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

IERS
Annual Report
2004

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IERS Annual Report 2004

Edited by Wolfgang R. Dick and Bernd Richter

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1 Foreword

The IERS Annual Report for 2004 closely follows the same scheme as the Report for 2003, reflecting the overall structure of the Service. However, the reader will find that the IERS established two new Working Groups (WG on Site Survey and Co-location and WG on Combination) that started their important work in 2004 and whose activities are described in subsection 3.7.

The IERS Combination Pilot Project that was launched at the IERS Retreat in 2003 (for details see IERS Annual Report for 2003, section 4.1) unfortunately proceeded somewhat slower than originally planned and expected. However, some progress has been made whose results were discussed at the IERS Workshop on the Combination Pilot Project (Napa, December 2004). Section 4 is devoted to this important meeting.

The year 2004 was also a year in which several changes in the composition of the IERS Directing Board were made – they are reflected in Appendix 2. Several colleagues, whose terms in DB expired, were replaced by newcomers. Among them, the change of the DB Chair, effective since the beginning of 2005, took place. My four-year term as chairman, as well as my extended term as IAU Representative, expired by the end of 2004. I was replaced in the position of IAU Representative by Nicole Capitaine (Observatoire de Paris), and the new members of the DB elected in December 2004 as the new Chair Chopo Ma (NASA GSFC). I am sure that both of these choices were excellent; I congratulate Nicole and Chopo to their new positions, and I wish them (and the other DB members, too) much success in their future work.

I would like to use this occasion to thank all outgoing DB members for their efforts in coordinating the complex work of the IERS, and, last but not least, to the personnel of the Central Bureau in Frankfurt a.M., headed by Bernd Richter, for their perfect work in assuring all administrative tasks of the whole Service.

This list of novelties is not meant to be complete – should you want to learn more about the rich IERS activities and products in 2004, please open the Report and read the sections that follow.

Jan Vondrák, past Chair of the IERS DB

2 The IERS
2.1 Structure

In 2004 and 2005, 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 2004 or 2005.

Analysis Coordinator

Markus Rothacher

Central Bureau

Director: Bernd Richter

Technique Centres

International GPS 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, Peter J. Shelus
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)
DORIS representatives to the IERS:
Hervé Fagard, Martine Feissel-Vernier (until 31 October 2005)
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

Convention 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:
Jean Souchay (until 31 December 2004),
Ralph A. Gaume (since 1 January 2005)

ITRS Centre
Primary scientist and representative to the IERS Directing Board: Claude Boucher (until 31 December 2004),
Zuheir Altamimi (since 1 January 2005)

Global Geophysical Fluids Centre
Head and representative to the IERS Directing Board:
Benjamin F. Chao (until 31 December 2004), 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

Special Bureau for the Core
Chair: Tim van Hoolst

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

Special Bureau for Loading
Chair: Tonie van Dam (until 31 December 2004), Hans-Peter Plag (since 1 January 2005), *Vice-chair*: Hans-Peter Plag (until 31 December 2004), 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

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 2004)

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

Institut Géographique National (IGN)
Primary scientist: Zuheir Altamimi

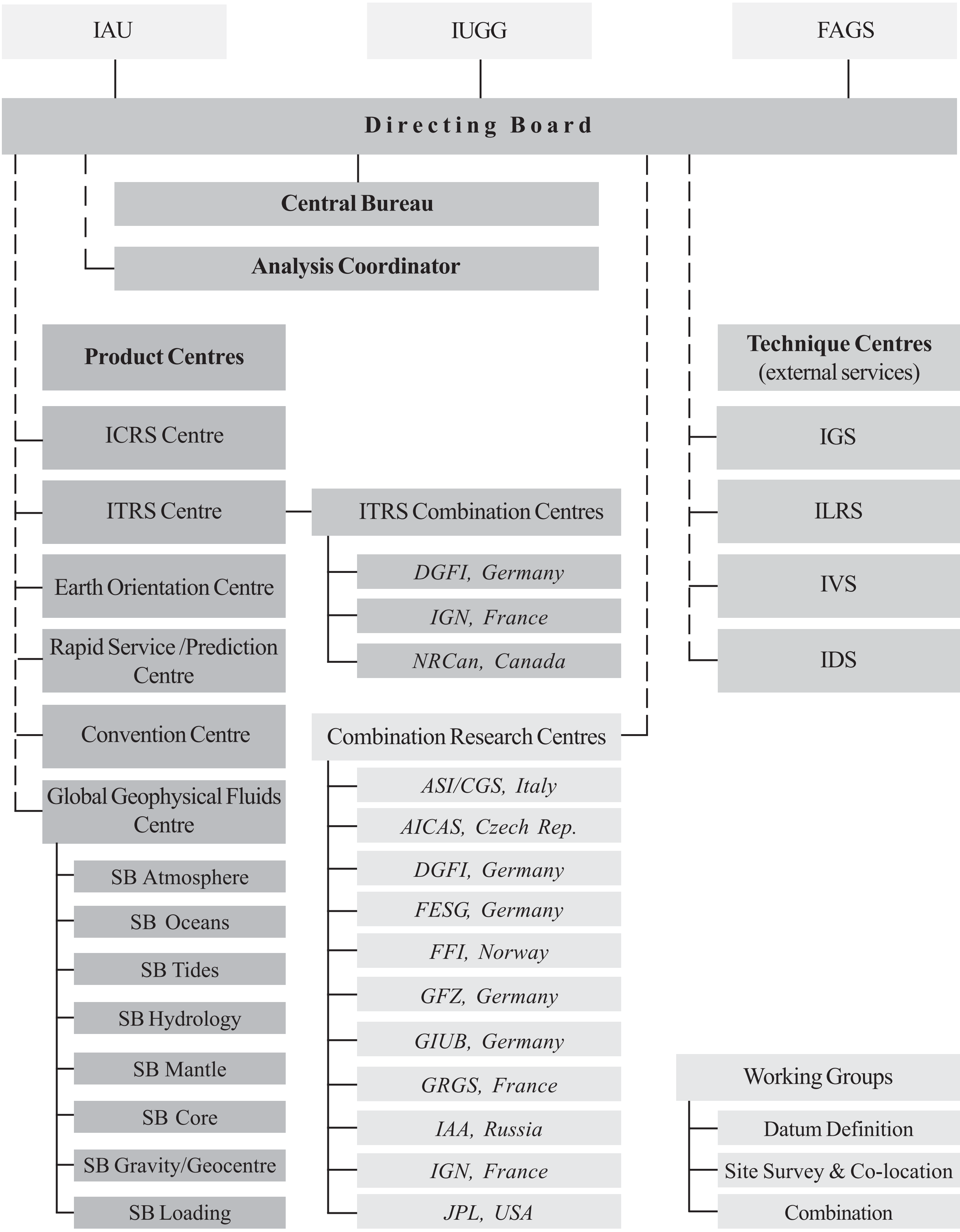
Jet Propulsion Laboratory (JPL)
Primary scientist: Richard S. Gross

Working Groups

Working Group on Site Survey and Co-location
(established in February 2004) *Chair*: John Dawson

Working Group on Combination
(established in January 2004) *Chair*: Markus Rothacher

2.1 Structure



2.2 Directing Board

In 2004 and 2005, the IERS Directing Board had the following members (for addresses see Appendix 2):

Chair	Jan Vondrák (until 31 December 2004) Chopo Ma (since 1 January 2005)
Analysis Coordinator	Markus Rothacher
Product Centres Representatives	
Earth Orientation Centre	Daniel Gambis
Rapid Service/Prediction Centre	William Wooden
Conventions Centre	Gérard Petit
ICRS Centre	Jean Souchay (until 31 December 2004) Ralph A. Gaume (since 1 January 2005)
ITRS Centre	Claude Boucher (until 31 December 2004) Zuheir Altamimi (since 1 January 2005)
Global Geophysical Fluids Centre	Benjamin F. Chao (until 31 December 2004) Tonie van Dam (since 1 January 2005)
Central Bureau	Bernd Richter
Combination Research Centres	Sheng Yuan Zhu (until 31 August 2005)
Technique Centers Representatives	
IGS	Gerd Gendt Angelyn W. Moore (since 1 January 2005)
ILRS	Ron Noomen Peter J. Shelus
IVS	Chopo Ma Axel Nothnagel
IDS	Hervé Fagard Martine Feissel-Vernier (until 31 October 2005)
Union Representatives	
IAU	Jan Vondrák (until 31 December 2004) Nicole Capitaine (since 1 January 2005)
IAG / IUGG	Clark R. Wilson
FAGS	David Pugh (until 31 December 2004) Nicole Capitaine (since 1 January 2005)

2.3 Associate Members

Andersen, Ole Baltazar
Andersen, Per Helge
Angermann, Detlef
Arias, Elisa Felicitas
Biancale, Richard
Bianco, Giuseppe
Boucher, Claude
Bruyninx, Carine
Carter, William E.
Chao, Benjamin F.
Dawson, John
Dow, John M.
Drewes, Hermann
Feissel-Vernier, Martine
Ferland, Remi
Gross, Richard S.
Gurtner, Werner
Herring, Thomas
Hoolst, Tim van
Kolaczek, Barbara
Kostelecký, Jan
Luzum, Brian
Malkin, Zinovy M.
McCarthy, Dennis D.
Melbourne, William G.
Neilan, Ruth E.
Pearlman, Michael R.
Plag, Hans-Peter
Pugh, David
Ray, Jim
Ray, Richard D.
Reigber, Christoph
Salstein, David
Schlüter, Wolfgang
Schutz, Bob E.
Souchay, Jean
Tavernier, Gilles
Vandenberg, Nancy
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: Oddbjørn Engvold
IUGG General Secretary: Jo Ann Joselyn
President of FAGS: David Pugh
President of IAG Commission 1: Hermann Drewes
President of IAG Subcommission 1.1: M. Rothacher
President of IAG Subcommission 1.2: C. Boucher
President of IAG Subcommission 1.4: S.Y. Zhu
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 November 2005*)

3 Reports of IERS components
3.1 Directing Board

The IERS Directing Board (DB) met once in the course of the year 2004. A summary of this meeting is given below.

Meeting No. 39

September 23, 2004, Bureau International des Poids et Mesures (BIPM), Sèvres, France

J. Vondrák welcomed the participants of the meeting and reported about the following activity since the last DB meeting: A letter with respect to the future of the *Standards Of Fundamental Astronomy* (SOFA) was sent to the Particle Physics and Astronomy Council (PPARC) of UK. In reply PPARC regrets that, due to dramatic cuts in the budget, it will not be able to provide the required resources to continue the SOFA development in the future. Nonetheless Dr. Vincent asked the general director of ESO whether she would allow them to count the SOFA work against their contribution to ESO operations. J. Vondrák also informed the DB that N. Capitaine will replace him as the IAU representative.

Concerning the necessary renewal of IERS components and the re-appointment of DB members, the DB decided the following: Changes of the ToR are not necessary presently. A general review of IERS components was made during the IERS Retreat 2003 in Paris. Currently the IERS is in transition again. Next year a lot of changes/transformations will appear, therefore an *internal* review is proposed by the end of 2005.

In the event that an *external* review will be planned later, the Directing Board should set up a review committee and organise a workshop with participants from other IAG / IAU components. The reviewers should take part in the workshop but report to the DB independently.

B. Richter summarized the present membership and the upcoming changes in the DB. The members are appointed for 4 years and can be re-appointed once (see ToR):

- Change from J. Souchay to R. Gaume (as announced in the proposal for the ICRS Centre)
- Change for the GGFC head (see below)
- Decisions have to be made to re-appoint the following scientific representatives: D. Gambis, C. Boucher, B. Richter. Their term will expire at the end of 2004.
- The term of the Analysis Coordinator will end in August 2005; M. Rothacher is willing to work for another term as AC. The IERS DB welcomed and accepted this offer.

To renew the term of the scientific representatives of the Earth Orientation Centre, the ITRS Centre and the Central Bureau, a letter should be written to the directors of the hosting institutions, expressing the IERS DB gratitude for their support of the IERS and asking them to prolong the term of the scientific representatives. The letter should be signed by the chair of the DB.

B. Chao gave a short summary on the status of the Special Bureaus of the GGFC. At the SB Loading a 6-hr atmospheric loading product has been created as a first step toward becoming operational as a real-time data provider. At the SB Atmosphere a 6-month post doc from China will start working soon on AAM data update and on uniform formatting of the data of the SBA, SBO, and SBH. The finances come from the Descartes prize. A data processing example with different views, description of data (metadata), xml format, ascii format, plots, etc. has already been realized.

After seven years B. Chao will resign as chair of the GGFC but will continue as head of the SB Mantle. He raised the question about what should be done to elect a new head of the GGFC. The Chair of the Directing Board and the Central Bureau will send a letter to the GGFC SB heads to initiate the process of finding a new GGFC representative in the IERS DB. It is the consensus of the DB that the new chair should be a SB chair and should be elected by the SBs themselves.

For the election of new Chair of the DB, the following procedure was proposed and accepted and should be organized by the Central Bureau: All present DB members will be asked by e-mail whether they are willing to be a candidate for election (mid of October). There will be an election by e-mail (end of October), deadline mid-November.

M. Feissel-Vernier proposed R. Noomen as IERS Representative to the IDS Governing Board. The proposal was accepted without dissenting votes.

B. Richter reported that B. Schutz is willing to continue for another term as IERS Representative to the ILRS Governing Board. The proposal was accepted without dissenting votes.

G. Petit reported about the status at the Conventions Centre. A new Web site has been set up at the BIPM containing a Conventions Discussion Forum. A session with respect to the IERS Conventions is planned for the EGU 2005 in Vienna. Less than 10 answers have been received to the “Questionnaire on the Conventions”. From these answers it could be concluded that the structure and overall quality of the Conventions 2003 are fine but the delay of the publication is a problem as well as some inconsistencies / deficiencies. To gather new and updated information for future Conventions there should be a survey to the community, expert groups, and technique services. This information should be used to update the Conventions by discrete increments (e.g. yearly). However, a paper version would be useful.

Updating the conventions means to update models, ensuring global consistency and providing all necessary information. It has to be discussed whether models for short-term periodic effects should be considered as well as which technique-dependent effects should be treated within the Conventions.

G. Petit proposed to implement an Advisory Board for the IERS Conventions update. The Board should advise the Conventions Centre in its work of updating the Conventions, review and propose directions to the Conventions Editorial Panel, and approve / recommend for approval the new official updates. It should represent the approach of users based on their needs and experience. Proposed members are a Chair named by the IERS Directing Board, one representative of each Technique Centre and each Product Centre, the IERS Analysis Coordinator, and additional members proposed by TCs / PCs. There should be one meeting per year and additional e-mail work.

The Directing Board welcomed the activity and supports the idea to set up an Advisory Board. It was decided that the Advisory board is an action of the Conventions Centre, i.e. the Directing Board just has to find consensus on the proposed procedure and then the Conventions Centre can proceed and set up the Advisory Board.

B. Richter presented the following considerations about the role of the IERS in the future and about legal aspects:

All IAG services including the IERS are set up according to their “Terms of Reference”. Calls for participation were issued to fill the duties within the services. The selected proposers provide their own financial resources to execute their obligations. Self-binding commitments are drawn up with the chairs of the respective IAG services with no legal status. Discussion on the participation in the IAG services come up episodically in conjunction with budget restrictions or national strategic reorganizations.

Since 2003 a GEOSS (Global Earth Observation System of Systems) initiative is under discussion to achieve comprehensive, coordinated and sustained Earth observations for the benefit of humankind. GEOSS will be a “system of systems” where those existing and future Earth observing systems that contribute to GEOSS retain their existing mandates (more information see http://www.epa.gov/geoss). At the beginning of this year IAG became a member of the GEOSS, and thanks to interaction on different levels, the IAG reference systems (and therefore indirectly the IAG services) are proposed to become the basis for all observation related to positions. If the document is signed by the participating nations (51 countries and 29 international organizations), it could become a basis for national activities to ensure the long-term geodetic activities concerning observations / analyses.

N. Capitaine reported the following on the status of FAGS:

As being, since October 2003, the IAU Representative on the Council of FAGS (Federation of Astronomical and Geophysical Data Analysis Services), I participated in a FAGS Council Meeting in Southampton (UK) (19 April 2004).

The Services belonging to FAGS, were reviewed during this meeting; the points that have been especially emphasized are the importance for the services of (i) having an active Directing Board and (ii) making the data available on an efficient website in order to have the activities worldwide known. No money will be allocated any more by ICSU (International Council for Science) due to the fact that that ICSU has decided, as part of a rationalization of its structure, to discontinue its sponsorship of FAGS as an ICSU Interdisciplinary Body. An option that is under study is to find a way to associate FAGS with UNESCO.

There will be a meeting in Paris in May 2005 of the FAGS Council with the Union representatives and the Directors of the Services which will be an opportunity to consider whether there is sufficient common interest between UNESCO and the present FAGS activities for the federation of services to present a proposal for the FAGS work to become a UNESCO-associated body. If this UNESCO association does not work, an other possibility would be to create a Joint Committee between the three supporting international Unions (IAU, IUGG, URSI) that will replace the FAGS Council and will be in charge of reviewing the activities of the Services and of allocating the (weak) financial support coming from these Unions.

C. Boucher reported on the status of the ITRF. The ITRF2000 goals have been achieved but now it is time to consider a new ITRF. An update is required because of new stations, improved estimates of positions and velocities, new data including local tie information, discontinuities (earthquakes, antenna changes, ...). He proposed the following procedure: specifications to be prepared for new solutions by the ITRS Product Centre together with the Analysis Coordinator for e-mail approval by the IERS Directing Board. A first ITRF 2004 solution should be available in April 2005, computation will be done according to the ToR by the ITRS Combination Centres IGN, DGFI and NRCan. The strategy to be used should be consistent with the Combination Pilot Project. The specifications for ITRF2004 are

- weekly input data: time series, single technique combined solutions plus additional individual solutions,
- the model: TRF+EOP combination.

The exact specifications are to be distributed by e-mail to the members of the Directing Board, the deadline is mid /end October, 2004.

Afterwards they should be distributed immediately to the Technique Centres and to other relevant people.

M. Rothacher presented the current status of the IERS Combination Pilot Project (CPP). The CPP should be extended into the past by including long time series of weekly SINEX files dated before the start of the CPP. With the call IERS 2005 he proposes a rigorous combination of ICRF/EOP/ITRF using these long-term series.

The IERS DB asks that both projects ITRF 2004 and IERS 2005 should be fully coordinated, because the same SINEX file time series are requested from the Techniques Centres.

M. Feissel-Vernier mentioned that both the IERS CPP and the proposed completion of ITRF2004 will bring in 2005 new knowledge and understanding of the time evolution of station coordinates, EOP and geocenter. As a result of these two complementary projects, key questions with respect to a truly integrated solution will have to be studied, e.g. consistency across techniques, station and radiosource instability, extended modelling of the combination. After these problems have been solved, the proposed IERS2005 can be realized. Chopo Ma mentioned that the naming ICRF 2005 might be misunderstood by astronomers, because there is only one official ICRF. R. Noomen mentioned that the IERS should emphasize the need for combined products from the TCs.

A CPP workshop will take place in the San Francisco Area prior to the AGU on December 9 and 10. The following sessions were proposed:

- Combination Pilot Project and CONT'02 („Weekly" SINEX)
- Long Time Series and their combination (ITRF, IERS2005, ...)
- Handling of Systematic Biases
- Conventions, Modeling, Parameterization
- Local Ties

W. Schwegmann gave a status report on the IERS Database as well as on the new Information System. The IERS Database is meant to archive all products of the IERS and the corresponding data to produce the products at a central place. The system is currently running in test mode. It already allows to mirror the products of the IERS product centres and to archive all relevant data. The data are transformed to XML (eXtensible Markup Language) to allow a comfortable exchange and combination of the data. Metadata of all products are going to be extracted from the product files and maintained in a specific database. These metadata can be included in "Metadata Information Systems", allowing users to search for data sets with respect to geosciences.

The Web pages are going to be re-designed. The new Information System is a dynamic database-driven system. Thus, it allows easy maintenance of the Web pages with respect to timeliness, redundancy and consistency. The contents of the Web pages are based on XML, also.

Interactive tools have to be developed to work with the data. Links to existing interactive tools, such as the interactive tools at the Earth Orientation Centre, will be included in the Web pages.

M. Feissel-Vernier suggested that the Web site should contain an overview of the characteristics of similar data sets (e.g. EOP data) and that the availability of data plots is important for the users. B. Chao mentioned that there is cooperation between the Central Bureau and the GGFC with respect to the usage of XML.

The IERS Working Groups 2 (on Site Survey and Co-location) and 3 (on Combination) presented reports about their work.

B. Richter reported that the IERS Annual Report 2003 is ready for electronic publication. The delay was caused by late submission of some of the contributions. The following IERS Technical Notes are in preparation.

No. 30: B. Richter et al. (eds.): Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids, 2003 *(printed, will be distributed soon)*

No. 31: C. Boucher, Z. Altamimi, P. Sillard, and M. Feissel-Vernier: The ITRF2000, 2004 *(printed, will be distributed soon)*

No. 32: D.D. McCarthy and G. Petit (eds.): IERS Conventions (2003), 2004 *(printed, will be distributed soon)*

No. 33: B. Richter et al. (eds): Proceedings of the IERS Workshop on site co-location *(in preparation)*

Because it was the last IERS DB meeting chaired by Jan Vondrak, the IERS DB thanked J. Vondrak for his dedicated engagement as IAU representative and chair of the IERS DB.

He led the IERS in a difficult phase, when its new structure had to be tested in everyday practice. We can state now that this test was successful – thanks to Jan's efforts. He could also use his authority, his diplomatic abilities and his close contacts with colleagues in Paris and other parts of the world to resolve issues inside IERS or between the scientific community and IERS.

J. Vondrak will soon have to retire not only from the IERS Directing Board, but also from his home organization, the Astronomical Institute of the Academy of Sciences of the Czech Republic in Prague. The DB wished him an enjoyable retirement, but also expressed hope that he would remain active in the field as long as possible.

The next DB meeting will be held in Vienna in conjunction with the EGU General Assembly 2005 from 25 to 29 April 2005.

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) Meeting No. 39, September 23, 2004, at BIPM, Sèvres, France. Between the meetings the CB co-ordinated the work of the DB.

The CB prepared an IERS Workshop on the Combination Pilot Project, held December 11, 2004, in Napa, CA, USA. 23 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 and the CB with oral and poster presentations at the IERS Workshop, at the FGS Workshop, at GeoLeipzig, and at Geotechnologien project meetings. A contribution on the IERS and its relation to astronomy was published in the book "Organizations and strategies in astronomy", vol. 5. The CB prepared an IERS report for 2003 to FAGS.

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 a large link list for IERS, Earth rotation in general and related fields. Throughout 2004 the web site was regularly enlarged and updated.

IERS Technical Notes (TN) No. 30, containing the Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids (edited by the Central Bureau), and No. 31 (The ITRF2000, by C. Boucher, Z. Altamimi, P. Sillard, and M. Feissel-Vernier) appeared as printed versions. The IERS Conventions (2003), edited by Dennis D. McCarthy and Gérard Petit, were published as TN No. 32 in online and in printed forms. Work started on editing the Proceedings of the Workshop on site co-location as TN No. 33.

The CB published also the IERS Annual Report 2003 in online form. It appeared in November 2004 in the form of PDF files for download from the web site. Besides the reports of the IERS components, it contains information on the IERS compiled by the CB.

During the year 2004, 16 IERS Messages (Nos. 51 – 66) were edited and distributed by the CB. They contain news from the IERS and from related services as well as announcements of conferences.

The CB continued to maintain its address database of IERS users. There were about 2500 users in 2004 with valid addresses who subscribed to IERS publications for e-mail and regular mail distribution. Address and subscription information has regularly been updated.

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 basics and the future of the UTC timescale were answered.

IERS Data and Information System

The new IERS Data and Information System is a dynamic and database-driven system and allows to maintain the data and information flow between the participating institutions and the users of the IERS. The IERS Data Centre will store and archive all IERS products as well as all data which are necessary for the IERS products and also those which are necessary to re-compute the IERS products (cf. Minutes of DB Meeting No. 32). Also information related to the IERS and its products will be presented. The new system provides the central access point to search within the data, to work with the data and to download the data. Therefore, all products are converted into a general format using the eXtensible Markup Language (XML) that can be regarded as the future standard format for data and information exchange over the Web. From the transformed data files extended meta information are extracted and stored in the database for search. Using XML the heterogeneous products of the IERS in their various formats can be easily described. Aside the original standard file output, the data and information can be presented multiformly.

The technical implementation of the new IERS Data and Information System has been finished and the work has been started to import all products, data and information into the system. Routines have been created to automatically download and process new data from the IERS Product Centres and to import them into the new system. The information from the old Web pages have been introduced without changes and work has been started to transform them into the XML-based format of the new information system. A solution has been worked out to automatically forward calls to URLs of old web pages to the respective URLs within the new system.

Publications

Dick, W. R.; Richter, B.: The International Earth Rotation and Reference Systems Service (IERS). In: André Heck (ed.), Organizations and Strategies in Astronomy, Vol. 5. (Astrophysics and Space Science Library; vol. 310) Dordrecht 2004, p. 159–168.

Dick, W. R.; Richter, B. (eds.): IERS Annual Report 2003. Frankfurt am Main: Verlag des BKG, 2004. 163 p.

Richter, B; Schwegmann, W.; Dick, W. R. (eds.): Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids. (IERS Technical Note; No. 30) Frankfurt am Main: Verlag des BKG, 2003. 235 p.

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3.3 Analysis Coordinator

IERS Combination Pilot Project

The motivation for initiating the IERS Combination Pilot Project was the situation that the various IERS products, i.e., International Terrestrial Reference Frame (ITRF), International Celestial Reference Frame (ICRF), Earth Orientation Parameters (EOP), were still combined independently. And even more, in most cases neither intra-technique combinations nor inter-technique combinations were performed using the full variance-covariance information. Therefore, the consistency of the different IERS products cannot be guaranteed, and the different strengths of the space techniques are not fully exploited to improve the products. From this background, the IERS Combination Pilot Project (CPP) was initiated and should be a major step towards more consistent IERS products that are generated on a routine basis.

The Call for Participation was sent out in February 2004. Several groups answered the call and proposed to participate in one or more of the major steps. The CPP is a three-step project with an additional fourth part. The main topics of the four steps / parts are the following:

1. Generate a combined weekly intra-technique solution for each space geodetic technique
2. Generate weekly inter-technique combinations based on solutions out of step 1
3. Validate the different combinations
4. Generate special products

More details can be found in chapter 3.7.2 of this volume, IERS Combination Working Group.

IERS Long Time Series

In December 2004 the call for IERS Long Time Series was sent out as it was recognized that the availability of long time series is essential for a weekly rigorous combination of space geodetic solutions. During the IERS Combination Pilot Project it came out that the weekly combined solutions cannot be generated consistently over longer time spans as long as there are no time series available as a reference.

Due to this project, homogeneous time series from all space geodetic techniques are available now:

<http://iers1.bkg.bund.de/info/listFileITRF2004.php>

More details can be found in chapter 3.7.2 of this volume, IERS Combination Working Group.

Future Products

The first new type of IERS products will be ITRF2004 that will include station coordinates, station velocities as well as daily Earth rotation parameters (pole coordinates and UT1–UTC) in one solution for the first time.

Besides this long time solution, the Combination Pilot Project delivers weekly single-technique solutions as well as combined inter-technique solutions.

Plans concerning the inclusion of additional parameters into the solutions mentioned above or the generation of other types of IERS products are explained in chapter 3.7.2 of this volume (IERS Combination Working Group).

Meetings and Workshops

- IERS Working Group on Combination and CPP Meeting during 1st EGU General Assembly, Nice / France, April 2004
- IERS Workshop on Combination, Nappa Valley / California, December 2004
- Meetings with a session dedicated to combination of space geodetic techniques:
  - EGU General Assembly, Nice / France, April 2004
  - COSPAR 2004, Paris / France, July 2004
  - AGU Fall Meeting, San Francisco / California, December 2004

Markus Rothacher, Robert Dill, Daniela Thaller

3.4 Technique Centres

3.4.1 International GPS 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 2004.

Table 1: Quality of the IGS Core Products as of December 2004 (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 2004 another 20 sites were added to the IGS network reaching now a total of 383 sites (<http://igscb.jpl.nasa.gov/network/ netindex.html>). In addition to the usual data transfer in daily batches, more than 170 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.

