precession (c.f. WG on Precession and the Ecliptic (P&E), Chair: J. Hilton). These recommendations, agreed by the WGs NFA, P&E, RCMAM, will be supplements to the IAU 2000 Resolutions (i.e. improvement of the nomenclature and recommendation of an improved precession). This issue will be discussed at the Journées 2005 (September 2005, Warsaw, Poland).

5. Following the 2003 European Descartes award that was given to the IAU–IUGG Nutation WG, a series of 4 Summer schools and Workshops are in preparation for the years 2006–2009, the first one being a School on „Precession–nutation" (to be held at Les Houches, France, May 2006).

6. The IAU is very much concerned by the future of FAGS (Federation of Astronomical and Geophysical Data Analysis Services) to which IERS is belonging as a service of IAG and IAU. FAGS will cease to be an Interdisciplinary Service of ICSU following the 28th ICSU General Assembly next October. New arrangements for the affiliation of the FAGS Services will be necessary. This issue will be discussed during a special meeting of the FAGS Council at UNESCO (2–3 May) in Paris where the FAGS Service Directors and the IAU and IUGG General Secretaries will participate.

C. Wilson presented news from IUGG and IAG. The next IUGG General Assembly will be held in 2007 in Perugia, Italy. The next IAG assembly will take place on August 22–26, 2005 in Cairns, Australia. It will be a joint assembly with IAPSO and IABO. The IUGG Resolutions from the General Assembly in Sapporo (2003) have not yet been reported at a DB meeting. Relevant for the IERS are resolutions number 3 (IGGOS, now GGOS), 4 (IAU Resolutions) and 10 (GNSS) (<http://www.iugg.org/assemblies/2003sapporo/comptesRendus.pdf>, page 37ff). The IAG has been re-organized. The new structure was adopted in 2003. The former Sections are now Commissions (1–4). GGOS has been declared to be the main project of IAG. The role of the services (Technique Services, IERS, etc.) within the IAG was clarified and the work of the services was recognized. The IERS became much more prominent than in the past thanks to the service representatives in the Executive Committee of the IAG.

International Projects: GEO and GEOSS

B. Richter gave an overview about international projects, especially about GEO and GEOSS. An ad-hoc group of senior political officials from all participating countries and organizations, named the Group on Earth Observations (GEO), was formed. GEO was charged to develop a “Framework Document” plus a more comprehensive report to describe how a collective effort could be organized to continuously monitor the state of our environment, increase understanding of dynamic Earth processes, and enhance forecasts on our environmental conditions all based upon existing observing systems (Global Earth Observation System of Systems – GEOSS). Furthermore, it was to address potential societal benefits if timely, high quality, and long-term data and models were available to aid decision-makers at every level, from intergovernmental organizations to local government to individuals. Through six meetings of GEO, from late 2003 through February 2005, the required documents were prepared for adoption. Presently GEO is supported by 59 nations and 43 organizations. During the summit in Tokyo 2004 IAG became a member organization and is represented by G. Beutler respectively by C. Reigber as chair of the group. The GEOSS 10-Year Implementation Plan establishes the intent, operating principles, and institutions relating to GEOSS. It is supported by a longer Reference Document, which is consistent with the Plan and provides substantive detail necessary for implementation. The Plan was negotiated by the ad hoc GEO in Ottawa in November 2004, and adopted at the third Earth Observation Summit in Brussels, in February 2005. The Reference Document was extensively reviewed by technical experts, countries, and international organizations. More details can be seen under <http://earthobservations.org/>. The 10-year roadmap for creating GEOSS as a distributed system of systems will be built step-by-step on current cooperation efforts among existing observing and processing systems. IAG’s pilot project, the Global Geodetic Observing System (GGOS), should become a prominent element of GEOSS and first steps for integrating GGOS into the GEO process have already been done. Contributions to the 10-Year Implementation Plan and the Reference document discussed during the 4th and 5th GEO meeting result in recognition of the geodetic reference frames as a common product for Earth observation.

Status of ITRF2004

Concerning the status of ITRF2004, the following reports were presented:

IGS (G. Gendt): For the submissions for ITRF2004 IGS generated a combined solution covering 9 years of data (1996–2005). The individual solutions cover different time spans. Generally recent (from 1999 on) solutions are of better quality. No re-analysis of original data has been done. The parameter set is inhomogeneous, because EOPs have not been estimated before 1999. Additionally, re-analysed solutions are available (SIO: covering data from 1991, GFZ and JPL announced re-analysed data series). Nevertheless, the official product that should be used for ITRF2004 is the combined solution; individual solutions should be used for quality checks and feed-back only.

ILRS (R. Noomen): The operational products for IERS long time series converged since November 2003 (the generation process already started in 1999). 5 individual solutions produced by four different software packages are being used for combination. The two combination solutions are completely independent using different software packages and following different analysis strategies. The official ILRS product is available since June 2004. Both solutions have to fulfil the same requirements and are equal in terms of quality. However, the official product comes from ASI (ilrsa) while the DGFI solution has to be regarded as a backup product (ilrsb). The combined solution is going to be generated with a delay of 4 days after the last data has been collected. At the moment ILRS is working hard to deliver the time series for the ITRF2004 (deadline from Z. Altamimi is May 31). In the future the time series should be extended backwards from 1992 to 1983 (in summer or fall 2005) and later back to 1976.

IVS (A. Nothnagel): To create the combined solutions for the IERS Long Term Series 6 individual solutions coming from 3 different software packages are being considered. The data goes back to 1984.

IDS (M. Feissel-Vernier): The IDS does not yet provide a combined solution. 4 individual analysis centre solutions exist. The DORIS contribution for the ITRF will have some strengths for the generation of ITRF2004.

IERS Data Centre (W. Schwegmann): All data for the CPP and ITRF2004 will be archived within the IERS Data Centre. Every hour it is being checked whether there are new weekly solutions available. New solutions will be downloaded and renamed with respect to the CPP file naming conventions. Metadata will be extracted with respect to every file. The data are available via anonymous ftp from <ftp://iers1.bkg.bund.de>. Dynamic Web pages with detailed information about the available files are provided. An e-mail message with this information will be sent out via the CPP e-mail exploder. The pages will be modified to underline which solutions are the official solutions and which ones should be used for validation only. A trial version of the Data and Information System for validation within the Directing Board will be activated on May 9.

ITRF Data Centre (Z. Altamimi): The new web site is now operational. Detailed information about all ITRF solutions can be found as well as information with respect to all stations. SINEX files containing specific stations can be downloaded. Online requests for Domes Numbers can be made and many more features are feasible. The pages are available at <http://itrf.ensg.ign.fr>.

ITRS CC NRCan (extract of an e-mail sent by R. Ferland): All recent work related to IERS has been to prepare the IGS contribution for ITRF2004 which was made available within the prescribed deadline. Hopefully, the contribution is in a state that will allow to generate ITRF2004 without delays. Details of that contribution have already been circulated, and he believes that the IGS coordinator (G. Gendt) will attend the meeting and provide more details. There has not been more activity on the „IERS ITRF CC“ simply due to lack of resources.

ITRS CC DGFI (H. Drewes]): The strategy for the generation of an ITRF2004 used at DGFI was reported. He pointed out that only one solution per technique will be included (the combined solutions from the technique services) and raised many questions that have to be clarified between the ITRS CCs.

ITRS CC IGN (Z. Altamimi): The activities of IGN as an IERS ITRF CC are presented together with the strategy for the ITRF2004 (next paragraph).

Z. Altamimi reported about the strategy for generating the ITRF2004. He repeated the description of requested data according to the call and mentioned that IERS has to give feedback to people with individual solutions to accomplish their work even if the individual solutions will not be considered. The ITRF2004 should be available in August 2005. He proposed to set up a validation group for the ITRF2004.

M. Rothacher gave some comments on the strategy: Each centre should be free to choose its own strategy to ensure a diversity of approaches and the best results. However, there are a lot of questions that have to be discussed and for that a consensus is necessary. We have to distinguish between two groups of users: For users who need a reference frame of best quality a first solution should be generated that covers only very good stations. For users from the fields geophysics and geodynamics a second solution can be generated considering also older and historic stations. He presented quality criteria to check the individual solutions as well as a validation strategy. The final validation criteria should be set up by the AC together with the ITRS CCs.

An extensive discussion took part on the ITRF2004 and on the proposed validation panel. The decision on the panel was postponed.

Working Groups

In a report of the Working Group on Site Survey, J. Dawson pointed out that this WG has a research focus and will not be an operational group. It is a very small group. Meetings took place in Nice 2004 and a few days before this DB meeting. A further meeting is planned in Cairns. One main activity is the set up of a pilot project to specify site survey standards. The Site Survey and Co-location Pilot Project (SSCPP) has been initiated. Four groups have sent a proposal for a contribution. An important task is the request for information about local ties, that should be sent to the observation stations. It was decided that the IERS CB will send out a list of stations with addresses of persons responsible for the station and the administration. This list should be completed by the Technique Centres. Finally the letter should be sent out as a joint action of all TCs (IDS, IGS, ILRS, IVS), the IERS and the IAG/GGOS working group on “Ground Networks and Communication” (chair M. Pearlman), to avoid that the stations and the officials will receive this letter more than once.

M. Rothacher presented a detailed report on the Working Group on Combination and on the Combination Pilot Project. He reported about the current status and future perspectives of the WG and possible consequences for the IERS. It is already a great success that now routinely weekly SINEX combination files are available from IGS, ILRS and IVS. IDS provides solutions from four individual analysis centres and hopefully will provide a combined solution in the near future. The solutions are available by far less than the requested delay of 8 weeks. First inter-technique combinations at the observation level are available from GRGS.

Possible new products of the IERS

C. Ma raised the possibility of organizing and presenting EOP and geophysical excitation data in a much more integrated way to facilitate scientific interpretation of events like the 2004 Sumatra earthquake and tsunami. This could be accomplished by more direct coordination and linking of data sets between the Earth Orientation Centre and the GGFC.

IAG project GGOS

M. Rothacher gave a detailed report on the latest developments of GGOS, the Global Geodetic Observing System. He showed the activities with respect to GGOS, the structure and ToR as well as the link to GEOSS, the Global Earth Observing System of Systems. He mentioned that there will be a GGOS programme for the IAG General Assembly in Cairns. H. Drewes mentioned that GGOS will take care that geodesy is visible within the Global Earth Observing Strategy GEOS. The GGOS programme in Cairns does still accept contributions. He proposed that the IERS DB should propose a meeting between the geometric services (TCs and IERS) and the International Gravity Field Service (IGFS).

IERS Conventions

G. Petit reported that the Web site is updated from time to time. The Advisory board has been installed in February 2005 and had its first meeting during the EGU General Assembly. Some expert groups have already started their work. The question was raised how updates should be handled and who probably has to accept them? It was agreed that proposals for significant updates should be circulated by e-mail to the DB before being introduced on the Web site and announced. B. Richter mentioned that it has already been decided that updates should be visible within the Web site. Additionally, they can be distributed via the distribution list for IERS messages and major updates should be included in the IERS Annual Report. Every 2 or 3 years a reprint of the Conventions should be made.

Report of the Central Bureau

B. Richter reported that the proceedings of the Matera workshop are finished and the Annual Report 2003 is in print. For the Annual Report 2004 the missing contributions were listed.

Proposal: EOP Prediction Comparison Campaign

H. Schuh presented a proposal for an EOP Prediction Comparison Campaign which should run under the auspices of the IERS. The proposal was accepted to be performed in cooperation with the IERS Rapid Service and Prediction Centre. It has been decided that H. Schuh should contact W. Wooden to work out the details.

Miscellaneous

The IERS DB decided that Claude Boucher's mandate as IERS representative in the IGS should be prolonged. The CB was asked to contact him to ask if he is willing to continue as IERS representative in the IGS.

The CB will contact Rene Forsberg to ask for an IGFS/IGeoidS representative as successor of Peter Schwintzer.

In fall of this year an IERS CPP workshop is planned. The workshop is planned at GFZ in Potsdam but there is a proposal to run the workshop in conjunction with the ILRS workshop in Sussex for cost saving reasons. The date and location will be fixed soon.

For 2006 there is an invitation of the European Centre for Geodynamics and Seismology ECGS to held a joint IERS/ECGS workshop dedicated to the subjects of the Geophysical Fluid Centres. The ECGS will provide financial support for the organisation of the workshop which can be used e.g. to invite people.

The next IERS DB Meeting will possibly be held during the AGU Fall Meeting 2005 at San Francisco.

Meeting No. 41

December 5, 2005, Marriott Hotel, San Francisco, USA

C. Ma welcomed the participants of the meeting and reported about the following activity since the last Directing Board (DB) meeting: In coordination with the DB he sent a letter of support for the Australian National Geospatial Reference System. He noted the departure of Martine Feissel and Sheng Yuan Zhu. Both were member of the IERS for a long time, especially Martine Feissel who served as the first director of the IERS Central Bureau.

Reports of the Unions (IAU, IAG/IUGG)

Nicole Capitaine as IAU and FAGS representative reported about the latest actions and information.

The XXVIth General Assembly of the IAU will take place in Prague from August 14 to 25, 2006. The GA is organised as four Invited Discourses, six Symposia, 17 Joint Discussions and seven special sessions. The details of the preliminary programme are given under http://astro.cas.cz/iau2006/SciProgram.html. The relevant Joint Discussion to IERS subjects is coordinated by Division I, Commission 19 together with Division X, Commissions 4, 5, 7, 8, 31, 40 and titled “Nomenclature, Precession, and New models in Fundamental Astronomy”. The six sessions of the Joint Discussion will cover the state of the art of the implementation of the IAU resolutions, the precession and the ecliptic, the high accuracy models for reducing astronomical observations, new terminology in fundamental astronomy, scientific applications of high accuracy astronomy and a general discussion. For 2007 the IAU Division I proposes an IAU symposium “A giant step for astrometry: Hipparcos to GAIA” in Shanghai, October 22–26.

During the 28th ICSU General Assembly in China, October 18–22, 2005, it was decided to extend ICSU’s sponsorship of FAGS for a period of three years. During this 3-year period, FAGS will continue to fulfil its role of coordination among the services, while ICSU will examine integration of this function within its activities in data and information. This decision is the result of an action from the IAU, IUGG and URSI, who submitted this alternative to the ICSU GA that received a strong majority of votes among both the national members and union delegates of ICSU. On March 29–31, 2006, there will be a FAGS council meeting in Paris to discuss with the service directors possible future steps to guarantee the continuation.

Clark Wilson summarized the scientific highlights of the IAG 2005 assembly in Cairns. During the Global Geodetic Observing System (GGOS) project meeting Markus Rothacher became the new chair with Ruth Neilan and Hans-Peter Plag as vice chairs. GGOS should become operational in 2007. The IAG Executive Committee adopted the following motion on UTC: "On the basis of … surveys conducted by the IERS, indicating that a large majority in the IAG user community would like to maintain the status quo, the IAG EC recommends at this time no change in the current method of relating UTC to UT1."

International Projects: GGOS and GEO

Markus Rothacher reported on GGOS. The goal is to implement GGOS as a functional system the next 2 to 3 years. Therefore it is necessary to strengthen the internal organization, develop a GGOS implementation plan and take into account the rapid external developments in GEO/GEOSS and IGOS-P. Presently GGOS is preparing a strategic paper to join the Integrated Global Observing Strategy – Partners (IGOS-P) programme. The proposed theme for IGOS-P is "Earth System Dynamics". GGOS will define its contribution to GEOSS with respect to the nine social benefit areas and will try to increase the visibility of GGOS (and geodesy) in GEO. Rothacher sees the coordination of the services as the main internal goal of GGOS. The goal is to generate a highly-accurate, consistent set of GGOS products for society, going from data to interpretation / information. A GGOS retreat is scheduled in early 2006.

B. Richter gave a short review on the process to establish the Group of Earth Observation (GEO) and the involvement of geodesy presented in the reference document. For 2006 a work plan exists to lay the foundation of GEOSS. E.g., GEO members and participating organizations are asked to reach agreements on GEOSS interoperability specifications, and an inventory should be produced, by societal benefit area, of existing in-situ observation networks.

Report of the Conventions Centre

Gérard Petit introduced Brian Luzum as his new partner in USNO and presented a short overview about the latest developments in the Conventions Centre. The advisory board started working in February 2005 and identified several topics which should be included in the Conventions like the pole tide correction and the diurnal / semidiurnal atmospheric pressure loading effect. Furthermore the Conventions Centre established a discussion forum and new web pages to report conventions updates.

Report on Combination Workshop in Potsdam, Oct. 10–11, 2005

In his talk Markus Rothacher summarized the highlights and the results of the workshop. The presentations given at the workshop are displayed at <www.iers.org/MainDisp.csl?pid=66-25727>. The workshop publication is under way.

Report of Technique Centres (Intra-technique combination, Input to ITRF2004 and CPP, CONT05)

IGS contribution

Remy Ferland recapitulated the status of the IGS solutions contributing to the ITRF. The input GPS series started in 1996 with improving accuracy from 10 to 2 mm for the horizontal and 30 to 10 mm for the vertical. Weekly solutions are available comprising an increasing number of stations from 75 in the beginning to 250 now. Earth Rotation Parameters and apparent geocentre variations are analysed from the second half of 1999 on. Today eight analysis centres routinely produce weekly solutions using six different software packages. About 50 % of the stations show discontinuities but the detection entails some subjectivity. With the change from relative to absolute antenna calibration most of the IGS users are affected.

ILRS contribution

On behalf of Ron Noomen Peter Shelus gave a brief overview about the ILRS analysis work. Six analysis centres contribute to the weekly combined solution, which is calculated by ASI with a backup solution prepared by DGFI. The combined ILRS solution is available each week on Wednesday and comprises about 10 – 25 SLR stations. A reanalysis has been done with observations from today to 1993. In a next step older SLR observations will be reanalysed as well. The reanalysed data sets are available for the new ITRF.

IVS contribution

Chopo Ma gave a short presentation about the implications of 0–24 h UT observations and the CONT05 campaign. Currently the session start times are arranged according to personnel working schedules and air freight times. Changing to 0–24 h UT sessions without additional costs and data transfer delays would require unattended operation and transmission of data via network. CONT05 had 15 continuous days with 11 stations. Preliminary results are good.

IDS contribution

Hervé Fagard said that a call has been issued to elect a new analysis coordinator because Martine Feissel-Vernier has retired. A new station at Monument Peak, USA is co-located with the SLR station. IGN supports more co-locations and would like to see recommendations from the IERS to the IDS for better co-location. Nine DORIS stations are co-located with SLR stations. The IDS network could have more new stations but nonetheless keep the old stations which are not co-located.

In view of ITRF2005, Pascal Willis and several colleagues provided a synthesis document for combination centres, describing specific problems related to DORIS station discontinuities and nonlinearity as well as specific DORIS data problems (P. Willis et al.: IDS recommendations for ITRF2004, version 1.0, November 2005, http://ids.cls.fr/html/report/reports.html).

Status of ITRF

The ITRS Combination Centres DGFI (Detlef Angermann) and IGN (Zuheir Altamimi) reported about their first results for the new ITRF. NRCan (Remy Ferland) was not able to produce a combined technique solution but gave more details about the IGS combined solution.

The DGFI and IGN used weekly SINEX solution files (positions and daily EOPs) as input:

- GPS (NRCan): 1996–2004 (updated up to July 2005). EOPs before June 1999 are not available.
- VLBI (GIUB): 1984–2005 (new version submitted in Oct. 05)
- SLR (ASI): 1993–2005 (new version submitted in Nov. 05, called V4 at IGN and V5 at DGFI)
- DORIS (3 Individual AC solutions: IGN, LCA, INA): 1993–2004. Co-location tie vectors (recently updated by IGN).

Discontinuity tables for station positions were provided by IGS, IVS, IDS but are still missing from ILRS. The adjusted parameters are station positions, velocities and EOPs.

The DGFI solution introduced an a priori datum by setting up Helmert-transformation parameters and accumulated the weekly normal equations. A new approach was tested: simultaneous estimation of the TRF and EOP where the EOP serve as a "global tie" between the different techniques so that the EOP provide valuable information to validate local tie selection. In a test case combining VLBI and GPS solutions 13 "good" co-location sites were identified.

Zuheir Altamimi prepared some time series analysis of the submitted solutions to ITRF2005. The quality of the combined technique solution is dependent on the quality of the individual stations. The effect was demonstrated using "all" SLR stations versus the quality of a combined solution built by selected "well performing" stations. Therefore the weekly WRMS (internal precision) of ILRS solutions is better than 1 cm when using the well performing stations. The SLR trend in the z-component and in scale, with respect to ITRF2000, might result from the fact that there is only one core ILRS site (Yarragadee: co-located with GPS and DORIS) in the Southern hemisphere. A new VLBI solution was provided by the IVS in November including all observations from 1980 on. The NASA SOLVE program had software problems in providing the NEQ for some sessions. For DORIS only the IGN and the LCA solutions were taken into account since a combined DORIS solution from the IDS was not available.

In total the new ITRF will comprise about 600 stations with the majority being GPS stations. EOP will include polar motion, UT1 (from VLBI) and LOD.

The Technique Centres' Analysis Coordinators will be informed about the results through a web site that is not accessible publicly.

Z. Altamimi promises a first "final" result in spring 2006. Because the data covers most of the year 2005 the new ITRF should be updated and named ITRF2005. The DB agreed with the renaming.

Consequences of ITRF2005: New polar motion/UT1/nutation series

Daniel Gambis characterized the current precision of various individual solutions with respect to other combined solutions. More critical than precision is the accuracy which reflects the real uncertainties of the solutions taking into account the inconsistency of the EOP system with respect to the terrestrial and celestial frames, inconsistencies, and systematic errors. In cooperation with IGN the CATREF software was used to derive polar motion, UT1 and LOD from a multi-technique combination of TRF and EOP. A first approach was given for corrections to align the C04 to the ITRF2005.

Based on these experiences the Earth Orientation Centre proposed to implement the new EOP solution based on ITRF2005 on 1 May 2006 with an extension of the combined solution to that date. The C04 would be then re-computed back to 1962 with all other combined EOP series (C01, C02) recomputed in the same frame. There would be a weekly update using CATREF for a combined TRF+EOP solution with a delay of some weeks. Moreover, the current computation based on techniques combined solutions (IGS, IVS, ILRS) and individual solutions would still be used for the permanent solution IERS C04 and prediction. After some discussion the IERS DB did not accept this new concept and will discuss the subject later again.

Possible "New Products and Structure of the IERS"

Markus Rothacher started this item on the agenda by giving his vision of new products and a future oriented structure of the IERS. Based on the experiences with the ITRF2005 and the WG on Combination possible future products could be:

- Multi-Year solutions (ITRF, EOP, ICRF – reprocessed high-accuracy combined long term intra-technique series),
- Weekly "Final" (EOPs, station coordinates – based on the "final" routine intra-technique combined products and the multi-year solutions),
- Daily "Rapid" (EOPs, station coordinates, (near real-time monitoring) – VLBI Intensive and IGS Rapid Products and, possibly SLR & DORIS),
- Daily "Predicted" (EOPs – combined daily rapid IERS products).

He proposed IERS Combination Centers (CCs) for multi-year, weekly "final" and daily "rapid" combined solution generation. The CCs should be selected through the usual IERS procedure, Call for Participation, asking institutions to apply for one or more of the combination tasks. Chopo Ma added that it is important to have more redundancy in the multi-year solutions, to include more institutions and make the IERS and the products more attractive for the outside users.

Claude Boucher emphasized that the IERS must continue to generate and document its unique products with a high consistency. Zuheir Altamimi stated that the IERS already has well defined products for the TRF, EOPs and CRF and that renewal of the basic products should be between 1 and 4 years. Both did not agree to weekly coordinate products because they did not see users or applications. For EOPs the situation is different.

In a lively discussion no common agreement was achieved and decisions were postponed.

Working Groups

William Wooden presented the concept of a new Working Group on Prediction. In a short presentation he explained the background, the goals, the expected outcomes, the organization and the schedule. The DB confirmed the working group.

John Dawson terminated his membership and his function as chair of the Working Group on Co-location because of other business obligations in Australia. Gary Johnston was proposed as the successor. Geoscience Australia will provide funds so that he can lead the working group and participate in meetings. Zuheir Altamimi will contact him to make the transition.

The Working Group on Datum Definition, a joint working group with IAG Commission I, was never set up. The proposed chair Geoff Blewitt is not willing to chair the administrative part of the working group. Because there is no urgent need the DB decided to close the effort in setting up this IERS working group.

Ad-hoc Committee for Leap Second

Due to a lack of time the presentation of Daniel Gambis was postponed to the next DB meeting.

Report of the Central Bureau

For the same reason the report of the CB was shortened. The DB encouraged the CB to create a concept for an IERS monograph. A workshop on geophysical fluids in Luxembourg, October 5–6, 2006, was supported by the DB.

Next IERS DB meeting

The next IERS Directing Board meeting will be in conjunction with the EGU General Assembly in Vienna, Austria. It will be a full day meeting held at the Technical University on April 8, 2006.

Bernd Richter, Wolfgang Schwegmann, Wolfgang R. Dick

3.2 Central Bureau

General activities

The IERS Central Bureau (CB), hosted and funded by Bundesamt für Kartographie and Geodäsie (BKG), organized and documented the IERS Directing Board (DB) Meetings No. 40, April 28, 2005, at Technical University Vienna, Austria, and No. 41, December 5, 2005, in San Francisco, USA. Between the meetings the CB coordinated the work of the DB.

The CB prepared an IERS Workshop on Combination, held October 10–11, 2005, at GeoForschungsZentrum Potsdam, Germany. 58 specialists took part in this workshop. The presentations were published at the IERS web site. For a summary see Section 4.

The CB presented the activities of the IERS with oral and poster presentations at the IAG Assembly in August 2005 at Cairns, Australia, at the Meeting of the Forschungsgruppe Satellitengeodäsie (FGS) in September 2005 at Kötzting, Germany, and at the IERS Workshop on Combination. In May 2005 B. Richter took part in a UNESCO Meeting in Paris about the future of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and gave a report on the IERS. The CB prepared an IERS report for the period 2002–2005 to IAU Commission 19.

IERS components maintain individually about 20 separate web sites. The central IERS site <www.iers.org>, established by the CB, gives access to all other sites, offers information on the structure of the IERS, its products and publications and provides contact addresses as well as general facts on Earth rotation studies. It contains also electronic versions of IERS publications, a list of meetings related to the work of the IERS, and an extended link list for IERS, Earth rotation in general and related fields. Throughout 2005 the web site was regularly enlarged and updated. By the end of 2005, work on a new layout and new organization of the web site was finished (see below).

The “Proceedings of the IERS Workshop on site co-location” (edited by the Central Bureau) were published as IERS Technical Note No. 33 in online and printed forms. The IERS Annual Report 2003 appeared in printed form. The CB published also the IERS Annual Report 2004 in online form. It appeared in December 2005 in the form of PDF files for download from the web site. Along with the reports of the IERS components, it contains information on the IERS compiled by the CB.

During the year 2005, 13 IERS Messages (Nos. 67 – 79) were edited and distributed. They include news from the IERS and from related services as well as announcements of conferences.

Address and subscription information has regularly been updated in the IERS user database. There were about 2500 users in 2005 with valid addresses who subscribed to IERS publications for e-mail and regular mail distribution.

Several questions from IERS users concerning IERS publications and products as well as Earth rotation and reference frames in general were answered or forwarded to other specialists. Also requests from journalists concerning the future of the UTC timescale were answered.

IERS Data and Information System

The new IERS Data and Information System is running in operational mode since the end of 2005. The content of all web pages of the old information system has been transferred to the new system and all links to old web pages are being forwarded automatically to the appropriate new web pages. The new system presents information related to the IERS and the topics of Earth rotation and reference systems. As the central access point to all products of the various IERS Product Centres it provides tools for search within the products (data and publications), to work with the products and to download the products.

The concept of the dynamic and database-driven IERS Data and Information System is based on the application of the eXtensible Markup Language (XML) and the generation and administration of ISO standardised metadata. XML can be regarded as the future standard format for data and information exchange over the web. Using XML the heterogeneous products of the IERS in their various formats can be consistently described based on one common markup language. Moreover, despite their originally heterogeneous formats all products can now be merged easily for further investigations. From these data files extended metadata are extracted and stored in the database for search and for the description of the available datasets. Additionally, the metadata can be explored by international meta information systems to enlarge the user community of IERS products. Aside the original standard file output, the data and information can be presented in multiform, e.g., html, pdf, ascii, or in any format that might be requested from the user community.

The whole process to incorporate new product versions into the system – i.e. downloading data files from the responsible IERS Product Centre, transforming them into XML, extracting metadata, and storing all information into a database – is being done automatically. The web pages to present the available product versions and the associated information like the metadata are being created automatically from the information stored in the database. The system is completed by an Administration Tool providing all necessary instruments to maintain the data and information.

The most important characteristics and functionalities of the IERS Data and Information System are:

- Dynamic generation of web pages, i.e. the content is being read from various MySQL databases like the product, web page, and address databases; thus the consistency, actuality and non-redundancy of the presented information can be guaranteed.
- The numerous databases (address, web site, product, meeting, workshop, metadata databases, etc.) are maintained by an Administration Tool.
- Availability of all IERS products from a central server in consistent formats, realised by one common technique, i.e. the eXtensible Markup Language (XML).
- Full text search as well as metadata search.
- On-line form to order products and distribution lists for the transmission of new product versions of ordered products.
- Automatic import of new product versions, transformation to XML and extraction of metadata.
- Management of e-mail exploder lists.
- Automatic forwarding of calls to URLs of old web pages to the respective URLs within the new web site.

Moreover, the IERS Data and Information System serves as reference data centre for the ITRF 2005 input data and guarantees the sustainable availability of the data.

A concept for a Plot Tool has been developed, in order to allow the user to visualise data from the various available products online. If reasonable, datasets can be presented in one plot and compared to each other. The data for the plots are being extracted from the product versions by using the XML format descriptions of the products. Likewise, the XML format description is being used by the administrator to define in beforehand which data from which products are available for a plot and which plot configurations are meaningful. The visualisation module provides all defined plot configurations to the user, who can choose a specific presentation from the available pre-defined configurations. The Plot Tool is expected to be available in mid 2006.

Publications

Dick, W. R.; Richter, B.; Schwegmann, W.: The ICRS and the IERS information system. In: O. Engvold (ed.), Highlights of Astronomy, Vol. 13, San Francisco, CA: ASP, 2005, p. 609

Richter, B.; Schwegmann, W.; Dick, W. R. (eds.): Proceedings of the IERS Workshop on site co-location. Matera, Italy, 23 – 24 October 2003. (IERS Technical Note; No. 33) Frankfurt am Main: Verlag des BKG, 2005. 148 p.

Richter, B.; Schwegmann, W.; Dick, W. R.: Development of an Information and Database System for the IERS: Status and outlook. Journal of Geodynamics 40 (2005) 487–493.

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3.3 Analysis Coordinator

Activities towards Future IERS Products

The analysis campaigns and pilot projects (IERS SINEX Combination Campaign, IERS Alignment Campaign, IERS Combination Pilot Project, IERS Long Time Series) during the last few years revealed that the IERS, as a service for data and products concerning Earth orientation/rotation and reference systems, cannot fully satisfy the demanding users in geodesy and geodynamics with the products presently available. The main goal for all the IERS products must be to reach as much consistency as possible between the products, especially between Earth orientation parameters and terrestrial and celestial reference frames. In order to achieve this goal, it is not adequate any longer to derive the official IERS products ITRF, ICRF and EOP independently from each other.

A first step towards more consistency is the IERS Combination Pilot Project (CPP) that started already in 2004 (see the IERS Annual Report 2004 for more details). The intention of the CPP is to derive combined inter-technique solutions on a weekly basis including at least station coordinates and Earth rotation parameters. The major achievement of the CPP up to now is that each of the technique services (except IDS) provides a combined solution based on the weekly SINEX files of the individual analysis centres on a routine basis. Unfortunately, the next step, i.e., a weekly inter-technique solution generated routinely is not yet realized.

Another step to make available consistent reference frames and EOP is the generation of the ITRF2005. ITRF2005 will contain station coordinates, velocities and daily pole coordinates altogether for the first time of an ITRF solution.

Both of the new developments within the IERS mentioned above match perfectly into the four different types of future IERS products that are thought to be fully or partly realized within the next years:

- Multi-year solutions for consistent ITRF, EOP and ICRF
- Weekly final solutions to generate combined EOP series on a routine basis
- Daily rapid combined solutions for EOP
- Predicted EOP for real-time users based on combined products

The ITRF2005 belongs to the first type of new products listed above, although it is restricted to a combined solution with only a subset of the five EOP. Nevertheless, a yearly or 2-yearly update of such long-time series is very important in order to:

- Include the data from the most recent year (especially for improving the coordinates and velocities of more recent sites and for generating highly consistent and accurate EOP series including the latest year)

- Take into account the improvements in the data analysis concerning the modelling
- Allow for improvements in the parameterization
- Combine additional common parameters, e.g. troposphere zenith delays

In order to bridge the time span between the latest and the forthcoming multi-year solution, the weekly final solutions should be generated as a second new product type. They coincide in principle with the inter-technique combination in the CPP. Their main purpose is providing accurate combined EOP estimates that can be used as a consistent continuation of the latest multi-year solution.

A further reduction of the time delay of IERS combined products can be achieved by providing daily rapid combined solutions. It became obvious that there is a need for monitoring the EOP, the terrestrial reference frame and especially the individual station coordinates in near real-time (Earthquakes, tsunamis, …). At the moment, the IGS is the only service generating rapid products. But in the context of daily rapid solutions, the VLBI intensive sessions are of great interest, e.g., for combining them with the already existing IGS rapid products (contribution of UT1 by VLBI).

The fourth product type is not completely new, as the IERS already provides predicted ERP time series. However, in future, the prediction should be based on the combined rapid inter-technique solutions or at least on the rapid technique-specific solutions instead of the confusing mixture of solutions belonging to different combination levels. Furthermore, as a long-term goal, it should be envisaged to provide daily updated predictions in order to increase the timeliness.

The main characteristics concerning parameter types, latency, generation cycle and computation strategy of the planned future IERS products are summarized in Tab. 1.

It is clear that the present structure of the IERS may have to change, if the IERS undergoes the change from the actual products to the new product types explained above. Especially the division into separate product centres for ITRF, ICRF and EOP will become meaningless if the transition to combined products is fully performed. Therefore, the establishment of “IERS Combination Centres” is proposed for the routine generation of the new IERS products.

The plan for future IERS products and an adapted structure of the IERS components has been presented at the IERS Workshop on Combination at GFZ Potsdam in October 2005 by the IERS Analysis Coordinator together with the chair of the IERS Directing Board (see IERS Technical Note 35).

Meetings and Workshops on Combination Issues

- IERS Working Group on Combination and CPP Meeting during 2nd EGU General Assembly, Nice / France, April 2005
- IERS Workshop on Combination, GFZ Potsdam / Germany, October 2005. Papers are available in the IERS TN 35.
- Meetings with a session dedicated to combination of space geodetic techniques: EGU General Assembly, Nice / France, April 2005

Table 1: Four different types of future IERS products.

Product Type	Main Parameters	Generation Cycle	Maximum Latency	Based on
Multi-Year	ITRF EOPs ICRF	Yearly	Maximum 1 year	Reprocessed high-accuracy combined long term intra-technique series
Weekly “Final”	EOPs Station Coordinates	Weekly	2 weeks	Based on the “final” routine intra-technique combined products and the multi-year solution
Daily “Rapid”	EOPs Station Coordinates Troposphere Param.	Daily	1 day	VLBI Intensives and IGS Rapid Products and …
Daily “Predicted”	EOPs	Daily	1 day	Combined daily rapid IERS products

Markus Rothacher, Daniela Thaller, Robert Dill

3.4 Technique Centres

3.4.1 International GNSS Service (IGS)

General

From its mission statement, the IGS is committed to provide the highest quality GPS+GLONASS observation data and products, openly and readily available to all user communities, as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multidisciplinary applications, and education. The IGS products support scientific objectives including realization of the International Terrestrial Reference Frame (ITRF) and its easy global accessibility, monitoring deformation of the solid Earth, monitoring Earth rotation, monitoring variations in the hydrosphere (sea level, ice-sheets, etc.), satellite orbit determination, ionosphere monitoring, climatological research, and time and frequency transfer. Table 1 gives an overview of the estimated quality of the IGS core products at the end of 2005.

Table 1: Quality of the IGS Core Products as of December 2005 (for details and further products see <http://igscb.jpl.nasa.gov/components/prods.html>)

Product	IGS Final	IGS Rapid	IGS Ultra Rapid	
			Adjusted	Predicted
Updates	Weekly	Daily	Every 6 h	Every 6 h
Delay	~13 days	17 hours	3 hours	Real-time
Orbits	2cm	3 cm	< 5 cm	<10 cm
Satellite Clocks	0.05ns	0.1 ns	~0.2 ns	~5 ns
Station Clocks	0.05ns	0.1 ns		
Polar Motion	0.05 mas	<0.1 mas	0.1 mas	
LOD	0.02 ms/day	0.03 ms/day	0.03 ms/day	
Station Coordinates (h/v)	3 mm / 6 mm			

Tracking Network

In 2005 another 8 sites were added to the IGS network reaching now a total of 379 sites (<http://igscb.jpl.nasa.gov/network/netindex.html>). This is the first decrease ever from 383 in 2004, due to a shift in policy to require a demonstrated benefit to a product or project, not just meeting the operational requirements of the IGS, in order to admit a station to the IGS network. In addition to the usual data transfer in daily batches, more than 200 sites (see Fig. 1) have already set up an hourly data transfer to support the IGS Ultra Rapid products and products for e.g. regional applications of various user groups, especially for near-real time tropospheric and ionospheric monitoring. A network of high-rate stations supporting Low Earth Orbiter missions (like CHAMP and GRACE) is also available for the scientific user community.

