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

IERS Annual Report 2003

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IERS Annual Report 2003

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Druckerei:

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1 Foreword

You are opening the IERS Annual Report for 2003. At a first glance, its overall structure closely resembles the Report for 2002, but an attentive reader will find that it contains several new sections, reflecting the inevitable development and modernization of the Service.

First of all, the International DORIS Service (IDS) was approved, after several years of testing, by the IAG as its full service at the IUGG General Assembly (Sapporo, August 2003). Consequently, it became the fourth Technique Centre of the IERS. I would like to use this occasion for welcoming most heartily this new component of the IERS, and express my conviction that it will contribute substantially to improve the IERS products. The report of IDS is to be found in Section 3.4.4.

Secondly, the family of Combination Research Centres grew by a new member. Agenzia Spaziale Italiana – Centro di Geodesia Spaziale is enriching the research component of the IERS since 2003, thus raising the number of CRCs to eleven (see Section 3.6.2.1 for their report).

Future activities of the IERS, reflecting the new challenges posed by the dramatic increase of accuracy of space geodetic observations achieved during the last years, were discussed and finally launched during two important meetings that took place in 2003:

- IERS Retreat 2003 (Paris, April 2003) led to establishing three new Working Groups (WG on Combination, WG on ITRF Datum, and WG on Site Co-location), and to starting the IERS Combination Pilot Project that should eventually lead to routinely made rigorous combination of different techniques, and to a set of mutually consistent products (for details see Section 4.1). According to the recommendation of the Retreat, the Directing Board changed the name of the IERS to *International Earth rotation and Reference systems Service*, without changing its acronym.
- IERS Workshop on site co-location surveys (Matera, October 2003) discussed the problems of precise site surveying, adjustment of local ties and networks, and other issues important for future improvements of the consistency of IERS products (Section 4.2).

This list of novelties in 2003 is far from being exhaustive – if you want to learn more about all IERS activities and products, please take the time and read the chapters that follow.

Jan Vondrák

2 The IERS
2.1 Structure

In 2003 and the beginning of 2004, 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 new components and for other changes in 2003 and 2004.

Analysis Coordinator

Markus Rothacher

Central Bureau

Director: Bernd Richter

Technique Centres

International GPS Service (IGS)
IGS Representatives to the IERS Directing Board:
Carine Bruyninx (until 31 December 2003), Robert Weber (until March 2003), Gerd Gendt (since April 2003)
IERS Representative to the IGS Directing 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:
Martine Feissel-Vernier, Hervé Fagard (since October 2003)

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 (since February 2003)

Convention Centre
Primary scientists: Dennis D. McCarthy, Gérard Petit
Representative to the IERS Directing Board:
Dennis D. McCarthy (until 31 December 2003),
Gérard Petit (since 1 January 2004)

ICRS Centre
Primary scientists: Ralph A. Gaume, Jean Souchay
Current representative to the IERS Directing Board: Jean Souchay

ITRS Centre
Primary scientist and representative to the IERS Directing Board: Claude Boucher

Global Geophysical Fluids Centre
Head and representative to the IERS Directing Board: Benjamin F. Chao

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

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, *Vice-chair*: Hans-Peter Plag

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)
(established in March 2003)
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

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

GeoForschungsZentrum Potsdam (GFZ)
Primary scientist: Sheng Yuan Zhu

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

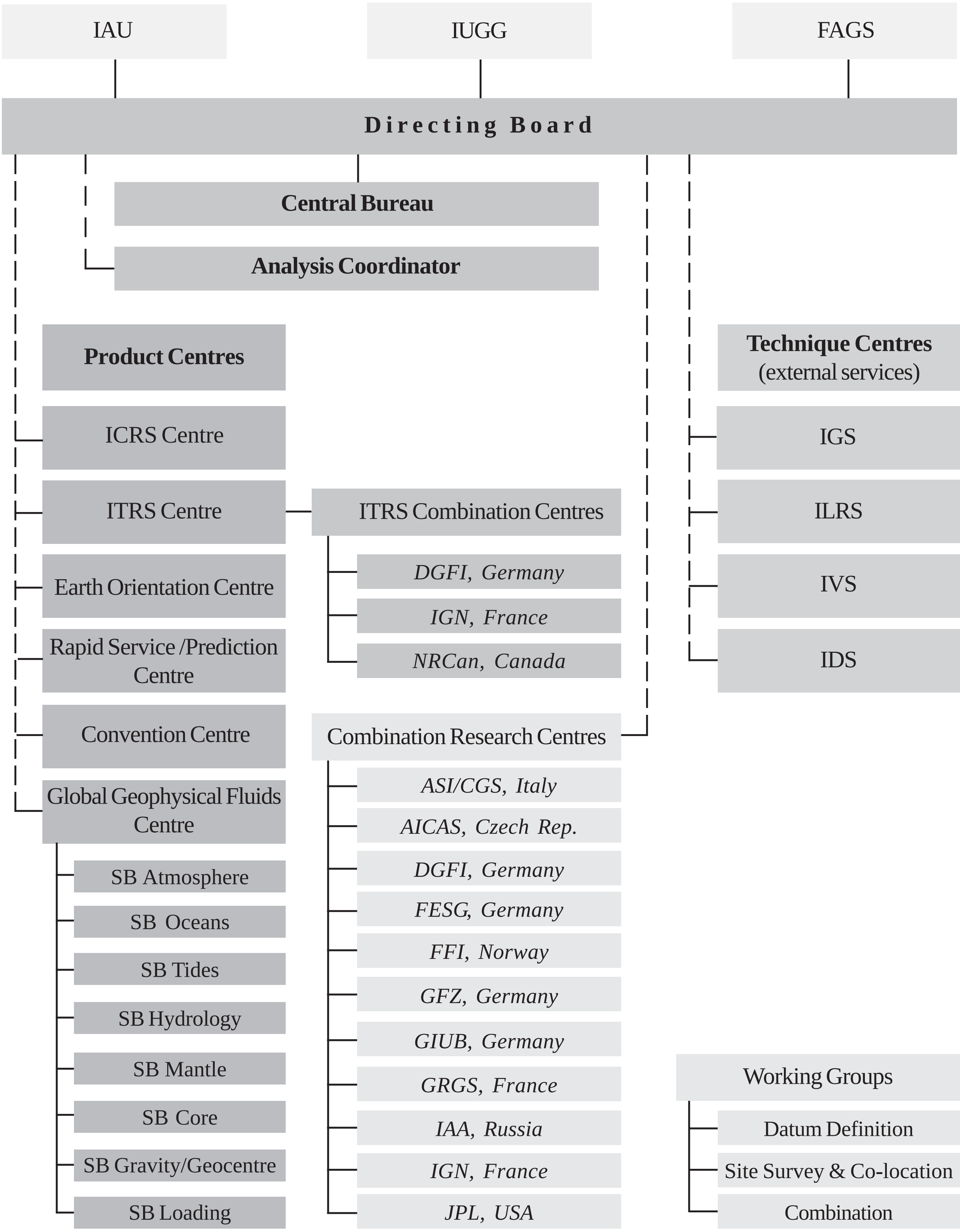
Jet Propulsion Laboratory (JPL)
Primary scientist: Richard S. Gross

Working Groups

Working Group on Datum Definition (WG 1)
(to be established)

Working Group on Site Survey and Co-location (WG 2)
(established in February 2004)
Chair: John Dawson

Working Group on Combination (WG 3)
(established in January 2004)
Chair: Markus Rothacher


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

2.2 Directing Board

In 2003 and 2004, the IERS Directing Board had the following members (for addresses see Appendix 2):

Chair	Jan Vondrák
Analysis Coordinator	Markus Rothacher
Product Centres Representatives	
Earth Orientation Centre	Daniel Gambis
Rapid Service/Prediction Centre	William Wooden (since March 2003)
Conventions Centre	Dennis D. McCarthy (until 31 December 2003) Gérard Petit (since 1 January 2004)
ICRS Centre	Jean Souchay
ITRS Centre	Claude Boucher
Global Geophysical Fluids Centre	Benjamin F. Chao
Central Bureau	Bernd Richter
Combination Research Centres	Sheng Yuan Zhu
Technique Centers Representatives	
IGS	Carine Bruyninx (until 31 December 2003) Robert Weber (until March 2003) Gerd Gendt (since April 2003)
ILRS	Ron Noomen Peter J. Shelus
IVS	Chopo Ma Axel Nothnagel
IDS	Pascal Willis (observing status, until July 2003) Martine Feissel-Vernier (since October 2003) Hervé Fagard (since October 2003)
Union Representatives	
IAU	Jan Vondrák
IAG / IUGG	Clark R. Wilson
FAGS	David Pugh

2.3 Associate Members

Altamimi, Zuheir
Andersen, Ole Baltazar
Andersen, Per Helge
Angermann, Detlef
Arias, Elisa Felicitas
Biancale, Richard
Bianco, Giuseppe
Bruyninx, Carine
Carter, William E.
Dam, Tonie van
Dawson, John
Dow, John M.
Drewes, Hermann
Ferland, Remi
Gaume, Ralph A.
Gross, Richard S.
Gurtner, Werner
Herring, Thomas
Hoolst, Tim van
Kolaczek, Barbara
Kostelecký, Jan
Malkin, Zinovy M.
McCarthy, Dennis D.
Melbourne, William G.
Neilan, Ruth E.
Pearlman, Michael R.
Plag, Hans-Peter
Ray, Jim
Ray, Richard D.
Reigber, Christoph
Salstein, David
Schlüter, Wolfgang
Schutz, Bob E.
Tavernier, Gilles
Vandenberg, Nancy
Veillet, Christian
Watkins, Michael M.
Weber, Robert
Willis, Pascal
Yatskiv, Yaroslav S.
Yokoyama, Koichi

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: Veronique Dehant
President of IAU Commission 31: Demetrios Matsakis
Head of IAU Division I: Toshio Fukushima

(*Status as of June 2004*)

3 Reports of IERS components
3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of the year 2003. Short summaries of these meetings are given below. Before Meeting No. 37, the DB met with other experts for an IERS Retreat, a report of which is given in Section 4.1.