Analysis Issues

The number of usable stations in the IGS realization of ITRF2000, named IGS00, decreased since its inception in December 2002 from 55 to about 45 stations. Therefore, a new realization IGb00 with 99 stations (IGS03P33_RS99.snx) was introduced in January

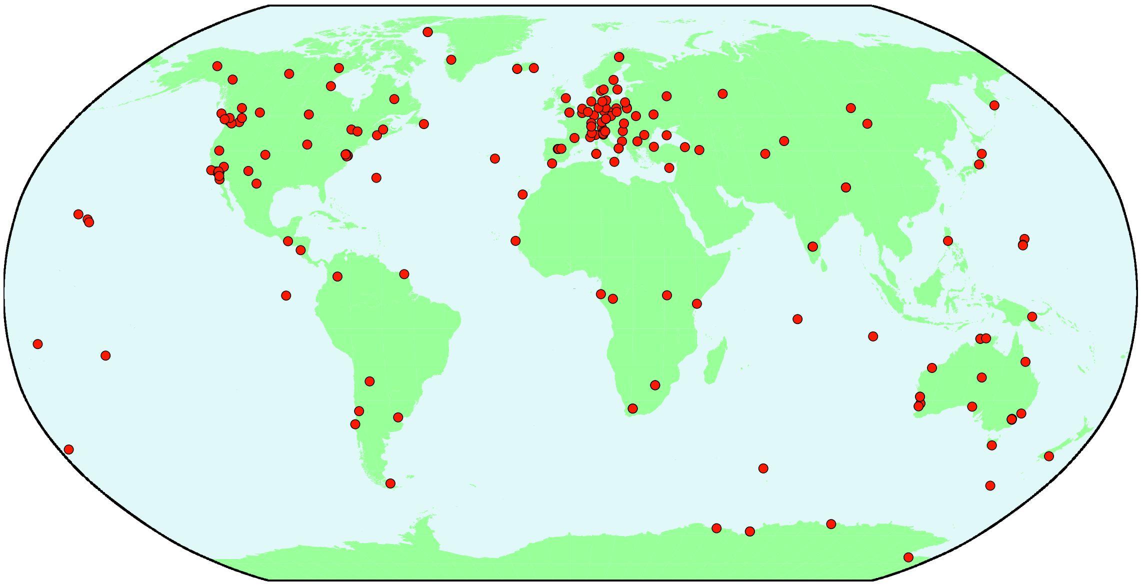

Fig. 1: IGS tracking network with hourly stations

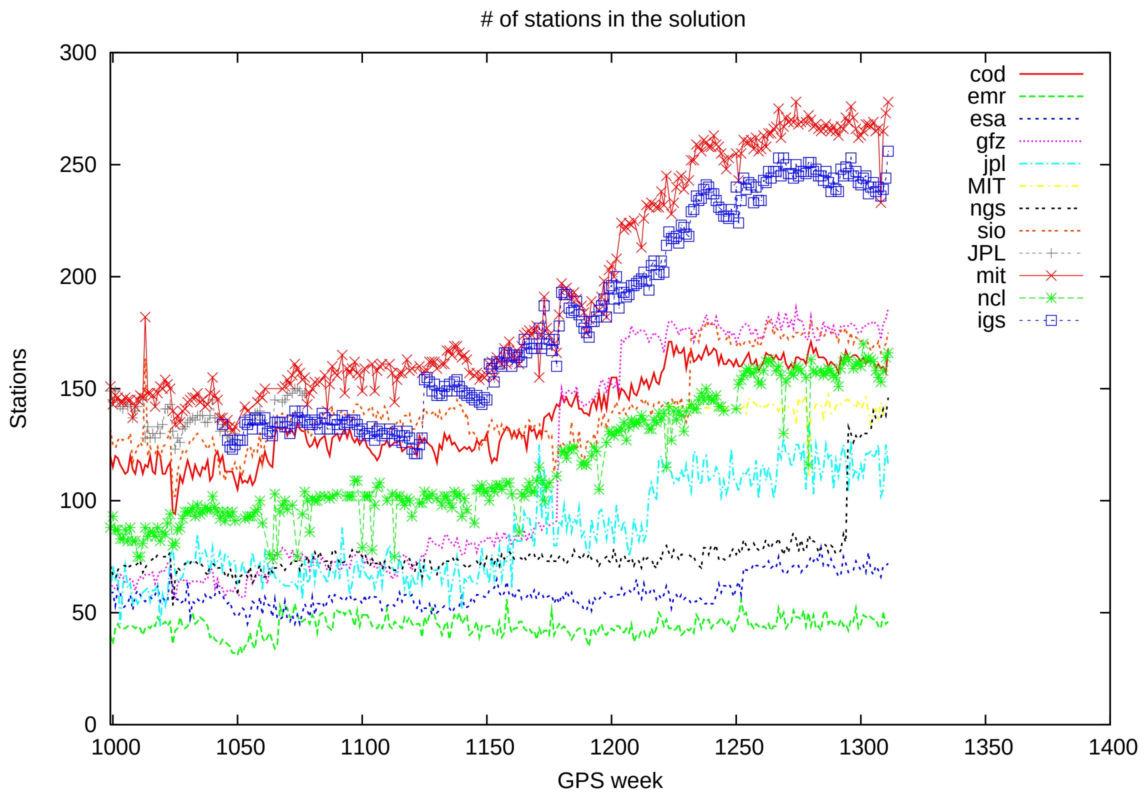

Fig. 2: Number of stations in the weekly AC/GNAAC/IGS solutions

2004 and will allow for a much more stable realization of the reference frame. As of February 2005, 85 reference frame stations are still defining the IGb00 realization. A reanalysis of most of the AC solutions was carried out to improve the weekly/cumulative IGS combined solutions in preparation for the upcoming ITRF.

The number of stations in the weekly SINEX products increased steadily and comprises now up to about 260 sites. Figure 2 shows the evolution of the number of stations used in the weekly AC/GNAAC/IGS analysis.

After comprehensive checking of their submitted products over several months, two new analysis centers were included in the official product combinations – Massachusetts Institute of Technology (MIT) for the Final products and Geodetic Observatory Pecny (GOPE) for the Ultra Rapid products.

Any user can directly and easily access to the reference frame by applying the Precise Point Positioning (PPP) technique based on the IGS orbits and clocks. To check the realized accuracy, a PPP is performed with each IGS Product (Rapid and Final) for all those stations included in the IGb00 reference frame definition. The stations' repeatability and the Helmert transformation parameters to IGb00 are computed and publicized at <http://www.gfz-potsdam.de/igsacc>.

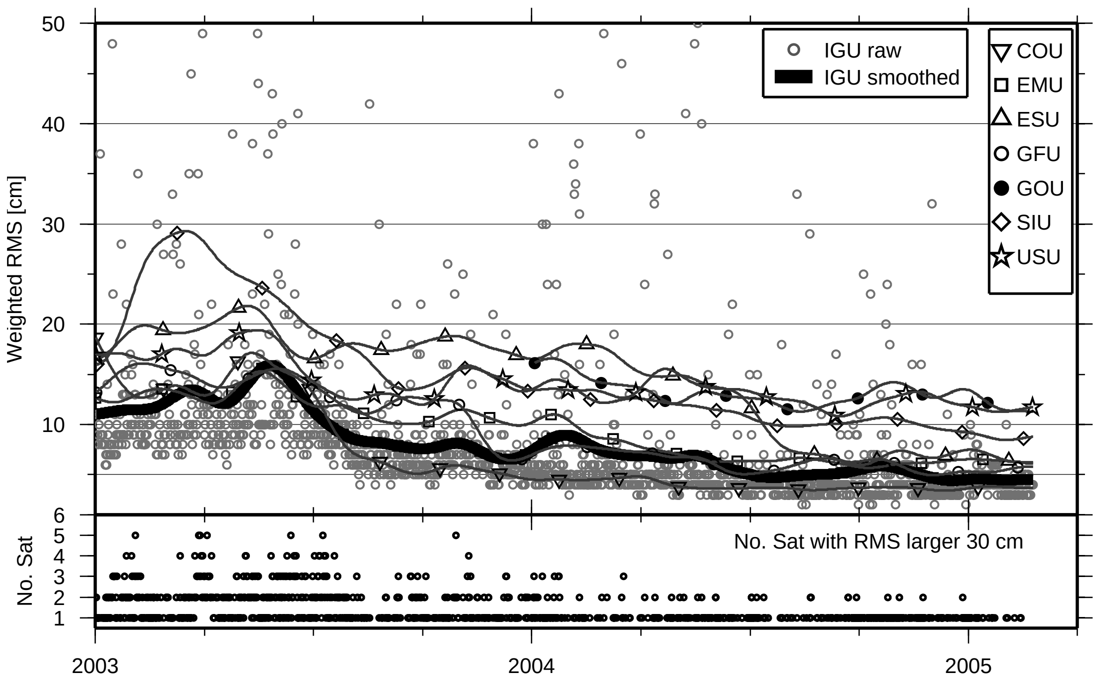

Fig. 3: Weighted orbit RMS of the Analysis Centers' Ultra Rapid orbits with respect to the IGS Rapid orbits (smoothed). The thick line shows the IGS Ultra Rapid orbits (smoothed), and the circles the daily RMS that is in a few cases affected by single bad satellites the number of those are given in the bottom plot.

Since May 2004 the update cycle for the Ultra Rapid product was increased from twice to four times per day. This way the nominal prediction interval, necessary for real time applications, could significantly be reduced from 15 to 9 hours, resulting in better predictions and, most of all, in a reduction of outliers for the not-so-well-predictable satellites (see Fig. 3).

IGS 10th Anniversary Symposium and Workshop, March 1-5, 2004

A one-day symposium was held aimed at celebrating the history, development and accomplishments of the IGS over the last decade and how this has benefited multi-disciplinary applications. A view of the evolution and future of Global Navigation Satellite Systems was provided, and the future of international cooperation, use of GNSS, and the evolving role of IGS explored. The establishment of an International GNSS Committee as a mechanism to further cooperation among system providers, international GNSS organizations, and users was strongly encouraged. The IGS and the IAG will support and contribute to the successful realization of such an effort.

The technical workshop set the stage for the future directions and developments of the IGS. The sessions were devoted to specific topics related to IGS components:

- IGS Reference Frame Maintenance
- Reference Frame Issues
- Network Issues
- Data Transfer and Data Centers
- Real-time Aspects
- Integrity Monitoring of IGS Products
- Global Navigation Satellite Systems
- Precise Orbit Determination
- Antenna Effects
- Ground Based Neutral Atmosphere and Ionosphere Sounding

For each session, a Position Paper was the basis for discussion. The workshop generated numerous recommendations in each session, which could not all be listed here.

Some of the key issues are:

- Stabilization and improvement of the reference frame
- Ways how the IGS can move towards real-time processes
- Adoption of absolute antenna calibrations including the derivation of absolute satellite antenna model
- Approach to generate a new IGS troposphere product based on PPP
- Positioning the IGS to influence and integrate future GNSS, as has been demonstrated with GLONASS.

A comprehensive list of all recommendations will be included in the proceedings.

New Name for IGS

In view of the increasing developments in the field of Global Navigation Satellite Systems (GNSS), the IGS Governing Board decided in March 2005 to modify the name of IGS. The acronym remains, but now stands for *International GNSS Service*.

Summary

The IGS celebrated its 10th anniversary by organizing a Symposium and a Workshop in March 2004. In 2004, as in the previous ten years, the IGS contributed significantly to the IERS activities like maintenance and extension of the ITRF and in the highly-accurate, daily-sampled Earth Rotations Parameters. The quality of the IGS products has further improved, especially for the low-latency products (Rapid and Ultra Rapid). 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

Dow, J., G. Gendt, A. Moore, R. Neilan, R. Weber: The International GPS Service – What's next? 10th Anniversary Assembly Charts Future Directions. Proceedings ION, 22 Sept 2004, Long Beach, USA

Celebrating a Decade of the International GPS Service, Workshop & Symposium 2004. Proceedings, Bern Switzerland, March 1-5, 2004, Astronomical Institute, University Bern, Switzerland, in print

2001-02 Technical Report. IGS Central Bureau, eds. Pasadena, CA: Jet Propulsion Laboratory, 2004.

2001-02 Annual Report. IGS Central Bureau, eds. Pasadena, CA: Jet Propulsion Laboratory, 2004.

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

Gerd Gendt

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 has matured over the years. From a technical point of view, the single-shot precision of an average station has been reduced from about 20 mm in the mid-1990s to better than 10 mm currently; the best stations go well below that number. A similar observation applies for the absolute quality of the range measurements: thanks to progress being made both in technical aspects and in the modeling of various elements of the range equation (such as the troposphere effect, the satellite signature and such) the absolute accuracy of present-day SLR/LLR observations is better than 10 mm for a representative station, again with a large number of stations doing much better. Figure 1 shows the performance of the global network over the past several years. In particular, it shows the number of stations that have tracked either LAGEOS-1 or LAGEOS-2 in a specific year, plus the number of passes on these satellites (divided by 100 to make numbers fit better in one plot). The data yield on these two satellites can be considered as being representative for the acquisition of measurements on most of the other satellites that are equipped with retroreflectors. It is clearly visible that the number of stations has leveled off at slightly more than 40, whereas the production of passes (and, equivalently, normal points, or minutes of data) is still on the rise. The latter effect is due to improvements in technology, smarter operating techniques, automation, and such. However, the plot does not properly reflect the geometric distribution of the network, and changes therein. Unfortunately, the operation of the SLR station on Haleakala (Hawaii) had to be stopped in 2004 because of budgetary reasons. There also has been a hiatus for SLR operations in Arequipa, Peru. Also, the number of operating shifts of other (U.S.) stations had to be reduced for the same reason. As a consequence, a gap has arisen in the global coverage of stations, with reductions in the quality of particular SLR products and observing/validation capabilities.

Missions

SLR has supported many satellite missions over the years. In 2004, a total of 29 satellites (including the Moon) were being laser-tracked (cf. Table 1). During this year, there were two newcomers: Gravity Probe B, a relativity mission equiped with gyroscopes, launched in April 2004 and ICESat, a laser altimeter mission to monitor the ice fields in Antarctica and Greenland, in addition to sea surface and atmospheric studies. Even though it was launched in 2003, ICESat has only become an active target in 2004, by a limited subset of stations of the worldwide SLR network. Clearly, this wealth of spacecraft customers may cause scheduling problems at individual stations (in particular when multiple satellites are in view of that station simultaneously). The general procedure applied to resolve this issue is the technique of so-called interleaving, where the telescope switches between satellites, and satellites at low altitudes (with short pass times) get highest priority.

Table 1: Overview of satellites (man-made and natural) that have been tracked routinely by the laser ranging network in 2004

Ajisai, Beacon-C, CHAMP, ENVISAT, ERS-2, Etalon-1, Etalon-2, GFO-1, Glonass-84, Glonass-86, Glonass-87, Glonass-88, Glonass-89, Gravity Probe B, GPS-35, GPS-36, GRACE-A, GRACE-B, ICESat, Jason, LAGEOS-1, LAGEOS-2, LARETS, Meteor-3M, Moon, Reflector, Starlette, Stella and TOPEX/ Poseidon.

Analysis

Of particular interest to IERS are the analysis products that the ILRS delivers. SLR plays a particularly important role in the assessment of the 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. Another area, where SLR plays an important role, is gravity field development. Although such solutions rely heavily on radiometric observations, the SLR measurements provide a unique tool to validate the orbital and gravity field solutions and independently assess their quality by virtue of their absolute, unbiased information content.

Specifically, the ILRS Analysis Working Group (AWG) coordinates the generation of a number of relevant data products. Since mid-2003, the AWG has been producing weekly time-series of solutions for station coordinates (and their derived parameters geocenter and scale) and Earth Orientation Parameters (EOPs; more specifically: x-pole and y-pole and excess Length of Day). After a test period of about one year, in which the length of the analysis intervals was modified and several fine-tuning modifications were made, the ILRS felt comfortable enough to label its products as “official ILRS”. At this moment, 5 different analysis institutes (ASI/Italy, DGFI/Germany, GFZ/Germany, JCET/USA and NSGF/UK) deliver weekly solutions for global station coordinates and EOPs on Tuesday of each week. These solutions are based on SLR data taken on the satellites LAGEOS-1, LAGEOS-2, Etalon-1 and Etalon-2. Subsequently, these solutions are merged into a combination solution, which is done by ASI and DGFI. During the AWG meeting in San Fernando (Spain) in mid-2004, ASI was "awarded" the name "official primary ILRS combination center", and is hence the first responsible for the generation of combination solutions which go to various external customers such as IERS. Alternatively, DGFI was "awarded" as the official backup ILRS combination center, and must satisfy the same requirements on the combination product as ASI has to; in case of a failure at ASI of whatever kind, the DGFI product will be readily available to take the place of the primary product.

The combination solutions are used for a variety of purposes: the IERS Combination Pilot Project, the IERS/NOAA Bulletin A, etc. Recently, and at the request of IERS, the ILRS AWG has started a backprocessing of older SLR data in a similar fashion to serve as input for a successor to ITRF2000 and possible other applications.

The ILRS is confident that the unique characteristics of the SLR/LLR measurements and the resulting analysis products will (continue to) play an important role in current and future descriptions of specific aspects of System Earth.

Ron Noomen, Peter J. Shelus

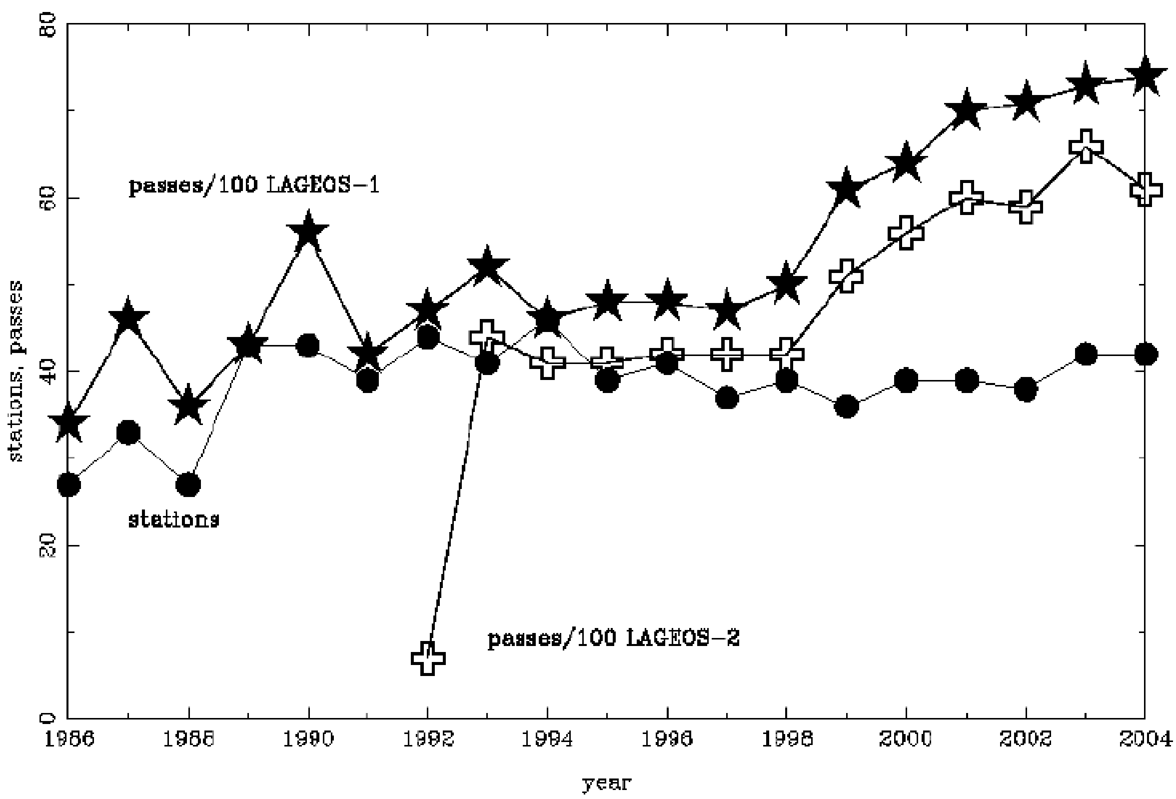

Fig. 1: Overview of tracking statistics on LAGEOS-1 and LAGEOS-2 of the global SLR network.

3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2004, 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 February 2004 IVS held its third General Meeting in Ottawa, Canada. Two IVS Directing Board meetings were held, one in February in Ottawa, and the other in October at Makuhari, Japan. IVS published its 2003 Annual Report in March 2004 and published three newsletter issues which keep the community informed about IVS activities. The IVS Pilot Project, led by the Analysis Coordinator Axel Nothnagel, "Time Series of Station Coordinates and Baseline Lengths", began work in 2004. Such a time series will be useful for many investigations of periodic and aperiodic variations caused by geophysical phenomena. The IVS began a 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, continued its work on developing a vision for VLBI in 2010. A report from the VLBI2010 Working Group, to be released in 2005, will become a guideline for the establishment of the next generation VLBI systems.

Network Stations

A total of 1109 station days were used in 192 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.5 days per week, similar to the two previous years. The number of station days also remained approximately the same. The major observing programs during 2004 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 USNO (R4).

Intensive

During 2004, Thursday and Saturday sessions were added, making daily UT1 measurements now available every day. 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 IV/5 (Wettzell-Kokee) and K4 (Wettzell-Tsukuba) technology. Comparisons of the two series showed good agreement with the IERS C04 series.

IVS-T2

Monthly sessions coordinated by the Geodetic Institute of the University of Bonn were expanded in mid-2004 to 16 stations. These sessions were observed monthly to monitor the TRF.

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. Svetloe, operated by the Institute of Applied Astronomy, Russia, was added to the E3 sessions in 2004.

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 2004 primarily in the southern hemisphere. Six 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 2004.

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

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had 11 sessions. These sessions included the dedicated 32-m dish at Tsukuba and are designed to monitor the domestic network within the ITRF.

Syowa The National Institute for Polar Research (NIPR) continued its sessions that included the Syowa station in Antarctica. The data were recorded with K4 and S2 and processed at the Mitaka (Japan) correlator.

IVS-R&D Ten sessions were observed in 2004 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 yield of 87.5%, slightly better (2%) compared to 2003. The most significant causes of data loss were antenna reliability (about 30%), receiver problems (20%), recorder problems (10%), and RFI (10%).

Correlators

The correlators at Haystack Observatory (USA), the U.S. Naval Observatory (USA), and at Max Planck Institute for Radioastronomy (Germany) expanded 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 about one 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 2004, six IVS Analysis Centers again contributed routinely to the IVS Combined EOP series. In this year the Main Astronomical Observatory (MAO), Kiev, Ukraine, replaced the Analysis Center of St. Petersburg University, now adding the contribution of a third software package, SteelBreeze. This third software package, which has been developed completely independently, helps to make the combination products even more robust and broadens the basis for investigations of systematic effects. Since all Analysis Centers use the same raw observation data for the computation of the EOP series, the input series cannot be considered to be independent. In the course of the year the combination of the EOP series has, thus, been refined further through implementation of correlation information between Analysis Centers.

The year 2004 marked a considerable step forward in the maintenance of the terrestrial reference frame (TRF) from geodetic VLBI observations. For the first time groups other than those using the Calc/Solve program were able to generate a TRF solution from a large number of high precision geodetic VLBI observations. Now, TRF solutions can also be computed by the Deutsches Geodätisches Forschungsinstitut (DGFI) in Munich, Germany, using the OCCAM VLBI software together with a DGFI combination program called DOGS-CS. Another TRF realization has been computed by MAO, Kiev, Ukraine, with the software package SteelBreeze.

First steps have been taken for a combination of a series of four TRF realizations (two from Calc/Solve, one from OCCAM and one from SteelBreeze) on the basis of coordinates, velocities and their formal errors. In order to map the results onto a common datum, the same procedures have been applied as described in Nothnagel (2003). After small global rotations and translations of only a few millimeters and a few µas, the solutions agree very well. In particular, the individual scales of the TRF realizations are very consistent indicating that the models of the three independent software packages agree rather well. Only in rare cases was the agreement unsatisfactory in the station coordinates at a common reference epoch. One of the reasons is that different data spans have been used for the computations leading to incomplete data sets for a few stations which observed only in the early 1980s. The other reason for unacceptable scatter in the results is differences in the values of the radio telescope axis offsets. Currently, re-computations of TRF realizations using recommended axis offsets are underway.

The official input of IVS to the 2004 IERS Combination Pilot Project consists of single session datum-free normal equations in SINEX V2.0 format combined from solutions of several IVS Analysis Centers. The parameters included are station coordinates and Earth Orientation Parameters plus their time derivatives. In the course of the year, the first combined SINEX files have been compiled. At the beginning only SINEX submissions from the Calc/Solve software package (GSFC, USNO, BKG) were available. Now, also DGFI regularly submits SINEX files while MAO is preparing to do so after the procedure is set up properly. The normal equations are being combined and submitted to the IVS Data Centers. The IERS Central Bureau collects them and includes them in the IERS CPP database. So far, more than 2000 VLBI sessions have been combined and submitted.

The "Fifth IVS Analysis Workshop" was held at Ottawa, Canada, on February 12, 2004. Detailed information on the presentations and discussions can be found in Nothnagel (2004).

Technology Development Centers

Development of e-VLBI, in which raw VLBI data are transferred electronically from the stations to a correlator, progressed rapidly. Tsukuba, Kashima, Onsala, and Westford are all, in principle, connected at 1 Gbps, though some issues remain in actually using some of the links at full speed. Wettzell and Kokee are connected at much lower speeds. Data acquired during the daily 1-hour UT1 sessions are transferred electronically to the USNO, USA, correlator (for Kokee-Wettzell data) or to the Tsukuba, Japan correlator (for Wettzell-Tsukuba data). It is anticipated that electronic transfer for these sessions will become routine during 2005.

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.

References

Nothnagel A. (2003) VTRF2003: A Conventional VLBI Terrestrial Reference Frame; In: Proceedings of the 16th Working Meeting on European VLBI for Geodesy and Astrometry, held at Leipzig, May 09–10, 2003, edited by W. Schwegmann and V. Thorandt, Bundesamt für Kartographie und Geodäsie, Frankfurt/Leipzig, 2003, 195–205

Nothnagel A. (2004): Summary of the Fifth IVS Analysis Workshop; In: IVS 2004 General Meeting Proceedings; NASA/CP-2004-212255, 509–513

Dirk Behrend, Axel Nothnagel

3.4.4 International DORIS Service (IDS)

General

The IDS website URL is <http://ids.cls.fr/html/about_ids.html>. 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 in Figure 1. Site logs are available at <http://ids.cls.fr/html/doris/sitelog.html>.

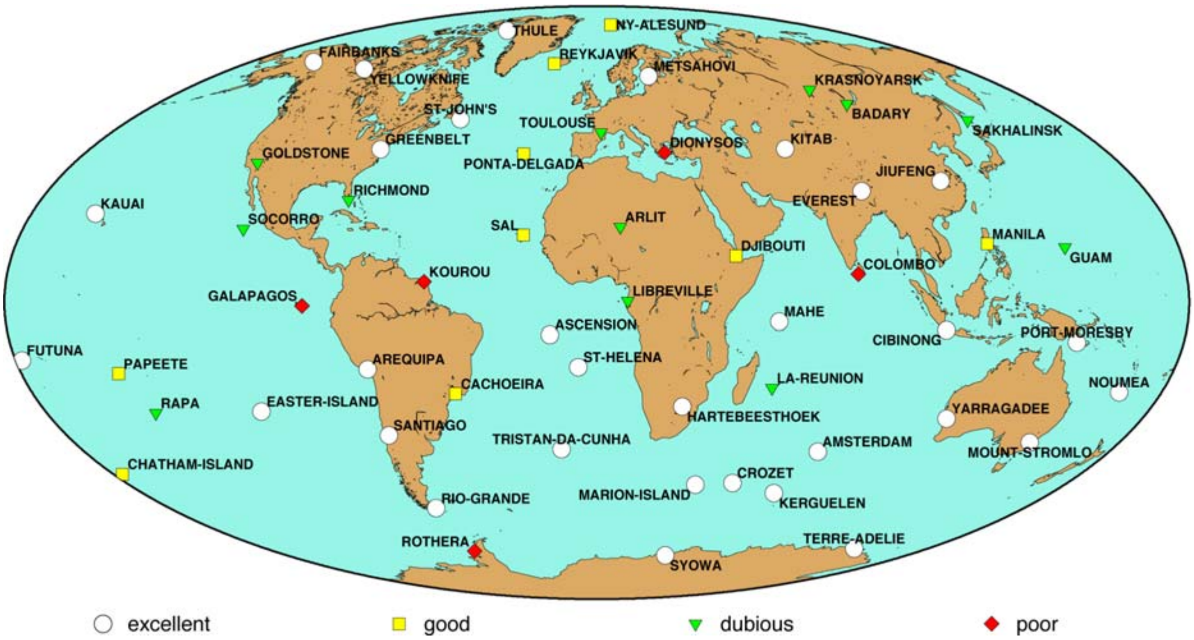

Fig. 1: The DORIS permanent stations and their estimated stability (January 2005)

The stations rejuvenation program initiated in 2000 was continued, as illustrated in Figure 2. In 2004 the following stations were renovated in order to improve the long-term stability of the antenna support:

- Mount Stromlo (Australia)
- Cachoeira Paulista (Brazil)
- Marion Island (South Africa)
- Badary (Russia)
- Yuzhno-Sakhalinsk (Russia)
- Reykjavik (Iceland)

This brings the total number of DORIS stations to 58. At the end of 2004, 41 out of 58 stations (in the permanent orbitography network) are considered to have good or excellent stability.