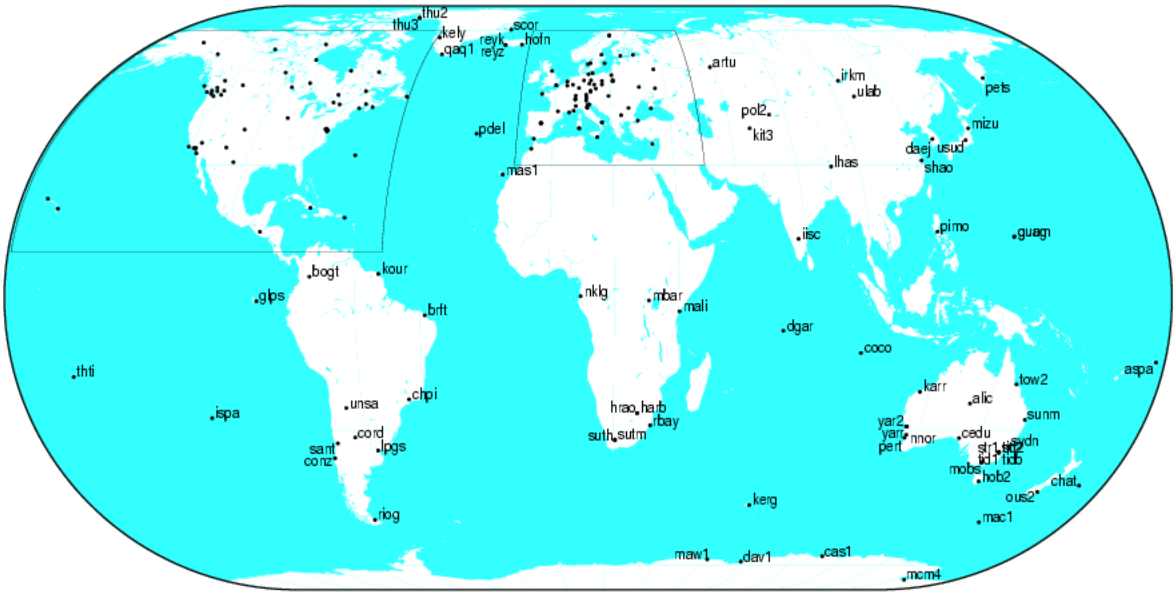


Fig. 1: IGS tracking network with hourly stations

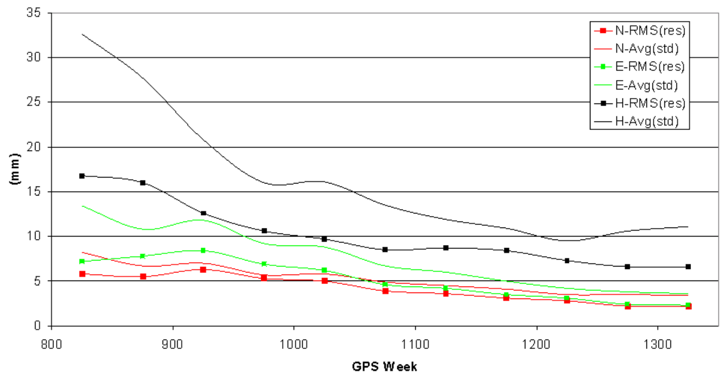
IGS contribution to ITRF2005

Weekly SINEX solutions were available starting 1996 (GPS week 837) including the following information:

- from 1996/01/21 to 1999/02/27 (837 – 998): Solutions only included station coordinates.
- from 1999/02/28 to 1999/06/05 (999 – 1012): Apparent geocenter was included
- since 1999/06/06: ERPs were included

The gradual increase of the number of stations, from about 100 in 1996 to more than 200 at present, was also accompanied with an improvement of the quality of the solutions. The time evolution statistics for the North, East and Up components for the weekly station coordinates residuals show an improvement of a factor of about 4–5 between 1996 and 2005 (Figure 2). The precision is currently at 3 mm horizontally and 6 mm vertically. Several factors are contributing to this gradual station coordinate precision improvement, namely: (1) improving station hardware, (2) processing software, and (3) gradual increase in the number of stations processed.

Fig. 2: Time evolution of residuals RMS and average Standard Deviation



One recommendation of the 2004 IGS Bern workshop was to prepare an inventory of station coordinate time series discontinuities. A list of confirmed as well as a lists of probable discontinuities were prepared. The discontinuities are considered confirmed when they are present in most time series and/or can be correlated to an equipment change or a geophysical event. For events before 1996 (the start of the IGS time series), JPL and SIO were the main sources of information. The IGS station logs were also used to attempt to correlate discontinuities with equipment changes. Attempts were also made to correlate time series discontinuities with earthquakes based on data available at the USGS earthquake center. Useful feedback was also provided by Dr. Pagarette from the University of Lisbon who shared his predictions of station displacement from recorded seismic information. The EUREF and NAREF groups also provided feedback using their time series analysis. This should ensure a high degree of consistency in the applied discontinuities between the global and regional solutions. There was also feedback from IGN and DGFI following preliminary combinations. More recently, Technical University of Munich (TUM) discontinuity information derived from their reprocessed GPS solutions was also provided and compared to the existing discontinuity list and time series. Events such as temporary excursions of station coordinates were not flagged. Some short station coordinates time series were flagged for deletion. There is some subjectivity in the identification of small discontinuities, which is, to some extent, “analyst” dependant.

Analysis Issues

Last year the quality of the submitted GPS orbit products have improved significantly by several Analysis Centers (AC) so that the overall consistency among all ACs is now better than 5 cm, 7 cm and 15 cm for the GPS Final, Rapid and predicted orbits, respectively.

For the GLONASS combination the pilot phase has ended and the official products are offered since December 2004. Four ACs (COD, BKG, ESA, since August 2005 also IAC) are contributing with analysis of GLONASS microwave data and one (MCC) with the analysis of laser data for 3 satellites. The later solution is used for validation only. The names of all products were switched from IGEX (igx) to IGLOS (igl). COD is the only AC analyzing combined GPS and GLONASS data in a rigorous way. The GLONASS orbit consistency is at a level of 5 to 10 cm.

Since February 2004 the IGS official satellite and station clock products have been aligned to a new, highly stable timescale realized by an internal ensemble of the available frequency standards dynamically weighted based on their individual instabilities. Both a Rapid (IGRT) and Final (IGST) timescale are formed with latencies of about 1 day and two weeks, respectively, and both are aligned to Universal Coordinated Time (UTC). All results and a variety of associated plots can be accessed at <https://goby.nrl.navy.mil/IGStime/index.php>. In addition to their value for clock diagnostics, these products can be used to monitor the general health of GPS tracking stations. The high stability of the IGS timescale ensures that day-boundary jumps in the station clock can be detected to better than 100 ps RMS. In determining the GPS TAI time links using a new "all-in-view" technique the BIPM is utilizing the IGS clock products and the IGS timescale in particular.

Since 2004 a new IGS Final Troposphere Product, which is based on the Precise Point Positioning (PPP) technique using the official IGS Final orbits and clocks, is provided. The PPP technique allows the generation of this product for all the available stations in the global IGS network and enables also an efficient consistent reprocessing of historical data (at present the new products are available back to 2000).

The IGS is discussing a switch to absolute calibrated antennas since the IGS Workshop in Ottawa. Those absolute models for GPS receiver antennas are available since several years and show a good consistency with values of the relative models. However, to avoid a scale bias in the TRF its introduction has to be accompanied with compatible models for the satellite antennas. Such models were derived by a common effort of GFZ and TUM, and in addition compatible GLONASS models were added by CODE. It is expected that the new model will give no scale change in the TRF and especially no significant scale drift by changing satellite constellations, as it is the case with the present model. Because any change in antenna parameters may have a significant impact on derived station heights, those changes have to be prepared very carefully. At the same time the IGS will start to apply the available radome calibrations, which will result in station coordinate changes too. Since June 2005 the IGS is running a test campaign for the new models (1) to test and validate the implementation in the software packages, (2) to study the effects on the IGS products, and (3) generate a new compatible RF. It is planned that the new absolute model will be officially adopted after the release of the ITRF2005.

The IGS is preparing a reprocessing of historical GPS data. A working group was established (1) to define the scope of the products and the data span to be included, (2) to work out a guideline for the processing strategies and standards, and (3) to call for participation and encourage involvement from the user community. The project will start after the adoption or the new absolute antenna model and the release of ITRF2005. Part of the project is an effort to complete the raw RINEX data archives.

Summary

In 2005, as in the previous years, the IGS contributed significantly to the IERS activities like maintenance and extension of the International Reference Frame and in the highly-accurate, daily-sampled Earth Rotations Parameters. The quality of the IGS products has further improved. The IGS is preparing for two major activities, the transition from the relative to the absolute antenna phase center models and the reprocessing of historical IGS data. For more detailed information on further IGS activities visit the web site at the Central Bureau at JPL (<http://igscb.jpl.nasa.gov>) or the Analysis Coordinator web pages at GFZ (<http://www.gfz-potsdam.de/igsacc>).

References

2003-04 Technical Report. IGS Central Bureau, eds. Pasadena, CA: Jet Propulsion Laboratory, 2005.

2003-04 Annual Report. IGS Central Bureau, eds. Pasadena, CA: Jet Propulsion Laboratory, 2005.

These documents are also available electronically at <http://igscb.jpl.nasa.gov/overview/pubs.html>.

Gerd Gendt, Angelyn Moore, Remi Ferland

3.4.2 International Laser Ranging Service (ILRS)

Introduction

The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of SLR/LLR missions, technique development, operations, analysis and scientific interpretation. A number of these aspects will be discussed here briefly.

Network

The network of SLR/LLR stations, under the aegis of the ILRS, has been subject to change over the years. From a technical perspective, the quality of the observations has improved drastically during the past decade. At this moment, the single-shot precision of an average station is better than 10 mm (the best stations go well below that number). Also, the absolute quality of the individual observations is at the 10 mm level, with a significant number of stations doing better.

The geometry of the SLR network has been a point of concern over the years. However, at this moment the layout of the network is in better shape (cf. Figure 1). Although the network has been

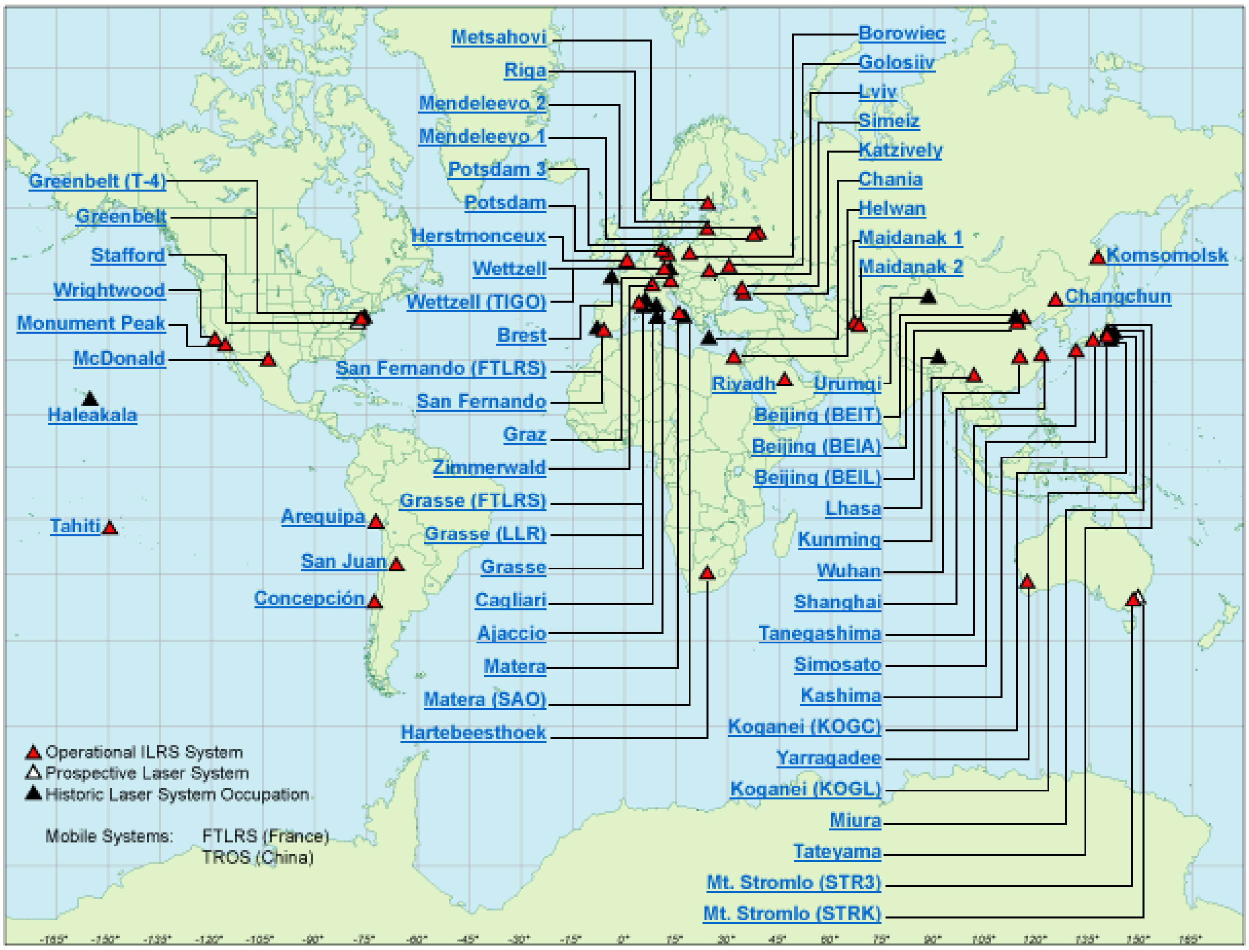


Figure 1: The global network of SLR stations (status early 2006).

dominated traditionally by stations in the Northern Hemisphere, the Southern Hemisphere now contains a number of high-quality stations, that have come on line recently or that have developed and proved themselves over the past few years. In French Polynesia, Tahiti is coming back on line; in South America, Arequipa is returning soon whereas Concepcion and San Juan are in operational service; in South Africa, Hartebeesthoek has proven itself to be a highly reliable, top-quality and productive station; and in Australia the station Mt. Stromlo is a role model for modern, autonomous operation. The contributions from stations in the Southern Hemisphere are of course complemented by the activities of Yarragadee, at the West coast of the continent, which has been the number one station in the network on many different aspects for a long time.

Missions

In 2004, a total of 29 satellites (including the Moon) were being laser-tracked. In 2005, 5 new SLR targets were orbited: on August 23, the Japanese satellite OICETS was put into orbit. On December 25, the trio Glonass-98, Glonass-99 and Glonass-100 was launched. The fifth satellite that is new in 2005 is the first test satellite of the future European satellite navigation system Galileo: GIOVE-A, launched on December 28. Clearly, the emphasis of these new missions is on navigation. All spacecraft, including these 5 newcomers, are regularly if not intensively tracked, depending on mission demands.

Noteworthy in this context is the fact that ICESat and ALOS, recently launched downward-looking satellites, have challenged the SLR network with several special requirements (any interference between the laser signal and the instrumentation is to be avoided). Many stations have responded quickly and carefully and are now compiling a good record of observational passes on both these targets.

Analysis and science

In combination with improvements in modeling the various entries in the range equation (satellite signature, tropospheric delay, etcetera) SLR provides an extremely valuable and unique tool to relate (the center-of-mass of) satellites to reference points on the Earth's surface with unprecedented absolute accuracy. The SLR observations find their way into many studies at the edge of our knowledge: crustal deformation (reference frame, origin, scale, motions), gravity field (direct inversion and/or calibration of solutions derived with other techniques), oceanography (sea-level change, tides), earth rotation (observation of relevant parameters), orbital mechanics (satellite motion). A number of these aspects will be elaborated hereafter.

Some ILRS analysis products are of particular interest to IERS. In particular, SLR plays an important role in the assessment of the

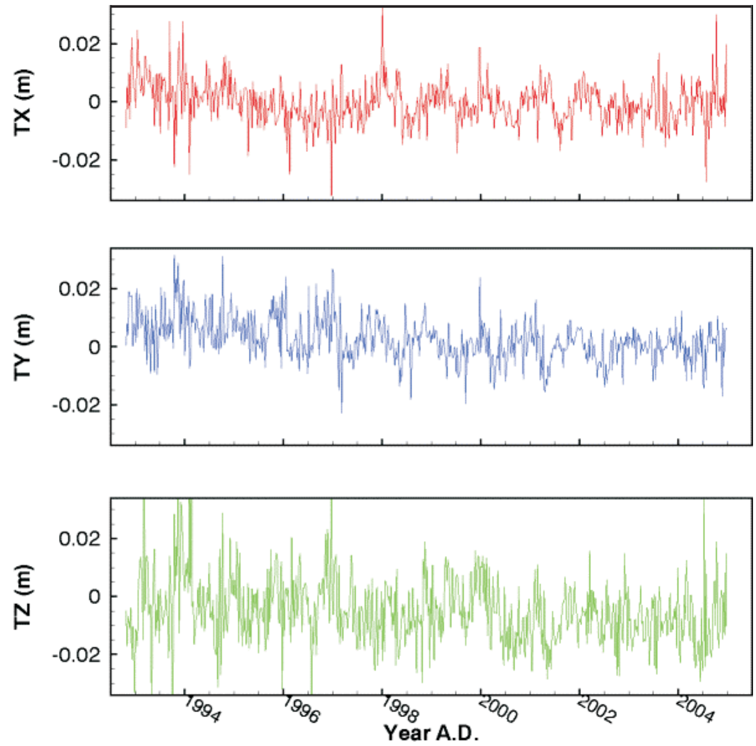


Figure 2: Time-series of solutions for geocenter as observed by with the SLR technique (covering 1993.0 – 2005.0) (courtesy of GFZ).

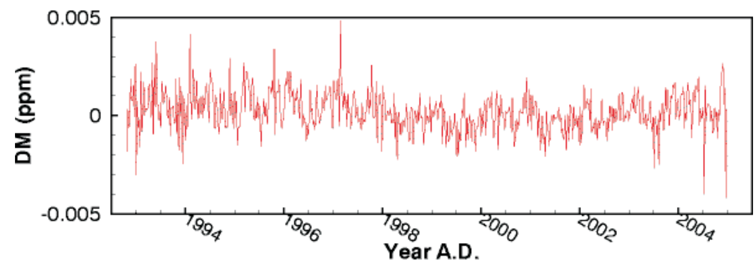


Figure 3: Time-series of solutions for global scale as observed by with the SLR technique (covering 1993.0 – 2005.0) (courtesy of GFZ).

terrestrial reference system, since the laser technique provides unique information on the exact location of the Earth's geocenter and (shared with VLBI) absolute scale.

Specifically, the ILRS Analysis Working Group (AWG) coordinates the generation of a number of relevant data products. Since 2003, the AWG produces weekly time-series of solutions for station coordinates (and their derivatives geocenter and scale) and Earth Orientation Parameters (EOPs; more specifically: x-pole and y-pole and excess Length of Day). These solutions are based on

SLR data taken on the satellites LAGEOS-1, LAGEOS-2, Etalon-1 and Etalon-2. Individual solutions are computed by 6 different institutes: ASI/Italy, BKG/Germany, DGFI/Germany, GFZ/Germany, JCET/USA and NSGF/UK. Next, these solutions are merged into two combination solutions, which is done by ASI (responsible for the official ILRS primary combination product) and DGFI (the official backup combination product center). The organization (of generating these solutions) is such that the backup institute is able to take over the role of the primary institute at any time. Such solutions are generated on a weekly basis, and are available on each Tuesday.

The combination solutions are used for a variety of purposes: the IERS Combination Pilot Project, the IERS/NOAA Bulletin A, etc. A very important target for their use is the new IERS ITRF2005 solution, which will be based on input from all 4 geodetic services, but with a primary role for SLR when it comes to defining origin and (shared with VLBI) global scale.

To improve the strength, value and reliability of its contribution, the ILRS has started an effort to extend the time-series of such solutions, and by the end of 2005 has been able to deliver similar solutions for the period from January 1, 1993 onwards. A clear illustration of the solutions is shown in Figures 2 and 3: these show the time-series of geocenter components and global scale, respectively. Seasonal effects are visible, but systematic effects are absent. The root-mean-square (RMS) of the geocenter positions and scale is 8.1 mm, 7.5 mm, 12.4 mm and 1.1 ppb, respectively.

Although not directly relevant to the new ITRF2005 product, the ILRS AWG has decided to extend the time-span of the solutions even further: an effort has been started to go back to September 1983, the onset of the so-called MERIT campaign (“Monitor Earth Rotation and Intercomparison of Techniques”). However, recognizing the reduced number of satellites available, the geometry of the network, the quality of the observations and other aspects, this re-analysis cannot be expected to result in data products that are of similar quality and resolution as what is being obtained from contemporary SLR observations. Nevertheless, this analysis effort will extend the time-span to 20+ years, and will provide valuable information on some of the most crucial elements of (understanding and describing) System Earth.

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3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2005, IVS continued to fulfill its role as a service within the IAG and IAU by providing necessary products for the maintenance of global reference frames: ITRF, ICRF and EOP. In May 2005 IVS held its third Technical Operations Workshop at Haystack Observatory, Westford, MA, USA. Two IVS Directing Board meetings were held, one in April at Noto Observatory, Noto, Italy, and the other in September at USNO, Washington, DC, USA. IVS published its 2004 Annual Report in April 2005 and published three newsletter issues which keep the community informed about IVS activities. The IVS continued the systematic monitoring program of CRF sources to support the re-determination of the ICRF. The third IVS Working Group, chaired by Alan Whitney and Arthur Niell, finalized its work and prepared a final report on a vision for VLBI in 2010 (Niell et al., 2005). The report, which will serve as a guideline for the establishment of the next generation VLBI system, was approved by the Directing Board at its September meeting and a printed version can be obtained from the Coordinating Center upon request. The VLBI2010 Working Group was closed at the September Board meeting. At the same meeting the standing committee “VLBI2010 Committee”, chaired by Bill Petrachenko, was created and was tasked with encouraging the implementation of the recommendations of the VLBI2010 Working Group.

Network Stations

A total of 1344 station days were used in 187 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.5 days per week, similar to previous years. The number of station days increased with respect to the previous year due to the observation of the two-week long continuous VLBI campaign 2005 (CONT05). The major observing programs during 2005 were:

IVS-R1, IVS-R4

Weekly (Mondays and Thursdays) 24-hour, rapid turnaround measurements of EOP. Data bases are available no later than 15 days after each session. These sessions are coordinated by NASA Goddard Space Flight Center (R1) and the U. S. Naval Observatory (R4).

Intensive

Daily 1-hour UT1 Intensive measurements are made on five days (Monday through Friday) on the baseline Wettzell (Germany) to Kokee Park (Hawaii, USA) and on weekend days (Saturday and Sunday) on the baseline Wettzell (Germany) to Tsukuba (Japan). The daily sessions are recorded using Mark 5 (Wettzell-Kokee) and K5 (Wettzell-Tsukuba) technology. Comparisons of the two series showed good agreement with the IERS C04 series.

CONT05 A fifteen day campaign of continuous VLBI sessions, observed in the second half of September 2005 and coordinated by the IVS Coordinating Center at NASA Goddard Space Flight Center. The goal of the campaign was to acquire state-of-the-art VLBI data over a two-week period to demonstrate the highest accuracy of which VLBI is capable.

IVS-T2 Bi-monthly sessions coordinated by the Geodetic Institute of the University of Bonn with 16 stations per session. These sessions were observed to monitor the TRF and all stations were scheduled at least 3–4 times during the year.

IVS-E3 Monthly sessions using the Canadian S2 technology, coordinated by Natural Resources, Canada, designed to measure EOP and monitor TRF. The Canadian mobile antenna occupied a location at St. John's (Newfoundland) all year.

IVS-CRF, IVS-CRD The Celestial Reference Frame (CRF) sessions and the CRF deep-south (CRD) sessions, both coordinated by the U.S. Naval Observatory, provide astrometric observations that are useful in improving the current CRF and in extending the CRF by observing "new" sources. Fifteen sessions were observed for the maintenance of the ICRF in 2005 primarily in the southern hemisphere. Nine of them were scheduled with emphasis on the far southern hemisphere (CRD).

VLBA The Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO), continued to allocate six observing days for astrometry/geodesy. These sessions included the 10 VLBA stations plus up to 10 geodetic stations, providing state-of-the-art astrometry as well as information for mapping ICRF sources.

Europe The European geodetic network, coordinated by the Geodetic Institute of the University of Bonn, continued with four sessions in 2005.

IVS-OHIG The IVS-OHIG (Southern Terrestrial Reference Frame) series, coordinated by the Geodetic Institute of the University of Bonn, was continued with six sessions in 2005. By optimally tying together the sites in the southern hemisphere a very accurate regional TRF around the South Pole is obtained.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions.

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had 12 sessions. These sessions included the dedicated 32-m dish at

Tsukuba and are designed to monitor the domestic network within the ITRF.

IVS-R&D

Ten sessions were observed in 2005 using Gbit/s recording rates to demonstrate the highest data rate available today.

The Network Coordinator's data base of station performance showed a data loss of 14.4%, slightly worse (2%) compared to 2004, but has returned to the level of loss seen in 2003. The most significant causes of data loss were antenna reliability (about 25%), receiver problems (24%), recorder problems (9%), and RFI (6%).

Correlators

The correlators at Haystack Observatory (USA), the U.S. Naval Observatory (USA), and at Max-Planck Institute for Radioastronomy (Germany) continued to expand their processing of data recorded on Mark 5 disk media, with a corresponding increase in efficiency. Some 24-hour sessions can now be correlated in less than a day.

Data Centers

The IVS Data Centers continued to receive data bases throughout the year and made them available for analysis within one day of correlation. The Data Centers also continued to receive solutions from Analysis Centers. All data and results holdings are mirrored several times per day among the three primary IVS Data Centers.

Analysis Coordinator

In early 2005, several realizations of terrestrial reference frames (TRF) have been made available by different IVS Analysis Centers, i.e. by Deutsches Geodätisches Forschungsinstitut (DGFI) in Munich, Germany, using the OCCAM VLBI software together with a DGFI combination program called DOGS-CS, by Geoscience Australia (GA), Belconnen, Australia, using the OCCAM software with a Kalman Filter setup, by the Main Astronomical Observatory (MAO), Kiev, Ukraine, with the software package SteelBreeze as well as by Bundesamt für Kartographie und Geodäsie (BKG) and NASA Goddard Space Flight Center (GSFC) both using the Calc/Solve software package. A combination has been carried out on the basis of coordinates, velocities and their formal errors mapping them onto the ITRF2000 datum using only those sites which carry the largest amount of the observing load today (Nothnagel, 2005a). The resulting coordinates and velocities (VTRF2005) are now widely used for EOP and atmosphere parameter estimation.

During 2005 quite some effort was invested into the ITRF2005 project in order to deliver combined datum free normal equations of all high precision geodetic VLBI sessions to the IERS in SINEX format. Datum free normal equations are the purest way of transferring the inherent information of the solutions like the covariances to further combination steps. Unfortunately, software packages which do not use normal equations, e.g. Kalman filter and Square Root Information filter software, cannot yet produce some of the statistical information which is necessary for the combination on the basis of normal equations. For this reason the combination had to be restricted to contributions which use least-squares algorithms based on the solution of normal equations.

The “Sixth IVS Analysis Workshop” was held at Noto, Italy, on May 21–22, 2005. Detailed information on the presentations and discussions can be found in Nothnagel (2005b).

Technology Development Centers

Routine use of e-VLBI continued to grow. All data recorded on the Japanese K5 systems at Tsukuba and Kashima were transferred via e-VLBI to Haystack Observatory, where it was transferred to Mark 5 disk modules and sent to target correlators at Haystack, USNO or MPIfR. Approximately 100 TB have been transferred over the last year, including all Tsukuba data from the CONT05 experiment. The weekday UT1 Intensive data from Wettzell were transferred via e-VLBI to a site near USNO in Washington, D.C., where it was picked up and taken to USNO for correlation. Wettzell’s weekend UT1 Intensive data were e-transferred to the correlator at the Geographical Survey Institute, Tsukuba, Japan.

Transfer rates, especially across international networks continued to improve. Japan–U.S. transfer rates as high as ~900 Mbps have been observed, with sustained rates as high as ~700 Mbps. Real-time e-VLBI experiments were conducted within the U.S. and between Europe and U.S. In November 2005 a successful 3-station real-time e-VLBI demonstration was conducted by sending data at 512 Mbps from Westford, GGAO and Onsala to the Mark IV correlator at Haystack Observatory. The biggest impediment to rapid e-VLBI expansion continues to be station connectivity to high-speed networks, but the situation is improving. Tsukuba, Kashima, Onsala, Westford and Medicina are all connected with 1 Gbps links, though some issues remain in actually using some of the links at full speed. Wettzell is connected at ~30 Mbps and TIGO at ~2 Mbps. Projects are underway to connect Ny Ålesund, Hobart, Fortaleza and Svetloe in 2006.

A reference implementation of the proposed international standard for VSI-E (VLBI Standard Interface for E-VLBI) specification has been developed. The VSI-E framework provides signaling, control, framing and statistics support and is an extension to the Internet standard RFC3550. Life testing of VSI-E was initiated between Kashima and Haystack as an ideal testbed since Kashima employs the K5 system whereas Haystack uses Mark 5A, enabling testing on heterogeneous systems. Once the reference implementation is fully checked out, attention will be turned to optimizing the code for high-speed operation and broader deployment.

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Nothnagel A. (2005a): VTRF2005: A Combined VLBI Terrestrial Reference Frame; In: Proceedings of the 17th Working Meeting on European VLBI for Geodesy and Astrometry, held at Noto, Italy, May 21–22, 2005, edited by M. Vennebusch and A. Nothnagel, 2005, 118–124

Nothnagel A. (2005b): Summary of the Sixth IVS Analysis Workshop. (http://vlbi.geod.uni-bonn.de/IVS-AC/workshop2005/)

Dirk Behrend, Axel Nothnagel

3.4.4 International DORIS Service (IDS)

General

The IDS website URL is <http://ids.cls.fr>. The IDS Terms of Reference are available at <http://ids.cls.fr/html/organization/tor.html>. The present organization of the IDS is similar to that of the other technique-oriented services. It is described at <http://ids.cls.fr/html/report/Organization_IDS_030701.pdf>.

Network

The DORIS permanent network is shown on Figure 1. Site logs are available at <http://ids.cls.fr/html/doris/sitelog.html>.

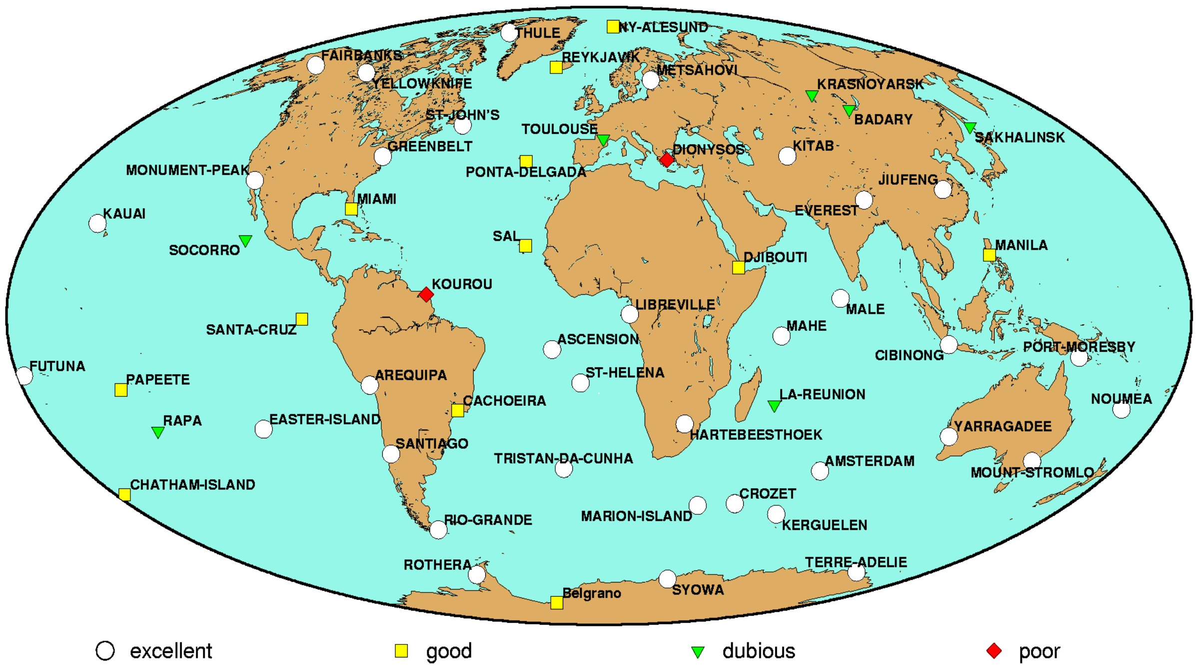


Fig. 1: Estimated stability of the DORIS permanent stations (January 2006)

The stations rejuvenation program initiated in 2000 was continued, as illustrated in Figure 2. In 2005 the following stations were renovated in order to improve the long term stability of the antenna support:

- Rothera (British base in Antarctica)
- Belgrano (Argentine base in Antarctica). This station, initially installed in 2004 following a joint AWI-IAA proposal to the IDS, is now included in the DORIS permanent network thanks to its excellent results.
- Nouméa (New-Caledonia)
- Libreville (Gabon)

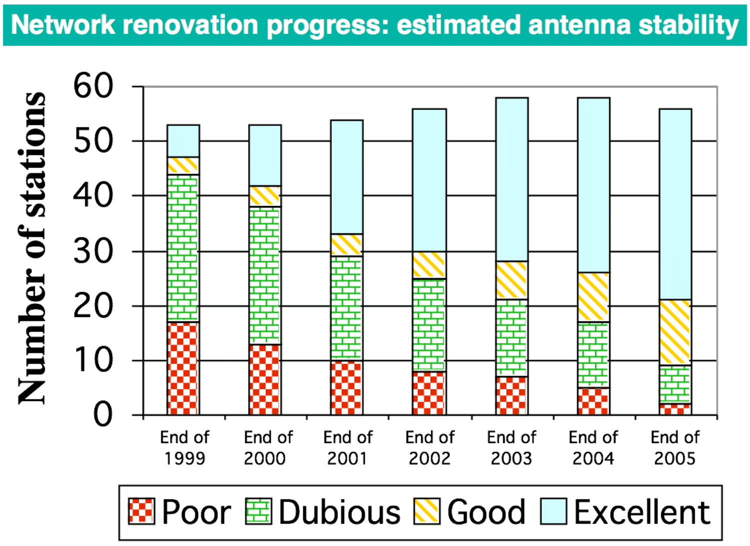
Moreover, the following new stations were installed:

- Male (Maldives), replacing Colombo
- Santa Cruz (Galapagos, Ecuador), replacing Galapagos

- Monument Peak (California, USA), replacing Goldstone

The total number of DORIS stations is down to 56, but this apparent decrease takes into account the official removal of several stations which actually had stopped transmitting several years ago. At the end of 2005, 47 out of 56 stations (in the permanent orbitography network) are considered to have good or excellent stability. We note that the VLBI operations closure at Fairbanks in 2005 has not resulted in the closure of the DORIS station there since the IGN has reached an agreement with the host agency (NOAA).

Figure 2: DORIS permanent network renovation



The status of co-locations with currently operating stations of the other techniques contributing to IERS (located less than 10 km away from DORIS) is as follows.

- GPS : 37 sites
- SLR : 9 sites
- VLBI : 7 sites

Observing satellites and data flow

Five DORIS-equipped satellites are currently operated: Spot 2, 4 & 5, Jason 1 and Envisat, with altitudes ranging from 800 to 1300 km. CryoSat was lost due to a launch failure on Saturday, October 8, 2005, but CryoSat-2 should be launched in March 2009 to replace it. Jason-2/OSTM should be launched in June 2008 and Alti-KA in June 2009.

The observations (including SPOT 3 and Topex/Poseidon missions) are stored at the two IDS Data Centers (NASA/CDDIS: <ftp://cddisa.gsfc.nasa.gov/pub/doris>; IGN: <ftp://lareg.ensg.ign.fr/pub/doris>). The Data Centers organisation is described at <http://lareg.ensg.ign.fr/IDS/doc/struct_dc.html>. The DORIS data delivery latency has stabilized at 20–30 days for most satellites, with latency of data delivery for DORIS data from ENVISAT showing the most improvement in 2005.

Currently the most active groups are IGN/JPL, INASAN and LEGOS/CLS as they have submitted long time series of solutions to the data centers, under the Sinex format when applicable. Other centers are providing partial results or are still in development: Geoscience Australia/GSFC, CNES/SOD, CNES/SSALTO, VUGTK (Prag) , IAA.

H. Capdeville and J.M. Lemoine (J. Geodesy, 2006) have prepared a model to correct the JASON-1 DORIS data for the perturbation due to the South Atlantic Anomaly (SAA). This radiation-related disturbances deleteriously affects station positioning performance through the impact on the JASON Doris oscillator. We plan in 2006 analysis campaigns to validate this model's utility. This is an important issue, as the number of satellites in the weekly solution directly affects the quality of the derived products. In this context, the continuation of a robust DORIS satellite constellation is extremely important.