Meeting No. 37

Wednesday, April 2, 2003, Observatoire de Paris, Paris, France

J. Vondrák welcomed the participants of the meeting and introduced the vice president of the Observatoire de Paris, Dr. Claude Zeippen. On behalf of the president of the Paris observatory Dr. Zeippen gave his warm welcome to the IERS meeting. The minutes of the IERS DB Meeting No. 36 were approved. J. Vondrák introduced William Wooden as new head of the IERS Rapid Prediction Centre at USNO.

M. Rothacher gave a summary of the IERS Retreat (see Section 4.1). In addition to the "formal" minutes the following comments were given: J. Souchay stated that there is a need for a better connection between the ICRS and the IAU; the upcoming meeting of the IAU in Sydney should be used to start activities. – Being confronted with the problems of keeping the Grasse Laser Station running there is a general request from the scientific community to strongly support the lunar laser ranging technique. – The TC group pointed out that ocean as well as atmosphere loading values should be provided by the SB for Loading; in addition series of geocentre values should be made available. No decision was made yet with respect to the demand for a new "ITRF2000A", i.e., for more frequent updates of the ITRF – a decision will be made later by the ITRS Centre / DB after a proposal of the WG on ITRF datum. In this context it was discussed to re-activate the WG on ITRF datum as part of the IERS; in addition a WG on site co-location should be created as part of the IERS – this WG has to be set up in cooperation with the CSTG.

The DB made several decisions on organizational consequences and on possible additions to the existing structure of the IERS (see Section 4.1).

J. Vondrak reported that GGFC has started some activities for information systems as part of INDIGO and as projects in the name of the IERS. – M. Rothacher was elected as IERS service representative in the IAG executive committee.

B. Richter gave a report of the Central Bureau. Contributions for the Annual Report 2002 were received more or less in time and are nearly complete; work on publication will start. – The deadline for

Technical Note No. 30 (Proceedings of the Munich workshop) has been closed and the editing will be done. – The IERS data base will now move from technical investigations to first realizations. It will run on an Apache Web Server using an open source data base system and PHP scripts as access to the database information from web browser. As a first step the IERS products and the data series will be stored within a simple file systems similar to CDDIS. It was discussed that sometimes the original data from the TCs have to be edited by the PCs and it is rather unclear whether to keep both versions of the data, because it might lead to capacity problems. However, an announcement to the PCs will be made to make the products and all input data available. – There were far more proposals than expected for the EU Networks of Excellence (NoE). As most of the proposals for a NoE, the IERS proposal EPISTAGE has been declined because the applications were targeting rather in the direction of “cooperation” than of “integration” as expected by the EU.

The Central Bureau will compile a list of all DB members containing the terms of their representation within the IERS DB as well as all representatives of the IERS in other organizations / institutions.

Meeting No. 38

Monday, December 8, 2003, Marriott Hotel, San Francisco, USA

J. Vondrák welcomed the participants of the meeting and introduced the new members of the Directing Board: G. Gendt (Representative of IGS), M. Feissel-Vernier (Representative of IDS), and W. Wooden (Rapid Service/Prediction Centre). The minutes of the IERS DB Meeting No. 37 were approved.

It was reported that (1) a letter with respect to the renaming of the IERS was sent to IAU, IUGG, IAG, and FAGS. (2) The IERS report for 1999–2003 was submitted to IAG. (3) Two letters asking for further support of SLR stations were sent to AUSLIG and OCA; so far no official responses were received. (4) The IAU EC prolonged the mission of J. Vondrak as IAU representative to the IERS DB until the end of 2004. (5) C. Ma has been nominated for the Steering Committee of IAG, Commission 1 – Reference Frames. (6) A description of the IERS has been sent as input for the IAG Geodesist’s Handbook. (7) A letter asking for further support of the NASA SLR activities was sent to William Watson. (8) R. Forsberg proposed P. Schwintzer as representative of the IGFS to the IERS DB.

D. Gambis presented the new tools for users of the Earth Orientation Centre (EOC). They have been developed by C. Bizouard and S. Lambert and are usable at EOC’s web site. He mentioned that the new web pages of the EOC were designed as a compromise between easy access for non-professional users and an access with detailed options for professional scientific users. All data series of the EOC are available with respect to the IAU1980 and IAU2000A precession-nutation system; the input data series are available, too. Links to data series from the GGFC Special Bureaus with respect to the excitation of the Earth rotation are also given. Additionally, statistics on all data series are available as well as the Earth Orientation Matrix and Earth Rotation Vector.

The *Standards Of Fundamental Astronomy* (SOFA) are a key part of the IERS Conventions software and sophisticated at a basic level. However, the support by Particle Physics and Astronomy Council (PPARC) of UK will end in April 2004. It was decided that J. Vondrak should write a letter asking for continuing support. The SOFA archive can be mirrored by the new IERS Archive and Database System.

D. McCarthy proposed a new product of the IERS Convention Centre: Opinions of the IERS Convention Centre. This series would consist of documents published electronically as needed to address questions regarding the application of some portion of the IERS Conventions. B. Richter mentioned that these opinions can be connected to the FAQs, Glossary, and Acronyms Web pages of the IERS Information System. The DB agreed that the Convention Centre should proceed in this direction.

M. Feissel-Vernier introduced the International DORIS Service (IDS). Some of the main tasks to be performed in the near future by IDS are the improvement of site co-locations, the creation of analysis centres outside France (proposals from AUSLIG and INASAN) and the start of an analysis campaign to study the impact of gravity fields on terrestrial reference frames. Products of the IDS are: orbits, global SINEX solutions, time series of SINEX solutions and time series of specific parameters. In the future more products will be available. A DORIS analysis workshop was held in February 2003.

J. Vondrak reported that during the IAU General Assembly several meetings of Division I that are of interest to IERS have taken place: (1) Session on the implementation of the IAU2000 resolutions. (2) Session on precession and astronomical standards. (3) Session on new Division I Working Groups (two new WGs should be set up). (4) Joint Discussion 16 – The ICRS: Maintenance and Future Realization. (5) Commission 8, 19, and 31 meetings.

At the IUGG General Assembly the results of the IERS Retreat were presented in a talk by M. Rothacher. In addition, two posters describing the IERS and the data and information system were presented by the Central Bureau. M. Rothacher reported that a new structure of the IAG has been set up: IAG Bureaus, IAG Commissions, IAG Inter-Commission Committees. Service representatives in the IAG executive committee are: R. Neilan, M. Rothacher, and H. Schuh.

C. Ma reported about the IERS Workshop on Site co-location (see Section 4.2). Z. Altamimi mentioned that the costs for the survey of one site are about 20.000 • to 30.000 •. Currently the site survey at Wuhan is being done by IGN/CNES, but support by other agencies will be necessary.

W. Schwegmann gave a status report on the IERS Database as well as on the new Information System. This Database is meant to archive all products of the IERS at a central place. The system is currently being developed. It will allow IERS to mirror easily the products of IERS Product Centres and to archive all relevant data. The data are going to be transformed to XML (eXtensible Markup Language) to allow a comfortable exchange and combination of the data. The use of XML as central format has several advantages; as an example formats like the SINEX will be automatically checked and an error message will be generated. Nevertheless, the data will also be available in original format. The Web pages are going to be re-designed. The new Information System is a dynamic database driven system. Thus, it allows an easy maintenance of the Web pages with respect to timeliness, redundancy and consistency. The contents of the Web pages are based on XML, too. 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.

A *Working Group on Reference Frames* in cooperation with IAG Subcommission 1.2 is going to be set up. The chair will be Geoff Blewitt, the goals, objectives and research agenda are described in a draft charter. The title of the working group should be IERS Working Group on Datum Definition of Global Terrestrial Reference Frames (jointly with IAG).

The main task of the *Working Group on Combination* is the coordination of the *Combination Pilot Project*. A draft of the charter was presented. M. Rothacher explained the time-table of future combination procedures. The results of the intra-technique combinations should be available within 7 weeks after the observation whereas the inter-technique combination results should be available 3 weeks later. M. Feissel-Vernier mentioned that DORIS data is not released until 8 weeks after the observation. Therefore the final deadlines should be discussed within the WG.

The main focus of the *Working Group on Co-location* is the co-location of space techniques at geodetic fundamental stations and especially the establishment of accurate local ties in SINEX format including the full variance-covariance information. A draft of the charter was presented.

The final charters of the Working Groups will be approved by e-mail.

B. Chao discussed future activities of the GGFC. The Web pages of the GGFC have been re-designed and new datasets are available, e.g. at the Special Bureaus for Hydrology, Oceans, and Tides. However, the SBs in the USA currently do not receive funding and in the future they won't be able to do work in the framework of the IERS. The GGFC appreciated the work done at the Earth Orientation Centre in Paris and at the Central Bureau in Frankfurt. It is important to consider the data of the GGFC Special Bureaus in this work.