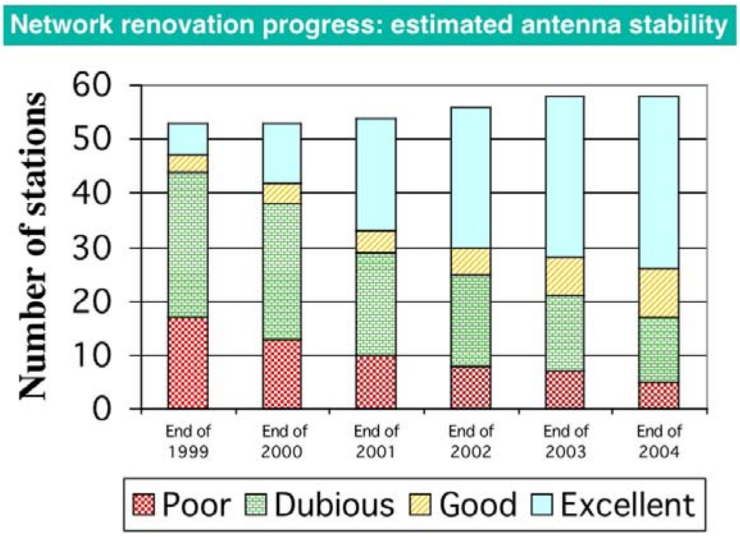

Figure 2: DORIS permanent network renovation

A new station was installed at Belgrano II, an Argentine base in Antarctica, following a joint proposal to the IDS by the Alfred Wegener Institute and the Instituto Antárctico Argentino.

The status of co-locations with currently operating stations of the other techniques contributing to IERS is as follows.

- GPS : 33 sites
- SLR : 8 sites
- VLBI : 7 sites

The following new co-locations were made available in 2004:

- DORIS-SLR tie at Jiufeng measured in December 2003
- DORIS-GPS tie at Yuzhno-Sakhalinsk measured in August 2004
- DORIS-VLBI tie at St-John's measured in 2003

Observing satellites and data flow

Six DORIS-equipped satellites are used: Spot 2, 4 & 5, Topex/Poseidon, Jason 1 and Envisat, with altitudes ranging from 800 to 1300 km. The DORIS receiver on board Topex/Poseidon ceased operation at the end of October 2004, thus ending a more than 12-year service, far beyond the instrument and spacecraft nominal lifetime.

The observations 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 organization of the Data Centers is described at <http://lareg.ensg.ign.fr/IDS/doc/struct_dc.html>.

Several analysis centers routinely analyze the data and provide their products to the data centers, under the SINEX format when applicable. Operational analysis centers are run at CNES/SOD, CNES/SSALTO, IGN-JPL, LEGOS-CLS, UT/CSR and INASAN. Other centers are providing partial results or are still in development: Geoscience Australia, IAA, VUGTK (Prag).

IDS products, contributions to IERS data analyses

As of January 2005, main IDS available products are as follows.

- weekly IGN-JPL time series of terrestrial reference frames (TRF) including daily polar motion contributed to the Combination Pilot Project;
- weekly IGN-JPL time series of station coordinates, TRF translation parameters (geocenter motion) and scale;
- IGN-JPL long-term cumulative solutions,
- monthly LEGOS-CLS time series of station coordinates.

LEGOS-CLS is preparing for the routine submission of weekly time series of terrestrial reference frames (TRF) including daily polar motion to contribute to the Combination Pilot Project.

Analysis Coordination

The Analysis Coordination tasks (<http://lareg.ensg.ign.fr/IDS>) are run jointly by the Analysis Coordinator at IGN/LAREG and the Central Bureau at CLS.

In the context of the DORIS Pilot Experiment, the Central Bureau had initiated in 2002 an Analysis Campaign that focused on time series of station coordinates derived from observations of the Spot 2, Spot 4 and Topex/Poseidon satellites. Five analysis centers participated: IGN-JPL, LEGOS-CLS, INASAN, CNES/SOD, CNES-CLS/SSALTO. The report of this Analysis Campaign is available at <http://lareg.ensg.ign.fr/IDS/events/2002_camp_report.pdf>.

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 is available at <http://lareg.ensg.ign.fr/IDS/events/2003_camp_report.pdf>.

An Analysis Workshop took place in May 2004 in Paris. The discussion topics included operational issues, DORIS orbits and ionospheric parameters, analysis strategies, and reference frame and combination issues. See the contributions at <http://lareg.ensg.ign.fr/IDS/events/prog_2004.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.

Hervé Fagard, Martine Feissel-Vernier

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 2004. 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. It is making available to users different products: 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 and one-day intervals (IERS C02 and C03) 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

During the year 2004 we continued the development of interactive tools, mostly written in PHP language and devoted to the EOP time series analyses. Hereafter we present the main new improvements:

1) Extension of numerical analyses of EOP series to operational series.
2) Implementation of comparison of operational series
3) Densification of some EOP series using their associated rates thanks to the approach of “combined smoothing” developed by Vondrák and Cepek (2000).
4) Dates converter has been set up in the home page, allowing to easily convert civil date to (Modified) Julian Date or inversely.
5) The comparison of EOP changes (1962–2005) with the atmospheric angular momentum can be done in selected frequency ranges by applying Vondrak Filtering.

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

Description of Bulletin B is available in the IERS Explanatory Supplement for Bulletin A and Bulletin B (Gambis and Wooden, 2004). Since formal uncertainties reported by the contributors are often under-estimated, they are calibrated by statistical assessment using the Allan Variance Analysis in order to reflect the real quality of the data (Gray and Allan, 1974; Gambis, 2002). This procedure leads to an optimal weighting of the individual series entering the combinations (Gambis, 2004). Table 1 gives the estimated accuracy with respect to IERS C04 of these series over 2003–2004 after removal of systematic variations, mainly a bias.

Recently the algorithm and Fortran program allowing to compute C04 series have been considerably improved. Presently under test, this new version, using Vondrák Combined Smoothing (Vondrák and Cepek 2000), will be set up during the year 2005.

Table 1: Estimated accuracies of individual solutions entering the combined solutions in 2004

Individual solutions				Estimated uncertainties				
				Time	Terrestrial Pole 0.001"	UT1 (0.0001s)	LOD (0.0001s)	Celestial Pole 0.001"
VLBI – 24 h								
EOP (AUS)	01	R	01	3-4d	0.12	0.04		0.10
EOP (BKG)	03	R	04	1-4d	0.17	0.06		0.12
EOP (GSFC)	04	R	02	1-4d	0.15	0.06		0.11
EOP (IAA)	03	R	04	1-4d	0.14	0.05		0.08
EOP (MAO)	03	R	01	1-4d	0.15	0.05		0.10
EOP (SPBU)	03	R	03	3-4d	0.14	0.05		0.08
EOP (USNO)	04	R	01	1-4d	0.15	0.05		0.10
VLBI – Intensive								
EOP (BKG)	03	R	02	1-3 d		0.13		
EOP (GSFC)	4	R	01	1-3 d		0.12		
EOP (IAA)	03	R	03	1-3 d		0.13		
EOP (SPBU)	02	R	01	1-3 d		0.16		
EOP (USNO)	5	R	01	1-3 d		0.14		
Satellite Laser Tracking								
EOP (ASI)	03	L	02	1d	0.10		0.24	
EOP (CSR)	95	L	01	3d	0.53	0.30		
EOP (DUT)	98	L	01	3d	0.14	0.40		
EOP (IAA)	02	L	1	1d	0.06	0.02*	0.02	
EOP (MCC)	97	L	01	1d	0.30		0.48	
EOP (ILRS)*	5	L	1	1d	0.30		0.40	
GPS								
EOP (CODE)	98	P	01	1d	0.01		0.25	
EOP (EMR)	96	P	03	1d	0.05		0.20	
EOP (ESOC)	96	P	01	1d	0.02		0.03	
EOP (GFZ)	96	P	02	1d	0.01		0.01	
EOP (IAA)	01	P	01	1d	0.04		0.06	
EOP (JPL)	96	P	03	1d	0.04		0.13	
EOP (NOAA)	96	P	01	1d	0.03		0.04	
EOP (IERS)**	95	P	01	1d	0.02	0.20	0.15	

* Since the beginning of 2005, the official combined ILRS solution derived at ASI is used in the combination, replacing the current quick-look individual solutions;

** 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.

Predictions

Different methods are used for prediction of the Earth Rotation Parameters.

Polar Motion

The formalism uses at first a floating period fit (Bevington, 1969) for both the Chandler and annual components estimation over a past time interval of several years. An autoregressive filter is then applied on the short-term residuals series and used for the prediction. The predictions of the celestial pole offsets Dy and De are based on an empirical model (McCarthy, 1996).

Universal Time

The present formalism used is based on the assumption that the long-term fluctuations (annual and semi-annual) of the preceding year are valid over the next few months. For short-term variations prediction, an autoregressive process is used. Table 2 shows the accuracy of the current EOP solutions and also the skills of the predictions.

Table 2: Uncertainty of the current solution and the estimated accuracies of the predictions for horizons of 5 days to 1 year for 2003

Solutions		Terrestrial Pole 0.001"	UT1 0.0001s	Celestial Pole 0.001"
Analysis daily	1-d	0.10	0.20	0.10
Prediction	1-d	0.50	1.40	0.10
	5-d	3.	10.	0.10
	10d	6.	21.	0.10
	30d	12.	38.	0.10
	90d	40.	45.	0.10
	180d	60.	80.	0.10
	1-yr	50.	120.	0.10

Table 3 present statistics concerning the agreement between official combined solutions derived from the Techniques Centres (IGS, IVS and ILRS), namely biases and standard deviations.

Table 4 gives the agreement and consistencies of the IERS C04 solution with two combined solutions obtained by the IERS Rapid Service at USNO (Bulletin A) and the JPL. These values reflect the mean precision reached, i.e. about 0.05 mas for polar motion and 10 microseconds for UT1. The overall accuracy taking into account the consistency between the terrestrial and celestial frames is in the range of 0.1 mas and 20 microseconds, respectively for polar motion and UT1.

Long-term series: C 01 (1846-2003)

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

Table 3: Mean and standard deviation of the differences between various combined techniques solutions and IERS C04 over 2004

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 2004

EOP	Unit	BullA – IERS C04		Comb JPL – IERS C04	
		Mean	Standard deviation	Mean	Standard deviation
X	μas	–115	88	–151	72
Y	μas	70	77	43	66
UT1	μs	4	44	–119	29

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 1960s, new geodetic techniques were used for geodynamics. Now, the global 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 2004. 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).

1962–2004: 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 fields models include the tesseral coefficients C21 and S21. 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 2000 (Shiskin et al. 1965). Figure 1 represents the polar motion over 2001–2003 and the path of the mean pole since 1900. The table is available in IERS Conventions (2003) (McCarthy and Petit 2004) and at the following address: <http://hpiers.obspm.fr/eop-pc/>.

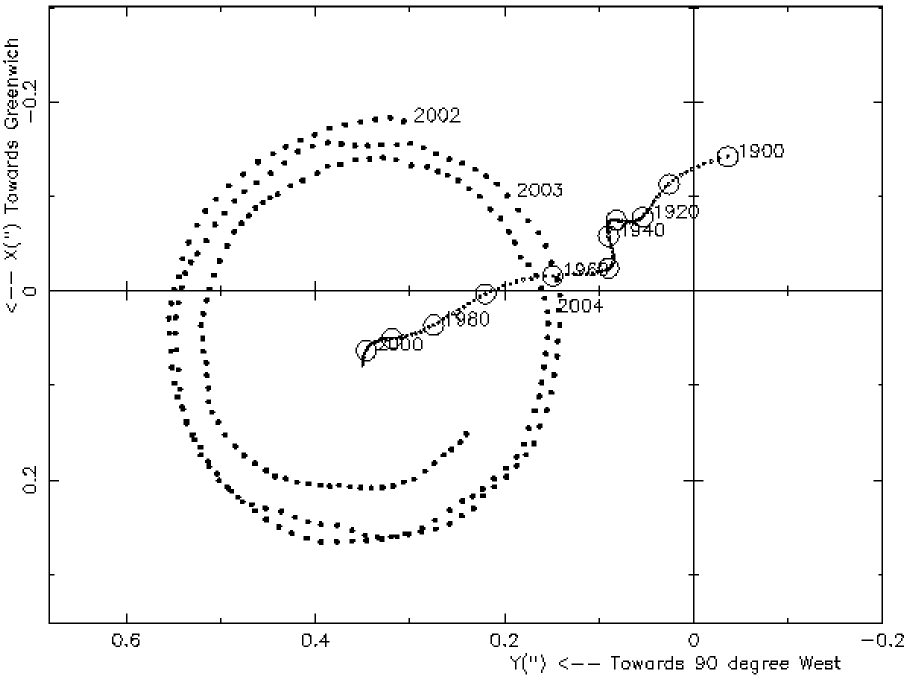

Fig. 1: Mean polar motion (1900–2003) and IERS C04 polhody over 2002–2004.

Normal Point Solutions: C 02 (1962-2003), C 03 (1993-2003)

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, $\delta\psi$, $\delta\varepsilon$), 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 implemented 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
2001–2005	.15	.15	.1	.3	.1

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, called 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. In these approaches, it is essential that the results be optimal for the different techniques before a global solution can be performed.

In order to study the feasibility of such a project, an analysis is performed on an operational basis starting from January 2005. 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 (D. Coulot, P.

Bério), LLR at CNES, Toulouse (R. Biancale) and et l'Observatoire de Paris (G. Francou), VLBI at CNES, Toulouse (R. Biancale) and Observatoire de Bordeaux (P. Charlot). The final combination as well as the validation and various analyses are performed at the Observatoire de Paris starting in January 2005 (T. Carlucci, D. Gambis, G. Francou, N. Capitaine, P. Sillard).

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References

Altamimi Z., Sillard P., Boucher C., 2002: ITRF2000: A new release of the International Terrestrial Reference Frame for Earth Science Applications. *JGR* **107**(B10), 2214, doi:10.1029/2001JB000561.

Altamimi Z., Boucher C., Gambis D., 2005: Long-term Stability of the Terrestrial Reference Frame, *Adv. Space Research*, in press

Anderson P.H., 1995: High-precision station positioning and satellite orbit determination. Ph.D. Thesis, NDRE/publication-95/01094, FFI/ E, Box 25, N-2007, Kjeller, Norway.

Bevington P.R., 1969: Data reduction and error analysis for the physical sciences, McGraw-Hill Book Company, New York, USA.

Biancale R., Lemoine J.-M., Marty J.-C., Capitaine N., Gambis D., Gontier A.-M., Chapront J., Francou G., 1. Exertier P., Coulot D., Soudarin L., Yaya Ph., Charlot P., 2002: GRGS activities on space technique combinations for the adjustment of Earth Orientation Parameters, presented at IERS Workshop, November 2002, Munich, Germany.

Bizouard C., Gambis, D., 2002, Evolution of consistency between EOP series and the international reference, presented at XVIIe General Assembly, April 2002, Nice, France.

Bougeard M., Gambis D., Ray R., 2000: Algorithms for box constrained M-estimation: fitting large data sets with applications to Earth Orientation Parameters series, *Physics and Chemistry of the Earth* **25**, 9–11, pp. 679–685.

Bougeard M.L., Rouveyrollis N., Gambis D., 2002: Comparison study of EOF techniques in the determination of episodic terms of polar motion, *Proc. Journées Systèmes de Référence* 2001 (N. Capitaine, ed.).

Capitaine N. et al. (eds.), 2002: Proceedings of the IERS Workshop on the Implementation of the New IAU Resolutions, *IERS Technical Note* No. 29, BKG, Frankfurt am Main.

Capitaine N., Chapront J., Lambert S., Wallace P.T., 2003: Expressions for the Celestial Intermediate Pole and Celestial Ephemeris Origin consistent with the IAU 2000A precession-nutation model, *Astron. Astrophys.* **400**, 1145–1154.

Eisop E., Gambis D., 1997: The combined solutions of the IERS Central Bureau, *Proc. Journées Systèmes de référence*, Praha, p. 104.

Fedorov E.P., Korsun A.A., Mayor S.P., Pantscheenko N.I., Tarady V.K., Yatskiv, YA. S., 1972: *Dvizhenie polyusa Zemli s 1890.0 po 1969.0.* Naukova dumka, Kiev [English translation of the text available].

Gambis D., 1997: Monitoring Earth Rotation using various techniques: current results and future prospects, *Dynamics and astrometry of natural and artificial celestial bodies, proceedings of IAU Colloquium 165*, I.M. Wytrzyszczak, J.H. Lieske, R.A. Feldman (eds.), Kluwer, Dordrecht, p. 475.

Gambis D. (ed.): IERS Annual Reports for 1998 and 1999, Observatoire de Paris, Paris, France.

Gambis D., 2002: Allan Variance analysis applied to Earth Orientation Analysis, *Adv. Space Research*, **30**/2, 207–212.

Gambis D., 2004: Monitoring Earth Orientation at the IERS using space-geodetic observations., *J. of Geodesy*, **78**, 295–303.

Gambis D., 2005: Earth Orientation Monitoring, State-of-the-art and prospects, *Artificial Satellites, Journal of Planetary Geodesy*, 40, 1, part 3, Earth rotation, 61–69.

Gambis D., Ray J., 2002: Explanatory Supplement for Bulletins A and B, Observatoire de Paris, also available by electronic access (<http://hpiers.obspm.fr/eop-pc>).

Gambis D., Bizouard C., Carlucci T., Jean-Alexis D., 2002: Comparative Study of the EOP Series Derived for the Second IVS Pilot Project, *IVS 2002 General Meeting Proceedings*, N.R. Vandenberg and K.D. Baver (eds.), NASA/CP-2002-210002, pp. 330–334.

Gambis D., Bizouard C., 2003: Consistency evolution between EOP series and reference frames, *Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids*, B. Richter, W. Schwegmann, W.R. Dick (eds.), *IERS Technical Note* No. 30, BKG, Frankfurt am Main, pp. 57–62.

Gray J.E., Allan D.W., 1974: *Proc. 28th Ann. Symp. on Frequency Control*, 243.

Lambert S., Bizouard, C., 2002: Positioning the Terrestrial Ephemeris Origin in the International Terrestrial Reference Frame, *Astron. Astrophys.* **394**, 317–321.

McCarthy D.D., 1996: IERS Conventions, *IERS Technical Note* No. 21, Paris Observatory, France.

McCarthy D.D., Petit, G. (eds.), 2004: IERS Conventions (2003), *IERS Technical Note* No. 32, BKG, Frankfurt am Main (Website: <http://tai.bipm.org/iers/conv2003/conv2003.html>).

Rothacher M., 2002: Future IERS products, Implementation of the IAU 2000 resolutions, *Proceedings of the IERS Workshop on the Implementation of the New IAU Resolutions*, Capitaine et al. (eds.), *IERS Technical Note* No. 29, BKG, Frankfurt am Main, 77–84.

Shiskin J., Young A.H., Musgrave J.C., 1965: The X-11 variant of the Census Method II seasonal adjustment program, *U.S. Dept. of Commerce, Bureau of the Census, Technical Paper No 15.*

Vondrak J., Ron C., Pesek I., Cepek A., 1995: New global solution of Earth orientation parameters from optical astrometry in 1900–1990, *Astron. Astrophys*. 297, 899–906.

Vondrák J., Cepek A., 2000: Combined smoothing method and its use in combining Earth orientation parameters measured by space techniques, *Astron. Astrophys. Suppl. Ser.* **147**, 347–359.

Yaya P., 2001: PhD Thesis, Paris Observatory, October 2001.

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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 & 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 2004.

Operationally, the weighted spline uses as input the epoch of observation, the observed value, and the weight of each individual 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, $\delta\psi$, and $\delta\varepsilon$ values are

Table 1. Estimated accuracies of the techniques in 2004. Units are milliseconds of arc for x, y, $\delta\psi$, $\delta\varepsilon$, 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	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
CSR 3-day SLR	0.43	0.36	0.103*			
DUT daily SLR	0.32	0.33				
IAA daily SLR	0.18	0.18				
MCC daily SLR	0.17	0.15				
GSFC daily VLBI Int			0.025			
SPBU daily VLBI Int			0.022			
GSFC twice-weekly VLBI	0.11	0.09	0.003		0.4	0.1
IAA[2] twice-weekly VLBI	0.10	0.09	0.004		(0.1)	(0.1)
IVS twice-weekly VLBI	0.06	0.07	0.003		0.4	0.1
USNO twice-weekly VLBI	0.10	0.08	0.004		0.4	0.1
IGS daily Final	0.07	0.05				
IGS daily Rapid	0.01	0.02		0.02*		
USNO daily GPS UT*			0.020*			
EMR daily GPS UT*			0.02*			
USNO daily AAM UT			0.013			

*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] IAA VLBI celestial pole offsets are in terms of dX/dY using IAU 2000A Nutation Theory.

computed at the epoch of zero hours UTC for each day. Since the celestial pole offset software is written in terms of $\delta\psi$ and $\delta\varepsilon$, the IAA VLBI dX and dY values are converted to $\delta\psi$ and $\delta\varepsilon$ 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 Center solutions and IERS Bulletin B and C04 EOP solutions for 2004. 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	–0.09	0.11	–0.12	0.12
Y	0.07	0.08	0.07	0.11
UT1–UTC	0.000	0.032	0.001	0.052
Bulletin A Weekly Solution (finals.data)[1]				
X	–0.08	0.10	–0.12	0.11
Y	–0.01	0.08	–0.02	0.11
UT1–UTC	0.008	0.053	0.009	0.067
Bulletin A Daily Solution (finals.daily)				
X	–0.07	0.13	–0.11	0.13
Y	–0.02	0.12	–0.02	0.14
UT1–UTC[2]	–0.011	0.067	–0.010	0.079

[1] Statistics computed over the 7-day combination solution period prior to solution epoch.
[2] Standard deviation computed over entire year, excluding periods with known VLBI intensive data problems and GPS rapid data issues.

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 shows the agreement between the Bulletin A running combination solution and the Bulletin B/C04 series for the entire year. The statistics for the weekly solution are computed from the combination results for the 7-days prior to the solution epoch for each of the 53 weeks. 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.

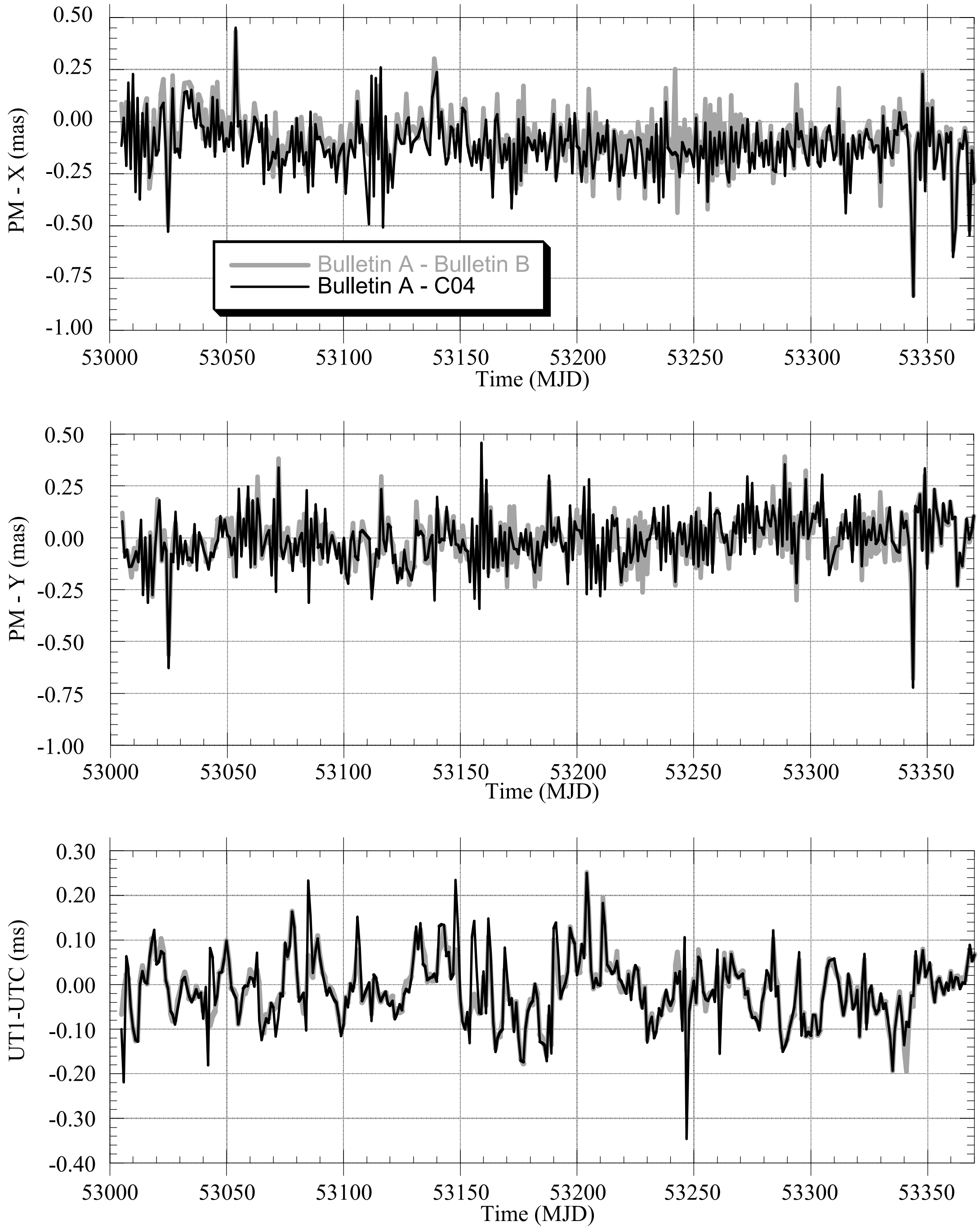

Fig. 1: Differences between Daily Bulletin A Rapid Solutions at each daily solution epoch for 2004 and the Earth Orientation Parameters available in Bulletin B and C04 series produced in March of 2005.

Figure 1 displays the data used in Table 2 for the determination of the Bulletin A daily solution statistics. Our analysis determined that the periods with larger residuals appear to be the result of one or more of the following: large latency of VLBI data, VLBI 24-hour sessions for which a station or two dropped out or had a large number of dropped scans, VLBI intensives with low observation numbers (UT1–UTC only), network problems with respect to obtaining the daily IGS EOP rapid files, or IGS rapid data that caused the UT1–UTC combination to fail. The Centre activities section provides more details. Overall, the agreement between the Bulletin A solutions and the IERS EOC solutions is quite good.

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, 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, $\langle(UT1R–TAI)_{-n}\rangle$ is subtracted from the most recent value, $(UT1R–TAI)_o$

$$(UT1–TAI)_n = 2(UT1R–TAI)_o – \langle(UT1R–TAI)_{-n}\rangle.$$

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.

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 $\delta\psi$ and $\delta\varepsilon$ 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.

Table 3. Standard Deviation of the differences between the Earth Orientation Parameter time series predictions produced by the Bulletin A Daily solutions and the C04 solutions for 2004.

Days in Future	PM–X	PM–Y	UT1–UTC
	mas	mas	ms
1	.46	.39	.129
5	2.26	1.66	.407
10	3.67	2.96	.935
20	6.09	4.77	3.00
40	8.87	6.74	5.43
90	12.7	10.2	10.9

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\varepsilon$ 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 2004 are given in Table 4.

Predictions of UT1–TAI up to 2014 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 given. These are based on analyses of the past performance of the model with respect to the observations.

Table 4. Standard Deviation of the differences between the Celestial Pole Offset time series predictions produced by the Bulletin A Daily solutions and the C04 solutions for 2004.*

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.09	.14	.27	.18
5	.10	.17	.27	.18
10	.12	.17	.28	.19
20	.13	.18	.28	.19
40	.13	.21	.30	.22

*Bulletin B combination used for dX and dY.

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

Centre Activities in 2004

During 2004 a number of changes occurred that affected the performance of IERS Bulletin A. In January a few routines in the combination process required modification. Some of these changes reduced the number of initializations required at the beginning of a new year.