IDS products, contributions to IERS data analyses

As of January 2006, main IDS available products are as follows.

- weekly IGN-JPL times series of terrestrial reference frames (TRF) including daily polar motion to contribute to the Combination Pilot Project
- weekly IGN-JPL time series of station coordinates
- weekly IGN-JPL time series of TRF translation and scale parameters
- weekly INASAN times series of terrestrial reference frames (TRF) including daily polar motion
- weekly INASAN time series of TRF translation and scale parameters
- weekly LEGOS-CLS times series of terrestrial reference frames (TRF) including daily polar motion
- monthly LEGOS-CLS time series of station coordinates
- weekly CNES/SSALTO times series of terrestrial reference frames (TRF) including daily polar motion
- weekly CNES/SSALTO time series of station coordinates
- weekly GSFC times series of terrestrial reference frames (TRF) including daily polar motion

The IDS submitted three SINEX time series to the ITRF2005 solution. An important issue for DORIS is the differing scale of the weekly time series combinations wrt to ITRF2000. For example the IGN/JPL and LEGOS/CLS scales differ by 50 mm (Tavernier et al., 2006, J. Geodesy). This might be traced to differing modelling standards at the analysis centers or details in the modelling of the troposphere refraction correction and mapping functions. We plan to elucidate this issue in 2006.

Journal of Geodesy special issue

In 2005, the IDS GB agreed to organize a special issue for DORIS data analysis and contributions. 18 manuscripts were submitted, and publication is set for 2006. Pascal Willis has served as guest editor for this special issue with Will Featherstone.

Analysis Coordination

Martine Feissel-Vernier retired at the end of October 2005 and left the function of IDS Analysis Coordinator that she initiated in February 2002. Frank Lemoine was then elected to replace her. The Analysis Coordination tasks (<http://lareg.ensg.ign.fr/IDS>) are run jointly by the Analysis Coordinator and the Central Bureau at CLS.

Following the release of the first gravity field models derived form the Grace mission in 2003, an analysis campaign was launched to study the impact of the gravity field model on the derived terrestrial and orbital reference frames, and to develop tools for the comparison, validation and combination of terrestrial reference frames. The final report of the campaign was issued in 2005.

An IDS Workshop took place in March 2006 in Venice. The discussion topics included DORIS system and network improvements, operational issues, analysis strategies, DORIS orbits and ionospheric parameters, and reference frame and combination issues. See the contributions at <http://ids.cls.fr/html/report/ids_workshop_2006/welcome.html>. This meeting provided an opportunity to intensify the technical discussions between the analysis centers.

Stability analyses of time series of station coordinates showed that the DORIS geodetic results are affected by white noise, while GPS time series are affected by flicker noise. This implies that the long term stability of the DORIS terrestrial reference frame results might be comparable to that of the other techniques.

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Frank Lemoine, Gilles Tavernier

3.5 Product Centres

3.5.1 Earth Orientation Centre

This section presents activities and main results concerning the Earth Orientation Centre located in Paris Observatory over 2005. General presentation of the IERS Earth Orientation Parameters (EOP), operational activities and yearly analyses are presented at the web site (<http://hpiers.obspm.fr/eop-pc>). According to the IERS Terms of Reference, the Earth Orientation Centre is responsible for monitoring Earth orientation parameters including long term consistency, publications for time dissemination and leap second announcements. The Earth Orientation is making available different products to a broad community of users: long-term and operational series of Polar motion, Universal Time (UT1), Length of Day (LOD) and Celestial pole offsets.

Determination of EOP is in the form of combined solutions derived by the analysis centres of the different techniques. Various solutions are computed: long-term solution (IERS C01), normal values at five-day intervals (IERS C02) and the operational smoothed solution Bulletin B at one-day intervals published monthly and providing EOP with a delay of 30 days with respect to the date of publication. Bulletin B is updated in an operational mode in the IERS C04 which is computed twice weekly. After the presentation of the new interactive tools implemented on our web site, we will present the different combined EOP solutions available.

WEB interactive tools: real time atmospheric excitation

We continued the development of interactive tools, mostly written in PHP language and devoted to the EOP time series analyses.

The principal novelty concerns the tool devoted to the comparison of the observed excitation in polar motion and LOD to atmospheric excitation. The procedure has been extended to the operational Atmospheric Angular Momentum function determined on a daily basis by the NCEP (National Centers for Environmental Prediction, USA). This allows the comparison with the up-to-date excitation derived from EOP.

Combined daily series: Bulletin B and EOP(IERS) C 04

As reported the last year, the algorithm and Fortran numerical code for the C04 series computation have been significantly improved. The new C04 solution is available on the WEB/FTP server (experimental solution). It should become the operational reference solution.

Predictions

Our service is participating in the EOP Prediction Campaign organized by Harald Schuh (TU Wien), by sending every week since October 2005 two predictions, one computed by D. Gambis, the other one computed by C. Bizouard.

Table 1: Estimated accuracies of individual and combined solutions entering the combined solutions in 2005.

Individual solutions		Estimated uncertainties				
		Time	Terrestrial Pole 0.001"	UT1 0.0001s	LOD 0.0001s	Celestial Pole 0.001"
VLBI – 24 h						
EOP (AUS)	1 R 1	3–4d	0.17	0.08		0.11
EOP (BKG)	3 R 4	1–4d	0.17	0.09		0.12
EOP (GSFC)	4 R 2	1–4d	0.14	0.07		0.10
EOP (IAA)	5 R 2	1–4d	0.14	0.09		0.10
EOP (MAO)	3 R 1	1–4d	0.19	0.10		0.13
EOP (SPBU)	3 R 3	3–4d	0.14	0.08		0.11
EOP (USNO)	6 R 1	1–4d	0.16	0.10		0.10
VLBI – Intensive						
EOP (BKG)	3 R 2	1–3 d		0.20		
EOP (GSFC)	4 R 1	1–3 d		0.22		
EOP (IAA)	5 R 1	1–3 d		0.15		
EOP (SPBU)	2 R 1	1–3 d		0.19		
EOP (USNO)	5 R 1	1–3 d		0.18		
SLR						
EOP (ASI)	3 L 2	1d	0.18		0.24	
EOP (IAA)	2 L 1	1d	0.15			
EOP (MCC)	97 L 1	1d	0.17		0.48	
EOP (OCA)	5 L 1	1d	0.19			
EOP (ILRS)	5 L 1	1d	0.16		0.40	
GPS						
EOP (CODE)	98 P 1	1d	0.03		0.19	
EOP (EMR)	96 P 3	1d	0.04		0.20	
EOP (ESOC)	96 P 1	1d	0.04		0.35	
EOP (GFZ)	96 P 2	1d	0.03		0.22	
EOP (IAA)	1 P 1	1d	0.13		0.33	
EOP (JPL)	96 P 3	1d	0.03		0.33	
EOP (NOAA)	96 P 1	1d	0.08		0.24	
EOP (IERS)*	95 P 1	1d	0.02	0.20	0.18	

** The satellite techniques provide information on the rate of change of Universal Time contaminated by effects due to unmodelled orbit node motion. VLBI-based results have been used to minimize drifts in UT estimates*

Long-term series: C 01 (1846–2006)

EOP(IERS) C 01 is a series of the Earth Orientation Parameters given at 0.1 year interval from 1846 to 1889 (polar motion only) and 0.05 year interval from 1890 until now (polar motion, celestial pole offsets, UT1–UTC since 1962). For many decades, the observations were made using mostly visual and photographic zenith telescopes. Since the advent of the space era in the 1960's, new geodetic techniques were used for geodynamics. Now, the global

Table 2: Uncertainty of the current solution and the estimated accuracies of the predictions for horizons of 5 days to 1 year for 2005.

Solutions		Terrestrial Pole mas	UT1 ms	Celestial Pole mas
Analysis daily	1-d	.08	.01	0.10
Prediction	1-d	.50	.20	0.10
	5-d	2	.60	0.10
	10d	6	1.5	0.10
	30d	12	2.	0.10
	90d	40	5.	0.10
	180d	20	8.	0.10
	1-yr	50	12.	0.10

Table 3: Mean and standard deviation of the differences between various combined techniques solutions and IERS C04 over 2005

EOP	IGS Comb – IERS C04		ILRS Comb – IERS C04		IVS Comb – IERS C04	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
X (μas)	–133	31	–50	246	–190	220
Y (μas)	296	38	255	251	176	112
UT1 (μs)	5	45			4	10
LOD (μs)	2	34	5	71		
Dψsinε (μas)					5	70
Dε (μas)					4	84

Table 4: Mean and standard deviation of the differences between various solutions and IERS C04 over 2005

EOP	Unit	BullA – IERS C04		Comb JPL – IERS C04	
		Mean	Standard deviation	Mean	Standard deviation
X	μas	–76	57	–159	37
Y	μas	120	41	38	28
UT1	μs	–106	18	–108	15

observing activity involves Very Long Baseline Radio Interferometry (VLBI), Lunar (LLR) and Satellite Laser Ranging (SLR), Global Positioning System (GPS) and more recently DORIS.

The C 01 series was recomputed in the course of 2003. It is a composite series based on following temporal solutions:

1846–1899: Fedorov *et al*. (1972) polar motion solution derived from three series of absolute declination programs (Pulkovo, Greenwich, Washington).

1900–1961: Vondrak *et al.* (1995) solution derived from optical astrometry analyses based on the Hipparcos reference frame. The series gives polar motion, celestial pole offsets and Universal Time (since 1956).

1962–2006: BIH and IERS solutions (BIH and IERS annual reports).

Mean Pole with respect to the IERS reference origin

The analyses of the observations of space geodesy require to perform the transformation between both terrestrial and celestial frames via the Earth Orientation Parameters. Gravity field models include the tesseral coefficients C21 and S21 coefficients. These terms describe the position of the Earth's figure axis with respect to the Terrestrial Reference Frame. This axis should coincide with the observed position of the rotation pole averaged over the same time period.

The mean polar motion is affected by a long-term drift westward (direction 70.7 deg West, rate: 4.2 mas/yr). The mean rotation axis with respect to the IERS Terrestrial Reference Frame, can be considered as the long-term trend obtained after filtering out the Chandler and seasonal terms, every year from 1900 to 2006 (Shiskin *et al.*, 1965). Figure 1 represents the polar motion over 2001–2006 and the path of the mean pole since 1900. The table is available in Conventions 2003 (McCarthy and Petit, 2004) and at the following address: <http://hpiers.obspm.fr/eop-pc/>.

Normal Point Solutions: C 02 (1962–2006)

Other series, based on normal points solutions given at various time intervals, are also proposed to users, i.e. C 02 (5-day intervals, polar motion, UT1–UTC, $d\psi$, $d\varepsilon$), C 03 (one-day intervals, polar motion, UT1–UTC) (Gambis, 1997; Eisop and Gambis, 1997). These series are respectively consistent one to another. They use the full correlation matrix when available. Recently there were new developments in the normal point series C 02 and C 03 in which the estimation of the solution given at the central dates of the n-day interval is made using a least-square fit for all EOP components. Although the L2 estimation has been extensively used for data analysis, it has some drawbacks linked to problems of ill-conditioning and in the non-detection of outliers. Alternative methods based on robust estimators like M-Huber can be used. These estimators are a generalization of both the L1 and L2 class. They have been imple-

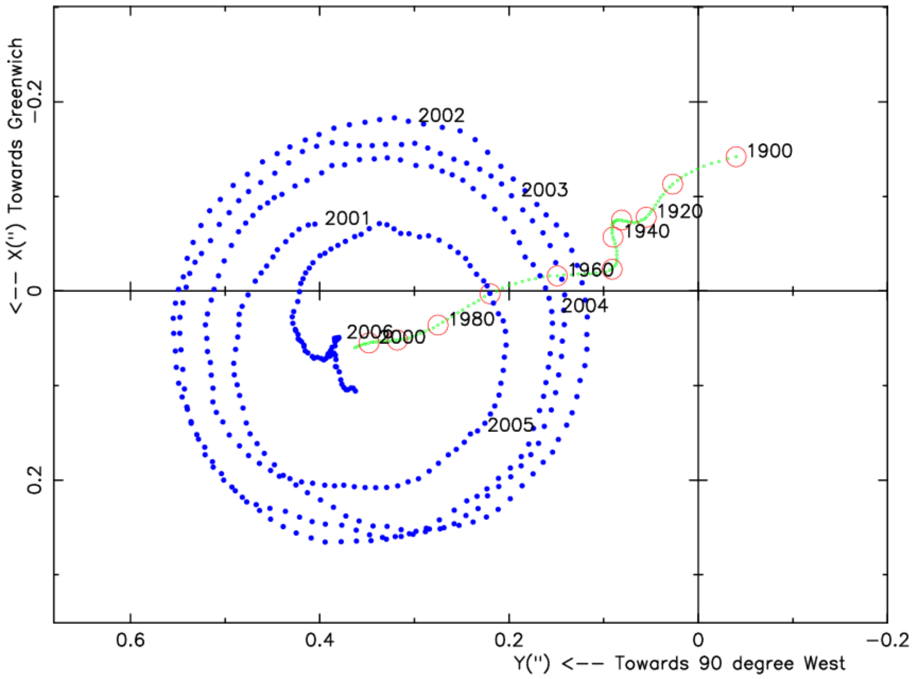

Figure 1 Mean polar motion (1900–2010) and IERS C04 polhody over 2002 – 2006.

mented in our analyses and are now currently used (Bougeard *et al.*, 2000). Table 5 reflects the evolution of the mean uncertainties of C02 solution since 1962.

Table 5: EOP(IERS) C 02 : Evolution of the mean uncertainty of the normal point solution given at five-day intervals

YEARS -- Unit	σ(X) -- 0.001"	σ(Y) -- 0.001"	σ (UT1) -- 0.0001s	σ(δψ) -- 0.001"	σ(δε) -- 0.001"
1962–1967	30	30	20	–	–
1968–1971	25	25	17	–	–
1972–1979	11	11	10	–	
1980–1983	2	2	3	2	1
1984–1989	.40	.40	.20	.5	.2
1990–2000	.20	.20	.20	.3	.1
2001–2006	.06	.06	.11	.09	.07

Evaluation of EOP derived from a simultaneous combination of TRF and EOPs

Although the current determination of reference frames and EOP temporal series are derived from the same software, rigorous approaches for simultaneously determining reference frames and EOP are not currently applied. This is however a more satisfactory approach to ensure a better consistency. Different approaches are currently being developed within the IERS (Altamimi *et al.*, 2005). The first approach is based on combination at the observation-equation level. Anderson (1995) has developed a software package, called GEOSAT, for the combined analysis of VLBI, GPS, SLR and other types of satellite tracking data (e.g., GLONASS, DORIS, Precise Range And Range-rate Estimation (PRARE) and satellite radar altimetry). Here, the observations are combined at the observation-equation level with a consistent model and consistent analysis strategies.

In another project (Yaya, 2001; Biancale *et al.*, 2002), the observations of the different techniques (VLBI, SLR, LLR, DORIS and GPS) are processed separately by the same single software package: GINS/DYNAMO, which has been developed at the GRGS (Groupe de Recherches de Géodésie Spatiale) since 1962. Here, the normal matrices are stacked to derive both the terrestrial frame and EOP. With this approach, it is essential that the results be optimal for the different techniques before a global solution be performed.

The project started in January 2005. Now the analyses are performed on an operational basis. For each individual technique, the processing of data is performed at different locations: GPS at Noveltis, Toulouse (S. Loyer), Doris at CLS, Toulouse (L. Soudarin), SLR at Cerga, Grasse (P. Bério), LLR at CNES, Toulouse (R. Biancale) and at the Observatoire de Paris (G. Francou), VLBI at CNES, Toulouse (R. Biancale) and at the Observatoire de Bordeaux (G. Bourda, P. Charlot). The final combination as well as the validation and various analyses are performed at the Observatoire de Paris (Gambis *et al.*, 2006).

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3.5.2 Rapid Service/Prediction Centre

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Centre for the determination of the quick-look Earth Orientation Parameters (EOP) is based on a weighted cubic spline with adjustable smoothing fit to contributed observational data (McCarthy and Luzum, 1991a). Contributed data are corrected for possible systematic differences. Biases and rates are determined with respect to the C04 system of the IERS Earth Orientation Centre (EOC). Statistical weighting used in the spline is proportional to the inverse square of the estimated accuracy of the individual techniques. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights in the algorithm may be either a priori values estimated by the standard deviation of the residual of the techniques or values based on the internal precision reported by contributors. Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Centre are given in Table 1. These estimates are based on the statistical reports that were generated weekly as a part of the Bulletin A Rapid Service EOP solution for 2005.

Operationally, the weighted spline uses as input the epoch of observation, the observed value, and the weight of each individual

Table 1: Estimated accuracies of the techniques in 2005. Units are milliseconds of arc for x, y, dψ, dε, dX, and dY and milliseconds of time for UT1–UTC and LOD.

Contributor Information	Estimated Accuracy					
Name, Sample Rate[1], Type	x	y	UT1	LOD	dψ (dX)	dε (dY)
CSR 3-day SLR	0.27	0.29	0.061*			
DUT daily SLR	0.35	0.36				
IAA daily SLR	0.17	0.17				
MCC daily SLR	0.15	0.18				
GSFC daily VLBI Intensives			0.019			
SPbU daily VLBI Intensives			0.018			
USNO daily VLBI Intensives[2]			0.020			
GSFC twice-weekly VLBI	0.06	0.07	0.003		0.4	0.1
IAA twice-weekly VLBI[3]	0.11	0.12	0.005		(0.1)	(0.1)
IVS twice-weekly VLBI	0.07	0.07	0.004		0.4	0.1
USNO twice-weekly VLBI	0.07	0.08	0.003		0.4	0.1
IGS daily Final	0.04	0.04				
IGS daily Rapid	0.02	0.04		0.01*		
USNO daily GPS UT*			0.016*			
EMR daily GPS UT*			0.03*			
USNO daily AAM UT			0.012			

*All satellite techniques provide information on the rate of change of Universal Time contaminated by effects due to unmodeled orbit node motion. VLBI-based results have been used to correct for LOD biases and to minimize drifts in UT estimates.

[1] The sample rate of provided data sets and not the series update rate.

[2] USNO VLBI Intensive series began in May 2005.

[3] IAA VLBI nutation values are in terms of dX/dY using IAU 2000A Nutation Theory.

data point. The software computes the spline coefficients for every data point which are then used to interpolate the Earth orientation parameter time series so that x, y, UT1–UTC, $d\psi$, and $d\varepsilon$ values are computed at the epoch of zero hours UTC for each day. Since the celestial pole offset software is written in terms of $d\psi$ and $d\varepsilon$, the IAA VLBI dX and dY values are converted to $d\psi$ and $d\varepsilon$ for the combination process. The only data points that are excluded from this process are the points whose errors, as reported by the contributors, are greater than three times their average reported precision or those points that have a residual that is more than four times the associated a priori error estimate. Since all of the observations are reported with the effects of sub-daily variations removed, no processing is done to account for these effects (see IERS Gazette No. 13, 30 January 1997).

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre solutions and IERS Bulletin B and C04 EOP solutions for 2005. Polar motion X and Y values are in milliseconds of arc and UT1–UTC values are in units of milliseconds of time.

	Bulletin A – Bulletin B		Bulletin A – C04	
	Mean	Std.Deviation	Mean	Std. Deviation
Bulletin A Rapid Running Solution (finals.data)				
X	–0.08	0.08	–0.08	0.06
Y	0.12	0.08	0.12	0.05
UT1–UTC	–0.010	0.020	–0.010	0.021
Bulletin A Weekly Solution (finals.data)[1]				
X	–0.05	0.08	–0.05	0.05
Y	–0.01	0.09	–0.01	0.06
UT1–UTC[2]	–0.012	0.036	–0.011	0.037
		0.028[3]		0.027[3]
Bulletin A Daily Solution (finals.daily)				
X	–0.04	0.12	–0.04	0.10
Y	–0.01	0.12	–0.01	0.10
UT1–UTC[2]	–0.023	0.060	–0.023	0.059
		0.048[3]		0.048[3]

[1] Statistics computed over the 7-day combination solution period prior to solution epoch.
[2] Standard deviations including periods with known VLBI intensive and GPS rapid data issues.
[3] Standard deviations, after implementation of e-VLBI intensives, using only the last 5 months of the year.

The uncertainties in the daily values listed in Bulletin A are derived from the quality of the spline fit in the neighborhood of the day in question. Table 2 shows the accuracies of Rapid Service/Prediction Centre's combination solution for the running, the weekly, and the daily products compared to the Bulletin B and C04 series maintained by the IERS EOC at the Paris Observatory. The running solution is the combination solution over the past 365-day period. The statistics for the running solution at year's end show the agreement between the Bulletin A running combination solution and the Bulletin B/C04 series for the entire year. The comparison of the 52 weekly solutions to the Bulletin B/C04 series gives the statistics of the residuals computed over the new combination results for the 7-days prior to the solution epoch. The statistics for the daily solution are the differences for the day of the solution epoch. EOP accuracies for the Bulletin A rapid weekly solution for the new combination for the day of the solution run and daily solution at the time of solution epoch are similar and therefore, not included in the table.

Figure 1 presents the data used in Table 2 for the determination of the Bulletin A daily solution statistics. This year Bulletin A had only small reductions in the standard deviations, while in August, UT1–UTC had larger reductions in standard deviations after the implementation of electronic VLBI (e-VLBI) data transfer. An examination of Figure 1 and Table 2 shows that the Centre's UT1–UTC solution accuracies were degraded from mid-May to late-June. Several difficulties had to be overcome in that time frame: problems with one of the UT GPS series, problems with software pre-processing of one of the VLBI Intensive series, and limited availability of valid AAM data sets for about a week while the operational weather model was being updated. These degradations were compounded by extended periods without VLBI data which further highlight the critical dependence of Earth orientation parameters on VLBI data.

The implementation and use of e-VLBI intensives has resulted in a 1 to 3 day reduction in delivery time of Intensive data. This coupled with the use of the "K"-intensives (KkSv-baseline) has resulted in an almost daily sample rate for VLBI intensives that are available in near real-time. This has improved the accuracy of the solution as reflected by improved standard deviations for both the weekly and daily UT1–UTC solutions. Compared to last year's standard deviations, the values for last 5 months of this year (after the introduction of e-VLBI data) indicate a 47% reduction computed over the last 7 days of the weekly UT1–UTC combination solution and a 20% reduction for the last day of the daily UT1–UTC combination solution.

Figure 1 shows the residuals between the daily Bulletin A rapid solution at the epoch time of the solution and two other series (i.e., Bulletin B and C04). These plots also show that during the months of February and April, the Bulletin B and the C04 EOP series had significantly larger differences. Bulletin A had better agreement with C04 during these periods. Overall, the agreement between the Bulletin A solutions and the IERS EOC solutions is quite good with a smaller variance than last year.

Prediction Techniques

Polar motion predictions are based on the extrapolation of an annual and semiannual ellipse and a Chandler circle fit to the previous 400 days of observed values of x and y (McCarthy and Luzum,

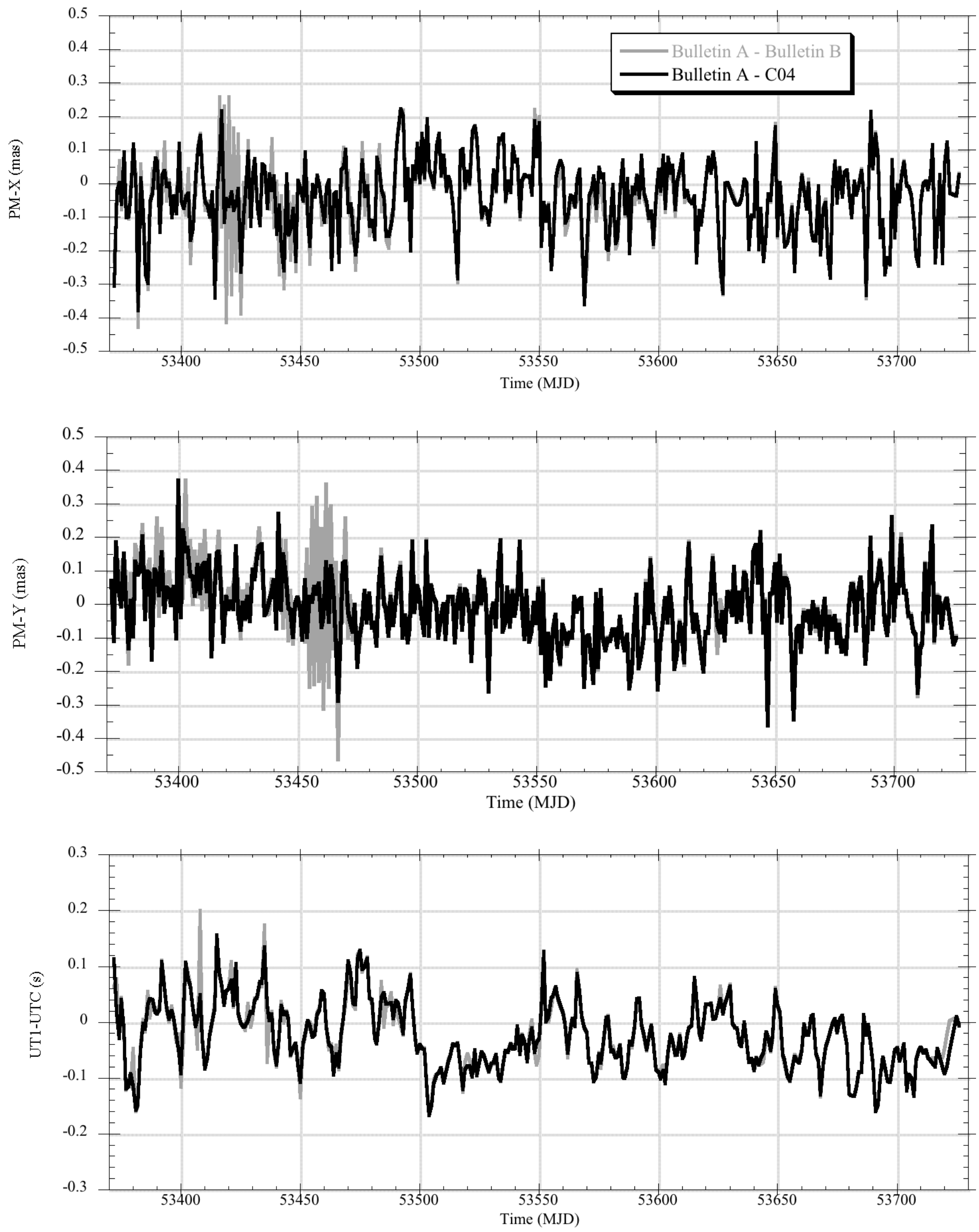

Fig. 1: Differences between daily Bulletin A rapid solutions at each daily solution epoch for 2005 and the Earth Orientation Parameters available in Bulletin B and C04 series produced in April 2006.

1991b; Johnson, 2002). The differences between the last observed pole position and rate and those of the curve are computed. These differences are then used to adjust the extrapolated curve by an amount that decreases with the length of the forecast. In February 1998, the near-term polar motion predictions (less than about 30 days) were improved significantly by modifying the transition process from the last observed polar motion result to the long-term predictions. Continuity in the first derivatives was enforced placing great weight on the observed polar motion rate reported by the IGS in their Rapid series. The improvement was most pronounced for the shortest prediction intervals. The procedure for UT1–UTC involves a simple technique of differencing (McCarthy and Luzum, 1991b). All known effects such as leap seconds, solid Earth zonal tides, and seasonal effects are first removed from the observed values of UT1–UTC. Then, to determine a prediction of UT1–UTC n days into the future, $(UT1–TAI)_n$, the smoothed time value from n days in the past, $<(UT1R–TAI)_{-n}>$ is subtracted from the most recent value, $(UT1R–TAI)_o$

$$(UT1–TAI)_n = 2(UT1R–TAI)_o – <(UT1R–TAI)_{-n}>.$$

The amount of smoothing used in this procedure depends on the length of the forecast. Short-term predictions with small values of n make use of less smoothing than long-term predictions. Once this value is obtained, it is possible to account for known effects in order to obtain the prediction of UT1–UTC. This process is repeated for each day's prediction.

The very near-term UT1–UTC prediction is strongly influenced by the observed daily Universal Time estimates derived at USNO from the motions of the GPS orbit planes reported by the IGS Rapid service. The IGS estimates for LOD are combined with the GPS-based UT estimates to constrain the UT1 rate of change for the most recent observation.

The near-term to sub-monthly UT1–UTC prediction also makes use of a UT1-like data product derived from the operational NCEP AAM analysis and forecast data (UTAAM). For the 5 days after the latest observation, AAM-based predictions of LOD excitation are combined smoothly with the longer-term UT1 predictions described above. Additional improvements to the combination and prediction process for UT1 have been implemented (Wooden et al., 2005).

Errors of the estimates are derived from analyses of the past differences between observations and the published predictions. Formulas published in Bulletin A are used to extend the tabular data. The predictions of $d\psi$ and $d\varepsilon$ are based on the IERS Conventions (McCarthy, 1996; McCarthy and Petit, 2004). Table 3 shows the standard deviation of the differences between the Bulletin A daily solution predictions and the C04 solution for 2003. Initial Centre estimates indicated that the UT1–UTC prediction performance would be improved by 42% at 10 days into the future (Johnson et al., 2005). However, comparisons of the UT1–UTC prediction performance from 2003 to those estimated in 2001 (before UTAAM was introduced) indicated a better than 50% improvement in prediction error at both 10 day and 20 days into the future by the addition of UTAAM to the combination and prediction routine.

For 2005, there was only a small improvement in the short-term UT1–UTC predictions. This was most likely the result of the addition of the e-VLBI Intensives. A comparison of a 4-month period at the beginning of 2005 to the last 4 months of 2005 did show a slight reduction in the standard deviations. However, the statistical significance of this improvement cannot be truly determined without a longer series of solutions. The longer-term polar motion predictions had large increases in their standard deviations. This was due to the presence of small sub-monthly retrograde loops in the polar motion. The operational prediction method could not solve for these loops.

Table 3: Standard deviation of the differences between the EOP time series predictions produced by the daily Bulletin A rapid solutions and the C04 combination solutions for 2005.

Days in Future	PM–X	PM–Y	UT1–UTC
	mas	mas	ms
1	.44	.37	.127
5	2.44	1.70	.380
10	4.13	2.77	.935
20	6.82	4.56	3.30
40	11.9	8.32	5.98
90	25.2	18.9	7.61

The predictions of celestial pole offsets (both dX/dY and $d\psi/d\varepsilon$ representations) are based solely on VLBI data. If no new VLBI 24-hour session observations are available, a new rapid combination/prediction of these angles is not determined. Therefore, the predictions of celestial pole offset start before the solution epoch time and the length of the prediction into the future can and does vary in the daily solution files. The differences between the daily Bulletin A predictions and those of the C04 for 2005 are given in Table 4.

Table 4: Standard deviation of the differences between the nutation prediction series produced by the daily Bulletin A rapid solutions and the C04 solutions for 2005.

Days in Future	dX mas	dY mas	$d\psi$ mas	$d\varepsilon$ mas
1	.08	.12	.21	.13
5	.11	.15	.27	.16
10	.12	.14	.33	.18
20	.12	.18	.36	.22
40	.15	.17	.44	.25

Predictions of UT1–TAI up to 2015 January 1, are given in Table 5. They are derived using a prediction algorithm similar to that employed in the Bulletin A predictions of UT1–UTC. Up to twenty years of past observations of UT1–TAI are used. Estimates of the expected one-sigma error for each of the predicted values are also

Table 5: Predicted values of UT1–TAI, 2006–2015. Note that TT–UT1 can be obtained from this table using the expression TT–UT1=32.184s – (UT1–TAI).

DATE		UT1-TAI (s)	Uncertainty (s)
2006	Jan 1	–31.659	.005
	Apr 1	–31.732	.006
	Jul 1	–31.78	.01
	Oct 1	–31.76	.04
2007	Jan 1	–31.81	.04
	Apr 1	–31.86	.05
	Jul 1	–31.80	.06
	Oct 1	–31.79	.07
2008	Jan 1	–31.79	.08
	Apr 1	–31.8	.1
	Jul 1	–31.8	.2
	Oct 1	–31.8	.2
2009	Jan 1	–31.8	.3
	Apr 1	–31.8	.4
	Jul 1	–31.8	.5
	Oct 1	–31.8	.6
2010	Jan 1	–31.8	.8
	Apr 1	–31.8	.9
	Jul 1	–31.8	1.
	Oct 1	–32.	1.
2011	Jan 1	–32.	1.
	Apr 1	–32.	1.
	Jul 1	–32.	1.
	Oct 1	–32.	2.
2012	Jan 1	–32.	2.
	Apr 1	–32.	2.
	Jul 1	–32.	2.
	Oct 1	–32.	2.
2013	Jan 1	–32.	2.
	Apr 1	–32.	2.
	Jul 1	–32.	3.
	Oct 1	–32.	3.
2014	Jan 1	–32.	3.
	Apr 1	–32.	3.
	Jul 1	–32.	3.
	Oct 1	–32.	3.
2015	Jan 1	–32.	4.

given. These are based on analyses of the past performance of the model with respect to the observations.

Additional information on improvements to IERS Bulletin A and the significance for predictions of GPS orbits for real-time users is available (Luzum et al., 2001; Wooden et al., 2004).

Centre Activities in 2005

During 2005 a number of changes occurred that affected the performance of IERS Bulletin A. An electronic-VLBI (e-VLBI) proof-of-concept experiment demonstrated the advantages of reducing the latency in VLBI data. Additional efforts included improving operational software, automating the process for updating data sets used in the combination, updating and monitoring currently used datasets, investigating potential new data sets, and investigating the improvement of polar motion prediction technique as well as preparing for the addition of a positive leap second in December 2005. To provide more robustness, an alternate site was established to mirror data storage for the combination processing.

The editing criteria in the combination program were modified to incorporate the number of useful scans as well as the formal error for the VLBI K-intensive data. In addition software was developed to estimate rates and biases between different observational data sets used in the EOP combination process. This new software applies similar editing criteria and a uniform statistical approach to that used within the combination software itself.

In July the IERS Earth Orientation Centre announced the addition of a positive leap second on December 31, 2005. As a consequence, the announcement was inserted into Bulletin A to alert users of the change, the leap second data file was updated, and the production software was modified to handle leap seconds automatically from the leap second file. The combination software was also modified to handle the problem of introducing a leap second into the UT1-like quantity derived from AAM.

New global solutions were received from GSFC, IAA, and USNO VLBI analysis centers. These new solutions were examined and new rates and biases were computed. Also, changes in rates and biases of currently combined SLR data were estimated. New data sets from the IDS, the ILRS, and IGS were examined. A careful analysis indicated that the addition of the ILRS-combined SLR solution series A and the IGS Ultra-rapid solutions may be useful in reducing errors in the polar motion combination. Some of this work was undertaken as a result of USNO's participation in the IERS Combined Pilot Project.

Collaborative efforts with colleagues at Poland's Center for Space Research showed the potential for improving our polar motion predictions by 20%–30% at 2 to 3 months into the future. Using updated software algorithms, an effort was begun to incorporate this new method into the operational software.

Availability of Rapid Service

The data available from the IERS Rapid Service/Prediction Centre consist mainly of the data used in the IERS Bulletin A. These data include: x, y, UT1–UTC, dX and dY from IAA VLBI; x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from GSFC VLBI; x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from USNO VLBI; x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from IVS combination VLBI; UT1–UTC from Saint Petersburg University 1-day Intensives; UT1–UTC from GSFC 1-day Intensives; UT1–UTC from USNO 1-day Intensives;

x, y, UT1–UTC from CSR LAGEOS 3-day SLR; x, y from Delft University of Technology 1-day SLR; x, y from Institute of Applied Astronomy 1-day SLR; x, y from the Russian Mission Control Centre 1-day SLR; x, y, LOD from the International GNSS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; x, y, UT1–UTC, dψ and dε from the IERS Rapid Service/Prediction Centre; x, y, UT1–UTC, dψ and dε from the IERS Earth Orientation Centre; and predictions of x, y, UT1–UTC from the IERS Rapid Service/Prediction Centre.

In addition to this published information, other data sets are available. These include: UT0–UTC from University of Texas as Austin LLR, UT0–UTC from JPL LLR; UT0–UTC from CERGA LLR; UT0–UTC from JPL VLBI; latitude and UT0–UTC from Washington PZTs 1,3,7; latitude and UT0–UTC from Richmond PZTs 2,6; x and y from CSR LAGEOS 5-day SLR; x and y from Delft 3- and 5-day SLR; and x, y, UT1–UTC, dψ and dε from IRIS VLBI.

The data described above are available from the Centre in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current ninety day's worth of predictions via electronic mail from

<ser7@maia.usno.navy.mil> or <http://maia.usno.navy.mil/>.

Internet users can also direct an anonymous FTP to

<maia.usno.navy.mil>

and change to the ser7 directory where the IERS Bulletin A and more complete databases can be accessed including the daily Bulletin solutions.

World Wide Web access is available at

<http://maia.usno.navy.mil/>.

Centre Staff

The Rapid Service/Prediction Centre staff consisted of the following members:

William Wooden	director
Thomas Johnson	program manager, research, and software maintenance
Arvid Myers	assists in operations, software maintenance, and support
Merri Sue Carter	assists in daily operations and support
Sebastien Lambert	research and software development

In September 2005 Arvid Myers retired after more than two decades of service to USNO and Sebastien Lambert accepted a position at the Royal Observatory of Belgium.

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Thomas Johnson, Merri Sue Carter, Arvid Myers,
Sebastien Lambert, William Wooden

3.5.3 Conventions Centre

The Conventions Center is provided jointly by the Bureau International des Poids et Mesures (BIPM) and the U.S. Naval Observatory (USNO). As of May 2005, Brian Luzum replaced Dennis McCarthy as the USNO principal scientist.