B. Richter reported that the IERS Annual Report 2002 was sent out. Technical Notes No. 30 (Proceedings of the Munich Workshop) and No. 31 (ITRF2000) are available in electronic form, the printed versions are in preparation. Technical Note No. 32 (Conventions 2003) is available in electronic form at the Web pages of the IERS Convention Centre, the printed version is currently being reformatted with respect to the layout of the IERS Technical Notes. The IERS Web pages maintained at the Central Bureau now contain FAQs, a Glossary, and Acronyms. Comments should be sent to W. Dick who continuously updates the pages. Possibilities of reducing the mailing costs for the IERS Annual Reports and Technical Notes were discussed.

M. Rothacher reported that the CONT Sessions in 2002 were very helpful to learn about the combination of data. Thus, he proposed to initiate new *COMBO-CONT Sessions* for 2004/5 considering all space geodetic techniques as well as meteorological data and other auxiliary data sets. The Central Bureau will send a proposal to encourage such new CONT Sessions.

It was decided that an IERS recommendation should be distributed, encouraging software developers to use UT1 instead of UTC.

Bernd Richter, Wolfgang Schwegmann, Wolfgang R. Dick

3.2 Central Bureau

The IERS Central Bureau (CB), hosted and funded by Bundesamt für Kartographie and Geodäsie (BKG), organized and documented two IERS Directing Board (DB) meetings: No. 37, April 2, 2003, Observatoire de Paris, Paris, France; No. 38, December 8, 2003, Marriott Hotel, San Francisco, USA (see Section 3.1). Between these meetings the CB coordinated the work of the DB.

The CB organized an IERS Retreat, held March 31 - April 1, 2003, at Observatoire de Paris, Paris, France. It was convened to determine the future direction of the IERS focusing on the improvement of the consistency and accuracy of its products. The Minutes of this meeting were published on the IERS web site. For more information see Section 4.1 in this Annual Report.

The CB prepared an IERS Workshop on site co-location, held October 23–24, 2003, in Matera, Italy. About 30 participants took part in this workshop. The main results were published at the IERS web site. For a summary see Section 4.2.

The CB was also involved in the organisation of a GGFC meeting held during the AGU Fall Meeting on December 8, 2003 (see Section 3.5.6).

A CB staff member took part in the Colloquium on the UTC Timescale (May 28–30, 2003, Torino, Italy). Requests from journalists concerning the basics and the future of the UTC timescale were answered.

The CB presented the activities of the IERS and the CB with oral and poster presentations at the IAU General Assembly, the IUGG General Assembly, and the Geotechnologien Statusseminar 2003. A description of the IERS was sent as input for the IAG Geodesist's Handbook. The CB prepared an IERS report for 2002 to FAGS and compiled together with J. Vondrak the IERS report for 1999–2003 to IAG.

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 2003 the web site was regularly enlarged and updated. FAQs and a Glossary were added, based mainly on draft FAQs for the IAU 2000 resolutions prepared by Chopo Ma with comments, suggested answers and a few corrections from P. Wallace, B. Guinot, N. Capitaine and D. McCarthy. Also an online list of acronyms related to IERS was compiled.

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 online versions in November 2003. Work started on reformatting the IERS Conventions (2003) to be published as TN No. 32.

The CB edited and published also the IERS Annual Report 2002 in online and printed form. It appeared in June (online) and October 2003 (printed). Besides the reports of the IERS components, it contains information on the IERS compiled by the CB. Funds for printing the Annual Report were provided by BKG and by FAGS.

During the year 2003, 13 IERS Messages (Nos. 38 – 50) 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 2000 users in 2003 with valid addresses who subscribed to IERS publications for e-mail and regular mail distribution. Address and subscription information has regularly been updated.

The implementation of the new IERS Data Center and the reorganized IERS Information System has been started. The goal is to realize a dynamic and database-driven system 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.

Bernd Richter, Wolfgang R. Dick, Wolfgang Schwegmann

3.3 Analysis Coordinator

Introduction

This annual report of the IERS Analysis Coordinator (AC) focuses on the following topics involving active IERS Analysis Coordination:

- IERS Analysis Campaign to align EOPs to ITRF2000 / ICRF
- IERS SINEX Combination Campaign
- IERS Retreat 2003
- IERS Combination Pilot Project (CPP)
- IERS Working Groups
- IERS Workshop in Matera

Together with the IERS Central Bureau considerable effort was put into the preparation and organization of scientific meetings during 2003. These included the IERS Retreat in April 2003, the IERS CRC Meeting at the EGU Meeting 2003 in Nice and the IERS Workshop 2003 in Matera. Up-to-date information about the IERS Analysis Coordination activities may be found at <http://tau.fesg.tu-muenchen.de/~iers/web/index.php>.

IERS Analysis Campaign to Align EOPs to ITRF2000 / ICRF

At the IERS Combination Workshop in Munich in November 2002 it was decided that the IERS Analysis Campaign to Align EOPs to ITRF2000/ICRF – with the goal to identify possible inconsistencies between the EOP series of various techniques correctly aligned to the ITRF2000/ICRF reference frames and the official C04-series – should be continued and finalized by the time of the EGS General Assembly, April 2003. At this meeting final results were shown by a few different groups (see, e.g., Annual Report 2003 of the CRC FESG, this volume, Section 3.6.2.4) clearly demonstrating that considerable biases do exist between official IERS products (e.g., between ITRF2000 and the C04 polar motion series). It was concluded that follow-up studies of these biases should be based on the SINEX files of the IERS SINEX Combination Campaign instead of the EOP time series alone, to allow for more detailed analyses and for rigorous combination approaches.

IERS SINEX Combination Campaign

In May 2002 the IERS SINEX Combination Campaign was started with a Call for Participation (CfP). The goals of this activity were:

- Combination of “weekly“ solutions from SINEX files of different space geodetic techniques (GPS, SLR, VLBI, DORIS,...) with station coordinates and EOPs
- Development of standards for common modeling and parameterization
- Assessment of systematic biases between the different techniques
- Combined weekly solutions as the basis for final routine EOP products

Eleven groups answered the CfP. The list of “weekly” SINEX series that were delivered to the IERS SINEX Combination Campaign is given in Table 1. All these series were archived in a SINEX data pool and are still available for combination tests. (see <http://tau.fesg.tu-muenchen.de/~iers/web/sinex/datapool.php>).

Table 1: “Weekly” SINEX Contributions to the IERS SINEX Combination Campaign

Solutions		Parameters contained in the solution							Normal equation	Constraints
		Coord.	Pole	Pole rates	UT1 - UTC	LOD	Nutation	Others		
GPS	CODE	X	X	X	X	X	-	-	-	NNR
	NRCan	X	X	X	-	X	-	Geocentre	-	inner constraints
	DGFI	X	-	-	-	-	-	-	-	1m for stations
SLR (monthly)	ASI	X	X	-	X	-	-	Biases	-	loose constraints
	DGFI	X	X	-	X	-	-	Biases	-	loose constraints
	JCET v1	X	X	X	X	X	-	Biases	-	1m for stations
	JCET v2	X	X	-	X	X	-	-	-	1m for stations
SLR (weekly)	ASI v1	X	X	-	X	-	-	-	-	loose constraints
	ASI v2	X	X	X	X	X	-	-	-	loose constraints
	JCET	X	X	-	-	LODR	-	-	-	1m for stations and ERP
VLBI	BKG	X	X	X	UT1	X	X	-	X	NNR + NNT
	DGFI	X	X	-	X	-	X	-	X	loose constraints
	GSFC (old)	X	X	-	UT1	X	X	-	-	loose constraints
	GSFC (new)	X	X	X	UT1	X	X	-	X	NNR + NNT
DORIS	IGN	X	X	X	X	LODR	-	-	-	
	INA	X	X	-	X	LODR	-	-	-	

First results of the campaign were presented at the IERS Workshop on Combination Research and Global Geophysical Fluids at the Bavarian Academy of Sciences, Munich, Germany, 18-21 November 2002 and published in the IERS Technical Note No. 30 (<http://www.iers.org/iers/publications/tn/tn30/>). In addition, major results were also presented in session G15 at the EGS-AGU-EGU Joint Assembly 2003 in Nice, April 6-11.

At the IERS Retreat in Paris (see below) it was decided that the IERS SINEX Combination Campaign should evolve into a pilot phase of routine product generation, i.e., into the IERS Combination Pilot Project (CPP).

For more information on the IERS SINEX Combination Campaign see <http://tau.fesg.tu-muenchen.de/~iers/web/sinex/campaign.php>.

IERS Retreat 2003

Together with the IERS Central Bureau a considerable effort was put into the organization of the IERS Retreat 2003 in Paris. At this retreat, among others, the following important decisions were taken:

- the IERS Combination Pilot Project (CPP) should be initiated,
- an IERS Working Group on “Site Survey and Co-location”,
- an IERS Working Group on “Combination” to coordinate the IERS CPP and
- an IERS Working Group on “ITRF Datum” should be established.

These decisions are described in more details in the next two sections. For more information concerning the outcome of the IERS Retreat 2003 we refer to <http://www.iers.org/iers/meetings/IERS-Retreat-2003/>.

IERS Combination Pilot Project (CPP)

Today the various products of the IERS, especially the International Terrestrial Reference Frame (ITRF), the International Celestial Reference Frame (ICRF) and the Earth Orientation Parameter (EOP) series, are still combined independently. With the exception of the ITRF and the IGS products neither intra-technique nor inter-technique combinations are correctly performed including the full variance-covariance information. In this way neither the consistency of the products can be guaranteed nor can the different strengths of the individual space geodetic techniques be exploited to improve the products. This means that there are clear deficiencies in the present IERS product generation. To achieve the highest accuracy and consistency, it is crucial to proceed towards a fully rigorous combination of all the parameters common to more than one space geodetic technique, especially in respect to the challenges the IERS is facing with the new satellite missions (gravity, altimetry, astrometry), with the Global Geodetic Observing System (GGOS) project of the International Association of Geodesy (IAG), and with many other applications.