In February biases and rates of the IVS VLBI series were adjusted to reduce their residuals and a library of SOFA routines was added. Unfortunately, the x-component of polar motion was over corrected which introduced a small drift. Shortly after this, new VLBI solutions were released by GSFC and the following week by USNO. The addition of these new solutions obscured the problem which required a couple of weeks to detect and correct. However, by this time a small bias had been introduced into the x-component of polar motion. The bias in the y-component of polar motion between the C04 and the Bulletin A was reduced.

In the April-May timeframe a number of software-related issues became apparent and a major effort was undertaken to update a number of our routines to FORTRAN90. The major enhancement was to shift from explicitly-sized arrays to dynamically-allocated arrays.

In June a sign error was discovered and corrected in the tidal correction algorithm used for GPS data. A new VLBI intensive data set became available from USNO's VLBI analysis group. After a careful evaluation of this data set, it was added to our weekly solution on 4 November. Improved data checks and editing criteria for VLBI were also incorporated into our combination process.

Table 5. Predicted values of UT1–TAI, 2005–2014. 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)
2005	Jan 1	–32.50	.02
	Apr 1	–32.57	.02
	Jul 1	–32.61	.03
	Oct 1	–32.58	.03
2006	Jan 1	–32.62	.04
	Apr 1	–32.67	.04
	Jul 1	–32.69	.06
	Oct 1	–32.72	.07
2007	Jan 1	–32.76	.08
	Apr 1	–32.8	.1
	Jul 1	–32.9	.2
	Oct 1	–32.9	.2
2008	Jan 1	–33.0	.3
	Apr 1	–33.0	.4
	Jul 1	–33.1	.5
	Oct 1	–33.2	.6
2009	Jan 1	–33.4	.8
	Apr 1	–33.8	.9
	Jul 1	–33.7	1.
	Oct 1	–34	1.
2010	Jan 1	–34.	1.
	Apr 1	–34.	1.
	Jul 1	–34.	1.
	Oct 1	–34.	2.
2011	Jan 1	–34.	2.
	Apr 1	–34.	2.
	Jul 1	–34.	2.
	Oct 1	–34.	2.
2012	Jan 1	–34.	2.
	Apr 1	–34.	2.
	Jul 1	–34.	3.
	Oct 1	–34.	3.
2013	Jan 1	–34.	3.
	Apr 1	–34.	3.
	Jul 1	–34.	3.
	Oct 1	–34.	3.
2014	Jan 1	–34.	4.

In November the software was modified to handle the VLBI K-series and the non-standard I-series intensives. The non-standard I-series involving the Svetloe station required special editing until the VLBI analysis centers were able to provide a new global solution for the station position.

On 20 and 27–28 November and 4–5 December, the inclusion of the IGS Rapid solution resulted in a bad combination solution for UT1–UTC. Therefore, the IGS Rapid solution was removed on those dates and the polar motion solution on those days had larger than normal errors.

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, $\delta\psi$ and $\delta\varepsilon$ from GSFC VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from USNO VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ 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 GPS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Rapid Service/Prediction Centre; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ 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, $\delta\psi$ and $\delta\varepsilon$ 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

References

Johnson, T.J, 2002, Rapid Service/Prediction Centre, *IERS Annual Report 2001*, 47–55.

Johnson, T.J, Luzum, B.J., and Ray, J.R., 2005, Improved near-term UT1R predictions using forecasts of atmospheric angular momentum, *J. Geodynamics*, **39**(3), 209.

Luzum, B.J., Ray, J.R., Carter, M.S., and Josties, F.J., 2001, Recent Improvements to IERS Bulletin A Combination and Prediction, *GPS Solutions,* **4**(3), 34.

McCarthy, D.D. and Luzum, B.J., 1991a, Combination of Precise Observations of the Orientation of the Earth, *Bulletin Geodesique,* **65**, 22.

McCarthy, D.D. and Luzum, B.J., 1991b, Prediction of Earth Orientation, *Bulletin Geodesique,* **65**, 18.

McCarthy, D.D. (ed.), 1996, IERS Conventions (1996), *IERS Technical Note* No. 21, Paris Observatory, France.

McCarthy, D.D. and G. Petit (eds.), 2004, IERS Conventions (2003), *IERS Technical Note* No. 32, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt, Germany.

Wooden, W.H., Johnson, T.J., Carter, M.S., and Myers, A.E., 2004, Near Real-time IERS Products, *Proc. Journees Systemes de Reference Spatio-Temporels*, St. Petersburg, 22–25 Sept 2003,160–163.

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

3.5.3 Convention Centre

The Conventions Center is provided jointly by the Bureau International des Poids et Mesures (BIPM) and the U.S. Naval Observatory (USNO). Beginning in September, 2003, for one year, the BIPM provided for a visiting scientist position, occupied by Jim Ray, from the U.S. National Geodetic Survey. In 2004, the work accomplished or in progress is the following.

1. Final edition of the IERS Conventions (2003)

The electronic edition of the IERS Conventions (2003) was released in November 2003 (see <ftp://maia.usno.navy.mil/conv2003/> and <ftp://tai.bipm.org/iers/conv2003/>), and the corresponding paper edition was released in 2004 as IERS Technical Note 32.

The electronic release was accompanied by a questionnaire to the general IERS community. Although less than ten filled questionnaires were returned, several replies contained detailed answers and suggestions, as summarized below: (i) On the value of the IERS Conventions (2003), the structure and overall quality were generally considered fine but the delay of publication was generally considered to be a problem. Some inconsistencies / deficiencies were pointed out (see next section). (ii) On the future IERS Conventions, there was unanimous agreement that any update should be by discrete increments (e.g. yearly) even though some continuously updated version may be available unofficially in the mean time. It was also recommended to continue with a paper version. To gather new and updated information, several techniques were proposed including a call to the general community, assembling groups of experts, and using the existing technique services. (iii) Finally on the interactions between the Conventions Center and the rest of the IERS, it was recommended to create an Advisory Board. The importance of a formal approval of any update of the Conventions was stressed, although the body for approval was sometimes discussed (Advisory Board or IERS Directing Board). It was recommended that the routine interactions with other groups should be enhanced, although no precise method was stated for this purpose.

2. Preparation for future versions of the Conventions

The IERS Conventions Center intends to provide updated versions of the Conventions in electronic form, after proper approval of the IERS Directing Board. These editions will be clearly marked regarding the date of their electronic publication. In the mean time, work on interim versions will also be 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.

2.1 Electronic tools

New tools have been developed to help in the process of updating the IERS Conventions. A new web site (<http://tai.bipm.org/iers/>) including a discussion forum (<http://tai.bipm.org/iers/forum>) has been installed at the BIPM. The web site includes new pages for the Conventions updates (<http://tai.bipm.org/iers/convupdt/convupdt.html>), which are continuously modified, as required by changes in the texts, routines or data files. However, the site is expected to retain the complete history of updates thus ensuring the archiving and the traceability of the changes. It should also contain new products such as numerical examples or explanatory material, as they become available. The discussion forum is for users to offer their comments, criticism, and suggestions regarding the update of the IERS Conventions. It is organized in themes following the present structure of the IERS Conventions (2003). Reading the contributions is open and anonymous but, to post a contribution, it is necessary to be registered. Registration is mandatory so that the forum administration can identify participants, but it is a very simple procedure and the only requirement is to accept the terms of the forum, which is designed only for "discussions on the IERS Conventions".

2.2 Technical topics

Corrections to the IERS Conventions (2003) are already under way, starting with typos that were discovered after the official release and with some limited text changes that improve the readability of the document (<http://tai.bipm.org/iers/convupdt/convupdt.html>). More technical or complex issues are first debated, e.g. on the discussion forum (<http://tai.bipm.org/iers/forum>), numerical examples and test cases are proposed, and 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. To be considered in updating IERS Conventions (2003) are, for example, models for sub-daily effects concerning geocenter motion due to ocean tides and atmosphere pressure loading, revision of models for tidal effects on Earth orientation parameters, etc. 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.

2.3. Advisory Board for the IERS Conventions update

Following the request of the IERS Directing Board at its 39th meeting, the Conventions Center has set-up an "Advisory Board for the

IERS Conventions update”. The board will advise the Conventions Center in its work of updating the Conventions, review and propose directions to the Conventions Editorial Panel, and recommend new official updates for approval. It should represent the approach of users based on their needs and experience. The Board’s chairman is named by the IERS Directing Board and its membership includes one representative from each Technique Center and each Product Center, the IERS Analysis Coordinator, and additional members proposed by Technique Centers or Product Centers. As of February 1, 2005, the board has been established by the IERS DB under the chairmanship of Jim Ray.

Gérard Petit, Dennis D. McCarthy

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 Working Group on the Reference System. 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

The process of maintenance and extension of the ICRF involves the examination and validation of individual reference frames contributed by various international organizations. During 2004, four individual celestial reference frames obtained from VLBI analysis have been validated by comparison with ICRF-Ext.1.

The reference frames analysed

RSC (AUS) 04 R 01 is the extragalactic celestial frame calculated at Geoscience Australia with VLBI observations acquired in the period April 1980 – May 2004. OCCAM 6.1 software has been used for the solution. The orientation of the celestial frame has been defined through no-net-rotation constraints to the positions of 207 ICRF defining sources. IERS 1996 and MHB2000 have been adopted as the a priori precession and nutation models respectively. Tropospheric gradients have been adjusted in the solution.

RSC (BKGI) 04 R 01 is the extragalactic celestial frame calculated by the Federal Agency for Cartography and Geodesy and the Geodetic Institute of the University of Bonn, in Germany. The software used for the solution is CALC 9.13, SOLVE release 2004.03.18. The celestial reference frame has been oriented by a no-net-rotation constraint to the positions of the 212 defining ICRF sources. The time span of the observations used in the solution is January 1984 – March 2004. The a priori precession and nutation models are both IERS 1996. Tropospheric gradients have been adjusted in the solution.

RSC (CGS) 04 R 01 is the extragalactic radio source catalogue produced by the Space Geodesy Centre in Matera, Italy from observations in the period April 1980 – October 2003. The software used is CALC 9.12 SOLVE release 2002.10.04, SOLVE revision 2002.10.11. The celestial frame has been oriented by a no-net-rotation imposed to the positions to 141 ICRF defining sources. The a priori precession and nutation models are both IERS 1996. Tropospheric gradients have been adjusted in the solution.

RSC (GAOUA) 03 R 01 is the extragalactic celestial frame from the Main Astronomical Observatory of the National Academy of Sciences of Ukraine, evaluated from observations acquired in the period August 1979 – September 2003. The software used is SteelBreeze-2.0.2. The orientation of the celestial frame has been made by no-net-rotation constraints to 23 ICRF defining sources. The IAU-2000A precession-nutation has been chosen as a priori model for the celestial pole position. Tropospheric gradients have been adjusted in the solution.

Table 1 gives the characteristics of the frames analysed. Four categories of sources appear in the table: *defining*, *candidate* and *other* sources correspond to the classification of ICRF sources (Ma and Feissel, 1997; Ma et al., 1998); *new* are the sources added in ICRF-Ext.1; *additional* represents sources not present in ICRF-Ext.1 but observed in other VLBI programs. 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) 04 R 01	571	202	0.13	247	0.18	4	0.25	56	0.20	62	0.36	–81;+84
RSC (BKGI) 04 R 01	668	207	0.07	218	0.07	101	0.03	45	0.12	97	0.23	–81;+84
RSC (CGS) 04 R 01	554	183	0.05	196	0.05	98	0.02	41	0.08	36	0.09	–80;+84
RSC (GAOUA) 03 R 01	1571	211	0.09	244	0.12	101	0.04	51	0.14	964	0.49	–81;+86

Comparison of individual celestial frames to ICRF-Ext.1

The catalogues listed in Table 1 have been compared to ICRF-Ext.1. The algorithm of comparison is the one developed and currently used at the ICRS Centre. 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_a is a slope in right ascension as a function of the declination, D_d is a slope in declination as a function of the declination, B_d is a bias between the principal plane of the frame and that of ICRF-Ext.1.

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

Under the hypothesis that ICRF-Ext.1 is free from deformations, the systematic effects detected in the comparisons should be interpreted as deformations in the individual frames.

Defining sources common to each individual frame and ICRF-Ext.1 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.

In the individual frames, formal uncertainties in radio source positions smaller than 0.01 mas were set to this value for the assignation of weights. The fitted parameters allow the transformation of coordinates in the individual frames into ICRS. Radio sources with residuals higher than 2.5 the rms residual of the fit are considered as outliers, and consequently deweighted.

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 rms and the weighted mean residuals.

Table 2: Relative orientation between individual frames and ICRF-Ext.1. 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) 04 R 01	202	–24.02±19.39	+49.64±19.17	–3.67±24.91
RSC (BKGI) 04 R 01(1)	207	–3.61±17.86	–19.19±17.75	–32.28±22.95
RSC (CGS) 04 R 01(2)	183	+16.46±22.49	+38.52±22.35	+7.44±30.67
RSC (GAOUA) 03 R 01	211	+13.70±18.63	+39.16±18.52	–21.72±23.87

(1): one source has been deweighted
(2): four sources have been deweighted

Table 3: Slopes and biases evaluated in the comparisons between VLBI individual reference frames and ICRF-Ext.1. D_α, D_δ are the slopes in right ascension and declination respectively, B_δ is the bias in declination; units are µas/deg for the slopes, µas for the bias.

Frame	N	D_α	D_δ	B_δ
RSC (AUS) 04 R 01	202	–1.79±0.78	+0.10±0.42	+15.32±21.26
RSC (BKGI) 04 R 01(1)	207	–0.95±0.73	–0.81±0.38	+19.88±18.65
RSC (CGS) 04 R 01(2)	183	–0.73±1.01	–0.85±0.56	+34.96±27.08
RSC (GAOUA) 03 R 01	211	–0.84±0.76	–0.43±0.39	–8.47±19.40

(1): one source has been deweighted
(2): four sources 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) 04 R 01	–2.18	–3.68	257.73
RSC (BKGI) 04 R 01	–6.73	+0.89	239.13
RSC (CGS) 04 R 01	+0.43	+2.58	277.89
RSC (GAOUA) 03 R 01	–9.47	–2.24	252.37

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 50 µas, and their uncertainties indicate that, after rotation, the inconsistency between the directions of the axes is at most 30 µas.

There is no evidence of deformations in the coordinates depending on the declination (see values of D_α, D_δ in Table 3); the principal planes of some of the individual frames are biased with respect to that of ICRS, this being the case of RSC (CGS) 04 R 01 (+34.96 µas), and with smaller amplitude, of RSC (BKGI) 04 R 01 and RSC (AUS) 04 R 01. The values of r_a and r_d in Table 4 indicate that the model represents well the inconsistencies between the orientations of frames at a level of 10 µas or better.

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Investigation of future realizations of the ICRS

Involvement by ICRS Centre personnel in the celestial reference frame VLBI program continued in 2004, 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. 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 2004, 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 2004. 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) 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 2004, 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 2004 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. Conclusion of the 8 month OBSS concept study was expected to continue into early 2005.

Ralph A. Gaume, Alan L. Fey, Norbert Zacharias, David A. Boboltz

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 2004. 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 2004, six VLBA RDV experiments were observed.

VLBA experiment RDV45 (2004JUL14) was calibrated and imaged, adding 160 (80 S-band; 80 X-band) images to the Radio Reference Frame Image Database including images of 11 sources (0316+413, 0426+273, 0602+673, 0620+389, 0656+082, 1030+074, 1226+023, 1240+381, 1417+385, 1738+499, 2235+731) not previously imaged. Unlike previous RDV experiments, the data from the geodetic antennas were flagged before processing leaving only the data obtained by the VLBA. This was done in an attempt to reduce the amount of time required to image these experiments by decreasing the amount of data actually used for imaging. The resultant images are essentially VLBA only, but in some instances have lower resolution due to the sub-netting of the array during the RDV observations. A comparison of the angular resolution of the images with previous experiments showed that on average the resolution of the RDV45 images is about a factor of 1.6 times worse than for a full RDV experiment and about a factor of 1.1 times worse than for a VLBA only experiment (i.e. a VLBA experiment with no sub-netting). The consensus opinion reached was that the resulting lower resolution images would hinder structure analysis. Future RDV experiments will be processed with all available data.

VLBA High Frequency Imaging

VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2004. 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 2004, two VLBA high frequency experiments (BL115B and BL115C) 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 $\delta = -20^\circ$.

VLBI images for a total of 69 Southern Hemisphere ICRF sources at a frequency of 8.4 GHz using the Australian Long Baseline Array were published by Ojha et al. (2004) and added to the Radio Reference Frame Image Database. The images were used to calculate a core fraction, i.e., the ratio of core flux density to total flux density, for all observed sources. The resulting distribution, with a mean value of 0.83, suggests that most sources are relatively compact. However, just over half the observed sources show significant extended emission in the form of multiple compact components. Images for an additional 60 sources have been made and are being prepared for publication.

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 3285 VLBA images of 463 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 783 images of 231 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/>.

A recent addition to the RRFID are Australian Long Baseline Array (LBA) images of 69 southern hemisphere ICRF sources at a radio frequency of 8.4 GHz.

Quantifying Source Structure

The images from the RRFID can be used to classify the sources in terms of their suitability for astrometric use based on their spatial compactness. The CLEAN component model from an image is used to calculate the visibility amplitude, $V(r, \varphi)$, in the u,v plane at 24 equally spaced baseline position angles, φ, spanning 180° and at 300 equally spaced u,v radii, r, (i.e. baseline lengths) ranging from zero to one Earth diameter.

The visibility amplitude is then averaged over baseline position angle at each u,v radii and then normalized by the zero spacing amplitude. The result is an estimate, $V(r)/V(0)$, of the “average” visibility amplitude change as a function of baseline length, r.

The next step is to calculate the standard deviation, $\sigma_V(r)$, over all baseline position angles, φ, for each u,v radii and then divide $\sigma_V(r)$ by $V(r)$ at each u,v radii. The result is a normalized estimate, $\sigma_V(r)/V(r)$, of the azimuthal asymmetry of the source, i.e. if the source is mostly circular, then $\sigma_V(r)/V(r)$ at all baseline lengths, r, will be small. If the source is highly elliptical, then $\sigma_V(r)/V(r)$ will become increasingly larger with increasing baseline length.

Finally, we calculate an estimate of the radio astrometric quality of the observed sources. For each observed source, a score is tabulated based on the following (higher scores are better):

- **compactness**: range [0 – 20], i.e., $20\times[V(r_1)/V(0)]$ where r_1 is the u,v radius at which $V(r)/V(0)$ reaches a minimum ($r_1 \le r_x$)
- **asymmetry**: range [0 – 40], i.e., $40\times[1-\sigma_V(r_2)/V(r_2)]$ where r_2 is the u,v radius at which $\sigma_V(r)/V(r)$ reaches a maximum ($r_2 \le r_x$)
- **baseline**: range [0 – 40], i.e., $40\times[r_x/r_{max}]$ where r_x is the u,v radius at which the normalized “average” visibility and its normalized variation first intersect and r_{max} is the maximum u,v radius

The last step is to sum the score for each source. The result is an estimate of radio astrometric quality, Q, and ranges from zero (for the worst astrometric sources) to one hundred (for the best astrometric sources).

Examples of $V(r)/V(0)$ and $\sigma_V(r)/V(r)$ calculated at an observing frequency of 8.4 GHz for several simple source models are shown in Figure 1. An example for the source 0138–097 at epoch 2004 Feb 15 is shown in Figure 2.

Initially applied to the high frequency (K/Q-band) data, the method has not yet been applied to the study of ICRF sources at the standard S/X frequencies.

Alan L. Fey, David A. Boboltz

Impact of the stability of the VLBI celestial reference frame on the determination of the sidereal orientation of the Earth

Following studies of the stability of radio source coordinates, Feissel-Vernier et al. (2005) studied the influence of the effective celestial reference frame on the derived precession, nutation and universal time. They showed that taking the most stable sources as the basis for defining the celestial reference frame orientation and treating the most unstable sources as arc sources improves the reference frame internal consistency at the level of 30% in the variance of source declinations. As a result, the determination of precession

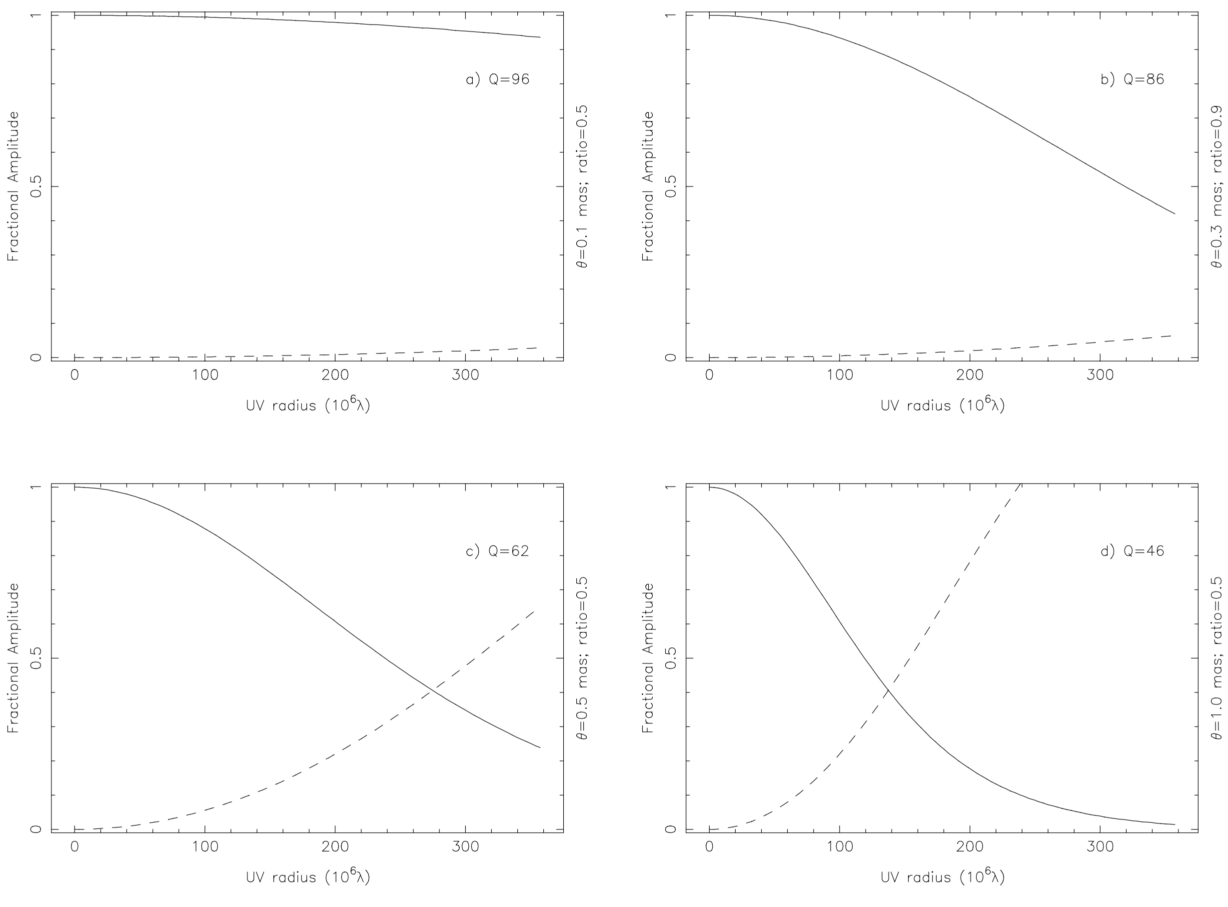


Fig. 1: Normalized "average" visibility, V (r)/V (0) (solid line), and its normalized variation, σ_V (r)/V (r) (dashed line), calculated at an observing frequency of 8.4 GHz. Source models are single Gaussian components with a) angular size, θ = 0.1 mas, axial ratio, R = 0.5; b) θ = 0.3 mas, R = 0.9; c) θ = 0.5 mas, R = 0.5; d) θ = 1.0 mas, R = 0.5. Q is an estimate of the radio astrometric quality which ranges from zero (for the worst astrometric sources) to one hundred (for the best astrometric sources).

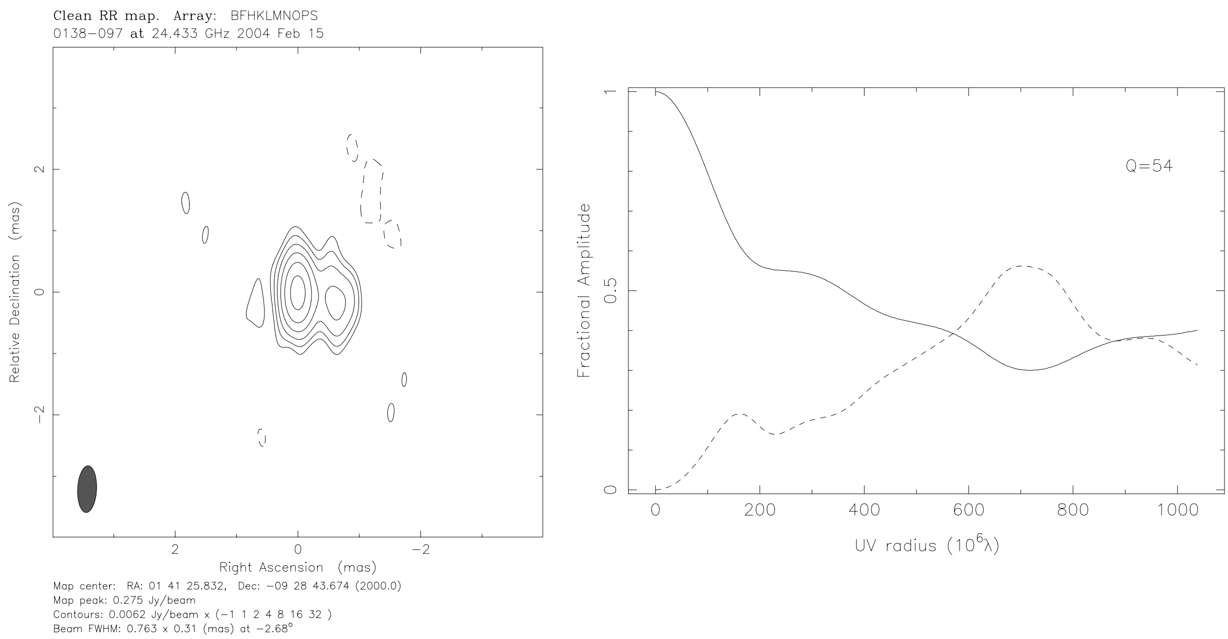


Fig. 2: Contour plot of the radio emission at K-band (24 GHz) from the source 0138–097 at epoch 2004Feb15; Right panel: *Normalized "average" visibility, V (r)/V (0), (solid line) and its normalized variation, σ_V (r)/V (r), (dashed line) for the same source.*

and nutation components is affected at various levels, depending on their frequency. In the seasonal and FCN frequency band, the effect is small in the 1980s and negligible in the 1990s. In the two- to three-year frequency band, it was shown that, even when considering the most stable sources, source instabilities may mimic transient oscillations with an amplitude up to 20 µas. For what concerns the principal term of nutation, the actual departure of VLBI results with the IAU2000 model may reach 50 µas in $\Delta\varepsilon$ and 320 µas in $\Delta\psi$. The latter discrepancy is larger than the 80 µas discrepancy mentioned by the authors of the IAU2000 Nutation model. The influence on the determination of the precession correction and the secular obliquity rate is lower than 10 µas. The precession correction departure from the IAU2000 model excluding the unstable sources is quite larger than that based on all sources. This discrepancy is not modified by the source instability effect. Finally, the departures from the IAU2000 values stay around 50 µas/year in precession and 30 µas/year in obliquity rate. The contribution of the instability of the right ascensions to the instability of the VLBI-derived UT1 was found to stay under one microsecond at J2000.0 and 0.5 µs/year, for both the conventional and proposed source selections. A possible common effect in right ascensions, with a period of six years and an amplitude of 15 µas, is suggested by the analysis of the use of the proposed source selection. Because of converging evidences about the improvement of the internal consistency of VLBI-derived celestial reference frames brought by the consideration of source stability, we suggest that future investigations of precession and nutation and sidereal time of the global Earth take full account of this new aspect of the VLBI data.

Martine Feissel-Vernier

Maintenance of the link to the Hipparcos catalog

During the reporting period (2004) progress has been achieved at USNO in 4 areas related to the maintenance of the Hipparcos link: UCAC project (current epoch observing and early epoch data), the extragalactic link, and URAT.

All-sky coverage was reached in May 2004 with the USNO CCD Astrograph. The last deep CCD fields were taken in December 2004 with the KPNO 0.9-meter telescope and parallel observing with the astrograph. This concludes the observational part of the UCAC project. By end of 2004 about 50% of the raw pixel data were loaded to RAID disk space in preparation for a final reduction of the UCAC data. UCAC3, the final catalog, will be released by mid 2006 at earliest. Measuring of Hamburg Zone astrograph and USNO Black Birch plates continued on StarScan (USNO plate measuring machine). These data will provide the first epoch for several million of stars to 14th magnitude, as part of UCAC3.