The Conventions Center provides updated versions of the Conventions in electronic form, after approval of the IERS Directing Board. In the mean time, work on interim versions is also available by electronic means. In addition to the electronic releases, printed versions of the Conventions will be provided at less frequent intervals or when major changes are introduced.

In 2005, the work accomplished or in progress is the following.

1. Advisory Board for the IERS Conventions update

Following the request of the IERS Directing Board at its 39th meeting, the Conventions center has created an “Advisory Board for the IERS Conventions update”. The Board began its work in February 2005 under the chairmanship of Jim Ray and has a membership of about 20, representing all IERS components. Initial goals for the work of the Board were described in its first newsletter as

- eliminate ambiguities including effects in the conventional displacements of station positions and provide suitable models for all recognized effects;
- provide a model for the oceanic pole tide deformation;
- provide a model for diurnal and semidiurnal atmospheric pressure loading;
- clarify treatment of geocenter motions and provide a model for the diurnal and semidiurnal effects of ocean tides;
- develop an updated model for diurnal and semidiurnal EOP variations;
- specify protocols for handling technique-specific effects;
- enforce SINEX documentation of models applied in data analyses;
- ensure full availability of software routines.

The Board held an open meeting during the EGU General Assembly in Vienna on 26 April 2005, and worked by e-mail. It started, or helped the Conventions Center start, small groups of experts working on different topics, whose work is reported in the technical items below.

2. Technical topics

The background work of keeping track of corrections, typos and small changes that improve the readability of the documents has continued in 2005. More technical or complex issues are first discussed, *e.g.* through the Advisory board or on the discussion forum (<http://tai.bipm.org/iers/forum>), where topics are being identified as needing investigation and possible new developments for future versions of the Conventions. Several such topics concern contributions to the difference between the instantaneous position of a site and its adopted position, such as the effects of geocenter motion or atmospheric loading. It is expected that all effects (such as station displacement) that are periodic and have a consistent and accurate *a priori* model, expressed in closed form, should be included in the IERS Conventions. Models for long-term or non-periodic effects, which have an impact on the definition of reference frames, are also to be studied, although their inclusion as conventional effects will need to be discussed.

Work on the following major topics was on-going or started in 2005:

2.1 Ocean pole tide

The ocean pole tide is generated by the centrifugal effect of polar motion on the oceans. Polar motion is dominated by the 14-month Chandler wobble and annual variations. At these long periods, the ocean pole tide is expected to have an equilibrium response, where the displaced ocean surface is in equilibrium with the forcing equipotential surface. The equilibrium model from S. Desai (*JGR* **107**, 2002) is now proposed as the conventional model. The updated Chapter 6 „Geopotential" was released on 13 March 2006. To compute the pole tide, a conventional mean pole needs to be defined. This change to Chapter 7 „Displacement of reference points" is being prepared. Also a model for the associated station displacement (loading effect) is being prepared.

Work on this topic involves mostly J. Chen, S. Desai, J. Ray, J. Ries and J. Wahr.

2.2 Atmospheric tidal loading

The diurnal heating of the atmosphere induces surface pressure oscillations at mostly diurnal S1 and semidiurnal S2 harmonics, which produce station displacement due to loading that can have an amplitude of 1.5 mm. Using the Ray and Ponte (*Annales Geophysicae* **21**, 2003) tidal model, a model is proposed to compute the station displacement as grid values along with an interpolation program. These can be found at <http://www.ecgs.lu/atm>. Implementation in Chapter 7 „Displacement of reference points" is not ready yet.

Work on this topic involves mostly T. van Dam and R. Ray.

2.3 Ocean tidal loading

As no conventional routine was available to implement the recommendations of section 7.1.1 of the IERS Conventions 2003 concerning local site displacements due to ocean tidal loading, a new Fortran routine has been written by Duncan Agnew (UCSD). The code can be found on the web site at <ftp://tai.bipm.org/iers/convupdt/chapter7/hardisp.f>. Regarding these matters, users should also note that Hans-Georg Scherneck has recently added the new TPXO.7.0 and FES2004 ocean models to his web site <http://www.oso.chalmers.se/~loading/>.

Work on this topic involves mostly D. Agnew, M. Bos, U. Hugentobler, J. Ray, and H.-G. Scherneck.

2.4 Tropospheric mapping function

Since the recommended NMF (A. Niell *JGR* **101**, 1996), as well as other mapping functions cited in the Conventions (2003), have now been shown to have deficiencies, work is starting to determine which version of the recently developed mapping functions should be recommended.

Work on this topic involves mostly J. Boehm, A. Niell, H. Schuh and J. Ray.

3. Dissemination of information

The Conventions web site (<http://tai.bipm.org/iers/>), including the discussion forum (<http://tai.bipm.org/iers/forum>), has been maintained. The web pages for the Conventions updates (<http://tai.bipm.org/iers/convupdt/convupdt.html>) are continually modified, as required by changes in the texts, routines or data files.

The list of updates to the Conventions published as of 15 March 2006 is the following (An updated list is available online at <http://tai.bipm.org/iers/convupdt/listupdt.html>):

Chapter 5: Transformation Between the Celestial and Terrestrial Systems.

• 19 September 2005: Subroutine PMsdnut.for has been added and section 5.4.2 of the previous version of the chapter has been updated.

• 5 November 2004: The corrections (provided by N. Capitaine) with respect to the previous version of the chapter have been implemented. The header of Table 5.3b in the text and in the corresponding file has been updated. The use of equation (23) has been clarified. Note 1 has been added. Information on the new web sites in the notes has been added.

Chapter 6: Geopotential.

• 13 March 2006: The main changes with respect to the previous version of the chapter: A new section 6.3 on Oceanic pole tide (from S. Desai and J. Chen) has been introduced. Information on the treatment of degree 1 harmonic coefficients has been added in the beginning of the chapter (from J. Ries).

• 23 September 2005: The corrections with respect to the previous version of the chapter: In section 6.3, the reference epoch for value C20 has been corrected (noted by E.C. Pavlis).

• 18 November 2004: The corrections with respect to the previous version of the chapter: The caption of Table 6.3b has been corrected (from S. Bettadpur and V. Dehant). The unnumbered equations at end of section 6.2 have been corrected (noted by S.Y. Zhu).

Chapter 8: Tidal Variations in the Earth's Rotation.

• 6 February 2006: The changes with respect to the previous version of the chapter: The second paragraph provides some recommendations for users and the last paragraph corrects errors in past publications. The caption of Table 8.1 has been expanded.

• 21 April 2005: The corrections with respect to the previous version of the chapter: The last paragraphs have been modified to provide further information on the subroutine interp.f by Ch. Bizouard.

• 15 November 2004: The corrections with respect to the previous version of the chapter: The last paragraph of the chapter has been expanded to provide information (provided by Ch. Bizouard) on the available subroutines and on Tables 8.2 and 8.3.

Chapter 10: General Relativistic Models for Space-time Coordinates and Equations of Motion.

• 15 October 2004: The correction of equation (1) in section 10.2 to remove an ambiguity.

• 24 June 2004: The archive containing the Time Ephemeris TE200 and TE405 and associated software and test data (provided by A.W. Irwin). See the README file.

Gérard Petit, Brian Luzum

3.5.4 ICRS Centre

Introduction

The IAU has charged the IERS with the responsibility of monitoring the International Celestial Reference System (ICRS), maintaining its current realization, the International Celestial Reference Frame (ICRF), and maintaining and improving the links with other celestial reference frames. Starting in 2001, these activities are run jointly by the ICRS Centre (US Naval Observatory and Observatoire de Paris) of the IERS and the International VLBI Service for Geodesy and Astrometry (IVS), in coordination with the IAU. The present report was jointly prepared by the U.S. Naval Observatory and Paris Observatory components of the ICRS Centre. The ICRS Centre web site <http://hpiers.obspm.fr/icrs-pc> provides information on the characterization and construction of the ICRF (radio source nomenclature, physical characteristics of radio sources, astrometric behaviour of a set of sources, radio source structure). This information is also available by anonymous ftp (<hpiers.obspm.fr/icrs-pc>), and on request to the ICRS Centre (<icrspc@ hpopa.obspm.fr>).

Maintenance and extension of the ICRF: validation of individual VLBI reference frames

Seven individual celestial reference frames obtained from VLBI analysis by three different laboratories have been validated by comparison to ICRF-Ext. 2 (Fey et al., 2004).

The reference frames analysed

Two solutions calculated at Geoscience Australia with the OCCAM 6.1 software are included in this report. In both solutions the orientation of the celestial frame has been defined by applying a no-net-rotation constraint to the positions of 207 defining sources in ICRF-Ext.2. The a priori models are IERS 1996 for the precession, MHB2000 (Mathews et al., 2002) for the nutation and tropospheric gradients have been adjusted. The solutions differ in the time span of the observations and in the tropospheric delay model used: VLBI observations analysed for RSC (AUS) 05 R 01 span over the period November 1979 – October 2004 and the IMF mapping function (Niell, 2001) has been applied for the troposphere modelling; the celestial frame RSC (AUS) 05 R 03 includes one more year of data (November 1979 – November 2005) and applied the VMF mapping function (Böhm and Schuh, 2004).

Four individual frames at the Federal Agency for Cartography and Geodesy and the Geodetic Institute of the University of Bonn (Germany) have been evaluated using CALC 9.13 / SOLVE release 2004.03.18. In all solutions the celestial reference frame has been oriented by a no-net-rotation constraint imposed to the positions of the 212 defining sources as in ICRF-Ext.1 (IERS 1999). The a priori precession and nutation models are IERS 1996. Tropospheric gradients have been adjusted in the solutions. The solutions differ only in the time span of the observations: RSC (BKGI) 05 R 01 data ranging January 1984 – February 2005; RSC (BKGI) 05 R 02 data has been acquired between January 1984 and June 2005; observations used to evaluate RSC (BKGI) 05 R 03 range the period January 1984 – October 2005; solution RSC (BKGI) 06 R 01 is based on data obtained from January 1984 to February 2006.

RSC (CGS) 05 R 01 is the extragalactic frame produced by the Space Geodesy Centre in Matera, Italy from observations in the period April 1980 – December 2004. The software used is CALC 9.12 / SOLVE release 2001.01.19, revision 2001.04.27. The celestial frame has been oriented by a no-net-rotation imposed to the positions of 179 defining sources in ICRF-Ext.1. The a priori precession and nutation models are both IERS 1996. Tropospheric gradients have been adjusted in the solution.

Table 1 gives the characteristics of the analysed frames. Four categories of sources appear in the table: defining, candidate and other sources correspond to the classification of ICRF sources (IERS, 1997; Ma et al., 1998); new are the sources added in ICRF-Ext.2; additional represents sources observed in VLBI programmes and not present in ICRF-Ext.2. The values of the median of the coordinate uncertainties indicate that all frames are of similar quality.

Table 1: Individual VLBI celestial reference frames analysed. n is the number of sources, m is the median of the coordinate uncertainties (unit: mas)

Frame	Total	Defining		Candidate		Other		New		Addit.		
	N	n	m	n	m	n	m	n	m	n	m	(°)
RSC (AUS) 05 R 01	639	202	0.04	251	0.17	4	0.23	58	0.19	124	0.30	–81;+84
RSC (AUS) 05 R 03	640	205	0.04	248	0.14	4	0.22	58	0.17	125	0.29	–81;+84
RSC (BKGI) 05 R 01	779	207	0.05	218	0.06	101	0.03	45	0.10	208	0.30	–81;+84
RSC (BKGI) 05 R 02	779	207	0.05	218	0.06	101	0.03	45	0.10	208	0.30	–81;+84
RSC (BKGI) 05 R 03	781	207	0.05	218	0.06	101	0.03	45	0.10	210	0.30	–81;+84
RSC (BKGI) 06 R 01	782	207	0.05	218	0.06	101	0.03	45	0.10	211	0.30	–81;+84
RSC (CGS) 05 R 01	537	179	0.05	186	0.05	98	0.02	42	0.08	32	0.10	–80;+84

Comparison of individual celestial frames to ICRF-Ext.2

The catalogues listed in Table 1 have been compared to ICRF-Ext.2. The algorithm of comparison is the one developed and currently used at the ICRS Centre in Paris Observatory. The coordinate differences between two frames are modelled by a global rotation of the axes, represented by the angles A_1, A_2, A_3, and by deformations represented by three parameters: D_α is a slope in right ascension as a function of the declination, D_δ is a slope in declination as a function of the declination, B_δ is a bias between the principal planes of the frame relative to that of ICRF-Ext.2.

$$\begin{array}{lllllll} A_1 \,\mathrm{tg}\,\delta \cos\alpha & + & A_2 \,\mathrm{tg}\,\delta \sin\alpha & - & A_3 & + & D_\alpha(\delta-\delta_0) & & = & \Delta\alpha \\ -A_1 \sin\alpha & + & A_2 \cos\alpha & & & + & D_\delta(\delta-\delta_0) & + B_\delta & = & \Delta\delta \end{array}$$

Under the hypothesis that ICRF-Ext.2 is free from deformations, the systematic effects detected in the comparisons should be interpreted as deformations in the individual frames.

The defining sources in ICRF-Ext.2, as well as their respective coordinates have been kept identical to those in ICRF (Fey et al., 2004). Defining sources common to each individual frame and ICRF-Ext.2 (or ICRF) have been used for the comparisons. The six parameters have been evaluated by a weighted least squares fit; the equations have been weighted using the inverse of the variance of the coordinate differences.

Formal uncertainties of radio source positions smaller than 0.01 mas in the individual frames were set to this value for the assignation of weights. The fitted parameters allow the transformation of coordinates in the individual frames into ICRS. Equations of observation with post-fit residuals higher than 2.5 times the rms residual of the fit are deweighted. By doing this, the respective source coordinate is considered as an outlier and is consequently eliminated from the fit.

Results

The results of the comparisons are shown in Tables 2 to 4. Table 2 gives the global orientation between the axes of the individual frames analysed and those of the ICRS. Table 3 gives the values of the deformation parameters representing systematic effects in the individual frames. Table 4 gives the values of the post-fit weighted mean residuals and the rms residuals.

Table 2: Relative orientation between individual frames and ICRF-Ext.2. N is the number of the common defining sources in each individual frame used for the comparison. Unit: µas.

Frame	N	A_1	A_2	A_3
RSC (AUS) 05 R 01 (*)	202	+12.50±*20.55*	+17.18±*20.29*	-40.98±*25.97*
RSC (AUS) 05 R 03 (*)	205	+8.09±*19.72*	+16.26±*19.51*	-37.48±*25.00*
RSC (BKGI) 05 R 01	207	+5.66±*17.55*	-19.12±*17.46*	-31.56±*22.54*
RSC (BKGI) 05 R 02	207	+3.95±*17.50*	-19.94±*17.40*	-32.21±*22.46*
RSC (BKGI) 05 R 03	207	+0.91±*17.56*	-22.57±*17.47*	-32.71±*22.55*
RSC (BKGI) 06 R 01	207	-0.11±*17.52*	-24.02±*17.43*	-35.43±*22.50*
RSC (CGS) 05 R 01 (*)	179	+29.06±*23.46*	+7.89±*23.01*	+10.14±*32.49*

(*): some source coordinates have been deweighted

Table 3: Slopes and biases evaluated in the comparisons between VLBI individual reference frames and ICRF-Ext.2. D_α, D_δ are the slopes in right ascension and declination respectively, B_δ is thebias in declination; units are µas/deg for the slopes, µas for the bias.

Frame	N	D_α	D_δ	B_δ
RSC (AUS) 05 R 01 (*)	202	-0.88±*0.83*	-0.78±*0.44*	+51.50±*21.95*
RSC (AUS) 05 R 03 (*)	205	-0.85±*0.80*	-1.05±*0.41*	+58.78±*20.58*
RSC (BKGI) 05 R 01	207	-1.02±*0.72*	-0.57±*0.37*	+11.73±*18.31*
RSC (BKGI) 05 R 02	207	-1.00±*0.72*	-0.64±*0.37*	+13.94±*18.24*
RSC (BKGI) 05 R 03	207	-0.94±*0.72*	-0.68±*0.37*	+15.46±*18.31*
RSC (BKGI) 06 R 01	207	-1.11±*0.72*	-0.65±*0.37*	+12.93±*18.26*
RSC (CGS) 05 R 01 (*)	179	-0.63±*1.07*	-1.16±*0.60*	+62.27±*28.82*

(*): some source coordinates have been deweighted

Table 4: Weighted mean residuals r_α and r_δ, and rms residual after fitting the global rotations and the deformation parameters between individual frames and ICRF; unit is µas.

Frame	r_α	r_δ	rms
RSC (AUS) 05 R 01	-6.57	-0.52	271.54
RSC (AUS) 05 R 03	-7.40	-0.49	262.97
RSC (BKGI) 05 R 01	-4.95	+4.76	235.16
RSC (BKGI) 05 R 02	-5.72	+4.71	234.42
RSC (BKGI) 05 R 03	-6.36	+4.73	235.32
RSC (BKGI) 06 R 01	-7.06	+4.61	234.82
RSC (CGS) 05 R 01	-8.73	+7.28	284.57

The values of the angles A_1, A_2, A_3 in Table 2 show that the individual reference frames realize the axes of the ICRF better than 40 µas, and their uncertainties indicate that, after rotation, the inconsistency between the directions of the axes is at most 30 µas.

The parameters listed in Table 3 represent deformations of the individual frames relative to ICRS. The values of D_α and D_δ indicate that any of the frames present small deformations in the coordinates depending on the declination. The B_δ parameter quantifies the bias between the principal planes of the individual frames and that of the ICRS. For the solutions computed by AUS and CGS the biases are significant, between 50 to 60 µas. On the contrary, the principal planes of the BKGI frames are aligned to that of ICRS at the level of 10 to 15 µas. The values of the weighted mean residuals r_α and r_δ in Table 4 indicate that the model represents well the inconsistencies between the orientations of frames at a level of 10 µas or better.

Investigation of future realizations of the ICRS

Involvement by ICRS Centre personnel in the celestial reference frame VLBI program continued in 2005, increasing the number of observations of ICRF quasars in the southern celestial hemisphere and continuing an extensive observing program in the northern hemisphere. This observing program will eventually result in a future extension and potentially a new realization of the ICRS, tentatively called ICRF 2. Plans for the formulation of ICRF 2 will be discussed at XXVIth General Assembly of the International Astronomical Union (IAU) to be held in Prague, Czech Republic in August 2006. In the Southern Hemisphere, the USNO and the Australia Telescope National Facility (ATNF) are collaborating in a continuing VLBI research program in Southern Hemisphere source imaging and astrometry using USNO, ATNF and ATNF-accessible facilities. These observations are aimed specifically toward improvement of the ICRF in the Southern Hemisphere by a) increasing the reference source density with additional S/X-band bandwidth-synthesis astrometric VLBI observations, and b) VLBI imaging at 8.4 GHz of ICRF sources south of $\delta = -20^{\circ}$. In the Northern Hemisphere a major source of VLBI data continues to be the series of RDV experiments, which consist of observations of International Celestial Reference Frame (ICRF) sources at radio frequencies of 2.3 GHz and 8.4 GHz using the Very Long Baseline Array (VLBA), together with up to 10 geodetic antennas. These VLBA RDV observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames. During calendar year 2005, six VLBA RDV experiments were observed. In addition VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2005. These observations are part of a joint program between the National Aeronautics and Space Administration, the USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory.

In the coming decades, there will be significant advances in the area of space-based optical astrometry. Proposed and scheduled missions such as the National Aeronautics and Space Administration's (NASA) *Space Interferometry Mission* (SIM-PlanetQuest) and the European Space Agency's (ESA) *Gaia* mission will achieve positional accuracies well beyond that presently obtained by any ground-based radio interferometric measurements. In 2005, ICRS Centre personnel continued their participation in the NASA SIM mission, through direct involvement in one of the SIM key science projects: *Astrophysics of Reference Frame Tie Objects*. In addition, during 2005 ICRS Centre personnel were funded by NASA to lead and execute a concept study for the *Origins Billions Star Survey (OBSS)* mission, a unique astrometric and astrophysical Galactic Exploration mission that will leave as a legacy the measurement of over two billion stellar positions, parallaxes, and proper motions, along with a scientifically rich database of extrasolar planet detections, binarity determinations, stellar photometry and variability, and low resolution spectrometry. ICRS Center personnel concluded the 8 month OBSS concept study in April 2005 and submitted a concept study report for the OBSS mission to NASA in May 2005. In addition, ICRS Centre personnel have been working on concept development for a microsatellite based astrometric mission, called the Milli-Arcsecond Pathfinder Survey (MAPS), to produce milliarcsecond level astrometry for all of the bright stars up to 12th magnitude (limiting magnitude ~15–16). Together with several industrial partners, in 2005 ICRS Centre personnel conducted a preliminary concept study with the goal of better understanding mission related costs, schedule, and risks.

Monitor source structure to assess astrometric quality

VLBA RDV Imaging

Observations of International Celestial Reference Frame (ICRF) sources at radio frequencies of 2.3 GHz and 8.4 GHz using the Very Long Baseline Array (VLBA), together with up to 10 geodetic antennas, continued in 2005. These VLBA RDV observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames. During the calendar year 2005, six VLBA RDV experiments were observed.

VLBA High Frequency Imaging

VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2005. These observations are part of a joint program between the National Aeronautics and Space Administration, the USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory. During the calendar year 2005, two VLBA high frequency experiments (BL122A and BL122B) were calibrated, imaged and added to the Radio Reference Frame Image Database.

ICRF Maintenance in the Southern Hemisphere

The USNO and the Australia Telescope National Facility (ATNF) are collaborating in a continuing VLBI research program in Southern Hemisphere source imaging and astrometry using USNO, ATNF and ATNF-accessible facilities. These observations are aimed specifically toward improvement of the ICRF in the Southern Hemisphere by a) increasing the reference source density with additional S/X-band bandwidth-synthesis astrometric VLBI observations, and b) VLBI imaging at 8.4 GHz of ICRF sources south of declination –20 deg.

VLBI images for a total of 48 Southern Hemisphere ICRF sources at a frequency of 8.4 GHz using the Australian Long Baseline Array were published by Ojha et al. (2005). These data, together with previously published data, were used to quantify the magnitude of the expected effect of intrinsic source structure on astrometric bandwidth synthesis VLBI observations by calculating a “structure index” for a total of 111 southern hemisphere sources; the structure index yields an estimate of their astrometric quality. Approximately 35 % of the sources were found to have a structure index indicative of compact or very compact structures. The remaining two-thirds of the sources are less compact and should probably be avoided in astrometric and geodetic VLBI experiments requiring the highest accuracy unless intrinsic source structure can be accounted for in the astrometric/geodetic analysis.

The Radio Reference Frame Image Database

The Radio Reference Frame Image Database (RRFID) is a web accessible database of radio frequency images of ICRF sources. The RRFID currently contains 3632 VLBA images of 502 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 976 images of 255 sources at frequencies of 24 GHz and 43 GHz. The RRFID can be accessed from the Analysis Centre web page or directly at <http://www.usno.navy.mil/RRFID/>.

Extension of the list of stable

One of the tasks of the ICRS Centre is the identification of those of the radio sources observed by the International VLBI Service program that are most suitable for the maintenance of the ICRF axes. Based on the analysis of time series of source coordinates, Feissel-Vernier (2003) had proposed a list of 199 well observed radio sources considered stable, and 163 sources considered unstable, based on the statistical analysis of time series of source directions. Using slightly modified selection scheme, Feissel-Vernier et al. (2006) extended the list to 71 new sources and downgraded 18 of the sources initially considered as stable, leading to a revised list of 247 sources. The new analysis is described hereafter.

A first extension concerns the sources with a relatively poor observation history. The Feissel-Vernier (2003) stability detection scheme, referred to MFV hereafter, is based on time series statistics of yearly averaged source coordinates. It has therefore the limitation of requiring time-density of observation. Over the 1990–2002 time span, 358 sources, i.e. about half of the total, were too sparsely observed to be submitted to the scheme. In order to learn more about their possible stability, a simplified selection scheme was applied to them. For sources observed in more than three sessions over more than two years, we assume that, in both $\alpha \cos \delta$ and δ, a standard deviation of the weighted mean position smaller than 0.5 μas and a linear drift smaller than 50 μas/year are an indication that the source might be stable. We thus select a set of 22 additional sources.

The second extension is based on a re-iterated computation of time series of coordinates provided by C. Ma (GSFC). The MFV scheme was applied to time series of source coordinates that were derived taking subsets of the ICRF *defining* sources as the background reference. As a sizeable part of those were detected as unstable, one could not rule out the possibility that the intrinsic instability of the set of reference sources create spurious instabilities in the sources under study. A slightly modified scheme was therefore applied to time series of source coordinates derived from a global analysis where the original 199 stable sources where held fixed relative to the ICRF through a No-Net-Rotation condition. The modified selection scheme includes the additionally rejecting sources with apparent drifts in $\alpha \cos \delta$ or δ larger than 10 mas/year, at a 5-σ significance. A set of 44 sources were detected as stable by this modified scheme.

Finally, when the above additional stability condition is applied to the time series used by Feissel-Vernier (2003), 18 sources are found to be unstable. This is the third change in the source selection.

In summary, 247 sources considered stable are selected. They are listed at URL <http://hpiers.obspm.fr/icrs-pc/icrf/stable_2006.txt>. Their observation history is illustrated by Figure 1.

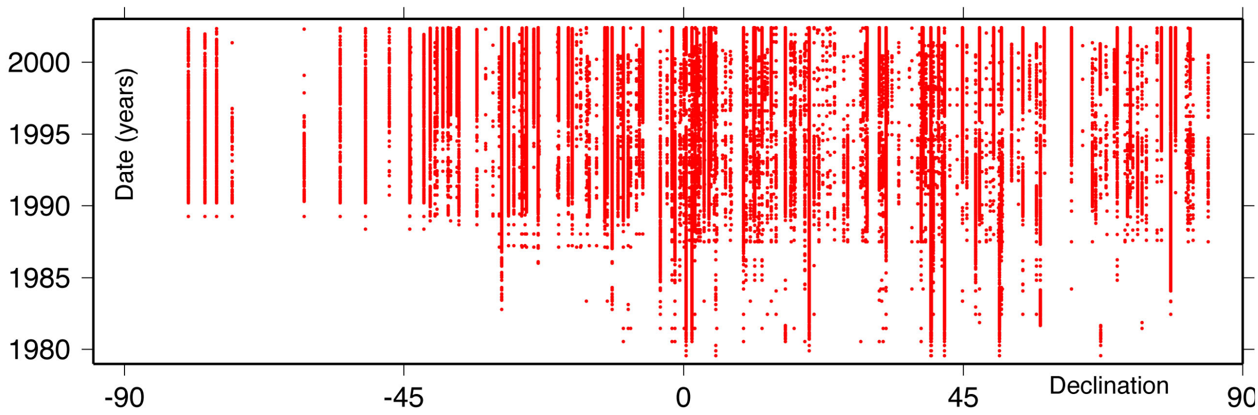

Fig. 1: 1979–2002 observations of the 252 most stable sources. Each dot represents a session in which the source was observed.

Maintenance of the link to the Hipparcos catalog

During the reporting period (2005) progress has been achieved in several areas related to the maintenance of the Hipparcos link: UCAC project (preparation for the final release), the extragalactic and galactic link to radio frame sources, and URAT.

All 4.5 TB compressed pixel data of the USNO CCD Astrograph Catalog (UCAC) project are now loaded from over 1200 tapes onto hard disk drives and software development started for the final reductions of the data. The goal is to achieve a much larger completeness for the final catalog, including solutions for "problem" sources, in particular double stars. Release of the UCAC3 will be in 2007.

As part of the UCAC project early epoch photographic plates are being measured on the StarScan machine at USNO to provide proper motions on the Hipparcos system. About 1500 Hamburg Zone Astrograph plates were measured in 2005.

Reduction of the deep CCD images taken of extragalactic, compact radio sources during the UCAC project continued. Results from the 2.1m KPNO run and a 0.9m CTIO run give optical-radio differences on the 15 mas level per source, the most accurate data of this kind ever taken. Systematic error analysis and optical to radio frame tie will be investigated after more runs are reduced.

Monitoring a sample of 12 ICRF optical counterparts continued at the 1.55m NOFS. This effort is part of the SIM preparatory science for the celestial reference frame key project (PI is K. Johnston).

As part of the preparatory science for the SIM PlanetQuest Key project Astrophysics of Reference Frame Tie Objects (K.J. Johnston, P.I.), investigations continued into the use of radio stars to link the optical frame to the ICRF. The Very Large Array (VLA), linked with the Pie Town Very Long Baseline Array antenna, was used to determine astrometric positions of 46 radio stars in the ICRF. Positions were obtained in the ICRF directly through phase referencing of the stars to nearby ICRF quasars. The derived radio star positions are estimated to be accurate at the 10 mas level, with position errors approaching a few milli-arcseconds for some of the stars observed. Measured positions were combined with previous measurements taken from as early as 1978 to obtain proper motion estimates for all 46 stars with average uncertainties of ~1.7 mas/yr. A comparison with the Hipparcos Catalogue data, shows consistency in the reference frames produced by each data set on the 1-sigma level, with errors of ~2.7 mas per axis for the reference frame orientation angles at our mean epoch of 2003.78. No significant spin was found between the radio data frame and the Hipparcos Celestial Reference Frame (HCRF). Results are consistent with a non-rotating Hipparcos frame with respect to the ICRF (Boboltz et al. 2006, AJ, submitted).

The optical design of the USNO Robotic Astrometric Telescope (URAT) was finalized. The field of view is now 4.5 degree in diameter obtained from the FASA2 design, consisting of 2 full-aperture and 2 sub-aperture lenses plus 2 mirrors. In July 2005 a contract was signed with EOST to procure the primary mirror for URAT. The detector development for URAT was funded by the Office of Naval Research (ONR) through a Small Business Innovation in Research (SBIR) phase 2 contract assigned in December 2005. A 10.5k by 10.5k monolithic CCD with test camera will be delivered by Semiconductor Technology Associates (STA) to USNO in 2006. URAT will provide a direct link between ICRF optical counterparts and the radio frame on the few mas per source, as part of an all-sky astrometric survey for the 13 to 21th magnitude range.

Linking the ICRF to frames at various wavelengths

The ICRF (International Celestial Reference Frame) was adopted as the fundamental celestial reference frame at the XXII General Assembly of the International Astronomical Union held in August 1997 in Kyoto. One of the interesting tasks which remained to be done by the ICRS Centre consisted in searching for the optical counterparts of the ICRF objects in catalogues already published. Souchay et al. (2006a) have done such a study starting from the largest optical catalogue of extra-galactic objects, that is to say the Véron-Cetty and Véron catalogue (Véron-Cetty and Véron, 2003), referred in the following as VV2003. The VV2003 catalogue contains 48 921 quasars, 876 BL LAC objects and 15 069 active galaxies (AGN). We have carried out the cross-identifications between the 717 extragalactic radio sources in ICRF-Ext.2 (Fey et al., 2004) and the VV2003 sources. For these cross-identifications we have chosen two different thresholds, respectively 2" and 4". We have shown that with a 2" threshold, 173 objects among the 212 objects of the defining sources of the ICRF were cross-identified (81.6%). The respective numbers are 205 among the 294 objects named as “candidate sources” (67.0 %) and 90 among the 102 objects named as “other sources” (88.2%). Therefore we can remark that a substantial amount of ICRF objects are not included in the VV2003 catalogues, which means that we have no real access to their optical characteristics.

The sky coverage of ICRF-Ext.2 as well as the VV2003 catalogue were also studied separately and compared to each together. In the first case the zones of the celestial sphere for which the angular distance to the closest quasar is larger than 10° represent about 50% of the celestial sphere. In the second case the zones for which this closest distance is larger than 1° is restricted roughly to a thin band surrounding the galactic plane. Moreover comparative plots of the histograms of the photometric (V magnitude) and redshift characteristics of the quasars belonging to the two above catalogues, as well as the histograms related to their radio flux at 6cm and 11 cm show fundamentally different profiles and peaks. All the results above are analysed in detail by Souchay et al. (2006a).

Maintenance of the link to the solar system dynamical reference frame through close approaches between planets and quasars

Some optical observations enable one to relate the positions of moving bodies (such as the planets) with respect to a fixed quasi-inertial reference frame through stars recognized as astrometric standards, or extragalactic objects. After suitable reductions, these observations can be used to link the ICRS and the dynamical systems. One of the most promising experiments consists in determining the relative position between a planet and a quasar during close approaches between these two kinds of objects.

Toward this end we have carried out a systematic analysis of all the close approaches occurring between Jupiter and the quasars of the Veron-Cetty and Veron catalog (2003), during the time span from J2005.0 to J2015.0 (Souchay et al., 2006b). For instance we have found 24 close approaches between J2010.0 and J2012.0, which roughly corresponds to data taking phase of the Gaia astrometric space mission. For that we have chosen a 300 arcseconds threshold not to be exceeded for the shortest distance between the quasar and Jupiter's photocentre. These phenomena, which could be observed from ground-based telescopes as well as from Gaia, might play a significant role in the link between inertial directions supposed to be fixed, as given by the quasars, and the dynamical system. Notice that for this purpose, Jupiter's satellites photocentres might be chosen instead of the planet photocentre itself, because of its excessive brightness. In addition to these astrometric reductions, relativistic deflections of light due to Jupiter's mass and J2 dipole moment have been systematically modelled. Notice that the angular changes in the directions of the quasar concerned could be easily detected by Gaia measurements.

Maintenance of the link to the solar system dynamical reference frame using Lunar Laser Ranging (LLR) analyses

The solar system dynamical reference frame is materialized by the dynamical mean ecliptic and equinox (epoch J2000.0) related to the orbit of the Moon through the ephemerides of the semi-analytical lunar solution ELP (Chapront-Touzé M. and Chapront J., 1997). The analysis of the LLR observations enables one to define the orientation of dynamical mean ecliptic and equinox of J2000 with respect to ICRS. In the same time, the LLR analysis enables one to determine other parameters and to update the ELP theory (Chapront J. et al., 2002, 2003).

The position of the dynamical mean ecliptic with respect to the ICRS is defined by two angles: $\varepsilon^{(ICRS)}$, the inclination of the dynamical mean ecliptic to the equator of ICRS, and $\varphi^{(ICRS)}$, the angle between the origin $o^{(ICRS)}$ of right ascensions on the equator of ICRS and the ascending node $\gamma_I^{(ICRS)}$ of the dynamical mean ecliptic on the equator of ICRS.

The evaluation of these two angles is involved in the transformation of the rectangular coordinates of the LLR stations from the terrestrial reference frame to the celestial reference frame taking into account the polar motion, the Earth rotation and the orientation of the celestial pole. The precession-nutation matrix is computed with the IERS conventions using the daily corrections of the nutation in longitude and obliquity provided by IERS (Earth Orientation Centre series C04).

This transformation is realized according to the lunar solution ELP which results from weighted fits to the observations provided between 1970 and 2005 by the LLR stations: 10646 observations from Grasse (Observatoire de la Côte d'Azur, France), 7097 observations from Fort-Davis (McDonald Observatory, Texas) and 482 observations from Maui (Haleakala Observatory, Hawai). The last determination is:

$$\varepsilon^{(ICRS)} = 23°26'21.41112'' \pm 0.09 \text{ mas}$$

$$\varphi^{(ICRS)} = o^{(ICRS)}\gamma_I^{(ICRS)} = -0.05441 \text{ mas} \pm 0.09 \text{ mas}$$

The uncertainties mentioned here represent formal uncertainties resulting from the least square fitting. Realistic uncertainties can be estimated between five and ten times these values.

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3.5.5 ITRS Centre

This report summarizes briefly the activities of the IERS ITRS Centre during the year 2005.

The main activities of the ITRS Centre during the year 2005 are:

- Re-adjustment of surveys in co-location sites
- Maintenance of the IERS network
- Preparation for the ITRF2005

Re-adjustment of surveys in co-location sites

The ITRS Centre has undertaken the initiative to animate the activity related to the reanalysis of available new and/or old surveys data of the ITRF co-location sites with the aim to generate SINEX files of local ties with full variance-covariance information. Starting with the available survey data at IGN, the ITRS Centre generated full SINEX files for approximately all DORIS co-located sites, using Geolab adjustment software. These SINEX files as well as other files made available by other groups (INA and CGS, Italy; BKG, Germany and Geoscience Australia) are posted at the ITRS Web site.

Maintenance of the IERS network

This activity includes update of the IERS network database in terms of new sites and stations, assignment of DOMES numbers, local ties, availability of IERS network information and ITRF products on the web and ftp server, as well as assisting the ITRF users for a proper use of ITRF products.

Moreover, a new ITRS Web site was developed and it is now open to the ITRF users: <http://itrf.lareg.ensg.fr>. This new Web site allows the users to interactively:

- retrieve site information
- on-line request DOMES number assignment
- select positions (at any epoch) and velocities in any ITRF version for any sub-set of stations, in SINEX or/and table list.

Preparation for the ITRF2005

See the IGN ITRS Combination Centre report (Section 3.6.1.2).

Zuheir Altamimi, Xavier Collilieux, Bruno Garayt

3.5.6 Global Geophysical Fluids Center (GGFC)

The Global Geophysical Fluids Center (GGFC), a product center of the International Earth Rotation and Reference Systems Service, serves the worldwide research community, by providing information on the geodetic effects of fluid motions within the Earth and on its surface. The products provided are estimates of the variations in the Earth's rotation, its shape, its gravitational field, and geocenter, (at various temporal and spatial scales) which are caused by the mass transport of geophysical fluids.