At the IERS Retreat in Paris in April 2003 (see previous section above) it was therefore decided, that

- an IERS Working Group (WG) on Combination should be set up and that
- the IERS SINEX Combination Campaign should be converted into a pilot project, namely the IERS Combination Pilot Project (CPP), to be started in spring 2004.

To establish the IERS WG on Combination (IERS WG3) according to the IERS Terms of Reference a charter and a preliminary list of participants were drafted and discussed during the December 2003 IERS Directing Board meeting. The working group was set up in the beginning of 2004 and, as a first action, the Call for Participation (CfP) for the IERS Combination Pilot Project was launched.

The IERS CPP consists of three steps (see Figure 1):

1. The computation of combined "weekly" SINEX files by the Technique Centers starting from SINEX files of the individual Analysis Centers of the service (intra-technique combination).
2. The computation of combined weekly SINEX files by so-called IERS Combination Centers based on the "weekly" intra-technique SINEX files and local tie information.
3. The validation of the combined inter-technique solutions through comparisons, repeatability studies, and use of external information (geophysical fluids, models, ...).

More information about the CPP and the present status may be found at <http://www.iers.org/iers/about/wg/wg3/cpp.html>.

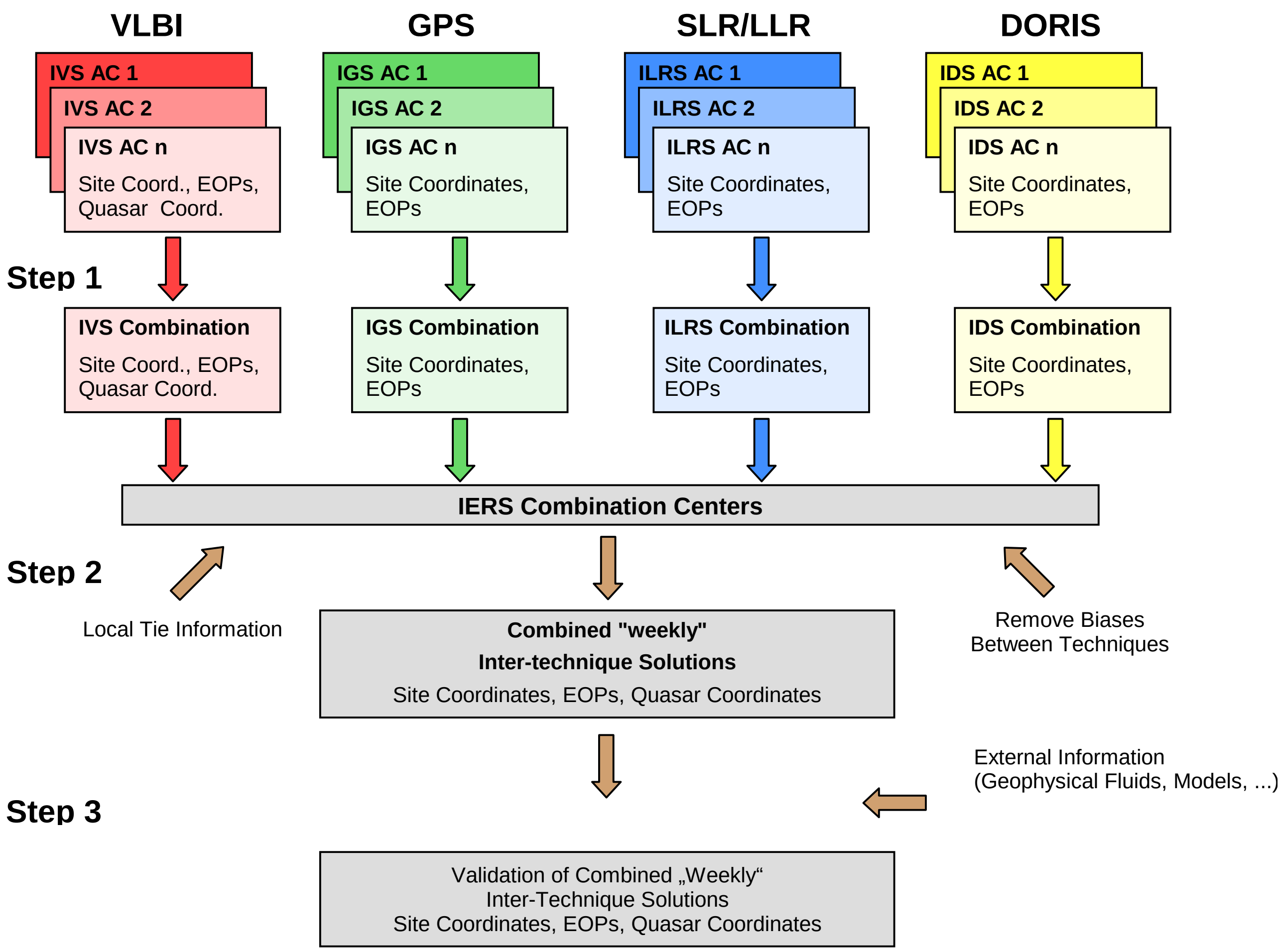


Fig. 1: Combination and validation of „weekly" SINEX solutions in the framework of the IERS Combination Pilot Project (CPP).

IERS Working Groups

At the IERS Retreat 2003, as mentioned above, it was also decided that two more IERS working groups should be established besides the IERS WG on Combination, namely the IERS WG1 on Datum Definition of Global Terrestrial Reference Frames, jointly with IAG Sub Commission 1.2 WG 1 (SC1.2-WG1) and IAG Inter-Commission Committee on Theory (ICCT), and the IERS WG2 on Site Survey and Co-locations, jointly with IAG Sub-Commission 1.2 WG 2 (SC1.2-WG2).

In the meantime two of the three working groups have been fully established (see <http://www.iers.org/iers/about/wg/>).

IERS Workshop on "Site Co-location" in Matera

For the first time in the IERS history a workshop was organized solely concentrating on the topic of site surveying, site co-location and all issues related to the co-location of instruments at fundamental geodetic observatories. It was one of the major goals of this workshop to demonstrate that the topic of site surveying etc. should play a much more prominent role in space geodesy and especially in the combination of the space geodetic results into a consistent set of IERS products (see IERS CPP). The two most important recommendations resulting from the workshop are listed here:

- All local ties between co-located instruments should be determined with an accuracy of 1 mm or better in the ITRF (global, cartesian) and the full variance / covariance information should be made available in SINEX format (Recommendation 1).
- Local survey measurements should have the same importance as and should be treated like any of the space geodetic techniques (Recommendation 2).

The establishment of highly accurate local ties for all fundamental geodetic observatories should be considered a "conditio sine qua non" for a successful combination of the space geodetic techniques and a consistent set of IERS products (i.e., consistency between techniques as well as consistency between parameter groups like site coordinates, EOPs and quasar coordinates). A major effort should therefore be devoted to this task. For additional information and the presentations given at the workshop see <http://www.iers.org/workshop_2003_matera/>.

Acknowledgement

The IERS AC work is partly funded by the Geotechnologien-Projekt of the German BMBF (Bundesministerium für Bildung und Forschung) .

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3.4 Technique Centres

3.4.1 International GPS Service (IGS)

General

Since 1994, the IGS is committed to provide the highest quality GPS+GLONASS observation data and products, as the standard for global navigation satellite systems (GNSS) in support of scientific activities such as improving and extending the International Terrestrial Reference Frame, monitoring deformations of the solid Earth, variations in the liquid Earth (sea level, ice sheets, etc.) and in Earth rotation, determining orbits of scientific satellites, and monitoring the troposphere and ionosphere. Table 1 gives an overview of the estimated quality of the IGS products at the end of 2003.

Table 1: IGS Products (the GPS broadcast values are included for comparison). The accuracy limits, except for predicted orbits, are based on comparisons with independent laser ranging results. The accuracy of all clocks is expressed relative to the IGS timescale, which is linearly aligned to GPS time in one-day segments.