Deep CCD images of ICRF optical counterparts where obtained in a total of 25 observing runs at KPNO and CTIO between December 1997 and December 2004. In October 2004 first results were presented at the Lowell, Flagstaff, AZ astrometry meeting. For the first time the dedicated astrograph wide-field observations taken in parallel, providing the secondary reference stars for the link. A large fraction of the 16 sources observed in the first 2 nights of the June 2001 KPNO 2.1m run show (optical-radio) position offset errors in the 10 to 20 mas range, better than anything else achieved to date.

Monitoring of a sample of 12 ICRF optical counterparts continued at the Naval Observatory Flagstaff Station (NOFS) 1.55-meter telescope. This effort is part of the SIM preparatory science for the celestial reference frame key project (K. Johnston, PI).

Optical design studies matured during 2004 for the USNO Robotic Astrometric Telescope (URAT). This will be a dedicated 0.85-meter aperture, 3-degree wide-field telescope for an all-sky survey to 20th magnitude with a goal of 5 to 10 mas positional errors on the HCRF for the 14th to 18th magnitude range. This telescope will be capable of directly linking to ICRF optical counterparts and to bright Hipparcos stars with special observing procedures. A detector development (large monolithic chip) was funded through a U.S. government Small Business Innovation in Research (SBIR) grant. The goal for first light is 2007.

Norbert Zacharias, Alan L. Fey, David A. Boboltz

Linking the ICRF to frames at various wavelengths

The number of recorded quasars at optical wavelengths has noticeably increased in the recent years, reaching the number of 48921 objects in a compilation of various catalogues (Véron-Cetty and Véron, 2003). Therefore, following the cross-identification between the above catalogue and the ICRF (see IERS Annual Report, 2003) showing that roughly 67% of the quasars belonged to the two catalogues, some photometric and astrometric properties of the cross-identified objects could be obtained. They show in particular that the quasars of the ICRF have been chosen so that their flux at 6cm is ranged for a large proportion between 0.5 Jy and 1.5 Jy, whereas the peak for the quasars of the Véron-Cetty and Véron compiled catalogue (quoted in the following as VCV catalogue) is roughly 5.0 Jy. Concerning the V-magnitudes of the objects, the histogram shows clearly a peak in the number of ICRF quasars between V = 18.0 and V = 18.5 whereas the majority of objects of the VCV catalogue is ranged between V = 19.0 and V = 20.5. Other histograms concerning the red-shifts show that ICRF contains proportionally much more objects with rather low red-shifts (more than 50% of quasars with $z < 1.5$) in comparison with VCV objects, for which the majority of quasars corresponds to the zone $1.0 < z < 2.5$.

Jean Souchay

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

The dynamical reference frame is materialized by the dynamical ecliptic and equinox (epoch J2000.0) related to the orbit of the Moon through the ephemerides of the lunar solution ELP (Chapront-Touzé M. and Chapront J.). The analysis of the LLR observations enables the orientation of dynamical ecliptic and equinox of J2000.0 with respect to ICRS.

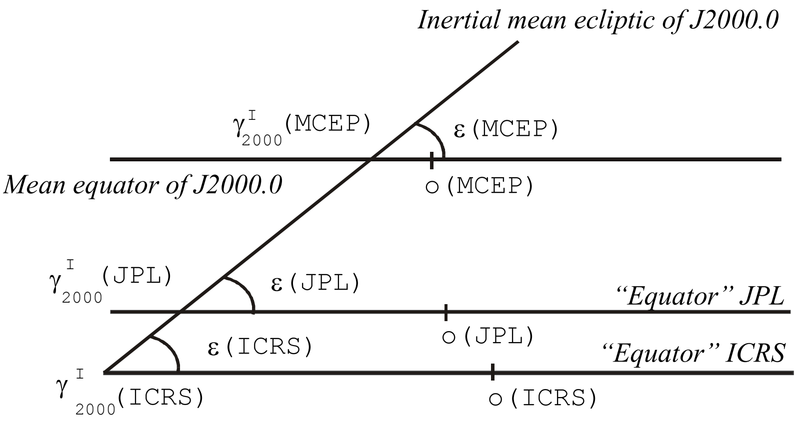
The orientation of the dynamical ecliptic reference frame can be also obtained with respect to the reference frame linked to the mean Celestial Ephemeris Pole (CEP), noted here MCEP.

Using the lunar ephemerides produced by the Jet Propulsion Laboratory (JPL) numerical integrations considered as ‘observational models’ instead of the LLR data, the dynamical reference frame can also be linked to the reference frames defined by these JPL numerical integrations (as DE403 or DE405).

The basic definitions are (see the figure) :

(R)	Equatorial reference frame (ICRS, MCEP, JPL),
γ^I_{2000}(R)	Ascending node of the ‘inertial’ mean ecliptic J2000.0 on the equator of (R),
o(R)	Origin of right ascensions on the equator of (R),
ε(R)	Inclination of the inertial mean ecliptic to the equator of (R),
φ (R)	Arc between o(R) and γ^I_{2000} (R) on the equator of (R),
ψ(R)	Arc between γ^I_{2000} (ICRS) and γ^I_{2000} (R) on the mean ecliptic of J2000.0.

Remark : $\gamma_I^{(MCEP)}$ is named the 'inertial' dynamical mean equinox of J2000.0; the separation from $\gamma_I^{(MCEP)}$ to the 'rotational' dynamical mean equinox of J2000 $\gamma_R^{(MCEP)}$ is 93.66 mas.



The evaluation of the angles $\varepsilon(R)$, $\varphi(R)$ and $\psi(R)$ are involved in the transformation of the rectangular coordinates of the LLR stations in the terrestrial reference frame to the celestial equatorial coordinates at the epoch J2000.0 taking into account the polar motion, the Earth rotation and the orientation of the celestial pole (precession-nutation matrix).

This transformation has been realized according to the lunar solution which results from weighted fits of the semi-analytical theory ELP of the orbital motion of the Moon to the LLR observations provided between 1970 and 2004 by the LLR stations: 9361 from Grasse (Observatoire de la Côte d'Azur, France), 6920 from Fort-Davis (McDonald Observatory, Texas) and 482 from Manui (Haleakala Observatory, Hawai).

The position of the inertial dynamical ecliptic of J2000 with respect to the ICRS is defined by the angles $\varepsilon^{(ICRS)}$ and $\varphi^{(ICRS)} = o^{(ICRS)}\gamma_I^{(ICRS)}$. In this case, 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).

The position of the inertial dynamical ecliptic of J2000 with respect to the MCEP is defined by the angles $\varepsilon^{(MCEP)}$, $\varphi^{(MCEP)} = o^{(MCEP)}\gamma_I^{(MCEP)}$ and $\psi^{(MCEP)} = \gamma_I^{(ICRS)}\gamma_I^{(MCEP)}$. In this case, the precession-nutation matrix is provided by analytical solutions.

The comparison between the ephemerides of the lunar solution ELP and the JPL ephemerides DE403 and DE405 enables the evaluation of the angles $e^{(JPL)}$, $j^{(JPL)}=o^{(JPL)}g_I^{(JPL)}$ and $y^{(JPL)}=g_I^{(ICRS)}\ g_I^{(JPL)}$.

The values of these angles are given in the following table.

Frame (R)	ε – 23°26'21"	φ (")	ψ (")
ICRS	0.41128 ± 0.00009	–0.05419 ± 0.00009	
MCEP	0.40585 ± 0.00009	–0.01410 ± 0.00011	0.0440 ± 0.0002
DE403	0.40928 ± 0.00001	–0.05294 ± 0.00001	0.0041 ± 0.0004
DE405	0.40960 ± 0.00001	–0.05028 ± 0.00001	0.0055 ± 0.0003

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.

The LLR analysis give also a determination of the correction Δp to IAU 1976 precession constant. The value obtained with the LLR data collected from 1970 to 2004 is :

$$\Delta p = -3.07 \pm 0.04 \text{ mas/yr}$$

Orbital parameters of the Moon and of the Earth-Moon barycenter have also been fit after comparison between ELP model and LLR data, in particular the tidal component of the secular acceleration of the lunar longitude Γ which is related to a decrease in Earth's rotation rate and an increase of the length of the day. The last determination is:

$$\Gamma = -25.858 \pm 0.003 \text{ "/cy}^2$$

Jean Chapront, Gérard Francou, Sébastien Bouquillon

Link to the solar system dynamical reference frame through pulsar analysis

Pulsar timing observations at the Nançay's radiotelescope have been carried out intensively during the whole year 2004, and specific studies have been devoted to the link between a rigid system related to the pulsars and the dynamical reference frame materialized by the ecliptic. As a first step we have studied the influence of the ephemerides of the solar system used in the reductions (to determine the position of the Earth on its orbit), on the positions of the pulsars themselves. A preliminary test (Souchay and Cognard, 2005) was done starting from a set of 5 pulsars (PSR1821–24, PSR1937+21, PSR1855+09, PSR0613–02 and PSR1643–12). The choice was done between three different kinds of ephemerides of the JPL (Jet Propulsion Laboratory), that is to say DE200, DE405 and DE407. We showed that although the equatorial coordinates of the pulsars were highly dependent on the ephemerides used, the uncertainties on the angular arcs between the pulsars were far smaller, by one or two orders, reaching for some of them the sub-milliarcsecond level. We schedule to keep on this kind of analysis with a larger set of 25 pulsars observed on a regularly basis. Our hope is to construct an astrometric pulsar catalogue in the near future, based on the arcs inter-pulsars and nearly unsensitive to the ephemerides used.

Ismael Cognard, Jean Souchay

Staff

Gaume	Ralph	Director	(USNO)
Souchay	Jean	Co-director	(OP)
Arias	Felicitas	Assoc. Astronomer	(BIPM / OP)
Boboltz	David	Astronomer	(USNO)
Bouquillon	Sébastien	Post-doc	(OP)
Chapront	Jean	Astronomer	(OP)
Chapront-Touzé	Michelle	Astronomer	(OP)
Cognard	Ismaël	Astronomer	(LPCE Univ. Orléans)
Feissel-Vernier	Martine	Astronomer	(OP)
Fey	Alan	Astronomer	(USNO)
Francou	Gérard	Astronomer	(OP)
Gontier	Anne-Marie	Astronomer	(OP)
Zacharias	Norbert	Astronomer	(USNO)

References

Chapront, J., Chapront-Touzé, M., 1997: Lunar motion, theory and observations, *Celest. Mech.* **66**, 31

Feissel-Vernier, M., Ma, C., Gontier, A.-M., Barache, C., 2005: *Astron. Astrophys*., **438**, 1141

Ma, C., Feissel, M. (eds.), 1997: IERS Technical Note No. 23, Observatoire de Paris.

Ma, C., Arias, E.F., Eubanks, T.M., Fey, A., Gontier, A.-M., Jacobs, C.S., Sovers, O.J., Archinal, B.A., Charlot, P., 1998: *Astron. J.*, **116**, 516

Ojha, R. et al., 2004: *Astron. J.*, **127**, 3609

Souchay, J., Cognard, I., 2005: IERS Technical Note No. 34, in prep.

Véron-Cetty, M.P., Véron, P., 2003: *Astron. Astrophys*. **412**, 399

3.5.5 ITRS Centre

This report summarizes the activities of the IERS ITRS Centre during the year 2004.

The main activities of the ITRS Centre during the year 2004 are:

- Surveys of co-location sites
- Relation with IGS
- Maintenance of the IERS network

Surveys of co-location sites

The Institut Géographique National participated on complete surveys of the following co-location sites:

- Hartebeesthoek, South Africa, comprising the 4 techniques: VLBI, SLR, GPS and DORIS
- Shanghai, China, comprising 3 techniques: VLBI, SLR and GPS
- Wuhan, China, comprising 3 techniques: VLBI, SLR and GPS

For each one of the above 3 sites, 3 IGN surveyors participated in the survey. The total cost of these 3 surveys is around 100 K-Euros.

Relation with the IGS

The ITRS Centre contributes to specifications for ITRF densification, initiated by the IGS for its part (regional solutions of weekly permanent GPS station positions). Work is still in progress for evaluation/comparison of the different proposed densification approaches.

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.

New Web site

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.

Zuheir Altamimi, Xavier Collilieux, Bruno Garayt, Claude Boucher

3.5.6 Global Geophysical Fluids Center (GGFC)

The Global Geophysical Fluids Center within the International Earth Rotation Service has the responsibility of supporting, facilitating, and providing services and products to the worldwide research community in areas related to the variations in Earth rotation, shape, gravitational field, and geocenter that are caused by mass transport in the geophysical fluids.

Eight Special Bureaus (SB) have been established to supply products in response to community requirements. These include: Atmosphere, Oceans, Hydrology, Tides, Mantle, Core, Loading, and Gravity/Geocenter (see attached reports). The products generated by the SBs are based on global observational data and/or state-of-the-art model output. The products are available through the individual SB web sites that can be accessed via the GGFC portal now housed at the European Center for Geodynamics and Seismology (<http://www.ecgs.lu/ggfc/>).

The biggest challenge remains to standardize the computed quantities, the algorithms, and the data formats of the products generated by the SBs. However, we must also take advantage of products generated by other research groups and not duplicate efforts or resources. For example, there are many products generated to support the GRACE mission that would be particularly useful to the community at large. We are in contact with the appropriate teams and will try to arrange to make the data available through the GGFC.

In December 2004 Ben Chao stepped down as Head of the GGFC and was replaced by Tonie van Dam. As the new head, I would first like to thank Ben for his service to the GGFC and the larger community throughout his term. Secondly, I would like to thank all the volunteers who chair and maintain the respective SBs, and who are constantly looking at ways to improve the products that we provide to the community.

Detailed reports from each SB follow.

Tonie van Dam

3.5.6.1 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. However, recent interest in the wind-based equatorial terms indicates that it may be contributing more significantly to the Chandler wobble frequency band. 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.

During the recent year, we hosted Dr. Yonghong Zhou, who visited from the Shanghai Astronomical Observatory. He helped update our atmospheric series in several ways. First for the NCEP-NCAR reanalyses, he reprocessed the data by integrations with a different lower boundary; second, he reconsidered and updated the constants dependent on Earth properties, and third, an independent set of atmospheric angular momentum was updated, not depending upon the solid Earth physical constants.

Some of his summary material is included here:

The atmospheric angular momentum (AAM) during the period of 1948–2004 is re-processed using the NCEP/NCAR reanalysis 6-

hourly wind and pressure data. In order to consider the Earth's topography effect, the AAM is computed by integrating winds from the Earth surface to 10 hPa, the top of atmospheric model, instead that from a set 1000 hPa bottom level to 10 hPa. For these two cases, only a minor difference (~0.004 milliarcseconds) exists with respect to the Chi-3 wind term. However, considerable differences (5~6 milliarcseconds) are found regarding Chi-1 and Chi-2 wind terms. We then compared the equatorial AAM (with and without the topographic effect) with the observed polar motion excitations during 1980–2003, and the improved coherences are found between the equatorial AAM and the observed excitation when the topography effect is considered.

Atmospheric thermal tides are known to cause diurnal variations in wind, which transfer here to variations in polar motion excitation. The two are seasonally modulated. Two functions (1 and 2) for polar motion, were analysed for all twelve months in 2002, as well as the axial (3) term, which is relatively much smaller. The polar motion terms have strong variations with magnitude of ~10 mas. They have 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.

In comparing operational AAM of NCEP, JMA and UKMO during 2004, the following results were obtained:

The NCEP AAM (6-hourly), JMA AAM (6-hourly) and UKMO AAM (twice daily) show similar patterns, though considerable gaps exist in the UKMO operational AAM. While the differences in the axial terms (χ^3) of the NCEP and JMA operational AAM are negligible, those in the equatorial terms (χ^1 and χ^2) remain significant. The differences in equatorial terms of the NCEP and JMA operational AAM are generally larger for the southern hemisphere than those for the northern hemisphere, which might be due to less observational data in the southern hemisphere.

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David Salstein

3.5.6.2 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 to December 2003 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 to December 2003 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.

Acknowledgments

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References

Dong, D., J. O. Dickey, Y. Chao, and M. K. Cheng, Geocenter variations caused by atmosphere, ocean, and surface water, *Geophys. Res. Lett.*, **24**, 1867–1870, 1997.

Gross, R. S., I. Fukumori, and D. Menemenlis, Atmospheric and oceanic excitation of the Earth's wobbles during 1980–2000, *J. Geophys. Res.*, **108**(B8), 2370, doi:10.1029/2002JB002143, 2003.

Gross, R. S., I. Fukumori, D. Menemenlis, and P. Gegout, Atmospheric and oceanic excitation of length-of-day variations during 1980–2000, *J. Geophys. Res.*, **109**, B01406, doi:10.1029/2003JB002432, 2004.

Gross, R. S., I. Fukumori, and D. Menemenlis, Atmospheric and oceanic excitation of decadal-scale Earth orientation variations, *J. Geophys. Res.*, in press, 2005.

Johnson, T. J., C. R. Wilson, and B. F. Chao, Oceanic angular momentum variability estimated from the Parallel Ocean Climate Model, 1988–1998, *J. Geophys. Res.*, **104**, 25183–25195, 1999.

Ponte, R. M., and D. Stammer, Role of ocean currents and bottom pressure variability on seasonal polar motion, *J. Geophys. Res.*, **104**, 23393–23409, 1999.

Ponte, R. M., and D. Stammer, Global and regional axial ocean angular momentum signals and length-of-day variations (1985–1996), *J. Geophys. Res.*, **105**, 17161–17171, 2000.

Ponte, R. M., D. Stammer, and J. Marshall, Oceanic signals in observed motions of the Earth's pole of rotation, *Nature*, **391**, 476–479, 1998.

Richard Gross

3.5.6.3 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 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>.

New research into oceanic and atmospheric tides includes:

- Determination of the Global character of the S1 ocean tide by numerical modeling and by analysis of Ocean Topography Experiment (TOPEX)/Poseidon satellite altimeter data
- Determination of the S3(p) pressure oscillation over the coterminous United States from the analysis of hourly barometer data from 180 stations [*Ray and Poulouse*, 2005]

The S1 ocean tide model is currently being tested in GPS operational data analysis software.

The IERS is considering including the Ray and Ponte [2003] S1 and S2 atmospheric tidal models as as part of the station motion model. Updates on the status of the IERS decision as well as the in-phase and out-of-phase components of the loading effects due to this model can be found in grid format at <http://www.ecgs.lu/atm>. At the same location, the amplitudes and phases (or the in-phase and out-of-phase components) of the 3-dimensional deformations can be determined for any location on the surface of the Earth using an online calculator.

The Bureau endeavors to obtain newer tidal EOP solutions for long-period tides and for atmospheric tides. Several groups are now working on these topics, and the Bureau expects that additional data relevant to these tides can be added in the near future.

References

Ray, R. and R.M. Ponte, Barometric tides from ECMWF operational analyses, *Annales Geophysicae, 21*, pp. 1897–1910, 2003.

Ray, R. and G. D. Egbert, The Global S1 tide, *Jour. of Phys. Oceanography, 34*, pp. 1922–1935, 2004.

Ray, R. and S. Poulose, Terdiurnal surface-pressure oscillations over the continental United States, *Monthly Weather Review, 113*, pp. 2526–2534, 2005.

Richard D. Ray, Tonie van Dam

3.5.6.4 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 three numerical models, the NCEP (National Center for Environmental Prediction) reanalysis, the ECMWF (European Center for Medium Range Weather Forecasting) reanalysis, and the CPC (Climate Prediction Center) Land Data Assimilation System (LDAS). Global terrestrial water storage changes estimated from GRACE (Gravity Recovery and Climate Experiment) time variable gravity observations are provided as the new addition to our online data archive (at <http://www.csr.utexas.edu/research/ggfc/>). The NCEP reanalysis and CPC LDAS data products are updated on a regular basis.

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 has 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. 2004. 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.

A new addition to our data archive is equivalent surface water storage estimated from GRACE time variable gravity observations provided by the GRACE team at the Center for Space Research, University of Texas at Austin. 22 monthly GRACE solutions covering the period April 2002 to 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.

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 terrestrial water storage change estimates from the NASA Global Land Data Assimilation System (GLDAS). GLDAS has been used in many GRACE related studies, as it covers the GRACE period and has a high temporal resolution of 3 hours. It's been demonstrated by recent studies that GLDAS appears to show major improvement in modeling large-scale surface water storage changes when compared with earlier models.

Another new product will be 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.

Below is a table found on the website that summarizes the current datasets in our online data archive.

Jianli Chen, Clark R. Wilson

THE IERS GLOBAL GEOPHYSICAL FLUIDS CENTER

Special Bureau for Hydrology

Data Resources:

Parameters	Sources	Information
Water Storage Change From GRACE (New!)	GRACE (Gravity And Climate Experiment)	Time Span: Apr/May 2002 - Jul 2004 Sampling Rate: Monthly, 22 Solutions Grid: 1 x 1 Degree Grid Gaussian Smoothing: 600, 800, 1000 km Truncation at degree 60, No C20
CPC Monthly Water Storage	CPC Land Data Assimilation System	Time Span: Jan. 1980 - Dec. 2004 Sampling Rate: Monthly Grid: 1 x 1 Degree
NCEP Daily Water Storage	NCEP/NCAR Reanalysis Soil Moisture and Snow	Time Span: Jan. 1979 - Dec. 2004 Sampling Rate: Daily Grid: Gaussian (T62), ~1.904 x 1.875 Degree
ECMWF Daily Water Storage	ECMWF Reanalysis Soil Moisture and Snow	Time Span: 1979 - 1993 Sampling Rate: Daily Grid: 2.5 x 2.5 Degree
Water Storage	NCEP/NCAR Climate Data Assimilation Syatem I (CDAS-1) soil moisture and snow	Time Span: 1993 - 1998 Sampling Rate: Monthly Grid: 1 x 1 degree
Water Flux	NCEP/NCAR Climate Data Assimilation Syatem I (CDAS-1) soil moisture and snow	Time Span: 1993 - 1998 Sampling Rate: Monthly Grid: 1 x 1 degree

NEW! Daily hydrological excitations of polar motion and LOD from NCEP/NCAR Reanalysis (1948-2004)!

NEW! Water storage and flux changes of global major basins !!! (Underconstruction)

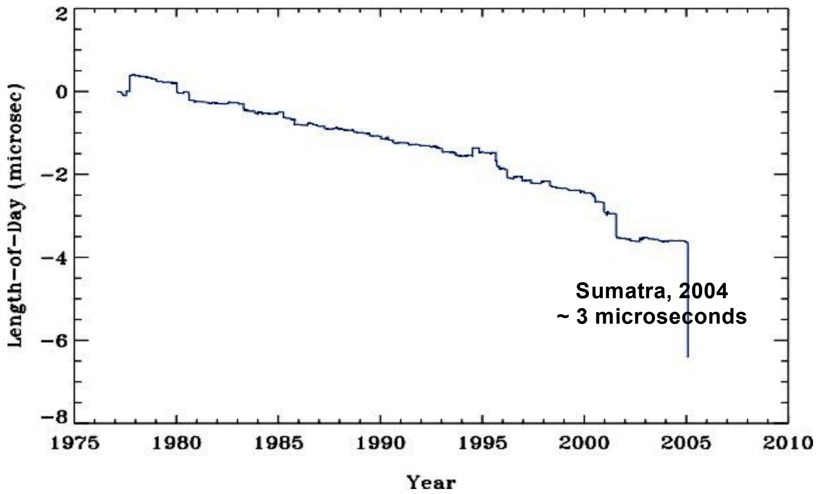
List of global major artificial reservoirs ! (by courtesy of Dr. Ben F. Chao)

3.5.6.5 Special Bureau for the Mantle

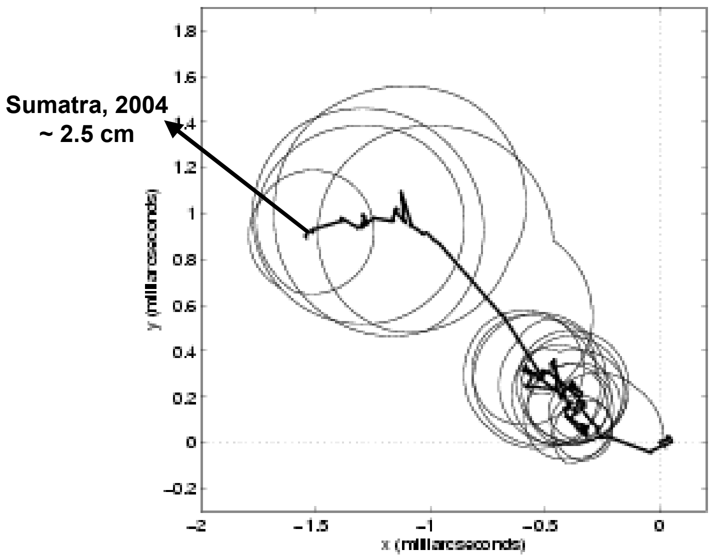
As with any geophysical processes that involve mass transports, large-scale motions in the mantle produce variations in Earth's rotation, gravity field, and geocenter. Among them, two topics have been extensively investigated:

(1) The co-seismic effects on various geodynamic parameters, including low-degree gravitational Stokes coefficients, Earth rotation parameters (length-of-day and polar motion excitation), and Earth's moments of inertia changes. They are shown as cumulative effects for 22,369 earthquakes spanning Jan 1977 through December 2004. The computation is based on Chao & Gross, 1987 (Chao, B. F. and Gross, R. S., Changes in the Earth's rotation and low-degree gravitational field induced by earthquakes, *Geophys. J. Roy. Astron. Soc., 91,* 569–596, 1987) using the centroid-moment tensor solutions of all major earthquakes larger than magnitude 5 as published in the Harvard CMT catalogue. In particular, during 2004, the seismic event of December 26 in Sumatra that resulted in the devastating tsunami in the Indian Ocean, has produced the following changes in Earth rotation: With a moment magnitude 9.0 ("standard" CMT solution), the change in length-of-day is –2.7 microseconds, in X-pole excitation –0.67 milliarcseconds (mas), in Y-pole excitation 0.50 mas. These calculated values manifest as the conspicuous jumps shown in Figure 1. Being "buried" in much larger signals from other geophysical sources, whether they can be actually detected and identified in Earth rotation data is currently under investigation. (For more detail see Chao and Gross, *EOS, Trans. Amer. Geophys. Union, 86*, 1–2, 2005; also <http://bowie.gsfc. nasa.gov/ggfc/sbm_plots.html>). Note that these values would be ~3 times larger if the moment magnitude of the Sumatra event was 9.3 as claimed by some seismological studies (as opposed to 9.0 adopted here).

(2) Post-glacial rebound, or glacial isostatic adjustment (GIA) modeling output from Erik Ivins (JPL). This set of data consists of graphics and spherical harmonic geopotential rates complete through degree 12 for each of three different cases. The geopotential rates are provided as a function of the lower mantle viscosity ranging from 10^{21} to 10^{23} Pa-sec. The first case uses ICE3G and a standard (Tushingham and Peltier, 1991) Earth model. The second case has an upper mantle viscosity of 3.2×10^{20} Pa-sec (Johnston and Lambeck, 1999) and lithosphere thickness = 80 km. The third case has a fixed deepest mantle (CMB to 650 km above) viscosity at $\eta = 7 \times 10^{22}$ Pa-sec, variable mantle viscosity from 650 km above the CMB to the 670 km seismic discontinuity, an upper mantle viscosity of 5×10^{20} Pa-sec and a lithospheric thickness of 100 km.



(a) Cumulative change in Length of Day by earthquakes since 1976



(b) Cumulative "Mean" Pole Position shift by earthquakes since 1976

Fig. 1: Cumulative change in Earth rotation due to earthquakes since 1976: (a) for length-of-day; (b) for polar motion excitation.

Also posted are a set of GIA modeling data from Prof. Richard Peltier (University of Toronto). This set consists primarily of the graphics from chapter 4 in the recent book "Sea Level rise: History and Consequences" (ed. B. Douglas, M. Kearney, and S. Leatherman, Academic Press, San Diego, 2001).

Benjamin F. Chao

3.5.6.6 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 (<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 ten different sets of model data on core flow and core angular momentum. The 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. The core flows and angular momentum variations are all very similar and agree remarkably well with the observed decadal LOD variations. In addition to the data, a description is given of the relevant theories and of the dynamical assumptions used for constructing the flows.