There are currently eight Special Bureaus (SB), which supply products in response to community requirements. These include: Atmospheres, Oceans, Hydrology, Tides, Mantle, Core, Loading, and Gravity/Geocenter (see attached reports). The various products generated by the SB's are based on global observations of surface fluid motion and/or state-of-the-art models, which estimate fluid motion within or on the surface of the Earth. The products are available through the individual SB web sites and can be accessed via the GGFC portal housed at the European Center for Geodynamics and Seismology (<http://www.ecgs.lu/ggfc/>).

In some SB's the yearly activity is high as new surface fluid models and data sets are constantly becoming available and are thus required by the geodetic research community. The annual activities of these SB's are included here in the annual report. In other SB's, the fluid models or data sets are well established and changes, if they occur, occur rarely and thus an annual report is not required. The annual report in this case, simply restates the model or data that are available from that particular SB. It is still valuable to have a single location where even established and validated fluid models and their predicted effects on geodetic observables can be found.

In 2005, the International Association of Geodesy established the Global Geodetic Observing System (<http://www.ggos.org/>). GGOS will provide observations of the three fundamental geodetic observables (the Earth's shape, the Earth's gravity field, and the Earth's rotational motion) and their variations. The official establishment of the GGOS potentially increases the importance of the GGFC, as now the GGFC represents a resource where anyone can obtain modeled estimates of geodetic effects due to the Earth's fluid motion to compare with the GGOS observations.

Members

Tonie van Dam (Univ. of Luxembourg, Head GGFC)
For other members see the lists of members of the individual Special Bureaus below.

Tonie van Dam

Special Bureau for the Atmosphere

In conjunction with the U.S. National Oceanic and Atmospheric Administration (NOAA) the SB Atmosphere has produced data from 4 different operational meteorological centres. We have also produced data from atmospheric reanalyses, spanning back to 1948. SB Atmosphere organized a system to operate in two modes. In the first, it supplies the data in near-real time through the services at NOAA, including analysis and forecast terms. In the second mode, it updates monthly archives of the data on the FTP server at Atmospheric and Environmental Research, Inc. (AER).

The principal data prepared relate to atmospheric excitations of the Earth rotation vector, as forced by changes in the winds and surface pressure of the atmosphere, known respectively as the motion and mass terms of the atmospheric angular momentum AAM. For the axial component, related to length-of-day, the stronger term is the motion one, and for the equatorial term, related to polar motion, the mass term generally dominates. An “inverted barometer” correction is produced to the mass terms, designed to model an equilibrium condition of the oceans in which the ocean depresses in response to a higher atmospheric pressure and rises in response to a lower one.

SB Atmosphere also computes the AAM terms locally, in a number of equal-area sectors distributed around the globe, as well as globally. In addition, SB Atmosphere computes the mean atmospheric surface pressure over the globe, and various spherical harmonics, which are related to the Stokes coefficients of the Earth gravity field, of particular interest to recent space-gravity missions. SB Atmosphere archives torques from the NCEP-NCAR reanalyses that relate to the angular momentum transfer from atmosphere to solid Earth, including topographic (mountain), friction, and gravity wave drag torques. Users log in to our ftp sites to obtain the desired information.

Dr. Yonghong Zhou became a member of the SBA. He has been processing the atmospheric data from his position at Shanghai Astronomical Observatory to help update the SBA archives. He processes both the NCEP-NCAR reanalyses using the revised codes that were developed while he was a visitor at Atmospheric and Environmental Research. The new procedure and related scientific results are detailed in Zhou et al. (2006). The revised procedure has improved on the treatment of the lower boundary and also updated a number of geophysical constants needed to calculate the atmospheric excitations.

Atmospheric thermal tides are known to cause diurnal variations in wind, which transfer here to variations in polar motion excitation. The diurnal signal, moreover, is seasonally modulated. Two functions (1 and 2) for polar motion were analysed for all twelve months in 2002; the axial (3) term was also processed, though it is relatively much smaller. The polar motion terms have strong variations with magnitude of ~ 10 mas. They have a distinct 'winter mode' (January to February, October to December) and 'summer mode' (March to September). The axial length of day term has very small daily variation with magnitude of ~ 0.009 ms. We established the similarity of these two terms from the NCEP and the JMA analyses.

During 2005 we investigated the possibility of using atmospheric models for more rapid subdiurnal scales. Fields from one of the NASA models can be extracted hourly, in between the six-hour analyses that are routinely used. We have been investigating the feasibility of calculations of the atmospheric excitation terms for the Earth orientation parameters. A test period was October 2002, during the special CONT02 campaign in which measurements from Very Long Baseline Interferometry developed high temporal resolution data.

Also during the year, Dr. Jolanta Nastula of the Space Research Centre of the Polish Academy of Sciences, Warsaw, visited AER for the purpose of calculating regional fields of the Earth orientation parameters to help understand better the atmospheric excitations of polar motion.

Acknowledgments

Dr. Zhou's visit to AER was sponsored by the Descartes-Nutation Program, chaired by V. Dehant, and we are grateful for this support. The U.S. National Science Foundation has supported activities, at AER of the SBA, and the visit of Dr. Nastula, under Grant ATM-0429975.

Members

A. J. Miller (NCEP)
David Salstein (AER, Head SBA)
Yonghong Zhou (Shanghai Astronomical Observatory)

David Salstein

Special Bureau for the Oceans

Introduction

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans. As part of the IERS Global Geophysical Fluids Center, the Special Bureau for the Oceans (SBO) is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO web site at <http://euler.jpl.nasa.gov/sbo> are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, and bottom pressure.

Data Products

Five different oceanic angular momentum series are currently available from the IERS Special Bureau for the Oceans:

(1) ponte98.oam, a series computed by Ponte *et al.* (1998) and Ponte and Stammer (1999, 2000) from the products of a simulation run of the MIT ocean general circulation model which spans January 1985 to April 1996 at 5-day intervals;
(2) johnson01.oam, a series computed by Johnson *et al.* (1999) from the products of version 4B of the Parallel Ocean Climate Model (POCM) which spans January 1988 to December 1997 at 3-day intervals;
(3) c20010701.oam, a series computed by Gross *et al.* (2003, 2004) from the products of a simulation of the oceans' general circulation run by the Estimating the Circulation and Climate of the Ocean (ECCO) group at JPL which spans January 1980 to March 2002 at daily intervals;
(4) ECCO_50yr.oam, a series computed by Gross *et al.* (2005) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1949 to December 2002 at 10-day intervals; and
(5) ECCO_kf049f.oam, a series computed by Gross *et al.* (2005) from the products of a data assimilating model of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2006 at daily intervals.

Five different oceanic center-of-mass series are also currently available from the IERS Special Bureau for the Oceans:

(1) dong97_mom.cm, a series computed by Dong *et al*. (1997) from the results of a version of the Modular Ocean Model (MOM) run at JPL which spans February 1992 to December 1994 at 3-day intervals;
(2) dong97_micom.cm, a series also computed by Dong *et al*. (1997) from the results of running the Miami Isopycnic Coordinate Ocean Model (MICOM) at JPL which also spans February 1992 to December 1994 at 3-day intervals;
(3) c20010701.cm, a series computed by Gross (personal communication, 2003) from the results of a simulation run of the ECCO ocean model done at JPL which spans January 1980 to

March 2002 at daily intervals;

(4) ECCO_50yr.cm, a series computed by Gross (personal communication, 2004) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1949 to December 2002 at 10-day intervals; and

(5) ECCO_kf049f.cm, a series computed by Gross (personal communication, 2004) from the products of a data assimilating model of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2006 at daily intervals.

Time series of the ocean-bottom pressure are currently available from the IERS SBO through a link to the JPL ECCO web site at <http://ecco.jpl.nasa.gov/external> from which two dimensional ocean-bottom pressure fields can be obtained that have been produced from purely surface flux-forced ocean models as well as ocean models that additionally assimilate satellite and in situ data. A link is also provided to the GLObal Undersea Pressure (GLOUP) data bank of ocean-bottom pressure measurements at <http://www.pol.ac.uk/psmslh/gloup/gloup.html>.

In addition to these data sets, a subroutine to compute oceanic angular momentum, center-of-mass, and bottom pressure from the output of general circulation models can be downloaded from the IERS SBO web site along with a bibliography of related articles.

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Richard Gross

Special Bureau for Tides

The IERS Special Bureau for Tides collects datasets related to the effects of tides on Earth rotation and geocenter motions. The Special Bureau for Tides generates most of its own product data sets by analyzing the results of numerical computer models of the relevant geophysical fluids, in this case both ocean tides and atmospheric tides. The Bureau is therefore dependent upon the work of modelers to release their solutions to the EOP community; in the case of tides, this means solutions for both tidal elevations and tidal current or wind velocities on a global (or nearly global) grid. The data archive that the Bureau maintains has slowly grown as individual tidal investigators contribute to their modeling results. The data collected by the Special Bureau are publicly available via the internet at <http://bowie.gsfc.nasa.gov/tides>.

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Special Bureau for Hydrology

The Special Bureau for Hydrology provides internet access to data sets of water storage load variations for major land areas of the world. The web site contains results from four numerical models, the NCEP (National Center for Environmental Prediction) reanalysis, the ECMWF (European Center for Medium Range Weather Forecasting) reanalysis, the CPC (Climate Prediction Center) Land Data Assimilation System (LDAS), and NASA's Global Land Data Assimilation System (GLDAS). Global terrestrial water storage changes estimated from GRACE (Gravity Recovery and Climate Experiment) time variable gravity observations during the period April 2002 and November 2005 are also provided in our online data archive (at <http://www.csr.utexas.edu/research/ggfc/>). The NASA GLDAS and CPC LDAS data products are updated on a regular basis.

As a new addition to our online data archive, GLDAS is an advanced land surface modeling system jointly developed by scientists at the NASA Goddard Space Flight Center (GSFC) and the NOAA NCEP. GLDAS parameterizes, forces, and constrains sophisticated land surface models with ground and satellite products with the goal of estimating land surface states (e.g., soil moisture and temperature) and fluxes (e.g., evapotranspiration). In this particular simulation, GLDAS drove the Noah land surface model version 2.7.1, with observed precipitation and solar radiation included as inputs. GLDAS estimates are the sum of soil moisture (2 m column depth) and snow water equivalent. Greenland and Antarctica are excluded because the Noah model does not include ice sheet physics. The GLDAS data are provided on 1° x 1° grids and at 3-hourly intervals. Daily average terrestrial water storage is computed from the 3-hourly model estimates. Antarctica is not included in the model and estimates over Greenland are not recommended to use, because of the lack of ice dynamics in the model.

The NCEP reanalysis model is a fixed data-assimilating global numerical model, designed mainly for atmospheric studies. It has been run for a period starting in 1948, up to the present. NCEP results are valuable for their global coverage and long duration. The hydrologic part of this model is mainly employed as a lower boundary condition in the model, and reflects a combination of an imposed (non data-assimilating) hydrologic cycle, and interaction with the atmosphere. The NCEP reanalysis variations are probably representative of the real Earth, but not accurate in detail. They lack the level of inter-annual variability expected in the real hydrologic cycle, and observed in some more sophisticated data-assimilating land surface model results. In addition, there are evident flaws over Antarctica and Greenland, which probably result from locating highly variable sea ice at land grid points. Therefore Antarctica and Greenland are excluded from geodetic calculations. The web site includes daily NCEP water storage in Gaussian grid (T62) form for Jan. 1979 – Dec. 2004, and polar motion and length of day excitation time series for Jan. 1948 – Dec. 2004, as well.

The ECMWF data-assimilating reanalysis model, similar to NCEP, also with a surface hydrologic cycle. We find that it appears more realistic than NCEP, showing greater interannual variability. In addition, its seasonal cycle resembles long-term average results based on local budget (Precipitation-Evaporation-Runoff) calculations. The web site includes 2.5-degree gridded values at daily intervals for the period 1979–1993.

CPC LDAS is forced by observed precipitation, derived from CPC daily and hourly precipitation analyses, downward solar and long-wave radiation, surface pressure, humidity, 2-m temperature and horizontal wind speed from NCEP reanalysis. The output consists of soil temperature and soil moisture in four layers below the ground. At the surface, it includes all components affecting energy and water mass balance, including snow cover, depth, and albedo. Monthly averaged soil water storage changes are provided on a 1 x 1 degree grid. These data are averaged from the original 0.5 x 0.5 degree grid and converted into NetCDF and standard ASCII format. The data cover the period Jan. 1980 through Dec. 2005. No estimate is provided over Antarctica. A README file and a few Matlab scripts used for doing the conversion are provided as a reference to the data format.

The README file with the NCEP and ECMWF data also includes details on the way in which actual loads are calculated from the soil moisture model field. Data are available in both ascii and NetCDF (.nc) formats. In addition, there are helpful sample Matlab commands lists and m-files for reading the data in NetCDF format with Matlab, and for interpolating from the original model grid to a uniform (for example 1 x 1 degree) grid.

We provide estimates of equivalent surface water storage using GRACE time variable gravity observations provided by the GRACE team at the Center for Space Research (CSR), University of Texas at Austin. 22 monthly, unconstrained GRACE solutions (RL01) covering the period April 2002 and July 2004 are used to estimate global surface mass change on a 1 x 1 degree grid. Results with 3 different spatial Gaussian smoothing scales, 600 km, 800 km, and 1000 km are provided. The GRACE spherical harmonics are truncated at degree and order 60, and the C20 term is not included. A newly added similar product is the equivalent surface water storage change derived from 3.5 years of GRACE RL01 constrained solutions provided by CSR. This new product is from 40 GRACE monthly solutions covering the period April 2002 and November 2005.

The Special Bureau for Hydrology is currently planning to provide the community a few new data products, which should be available online in late 2005. The new data products include combined surface mass load changes from the atmosphere, ocean, and land water. The purpose is to provide a product similar to the GRACE atmospheric and oceanic dealiasing (AOD) dataset, but to also include the hydrology part and apply a full baroclinic ocean general circulation model. The plan is to combined NCEP reanalysis 6-hourly atmospheric pressure change, 12-hourly ocean bottom pressure change from the ECCO (Estimating the Circulation and Climate of the Ocean) data assimilating ocean general circulation model, and the GLDAS 3-hourly terrestrial water storage change to generate a 6-hourly AOW (atmosphere, ocean, and water) surface mass load product. A number of issues need to be addressed, including mass conservation of a dynamically coherent system, data representation (spherical harmonics and surface grids), data format, and etc.

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Special Bureau for Mantle

The Special Bureau for Mantle was established to provide services for information and data exchange to facilitate research in the geodynamic effects due to motions in the mantle. Accounting for 68% of the mass and 89% of the moment of inertia of the entire Earth, the solid, but non-rigid, mantle is perpetually in motion. There are motions caused by external forces, including tidal deformation, atmospheric and oceanic loading, and occasional meteorite impacts. For internal processes, volcanic eruptions and pre-seismic, coseismic and post-seismic dislocations associated with an earthquake act on short timescales. On longer timescales, present-day post-glacial rebound, surface processes of soil erosion and deposition, and tectonic activity such as plate motion, orogeny, and internal mantle convection, all transport large masses over long distances. Finally, the entire solid Earth undergoes an equilibrium adjustment in response to the secular slowing down of the Earth's spin due to tidal friction.

As with any geophysical processes that involve mass transports, these large-scale motions produce variations in Earth's rotation, gravity field, and geocenter. Among them, however, currently only two topics have been extensively investigated: co-seismic excitation of Earth rotational and gravitational changes and glacial isostatic adjustment.

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Special Bureau for the Core

Introduction

Flow in the fluid outer core, and also motion of the inner core with respect to the outer core, can result in various geodetic phenomena observable from the Earth's surface or space. These phenomena include variations in the Earth's rotation and orientation, surface gravity changes, geocenter variations, and surface deformations. Although small, these variations can or could be observed by very precise space geodetic techniques. Observation of these effects yields unique insight into the core, which cannot be observed directly, and the resulting better understanding of the core will lead to improved models and predictions for the geodetic quantities.

Activities

The Special Bureau for the Core is responsible for collecting, archiving, and distributing data related to the core and plays a role in promoting and coordinating research on this topic. In particular, the SBC focuses on theoretical modelling and observations related to core structure and dynamics (including the geodynamo), and on inner core – outer core – mantle interactions. The SBC has about twenty members from the fields of geomagnetism, Earth rotation, geodynamo modelling (numerical and experimental), and gravimetry. The SBC has set up a web site (<http://www.astro.oma.be/SBC/main.html>) as the central mechanism for providing services to the geophysical community. Since one of the goals of the SBC is to distribute general information on the core, to make the geophysical community aware of the various geodetic effects that could be linked with the core, and to stimulate, support and facilitate core research, we present on our website concise explanations on topics as core convection, core flow, geomagnetism, core-mantle boundary torques, inner core differential rotation, Earth's rotation changes due to the core, and core composition. Additionally, we have built and continuously update a bibliography of articles relevant to the core that at present contains more than a thousand references.

Data products

The web site presently contains model data on core flow and core angular momentum. Most data are based on the observed surface geomagnetism field, and various hypotheses and physical assumptions are used to determine the flow and the angular momentum of the core. Moreover, a high-resolution time series is given that is determined by subtracting computed atmospheric angular momentum series from a time series for length of day variations. In addition to the data, a description is given of the relevant theories and of the dynamical assumptions used for constructing the flows.

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Special Bureau for Gravity/Geocenter

The Special Bureau for Gravity/Geocenter continued its focus on building a gateway to the GRACE and CHAMP primary gravity and ancillary analysis data permanently archived at the Physical Oceanography Distributed Archive (PO.DAAC) at JPL and the ISDC in Potsdam, as well as various SLR and GPS solutions. The Head of the SBGG also worked with a NASA-funded team to develop a user-focused gateway for GRACE products (<http://grace.jpl.nasa.gov>). This site provides useful interactive post-processing products of the primary gravity products archived at PO.DAAC and ISDC, and may be more useful for many SBGG customers.

The US/European joint science team for GRACE provided a major release of new gravity field solutions in November of 2005. These solutions include the mean gravity field, the monthly variations, and the 6-hr dealiasing products based on a barotopic and baroclinic ocean models (driven by ECMWF pressure and winds over the ocean) and ECMWF pressure over the land. Links are available to these solutions from the SBGG website.

Associates of the Special Bureau continue to play major roles in seeking additional dealiasing and data correction (loading) models through discussion with associates of other special bureaus.

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Special Bureau for Loading

Introduction

All mass movements on the Earth's surface load and deform the solid Earth and impact the gravity field and rotation on a level significant for the geodetic reference frame and the interpretation of geodetic time series. Mass transport in the atmosphere, oceans, continental hydrosphere, and cryosphere takes place on a wide range of temporal and spatial scales, thus introducing load-induced signals in all geodetic observations from sub-hourly (in the case of tsunamis, Plag et al., 2006) to millennium time scales (in the case of postglacial rebound, PGR) and from local to global spatial scales. In the vertical component, loading signals significantly exceed and are at the 10 mm level at diurnal and seasonal time scales, respectively, while secular signals associated with PGR are on the level of 10 mm/yr. On global scale, surface displacements induced by seasonal exchanges between ocean and terrestrial hydrosphere are of the order of 10 mm (Blewitt & Clarke, 2003), affecting the geodetic reference frame at the same order of magnitude.

SBL goals and contributions

As part of the IERS Global Geophysical Fluid Center, the Special Bureau for Loading (SBL) has the long-term goal to provide predictions of surface-load induced changes in the Earth's geometry, gravity field and, eventually, rotation. When established in 2002, the short-term goal of the SBL was the provision of predictions of changes in Earth's geometry induced by atmospheric loading, preferably in near-real time. In 2003, time series of atmospheric load induced station displacements for the main global and regional geodetic networks were made available, and in 2004, the semi-operational near-real time provision of station displacement as well as global grids was started. While the former (denoted as Research Products) were provided for different atmospheric pressure data sets, Earth models, and computational approaches (see Van Dam et al., 2003, for more details), the latter (denoted as Operational Products) were made available for air pressure provided by the *European Center for Medium Range Weather Forecast* (ECMWF), only (see <http://www.sbl.statkart.no/products> for more information on these products).

Atmospheric loading

In 2005, one focus was on the intercomparison of the research products. The maximum differences found for predictions given in the same reference frame are of the order of 4 mm and 1 mm for the vertical and horizontal components, respectively, though strongly depending on location. Results from other web pages providing access to loading predictions were included in the comparison (which also identified errors in some of these predictions). Main sources for the discrepancies are seen in the different air pressure data sets and the implementation of the inverted barometer response of the ocean, while differences in Earth models and computational approaches appear not to be important (see also Van Dam et al., 2003). The comparisons so far show that the detailed error budget of the loading computations is not well understood.

For the computation of the atmospheric loading signal, the air pressure anomaly is required at the Earth's surface, where the surface needs to be given with sufficient spatial resolution. In the meteorological models, the Earth's surface is represented by a model orography, typically given with a resolution of one or more degrees. The ECWMF does not routinely give access to the model surface pressure as computed on the model orography. In 2004, the SBL was advice to compute the pressure at topographic height from the air pressure and temperature at mean sea level. However, it was later discovered that the pressure at sea level is derived by a coarse approximation from the model surface pressure (see Section 2.4.3 in White, 2003), which leads to large, time-dependent errors particularly under the large ice sheets and high mountain areas. Thus, this parameter is found to be inadequate for the computation of air pressure anomalies at topographic height. As a result of using the ECMWF pressure at mean sea level for the near-real time loading calculations, these products are biased at seasonal time scale particularly over Antarctica, Greenland, and Central Asia.

Postglacial rebound

On global and regional scales, one of the main secular signal in geodetic quantities results from PGR. For many studies utilizing geodetic time series, this signal has to be removed (e.g. Velicogna & Wahr, 2006; Sato et al., 2006), while for others, it provides a means to validate the geodetic observations (e.g. Plag & Kreemer, 2006). In order to make available predictions of the present-day PGR signal in geodetic quantities, the SBL issued a Call for Submission of predictions early in 2005, which was widely distributed to the PGR research community. The predictions submitted so far (3 groups), which include also the ice history and the Earth models, are made available through <http://www.sbl.statkart.no/projects/sbl>. The intercomparison of the predictions as well as the comparison to geodetic observations is in progress.

Perspective

The near-real time provision of atmospheric loading predictions has to be based on model surface pressure and temperature, from which the pressure at topographic height can be computed. However, the spatial resolution of the surface topography is a parameter affecting the overall error budget of the predictions. The SBL in 2006 focuses on establishing the detailed error budget of the loading calculations at the sub-millimeter level. The determination of the required spatial resolution of the Earth topography in order to keep the error contribution due to topography on the 0.1 mm level is one of the goals in studying the full error budget.

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3.6 Combination Centres

3.6.1 ITRS Combination Centres

3.6.1.1 Deutsches Geodätisches Forschungsinstitut (DGFI)

During the year 2005 the DGFI activities as ITRS Combination Centre concentrated on the ITRF2005 computations, which are based on the combination of epoch normal equations (weekly/session data sets) of station positions and Earth orientation parameters (EOP) from the geodetic space techniques VLBI, SLR, GPS and DORIS. In addition to this report, several publications of the ITRS Combination Centre at DGFI are available (see references).

Input data for ITRF2005

Single-technique combined GPS, SLR and VLBI solutions were submitted by the Techniques' Combination Centres, namely the National Resources Canada (NRCan, IGS), the Geodetic Institute of the University Bonn (GIUB, IVS), and the Agenzia Spaziale Italiana (ASI, ILRS). Until now, no combined DORIS solutions are available by the IDS. Two individual solutions of DORIS Analysis Centres (IGN/JPL, LCA) are provided for the ITRF2005. In addition to the SINEX solutions the Technique Centres also provided a list with information about discontinuities (e.g. equipment changes, earthquakes) in station positions, which are used as input by the ITRS Combination Centres. Furthermore an updated version of local tie information was provided by the ITRS Centre.

Tab. 1: Input data sets for ITRF2005

Technique	Service / AC	Data	Time period	Parameters	Constraints
GPS	IGS NRCan	Weekly solutions	1996–2005 from June 1999 from March 1999	Station positions EOP (pole + rates, LOD) Geocentre	NNT: 0.1 mm NNR: 0.3 mm NNS: 0.02 ppb
VLBI	IVS GIUB	Daily sessions' free NEQs	1984–2005	Station positions EOP (pole, UT1 + rates)	None None
SLR	ILRS ASI	Weekly solutions	1993–2005	Station positions EOP (pole + LOD)	1 m 1 m
DORIS	IGN/JPL	Weekly sol.	1993–2005	Station positions EOP (pole, UT1 + rates)	Loose
	LCA	Weekly sol.	1993–2005	Station positions EOP (pole)	Loose

Combination methodology

The general concept of the ITRS Combination Centre at DGFI is based on the combination of normal equations and the common adjustment of station positions, velocities and EOP using the DGFI Orbit and Geodetic Parameter Estimation Software (DOGS). The processing procedure for the ITRF2005 computation is shown in Figure 1.

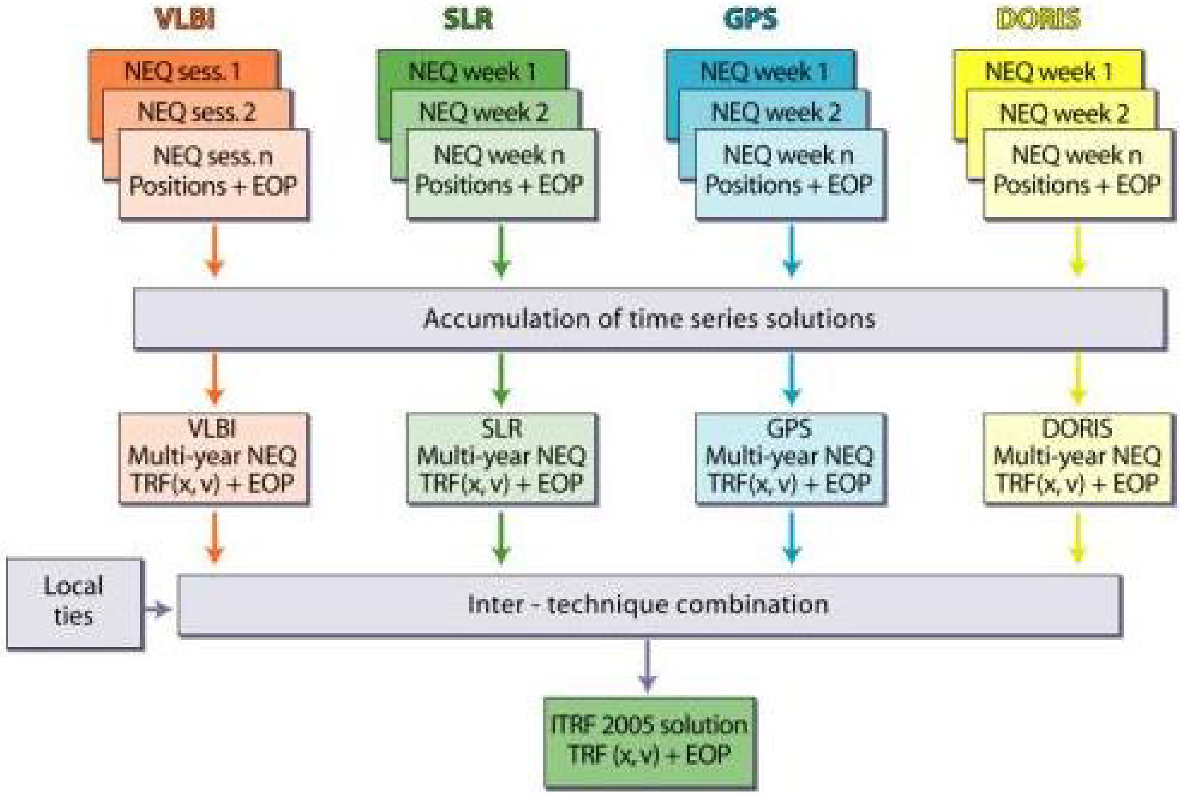

Fig. 1: Processing procedure for ITRF2005

Accumulation of time series solutions

For each technique the epoch normal equations were accumulated separately to compute multi-year solutions with station positions, velocities and EOP. In the case of discontinuities (provided by the Technique Centres) new position and velocity parameters for the corresponding station were introduced. Epoch solutions were computed by applying minimum datum constraints w.r.t. the multi-year solutions. The resulting time series of station positions and datum parameters were analysed in detail. Figure 2 as an example shows the time series for the station heights of the GPS station Irkutsk (Siberia) with a significant annual signal. Especially in short time intervals (e.g. less than 2.5 years) annual signals may affect the linear approach with station positions and velocities (see Table 2).

Tab 2: Station height velocity differences between a linear model and the estimation of additional annual signals for GPS station IRKT.

Data time span [yrs]	0.5	1.0	1.5	2.0	2.5	3.0	4.0	7.0
Δ velocities [mm/yr]	–37.5 ± 3.2	–3.7 ± 2.3	0.1 ± 1.0	2.7 ± 0.8	1.0 ± 0.6	–0.1 ± 0.5	–0.5 ± 0.3	0.03 ± 0.1

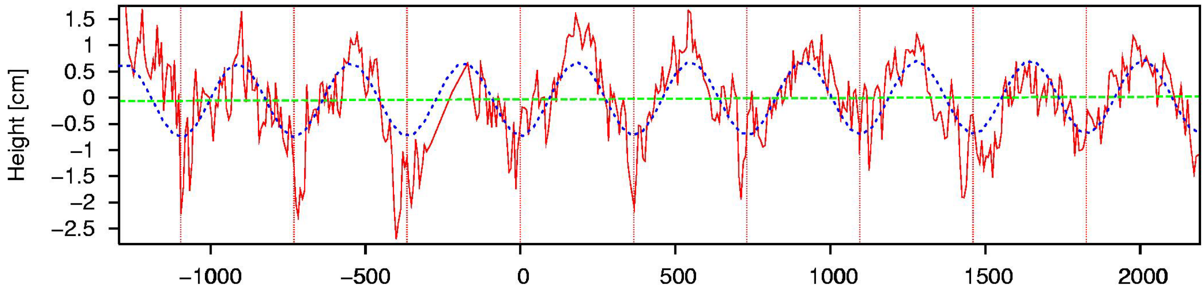

Fig. 2: Time series for the station heights of GPS station IRKT (Irkutsk, Siberia)

The repeatabilities of the weekly (daily) position estimates provide valuable information to assess the internal accuracy of the space geodetic solutions. The results obtained for the different space techniques are summarized in Table 3.

Tab. 3: Repeatability of station position estimates for different space techniques. Note, that in the case of VLBI daily sessions were used, whereas the other technique solutions are weekly.

Technique	TC / AC	North [cm]	East [cm]	Up [cm]
GPS	IGS	0.22	0.26	0.64
VLBI	IVS	0.53	0.52	1.5
SLR	ILRS	1.2	1.2	1.3
DORIS	IGN/JPL	2.7	3.7	2.5

The status of the computations at the end of the year 2005 was the following: The intra-technique combinations were almost finalized for GPS; only a few weekly solutions until 2006.0 had to be added in early 2006. The intra-technique combinations for VLBI and SLR were preliminary as new input data had to be submitted in the beginning of 2006. As the IDS does not provide combined DORIS solutions as input for ITRF2005, the DORIS intra-technique combination has to be performed by the ITRS Combination Centres.

Inter-technique combination

Input for the combination are the accumulated intra-technique normal equations of VLBI, SLR, GPS and DORIS solutions. The parameters comprise station positions, velocities and daily EOP. Concerning the combination of EOP of the different space techniques it has to be considered, that the VLBI estimates are referred to the midpoint of a daily VLBI session (from 17 hr to 17 hr), whereas the EOP values of the other techniques are referred to 12 h. Thus, the VLBI EOP estimates have to be transformed to the reference epochs of the other techniques. A key issue within the inter-technique combination is the implementation of local tie information. For this purpose the EOP are essential to validate the local tie selection and to stabilize the inter-technique combination as additional „global ties“. Other issues include the equating of station velocities of co-located instruments and the weighting between different techniques. In 2005 specific investigations concerning the inter-technique combination were performed and refined methods have been developed, which will be applied for the computation of the ITRF2005 solution as soon as the intra-technique combinations are finalized.

Comparison among ITRS Combination Centres

The new IERS structure with three ITRS Combination Centres (IGN, NRCan and DGFI) provides an optimal basis for the accuracy evaluation of the terrestrial reference frame computations. For first comparisons among the ITRS Combination Centres results of the GPS intra-technique combination were used, which were based on different strategies (e.g. at DGFI and NRCan velocities of different solutions for a station were not equated, IGN equated most of the velocities). We used for the comparisons a subset of about 65 IGS reference frame stations without discontinuities to estimate RMS differences for station positions and velocities between the different GPS solutions. As shown in Table 4 the results of the three ITRS Combination Centres are in a good agreement.

Tab. 4: RMS differences for station positions and velocities.

ITRS Combination Centres	RMS position differences [mm]			RMS velocity differences [mm]		
	North	East	Up	North	East	Up
DGFI – IGN	0.70	0.62	1.89	0.34	0.32	0.56
DGFI – NRCan	0.89	0.84	1.22	0.39	0.38	0.46
IGN – NRCan	0.91	0.83	1.56	0.38	0.42	0.54

Kinematic reference frame

The reference for the station velocities in the ITRF2005 will be given by an actual plate kinematic and crustal deformation model (APKIM) derived from the geodetically observed station coordinate variations. A preliminary model (APKIM2004P) was computed from the preliminary ITRF2005 input data (status end of 2005). It comprises 17 rigid plates of the geophysical PB2002 model and 4 deformation zones (Alps, Persia-Tibet-Burma, Gorda-California, and Andes). The rotation velocities of the principal lithospheric plates (Africa, Australia, Eurasia, North and South America) are determined with a precision of ± 0.05 mrad/Myr.

Conclusions and outlook

The new approach for the terrestrial reference frame computation based on time series combination of station positions and EOP has major advantages compared to the past TRF realizations. The advanced methodology allows to account for nonlinear effects in site motions and ensures consistency between the terrestrial reference frame and the EOP. The results obtained from first comparisons among the ITRS Combination Centres are very promising. However, especially for SLR and VLBI there are several "poorly observed" stations, which should not contribute to the final ITRF2005 solution. Also GPS and DORIS stations with a data time span less than 2.5 years should not be included to ensure reliable velocity estimations. According to the current schedule the ITRF2005 computations will be finalized by the ITRS Combination Centres end of May 2006, followed by a two-weeks validation phase performed by the Technique Centres, before the final ITRF2005 product will be officially released.

Acknowledgement

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Manuela Krügel, Barbara Meisel, Horst Müller,
Wolfgang Seemüller

3.6.1.2 Institut Géographique National (IGN)

The IGN ITRS Combination and Research Centre concentrates its activity on software enhancement, new combination strategy development and regular analysis of Global TRF solutions as well as time series solutions of TRF and EOP.

Data analysis and software enhancement

With interaction of IERS Analysis Centres (AC), individual solutions from the different techniques are frequently evaluated and tested, in order to improve the individual analyses as well as the ITRF combination. Thus both the individual ACs as well as the ITRS Combination Centre regularly test new analysis strategies. This cooperation between the IERS ACs and the ITRS CC is vital for quality control and improvement of IERS products. To achieve this goal, the software package Combination and Analysis of Terrestrial Reference Frames (CATREF), developed by IGN, is regularly updated and enhanced in order to perform proper analysis of the different solutions prepared by the IERS ACs. In particular modelling of the Earth Orientation Parameters (EOP) is included in the CATREF software, to be able to combine concisely and coherently station positions/velocities and EOPs.

Preparation for the ITRF2005: Analysis of Time Series of Station Positions and Earth Rotation Parameters

Unlike the previous ITRF versions, the ITRF2005 (previously ITRF2004) was designed to be built over time series of station positions and Earth Orientation Parameters. The ITRF2005 input time-series solutions are provided in a weekly sampling by the IAG International Services of satellite techniques (the International GNSS Service–IGS, the International Laser Ranging Service–ILRS and the International DORIS Service–IDS) and in a daily (VLBI session-wise) basis by the International VLBI Service (IVS). Each per-technique time-series is already a combination, at a weekly basis, of the individual Analysis Centre (AC) solutions of that technique, except for DORIS where two solutions are submitted by two ACs, namely the Institut Géographique National (IGN) in cooperation with Jet Propulsion Laboratory (JPL) and the Laboratoire d'Etudes en Geophysique et Oceanographie Spatiale (LEGOS) in cooperation with Collecte Localisation par Satellite (CLS), designated hereafter by (LCA).

Almost all the entire year 2005 was spent and devoted to the analysis of experimental solutions under the form of time series, submitted by the Technique Centres for the ITRF2005. This is because the individual Analysis Centres and their Technique Centres, except the IGS, were not sufficiently prepared to deliver the best of their results. The interaction between the ITRS Centre and Technique Centres and the regular feedbacks from the ITRS Centre allowed finally to have all the time series available at the end of 2005 as listed in Table 1.