		Accuracy	Latency	Updates	Sample Interval
GPS Satellite Ephemerides/Satellite & Station Clocks					
Broadcast	Orbits	~ 200 cm	Real time	--	Daily
	Sat. clocks	~ 7 ns			
Ultra-Rapid (predicted half)	Orbits	~ 10 cm	Real time	Twice daily	15 min
	Sat. clocks	~ 5 ns			
Ultra-Rapid (observed half)	Orbits	< 5 cm	3 hours	Twice daily	15 min
	Sat. clocks	~ 0.2 ns			
Rapid	Orbits	3 cm	17 hours	Daily	15 min
	Sat.& station clocks	0.1 ns			5 min
Final	Orbits	2 cm	~13 days	Weekly	15 min
	Sat.& station clocks	0.05 ns			5 min
GLONASS Satellite Ephemerides					
Final	Orbits	30 cm	~ 4 weeks	Weekly	15 min
Geocentric Coordinates of IGS tracking stations (> 130 sites)					
Final positions	Horizontal	3 mm	12 days	Weekly	Weekly
	Vertical	6 mm			
Final velocities	Horizontal	2 mm/y	12 days	Weekly	Weekly
	Vertical	3 mm/y			
Earth Rotation Parameters : Polar Motion (PM), Polar Motion Rates (PM rate), Length-of-day (LOD)					
Ultra-rapid (predicted half)	PM	0.3 mas	Real time	Twice daily	Twice daily (00 & 12 UTC)
	PM rate	0.5 mas/day			
	LOD	0.06 ms			
Ultra-rapid (observed half)	PM	0.1 mas	3 hours	Twice daily	Twice daily (00&12 UTC)
	PM rate	0.3 mas/day			
	LOD	0.03 ms			
Rapid	PM	< 0.1 mas	~ 17 hours	Daily	Daily (12 UTC)
	PM rate	< 0.2 mas/day			
	LOD	0.03 ms			
Final	PM	0.05 mas	~ 13 days	Weekly	Daily (12 UTC)
	PM rate	< 0.2 mas/day			
	LOD	0.02 ms			
Atmospheric parameters					
Final tropospheric zenith path delay		4 mm	< 4 weeks	Weekly	2 hours
Ultra-rapid tropospheric zenith path delay		6 mm	2-3 hours	Every 3 hours	1 hour
Ionospheric TEC grid		2-8 TECU	~ 11 days	Weekly	2 hours ; 5°x2.5°

All products are based on a combination process of the individual IGS Analysis Center (AC) solutions to gain highest quality and to ensure reliability. During 2003 the quality of the products were further enhanced (see Figure 1 as example). A significant improvement could be obtained for the Ultra Rapid products, where the prediction for the majority of the satellites has reached a level of 6 cm. The observed part of the ultra rapid products has a high quality and is available already after three hours (twice daily), so that for special applications it can be used instead of the Rapid product.

Mid 2003, the responsibilities of Analysis Coordinator were switched from R. Weber to G. Gendt (GFZ).

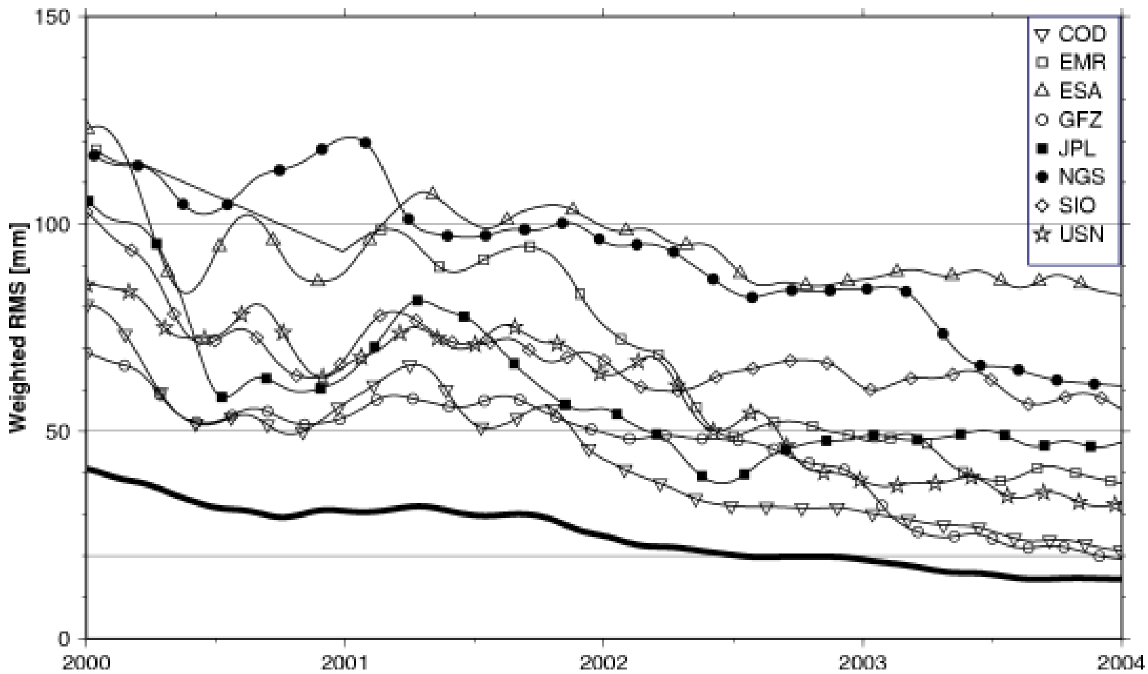

Fig. 1: Weighted orbit RMS of the Analysis Center orbits with respect to the IGS Rapid orbits (smoothed). The thick line shows the IGS Rapid orbits compared to the IGS Final orbits.

Tracking Network and its Coordination

In 2003, the IGS network (Figure 2) grew with 23 new sites to reach a total of 362 sites. 128 of these sites are global stations which means that their data are regularly analyzed by at least three different Analysis Centers, one of which must be located on another continent from the station.

The IGS Central Bureau improved its monitoring of the IGS sites by adding to the station web pages change point analysis which flags potential incidents based on data characteristics. Other enhancements to the station web pages are graphs of the SINEX residuals as calculated by the Reference Frame Coordinator, and tables indicating which Analysis Centers have chosen that site for which products.

In addition, a full revision of the IGS site guidelines was started.

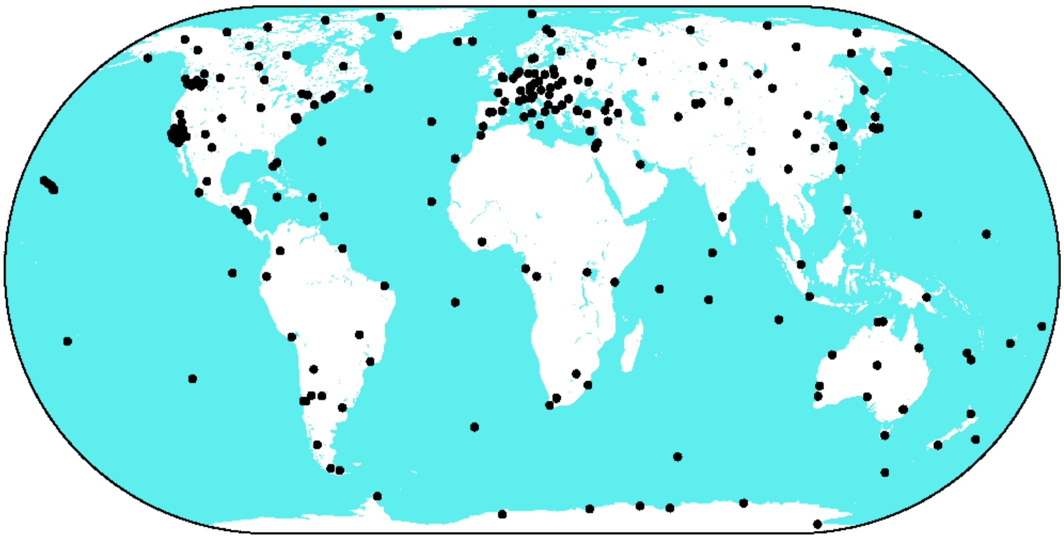

Fig. 2: IGS tracking network

IGS Working Groups/Pilot Projects

Within the IGS a number of Working Groups (WG) focus on selected topics related to the IGS components. Furthermore Pilot Projects have been launched to develop new products and services. The activities of a few of them are briefly presented below. For a complete list and descriptions see http://igscb.jpl.nasa.gov/projects/projindex.html.

Galileo/GNSS Working Group

This WG is presently concentrating on two studies related to GPSIIF/GPSIII and Galileo: the anticipated improvements in the IGS products, and the standardization of products. Draft recommendations on signal tracking will be provided to manufacturers as well.

Real-time Working Group

Under the initiative of this WG, an initial set of about 10 IGS stations has been running with at least 98% of data arriving with less than 2 seconds latency. An expanded prototype network of 20-30 stations is hoped for March 2004.

LEO Working Group

The Associate Analysis Centers attain LEO orbits of 3-4 cm precision, but improvements are still needed. Integrated GPS+LEO processing will be utilized to assess the impact of LEO data on IGS products. However, presently the IGS Analysis Centers do not have the capacity to include LEOs in their GPS processing.

Ionosphere Working Group

The individual ionospheric maps obtained by the WG members have been calibrated using Envisat altimeter data. These maps are the basis for a new official IGS product: the IGS combined ionospheric maps (TEC grid) targeting users from the science community, SCAR, and ESA (for EGNOS comparisons).

Time Transfer Pilot Project

Ken Senior (Naval Research Laboratory, US) has been appointed as Product Coordinator. In 2003, the robustness of the IGS timescale products has improved.

Troposphere Working Group

The chair of this WG switched from G. Gendt (GFZ) to J. Bar-Sever (JPL), who is now also responsible for the generation of the IGS combined troposphere product.

Reference Frame Working Group

The current IGS reference frame realization “IGS01P37_RS54.snx”, which starts to degrade the realization, was reviewed. Since its creation two years ago, almost a dozen of stations had to be discarded for various reasons. Therefore a new improved realization “IGS03P33_RS106.snx” will be introduced starting 2004.

Summary

In 2003, as in the previous years, the IGS contributed significantly to the IERS activities like maintenance and extension of the International Reference Frame and in the highly accurate, daily sampled Earth Rotations Parameters.

The accuracy of the IGS products has further improved and approaches for the orbit already the 1 cm level and the mm level for other parameters. For the future the focus will therefore be on the integrity for all the IGS products, 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).

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2001 IGS Annual Report. IGS Central Bureau, eds. Pasadena, CA: Jet Propulsion Laboratory, 2003

A Guide to using International GPS Service (IGS) Products. Jan Kouba, Geodetic Division, NRCan, Feb. 2003. IGS Central Bureau, Pasadena, CA: Jet Propulsion Laboratory

These documents are also available via FTP at
<ftp://igscb.jpl.nasa.gov/igscb/resouces/pubs/>.