Tim van Hoolst

3.5.6.7 Special Bureau for Loading

In 2005, the Special Bureau for Loading (SBL) began making available near-real time predictions of the surface displacements due to atmospheric loading. The predictions are provided as global grids, time series for the ITRF sites and other selected global and regional networks, and as files comprising the point displacements for the different networks for a given epoch. All products are given for a sampling interval of 6 hours and are updated with a latency of currently 10 hours. The global grids are provided with a spatial resolution of 2.5 degrees. The air pressure anomalies are derived from the operational European Center for Medium Range Weather (ECMWF) Forecast sea-level pressure. The pressure anomalies are computed for the Earth's surface using the ETOP5 surface topography and the ECMWF temperature data to propagate sea level pressure to the Earth's surface. The air pressure reference surface is computed as the average of the surface pressure over 10 years. The solar tides S1 and S2 are not removed from the predictions. The displacement predictions are provided for a validation step involving the Analysis Centres of the IAG services as well as the SBL itself. After that validation step, the use of the products in monitoring the reference frame or in providing corrections for geodetic analysis will be possible.

The SBL has also updated the time series of predicted displacements to included results through the end of 2004. These time series, which are mainly provided for research purposes, represent the predicted 3-D deformation for all ITRF sites as well as a number of selected global and regional networks (e.g. IGS, SLR, VLBI, EUREF, etc.). Time series are available for the NCEP and ECMWF pressure data sets and calculations are done by different investigators using different earth models, different computational algorithms, and different reference frames. All available data sets are fully documented on the web site. The geodetic community has been comparing these data sets and the discrepancies found, besides those due to differences in the reference frame, are found to be mostly on the sub-millimeter level. However, a remaining uncertainty in the prediction is still due to the inverted barometer assumption, which is applied to the air pressure anomaly field for both the near-real time products and the station time series.

Members of the SBL have been conducting research to assess and improve the quality of the products provided by the SBL. Validation has been based largely on inter-comparison of the displacements computed by different authors and the comparison with the displacements observed by the IGS global GPS Network. For the improvement of the products, we have addressed the issue of the air pressure data set used, the effect of surface topography, the choice of a reference surface, and the ocean's response to air pressure forcing [Haakonsen et al., 2004, Plag, 2004, Haakonsen et al. 2005].

Finally, we have successfully established a mirror site for the SBL at <http://www.ecgs.lu>.

References

Haakonsen, T.A., Plag, H.-P., Kierulf, H.P., 2004c: Validation of modelled displacements due to atmospheric loading using the European CGPS network. In Plag, H.-P., and Zhang, X. (eds): Workshop on Observing and Understanding Sea Level Variations. Book of Abstracts, page 32.
Available at <http://eseas.org/eseas-ri/management/meetings/ws_midterm/book_of_abstracts_mt.pdf>.

Haakonsen, T.A., Plag, H.-P., Kierulf, H.P., Blewitt, G., 2004b: Improving reference frame stability by modelling common modes of surface displacements using Empirical Orthogonal Functions. EOS Trans. AGU, 85(47), Fall Meet. Suppl., Abstract G21B-03.

Plag, H.-P., 2004: On the status of modelling surface load induced displacements. In Plag, H.-P., and Zhang, X. (eds): Workshop on Observing and Understanding Sea Level Variations. Book of Abstracts, page 30.
Available at <http://eseas.org/eseas-ri/management/meetings/ws_midterm/book_of_abstracts_mt.pdf>.

Haakonsen, T.A., Plag, H.-P., Kierulf, H. P., in review: Common modes in vertical land motion and their relation to atmospheric loading. J. Geophys. Res.

Tonie van Dam, Hans-Peter Plag, Halfdan P. Kierulf

3.6 Combination Centres
3.6.1 ITRS Combination Centres
3.6.1.1 Deutsches Geodätisches Forschungsinstitut (DGFI)

This report summarizes the DGFI activities in its function as ITRS Combination Centre during the year 2004. For more information refer to other TRF related publications (see references), and to the DGFI reports in the previous IERS Annual Reports.

TRF realization 2003

Input are multi-year solutions with station positions and velocities of the different space geodetic techniques (VLBI, SLR, GPS, and DORIS). The TRF computations were finished at the end of the year 2003. During this year the work concentrated on a detailed analysis and validation of the TRF results. The input data, the combination methodology, and first results were presented in the IERS Annual Report 2003. A detailed documentation of the TRF realization 2003 is provided in Angermann et al., 2004.

TRF validation and accuracy assessment

The TRF computations provide valuable results to assess the current accuracy of the terrestrial reference frame. The combined intra-technique solutions were used to evaluate the TRF accuracy by comparing the space geodetic solutions with local ties, and the velocity estimations of co-located instruments. Since GPS is the dominant technique regarding the number and spatial distribution of co-locations with the other techniques we consider the GPS solution as reference for this specific TRF accuracy evaluation. We used the co-locations and local ties selected within the inter-technique combination to refer the DORIS, SLR and VLBI solutions to the GPS reference frame. This was done by adding the local tie components to the DORIS, SLR and VLBI station coordinates. Then we applied a 14 parameter Helmert transformation between the GPS solution and the „transformed“ solutions of the other techniques. A great advantage of this approach is, that the transformation results are independent from a specific TRF datum (e.g., ITRF2000), as the comparisons are performed in an (arbitrary) GPS reference frame. However, as also for any other accuracy evaluation method, it is not possible to fully separate local tie errors from errors in the space geodetic solutions. This again underlines the importance of accurate local tie information.

The transformation results between GPS and the other techniques are summarized in Table 1. In the case of VLBI and SLR the discrepancies are in the order of a few mm for the transformation parameters. The RMS residuals of station positions and velocities for the co-located instruments are 5 mm and 1 mm/yr, respectively. Larger discrepancies do exist for co-locations between GPS and DORIS.

Table 1: Helmert-transformation results of the DORIS, SLR and VLBI network w.r.t. the GPS network.

Parameter	DORIS	SLR	VLBI
Tx [mm]	-9.6 ± 3.4	2.7 ± 1.4	-0.4 ± 1.7
Ty [mm]	8.4 ± 3.3	0.0 ± 1.3	-2.8 ± 1.7
Tz [mm]	2.9 ± 3.3	-2.2 ± 1.3	3.1 ± 1.7
Rx [mm]	3.2 ± 4.1	-3.3 ± 1.6	-4.6 ± 2.2
Ry [mm]	2.1 ± 4.0	-1.2 ± 1.6	1.8 ± 2.2
Rz [mm]	-18.9 ± 5.2	-2.2 ± 1.6	1.8 ± 2.2
Scale [mm]	-3.0 ± 3.2	1.9 ± 1.2	-4.7 ± 1.6
Pos RMS [mm]	8.2	4.1	5.4
Vel RMS [mm/yr]	1.5	0.87	0.92

Comparison with ITRF2000

A comparison of the TRF realization with ITRF2000 provides an optimal basis for a quasi-independent validation and quality control of the ITRS products. Figure 1 shows the RMS residuals of a similarity transformation between both TRF realizations for station positions and velocities. The agreement for VLBI and GPS station positions is better than for the other techniques. The discrepancies are largest for DORIS. Figure 2 represents histograms for the distribution of station position and velocity differences between both TRF realizations for the 369 common VLBI, SLR, GPS and DORIS stations in north, east, and height component. For about 60% of the stations the position and velocity differences are below 1 cm and 2.5 mm/yr, respectively. But on the other hand, there are too many stations (10%) with position and velocity differences larger than 5 cm and 1 mm/yr, which is not tolerable for a precise reference frame.

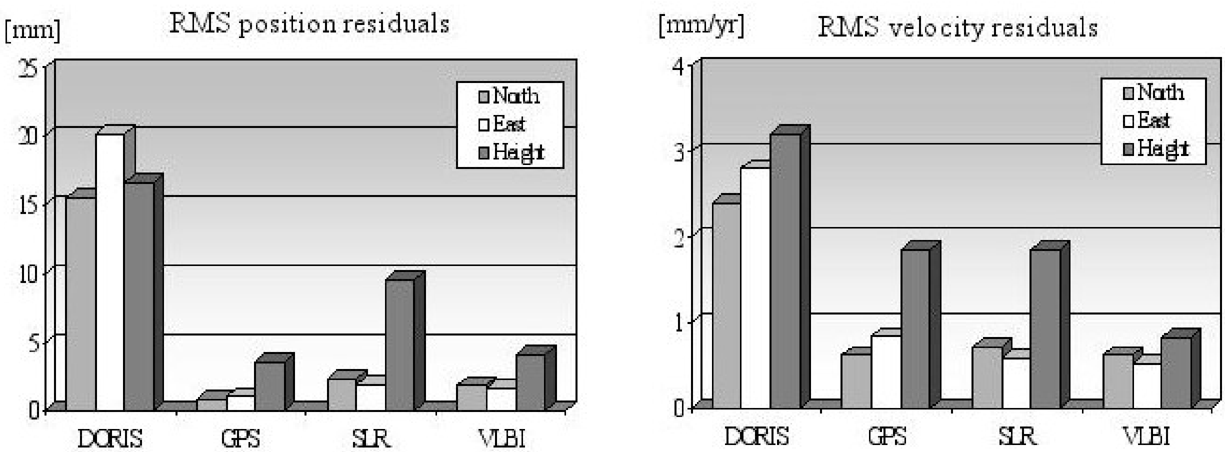


Fig. 1: RMS station position and velocity residuals in North, East, and Up component obtained from a similarity transformation between the combined DGFI solution and ITRF2000.

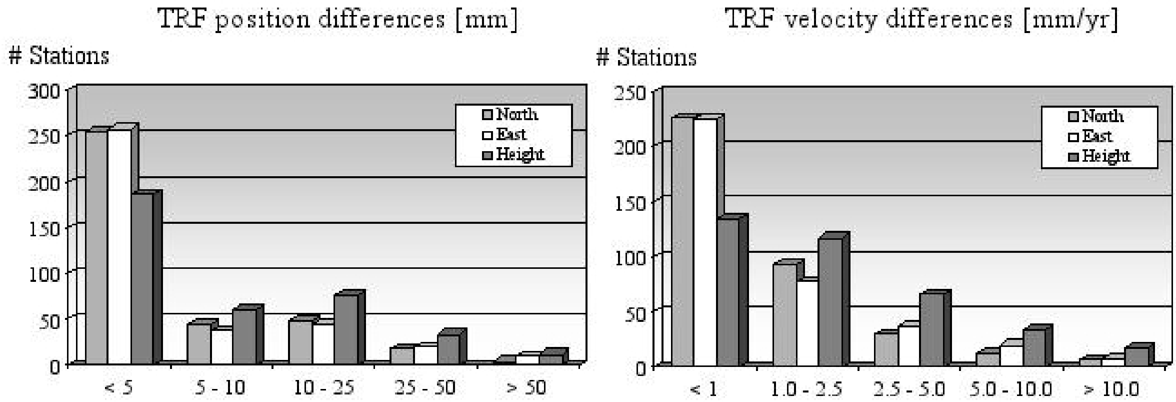


Fig. 2: Histograms representing the differences between the combined DGFI solution and ITRF2000 in station positions (left) and velocities (right) for the 369 common stations (75 VLBI, 69 SLR, 172 GPS and 53 DORIS).

Towards a refined TRF realization

The high accuracy of the space geodetic observations is not reflected by current realizations of the terrestrial reference frame. A major error source are remaining systematic effects (biases) between different space techniques, which have to be investigated and minimized. An additional problem is that non-linear station motions (among others post-seismic deformations, periodic movements) are not taken into account in previous ITRF realizations. As a first step towards a refined TRF realization we analysed the time series of station positions and datum parameters derived from weekly solutions. The position time series show non-linear motions and discontinuities for a large number of sites. The reasons are manifold, e.g.:

· seasonal signals caused by loading effects;
· effects of seismic deformation processes;
· equipment changes due to system upgrades, etc.;
· changes of softwares, models, and processing strategies.

We computed a first TRF realization based on weekly normal equations of the different space techniques. This new approach has major advantages compared to past TRF realizations based on multi-year solutions with station positions and constant velocities. First results obtained from an accumulated five years solution using data from 1999 until 2004 are promising (see Meisel et al., 2004).

Conclusions and outlook

The TRF computations at DGFI provide valuable results to assess the current accuracy of the terrestrial reference frame, to identify remaining deficiencies and to enhance the combination methodology. With the high accuracy of the space geodetic techniques time-variable effects of station positions and datum parameters (e.g., TRF origin) become detectable, that were not considered in past

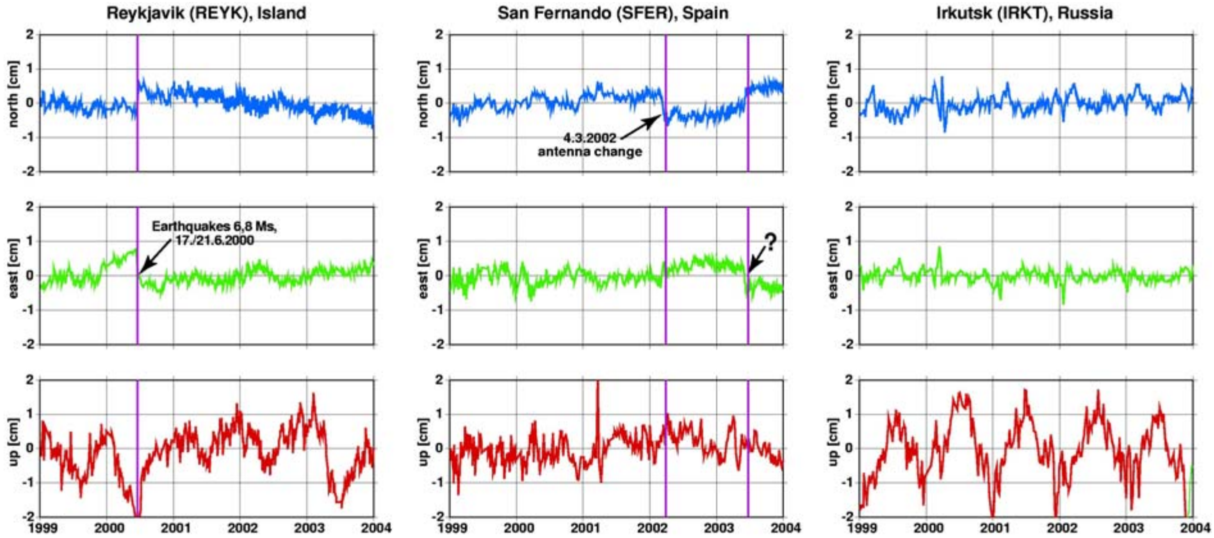


Fig. 3: Examples of position time series of three GPS stations that show jumps (earthquakes or instrumental changes) and annual signals.

TRF realizations. These time-variable effects have to be identified and properly modelled in future TRF computations.

A call for long-time series of "weekly" SINEX files for a new ITRF2004 and a supplement for the IERS Combination Pilot Project has been released in December 2004. The ITRF2004 will be based on the combination of time series of station positions and EOPs. The ITRS Combination Centres, namely DGFI, IGN, and NRCan, coordinated by the ITRS Centre, will perform the computation of the ITRF2004 solution.

Acknowledgement

The ITRS Combination Centre at DGFI is supported by the Federal Ministry of Education and Research (BMBF), grant 03F0336C within the programme GEOTECHNOLOGIEN.

References

Angermann, D., H. Drewes, M. Krügel, B. Meisel, M. Gerstl, R. Kelm, H. Müller, W. Seemüller, V. Tesmer: ITRS Combination Center at DGFI: A terrestrial reference frame realization 2003. Deutsche Geodätische Kommission, Reihe B, Heft Nr. 313, 2004.

Angermann, D., H. Drewes, M. Gerstl, R. Kelm, M. Krügel, B. Meisel: ITRF combination - Status and recommendations for the future. In: Sanso, F. (Eds.): A Window on the Future of Geodesy. IAG Symposia, Vol. 128, Springer, 2005a.

Angermann, D., M. Krügel, B. Meisel, H. Müller, V. Tesmer: Time evolution of the terrestrial reference frame. In: Sanso, F. (Eds.): A Window on the Future of Geodesy. IAG Symposia, Vol. 128, Springer, 2005b.

Meisel, B., D. Angermann, M. Krügel, H. Drewes, M. Gerstl, R. Kelm, H. Müller, V. Tesmer: Refined approaches for terrestrial reference frame computations, submitted to Adv. Space Res., 2004.

Detlef Angermann, Hermann Drewes, Michael Gerstl, 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. The experience gained in time series analysis leads to the conclusion that the upcoming ITRF solution should combine TRF and EOPs, based on times series of TRF and EOP of the individual techniques. It is preferable to use weekly solutions in order to better monitor station non linear motions. The EOP parameters resulted from this combination would be used then to recalibrate the current IERS C04 series, so that ITRF and IERS EOP consistency will be ensured. Therefore preparation of the ITRF2004 was commenced in 2004 and a call for participation was issued.

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 ITRF 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 performed 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.

Analysis of time series of station positions and Earth Rotation Parameters

We performed time series analysis using CATREF software, using the following data:

- VLBI: 24h-session SINEX files over 1990–2004, provided by Goddard Space Flight Center (GSFC) VLBI Group, using the terrestrial reference frame of gsfd001
- SLR: weekly solutions provided by Italian Space Agency over the period 1993–2004
- GPS: Official IGS weekly combined solutions over the period 1999–2004
- DORIS: weekly solution provided by Institut Geographique National/Jet Propulsion Laboratory over the period 1993–2004

A multi-technique combination was performed using the above described solutions over the period 1990–2004. In order to avoid the impact of dubious local ties in the combination, we added 77 precise local tie vectors (as internally determined by our own analysis) located in 58 collocated sites, using only one point per technique in each site. We noticed that the post fit local tie residuals are generally 2–3 mm larger when EOPs are included in the combination.

As results of this combination test, Figure 1 shows the polar motion post-fit residuals over the 4 techniques.

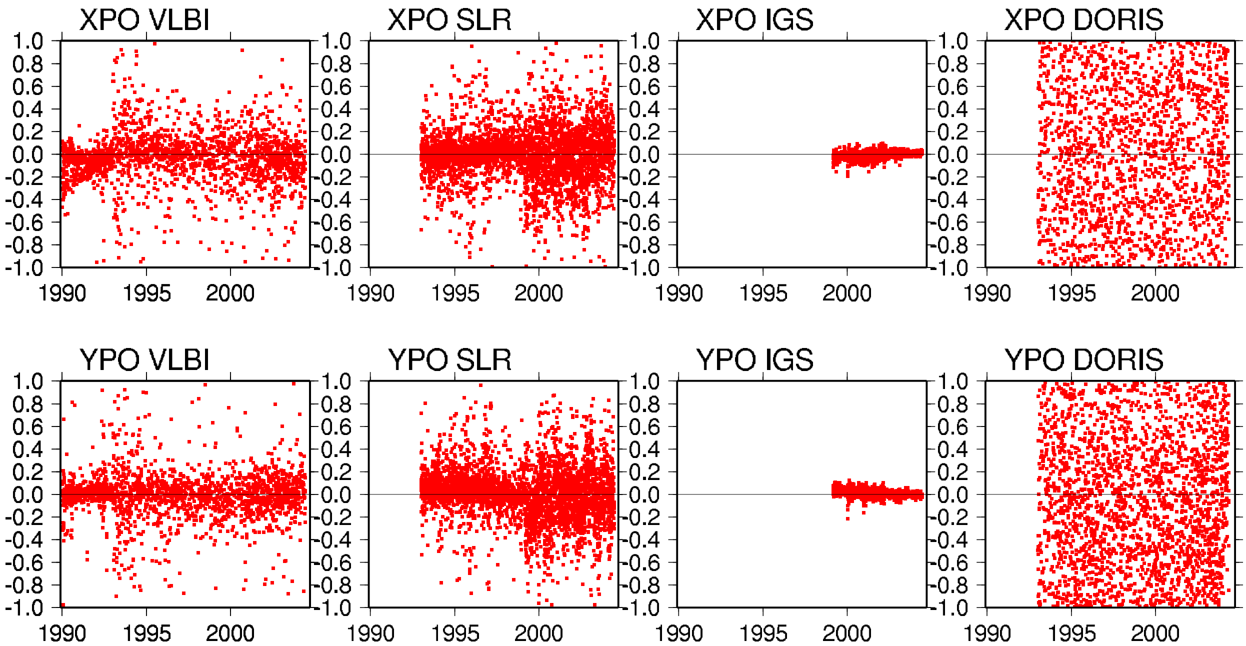


Fig. 1: Post fit residual of Polar motion per technique (mas)

The EOP IGS results appear to dominate the other technique results. This is mainly due to the fact that the IGS solution is already a combination of 7 analysis centres, whereas the others are provided from one analysis centre per technique. In addition, the IGS EOP estimates are based on continuous observations from more than 300 sites homogenously distributed.

Publications

Altamimi, Z., C. Boucher and P. Willis, 2004, Terrestrial Reference Frame Requirements within GGOS Perspective, *J. Geodynamics*, accepted for publication.

Altamimi, Z., C. Boucher and D. Gambis, 2005, Long-term Stability of the Terrestrial Reference Frame, *Adv. Space Res.*, in press.

Zuheir Altamimi, Xavier Collilieux, Claude Boucher

3.6.1.3 Natural Resources, Canada (NRCan)

The activities related to ITRS CC for 2004 also overlap some IGS priorities for the Reference Frame Working Group. They are mainly related to 1) the maintenance of the IGS realization of the ITRF2000, 2) the reanalysis of weekly combinations and 3) the preparation of station coordinates discontinuity tables.

The alignment of the IGS products to ITRF2000 provides a convenient way for the GPS community to have access to ITRF. The IGS SINEX solutions are aligned to an intermediate solution to improve their internal consistency. This intermediate solution, the so-called "IGS realizations of ITRF", is itself aligned to ITRF2000. The original IGS realization of ITRF2000 included 54 globally distributed stations. It was used from GPS week 1143 (01/12/02), until GPS week 1252 (04/01/10), when it had ~40–43 active stations remaining in the realization. Starting with GPS week 1253, a new IGS realization of ITRF2000 was used, nominally including 99 active stations. The main objective of this denser realization was to improve the stability. As experienced with earlier realizations, the IGS realization network tends to "decays" at a rate of about 5–10% per year. Some stations have to be removed due to time series discontinuities; others do stop contributing timely data required for their participation. So far, 6 stations had to be removed from the IGS Reference Frame realization, at 3 different epochs: 1) FAIR, MAG0, SFER and YSSK excluded starting at GPS week 1268 (04/04/25), 2) KOKB excluded starting at GPS week 1274 (04/06/06) and 3) TRO1 excluded starting at GPS week 1284 (04/08/15). In the production environment, it sometimes requires a few weeks to confirm anomalous station behavior. For the reprocessed solutions contributing to ITRF, stations are excluded starting at the time anomalies do occur. Figure 1 shows the weekly Reference Frame stations usage by the AC, GNAAC and combined IGS solution.

The reanalysis effort contributed to improve the IGS weekly solutions and indirectly the upcoming ITRF2004. Occasionally, AC/GNAAC solutions missed the combination deadline; however, when available, they were included in the reanalyzed solutions. Some known modeling problems were also corrected. Reported incorrect antenna heights were also corrected from the time they occurred, thus removing some "artificial" discontinuities. From time to time, the improvements made in the reprocessed solutions, were included in the IGS cumulative solution. Critical information such as DOME #, may also have prevented some station coordinates estimates from being released in the official solutions. When such information became available, corresponding station coordinates could be released in the weekly reprocessed solutions.

Station coordinates time series are sometimes affected by discontinuities. Properly accounted for discontinuities are essential to improve the ITRF. Those discontinuities can be caused by geophysical events such as earthquake, or for GPS, also be caused by changes in the station local environment or electronics. Changes in equipment performance, combined with different processing strategy may also influence the magnitude of observed discontinuities. The detection of large discontinuities is easy. However, smaller discontinuities are more difficult to correctly identify, and may potentially be biased by the analyst interpretation. Coordinates time series from IGS, JPL, MIT and SIO were compared to help identify discontinuities. EUREF and NAREF time series as well as very valuables feedback from the regional centers analysts helped to identify several discontinuities and ensure consistency between the global and regional solutions. Correlation with known geophysical events or equipment changes often helped explain small discontinuities; this significantly improved the discontinuity detection confidence level. Several people contributed to the detection/identification of discontinuities, thus reducing analyst bias, their contribution is acknowledged. The relentless effort of all the people contributing to IGS is also acknowledged.

Rémi Ferland

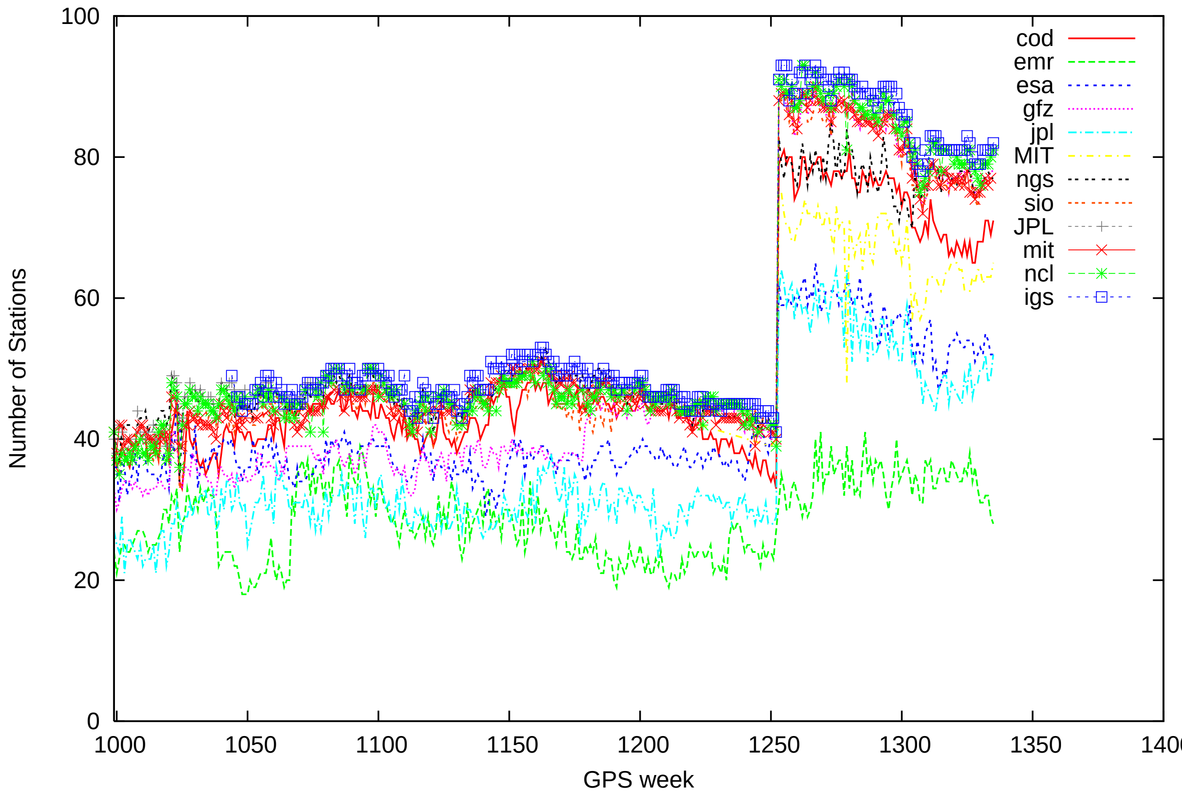


Fig. 1: Evolution of the Reference Frame stations usage. For a colour version of this figure see the online version of this report.

3.6.2 Combination Research Centres

3.6.2.1 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 five 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 2004.

We combined celestial pole offsets in the interval 1994.3 – 2003.8 (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. Its period in the celestial reference frame has an average value of 435 days, if only VLBI observations are used in the interval 1984 – 2003. From the combined solution however follows that the period is, after 1994, slightly longer, of about 455 days (Vondrák and Weber 2004). In addition we found small but statistically significant corrections of the IAU2000A nutation model with periods 18.6 and 9.3 years, and also 365.26, 182.56, 31.81, 27.55, 13.66, 13.63 and 5.64 days.

Our more recent combination of celestial pole offsets, covering a longer interval (1994.3 – 2004.6), confirmed these findings and hinted that the FCN period was even longer, 460 days (Vondrák and Ron 2004, Vondrák et al. 2004, Vondrák and Ron 2005). This value is in contradiction with the model IAU2000A, but in surprisingly good accordance with the older Wahr's model IAU1980. The corrections of 9 nutation terms were derived whose amplitudes attain a few tens of microarcseconds.

We also made a combination of the length-of-day 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 2004, Vondrák and 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.

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 tested using VLBI, GPS, SLR and Doris data, collected for IERS Sinex Combination Campaign. 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 (Pešek & Kostelecký 2004).