Table 1. ITRF2005 Submitted solutions

TC – AC	Time span	Type of constraints/solution	EOPs
IVS	1980–2006.0	Normal Equation	Polar Motion, rate, LOD, UT1
ILRS	1993–2005.9	Loose; var-covar	Polar Motion, LOD
IGS	1996–2006.0	Minimal/Inner; var-covar	Polar Motion, rate, LOD
IDS – IGN/JPL	1993–2006.0	Loose; var-covar	Polar Motion, rate, LOD
IDS – LCA	1993–2005.8	Loose ; var-covar	Polar Motion

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3.6.1.3 Natural Resources, Canada (NRCan)

Preliminary solutions between the GPS component of the IGN, DGFI and EMR solutions were compared. The first comparisons were made during the summer of 2005 with the files available. A few stations with significant coordinate and velocity differences were identified and reported. These coordinate and velocity differences could be attributed for the most part to minor variations in the time series used, the discontinuities used, the stations included, conditions imposed, etc. In those preliminary solutions the IGN, DGFI and EMR solutions had respectively 497, 317 and 501 station coordinate and velocity segments. The validity of the matrices was also checked. The number of common segments was about 300 for all comparison pairs. After alignment using a 14-parameters Helmert transformation at a common epoch, the most reliable stations had position and velocity agreement approaching the mm and mm/y level, respectively. The original combination of the weekly solutions included the following information:

GPS weeks 837 – 998 (96/01/21 – 99/02/27): in most cases the AC solutions only included station coordinates. The daily ERP's (pole position, pole rate and calibrated LOD) were only included by a few ACs and only toward the end. A requirement to extract weekly implicit geocenter information from the ACs solutions was only agreed at the beginning of the pilot project and thus not available for this period.

GPS weeks 999 – 1012 (99/02/28 – 99/06/05): the apparent geocenter was included, but the ERP's were not available from all the ACs and thus not included in the combined product.

GPS weeks 1013 – 1308 (99/06/06 – 05/02/05): the apparent geocenter and the ERP's were included in the weekly solutions. The contribution eventually included up to the end of 2005 (GPS week 1355 (05/12/31)).

Two updates were added for ITRF2005, they are:

GPS weeks 1309 – 1333 (05/02/06 – 05/07/30) and

GPS weeks 1334 – 1355 (05/07/31 – 05/12/31).

Along with the added data since ITRF2000, the combination with the discontinuity table is probably the more significant change. Exchanges with IGN and DGFI also helped improve the list of station discontinuities. During the review of the time series, segments with questionable station coordinates time series were identified for removal and summarized using the discontinuity table format. The format could/should also be used to list stations with significant periodicity or exponential decay in the case of large earthquakes. For more refined analysis, modeling can be limited to one coordinate component at a time (e.g.: vertical). Coordination of the discontinuity list for common stations with the EUREF and NAREF regional analysis centers will also ensure the consistency of the global and regional solutions. This will facilitate the integration of the regional solutions in the new ITRF2005. Some velocity discontinuities were also included and could be correlated to large earthquakes. Only a subset (~200) of the discontinuities identified (~600) are relevant for this ITRF2005 realization. Many of the discontinuities could be correlated to events such as earthquakes or equipment changes, while several still have an unknown cause. For events before GPS week 837 (1996/01/21), the JPL and SIO station coordinates time series were the main sources of information.

The provided discontinuity table has also been subdivided in two subsets, one where the events are fairly certain, and the other where there is significant uncertainty. In general, in the first group, discontinuities could be observed from multiple time series and/or could be correlated with known events and/or had a large offset. Several individuals and organizations (e.g. TUM) also provided valuable information to improve the list of discontinuities.

These discontinuities may potentially cause some difficulties at collocated sites especially where no local markers relative motion is involved (e.g.: equipment change). The issue has to do with properly connecting the GPS measurements to the marker which may not necessarily be best for the epoch of the measurement tie.

The IGS weekly solutions are characterized by a gradual increase of the number of stations which was also accompanied with an improvement of the accuracy of the solutions since 1996. The time evolution of statistics for the North, East and Up components for the weekly station coordinates residuals show an improvement of a factor of about 4–5 between 1996 and 2005. The precision is currently at 3mm horizontally and 6mm vertically. Several factors are contributing to this significant improvement namely: 1) improving station hardware, 2) processing software and 3) increase in the number of stations processed.

A subset of the ITRF2005P solutions was compared to the IGS weekly combined “official” solutions for GPS weeks 1356–1370 (06/01/01 – 06/04/15) which were not included in ITRF2005. This subset was composed of the 139 stations in the IGS proposed realization of ITRF2005. The ITRF2005P subset was propagated to the epoch at the middle of the week corresponding to each weekly solution. The weekly solutions were aligned by estimating translations, rotations and scale to the proposed realization of the corresponding epoch before computing the residuals. The standard deviation of those residuals (N, E, and H) is 2.0 mm, 1.9 mm and 5.9 mm. These statistics are consistent with the expected noise level. The estimated noise level is consistent with past IGS realizations of ITRF. As in the previous realizations, the sample used includes of the best stations. In this case, the sample has over 40% of the GPS stations in ITRF2005P.

Rémi Ferland

3.6.2 Combination Research Centres

3.6.2.1 Agenzia Spaziale Italiana (ASI) – Centro di Geodesia Spaziale

Introduction

The Matera ASI Space Geodesy Center (CGS) is a Fundamental Station, hosting three permanent Space Geodetic systems (SLR since 1983, VLBI since 1990, GPS since 1995) providing raw observation data, acquired, screened and archived continuously and then forwarded to the technique-dedicated organisations (ILRS, IVS, IGS). Since several years, besides the single-technique data analysis providing many geodetic products on routinely basis compliant with the needs from international geodetic organisations (ILRS, IVS, IGS, IERS) as Analysis Center (AC), ASI-CGS is involved in combination activities aiming to provide specific products and as well as to test combination methodologies; in particular, since June 2004, ASI-CGS is the primary ILRS Combination Center (ILRS CC).

Intra-technique combination research activity and products

The main lines of the ASI-CGS combination methodology rely on the direct combination of loose constrained solutions; this straightforward method (e.g. "*Methodology for global geodetic time series estimation: A new tool for geodynamics*", P. Davies and G. Blewitt, JGR, vol. 105, no. B5, pages 11083–11100, May 10, 2000) allows handling input solutions easily, with no inversion problems for the solution variance-covariance matrix and no need to know a-priori values for the estimates. The reference frame is defined stochastically and is unknown; no relative rotation between the reference frames is estimated and removed. The combination is performed along the lines of the iterative Weighted Least Square technique, in which each contributing solution (and related variance-covariance matrix) plays the role of an 'observation' whose residuals with respect to the combined solution must be minimized; each solution is stacked using its full covariance matrix rescaled by a factor, computed at each iteration, fulfilling the conditions that the variance factor of the combination be close to unity and that each solution contribution be equally balanced. This loose combination methodology has been implemented and tested to handle site coordinates, site velocities, EOP, EOP rates coming from the same and/or different techniques.

1. Weekly contribution to ILRS "Pos+EOP" Pilot Project

At the end of 2002, the ILRS promoted a Pilot Project to set up an operational service able to provide each week, from individual contributing SLR solutions based on the observations to Lageos 1-2 and Etalon 1-2, an official ILRS set of combined:
1. weekly coordinates of the worldwide SLR tracking network;
2. daily EOPs (xpole, ypole, LOD), ITRF2000-framed for IERS Bulletin B.

ASI-CGS acts from June 2004 as primary ILRS Combination Centre, being in charge of providing weekly combined SLR solutions

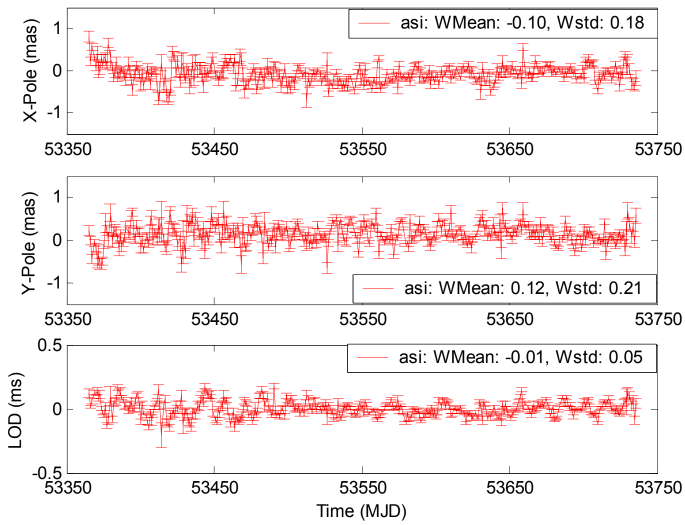

Fig. 1: ILRSA EOP differences w.r.t. IERS final values for 2005

available (labelled as 'ilrsa.pos+eop.*yymmdd*.v1.snx', SSC/EOP, and 'ilrsa.eop.*yymmdd*.v1', EOP only) to the users at the CDDIS and EDC archives. In Figure 1 the residuals of ILRSA EOP values w.r.t. the IERS final values are plotted.

2. Contribution to ITRF2005

ASI-CGS, as ILRS primary CC, applied the loose combination methodology 'backwards' also on the individual sets of weekly SLR solutions in the period 1993–2005 provided by the ILRS ACs in support of the ITRF2005 creation. The weekly combined solutions, labeled as 'ilrsa.pos+eop.*yymmdd*.v50.snx' and available at CDDIS and EDC archives, have shown a sub-centimeter agreement in the case of long-history, stable reference sites, once framed into ITRF2000.

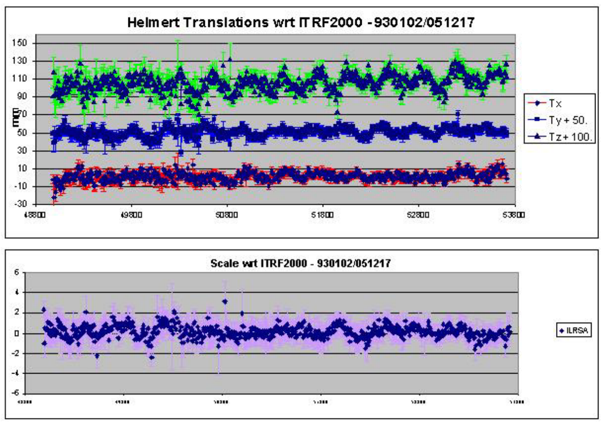

Fig. 2: ILRSA v50 contribution to ITRF2005

3. The API joint scientific group: a contribution to IERS Combination Pilot Project

API is a joint scientific group formed by ASI-CGS, Istituto Nazionale di Geofisica e Vulcanologia (INGV) and Politecnico di Milano (PoliMI) in order to study and develop geodetic inter-technique combination methods.

In 2005 the combination procedure used in the frame of ILRS “Pos+EOP” Pilot Project has been adapted to handle the intra-technique solutions in order to combine them. Local ties have been introduced as pseudo-observations in the loose constrained solution combination scheme. The inter-technique procedure is operational and satisfactorily preliminary results have been obtained.

4. Matera Geodetic Survey

In 2005 ASI-CGS has recomputed the Matera geodetic survey solution, including the IVP of the VLBI antenna modeled as ‘spindle torus’, with a renewed local data processing procedure, developed on site, designed to analyze data with a Weighted Least Square methodology using minimal inner constraints to avoid solution distorsion. The local data have been taken during a dedicated survey measurement campaign in which corner cube reflectors have been placed on the antenna dish as in Figure 3.

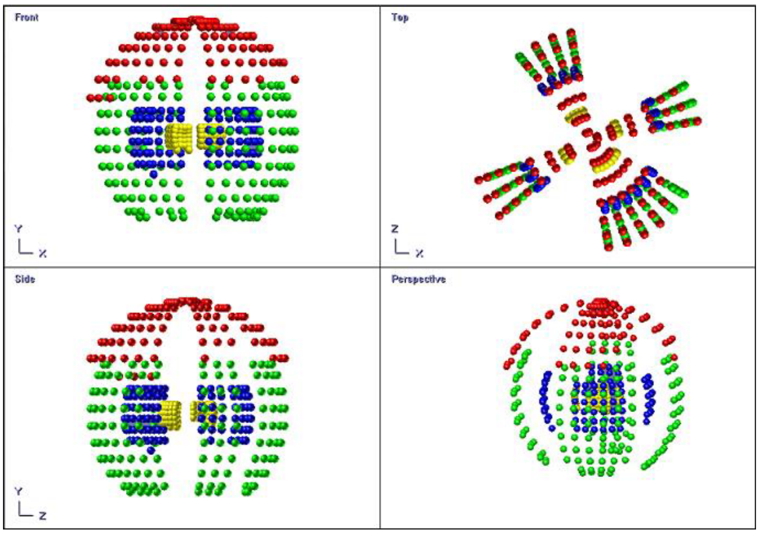

Fig. 3: Places of corner cube reflectors on the VLBI antenna dish during survey measurements

The new geodetic survey results have been provided to IERS and will be of key importance in the inter-technique combination to be performed in the ITRF2005 construction and in the IERS CPP.

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3.6.2.2 Astronomical Institute, Academy of Sciences of the Czech Republic, and Department of Geodesy, Czech Technical University, Prague

Introduction

The CRC is an integral part of the Center for Earth Dynamics Research (CEDR) that joins four Czech institutions active in astronomy and geosciences research. The combination research is maintained principally in two different directions. On the one hand, we combine some of the Earth Orientation Parameters using the 'combined smoothing' algorithm that we recently proposed, without changing the underlying reference frames (terrestrial, celestial). On the other hand, we follow the direction of combining non-SINEX particular solutions of different techniques to determine the Earth Orientation Parameters simultaneously with station coordinates.

Combination of EOP

We used our original combined smoothing algorithm (Vondrák & Cepek, 2000), with slight modifications to account for long-periodic (60 days and longer) systematic errors in GPS observations, to produce several more combinations in 2005.

We made a combination of the length-of-day (LOD) measured by GPS with UT1–TAI measured by VLBI and found that again the combination with GPS helps to improve the VLBI-only solution (Vondrák & Ron, 2005). We found that almost all observed variations of LOD for the periods going from several tens of days to 11 years can be explained by the combined effects of Earth tides and the atmosphere. The comparison of the solution with excitations by the atmosphere and oceans (Kouba & Vondrák, 2005) reveals that it yields the best correlation in short-period domain, of all series compared (IERS Bull. A, C04, IGS, SPACE93).

IGS uses empirical calibration of GPS-based LOD to VLBI-based UT1–TAI, in order to remove long-periodic errors of the former series. We attempted to find a more optimal method of combining VLBI with GPS to obtain mutually consistent series of UT1 and LOD. To do so, we used the method of combined smoothing to combine the VLBI-based values of UT1–TAI (IVS solution) with two GPS-based series of LOD, one calibrated (IGS) and one not calibrated (CODE) with respect to VLBI. These solutions are then compared with the atmospheric and oceanic excitation. The combination of VLBI-based UT1–TAI with GPS-based LOD helps to improve the VLBI-alone solution, both in resolution and accuracy. The combination demonstrated that the accuracy is consistent with formal errors, for both techniques, only when a priori calibration of GPS to VLBI is made. The correlation of combined LOD with atmospheric and oceanic excitation is very good, for shortest periods it is the highest of all series studied. Even if the calibration of GPS against VLBI is not used, the method of combined smoothing assures that the combined LOD is consistent with VLBI in a long-period sense

(Vondrák et al., 2006).

We also combined celestial pole offsets in the interval 1994.3–2004.6 (measured by VLBI) with their rates (measured by GPS), first referred to the old precession-nutation model IAU1980, and then transformed to the system of the new model IAU2000A. In the new system, the Free Core Nutation (FCN) becomes dominant. The period of FCN estimated from resonance effects from the combined VLBI/GPS solution is equal to 430±0.11 mean solar days (Vondrák et al. 2005).

Combination of EOP and station coordinates

A method of non-regular combination of different techniques to obtain simultaneously station coordinates and Earth Orientation Parameters was further developed. The method is based on combining position vectors of the stations in the celestial reference frame, with constraints to separate celestial pole offset from polar motion and to tie EOP between different epochs. Station coordinates are combined using seven-parametric transformation for each input technique instead of transforming the coordinates themselves.

Some techniques provide the IERS Combination Pilot Project (CPP) data base with the unconstrained data. This is not suitable for our case. Therefore, the ilrsb and ign-wd04 solutions were used for SLR and DORIS, respectively, instead of those collected in CPP, while for VLBI, the data is recovered from CPP singular normal equations using vtrf2005 station coordinates.

Basically, two approaches were studied – the short-term and the long-term combinations. The main difference of the two approaches is, that the former reflects short periodic changes in both the EOP and the station coordinates, while the latter accents general trends in the unknowns.

i) The input data was combined piecewise in shorter (e.g. monthly) periods. This reduces the effect of systematic biases, on one hand, but it yields discontinuities of EOP between the successive blocks, on the other. The discontinuities can be reduced substantially when data overlaps are applied. Namely, the monthly solutions were derived from two-monthly data. Newly, a trapezoid windowing was applied, so that the data in the overlaps is weighted from 1 at the middle to 0.1 at the ends (Pešek & Kostelecký, 2005, 2006).

ii) Good quality data allows the combination over a long period, in one step. In this case, rates of the transformation parameters are introduced to derive evolution of the station coordinates (Kostelecký & Pešek, 2006).

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3.6.2.3 Deutsches Geodätisches Forschungsinstitut (DGFI)

The DGFI activities as IERS Combination Research Centre during the year 2005 can be divided into the following major topics:

- Refinements of the SLR intra-technique combination (ILRS-B)
- Simultaneous estimation of a TRF, the EOPs and a CRF
- Combination of homogeneously processed VLBI and GPS data
- DGFI contributions to the IERS Combination Pilot Project

SLR intra-technique combination

Since June 2004, DGFI serves as the official ILRS Backup Combination Centre (ILRS-B). It computes weekly a combined SLR solution as an official product (SINEX files with station positions and EOPs) for the ILRS and as input for the weekly combination of SLR data with other techniques within the IERS Combination Pilot Project (CPP). During this period, DGFI has refined the intra-technique combination methodology and software for an automated processing to guarantee an operational combination of the individual SLR solutions on a weekly basis.

Simultaneous estimation of a TRF, the EOP and a CRF

DGFI has computed a VLBI solution with simultaneous estimation of station positions and velocities (TRF), celestial coordinates of the radio sources (CRF), and the full set of Earth orientation parameters (EOP) using the VLBI software OCCAM (Tesmer et al., 2004, Titov et al., 2004). The results of this completely undistorted VLBI solution were compared with the official IERS products, namely the IERS C04 series for the EOP, the ITRF2000, and the ICRF-Ext1. Assuming that the VLBI solution is free of (systematic) errors the results indicate inconsistencies between the IERS C04, ICRF-Ext1, and the VLBI part of ITRF2000 (Angermann et al., 2006). The observed discrepancies demonstrate the need for the development of rigorous combination methods for the generation of consistent IERS products, as for example envisaged within the IERS CPP.

Combination of homogeneously processed VLBI and GPS data

In close cooperation between DGFI, the Forschungseinrichtung Satellitengeodäsie TU München (FESG), and the GeoForschungs-Zentrum Potsdam, homogeneous normal equations were generated by a careful adoption of the models and parameterisations of the VLBI software OCCAM and the Bernese GPS software. The results based on the data of the continuous IVS campaign CONT02 have delivered very promising results for all parameters common to both techniques such as station positions, troposphere parameters, and sub-daily EOP (Thaller et al., 2006). Furthermore long time series solutions of VLBI and GPS of homogeneously re-processed VLBI and GPS data were generated and analysed. The results demonstrate that the estimated parameter series of both techniques are in a good agreement. It turned also out, that the differences compared to the results of the 14-days CONT02 campaign – especially for the estimated troposphere parameters – are very small.

IERS Combination Pilot Project

The IERS Combination Pilot Project (CPP) aims at more consistent, routinely generated IERS products. „Weekly“ SINEX solutions, which are available from the different technique services containing station positions, EOPs, and, possibly, quasar coordinates. These solutions shall be rigorously and routinely combined into consistent IERS products. In the frame of the CPP, DGFI provides individual SLR and VLBI solutions and combined SLR solutions (ILRS-B) to the ILRS and IVS, respectively. DGFI has been nominated by the IERS as a combination centre for the inter-technique combination. The presently available SINEX files were analysed regarding the suitability for a rigorous combination. The methodology for the weekly inter-technique combination of station positions and EOPs has been developed and implemented in the DGFI software DOGS-CS. During the CPP and within the IERS Working Group on Combination it was recognized that the weekly SINEX solutions now routinely generated by the Technique Centres are not sufficient to generate combined inter-technique solutions over longer time periods. It was found, that a refined TRF realization is an essential prerequisite for the weekly inter-technique combination. The computation of a new ITRF2005 solution is currently in progress by the ITRS Combination Centres.

Acknowledgement

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3.6.2.4 Forschungseinrichtung Satellitengeodäsie, Technical University of Munich (FESG)

Introduction

During the year 2005 the major activities of the FESG IERS CRC were concentrating on the following two combination and comparison topics:

1. Long Time Series: Comparison of troposphere parameters from GPS and VLBI
2. CONT02: GPS/VLBI combination studies

Homogeneously reprocessed time series of troposphere parameters for GPS (generated by FESG) and VLBI (generated by DGFI) were generated to detect common signals but also systematic differences between the troposphere results of the two space geodetic techniques. Such comparisons are an important first step before a rigorous combination of the troposphere parameters can take place.

The combination studies using VLBI and GPS normal equations for the time span of the CONT02 campaign started already in 2003 (see previous IERS Annual Reports) and have been continued in 2005, again making use of the good cooperation with the Deutsches Geodätisches Forschungsinstitut (DGFI). The topics of major interest in 2005 were:

- More detailed studies devoted to the combination of troposphere parameters derived from VLBI and GPS,
- Handling of the singularity between a retrograde diurnal term in polar motion and the nutation angles (including offsets and drifts),
- Dependency of the combined UT1–UTC time series on the selected local ties introduced into the combination.

Homogeneous Long Time Series of Troposphere Parameters from GPS and VLBI

Troposphere zenith delays and gradients covering the time period from 1994 to 2005 have been estimated within the reprocessing of a global GPS network, a cooperation of TU Munich and TU Dresden (Steigenberger et al., 2006). The complete and homogeneous reprocessing is essential for the inter-technique comparison with VLBI to avoid inconsistencies due to, e.g., model changes. Comparisons of the zenith total delay (ZTD) at sites with two or more GPS receivers (GPS/GPS co-locations) for our reprocessed GPS solution and for the combined IGS troposphere product revealed the inconsistency of the latter. Fig. 1 shows the ZTD differences for the sites TROM and TRO1 at Tromsø (Norway). The ZTD difference of the IGS series shows a clear annual signal at the beginning whereas the reprocessed solution only shows an increase in the scatter in the summer months.

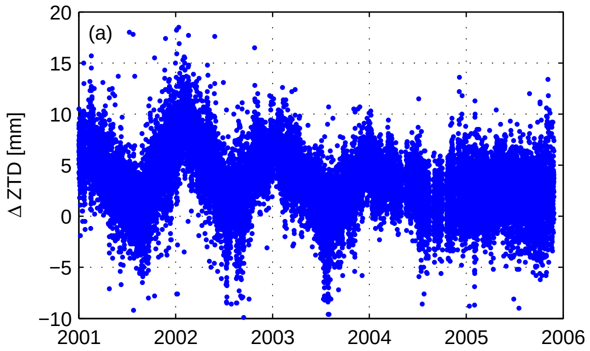

Fig. 1: ZTD differences for the GPS/GPS co-location Tromsø: (a) IGS time series; (b) reprocessed time series. The bias present in both solutions arises from the different antenna heights of TROM and TRO1.

The VLBI solution used for the comparisons was computed by DGFI Munich. The GPS/VLBI difference time series of the estimated zenith wet delay (ZWD) for Wettzell is shown in Fig. 2. The RMS of the difference is only 4.6 mm, the correlation of the GPS and VLBI ZWD time series is 0.994. For other stations, the correlation is in general larger than 0.95 and the RMS varies between 4 and 10 mm. Further details on the comparison of the GPS- and VLBI-derived troposphere zenith delays and gradients are given in Steigenberger et al. (2007). Although the GPS as well as the VLBI series are homogeneously reprocessed, there are still technique-specific systematic errors contained in the results of both techniques that remain the topic of future studies: multipath and receiver antenna phase center variations for GPS; thermal and gravitational deformations of the telescopes for VLBI.

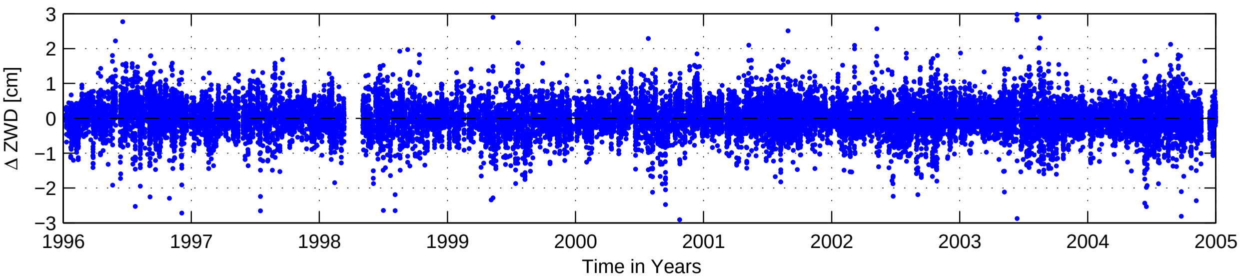

Fig. 2: Time-series of estimated zenith wet delays for Wettzell (Germany): difference between GPS and VLBI.

Inclusion of Troposphere Parameters in the Combination of GPS and VLBI

The parameter space common for the two microwave techniques VLBI and GPS does not comprise solely station coordinates and Earth Orientation Parameters (EOP) but as well the troposphere parameters. This fact has been completely neglected in combination studies up to now. Based on the normal equation systems generated for CONT02 it could be demonstrated that in general a combination of the troposphere zenith delays derived from GPS and VLBI is possible and stabilizes the combined solution (see Thaller et al., 2006). However, technique-specific specialties like, e.g., radomes on the GPS and/or VLBI antennas or the modelling of the GPS phase centres (relative vs. absolute phase centre calibrations) largely influence the results and could even make them non-interpretable. Consequently, it is indispensable to carefully adapt the a priori troposphere models used for both techniques.

Nutation and Retrograde Diurnal Terms in Polar Motion

The pole coordinates have been estimated with a temporal resolution of one hour. As a consequence of this setup, a singularity between the nutation angles and a retrograde diurnal term in polar motion is present. In order to remedy the singularity a special constraint can be applied in the Bernese GPS Software which prevents retrograde diurnal terms in polar motion by constraining their amplitude to zero. Fig. 3 demonstrates the impact of the singularity on the polar motion estimates (exemplarily for the x-pole): a retrograde diurnal signal with large amplitude is visible which corresponds to an offset in the nutation angles (not shown here). The standard application of the constraint is based on the entire time span of the solution, i.e., 14 days in the case of CONT02. Applying this method, the major part of the singularity is removed (grey line in Fig. 3). However, a retrograde diurnal signal with decreasing and increasing amplitude is still present and corresponds to the linear drift estimated for the two nutation angles. In order to remedy this singularity as well, the third procedure applies the constraint on a daily basis. Fig. 3 shows that this method works well. More details can be found in Thaller et al. (2007).

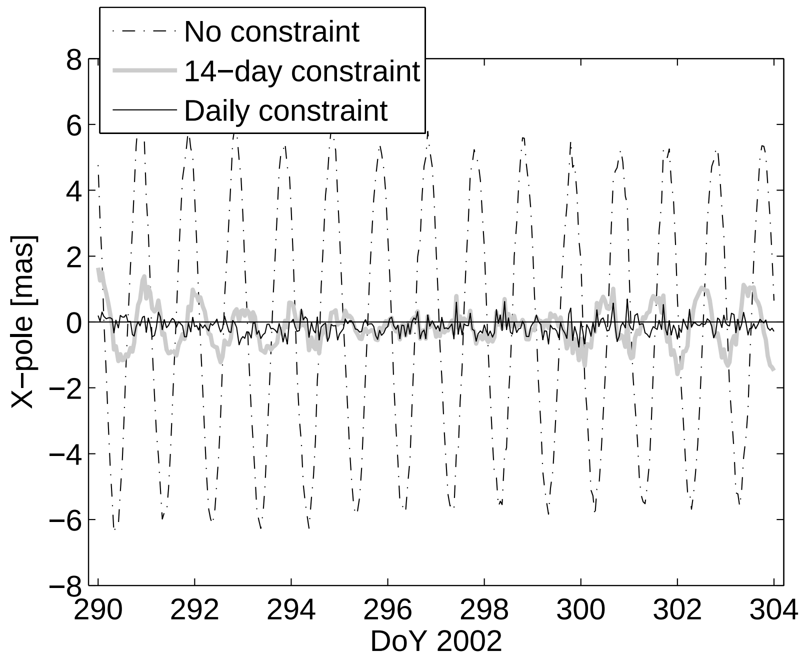

Fig. 3: Hourly polar motion estimate (x-pole component) derived from a VLBI-only solution with different handling of the retrograde diurnal constraint.

Local Ties and the Combination of UT1–UTC

The third topic mentioned at the beginning becomes especially important if the terrestrial reference frame and the EOP are treated together. Using the CONT02 data it could be demonstrated that the introduction of wrong or bad local ties causes a bias in the combined UT1–UTC time series (Thaller et al., 2007): the VLBI-only solution has an offset of only 1 μs compared to C04 whereas the combination, with all eight local ties applied, is shifted by 14 μs compared to C04. As it is well known that the local ties for Fairbanks and Westford do not fit very well to the space techniques they were ignored in another combined solution and, fortunately, the bias of the resulting UT1–UTC time series compared to C04 is reduced to 6 μs. However, the remaining shift of 5 μs w.r.t. the VLBI-only solution cannot be reduced by ignoring additional local ties. But the results clearly demonstrate that the local ties have to be carefully selected in view of a good determination of all parameters involved in the combination.

Acknowledgements

The GPS reprocessing project of the Universities of Technology in Dresden and Munich is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation). The combination research work is funded as part of the Project “GGOS-D” within the Geotechnologien-Projekt of the Deutsches Bundesministerium für Bildung und Forschung (BMBF, Federal Ministry of Education and Research).

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3.6.2.5 Forsvarets forskningsinstitutt (FFI)

Introduction

FFI has during the last 21 years developed a software package called GEOSAT (Andersen, 1995) for the combined analysis of VLBI, GNSS (GPS, GALILEO, GLONASS), SLR and other types of satellite tracking data (DORIS, PRARE and altimetry). The observations are combined at the observation level with a consistent model and consistent analyses strategies. The data processing is automated except for some manual editing of the SLR observations.

In the combined analysis of VLBI, GNSS and SLR observations, the data are processed in arcs of 24 hours defined by the duration of the VLBI session. The result of each analysed arc is a state vector of estimated parameter corrections and a Square Root Information Filter array (SRIF) containing parameter variances and correlations. The individual arc results are combined into a multiyear global solution using a Combined Square Root Information Filter and Smoother program called CSRIFS. With the CSRIFS program any parameter can either be treated as a constant or a stochastic parameter between the arcs. The estimation of multiday stochastic parameters is possible and extensively used in the analyses. The advantages of the combination of independent and complementary space geodetic data at the observation level is discussed in (Andersen, 2000).

Status

The GEOSAT software has during 2005 undergone extensive changes and improvements. The most important changes implemented in 2005 are described in the following.

A new major software component of GEOSAT for 3D raytracing through the atmosphere has been developed and validated during the last two years. A complete 3D atmospheric model provided four times daily by ECMWF is input to the software. Based on the available tracking (VLBI, GPS, or SLR) for that specific date, a set of tables for each active station is automatically generated with information about the time delay in the different elevation and azimuth directions. If surfmet data are available for a given station the measured pressure values are used to re-scale the hydrostatic delay obtained from the raytracing calculations. Since the raytracing starts at the position of the phase centre for each instrument/antenna, the effect of different antenna heights will automatically be accounted for to the level of accuracy of the numerical weather model. The Grueger model is default for the MW refractive index and the Ciddor model is default for the optical or near optical wavelengths. The Ciddor model has been validated against Ciddor’s own software.

Also statistical information concerning the variability of relevant parameters are extracted from the ECMWF data. This information is used in the estimation filter as time-dependent parameter constraints in the estimation of atmospheric signal delay scaling parameters. The raytracing procedure can also be used to detect periods with rapidly changing atmospheric conditions which cannot be modelled accurately. This information can be used to edit such data leading to more stable values for the atmospheric scaling parameters. This strategy is expected to be especially valuable for the combined analysis of GPS and future Galileo tracking data due to the great redundancy of such datasets.

Also the GNSS part of GEOSAT has undergone extensive changes, e.g. with the inclusion of a second and third order ionospheric correction, absolute phase centre corrections for all antennas etc. The ionospheric correction for GNSS applications in GEOSAT is expected to be accurate to around 1 mm.

The pressure loading tables provided by Leonid Petrov is used by GEOSAT. For stations not included in these tables a simple pressure scaling model is used where the load scale parameter is automatically estimated in the analysis. A grid of reference pressure values has been derived by averaging the surface pressure levels provided by NCEP during the last 20 years.

In the global processing of several years of data the stable sources listed by Feissel et al. are automatically estimated as constants while the others are estimated as random walk parameters or session parameters.

The new version of GEOSAT is expected to be ready for routine processing within 2 years. The new version of GEOSAT will have two additional very useful features:

1) It can simultaneously combine data from virtually any number of VLBI, SLR, and GNSS instruments at a collocated site either observing simultaneously or in different time windows. All information will contribute to the estimation of the migration of an automatically selected master reference point at each station.

2) The solve-for model parameters in combined processing of the VLBI + SLR + GNSS can either be instrument-dependent, technique-dependent, microwave-dependent, optical-dependent, or site-dependent. The switching between the different types is extremely simple. A simple application would be to treat in a first run the zenith wet delay parameters as instrument-dependent parameters which means that, e.g., a station with two GPS receivers and one VLBI instrument will have three estimates of this parameter. If the results are consistent, these parameters can be estimated as a single parameter represented by a microwave-dependent parameter in a second run. The same can be tested for clock parameters for colocated clocks etc.

A new software component for the generation of a Geophysical Events file has been included in GEOSAT. This file contains information about Earthquakes, the magnitude, and distance to stations included in the ITRF. Based on this information we plan to develop an estimation strategy where noise, dependent on the distance to the epicentre, is added to the station reference point motion for stations affected by Earthquakes.

Instrumental Events files for VLBI, GPS, and SLR have also been included in GEOSAT. These files give the epochs of changes in software or hardware of the instrument and the type of change. Every time an instrumental event occur noise will be added to the relevant estimated eccentricity vector.

The status is that twelve years of VLBI-only sessions have been analysed. A clear reduction in a posteriori residuals is observed.

The validation of GEOSAT with LAGEOS SLR tracking data is almost completed also with very promising results. The use of a detector-dependent centre of mass corrections, 3D raytracing, and taking into account a signal strength dependent range bias for some stations, lead to a slight change in the value of GM. The use of multicolour laser data has been implemented and gives excellent post-fit residuals. This will be further investigated in 2006 when we plan to estimate a new and consistent value for GM.

Future plans

Observations from the GALILEO navigation system will be applied when available. Only minor changes in GEOSAT are required for this extension.

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Per Helge Andersen

3.6.2.6 Geodetic Institute of the University of Bonn (GIUB)

The Geodetic Institute of the University of Bonn has been operating an IERS Combination Research Centre since 2001. In 2005, most of the investigations concentrated on the generation of the input files for ITRF2005 since the VLBI Group of the Geodetic Institute is responsible for generating the official input series of the International VLBI Service for Geodesy and Astrometry (IVS).

In this process, contributions of the IVS Analysis Centres in the form of individual SINEX files for each 24-hour session have been combined to the official IVS series of SINEX files. For this purpose, the IVS had decided that it will carry out its official combination activities purely on the basis of datum-free normal equations. So, combinations of output from software packages using least-squares algorithms based on the solution of normal equations did not pose any basic difficulties. However, software packages using Kalman Filter or Square Root Information Filter techniques are not able to generate normal equations directly. Possible ways of reconstructing normal equations from covariance matrices have been investigated but a satisfying solution has not been reached yet due to a deficit in transferring necessary statistical information. For this reason, the official IVS VLBI series has been combined only on the basis of contributions of analysis centres which were able to produce genuine datum-free normal equations (Vennebusch et al. 2006). In connection with the combination of EOP results on the basis of EOP time series, it was found out that the IVS Analysis Centres use slightly different realisations of the terrestrial reference frame (TRF) in their data analysis for EOP determinations. This introduces an extra noise component which can be eliminated through the use of a single TRF realisation to be applied after the combination process. For this reason, the IVS will change to carry out combinations of datum-free normal equations in SINEX format exclusively from January 1, 2007.

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Axel Nothnagel, Sarah Böckmann, Markus Vennebusch

3.6.2.7 GeoForschungsZentrum Potsdam (GFZ)

Reference Frame Solutions Including Low Degree Gravity Field Coefficients

The objective of the IERS CRC at GFZ is to determine, apart from station positions and Earth Orientation Parameters (EOPs) accurate low degree, long wavelengths gravity field parameters with a high temporal resolution. Dense and continuous GPS observations from the CHAMP and GRACE satellite missions set the basis for a high resolution of the solved for parameters. The quality and type of the data lead to high accuracy, and the low altitude of the considered satellites (Low Earth Orbiters, LEOs) assures high sensitivity.

For the processing of the CHAMP and GRACE measurements we follow the strategy of the so-called “integrated” approach, i.e., the combination of multiple satellites with various kinds of tracking observations and of space geodetic data, respectively, at the observation level. The EPOS software at GFZ is well-suited to handle this variety of data and sensors types. Using this “integrated” approach, the homogeneity and consistency of the combined solutions can be maximized. In the case of CHAMP and GRACE we integrate ground and space-borne GPS receiver observations, SLR observations, accelerometer measurements, K-band data and mission-specific data to solve for the orbits of all the satellites, including the GPS constellation, with dynamical models, the ground station coordinates, the EOPs and the low degree spherical harmonic coefficients of the Earth gravity field. Results have been published by König et al. (2005a) and Hu et al. (2005).