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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. Within the organizational structure of the IERS, the ILRS is one of several Technique Centers, having accompanying responsibilities for the generation and quality assurance of Earth Orientation Parameters and related products that are generated within the laser technique. A clear example is the contribution to the implementation of the terrestrial reference system (i.e. the ITRF), where 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 the solutions rely heavily on radiometric observations, the SLR measurements by virtue of their absolute, unbiased character provide a unique tool to validate the orbital and gravity field solutions and independently assess their quality. As an illustration, Figure 1 shows the twin GRACE satellites, launched in March 2002. Although their primary means of navigation is the onboard GPS receiver, the independent and bias-free SLR measurements support the achievement of the science goals of this mission.

Activities in 2003

The ILRS activities cover a broad spectrum, but this IERS-specific overview concentrates on analysis activities. The ILRS Analysis Working Group (AWG) is the entity which is responsible for the coordination of these activities, including the development of quality control procedures as well as official ILRS analysis products. Two AWG workshops were held in 2003, notably in Nice/France (April) and in Koetzting/Germany (October). Here, analysts and program managers met to discuss analysis and data product issues, initiate projects and/or campaigns and evaluate their results.

With the development of (an) official ILRS product(s) and the quality control (QC) issue (of observations and products) in mind, the AWG has initiated a number of pilot projects. They are clearly developing with time. One pilot project concerns the harmonization of semi real-time QC results, the quality assessment of the SLR observations in particular. In 2001 it was recognized that the model for station coordinates plays a major role in the diversity of quality „verdicts“ that are generated and distributed to the stations each week. To bring more uniformity to this, the AWG has strongly recommended that its members use the ITRF2000 solution as a common element in the weekly (or more frequent) analyses. At the time of writing, almost all of the relevant analysis centers have switched to this model. Although no a posteriori evaluation has been made yet, it is expected that this will also have consequences for the semi real-time EOP solutions which are generated and submitted to IERS.

The second project is aimed at quality control of the software that is used within the SLR/LLR community. Its purpose is to benchmark the various computer programs and to detect blunders and other possible problems. It focuses on satellite orbits and specific parameter solutions, which may evolve into (the development of) an official ILRS product for satellite orbits. This project has made good progress in 2003, and plays an additional role in acceptance and/or rejection of contributors to a third project.

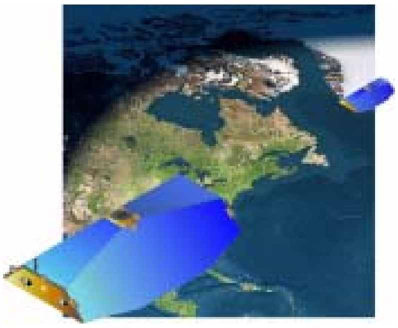

Fig. 1: The GRACE satellites nicely illustrate the characteristic and crucial role that SLR plays in modern space geodesy (courtesy NASA/GFZ).

This third project focuses on two traditional products, i.e. station coordinates and EOPs. The purpose here is to develop an official ILRS solution, currently for EOPs and station coordinates (the former to be included in the IERS Bulletin A). In the future, the analysis system may evolve further to provide other parameters of interest.

Following the release of an official Call for Participation, this project for EOPs and station coordinates has entered a test phase, where the actual data flows and processing schemes are tested, and analysis results evaluated. At this moment (early 2004), 5 analysis groups (using 4 different software packages) provide solutions of station coordinates and EOPs on a weekly, operational basis. These institutes are ASI/Italy, DGFI/Germany, GFZ/Germany, JCET/USA and NERC/UK. The solutions currently cover the period from June 2003 until now. In addition, other research groups (Geosciences Australia, IAA/Russia) have also expressed their intention to contribute to such operational products. The solutions are based on SLR data to the satellites LAGEOS-1 and -2, and Etalon-1 and -2. This computation is followed by a combination of these individual contributions. This step is currently being tested by ASI/Italy, DGFI/Germany and NCL/UK. These results, too, cover the period from mid-2003 until now. In the course of 2003 a change in the analysis scheme was implemented at the request of the client (IERS), i.e. the time-period covered by the weekly analyses was modified from 28 days to 7 days. Having done so, the intervals are consistent with the GPS weeks.

The current test phase of this operational data delivery goes back a number of years in time. Based on the experience gained in preliminary tests, it has been decided to consider solutions for the x-pole and y-pole coordinates and excess Length of Day (LOD) as the prime products of the ILRS analysis activities concerning EOPs. This deviates from the historic situation, where solutions for UT1-UTC were submitted as representative parameters. However, it must be realized that the UT time difference is directly correlated with the right ascension of the ascending node of the satellites(s), so by definition it cannot be observed by any of the satellite techniques.

To improve the quality of the EOP results, the ILRS has given the Etalon satellites (which are analyzed in addition to the (standard) LAGEOS spacecraft) a higher tracking priority than was the case before 2002. Analyses have convincingly shown that the quality of the EOP solutions improves dramatically if even a small amount of Etalon data is included in the data reduction process.

The analysis activities within the ILRS, related to the IERS, are not restricted to just these pilot projects. The ILRS community is providing input to other projects, like the SINEX Campaign, the EOP Alignment Project and the future (IAG) IGGOS Project. Results on these projects can be found elsewhere.

Outlook

The AWG pilot projects, that can be considered as the focal point of the ILRS analysis activities, will proceed with the momentum that they have shown so far. The harmonization project is expected to converge to unambiguous quality assessments soon. The benchmarking/orbits project has embarked upon a strict and ambitious scheme. A first round of results revealed a number of shortcomings, and the current activities will undoubtedly yield a better consistency of the results. The project on station positions and Earth orientation is entering the phase of official product combination. As a first step, by the time that this report officially appears, the ILRS analysis groups and combination centers will have geared up to serve the IERS community with a consistent and high-quality product of EOPs. The EOP/coordinates product is also intended to serve as the ILRS contribution to the IERS Combination Project. The ILRS AWG expects this official product to be available in mid-2004.

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3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2003, 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 September 2003 IVS held its second Technical Operations Workshop (TOW) at Haystack Observatory, USA. The TOW is a rare opportunity for technical station staff to receive VLBI training and to interact with the staff of the IVS Correlators, Coordinating Center, and Technology Development Centers. Two IVS Directing Board meetings were held, one in April in Paris, and the other in October at Haystack Observatory. IVS published its 2002 Annual Report in March 2003 and published three newsletter issues which keep the community informed about IVS activities. The Pilot Project “Tropospheric Parameters”, led by the University of Vienna, was completed successfully and tropospheric parameters became an official IVS service product. A new Pilot Project, led by the Analysis Coordinator Axel Nothnagel, “Time Series of Station Coordinates and Baseline Lengths”, was set up with plans to begin work in 2004. Such a time series will be useful for many investigations of periodic and aperiodic variations caused by geophysical phenomena. The board established its third Working Group, chaired by Alan Whitney and Arthur Niell, which is tasked with developing a vision for VLBI in 2010. A report from the VLBI2010 Working Group should be made available in 2004 which will become a guideline for the establishment of the next generation VLBI systems.

Network Stations

A total of 1111 station days were used in 186 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.5 days per week, similar to the previous year. The number of station days also remained approximately the same. The major observing programs during 2003 were:

IVS-R1, IVS-R4

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

Intensive

Daily 1-hour UT1 Intensive measurements were made on four days (Monday, Tuesday, Wednesday, Friday) on the baseline Wettzell (Germany) to Kokee Park (Hawaii, USA) and on Sunday on the baseline Wettzell (Germany) to Tsukuba (Japan). The daily sessions were 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, 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.

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. An additional five sessions were scheduled for maintenance of the ICRF in the southern hemisphere.

Europe The European geodetic network, coordinated by the Geodetic Institute of the University of Bonn, continued with four sessions in 2003.

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 2003 with the goal of comparing results from similar networks using different recording bandwidths and data rates. These sessions will be analyzed in 2004.

The Network Coordinator's data base of station performance showed data loss of 14.2%, slightly higher than in 2002. The most significant problems in 2003 were due to receiver and antenna problems, probably reflecting the aging equipment.

Correlators

The correlators at Haystack Observatory (USA), the U.S. Naval Observatory (USA), and at Max-Planck Institute for Radioastronomy (Germany) gradually upgraded to the use of Mark 5 units, replacing the Mark IV tape playback units. The Mark 5 systems greatly increased the correlator efficiency and enabled all correlators to eliminate their processing backlog.

Data Centers

The IVS Data Centers continued to receive data bases throughout the year and make 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

The Fourth IVS Analysis Workshop was held at Observatoire de Paris in Paris, France, April 3 – 4, 2003. Detailed information on the presentations and discussions can be found under <http://giub.geod.uni-bonn.de/vlbi/IVS-AC>.

A conventional VLBI terrestrial reference frame (VTRF2003) was developed with its axis and geocenter definition closely aligned to ITRF2000 in order to accommodate modifications for some of the station coordinates and velocities which have been detected in VLBI analyses (Nothnagel, 2003).

Early in 2003 routine analysis and combination of the earth orientation parameter (EOP) series submitted by the six IVS Analysis Centers has seen a change with respect to the underlying terrestrial reference frame. Until the end of 2002 the IVS combined EOP series were closely linked to the ITRF2000. Owing to some deficiencies of ITRF2000 listed above, VTRF2003 was used as the TRF for a consistent alignment of the TRF and the IVS EOP series.