Formerly it was found that the effect of systematic biases in the input data can be reduced by combining them piecewise in shorter (e.g. monthly) periods. Nevertheless this approach yields discontinuities of EOP between successive blocks. These biases practically completely disappear when the solution is derived from the data covering a longer period, and as a result only a middle part is used. Namely, the monthly solution is derived from two-monthly data.

The effect of combination on EOP is characterized by increments from the adjustment of 0.09 mas and 0.034 ms for polar motion and Universal Time, respectively. Uncertainty of station coordinates decreased from 0.050 m to 0.039 m.

The method was also applied to IERS Combination Pilot Project data with still only preliminary results.

In 2004 an object-oriented mathematical model for a general unconstrained adjustment of observational data was tested and implemented on combinations of coordinates obtained from different techniques (Cepek & Pytel 2004). Although most of the solutions seemed to be satisfactory and resulted in coordinates with reasonable covariance matrix, some combinations led to totally singular systems.

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Department of Geodesy:
Prof. Jan Kostelecký (Head of CEDR)
Dr. Ivan Pešek
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References

Cepek A., Pytel J.: 2004, Acyclic Visitor Pattern in Formulation of Mathematical Model, Presented at FIG Working Week 2004, May 22-27, Athens, Greece

Pešek I., Kostelecký J.: 2004, Simultaneous determination of Earth orientation and station coordinates from combination of results of different observation techniques, Presented at EGU 1st General Assembly, G7, 25-30 April 2004, Nice, France

Vondrák J.: 2004, Celestial pole offsets and universal time – combination of VLBI/GPS measurements, Presented at Workshop IERS Combination Pilot Project, December 2004, Napa, USA

Vondrák J., Cepek A.: 2000, Combined smoothing method and its use in combining Earth orientation parameters measured by space techniques, Astron. Astrophys. Suppl. Ser., 147, 347-359

Vondrák J., Ron C.: 2004, Combining GPS and VLBI measurements of celestial motion of the Earth's spin axis and universal time, Presented at 6th Czech-Polish Workshop on Recent Geodynamics, November 2004, Lezyce, Poland

Vondrák J., Ron C.: 2005, Combining GPS and VLBI measurements of celestial motion of the Earth's spin axis and Universal time, Acta Geodynamica et geomaterialia, in press

Vondrák J., Weber R.: 2004, Free core nutation and corrections to some nutation terms derived from combined VLBI/GPS solution, Presented at EGU 1st General Assembly, G5, 25-30 April 2004, Nice, France

Vondrák J., Ron C., Weber R.: 2004, Celestial motion of Earth's spin axis derived from the combination of VLBI and GPS observations, Presented at AGU Fall Meeting, December 2004, San Francisco, USA

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3.6.2.2 Deutsches Geodätisches Forschungsinstitut (DGFI)

The DGFI activities as IERS Combination Research Centre during the year 2004 can be divided into four major topics:

- Refinements of the SLR intra-technique combination
- Steps towards a rigorous combination of VLBI, GPS and SLR data using CONT02 data
- Simultaneous estimation of a TRF, the EOPs and a CRF
- DGFI contributions to the IERS Combination Pilot Project

SLR intra-technique combination

During the ILRS AWG meeting in San Fernando, Spain on June 5, 2004, DGFI was nominated as official ILRS Backup Combination Centre, ASI was nominated as official ILRS Primary Combination Centre. Both centres are obliged to weekly compute a combined SLR solution as official product (SINEX files with station positions and Earth Orientation Parameters) for the ILRS. The input data are SINEX files with loosely constrained solutions provided by official ILRS analysis centres (in 2004: ASI, DGFI, GFZ, JCET, NSGF). To guarantee the operational combination of the individual SLR solutions on a weekly basis, DGFI has refined the intra-technique combination methodology and software for an automated processing.

CONT02 combination

The VLBI campaign CONT02, initiated by the IVS, provides 15 days of continuous VLBI measurements of eight participating telescopes. This data set was used in a joint research project of DGFI and the FESG for detailed combination studies (Krügel et al., 2004; Thaller et al., 2004). For this purpose, free daily normal equations were generated for GPS (at FESG with Bernese GPS Software) and VLBI (at DGFI with OCCAM software) using identical models and the same parameterization to avoid any inconsistencies. This provides the opportunity to study all common parameters (not only station coordinates and EOPs, but also tropospheric zenith delays and gradients) within this rigorous combination. The results demonstrate the potential of such a rigorous combination, though some details need to be further investigated.

TRF, CRF, and EOPs

In cooperation with the Technical University of Vienna and Geoscience Australia, DGFI is intensively involved in the development and enhancement of the VLBI software OCCAM (Titov et al., 2004). 2600 VLBI sessions from 1984–2004 were re-processed and station positions, station velocities, quasar coordinates and Earth Orientation Parameters (EOP) were estimated in a common adjustment (Tesmer et al., 2004). In these first investigations, systematic effects w.r.t. such simultaneously estimated TRF and CRF were found in the TRF estimates if CRF was fixed to ICRF-Ext1, as well as in the CRF estimates if ITRF2000 was fixed. This will be studied in more detail.

IERS Combination Pilot Project

The IERS Combination Pilot Project was initiated by the IERS Analysis Coordinator and the IERS Working Group on Combination in the beginning of 2004 as a follow-on project of the IERS SINEX Combination Campaign (Angermann et al., 2003). It aims towards more consistent, routinely generated IERS products. „Weekly“ SINEX solutions, made available by the various Technique Centres, containing site coordinates, EOPs, and, possibly, Quasar coordinates, shall be rigorously and routinely combined into consistent weekly IERS products (SINEX files). Within this project, DGFI provides individual SLR and VLBI solutions and combined SLR solutions for the intra-technique combination. Furthermore DGFI has been accepted by the IERS as an Combination Centre for the inter-technique combination. The presently available SINEX files were analysed concerning various issues, such as format and suitability for a rigorous combination. A suitable strategy for the weekly inter-technique combination, including input data check and validation of results is under development.

Acknowledgement

The IERS Combination Research Centre at DGFI is supported by the Federal Ministry of Education and Research (BMBF), grant 03F0336C within the programme GEOTECHNOLOGIEN.

References

Angermann, D., D. Thaller, M. Rothacher: IERS SINEX Combination Campaign, Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids, IERS Technical Note 30, Bundesamt für Kartographie und Geodäsie, Frankfurt a. M., 2003, 94–101.

Krügel, M., V. Tesmer, D. Angermann, D. Thaller, M. Rothacher, R. Schmid: CONT’02 campaign – Combination of VLBI and GPS, In: Vandenberg, N., K. Baver (Eds.): IVS General Meeting Proceedings, NASA/CP-2004-212255, 2004, 418–422.

Tesmer, V., H. Kutterer: An advanced stochastic model for VLBI observations and its application to VLBI data analysis, IVS General Meeting Proceedings, NASA/CP-2004-212255, 2004, 296–300.

Tesmer, V., H. Kutterer, H. Drewes: Simultaneous estimation of a TRF, the EOP and a CRF, IVS General Meeting Proceedings, NASA/CP-2004-212255, 2004, 311–314.

Thaller, D., R. Schmid, M. Rothacher, V. Tesmer, D. Angermann: Towards a rigorous combination of VLBI and GPS using the CONT02 campaign, IAG Proceedings, Springer, 2004, in print.

Titov, O., V. Tesmer, J. Böhm: OCCAM v.6.0 software for VLBI data analysis, IVS General Meeting Proceedings, NASA/CP-2004-212255, 2004, 267–271.

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3.6.2.3 Forschungseinrichtung Satellitengeodäsie, Technical University of Munich (FESG)

Introduction

The following research topics were covered during 2004 at the FESG as a Combination Research Centre (CRC) of the IERS:

- Combination studies using the CONT02 campaign
- Combination of sub-daily EOPs
- Analysis of troposphere parameters
- Analysis of nutation series

Combination Studies Using the CONT02 Campaign

CONT02 was a two-weeks continuous VLBI campaign and is therefore well-suited for combination studies with other space geodetic techniques, e.g. with GPS and SLR. The combination strategies we were studying are based on free normal equations generated for all techniques, including station coordinates, sub-daily Earth Rotation Parameters (ERP), daily nutation estimates, sub-daily tropospheric zenith delays for GPS and VLBI, and daily tropospheric gradients. Compared to former analyses, the temporal resolution for ERP and tropospheric zenith delay parameters were increased from two hours to one hour.

The combined pole coordinate series shows a better agreement with an independent sub-daily pole model (IERS2000) than the single technique solutions. This can be demonstrated by means of RMS values from the comparison with the IERS2000 model: for the x-pole the RMS decreased from 0.143 mas for a GPS-only and 0.259 mas for a VLBI-only solution, respectively, to 0.120 mas for the combined solution. A similar improvement can be recognized for the y-pole: 0.144 mas (GPS-only) and 0.253 mas (VLBI-only) for the single technique solutions compared to 0.130 mas for the combined solution.

With the results from the CONT02 combination studies it can be shown that the combination of UT1–UTC values from VLBI and LOD values from the satellite techniques is possible for a sub-daily resolution as well as for daily values. For all techniques the parameterization was changed from offset and rate to an offset-only piece-wise linear parameterization, and then the offsets at the predefined one-hour interval boundaries were combined. Figure 1 nicely demonstrates that the information on UT1–UTC coming from VLBI is not destroyed by the LOD values (with systematic biases) from GPS. And regarding the agreement with the IERS2000 sub-daily model it can be seen that the GPS LOD contribution even stabilizes the UT1–UTC time series, since the RMS for a VLBI-only solution is 0.015 ms, whereas it is only 0.011 ms for the combination.

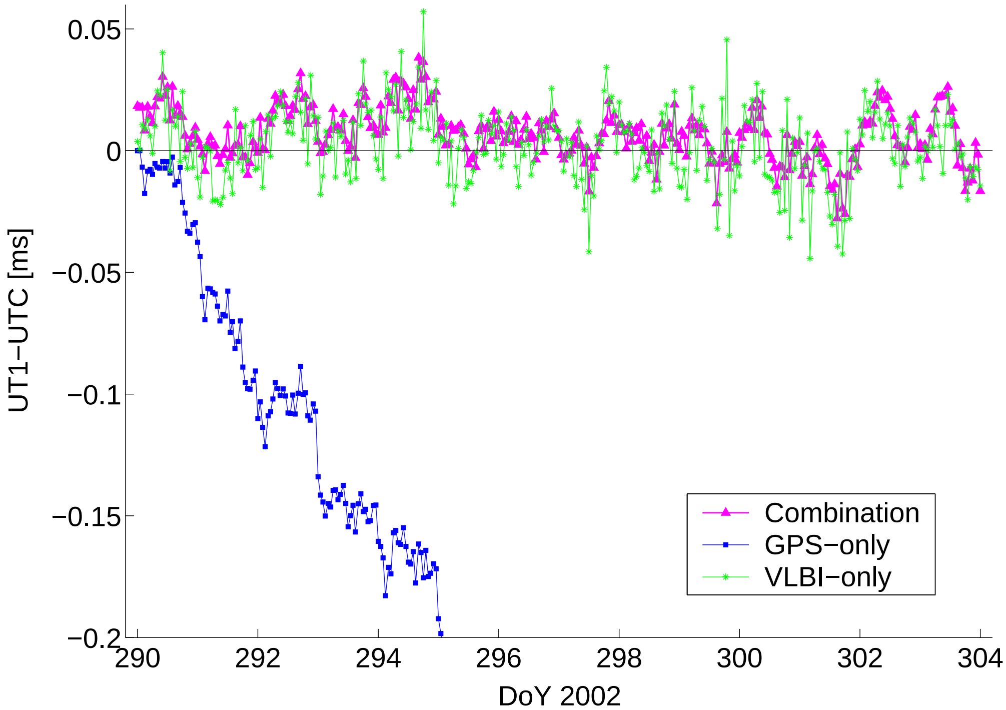

Fig. 1: Hourly UT1–UTC estimates derived from VLBI, GPS and a combined solution w.r.t. C04/IERS2000.

Combination and Analysis of Sub-Daily ERPs from GPS and VLBI

The latest harmonic analysis of sub-daily Earth rotation parameter (ERP) series from GPS and VLBI show already a very good agreement with studies of the sub-daily tidal excitation in polar motion and variation of length of day. Nevertheless, there are still many inconsistencies between the results from GPS, VLBI and geophysical models. Besides a rigorous combination of normal equations (or variance-covariance matrices) from different geodetic space techniques, a combination of the sub-daily ERP time series in advance of any further analysis could be useful to obtain a single sub-daily geodetic time series. Therefore we extended J. Vondrak's combined smoothing method (Vondrak and Cepek, 2000) to use it for high-frequency data. Combined smoothing is a constrained combination procedure, fitting the original GPS and VLBI time series by a weighted least squares estimation minimizing the sum of three coefficients for smoothness, fidelity to the original GPS series and fidelity to the original VLBI series. This method allows also the combination of UT1–UTC series from VLBI with ΔLOD from GPS within one step. Due to the necessary smoothing the original combined smoothing method filters out frequencies higher than two days (using hourly input data).

In order to use combined smoothing for sub-daily ERP data, we split the input series into a high-frequency and a low-frequency part by using either a low-pass filter or the combined smoothing method on a single time series setting the weights for a high smoothing. Adapting different smoothing coefficients to each frequency part we can preserve even the highest frequencies while solving the problems with larger data gaps and unevenly spaced data of VLBI including the adjustment of different, time variable offsets and different error levels between GPS and VLBI. The combined series is much more homogeneous, the RMS is reduced due to the smoothing process and the elimination of outliers, and the signal-to-noise ratio is enhanced due to the higher density of observation points (sum of GPS and VLBI observations). The improvement of the new combination procedure became more apparent for UT1–UTC than for the prograde polar motion component. The GPS series can benefit from VLBI observations by adjusting the integration of ΔLOD to UT1–UTC with well defined sampling points. On the other hand the VLBI series gets much more homogeneous, because the adjustment to the smoother GPS series eliminates time variable offsets, drifts and outliers. The quality of the combined series was tested by an estimation of tidal harmonic coefficients and spectral analysis.

For GPS we used hourly data from 02.01.1995 until 21.12.2000 with 52584 sample points delivered from the IGS analysis centre CODE. For VLBI we used sessions from 03.01.1995 until 29.12.1999 with 12464 hourly ERP values from the IVS analysis centre GSFC. We obtained 63008 different sample points for the combination. Further information on the original GPS and VLBI input series can be found in Rothacher et al. (2001). The analysis of 68 sub-daily tidal harmonic constituents for the new VLBI/GPS combination matches generally very well to the latest estimations of Rothacher et al. (2001) using a combined estimation of both series. Both analyses were based on the same GPS and VLBI series. We also compared these geodetic results with the official tidal harmonics from the IERS, based on hydrodynamic ocean models and additional assimilation of TOPEX/Poseidon sea-surface height differences. The atmospheric tidal excitations of polar motion and UT1–UTC were neglected, because they are much smaller than the oceanic ones: 1–2 orders of magnitude for prograde polar motion and 30 times for UT1–UTC (Brzezinski et al., 2002).

The number of tidal constituents, estimated with more than 95% confidence, increases from 21 (GPS-only) to 23 (new combination). The estimated tidal constituents can reproduce 77.4% of the sub-daily UT1–UTC variations (51.9% for VLBI-only, 66.9% for GPS-only series) and 64.3% of sub-daily prograde polar motion (37.7% for VLBI-only, 58.4% for GPS-only).

The main advantage of the combination arises from the reduced errors of the amplitude and phase estimation of the major tidal constituents. But there are also some small tidal harmonics, where the uncertainty in phase of the estimated tidal constituents increases, probably due to small phase inconsistencies in the harmonic components between the GPS and the VLBI input series. In conclusion the results from the new combination fit somewhat better to the hydrodynamic tidal model results than the estimations from each single input time series.

The spectral analysis offers the possibility to check, if the smoothing process in the combination is weak enough to preserve the sub-daily signal content of the input series.

The combination process suppresses most of the GPS-specific, unexplained periods between 2 and 6 hours, mainly due to the missing of equivalent signals in the VLBI series and partly because of the inevitable smoothing process within the combination. The known peaks of solar and lunar tides are smeared, but the amplitude power over the whole series remains at almost the same level. In conclusion the smoothing in the combination procedure seems to be weak enough to preserve even the highest frequencies. Furthermore, the combined series brings out some new, not reasonably explained periods, especially between 20 h and one day. There are almost no corresponding sub-daily tidal constituents. These characteristics can be found in the spectra for polar motion as well as in the UT1–UTC spectra. Further investigations should clarify the origin of these new periods. The extended smoothing method seems to be a practicable procedure to obtain long and stable sub-daily time series for geodetic and geodynamic investigations.

Homogeneously Reprocessed GPS and VLBI Troposphere Parameters

In cooperation with the Technical University in Dresden, FESG has reprocessed 11 years of GPS observations starting from the raw RINEX files (Steigenberger et al., 2004). The troposphere parameters of this homogeneously reprocessed solution have been compared with the also reprocessed VLBI solution DGFI04R04, computed by DGFI Munich. Much effort has been spent to use identical modelling and parameterization to minimize systematic effects. 36 co-located GPS antennas at 27 stations could be used for comparisons. First results were presented at the EGU General Assembly 2005 in Vienna (Steigenberger et al., 2005). The comparison of zenith wet delays (ZWD) and troposphere gradients showed in general a good agreement: the RMS of the ZWD difference time series is in the order of 4–10 mm and the correlation for most of the stations above 0.98. But also some critical issues could be identified by comparing the GPS and VLBI troposphere parameter time series: discontinuities due to equipment changes as well as systematic effects due to degradations in the tracking performance of GPS receivers and antennas. The bias between troposphere ZWDs from GPS and VLBI (corrected for the height difference between the GPS and VLBI antennas) can also be used as a tool for validation of different solutions: by using absolute antenna phase centre correc-

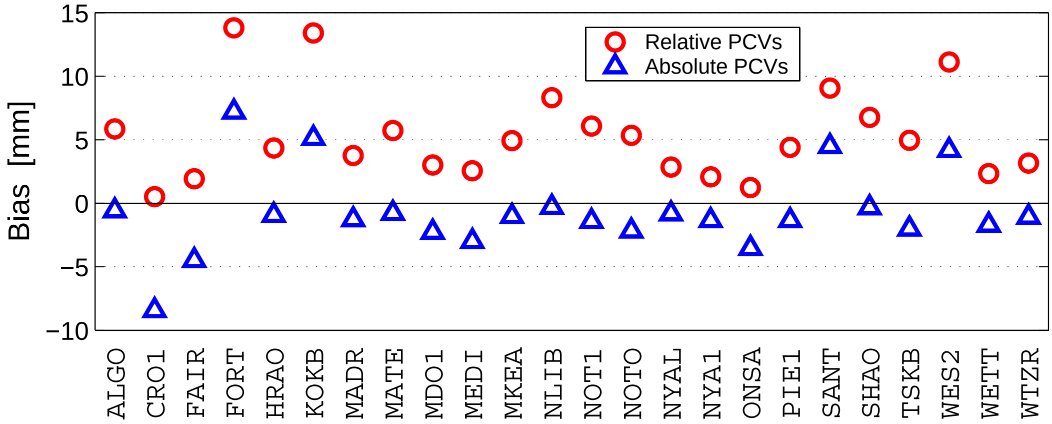

Figure 2: Bias between GPS and VLBI zenith wet delays corrected for station height differences using relative (for receivers only) and absolute (for receivers and satellites) GPS antenna phase centre corrections.

tions (for receivers and satellites) instead of relative ones (for receivers only), the mean bias between GPS and VLBI could be reduced from 5.3 to –0.8 mm (see Figure 2). With a careful handling of tracking problems and discontinuities a rigorous combination of the GPS and VLBI time series looks promising and is a future area of research.

Nutation

Although the direct estimation of nutation parameters using GPS is not possible due to the correlation with the orbital elements, GPS is capable to solve for nutation rates. In a special solution of the GPS reprocessing mentioned above, daily nutation rates in longitude and obliquity have been estimated. The comparison of a nutation model estimated from these nutation rates with earlier results by Rothacher et al. (1999) showed that a significant improvement could be achieved by the longer time series and the homogeneity due to the reprocessing. Figure 3 shows differences of the estimated nutation amplitudes for periods below 16 days with respect to the IAU2000 nutation model. A combination of the GPS nutation rates with VLBI nutation parameters is planned in the near future.

Acknowledgements

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The GPS reprocessing project of the Technical Universities in Dresden and Munich is funded by the Deutsche Forschungsgemeinschaft (DFG).

References

Brzezinski, A., Ch. Bizouard, and S. Petrov (2002): Influence of the atmosphere on Earth rotation: What new can be learned from the recent atmospheric angular momentum estimates?, *Surv. Geophysics*, **23**, 33–69.

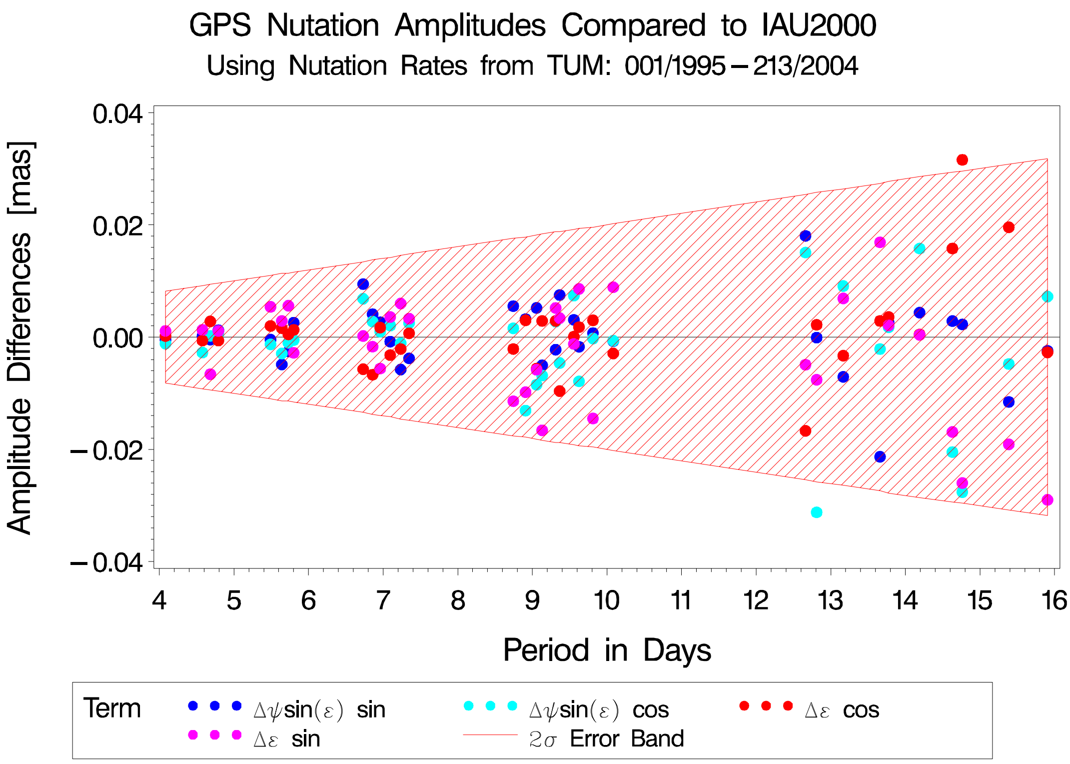

Figure 3: Differences between the GPS-derived nutation model and the IAU2000 nutation model. Noisy data from 1993 and 1994 has been excluded from the analysis and only periods smaller than 17 days are shown.
(For a colour version of this figure see the online version of this report at <www.iers.org>.)

Rothacher M., G. Beutler, T. Herring, R. Weber (1999): Estimation of nutation using the Global Positioning System, Journal of Geophysical Research, **104**, No. B3, p. 4835–4859.

Rothacher, M., G. Beutler, R. Weber, J. Hefty (2001): High frequency variations in earth rotation from Global Positioning System Data. *Journal of Geophysical Research*, American Geophysical Union, **106**, B7, 13711–13738.

Steigenberger P., M. Rothacher, R. Dietrich, M. Fritsche, A. Rülke (2004): Reprocessing of a Global GPS Network, European Geosciences Union, 1st General Assembly, 25–30 April 2004, Nice, Geophysical Research Abstracts, **Vol. 6**.

Steigenberger P., R. Schmid, M. Rothacher, V. Tesmer, M. Krügel, S. Vey (2005): Homogeneous long-time series of GPS and VLBI troposphere parameters, European Geosciences Union, General Assembly, 24–29 April 2005, Vienna, Geophysical Research Abstracts, **Vol. 7**.

Vondrak, J., A. Cepek, 2000: Combined smoothing method and its use in combining Earth orientation parameters measured by space techniques. *Astron. Astrophys. Suppl. Ser*. **147**, 347–357.

Markus Rothacher, Daniela Thaller, Robert Dill, Peter Steigenberger

3.6.2.4 Forsvarets forskningsinstitutt (FFI)

Introduction

FFI has during the last 20 years developed a software package called GEOSAT (Andersen, 1995) for the combined analysis of VLBI, GPS, SLR and other types of satellite tracking data (GLONASS, DORIS, PRARE and altimetry). The observations are combined at the observation level with a consistent model and consistent analysis strategies. The data processing is automated except for some manual editing of the SLR observations.

In the combined analysis of VLBI, GPS 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 2004 undergone extensive changes and improvements. This work will continue through 2005.

The most important changes implemented in 2004 are described in the following. The GEOSAT software has recently been upgraded to use numerical weather models (ECMWF) and 3D ray tracing for the calculation of signal delays due to the troposphere. Ten years of VLBI data have been analysed with this feature and the improvement of the results is remarkable. A lot of experimentation must be performed before final conclusions can be drawn, but it seems that the ECMWF model needs to be scaled by one or more estimated parameters in the VLBI analyses. Plots of these estimates and spectral analyses of the results reveal interesting results. The general trend is that the ECMWF model seems to perform better at low latitudes than at higher latitudes. There is a clear seasonal signal especially for the higher latitudes. The noise level of the estimated Earth orientation parameters is typically at the level of 50 microarcseconds for the angles and 2-3 microtimeseconds for UT1. The results suggest that the applied procedure can be used to investigate how well the ECMWF model is able to describe climatic changes. Of cause, many more years of data must be analysed for such applications.

Some months of SLR Lageos 1&2 data have been analysed with promising results.

A model for thermal deformation of the VLBI antenna structure has been included. Thermal coefficients and thermal time delays can in principle be estimated. Empirical VLBI axis offsets distributed by Axel Nothnagel recently, have been implemented in GEOSAT and are used as a priori values for the axis offsets.

Station-dependent centre-of-mass corrections for the two Lageos satellites have been implemented according to recommendations of the ILRS signal processing working group. An ocean tide gravity model derived from Topex data has been implemented in GEOSAT.

The IERS 2004 Conventions, including the new EOP parameterisation, has been fully implemented and tested.

The GEOSAT software has been extended for analysis of tracking data from spacecrafts in the Solar systems.

Future plans

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

References

Andersen, P. H. (2000) Multi-level arc combination with stochastic parameters. Journal of Geodesy (2000) 74: 531-551.

Andersen, P. H. (1995) High-precision station positioning and satellite orbit determination. PhD Thesis, NDRE/Publication 95/01094.

Per Helge Andersen

3.6.2.5 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. During 2004, the IVS combination process of EOP time series has been improved further. Here, a procedure for considering correlations between the different IVS Analysis Centres has been developed and further refined (Steinforth and Nothnagel 2004).

The second activity concerns the combination of EOP and station coordinates of VLBI solutions using SINEX V2.0 output files (Vennebusch 2004). Here, the output of solutions in the form of datum-free normal equation matrices is used as input for the combination. The output is again a datum-free normal equation system containing all the information of the input solutions. This can then be used for further combination with the other space geodetic techniques. In previous years, input solutions were only provided by IVS Analysis Centres using the Calc/Solve VLBI analysis software. This fact facilitated the first steps of SINEX-based combinations in the past since the identical software guaranteed a consistent handling of certain geophysical effects. In 2004, input has also been provided on the basis of the OCCAM and the SteelBreeze software. The new challenge now is that the nutation models used as apriori information as well as the paradigms, old (IAU1976/1980) and new (IAU2000), may be quite different for the input series. The preprocessing of the combination is, thus, not only necessary for a transformation to an identical reference epoch but also for the nutation model as such. Since this is quite a complex task which will not be necessary any more when all analysis centres use the IAU2000 paradigm, it was decided to spare the development of the necessary routines for the time being. The input normal equations are, thus, first being processed individually in order to eliminate the elements of the two nutation parameters through further steps of de-composition. Through this procedure the elements for the nutation parameters are automatically excluded in the subsequent combination process and the output SINEX files contain only elements for polar motion, UT1–UTC with their rates and for the station coordinates. This procedure has been used for the IVS contribution to the IERS Combination Pilot Project and will also be used for the IVS submissions to the ITRF2004 initiative.