In parallel to the “integrated” approach, the standard strategy of processing Satellite Laser Ranging (SLR) data to the geodetic-type satellites LAGEOS-1 and -2 delivers comparable ensembles of parameters with less time resolution though, but with the confidence of a well-established technique. This opens up the possibility to compare the two types of results in detail. In the reporting period, time series of C20 parameters were computed and compared to published results in order to validate the procedures. Also combinations with GRACE monthly gravity field solutions were generated to verify GRACE C20 variations. Results and comparisons to the integrated approach were presented in König et al. (2005b).

Our third approach is the so-called “on-board co-location”, where the conventional co-location of instruments at ground stations is reversed: local ties are replaced by the centre of mass offsets of the instrument locations on the satellites. We used the combined GPS/CHAMP/GRACE constellation to compare SLR and GPS-based reference frames. For this, GPS and LEO orbits were determined from GPS observations only. Then, by freezing the orbits and therefore the GPS reference frame, ground station coordinates were determined for the SLR sites, solely based on SLR observations to GPS-35, GPS-36, CHAMP and GRACE. Systematic differences of the derived coordinates to the purely SLR-based coordinates in the ITRF2000 were not found. Results were presented in Neumayer et al. (2005).

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3.6.2.8 Groupe de Recherches de Géodésie Spatiale (GRGS)

We present thereafter the status of the GRGS concerning the IERS Combination Pilot Project (CPP). We have demonstrated the possibility of deriving both station coordinates and Earth Orientation Parameters (EOP) based on weekly solutions on a regular basis since the beginning of 2005. Results are made available in the form of SINEX files at the IERS site (ftp <iers1.bkg.bund.de>) (Gambis et al., 2006a). However, before such products are adopted as references, different problems concerning the stabilization of the terrestrial reference frame have to be solved in addition to upgrade the individual techniques processing to the best level of accuracy. After a general presentation of individual technique processing we present the analyses concerning the combination procedures performed on two modes: the weekly mode and the long-term one over a full year (2005).

1 General approach

Observations of the different techniques (VLBI, SLR, LLR, DORIS and GPS) are processed separately using a unique software package: GINS/DYNAMO, developed and maintained at the GRGS (Groupe de Recherches de Géodésie Spatiale) since 1965.

The normal matrices derived from the analyses of individual techniques are stacked to give both the terrestrial frame materialized by station positions and Earth Orientation Parameters (EOP). The project started in January 2005 on an operational mode. This project, ambitious and too important to be run by a single analysis centre is distributed at different institutes where in addition the expertise can be found for the dedicated technique: GPS at Noveltis, Toulouse (S. Loyer), DORIS at CLS, Toulouse (L. Soudarin), SLR at the Observatoire de la Côte d'Azur, Grasse (P. Bério), LLR at CNES, Toulouse (J. Ch. Marty) and at the Observatoire de Paris (G. Francou), VLBI at the Observatory of Bordeaux (G. Bourda, P. Charlot).

The final combination as well as the validation and various post analyses are performed at the Observatoire de Paris (D. Gambis and T. Carlucci). In addition the expertise of Z. Altamimi concerning terrestrial frame is appreciated.

Data processing is performed using the GINS software with identical up-to-date models and standards (Figure 1).

2 The GINS/ DYNAMO package

The a priori dynamical and geometrical models are:

- A priori dynamical models are the GRIM5-C1 gravity field model and the three body point mass attraction from the Sun, the Moon (+ J2 Earth's indirect effect) and planets, Mercury, Venus, Mars, Jupiter and Saturn.
  - Earth tide model according to IERS Conventions (2003)

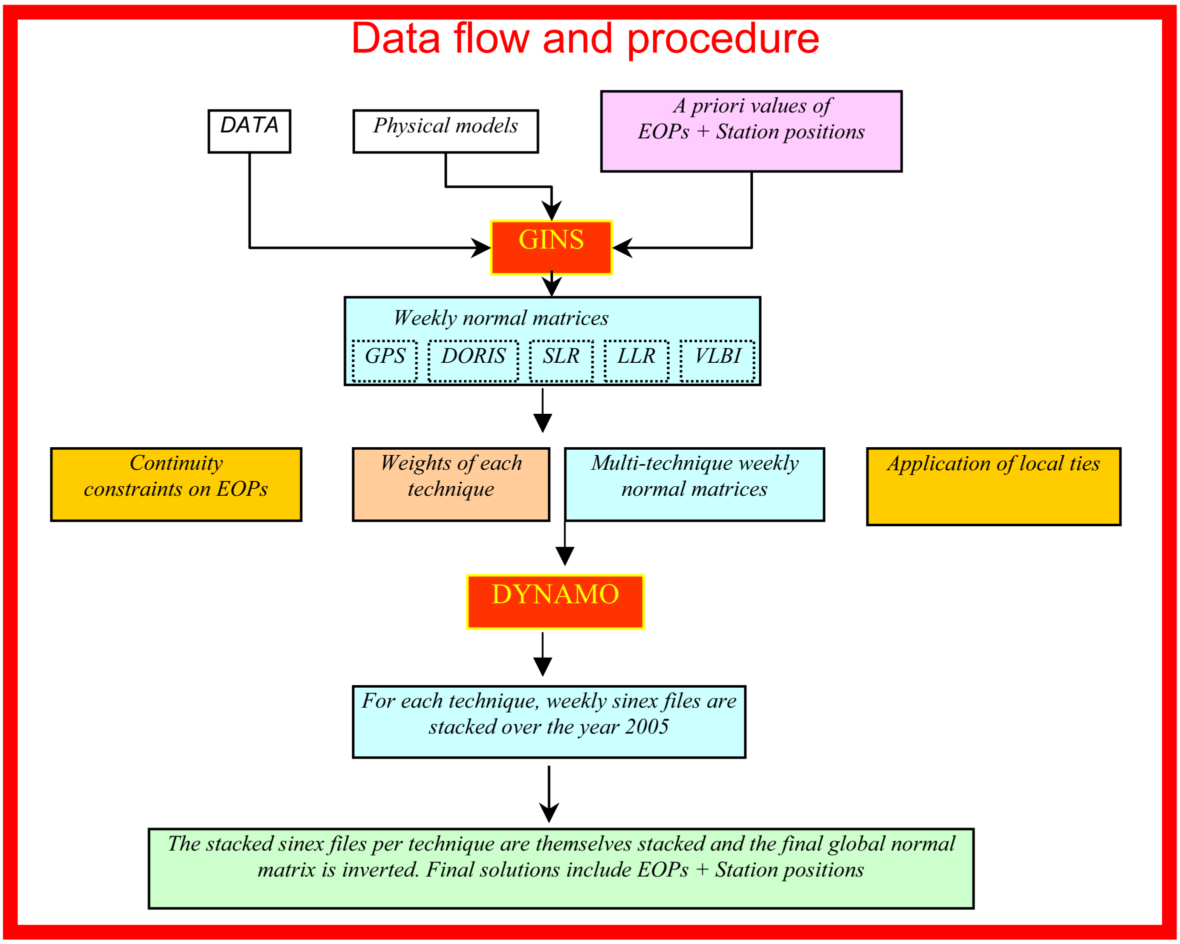


Fig. 1: Chart showing the organisation of the project and the data flow

- FES-2004 ocean tide model
- 6h-ECMWF atmospheric pressure fields only over continents (IB hypothesis)
- DTM94bis thermospheric model
- Albedo and Infra-Red grids from ECMWF (resolution of 4.5 degrees)

• A priori geometrical models :
- Coordinates derived from ITRF 2000
- A priori EOPs from IERS C04 series
- Earth tide model according to IERS Conventions (2003)
- Oceanic loading effect from FES-2004 ocean tide model
- Atmospheric loading effect from 6h-ECMWF atmospheric pressure fields only over continents

3 Processing of individual techniques

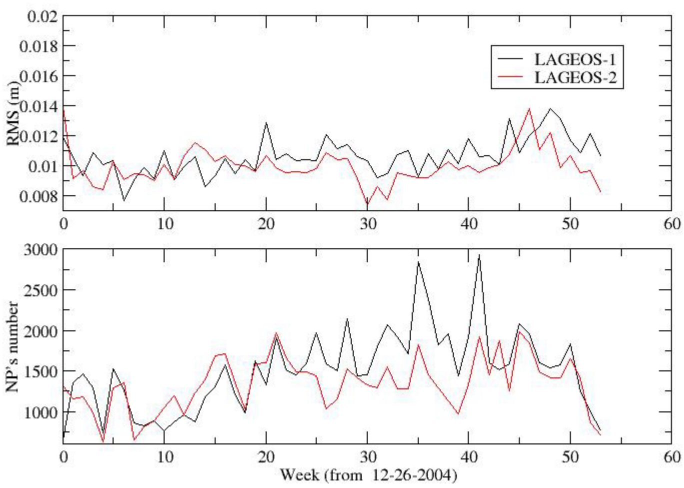
We present thereafter the main characteristics and recent improvements of the processing concerning the different techniques.

3.1 Satellite Laser Tracking (SLR)

Observations of LAGEOS 1 and 2 satellites have been processed over 9-day arcs with 2-day overlappings. The network comprises 31 observing stations with a number of normal points per week of respectively 1504 and 1338. The final RMS are respectively 1.06 cm and .99 cm for both satellites. Weekly normal matrices are derived relative to a range bias per week, per station and per satellite, station coordinates and EOPs at 6-hour intervals. Final results are obtained with a two week delay. Two modifications were recently implemented to improve results: taking into account the difference between the centre of reflection mass and centre of mass as dependant of the type and power of the laser and the application of the tropospheric correction derived from ECMWF meteorological models rather than state parameters at the ground level. Figures 2 and 3 present the SLR network and statistics concerning the normal point numbers and the final RMS of the fit.

Fig. 2: SLR core stations network

Fig. 3: RMS and normal points number



3.2 DORIS Analyses were performed from January 2005 (GPS week 1304 day 0) to the end of 2005 (GPS week 1355 day 6). Satellites processed are SPOT2, SPOT4 and SPOT5. Recently the upgrading of the GINS allows processing ENVISAT observations with the right centre of phase correction as well as Jason's, the effect of the South-Atlantic Anomaly was introduced as a model. Residuals are in the range of 0.4 mm/s.

Arc lengths extend over 3.5 days starting on Sunday 0:00 or Wednesday 12:00 (between 1 and 3.5 days in case of orbit correction manoeuvres or data lacks) .

Fitted parameters are orbital elements, drag and solar pressure coefficients, tropospheric zenithal bias, frequency bias and Hill parameters. The application of the tropospheric correction derived from ECMWF meteorological models has lead recently to the suppression of the abnormal scaling factor in the network. Figure 4 shows the DORIS network.

Fig. 4: Network of DORIS stations

3.3 GPS

The recent improvement concerns the implementation of the undifferenced measurements on an operational mode. The comparison of the satellite orbits and IGS ones show differences of about 10 to 15 cm with a small radial bias. Final results are obtained with a delay of 3 to 9 weeks. One recent implementation concerns the double differences mode taking into account integer ambiguities in the data processing. Another improvement should come from the introduction of empirical corrections during eclipses. Figures 5 and 6 show respectively the network of participating stations and the number of stations involved in the solution and the phase residual in mm.

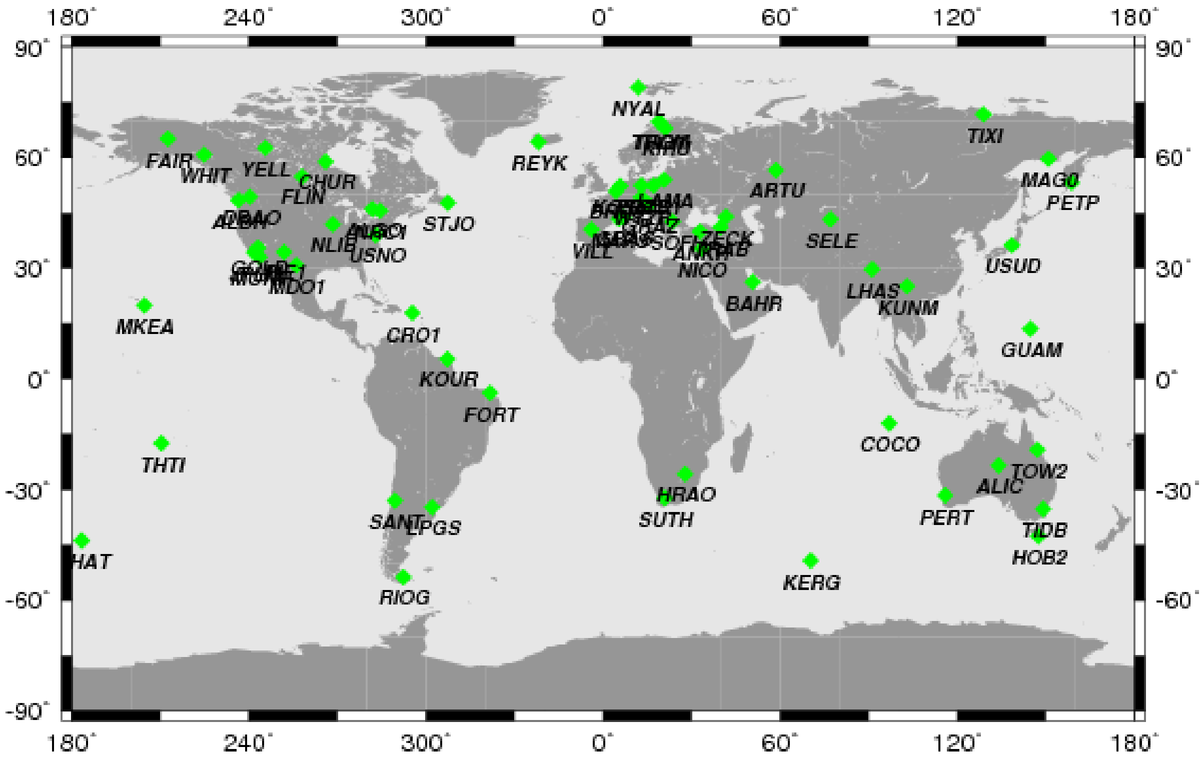


Fig. 5: Network of participating GPS stations in the GRGS project

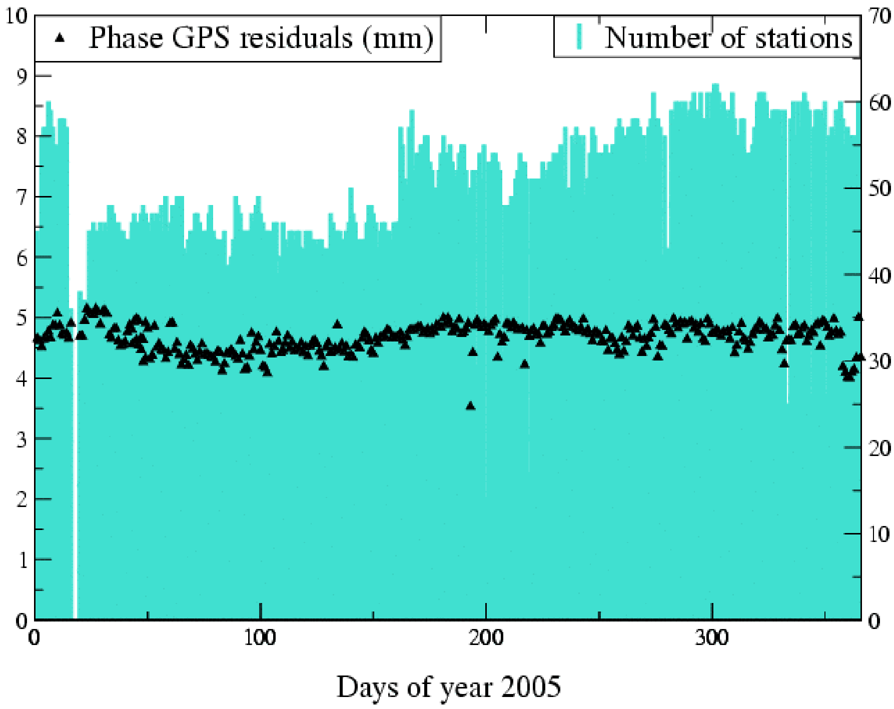


Fig. 6: Number of stations involved in the GPS solution and phase residual in mm

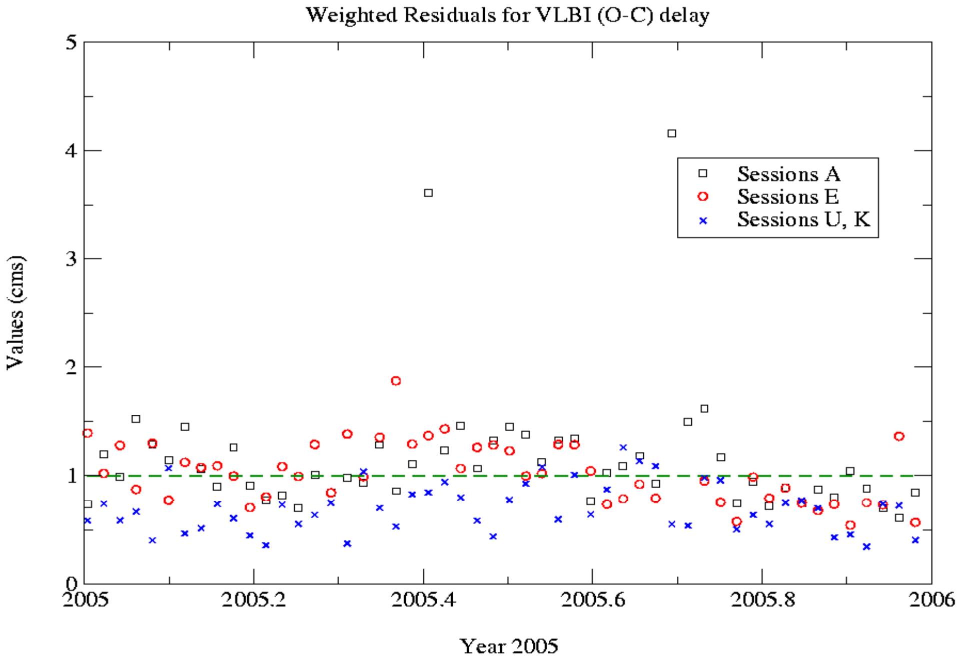


Fig. 7: Weighted residuals for A,E, U and K sessions

3.4 Very Long baseline Interferometry (VLBI)

R1, R4 and the intensive sessions are computed using the software GINS, for each week of 2005. The a priori terrestrial reference frame VTRF2005 is used (Nothnagel 2005). Two series of computations were performed:

- R1 and R4 IVS sessions (also called A and E), one time bias parameter over 2 hours, and one zenithal tropospheric bias parameter over each hour are fitted
- Intensive sessions (called U and K), the determination concerns a value and a trend per session (which lasts more or less one hour) for the time bias and the zenithal tropospheric bias parameters.

Comparisons made between two different softwares GINS et MODEST show a good agreement, i.e. about 8 mm on data residuals in the barycentric system. It is also important to check the compatibility between nutation models, i.e. IAU 1980 and 2000.

Residuals of processings over 2005 on sessions A and E are in the range of 1 cm (Figure 7).

3.5 Lunar Laser Ranging (LLR)

The LLR observation equations were implemented in the GINS software based on 6 hour lunar ephemeris as well as libration parameters series derived from the CAROLL software of the Paris Observatory. However the LLR station has now been stopped to be upgraded in the T2000 program. The analyses of Grasse and MacDonald observations over the previous years show residuals with an RMS of about 13 cm.

4 Combination process and validation

The optimal relative weights between techniques were obtained by using the Helmert's optimal variance-covariance method. The global final solution is derived from the stacking of the technique normal equations relative to EOP and station coordinates. In the processing of GPS and VLBI, pole components and UT1 are estimated at 6 h intervals whereas nutation corrections in obliquity and longitude are obtained every 12 hours. In the multi-technique combination a daily solution is derived applying a piece-wise linear function over the 6h estimates. Solutions were stabilized applying minimal constraints through the classical Helmert's transformation on stations coordinates in order to constrain the whole network to stay close to the ITRF2000 reference system.

Results in the form of Earth Orientation Parameters and stations coordinates are available in SINEX files in the IERS database. Different tests have been performed, taking into account or not the critical parameters, i.e. the local ties, minimal constraints on stations, EOP continuity constraints as well as the weighting of the different techniques. The effects of the choice and the tuning of these parameters are exhaustively discussed in Gambis et al. (2006b).

4.1 Weekly process

Normal equations derived from the different techniques are cumulated on a weekly basis. Minimal EOP continuity constraints, local ties (ITRF2000) are used; piece-wise linear fits are applied over 6 h time intervals for pole components. Figure 8 gives the differences between this multi-technique combined solution, referred as EOP (GRGS) and the IERS C04 with the corresponding statistics, i.e. biases and RMS. We can note the significant jumps in the pole components, up to 150 µas. These jumps are due to inconsistencies between the realisations of the successive weekly station coordinates solutions, to the poor accuracy of the local ties and possibly to the values of minimal constraints adopted. We expect that the complete local ties associated to the forthcoming ITRF2005 will partly solve this problem. Results concerning the reference frame are not presented here.

4.2 Multi-technique combined solution over a full year analysis (2005)

Intra-techniques solutions are firstly independently cumulated over the year 2005. The 4 matrices are then stacked to derive the global multi-technique solution. Stations coordinates offsets are given for the whole year. Stations rates have been set to their ITRF2000 values. Minimal constraints, EOP continuity constraints and local ties (ITRF2000) are applied. A piece-wise linear fit was not applied over 6h estimates for pole components. This might be the cause of the significant short-periodic oscillation appearing in the beginning of 2005. Figure 9 shows differences between the combined solution and the IERS C04 used as the reference. The EOP solution is more

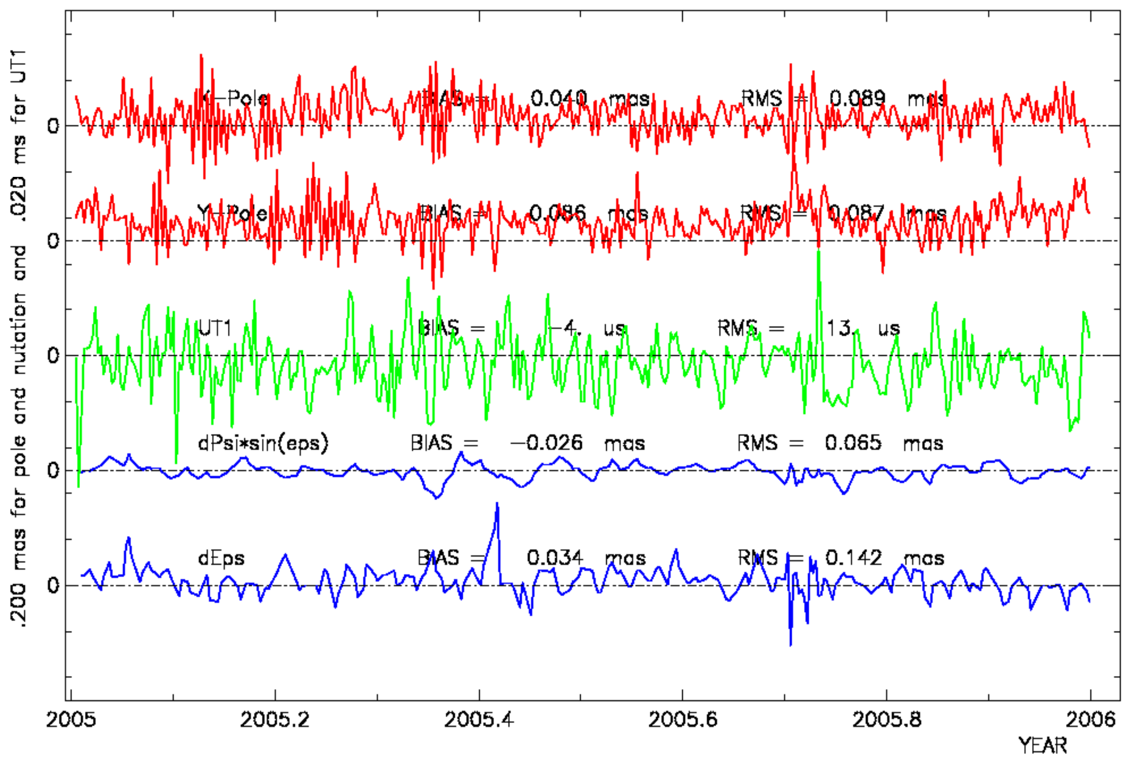


Fig. 8: Differences for X- and Y-Pole, UT1 and nutation offsets between the combined solution obtained from the successive weekly solutions and the IERS C04 used as the reference

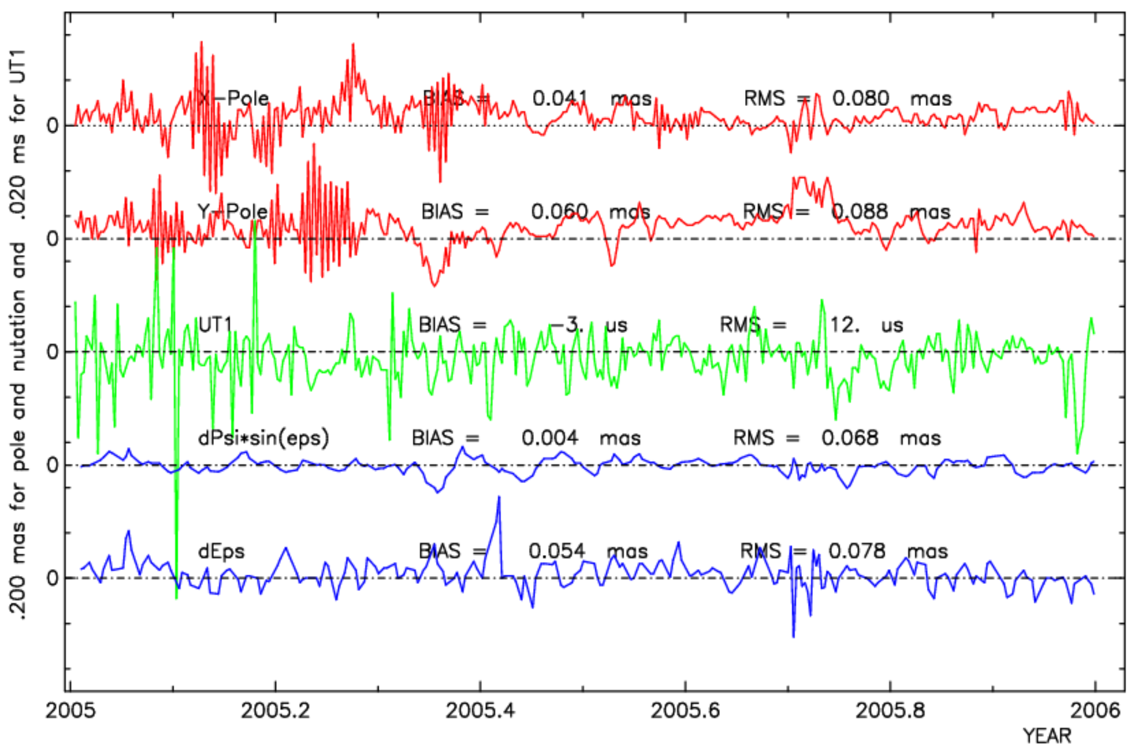


Fig. 9: Differences for X- and Y-Pole, UT1 and nutation offsets between the combined solution derived over the full year 2005 and the IERS C04 used as the reference

Table 1: RMS of the difference between individual technique solutions and IERS C04

	DORIS only	SLR only	GPS only	VLBI only	Multi-technique GRGS	Best current solution
X-Pole in µas	176	136	91	156	80	34 (IGS)
Y-Pole in µas	150	133	73	167	88	30 (IGS)
UT1 in µs				13	12	11 (IVS)
$D\psi.\sin\varepsilon$ in µas				65	68	21 (IVS)
$D\varepsilon$ in µas				70	78	37 (IVS)

homogeneous than the weekly solution one although RMS are larger. We can note that including the intensive VLBI sessions densifies UT1 series to one-day intervals.

Table 1 shows the comparison, i.e. the RMS of the differences between the individual intra-technique solution on one hand and the combined final multi-technique solution "GRGS" on the second hand and the IERS C04 used as the reference. It appears that the multi-technique solution is not better than individual technique solutions. This is assumed to be mainly due to the terrestrial reference frame instabilities.

The effect on the combined UT1 of LOD derived GPS is not clear since this quantity is affected by a significant bias due to errors propagated by mismodelling in the ascending node of satellites orbits (Gambis, 1996, Ray 1996, Gambis 1997). This should be carefully investigated.

For comparison purpose, the last column gives the current best solution accuracy yielded by international services, IGS for pole components and IVS for UT1 and nutation offsets.

Table 2: Reference frame solution: 7-parameter transformion with respect to ITRF2000

	Tx cm	Ty cm	Tz cm	Scale cm	Rx cm	Ry cm	Rz cm
DORIS	1.2	1.3	2.3	–1.4	0.0	–0.6	–0.6
GPS	0.9	1.0	4.0	0.3	–0.2	0.0	0.0
SLR	0.1	–0.4	–1.3	0.4	–0.2	0.4	–0.6
VLBI	0.0	0.8	0.0	0.5	–0.4	0.2	0.6
COMBINED	0.6	0.5	0.8	0.5	0.0	0.0	–0.9

Table 3: Accuracy of individual reference frame solution with respect to ITRF2000

		Bias/RMS in mm		
	Nb of stations	dX	dY	dZ
GPS	55	0/1	0/1	0/1
SLR	28	0/1	0/1	0/1
VLBI	15	0/3	0/4	0/3
DORIS	52	-11/23	-14/36	-21/27
COMBINED	150	-8/13	-4/17	2/15

Table 2 to Table 4 show the statistics concerning the transformation between individual reference frames per technique and ITRF2000. Table 2 gives the 7-parameter transformation, rotation, translation and scaling factors between each individual terrestrial frame and ITRF2000 for the various techniques; we note an abnormally high estimate for the scaling factor derived from DORIS. In recent analyses where the tropospheric correction derived from ECMWF meteorological models is applied, this scaling factor decreases significantly.

5 Conclusions

Different approaches are carried out to deliver robust solutions concerning both station coordinates and Earth Orientation Parameters. One uses SINEX files derived from the analysis of observations of the various techniques processed by independent softwares like the ITRF2005 (Altamimi, 2006). Our approach within the GRGS (Groupe de Recherches de Géodésie Spatiale, federative organism involving different French institutes) is to use a single software/ package, the GINS/DYNAMO developed and maintained at the CNES/GRGS. The advantages of this method come from the fact that all constants and models are identical for the analyses of the different techniques and in addition in assuming that the final combined solution will be reinforced by the strengths of the complementary aspects of these techniques.

We are combining both stations coordinates and Earth Orientation Parameters at the normal equation level. Observations of astro-geodetic techniques, VLBI, GPS, SLR, LLR and DORIS are processed at different dedicated analysis centres. Normal equations derived are thus processed and stacked at Paris Observatory. Two main approaches have been carried: the first one made on a routine basis leads to a weekly solution of both EOP and station coordinates. The second one gives a homogeneous solution over a full year, i.e. 2005. The analyses we have performed show that the EOP solution is sensitive to a number of critical parameters mostly linked to the terrestrial reference frame realization that need to be carefully tuned in order to regularly deliver an accurate and stable

Table 4: 3-D comparison of individual solutions with respect to ITRF2000. For VLBI the initial reference frame is VTRF2005 (Nothnagel, 2005)

	SLR	DORIS	GPS	VLBI
3-D difference with ITRF2000	1.6 cm	5.7 cm	1.7 cm	1.4 cm

solution. These parameters are station minimal constraints, local ties, EOP continuity constraints, piece-wise linear fitting for the Earth Orientations Parameters. Another critical point concerns the weighting of the different techniques by the Helmert's method.

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Jean Michel Lemoine, Jean Charles Marty, Philippe Bério,
Géraldine Bourda, Patrick Charlot, Sylvain Loyer,
Laurent Soudarin, Zuheir Altamimi

3.6.2.9 Institut Géographique National (IGN)

Please see the joint report of the ITRS Combination Centre and the Combination Research Centre at IGN (section 3.6.1.2).

3.6.2.10 Institute of Applied Astronomy (IAA)

Comparison and combination of EOP series

During the last year, we continued to develop software for comparison and combination of EOP series with the purpose to generate an independent combined EOP series with better uncertainty and systematic stability than individual ones computed at the IAA (24h and Intensives VLBI, GPS and SLR). Special goals of this study are the computation of dense UT1 series for alignment of satellite free-running UT1 series and the analysis of combined celestial pole offset series for investigation of the nutation models. Special attention is paid to long-term stability of computed EOP series. Developed algorithms and software are routinely used in the framework of every-day IAA EOP Service activity for the control of data and result quality, and for the study of systematic errors of EOP series.

On the basis of this researches, we have been performing an experimental computation of combined EOP series (LOD, UT1, PM) based on VLBI, GPS and SLR series routinely computed at the IAA in the framework of the regular IAA EOP Service, and also combined CIO offset series using results of other IVS Analysis Centres.

Combination of the EPN Analysis Centres' solutions

We have finished the development of the first version of software for combination of the EPN Analysis Centres' solutions for the coordinates of the GPS stations of the EUREF Permanent GPS Network (EPN). The combination is done in three steps: first the stated constraints on coordinates are removed from the individual solutions of the Analysis Centres using a priori information provided in SINEX files. Then de-constrained solutions are aligned to ITRF2000 using 7-parameter Helmert transformation, ITRF2000 station velocities are used here for the propagating ITRF2000 stations' coordinates from the catalogue's epoch 1997.0 to each GPS week. Finally all individual solutions are combined using a sequential Least-Squares Adjustment method.

Starting with 2005 we perform routine computation of the coordinates of all EPN stations, after the Analysis Centres' solutions became available. Our combined solution is available in SINEX format at web page <http://www.ipa.nw.ru/PAGE/DEPFUND/GEO/ac_gps/> or directly via <ftp://quasar.ipa.nw.ru/pub/EOS/IAA/epn/combined>. A homogeneous series of weekly solutions from GPS week 900 is available.

This work is supposed to be followed by a TRF+EOP combination in the framework of the IERS activity.

Comparison and combination of radio source catalogues

Research on comparison and combination of the radio source catalogues is being conducted in the framework of the IVS and IAU activity on new ICRF realization. The purpose is to compare the individual CRF solutions, analyse their systematic and random errors, and to compute a combined CRF solution with focus on the choice of the optimal strategy for the next ICRF realization.

Eight radio source catalogues provided by the IVS Analysis Centres (GA, SHAO, DGFI, GIUB-BKG, JPL, MAO NANU, GSFC, USNO) have been analysed. In the present study, four analytical models were used to investigate the systematic differences between solutions: solid rotation, rotation and deformation, and expansion by orthogonal functions: Legendre-Fourier polynomials and spherical functions. It was found that expansions by orthogonal function fit the differences between individual catalogues better than the two former models.

Finally, a combined radio source catalogue was generated. Test EOP series obtained with the combined CRF realization showed improvement of EOP precision with respect to the solution obtained with the ICRF radio source positions.

Zinovy Malkin, Natalia Panafidina, Yulia Sokolova

3.6.2.11 Jet Propulsion Laboratory (JPL)

Introduction

The uncertainty in our knowledge of the Earth's changing orientation in space is a major source of error in tracking and navigating interplanetary spacecraft. Because the Earth's orientation changes rapidly and unpredictably, measurements must be acquired frequently and processed rapidly in order to meet the near-real-time Earth orientation requirements of the interplanetary spacecraft navigation teams. These requirements are currently met at JPL by using the global positioning system (GPS) to provide daily determinations of polar motion and length-of-day within 24 hours of acquisition. Single baseline very long baseline interferometry (VLBI) measurements are taken twice-per-month by the Time and Earth Motion Precision Observations (TEMPO) project in order to provide the benchmark Universal Time (UT) measurements between which the GPS length-of-day measurements are integrated. The Kalman Earth Orientation Filter (KEOF) is then used to combine the GPS polar motion and length-of-day measurements with the TEMPO VLBI variation-of-latitude and UT0 measurements, along with other publicly available Earth orientation measurements including proxy measurements such as atmospheric angular momentum, in order to generate and deliver the required polar motion and UT1 Earth orientation parameters to the spacecraft navigation teams.

Data Products

Reference series of Earth orientation parameters are generated annually at JPL. During 2005, three such reference series were generated: (1) SPACE2004, consisting of values and rates for polar motion and UT1 spanning September 28, 1976 to January 22, 2005 at daily intervals, was generated by combining Earth orientation measurements taken by the space-geodetic techniques of lunar and satellite laser ranging (SLR), VLBI, and GPS; (2) COMB2004, consisting of values and rates for polar motion and UT1 spanning January 20, 1962 to January 22, 2005 at daily intervals, was generated by additionally including the BIH optical astrometric measurements with the space-geodetic measurements used to generate SPACE2004; and (3) POLE2004, consisting of values and rates for just polar motion spanning January 20, 1900 to January 20, 2005 at monthly intervals, was generated by additionally including the ILS optical astrometric measurements with the other optical astrometric and space-geodetic measurements used to generate COMB2004. These reference series can be obtained by anonymous ftp to <ftp://euler.jpl.nasa.gov/keof/combinations/2004>. A report describing the generation of these series [Gross, 2005] is also available at this site.