On January 1, 2003, the IAU2000 resolutions were planned to take effect. However, some of the numerical constants of the IAU2000 precession, nutation and non-rotating origin models had not been finalized early enough. Therefore, modifications in the VLBI analysis software packages for the IAU2000 resolutions had not yet been completed for a timely start of producing the new type of EOP. In order to provide celestial pole offsets in the new paradigm (X, Y) a conversion program was developed on the basis of software kindly provided by Christian Bizouard, Observatoire de Paris. Consequently, the rapid service EOP series (e.g. ivs03r1e.eops) as well as the complete (since 1979) IVS series are routinely complemented by the files ivs03r1X.eops and ivs03q1X.eops which contain celestial pole offsets (X, Y) instead of the classical nutation offset då, dø w.r.t. to IAU1980.

Technology Development Centers

The major effort in 2003 was continued deployment and usage of Mark 5 disk-based recording systems as a direct replacement for the Mark IV/VLBA tape recorders. The Mark 5 recorders were also used for e-VLBI, in which data was recorded at a station and then transmitted electronically from the station to the correlator. Two 24-hour CRF sessions and one TRF session were recorded at Kashima, Japan in this mode. Full deployment of the Mark 5 systems is planned by mid-2004. Plans for routine e-VLBI sessions are to record the daily Intensive sessions on Mark 5 or K5 and then transmit the data to a correlator electronically.

Reference

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(web reference: <http://giub.geod.uni-bonn.de/vlbi/IVS-AC/vtrf2003/vtrf2003.html>).

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3.4.4 International DORIS Service (IDS)

General

The International DORIS Service (IDS) officially started on July 1, 2003 as an IAG Service after the decision of the IAG Executive Committee at the IUGG General Assembly in Sapporo. 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>. The IDS website URL is <http://ids.cls.fr/html/about_ids.html>.

Network

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

The following new stations have been added in 2003:

- Crozet (French Southern Indian Ocean territories),
- Jiufeng (China) which should replace Purple Mountain.

Fig. 1: Estimated stability of the DORIS permanent stations (January 2004)

In response to proposals submitted by candidate host agencies in the frame of the DORIS Pilot Experiment, the following stations were installed:

- Wettzell (Germany) from May 2003 to January 2004,
- Gavdos (radar altimeter calibration site in Crete), which may in the future replace Dionysos,

- Sorsdal (Glacier movement monitoring in Antarctica) from November 2003 to January 2004, following last year's experiment at the same site.

The stations rejuvenation program initiated in 2000 was continued, as illustrated in Figure 2. In 2003 the stations at Manila, Ascension, St-Helena, Ny-Alesund and Yaragadee were renovated in order to improve the long term stability of the antenna support. At the end of 2003, 37 out of 58 stations are considered of good or excellent stability.

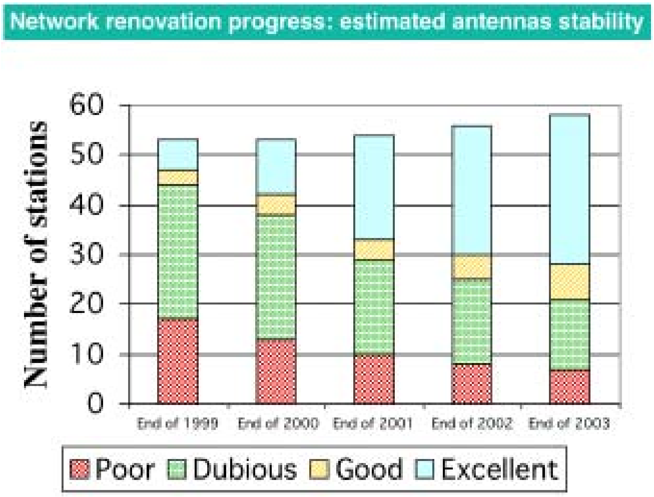

Fig. 2: DORIS permanent network renovation

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

- GPS : 32 sites
- SLR : 7 sites
- VLBI : 6 sites

According to the report of the IERS colocations workshop held in Matera in 2003, the local ties at a few sites need to be improved. On the other hand, it should be mentioned that the extension of the DORIS-VLBI colocations awaits the results of an investigation on the signal interferences issue.

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 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 Data Centers organisation and IDS data flow were reorganized in 2003. See <http://lareg.ensg.ign.fr/IDS/doc/struct_dc.html> for more details.

Several analysis centers routinely analyse the data and provide their products to the data centers, under the Sinex format when applicable. The active analysis centers as of January 2004 are CNES/SOD, CNES/SSALTO, IGN-JPL, LEGOS-CLS, INASAN and UT/CSR. Other centers are planning to join IDS: Geoscience Australia, IAA, VUGTK (Prague).

IDS products

The IDS products are listed in Table 1, together with the status of their availability and valorisation as of January 2004. The valorisation may take place within IDS, at the IERS product centers, or in the framework of space oceanography projects.

Table 1. IDS products availability and valorisation

Product	Availability	Comparison	Combination
Orbits	Yes	Yes	No
Global TRF SINEX	Yes	Yes	Yes
TRF-EOP SINEX time series	Yes	Yes	Yes
Time series of			
- station coordinates	Yes	Yes	No
- TRF origin	Yes	Yes	No
- EOP	Yes	Yes	Yes
- Ionosphere	Yes	No	No

Analysis Coordination

In the context of the DORIS Pilot Experiment, the Central Bureau ran 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 data were collected under the form of time series of Sinex files with station coordinates. The analysis made use of the CATREF software (Z. Altamimi, P. Sillard, C. Boucher, 2002, JGRB, 107, 1029). The data were analysed in terms of series of coordinates of the origin and scale of the terrestrial reference frame, and the series of station residuals (available at <ftp://ftp.cls.fr/pub/ids-cls/camp02>). The analysis included also the detection of outliers and the investigation of breaks in the station histories. The report of the 2002 Analysis Campaign is available at <http://lareg.ensg.ign.fr/IDS/events/2002_camp_report.pdf>.

An analysis Workshop took place in February 2003 in Marne la Vallée. See the contributions at <http://lareg.ensg.ign.fr/IDS/events/prog_2003.html>. The conclusions of interest to IERS were as follows.

- Privileged topics for analysis
  - Further develop TRF+EOP combination and unification
  - Initiate ‘geocenter’/TRF origin comparison & unification effort
- Inter-technique and IERS cooperation
  - Identify a DORIS Core network
  - Make more use of DORIS-SLR ground + space colocations
  - Establish contacts with ILRS, IVS, IGS for network evolutions
  - Consider colocations with SLR and VLBI in managing the evolution of the IDS network

A new Analysis campaign was started in the fall of 2003, with the aims to investigate the influence of the reference gravity field on the derived terrestrial reference frames, and also to further develop the intra-technique combination capabilities.

For general information on Analysis Coordination see <http://lareg.ensg.ign.fr/IDS/index.html>.

Summary

The IDS is now officially in existence, in continuation of the DORIS Pilot Experiment. It makes use of six equipped satellites, permanently observed by over 50 well distributed stations. The 2003 highlights include the renovation of a number of stations, reorganisation of the Data Centers, and new developments in the coordination of analyses. While the Analysis Centers continue their support to IERS, the Analysis Coordinator and the Central Bureau are jointly developing comparison and combination activities that eventually aim at benefiting to the IERS Combination Pilot project.

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 2003. 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 centers 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

On the Web site of the Earth Orientation Centre <hpiers.obspm.fr/eop-pc> has been set up this year interactive tools, mostly written in PHP language, devoted to the EOP time series and most generally to Earth rotation studies.

1) First is devoted to the selection and plot of various EOP time series (“combined”, “long term” and “operational”).
2) Second allows users to compute the Earth orientation matrix at any epoch from EOP time series, and derive associated parameters.
3) Third is devoted to the numerical analysis of long term EOP series (Fast Fourier Transform, periodogram, filter, least square, Singular Spectral Analysis).
4) Fourth enables the mutual comparisons of operational series.
5) Last tools allow to compute the excitation functions associated with Earth rotation irregularities and to compare them to the atmospheric angular momentum functions.

Interactivity is especially interesting for focusing on a given data span or fitting poorly known physical parameter linked with Earth rotation.

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 Ray, 2003). Since formal uncertainties reported by the contributors are often underestimated, 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, 2003). Table 1 gives the estimated accuracy with respect to IERS C04 of these series over 2002–2003 after removal of systematic variations, mainly a bias.

Table 1: Estimated accuracies of individual solutions entering the combined solutions in 2003.

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	0.20	0.05		0.12
EOP (BKG)	03 R 04	1-4d	0.22	0.05		0.15
EOP (GSFC)	03 R 06	1-4d	0.16	0.04		0.10
EOP (IAA)	03 R 04	1-4d	0.14	0.04		0.08
EOP (MAO)	03 R 01	1-4d	0.21	0.05		0.17
EOP (SPBU)	03 R 03	3-4d	0.22	0.05		0.13
EOP (USNO)	03 R 04	1-4d	0.15	0.04		0.13
VLBI – Intensive						
EOP (BKG)	03 R 02	1-3 d		0.13		
EOP (GSFC)	03 R 05	1-3 d		0.12		
EOP (IAA)	03 R 03	1-3 d		0.13		
EOP (SPBU)	02 R 01	1-3 d		0.14		
Satellite Laser Trackin						
EOP (ASI)	03 L 02	1d	0.30		2.33	
EOP (CSR)	95 L 01	3d	0.66	1.15		
EOP (DUT)	98 L 01	3d	0.56			
EOP (IAA)	02 L 02	1d	0.27	0.27 *	0.13	
EOP (MCC)	97 L 01	1d	0.30		0.48	
GPS						
EOP (CODE)	98 P 01	1d	0.06		0.26	
EOP (EMR)	96 P 03	1d	0.10		0.31	
EOP (ESOC)	96 P 01	1d	0.13		0.25	
EOP (GFZ)	96 P 02	1d	0.09		0.29	
EOP (IAA)	01 P 01	1d	0.24		0.37	
EOP (JPL)	96 P 03	1d	0.08		0.48	
EOP (NOAA)	96 P 01	1d	0.25		0.49	
EOP (SIO)	96 P 01	1d	0.10		0.32	

** 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. New procedures for prediction are under investigation, they are based on Singular Spectrum Analysis SSA and Neuronal networks.