References

Steinforth, C., Nothnagel, A. (2004): Considering a Priori Correlations in the IVS Combined EOP Series; N.R. Vandenberg, K.D. Baver (eds.), IVS 2004 General Meeting Proceedings, NASA-CP-2004-212255, Greenbelt MD, 413–417

Vennebusch, M.(2004): First Results of SINEX Combinations; N.R. Vandenberg, K.D. Baver (eds.), IVS 2004 General Meeting Proceedings, NASA-CP-2004-212255, Greenbelt MD, 423–426

Axel Nothnagel, Dorothee Fischer, Christoph Steinforth, Markus Vennebusch

3.6.2.6 GeoForschungsZentrum Potsdam (GFZ)

Inclusion of low degree gravity coefficients into reference frame solutions

Low degree/order gravity coefficients are closely related to the definition of a reference frame. Actually, degree one coefficients define the geocentre, C21 and S21 fix the position of the rotation axis of a reference frame, etc. Theoretically, these coefficients should be included as part of the reference-frame-related products, just like EOP and station positions. It had been impossible in practice, since EOP and site positions can be determined on daily (or weekly) basis, the gravity solution could not be estimated so densely and accurately. It was the long term aim of GFZ to make it be realized.

Within the report period, GFZ has used its newly revised EPOS software and the data from LEO satellite missions (CHAMP, GRACE) to solve this problem. A three months period (Jul–Sep 2004) has been taken as the test period. The tracking data from the ground stations to GPS satellites plus the GPS and K-band data from GRACE were used to solve GPS and LEO orbits, site positions of the GPS stations, EOP, gravity coefficients up to degree/order 10/10 (altogether 120 gravity coefficients) simultaneously on a daily basis.

The test results are very positive:

1) gravity coefficients can be solved on a daily basis;
2) they are solved simultaneously with other reference frame products (EOP, site positions), therefore these products are homogeneous and consistent;
3) the daily gravity coefficients have similar accuracy as EOP and station coordinates, the daily repeatability of gravity coefficients is 1×10^{-9} for degree one, 1×10^{-10} for degree two, and around $2–5\times10^{-11}$ for degree 3 to 10 coefficients.

This three months test solution can be extended to an operational procedure, if enough man power is available. It is recommended that in the future low degree/order gravity coefficients should be officially adopted as part of the IERS reference frame products.

Franz-Heinrich Massmann, Chuang Shi, Sheng Yuan Zhu

3.6.2.7 Groupe de Recherches de Géodésie Spatiale (GRGS)

In the framework of the IERS Combination Research Centres, the "Groupe de Recherches de Géodesie Spatiale" (GRGS) has organized the different tasks in order to participate in the IERS Combination Pilot Project (CPP) and to deliver routinely from beginning of 2005 weekly SINEX files from combination of five space techniques.

GRGS' organisation

Groups of the Paris Observatory (N. Capitaine, D. Gambis, A.-M. Gontier, J. Chapront, G. Francou, T. Carlucci) , of the Observatory of the "Côte d'Azur" (P. Exertier, D. Coulot, Ph. Bério), of CNES (R. Biancale, J.-M. Lemoine, J.-C. Marty), of the Noveltis (S. Loyer) and CLS (L. Soudarin) companies and with the expertise of P. Charlot (Bordeaux Observatory) and Z. Altamimi (IGN) have worked together in the framework of GRGS to succeed in combining at the observation level SLR, LLR, GPS, DORIS and VLBI observations for providing consistent Earth Rotation Parameters and station network coordinates on a weekly basis.

All processing are made with the GINS software and using the same up-to-date standards. In the test phase which took place in 2004, we have chosen for validating our combination approach to process data from the five techniques over the whole year 2002: SLR has been processed in OCA, VLBI and LLR in Paris Observatory and CNES, DORIS in CLS, GPS in Noveltis. The combination have been performed in OCA with the DYNAMO software package and in IGN. In the routine phase from 2005 onward, roles will be somewhat different, VLBI amounting to the Bordeaux Observatory and the combination process to the Paris Observatory.

Processing of individual techniques

At first some improvement has been achieved and orbit standards have been fixed before processing individual techniques. We took care particularly of GPS processing in order to approach the IGS level of quality. Produced GPS orbits obtained with the GRGS' GINS software compare now globally at 10 cm in 3D rms.

Moreover the LLR technique has been introduced in the GINS software, based on Moon 6-h ephemeris and libration parameter series derived from the CAROLL software of the Paris Observatory. Results over the year 2002 have shown residuals around 13 cm rms from measurements of both stations, Grasse and Mac Donald.

SLR residuals on Lageos-1 and -2 reach 1 cm in average. It is to notice that D. Coulot and Ph. Bério have even detected in their computation a sudden change in the orbit of Lageos on April 5th which is probably due to a space particle impact.

Classical DORIS residuals on the SPOT satellites are around .4 mm/s. ENVISAT measurement residuals are a little bit higher, due to a small bug on the attitude detected later on. Routinely Jason should replace TOPEX (because of the definitive failure of the on-board DORIS receiver end of 2004 after having worked more than 12 years) when the oscillator anomaly in the SAA will be corrected by modelling.

At last, four VLBI sessions (A, F, E and U) were processed over 2002: they give residuals of the order of 30 ps (~1 cm).

Combination of techniques

The combination process of weekly normal equations has been intensively studied and assessed by D. Coulot and Ph. Bério in OCA over the test year 2002. The optimal relative weights between each technique were obtained weekly by using the Helmert's optimal variance-covariance method for combining normals of x- and y-pole parameters and UT1 every 6 hours, nutation corrections in obliquity and longitude every 12 hours and weekly stations coordinates from all techniques. Solutions were stabilized applying minimal constraints per technique and per week through the classical Helmert's transformation on station coordinates in order the whole network stays close to the ITRF2000 reference system. This strategy applied for combination in the 2002 test year has been slightly modified for the CPP.

Results

Comparisons of the adjusted Earth Rotation Parameters have shown rms differences to the official EOPC04 series of .07 mas for the pole and of .01 ms for UT1. All station coordinates have been adjusted weekly and we have particularly looked at collocated stations which present a fair homogeneous behaviour.

These results for instance in the polar motion and UT1 have shown sufficient quality with respect to results of individual techniques that we decided to pursue the experiment in participating to the CRC's CPP from beginning of 2005. For that purpose we have developed an interface software for converting the DYNAMO format into SINEX files which are then delivered to the IERS server beside the SINEX files of the international services (ILRS, IGS, IVS, …).

Richard Biancale

3.6.2.8 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).

3.6.2.9 Institute of Applied Astronomy (IAA)

Research groups and staff

Two labs of the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA) were involved in 2004 in the IERS CRC related activity:

1. Laboratory of Space Geodesy and Earth Rotation (LSGER)

   Dr. Zinovy Malkin, malkin@quasar.ipa.nw.ru
   Natalia Panafidina, nap@quasar.ipa.nw.ru

2. Laboratory of Ephemeris Astronomy (LEA)

   Nadia Shuygina, nvf@quasar.ipa.nw.ru

LSGER group

Comparison and combination of EOP series

During the last year we continued to develop software for comparison and combination of EOP series. This software is 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 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. This job is planned to be fulfilled in several steps:

- UT1(VLBI) solution with daily resolution obtained from combination of 24h and intensive VLBI series;
- LOD(Sat) solution with daily resolution obtained from combination of GPS and SLR data;
- UT1(Sat) series computed by means of integration of LOD(Sat);
- final combined UT1 series obtained from the VLBI and satellite solutions;
- PM(Sat) solution with daily resolution obtained from combination of GPS and SLR data;
- final combined PM series obtained from the VLBI and satellite solutions.

Combination of EPN Analysis Centres' solutions

The observations from the European Permanent GPS Network (EPN) are processed by a set of Analysis Centres and official combined coordinate solutions are available on weekly basis. The fiducial approach used in the processing and changes of the reference frame can cause jumps in coordinates and distortion of the network. For that reason a new combined coordinate solution for stations of EPN was obtained with the minimum constraint approach.

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 a 7-parameters Helmert transformation, catalogue velocities were used here for 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.

All data from the week 900 till the week 1302 were used. An investigation of the stability of the new combination was performed. Time series of transformation parameters from the new combined solution into ITRF2000 were expected to be stable, with no linear trends since here also for each GPS week the catalogue coordinates were propagated to the epoch of the respective week. Some systematic components occur in the time series for y-translation and scale. This effects can be caused by an insufficient constraints removal, and decreasing of the number of common EPN and ITRF2000 stations to the end of the interval of processing.

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

LEA group

Determination of EOP from combination of SLR and VLBI data

The main goal of this investigation is to determine EOP series from the analysis of VLBI and SLR measurements at the observation level. Laser ranges to the geodetic satellites Lageos, Lageos-2, Etalon-1, and Etalon-2 obtained on one month period are processed along with the 4 sessions of VLBI measurements of extragalactic sources obtained in the NEOS-A campaign at the same time interval. A Kalman filtering procedure was used for modelling time variations of all Earth Orientation Parameters. It appears that combining SLR and VLBI measurements makes it possible to get standard deviations of parameters evaluated 1.3 times smaller to compare with those obtained by means of each technique separately. Comparison with EOP (IERS) C04 shows that root mean square residuals of this monthly series of EOP are the following: 0.16 mas for Xp, 0.20 mas for Yp, 0.013 ms for UT1–UTC, 0.27 mas and 0.23 mas for the coordinates of the celestial pole. It is important that applying the Kalman filtering permits us to derive Earth Rotation Parameters with a subdiurnal resolution.

Zinovy Malkin, Natalia Panafidina, Nadia Shuygina

3.6.2.10 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 2004, three such reference series were generated: (1) SPACE2003, consisting of values and rates for polar motion and UT1 spanning September 28, 1976 to January 31, 2004 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) COMB2003, consisting of values and rates for polar motion and UT1 spanning January 20, 1962 to January 31, 2004 at daily intervals, was generated by additionally including the BIH optical astrometric measurements with the space-geodetic measurements used to generate SPACE2003; and (3) POLE2003, consisting of values and rates for just polar motion spanning January 20, 1900 to January 21, 2004 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 COMB2003. These reference series can be obtained by anonymous ftp to <ftp://euler.jpl.nasa.gov/keof/combinations/2003>. A report describing the generation of these series [Gross, 2004] 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 2004 were largely concerned with updating the stochastic model used by the Kalman filter that describes the polar motion excitation process. The existing model for the x- and y-components of polar motion excitation includes an isotropic random walk with equal noise forcing both components and having a white noise power spectral density of 246.6 mas^2/day. In order for the filter to work properly, the stochastic model must be appropriate in the region of the excitation spectrum where the signal-to-noise ratio is near unity. Twenty years ago, when the stochastic model was first developed, the signal-to-noise ratio was near unity at periods of about 20 to 40 days. But with accurate GPS measurements of polar motion and polar motion rate now being routinely available at daily intervals, the polar motion excitation signal-to-noise ratio is currently near unity at a period of about 5 days. Increasing the white noise power spectral density by a factor of 3, to 739.2 mas^2/day, was found to give a better match to the observed polar motion excitation spectrum at a period of 5 days. This change to the stochastic model used by the Kalman filter to describe polar motion excitation will result in polar motion and polar motion excitation estimates that are not as smooth as before.

Acknowledgements. 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.

References

Gross, R. S., Combinations of Earth orientation measurements: SPACE2003, COMB2003, and POLE2003, Jet Propulsion Laboratory Publ. 04-12, 28 pp., Pasadena, Calif., 2004.

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.

- Future Planning
  - The WG will make recommendations and prepare for the future in respect to the ongoing site survey needs of the community and how these needs will be met in the long term (to address issues outside of the scope of this WG). Develop recommendations as to how the community can provide the IERS database with all information relevant to inter-technique combination and to the maintenance of the ITRF.

WG Meetings

The first meeting of the IERS Working Group was held at the April 2004 EGU in Nice, there were 18 attendees. As a result of this meeting WG members have agreed:

- To undertake a Pilot Project (PP) in site survey and co-location;
- To draft survey standards document is to be revised in parallel with the WG pilot project activities. This document will provide more details and explanatory content and include a full site survey report example – it will be useful to those new to site surveys at co-located observatories;
- To draft a brief explanation for the need of precise terrestrial ties (to be included in site survey documentation);
- Establish an IERS WG web site. The web site will initially provide links to the template survey documents and example survey reports;
- The WG is to collate all existing site survey reports for the WG web site (or provide web links to them);
- WG to clearly define output products including a detailed explanation of the SINEX requirements; and
- WG to address the issue of VLBI antenna deformation including its observation and to quantify its impact on VLBI results.

Attendees of the Nice meeting felt that the WG pilot project would not address the broader problems of the IERS in respect to local ties, the WG will continue in its research focussed role and provide technical support to a broader strategy by the IERS to address the local tie problem.

WG Web Site

The IERS Central Bureau has established a web site at <http://www.iers.org/iers/about/wg/wg2>. The web site provides links to relevant WG documents, including the draft survey report format document. It is the WG's intention to use the web site as a forum for discussions related to local tie survey.

WG Site Survey and Co-location Pilot Project

The dissemination of a Call for Participation in the Site Survey and Co-location Pilot Project (SSCPP) was made in November, 2004. A review of the SSCPP activities will be undertaken in April 2005 at the EGU meeting in Vienna.

The SSCPP will broadly address the following technical issues: observational techniques; survey network design and monumentation; classical geodetic adjustment; indirect geometrical modelling and/or direct measurement techniques for invariant point determination; reference point definition and access; local to global reference frame alignment; structural and network deformation modelling; and SINEX generation.

Future Meetings

The working group has planned to meet again at the EGU05 in Vienna, Austria (April 2005) and at the IAG General Assembly, Cairns, Australia (August 2005).

John Dawson

3.7.2 Working Group on Combination

Status and Future of the IERS Combination Pilot Project

The IERS Combination Pilot Project (CPP) is a major step towards more consistent IERS products that are generated routinely.

Starting with GPS week 1260 (i.e., February 29, 2004) the technique services IGS, ILRS, IVS and IDS are asked to provide a weekly combined SINEX solution of the respective technique, including station coordinates, Earth Orientation Parameters (EOP), and, in the case of VLBI, possibly quasar coordinates. Eight weeks after the respective week of observations, the combined intra-technique solutions should be available for the second step, i.e., the inter-technique combination. Six institutions proposed to participate in the inter-technique combination and will deliver a weekly combined solution after another four weeks, i.e., 12 weeks after the observations. The last step consists of comparisons and quality checks of the inter-technique solutions. Besides the combination centres doing internal quality checks of their inter-technique solutions themselves, two independent institutions proposed to participate in this third step of the pilot project. The deadline for the validation report is 16 weeks after the observations, thus allowing four weeks of time for the validation process.

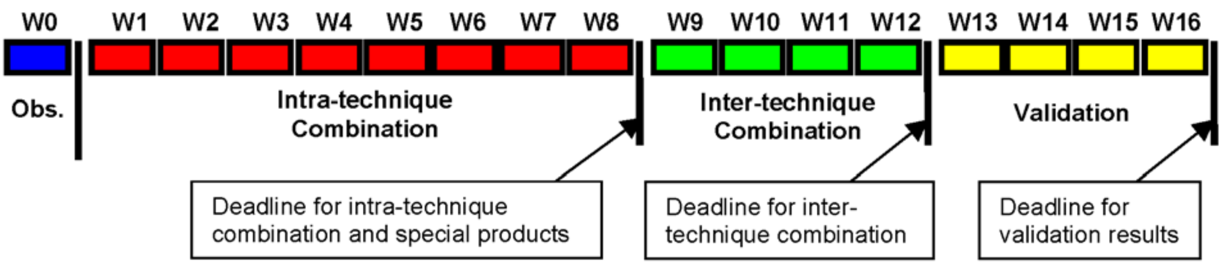

Fig. 1: Schedule of the Combination Pilot Project

Additionally, several institutions answered the call and proposed to deliver some special products, e.g., sub-daily Earth Rotation Parameters, a solution combined on the observation level, etc.

The status at the end of 2004 is, that the combined intra-technique solutions are routinely available in time (all combinations except DORIS). The files / solutions are accessible via the web site <http://iers1.bkg.bund.de/info/listCPP.php>.

However, the inter-technique combination results are still missing and therefore also the validation part. To support the IERS CPP with more weekly solutions (but mainly to generate a new ITRF2004 solution) a Call for long time series was issued.

More information may be found at the IERS web site (<http://www.iers.org/>).

Status and Future of the IERS Long Time Series

As already mentioned in chapter 3.3 (Analysis Coordination) of this volume, the availability of long time series is essential for a weekly rigorous combination of space geodetic solutions.

The derivation of weighting schemes and the application of local ties is only possible reasonably if a longer series of weekly solutions or a long time solution is available.

Due to the call for IERS Long Time Series, combined intra-technique solutions from all techniques are available for long time spans. It must be emphasized that this is the first time that all the technique services IGS, IVS and ILRS place a combined solution of the respective technique including station coordinates and EOPs at the disposal. Additionally, all the solutions were reprocessed, except for IGS, so that they form a homogeneous time series.

The available files / solutions are accessible via the website maintained by the IERS Central Bureau: <http://iers1.bkg.bund.de/info/listFileITRF2004.php>

Furthermore, for future products 'ITRF + EOP', the long time series build the basis for the generation of these products. The next main step for this topic is the generation of the ITRF2004 (station coordinates, velocities and EOP) by the ITRF Combination Centres IGN, DGFI and NRCan. The envisaged date for presenting the final solution is August 2005 at the IAG Scientific Assembly at Cairns / Australia.

Meetings and Workshops

Several meetings during 2004 had a session dedicated to combination of space geodetic techniques. A detailed overview is given in section 3.3 of this volume (IERS Analysis Coordinator).

Future Activities

Regarding the weekly combinations, it should be envisaged for the future to include other parameters as well: To complete the group of reference frame related parameters, the quasar coordinates representing the celestial reference frame and the nutation parameters (offsets and rates according to IAU2000) are of special interest. But also the troposphere parameters (zenith delays and horizontal gradients) should not be forgotten as they are common to all microwave techniques and they are influencing the terrestrial reference frame due to their correlation with station coordinates. Other parameters that are common to more space techniques like orbits or clocks could be included in the combination as well.
Furthermore, it is worth to think about a sub-daily resolution for Earth rotation parameters as an additional product.
Concerning the latency of the combined IERS products, it is the question whether it would be possible to reduce the latency from now 2 months for the weekly inter-technique combination in the CPP to a date closer to the observations. Additionally, to go even a step further, it would be an option to generate so-called rapid IERS

products which are then based on daily combinations and not on weekly solutions.

And finally, groups that can do a combination on observation level are encouraged to contribute to the IERS combination activities, and probably additional groups will work towards a combination on observation level.

As the IVS has decided to initiate a two-week continuous VLBI campaign in 2005 (as already done in 1996 and 2002), named CONT05, there will be additional observation material that can be used for special and very detailed combination studies.

Markus Rothacher, Daniela Thaller

4 IERS Workshop on the Combination Pilot Project

A workshop devoted to the „IERS Combination Pilot Project" has been organized by the International Earth Rotation and Reference Systems Service (IERS).

To discuss the future aspects and consequences of the IERS Combination Pilot Project (CPP) experts of the IERS Working Group on Combination, the participants in the Combination Pilot Project together with representatives of the Technique Services – in total 23 persons – came together at the Chateau Hotel & Conference Centre in Napa, CA, USA on December 11, 2004.

The following topics were discussed:

1) Combination Pilot Project and CONT'02 („Weekly" SINEX)

2) Long Time Series and their combination (ITRF, IERS200x, ...)

3) Database and Information Systems

with the main focus on aspects concerning the IERS CPP.

From the presentations and discussions during the workshop the following preliminary conclusions for the CPP can be drawn:

- It took some time for the Technique Centres to start to compute combined intra-technique solutions.
- It is very important to have the Technique Centres fully involved, taking their responsibility for the technique-specific products (SINEX).
- Difficulties within the CPP showing up already now:
  - proper weighting of the technique solutions on a weekly basis,
  - proper datum definition for each week.
- Long time series from new ITRF2004/IERS200x are very important to support and complement the CPP.

The programme, the presentations and the list of participants can be reviewed and downloaded at

<http://www.iers.org/workshop_2004_napa/>.

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.
- Convention 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,

  - o 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

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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/iers/products/>.

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://lareg.ensg.ign.fr/ITRF/
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/iers/publications/messages/

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/iers/publications/bulletins/

IERS Technical Notes
http://www.iers.org/iers/publications/tn/

IERS Annual Reports
http://www.iers.org/iers/publications/reports/

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

IERS Components

Directing Board
Web page: http://www.iers.org/iers/about/db/

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

Central Bureau
Web site: http://www.iers.org/

Product Centres

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

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

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

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

ITRS Centre
Web site: http://lareg.ensg.ign.fr/ITRF/

Global Geophysical Fluids Centre
Web site: http://www.ecgs.lu/ggfc/
Special Bureaus:
Special Bureau for the Atmosphere
Web site: http://www.aer.com/groups/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

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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/dgfi/IERS/

Forschungseinrichtung Satellitengeodäsie, Technical University Munich (FESG)
Web page: http://www.iers.org/iers/crc/fesg/

Forsvarets forskningsinstitutt (FFI, Norwegian Defence Research Establishment)
Web page: http://www.iers.org/iers/crc/ffi/

GeoForschungsZentrum Potsdam (GFZ)
Web page: http://www.iers.org/iers/crc/gfz/

Geodetic Institute of the University of Bonn (GIUB)
Web page: http://www.iers.org/iers/crc/giub/

Groupe de Recherches de Géodésie Spatiale (GRGS)
Web page: http://www.iers.org/iers/crc/grgs/

Institute of Applied Astronomy, St. Petersburg (IAA)
Web page: http://www.iers.org/iers/crc/iaa/

Institut Géographique National (IGN)
Web page: http://www.iers.org/iers/crc/ign/

Jet Propulsion Laboratory (JPL)
Web page: http://www.iers.org/iers/crc/jpl/

Appendix 5: Acronyms

AAM	Atmospheric Angular Momentum
AC	Analysis Centre
AC	Analysis Coordinator
AER	Atmospheric and Environmental Research Inc.
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
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
CEP	Celestial Ephemeris Pole
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques
CGS	Centro di Geodesia Spatiale, ASI
CLS	Collecte, Localisation, Satellites
CMB	core-mantle boundary
CMT	Centroid Moment Tensor
CNES	Centre National d'Etude Spatiale
COD	= CODE
CODE	Centre for Orbit Determination in Europe
CONT	continuous VLBI session
COSPAR	Committee on Space Research
COU	CODE Ultra Rapid orbits
CPC	Climate Prediction Center
CPP	IERS Combination Pilot Project
CRC	Combination Research Centre
CRF	Celestial Reference Frame
CSR	Center for Space Research
CSRIFS	Combined Square Root Information Filter and Smoother
CTIO	Cerro Tololo Inter-American Observatory
DANOF	Département d'Astronomie Fondamentale
DB	Directing Board
DEOS	Delft Institute for Earth-Oriented Space Research
DGFI	Deutsches Geodätisches Forschungsinstitut
DOMES	Directory Of MERIT Sites (originally; now of more general use)
DORIS	Doppler Orbit determination and Radiopositioning Integrated on Satellite
DUT	Delft University of Technology
DUT1	= UT1-UTC
ECCO	Estimating the Circulation and Climate of the Ocean
ECMWF	European Center for Medium Range Weather Forecasting
EGU	European Geosciences Union
EMR	Energy, Mines and Resources Canada (replaced by NRCan)
EMU	NRCan Ultra Rapid orbits
ENSG	Ecole Nationale de Sciences Geographiques
EOC	Earth Orientation Centre
EOP	Earth Orientation Parameters
EPN	European Permanent GPS Network
ERP	Earth Rotation Parameters
ESA	European Space Agency
ESO	European Southern Observatory
ESOC	European Space Agency Operational Center
ESU	ESOC Ultra Rapid orbits

EUREF	European Reference Frame
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
GAOUA	Main Astronomical Observatory of the Ukrainian Academy of Sciences
GEOSS	Global Earth Observation System of Systems
GFU	GFZ Ultra Rapid orbits
GFZ	GeoForschungsZentrum Potsdam
GGFC	Global Geophysical Fluids Centre
GGOS	Global Geodetic Observing System
GIA	glacial isostatic adjustment
GIUB	Geodetic Institute of the University of Bonn
GLDAS	Global Land Data Assimilation System
GLONASS	Global Orbiting Navigation Satellite System, Russia
GLOUP	GLObal Undersea Pressure
GNAAC	IGS Global Network Associate Analysis Center
GNSS	Global Navigation Satellite System
GOPE	Geodetic Observatory Pecny
GOU	GOPE Ultra Rapid orbits
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
IAG	International Association of Geodesy
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)
IGN	Institut Géographique National
IGS	International GNSS Service (formerly: International GPS Service)
IGU	IGS Ultra Rapid orbits
ILRS	International Laser Ranging Service
INASAN	INstitut AStronomii Rossijskoj Akademii Nauk (Institute of Astronomy of the Russian Academy of Sciences)
IRIS	International Radio Interferometric Surveying
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
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
LBA	Australian Long Baseline Array
LDAS	Land Data Assimilation System
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LEA	Laboratory of Ephemeris Astronomy, IAA
LEO	Low Earth Orbit(er)
LLR	Lunar Laser Ranging
LOD	Length of Day
LPCE	Laboratoire de Physique et Chimie de l'Environnement
LSGER	Laboratory of Space Geodesy and Earth Rotation, IAA
MAO	= GAOUA

mas	milliarcsecond(s)
µas	microarcsecond(s)
MCC	Russian Mission Control Centre
MCEP	mean Celestial Ephemeris Pole
MICOM	Miami Isopycnic Coordinate Ocean Model
MIT	Massachusetts Institute of Technology
MJD	Modified Julian Day
MOM	Modular Ocean Model
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
NCL	University of Newcastle upon Tyne
NERC	Natural Environment Research Council, UK
NetCDF	Network Common Data Form
NGS	U.S. National Geodetic Survey
NIPR	National Institute for Polar Research, Japan
NOAA	U.S. National Oceanic and Atmospheric Administration
NOFS	USNO Flagstaff Station
NRAO	U.S. National Radio Astronomy Observatory
NRCan	Natural Resources, Canada (formerly: EMR)
NSGF	NERC Space Geodesy Facility
NUVEL	Northwestern University Velocity Model
OCA	Observatoire de la Côte d'Azur
OP	Observatoire de Paris
PC	Product Centre
PCV	phase-center variations
PDF	Portable Document Format
PHP	PHP: Hypertext Preprocessor
PM	Polar Motion
POCM	Parallel Ocean Climate Model
PP	Pilot Project
PPARC	Particle Physics and Astronomy Council, UK
PPP	Precise Point Positioning
PRARE	Precise RAnge and Range-Rate Equipment
PZT	Photographic Zenith Tube (Telescope)
R&D	Research and Development
RDV	Research and Development (sessions) with the VLBA
RINEX	Receiver INdependent EXchange format
rms, RMS	Root Mean Square
RRFID	USNO Radio Reference Frame Image Database
SB	Special Bureau
SBA	Special Bureau for the Atmosphere
SBC	Special Bureau for the Core
SBH	Special Bureau for Hydrology
SBL	Special Bureau for Loading
SBO	Special Bureau for the Oceans
SIM	NASA's Space Interferometry Mission
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SIU	SIO Ultra Rapid orbits
SLR	Satellite Laser Ranging
SOD	CNES Service d'Orbitographie DORIS
SOFA	Standards Of Fundamental Astronomy
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
TAI	Temps Atomique International (International Atomic Time)
TC	Technique Centre
TEMPO	Time and Earth Motion Precision Observations
TN	IERS Technical Note
ToR	Terms of Reference
TRF	Terrestrial Reference Frame
TT	Terrestrial Time
UCAC	USNO CCD Astrograph Catalog
UKMO	Met Office, UK
UNESCO	United Nations Educational, Scientific and Cultural Organization
Univ.	University

URAT	USNO Robotic Astrometric Telescope	UTC	Coordinated Universal Time
URL	Uniform Resource Locator	VLBA	Very Long Baseline Array, NRAO
URSI	Union Radio-Scientifique Internationale / International Union of Radio Science	VLBI	Very Long Baseline Interferometry
		VSI-E	VLBI Standard Interface for E-VLBI
USNO	United States Naval Observatory	VUGTK	Research Institute of Geodesy, Topography and Cartography, Czech Republic
USU	USNO Ultra Rapid orbits		
UT	University of Texas	WG	working group
UT, UT0, UT1, UT1R	Universal Time	XML	eXtensible Markup Language
		yr	year
UTAAM	NCEP AAM analysis and forecast data	ZWD	zenith wet delays