The near-real-time Earth orientation requirements of the interplanetary spacecraft navigation teams are met by twice-per-week updating the annually generated reference series. The updated Earth orientation series are generated by additionally incorporating measurements that are rapidly available such as the GPS measurements from the JPL Analysis Center of the IGS and the atmospheric angular momentum measurements from NCEP that are used as proxy length-of-day measurements. In addition, short-term predictions of the EOPs are produced in order to provide the navigation teams with an uninterrupted series of Earth orientation parameters. The updated and predicted EOP series can be obtained by anonymous ftp to <ftp://euler.jpl.nasa.gov/keof/predictions>.

Research activities

Research activities during 2005 were largely concerned with improving KEOF's real-time determinations of UT1. This was accomplished by interpreting the GPS length-of-day measurement as being a finite difference of UT1 over some time interval, rather than as being an instantaneous time derivative of UT1. As a finite difference, an estimate of UT1 valid at the end of the time interval can be obtained by adding the length-of-day value to an initial estimate of UT1 valid at the beginning of the time interval. In practice, the initial UT1 value is taken to be the latest UT1 measurement, and all length-of-day values available after that latest UT1 measurement are summed. In this manner, estimates of UT1 can be extended to near real-time, greatly improving the accuracy of real-time UT1 determinations. In fact, with this approach, the accuracy of KEOF's real-time UT1 determinations was found to increase by about 33%.

Acknowledgments

The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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Richard Gross

3.7 IERS Working Groups
3.7.1 Working Group on Site Survey and Co-location

The IERS Working Group on Site Survey and Co-location (*jointly with IAG Sub-Commission 1.2 – WG 2, SC1.2-WG2*) was established in February 2004. The major goals and objectives of the WG are:

- Site Survey and Standards
  - Develop, test, compare and set standards on site survey methods, including observational techniques, network design, classical adjustment, geometrical modelling and/or direct measurement techniques for invariant point determination, reference frame alignment, software implementation and SINEX generation. This will include the development of a standards document for undertaking site surveys;
  - Preparation and coordination of a Pilot Project (PP) on site survey. The PP will include a test campaign(s) to be used for the comparison of different approaches to local tie surveys addressing each of the technical elements;
  - Develop standards for the documentation of site surveys, including survey report content and format; and
  - Suggest a pool of expertise to provide advice to survey teams, as required, on standards for site surveys.
- Coordination
  - Liaise with local and international survey teams undertaking site surveys at important co-location sites;
  - Liaise with the technique combination groups to ensure WG site survey products meet user requirements;
  - Coordinate as required and make recommendations to observatories as to survey scheduling and re-survey frequency;
  - Develop and distribute software tools to the community to assist in the generation of site survey products, including SINEX generation software; and
  - Provide a forum to raise the profile of site survey as a critically important independent geodetic technique.
- Site Survey Research
  - Investigate new site survey methodologies, including observational techniques, observational modelling, invariant point definition, geometrical modelling and/or direct measurement techniques for invariant point determination, ref-

erence frame alignment and structural deformation analysis.

Meetings

The IERS Working Group on Site Survey and Co-location met twice in 2005: in April 2005 at the EGU in Vienna and also at the IAG General Assembly, Cairns, Australia (August 2005).

At the IAG General Assembly, in Cairns, activity reports where provided by a number of institutions from Australia, Italy, Sweden and France. Recent surveys have been performed at Parkes, Hobart and Mount Stromlo (Australia); Noto and Medicina (Italy). Additional surveys will be undertaken in Tidbinbilla, Yarragadee (Australia).

Research

The WG continued research associated with Gravitational Sag and thermal Modelling of Antennas.

Further Information

Three detailed reports in the IERS recommended local survey format have been prepared for general access. These are Yarragadee Mobile SLR system, Hobart X-Y System VLBI antenna and Mt. Stromlo SLR System. These reports can be accessed from <http://www.ga.gov.au/geodesy/reports/localties>.

A summary report of the Site Survey and Co-location Pilot Project (SSCPP) is in preparation.

John Dawson is unable to continue to chair the WG. Gary Johnston from Geoscience Australia has replaced him.

John Dawson

3.7.2 Working Group on Combination

IERS Combination Pilot Project

The main project of the Working Group on Combination is the IERS Combination Pilot Project (CPP) that started in 2004 (see IERS Annual Report 2004 for more details). However, many developments within the IERS during the last year were, with due reason, pursued with much higher priority than the CPP: the generation of the long-time series of reprocessed intra-technique combined solutions and the computation of the new ITRF. Therefore, the original intention of the CPP, i.e., the routine generation of weekly combined inter-technique solutions has not been achieved yet. Nevertheless, the developments concerning the weekly combined intra-technique solutions provided by each of the technique services were making considerable progress during 2005. Thanks to these efforts, official weekly routine solutions are available now in SINEX format for all space geodetic techniques. These solutions are the basis for the planned IERS product: a weekly combined inter-technique solution. The future IERS products are described in more detail in Section 3.3 “Analysis Coordinator” (this volume).

Standards and Conventions for Reprocessing Activities

The definition of standards and conventions, be it for modelling of the observations or for the parameterization of unknown quantities, is always a tightrope walk between

(1) consistency (limiting the degrees of freedom of each individual group, but giving a well-defined product with a well-defined interpretation when combining the solutions) and
(2) diversity in solutions (leading to interesting comparisons, progress, but also to a combined solution, that is a mixture of apples and pies).

In each individual case a balance has to be found between these two extremes, based on a consensus among the member of the Working Group on Combination or even better, among all the groups in the geodetic/geophysical community, which are “affected” in one way or the other by such a standard or convention. The point of view depends, to a large extent, on the products one has in mind: if the products of the individual analysis centers are considered, one may want to have a large variety of approaches for comparisons and information, called “bio-diversity” in a totally different field of science; if the combined product and its optimum use by the community concerning consistency and its interpretation is crucial, one may want to combine solutions with modelling standards (and a parameterization) as consistent as possible and not a mixture of different sets. A combination may not even make sense or be possible in the latter case.

The agreement on standards is especially important in view of new realizations of the ITRS, i.e. ITRF200x solutions and for the upcoming IGS reprocessing effort. Since a reprocessing within the IGS is not yet a routine effort, the standards have to be carefully considered and agreed upon. This is of special importance for modelling issues that are common to more than one observing technique (e.g. oceanic and atmospheric loading or tropospheric mapping functions), and that should, therefore, be consensus among all technique services.

A considerable effort was put in the development of common standards within the project GGOS-D, funded as part of the German "Geotechnologien-Programm 'Observation of the Earth from Space'". The standards for modelling and parameterization adopted within this project have been presented at one of the meetings of the IERS WG on Combination and are available (e-mail to Peter Steigenbegrer: steigenberger@gfz-potsdam.de).

CONT02 and CONT05 Combination Work

Quite a few groups were investigating combination strategies during the last year based on the data of the continuous VLBI campaigns of 2002 and 2005, i.e., CONT02 and CONT05. Because of the continuous observations from VLBI over at least 14 days, these datasets are especially suited for such studies. In addition, a considerable effort was put into the collection of auxiliary data, e.g., the data of water vapour radiometers, giving additional independent information to validate the results obtained by the space geodetic techniques.

All participants in the combination work are very much encouraged to use the data of the CONT02, the CONT05, but also the data of previous CONT-campaigns for combination studies. A considerable amount of results already exist for these periods (e.g., by Manuela Krügel, DGFI, and Daniela Thaller, GFZ) and can be made available for comparisons.

Combination of VLBI Intensive Session Solutions with IGS Rapid Solutions

The VLBI Intensive Sessions are mainly used to determine UT1 with low latency. Due to the fact that only two VLBI stations are involved in each of these sessions (Wettzell/Hawaii or Wettzell/Tsukuba), most of the parameters cannot be estimated simultaneously. Polar motion values are, typically, not estimated but taken from the most recent IGS determination. Thinking of a very low-latency Earth rotation parameter product, it makes a lot of sense to consider the combination of the VLBI Intensive Sessions with IGS rapid solutions. VLBI will mainly contribute to the estimation of UT1 and GPS to polar motion. Initial tests to combine SINEX files from VLBI Intensive Sessions (computed by DGFI) and from GPS rapid solutions (computed by GFZ) have been performed and the results are very encouraging.

Meetings and Workshops

- IERS Working Group on Combination and CPP Meeting during 2nd EGU General Assembly, Nice / France, April 2005
- IERS Workshop on Combination, GFZ Potsdam / Germany, October 2005. Papers are available in the IERS TN 35.
- Meetings with a session dedicated to combination of space geodetic techniques: EGU General Assembly, Nice / France, April 2005

Markus Rothacher, Daniela Thaller

4 IERS Workshop on Combination

A workshop devoted to combination issues of geodetic space techniques has been organized by the International Earth Rotation and Reference Systems Service (IERS) in Potsdam, Germany, on October 10 – 11, 2005.

During the last one and a half years the IERS Working Group on Combination has been coordinating the steps towards a set of IERS combined products. The solutions are based on a rigorous combination of “weekly” SINEX files produced by intra-technique combinations within the Technique Centres. The new products resulting from these combination procedures are expected eventually to replace a considerable part of the current IERS products.

The workshop brought together nearly 60 experts from the fields of Terrestrial Reference Frame (TRF), Celestial Reference Frame (CRF) and Earth Orientation Parameters (EOP) to discuss the combination and validation strategies, the present status of combined intra- and inter-technique products, their development and adoption in the future.

During the first day two sessions took place – Session 1: Multi year solutions: ITRF200x/local ties, chaired by Z. Altamimi and D. Angermann, and Session 2: Weekly solutions: station coordinates, non-linear station behaviours, systematic effects, etc., chaired by E. Pavlis and R. Biancale.

Session 1 was devoted to the review of the status of the ITRF2004 being under development, the analysis of the submitted time series and the discussion on future plans for the ITRF solutions. The recommendations of the past IERS workshop on combination held in Munich in 2002 were also reviewed in this session, and in particular those relevant to the ITRF solutions. As far as the ITRF2004 is concerned, the call for participation issued in December 2004 descripts the background, the requested time series solutions, the analysis strategy as well as the expected main results of the ITRF2004.

Session 2 of the IERS Workshop focused on the problems and issues faced by all techniques in striving to deliver timely weekly products of high and consistent quality. The status of the process within each space technique, the way each of them has attempted to address and solve the requirements were presented together with comparisons of homogeneously reprocessed GPS and VLBI long time series and investigations about the stability of origin, scale and orientation of space-geodetic terrestrial reference frames.

The next day three sessions completed the workshop – Session 3: EOPs: Multi-year solutions, current analysis, weekly solutions, rapid products, chaired by D. Gambis, J. Vóndrak, and W. Wooden, Session 4: Comparison / validation with other time series, chaired by R. Gross and T. van Dam, and Session 5: Status of projects, future products and structure of the IERS, chaired by C. Ma and M. Rothacher.

The first session on October 11 addressed the different Earth Orientation Parameter (EOP) products that are currently computed and made available for various applications. These products include long-term and current analysis series as well as rapid series and predictions. Since the 1970s, these time series have been derived from the combination of individual astro-geodetic techniques, Very Long Baseline Interferometry (VLBI), Lunar Laser Ranging (LLR), Global Positioning System (GPS), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). Previously, the time series were based on astrometric observations for many decades. The ultimate objective of combination is to derive EOP time series taking advantage of the qualities of the various techniques after removing the instabilities and systematic behaviour of each individual technique. The resulting series must have the following characteristics: continuous, given at equidistant intervals without any gaps, homogeneous, stable at the various time scales with negligible systematic errors. Six presentations and two posters addressed the issues in detail.

In Session 4 the focus was on the comparison and validation of time series originated from different space techniques versus other time series or models. The problems were addressed by using different epochs, constraint and unconstraint solutions and by comparing which models give sufficient information for independent investigations.

The last session summarized the topics of the previous ones and pointed towards a generation of a new set of rigorously combined IERS products. This would also necessitate, to a certain extent, modifications in the structure of the IERS and its components. To achieve the highest accuracy and consistency for future IERS products, it is crucial to proceed towards a rigorous combination of all the parameters common to more than one space geodetic technique. Such a combination of techniques should eventually be performed for all the major products of the IERS, from multi-year solutions for reference frame realizations generated on, e.g., a yearly basis, to near real-time products such as EOP estimates produced on a daily basis. More details were given by contributions of the heads of the IERS Earth Orientation Centre and of the ITRS Centre, as well as by the IERS chair and the analysis coordinator.

The detailed programme of the workshop, summaries and presentations are available at

<http://www.iers.org/MainDisp.csl?pid=66-25725>.

Bernd Richter

Appendix 1: IERS Terms of Reference

The IERS was established as the International Earth Rotation Service in 1987 by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG) and it began operation on 1 January 1988. In 2003 it was renamed to International Earth Rotation and Reference Systems Service. IERS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

The primary objectives of the IERS 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.

IERS is composed of a broad spectrum of activities performed by governmental or selected commercial organizations.

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 satellite orbit determination.
- Geophysical and atmospheric research, studies of dynamical interactions between geophysical fluids and the solid earth.
- Space navigation.

The IERS accomplishes its mission through the following components:

- Technique Centers.
- Product Centers.
- Combination Center(s)
- Analysis Coordinator.
- Central Bureau.
- Directing Board.
- Working Groups.

Some of these components (e.g., Technique Centers) may be autonomous operations, structurally independent from IERS, but which cooperate with the IERS. A participating organization may also function as one or several of these components (except as a Directing Board).

TECHNIQUE CENTERS (TC)

The TCs generally are autonomous independent services, which cooperate with the IERS.

The TCs are responsible for developing and organizing the activities in each contributing observational technique to meet the objectives of the service. They are committed to produce operational products, without interruption, and at a specified time lag to meet requirements. The products are delivered to IERS using designated standards. The TCs provide, as a minimum, earth orientation parameters and related reference frame information, as well as other products as required.

The TCs exercise overall control of observations from their specific techniques, archiving, quality control and data processing including combination processing of data and/or products received from their participating organizations. TCs are the various international technique specific services: IGS, ILRS, IVS, IDS and possible future TCs.

PRODUCT CENTERS (PC)

PCs are responsible for the products of the IERS.

Such centers are the following:

- Earth Orientation Center, responsible for monitoring earth orientation parameters including long term consistency, publications for time dissemination and leap second announcements.
- Rapid Service/Prediction Center, responsible for publication of semiweekly (possibly daily?) bulletins of preliminary and predicted earth orientation parameters.
- Conventions Center, under the guidance of the IERS Conventions Editorial Board, responsible for the maintenance of the IERS conventional models, constants and standards.
- ICRS Center, responsible for the maintenance of the ICRS/ICRF.
- ITRS Center, responsible for the maintenance of the ITRS/ITRF, including network coordination (design collocation, local ties, and site quality). For this purpose the Center is also responsible to provide the ITRS Combination Centers (see below) with specifications, and to evaluate their respective results.
- Global Geophysical Fluids Center, responsible for providing relevant geophysical data sets and related computational results to the scientific community.

COMBINATION CENTER(S)

- Combination Research Center(s) are responsible for the development of combinations from data and/or products emanating from the different techniques (TCs). These research combination solutions are provided to the Analysis Coordinator.
- ITRS Combination Center(s) are responsible to provide ITRF products by combining ITRF inputs from the TCs and others. Such products are provided to the ITRS Product Center.

IERS ANALYSIS COORDINATOR (AC)

The AC is responsible for the long-term and internal consistency of the IERS reference frames and other products. He is responsible for ensuring the appropriate combination of the TC products into the single set of official IERS products and the archiving of the products at the Central Bureau or elsewhere.

The AC serves for a four-year term, renewable once by the DB. The responsibility of the AC is to monitor the TC and PC activities to ensure that the IERS objectives are carried out. This is accomplished through direct contact with the independent TC Analysis Coordinators or equivalent. Specific expectations include quality control, performance evaluation, and continued development of appropriate analysis methods and standards. The AC interacts fully with the Central Bureau, the Product Centers and the Combination Research Center(s).

CENTRAL BUREAU (CB)

The Central Bureau is responsible for the general management of the IERS consistent with the directives and policies set by the Directing Board, i.e., acts as the executive arm of the Directing Board. The CB facilitates communications, coordinates activities, monitors operations, maintains documentation, archives products and relevant information and organizes reports, meetings and workshops.

Although the Chairperson of the Directing Board is the official representative of the IERS at external organizations, the CB is responsible for the day-to-day liaison with such organizations. The CB coordinates and publishes all documents required for the satisfactory planning and operation of the Service, including standards/conventions/specifications regarding the performance, functionality and configuration requirements of all elements of the Service including user interface functions.

The CB operates the communication center for the IERS. It distributes and/or maintains a hierarchy of documents and reports, both hard copy and electronic, including network information, standards, newsletters, electronic bulletin board, directories, summaries of performance and products, and an Annual Report.

DIRECTING BOARD (DB)

The Directing Board consists of the following members appointed for four-year terms, renewable once:

- Two representatives from each Technique Center to be selected by the Technique Center's governing board or equivalent. The two representatives will represent that technique regarding
    a. its network and coordination with other techniques,
    b. the details of the technical analyses.

It is desired that, as part of reciprocity agreements, IERS representatives are to become members of the Technique Centers' directing boards.

- One representative from each Product Center.
- One representative from the Combination Research Center(s).
- Representative of the Central Bureau.
- IERS Analysis Coordinator.
- Representatives of IAU, IAG/IUGG and FAGS.

The Chairperson is one of the members of the DB elected by the Board for a term of four years with the possibility of re-election for one additional term. The Chairperson does not vote, except in case of a tie. He/she is the official representative of IERS to external organizations.

The DB exercises general control over the activities of the service and modifies the organization as appropriate to maintain efficiency and reliability, while taking full advantage of the advances in technology and theory.

Most DB decisions are to be made by consensus or by a simple majority vote of the members present, provided that there is a quorum consisting of at least one half of the membership. In case of a lack of a quorum, the voting is by correspondence. Changes in the Terms of Reference and Chairperson of the DB can be made by a two third majority of the members of the DB.

For the DB to effectively assess the value of IERS services to the user communities, and to ensure that the service remains up to date and responsive to changing user needs, the DB will organize reviews of the IERS components at appropriate intervals. The DB will decide, on an annual basis, those components that are to be reviewed and from time to time may select other activities for review, as it deems appropriate. The Central Bureau provides the secretariat of the DB.

The Board shall meet at least annually and at such other times as shall be considered appropriate by the Chairperson or at the request of five members.

WORKING GROUPS

Working Groups may be established by the DB to investigate particular topics related to the IERS components. Working groups are limited to a term of two years with a possible one-time re-appointment. The IERS Analysis Centre Coordinator and the Director of the Central Bureau are ex officio members of each working group, and may send official representatives to meetings which they are unable to attend. Working groups may also collaborate with other scientific organizations like, e.g., IAG, CSTG.

The chair of a working group must prepare, at least annually, a report about the activities of the group to be included in the IERS Annual Report. Working group chairs are invited to participate in DB meetings.

Individuals or groups wishing to establish an IERS Working Group must provide the following at least two weeks prior to the IERS Directing Board Meeting where DB approval is requested.

- Draft charter clearly specifying:
  - Proposed goals (two pages at maximum),
  - Proposed structure of the group or project,

    - Working plan including schedule / deadlines including the anticipated end of work,
- Candidate for a chairperson to be appointed by the DB (optional),
- Initial list of members,
- Proposed plans for an operational phase (if applicable),
- Draft IERS message to inform the IERS community.

IERS ASSOCIATE MEMBERS

Persons representing organizations that participate in any of the IERS components, and who are not members of the Directing Board, are considered IERS Associate Members. Ex officio IERS Associate Members are the following persons:

IAG General Secretary

IAU General Secretary

IUGG General Secretary

President of FAGS

President of IAG Commission 1

President of IAG Subcommission 1.1

President of IAG Subcommission 1.2

President of IAG Subcommission 1.4

President of IAG Commission 3

President of IAG Subcommission 3.1

President of IAG Subcommission 3.2

President of IAG Subcommission 3.3

President of IAU Commission 8

President of IAU Commission 19

President of IAU Commission 31

Head of IAU Division I

IERS CORRESPONDENTS

IERS Correspondents are persons on a mailing list maintained by the Central Bureau, who do not actively participate in the IERS but express interest in receiving IERS publications, wish to participate in workshops or scientific meetings organized by the IERS, or generally are interested in IERS activities.

June 21, 2004

Appendix 2: Contact addresses of the IERS Directing Board

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Chopo Ma
(address see below)

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Product Centres Representatives

Earth Orientation Centre Representative

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Combination Research Centres Representative

N.N.

Technique Centers Representatives

IGS Representatives

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ITRS Combination Centres

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(*Status as of July 2007*)

Appendix 4: Electronic Access to IERS Products, Publications and Components

Central IERS web site

http://www.iers.org/
Please note that all other products, publications and centres may be accessed via this web site.

Products

For a complete list of all IERS products see <http://www.iers.org/MainDisp.csl?pid=34-8>.

Earth orientation data

Rapid data and predictions
Web access: http://maia.usno.navy.mil/
ftp access: `maia.usno.navy.mil` - directory `ser7`

Monthly earth orientation data
Web access:
http://hpiers.obspm.fr/eop-pc/products/bulletins/bulletins.html
ftp access: `hpiers.obspm.fr` - directory `iers/bul/bulb`

Long term earth orientation data
Web access: http://hpiers.obspm.fr/eop-pc/products/eopcomb.html
ftp access: `hpiers.obspm.fr` - directory `iers/eop`

Leap second announcements
Web access:
http://hpiers.obspm.fr/eop-pc/products/bulletins/bulletins.html
ftp access: `hpiers.obspm.fr` - directory `iers/bul/bulc`

Announcements of DUT1
Web access:
http://hpiers.obspm.fr/eop-pc/products/bulletins/bulletins.html
ftp access: `hpiers.obspm.fr` - directory `iers/bul/buld`

Conventions

Web access:
IERS Conventions 2003:
http://tai.bipm.org/iers/conv2003/conv2003.html

International Celestial Reference Frame

Web access: http://hpiers.obspm.fr/icrs-pc/
ftp access: `hpiers.obspm.fr` - directory `iers/icrf`

International Terrestrial Reference Frame

Web access: http://itrf.ensg.ign.fr/
ftp access: `lareg.ensg.ign.fr` - directory `pub/itrf`

Geophysical fluids data

Web accesss: http://www.ecgs.lu/ggfc/

Publications

IERS Messages
http://www.iers.org/MainDisp.csl?pid=45-25788

IERS Bulletins
http://maia.usno.navy.mil/ (Bulletin A)

http://hpiers.obspm.fr/eop-pc/products/bulletins/bulletins.html
(Bulletins B, C, D)
http://www.iers.org/MainDisp.csl?pid=44-14

IERS Technical Notes
http://www.iers.org/MainDisp.csl?pid=46-25772

IERS Annual Reports
http://www.iers.org/MainDisp.csl?pid=47-25778

ITRF Mail
http://list.ensg.ign.fr/wws/arc/itrfmail

IERS Components

Directing Board
Web page: http://www.iers.org/MainDisp.csl?pid=17-1

Analysis Coordinator
Web site: http://tau.fesg.tu-muenchen.de/~iers/

Central Bureau
Web site: http://www.iers.org/MainDisp.csl?pid=19-31

Product Centres

Earth Orientation Centre
Web site: http://hpiers.obspm.fr/eop-pc/

Rapid Service/Prediction Centre
Web site: http://maia.usno.navy.mil/

Conventions Centre
Web site: http://tai.bipm.org/iers/

ICRS Centre
Web site: http://hpiers.obspm.fr/icrs-pc/

ITRS Centre
Web site: http://itrf.ensg.ign.fr/

Global Geophysical Fluids Centre
Web site: http://www.ecgs.lu/ggfc/
Special Bureaus:
Special Bureau for the Atmosphere
Web site: http://www.aer.com/scienceResearch/diag/sb.html
Special Bureau for the Oceans
Web site: http://euler.jpl.nasa.gov/sbo/
Special Bureau for Tides
Web site: http://bowie.gsfc.nasa.gov/ggfc/tides/
Special Bureau for Hydrology
Web site: http://www.csr.utexas.edu/research/ggfc/
Special Bureau for Mantle
Web site: http://bowie.gsfc.nasa.gov/ggfc/mantle.htm
Special Bureau for the Core
Web site: http://www.astro.oma.be/SBC/main.html

Special Bureau for Gravity/Geocenter
Web site: http://sbgg.jpl.nasa.gov/
Special Bureau for Loading
Web site: http://www.sbl.statkart.no/

Technique Centres

International GNSS Service (IGS)
Web site: http://igscb.jpl.nasa.gov/

International Laser Ranging Service (ILRS)
Web site: http://ilrs.gsfc.nasa.gov/

International VLBI Service (IVS)
Web site: http://ivscc.gsfc.nasa.gov/

International DORIS Service (IDS)
Web site: http://ids.cls.fr/

Combination Centres

ITRS Combination Centres

Deutsches Geodätisches Forschungsinstitut (DGFI)
Web site: http://www.dgfi.badw.de/index.php?id=122

Institut Géographique National (IGN)
Wep page: http://www.iers.org/iers/itrscc/ign/

National Resources Canada (NRCan)
Web page: http://www.iers.org/iers/itrscc/geocan/

Combination Research Centres

Web site: http://tau.fesg.tu-muenchen.de/~iers/

Astronomical Institute, Academy of Sciences of the Czech Republic, Prague
Web site: http://www.asu.cas.cz/~ron/ierscrc/

Deutsches Geodätisches Forschungsinstitut (DGFI)
Web site: http://www.dgfi.badw.de/index.php?id=122

Forschungseinrichtung Satellitengeodäsie, Technical University Munich (FESG)
Web page: http://tau.fesg.tu-muenchen.de/~iers/

Forsvarets forskningsinstitutt (FFI, Norwegian Defence Research Establishment)
Web page: http://www.iers.org/MainDisp.csl?pid=114-73

GeoForschungsZentrum Potsdam (GFZ)
Web page: http://www.iers.org/MainDisp.csl?pid=115-74

Geodetic Institute of the University of Bonn (GIUB)
Web page: http://www.iers.org/MainDisp.csl?pid=116-75

Groupe de Recherches de Géodésie Spatiale (GRGS)
Web page: http://www.iers.org/MainDisp.csl?pid=117-76

Institute of Applied Astronomy, St. Petersburg (IAA)
Web page: http://www.iers.org/MainDisp.csl?pid=118-77

Institut Géographique National (IGN)
Web page: http://www.iers.org/MainDisp.csl?pid=119-78

Jet Propulsion Laboratory (JPL)
Web page: http://www.iers.org/MainDisp.csl?pid=120-79

Appendix 5: Acronyms

AAM Atmospheric Angular Momentum
AC Analysis Centre
AC Analysis Coordinator
AER Atmospheric and Environmental Research Inc.
AGN Active Galactic Nuclei
AGU American Geophysical Union
AICAS Astronomical Institute, Academy of Sciences of the Czech Republic
AOD atmospheric and oceanic dealiasing
AOW atmosphere, ocean, and water
APSG Asia-Pacific Space Geodynamics
ASCII American Standard Code for Information Interchange
ASI Agenzia Spaziale Italiana
ATNF Australia Telescope National Facility
AUS = AUSLIG
AUSLIG Australian Surveying and Land Information Group (now: Geoscience Australia)
AWG Analysis Working Group
AWI Alfred Wegener Institute for Polar and Marine Research
BIH Bureau International de l'Heure
BIPM Bureau International des Poids et Mesures
BKG Bundesamt für Kartographie und Geodäsie
BKGI BKG in cooperation with GIUB
BMBF Bundesministerium für Bildung und Forschung, Germany
CATREF Combination and Analysis of Terrestrial Reference Frames
CB Central Bureau
CC Combination Centre
CCD Charge-Coupled Device
CDDIS NASA Crustal Dynamics Data Information System
CEDR Center for Earth Dynamics Research
CERGA Centre d'Etudes et de Recherches Géodynamiques et Astronomiques
CGS Centro di Geodesia Spatiale, ASI
CHAMP CHAllenging Minisatellite Payload
CLS Collecte, Localisation, Satellites
CNES Centre National d'Etude Spatiale
COD = CODE
CODE Centre for Orbit Determination in Europe
CONT continuous VLBI session
COSPAR Committee on Space Research
CPC Climate Prediction Center
CPP IERS Combination Pilot Project
CRC Combination Research Centre
CRD CRF deepsouth sessions
CRF Celestial Reference Frame
CSR Center for Space Research, University of Texas
CSRIFS Combined Square Root Information Filter and Smoother (program)
CTIO Cerro Tololo Inter-American Observatory
DB Directing Board
DEOS Department of Earth Observation and Space Systems, Delft University of Technology (formerly: Delft Institute for Earth-Oriented Space Research)
Dep., Dept. Department
DFG Deutsche Forschungsgemeinschaft, Germany
DGFI Deutsches Geodätisches Forschungsinstitut
DOMES Directory Of MERIT Sites (originally; now of more general use)
DORIS Doppler Orbit determination and Radiopositioning Integrated by Satellite
DUT Delft University of Technology
DUT1 = UT1–UTC
EC Executive Committee
ECCO Estimating the Circulation and Climate of the Ocean
ECGS European Centre for Geodynamics and Seismology
ECMWF European Center for Medium Range Weather Forecasting
EDC EUROLAS Data Center
EGU European Geosciences Union
EMR Energy, Mines and Resources Canada (replaced by NRCan)
ENSG Ecole Nationale de Sciences Geographiques
EOC Earth Orientation Centre

EOP	Earth Orientation Parameters
EOPGS	Ecole et Observatoire de Physique du Globe de Strasbourg
EOST	Ecole et Observatoire des Sciences de la Terre
EPN	EUREF Permanent GPS Network
ERP	Earth Rotation Parameters
ESA	European Space Agency
ESOC	European Space Operations Center, ESA
EUREF	IAG Reference Frame Sub-Commission for Europe
e-VLBI, E-VLBI	Electronic transfer VLBI
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FCN	Free Core Nutation
FESG	Forschungseinrichtung Satellitengeodäsie, Technical University of Munich
FFI	Forsvarets forskningsinstitutt
FGS	Forschungsgruppe Satellitengeodäsie
FTP	File Transfer Protocol
GA	General Assembly
GAOUA	Main Astronomical Observatory of the Ukrainian Academy of Sciences
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFZ	GeoForschungsZentrum Potsdam
GGAO	Goddard Geophysical and Astronomical Observatory
GGFC	Global Geophysical Fluids Centre
GGOS	Global Geodetic Observing System
GGOS-D	GGOS – Deutschland (Germany)
GIUB	Geodetic Institute of the University of Bonn
GLDAS	NASA's Global Land Data Assimilation System
GLONASS	Global Orbiting Navigation Satellite System, Russia
GLOUP	GLObal Undersea Pressure
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRGS	Groupe de Recherches de Géodésie Spatiale
GSFC	Goddard Space Flight Center
HCRF	Hipparcos Celestial Reference Frame
hr	hour
IAA	Institute of Applied Astronomy, St. Petersburg
IABO	International Association for Biological Oceanography
IAC	Information-Analytical Centre, Russia
IAG	International Association of Geodesy
IAPSO	International Association for the Physical Sciences of the Oceans
IAU	International Astronomical Union
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
ICSU	International Council for Science
IDS	International DORIS Service
IERS	International Earth Rotation and Reference Systems Service (formerly: International Earth Rotation Service)
IGEX	International GLONASS Experiment
IGFS	International Gravity Field Service
IGGOS	Integrated Global Geodetic Observing System (now GGOS)
IGLOS	International GLONASS Service
IGN	Institut Géographique National
IGOS-P	Integrated Global Observing Strategy – Partners
IGRT	IGS rapid time (products)
IGS	International GNSS Service (formerly: International GPS Service)
IGST	IGS time scale
ILRS	International Laser Ranging Service
INA	= INASAN
INASAN	INstitut AStronomii Rossijskoj Akademii Nauk (Institute of Astronomy of the Russian Academy of Sciences)
INGV	Istituto Nazionale di Geofisica e Vulcanologia
IPGP	Institut de Physique du Globe de Paris
IRIS	International Radio Interferometric Surveying
ITRF	International Terrestrial Reference Frame

ITRS	International Terrestrial Reference System
ITSS	see Raytheon ITSS
IUGG	International Union of Geodesy and Geophysics
IVS	International VLBI Service for Geodesy and Astrometry
JADE	JApanese Dynamic Earth observation by VLBI
JCET	Joint Center for Earth System Technology, GSFC
JMA	Japanese Meteorological Agency
JPL	Jet Propulsion Laboratory
KEOF	Kalman Earth Orientation Filter
KPNO	Kitt Peak National Observatory
LAREG	Laboratoire de Recherche en Geodesie
LCA	= LEGOS-CLS
LDAS	Land Data Assimilation System
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LEO	Low Earth Orbit(er)
LGIT	Laboratoire de Géophysique Interne et Tectonophysique
LLR	Lunar Laser Ranging
LOD	Length of Day
LPCE	Laboratoire de Physique et Chimie de l'Environnement
MAO	= GAOUA
MAPS	Milli-Arcsecond Pathfinder Survey
mas	milliarcsecond(s)
µas	microarcsecond(s)
MCC	Russian Mission Control Centre
MERIT	Monitoring Earth Rotation and Intercomparison of Techniques
MICOM	Miami Isopycnic Coordinate Ocean Model
MIT	Massachusetts Institute of Technology
MJD	Modified Julian Day
MOM	Modular Ocean Model
MPIfR	Max-Planck-Institut für Radioastronomie / Max Planck Institute for Radio Astronomy
ms	millisecond(s)
µs	microsecond(s)
NAREF	North American Reference Frame Densification
NASA	U.S. National Aeronautics and Space Administration
NCAR	U.S. National Center for Atmospheric Research
NCEP	U.S. National Centers for Environmental Prediction
NEQ	normal equation
NERC	Natural Environment Research Council, UK
NetCDF	Network Common Data Form
NMF	Niell Mapping Function
NOAA	U.S. National Oceanic and Atmospheric Administration
NOFS	USNO Flagstaff Station
NPS	(U.S.) Naval Postgraduate School
NRAO	U.S. National Radio Astronomy Observatory
NRCan	Natural Resources, Canada (formerly: EMR)
NSGF	NERC Space Geodesy Facility
OBSS	Origins Billions Star Survey
OCA	Observatoire de la Côte d'Azur
ONR	(U.S.) Office of Naval Research
OP	Observatoire de Paris
PC	Product Centre
PDF	Portable Document Format
PGR	postglacial rebound
PHP	PHP: Hypertext Preprocessor
PI	Principal Investigator
PM	Polar Motion
POCM	Parallel Ocean Climate Model
PoliMI	Politecnico di Milano
PP	Pilot Project
PPP	Precise Point Positioning
PRARE	Precise RAnge and Range-Rate Equipment
Raytheon ITSS	Raytheon Systems Company Information Technology & Scientific Services
RCMAM	(IAU WG) Relativity in Celestial Mechanics, Astrometry and Metrology
R&D	Research and Development
RDV	Research and Development (sessions) with the VLBA
RF	Reference Frame
RFI	radio frequency interference

RINEX	Receiver INdependent EXchange format
rms, RMS	Root Mean Square
ROB	Royal Observatory of Belgium
RRFID	USNO Radio Reference Frame Image Database
SAA	South Atlantic Anomaly
SB	Special Bureau
SBA	Special Bureau for the Atmosphere
SBC	Special Bureau for the Core
SBGG	Special Bureau for Gravity/Geocenter
SBH	Special Bureau for Hydrology
SBIR	Small Business Innovation in Research
SBL	Special Bureau for Loading
SBM	Special Bureau for Mantle
SBO	Special Bureau for the Oceans
SBT	Special Bureau for Tides
SHAO	Shanghai Observatory
SIM	NASA's Space Interferometry Mission
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SLR	Satellite Laser Ranging
SOC	Scientific Organizing Committee
SOD	CNES Service d'Orbitographie DORIS
SPBU	St Petersburg University
SRIF	Square Root Information Filter array
SSALTO	Segment Sol multi-mission d'ALTimétrie, d'Orbitographie et de localisation précise
SSCPP	Site Survey and Co-location Pilot Project
STA	Semiconductor Technology Associates
SYRTE	(Laboratoire) Systèmes de Référence Temps-Espace
TAI	Temps Atomique International (International Atomic Time)
TC	Technique Centre
TEMPO	Time and Earth Motion Precision Observations
TIGO	Transportable Integrated Geodetic Observatory
TN	IERS Technical Note
ToR	Terms of Reference
TRF	Terrestrial Reference Frame
TT	Terrestrial Time
TU	Technical University
TUM	Technical University of Munich
UCAC	USNO CCD Astrograph Catalog
UCLA	University of California, Los Angeles
UCSD	University of California, San Diego
UNESCO	United Nations Educational, Scientific and Cultural Organization
Univ.	University
URAT	USNO Robotic Astrometric Telescope
URL	Uniform Resource Locator
URSI	Union Radio-Scientifique Internationale / International Union of Radio Science
USGS	U.S. Geological Survey
USNO	United States Naval Observatory
UT, UT0, UT1, UT1R	Universal Time
UTA	University of Texas at Austin
UTAAM	NCEP AAM analysis and forecast data
UTC	Coordinated Universal Time
VLA	Very Large Array
VLBA	Very Long Baseline Array, NRAO
VLBI	Very Long Baseline Interferometry
VMF	Vienna Mapping Function
VSI-E	VLBI Standard Interface for E-VLBI
VUGTK	Research Institute of Geodesy, Topography and Cartography, Czech Republic
WG	working group
WRMS	Weighted Root Mean Square
XML	eXtensible Markup Language
yr	year
ZTD	zenith total delay
ZWD	zenith wet delay(s)