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	1-d	0.15	0.20	0.10
Prediction				
	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 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 offsets; UT1–UTC since 1962). For many decades, the observa-

Table 3: Mean and standard deviation of the differences between various IERS solutions for 2003

EOP	Unit	Comb JPL – IERS C04		BullA – IERS C04	
		Mean	Standard deviation	Mean	Standard deviation
X	mas	–0.19	0.07	–0.03	0.05
Y	mas	0.03	0.04	0.05	0.05
UT1	0.1 ms	–0.07	0.16	–0.05	0.20

tions 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 2003. It is a composite series based on following temporal solutions:

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

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

1962–2003: 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 of the Earth Orientation Parameters. Gravity field 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 International 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 Conventions 2003 (McCarthy and Petit, 2004) and at the following address: <http://hpiers.obspm.fr/eop-pc/>.

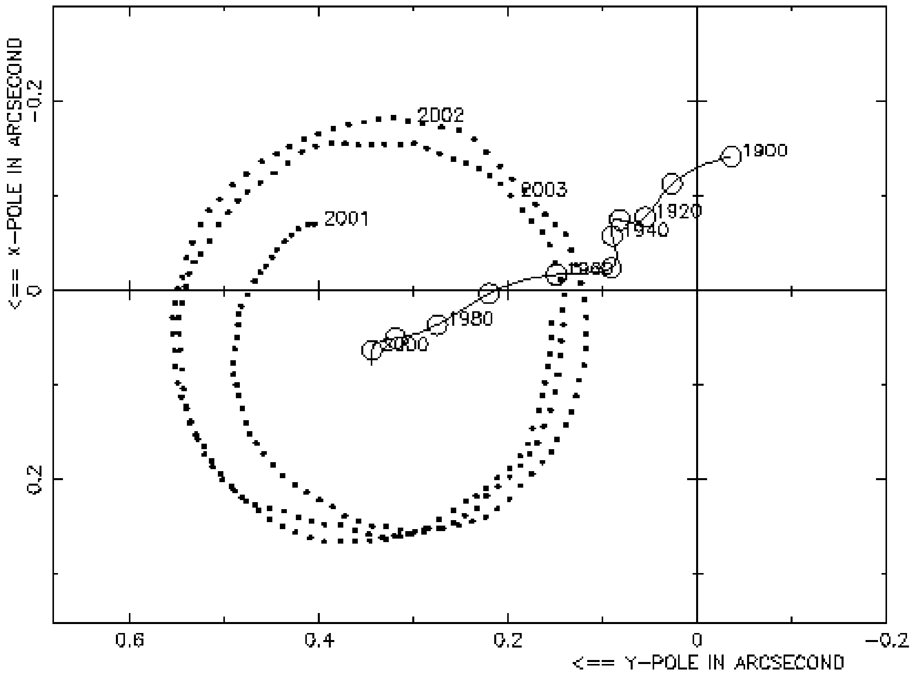

Fig. 1: Mean polar motion (1900–2003) and IERS C04 polhody over 2001 – 2003.

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, 1996; 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 4 reflects the evolution of the mean uncertainties of C02 solution since 1962.

Impact of IAU2000 Resolutions on EOP

Resolutions adopted at the 24th General Assembly of the International Astronomical Union recommend the implementation of new procedures concerning the transformation between the celestial and terrestrial reference systems: adoption of a new precession-nutation model (IAU 2000), of a new celestial pole (the Celestial Intermediate Pole) and of a new transformation between the terrestrial and celestial systems defining UT1 as directly proportional to the Earth Rotation Angle.

Table 4: 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(dψ) — 0.001"	σ(dε) — 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
2001–2004	.15	.15	.1	.3	.1

The IERS Workshop held in Paris in April 2002 had the objective to discuss the impact of these resolutions on the various IERS Products (Capitaine *et al*., 2002). The description of all these changes for the IERS is presented in Rothacher (2002). Complete expressions and tables are described in Chapter 5 of the IERS Conventions 2003.

To comply with these resolutions, since 1 January 2003, Bulletin B and IERS C04 are providing new products in addition to those already published. These products include the celestial pole offsets relatively to the new precession-nutation model IAU2000A and using the new formulation described in the following.

The changes in the EOP

New parameterisation of the Earth orientation

The most important changes are those introduced by IAU Resolutions B1.6 (IAU 2000 Precession-Nutation Model), B1.7 (Definition of Celestial Intermediate Pole) and B1.8 (Definition and Use of Celestial and Terrestrial Ephemeris Origins). Although it is not directly mentioned in the Resolutions, the new precession-nutation model is accompanied by a new formulation for the transformation between the celestial (*CRS*) and terrestrial (*TRS*) reference systems in the form recommended in the IERS Conventions 2003:

$$[CRS] = Q(t) \cdot R_3(-\theta) \cdot W(t) \cdot [TRS],$$

in which $Q(t)$, $R_3(-\theta)$ and $W(t)$ are time-dependent transformation matrices to account for the precession-nutation, proper rotation of the Earth about the axis corresponding to CIP and polar motion, respectively:

$$Q(t) = \begin{pmatrix} 1 - aX^2 & -aXY & X \\ -aXY & 1 - aY^2 & Y \\ -X & -Y & 1 - a(X^2 + Y^2) \end{pmatrix} \cdot R_3(s), \quad a = \tfrac{1}{2} + \tfrac{1}{8}(X^2 + Y^2)$$

$$W(t) = R_3(-s') \cdot R_2(x) \cdot R_1(y)\ .$$

The Earth Rotation Angle (ERA) between the CEO and TEO is given as function of UT1 by a simple linear relation:

$\theta(T_u) = 2\pi(0.779\,057\,273\,264\,0 + 1.002\,737\,811\,911\,354\,48\ T_u)$

where $T_u = \mathrm{JD(UT1)} - 2451545.0$.

Here X, Y, s and y, y, s' describe the position of the Celestial Intermediate Pole (CIP) and the Celestial/Terrestrial Ephemeris Origins (CEO, TEO) in the Geocentric Celestial Reference System (GCRS) and International Terrestrial Reference System (ITRS), respectively (see <http://maia.usno.navy.mil/ch5tables.html>). The novelty are the quantities X, Y, s whose developments into Poisson series, based on the IAU 2000A precession-nutation model, are published by Capitaine et al. (2003). Expressions for the classical transformation based on the new IAU 2000 model have been developed to be equivalent in the new transformation (McCarthy and Petit, 2004).

Celestial pole offsets

Precession-nutation is referred to CIP that exhibits, by definition, only long-periodic motions with periods of two days and longer in space. The IERS is now publishing the celestial pole offsets δX_{2000}, δY_{2000}, referred to the new model IAU 2000 following the new formalism and the quantity s. Classical nutation angles, the celestial pole offsets in longitude and obliquity $\delta\Delta y_{2000}$, $\delta\Delta e_{2000}$. respectively, referred to the new model can be easily derived from (δX_{2000}, δY_{2000}) using equations 23 of Chapter 5 of the IERS Conventions (2003) or the relative Fortran subroutine dXdY_dpsideps included in the package uai2000.package (see next paragraph for its availability). These values δX, δY are now smaller than 1 mas, reflecting mostly the effect of the Free Core Nutation (FCN) that is not predictable and therefore not incorporated into the new model. The position of the CEO, given by *s*, is insensitive to any small change of the precession-nutation at the level of one mas, so only its model values are to be used (<http://maia.usno.navy.mil/ch5tables.html>). Parallel to these values, the values of 'classical' celestial pole offsets $\delta\Delta_{1980}$, $\delta\Delta e_{1980}$, referred to the old IAU 1976 precession and 1980 nutation model, are also being published for a limited period in Bulletin B and in the operational combined series C04.

Polar motion

Polar motion is not affected by adopting the IAU 2000 resolutions. Polar motion contains (relatively small) diurnal and sub-diurnal terms, due to ocean tides and high-frequency nutation terms. These are *not* part of the polar motion values published by the IERS at daily intervals; they are represented by a model (IERS Conventions 2003, Chapters 5 and 8) and should be added after interpolation. The Earth Orientation Centre makes available a Fortran subroutine for such an interpolation (<ftp://hpiers.obspm.fr/eop-pc/models/interp.f>). The position of the TEO, given by *s'*, depends on the actual polar motion, but the value of *s'* is so small that a simple linear approximation (Lambert and Bizouard, 2002) is sufficient:

$s' = -47\ \mu as\ (t - 51544.5) / 36525$ where t is expressed in Modified Julian Days (MJD).

Universal Time

UT1–UTC is theoretically not affected by the resolutions. Although UT1 is now directly linked to the Earth Rotation Angle through the linear relation above, the positioning of CEO (represented by the quantity *s*) and IAU2000 expressions between sidereal time and Universal Time UT1 are such that continuity in UT1 is ensured at the epoch of change from the old system.

There are short-periodic (diurnal, semi-diurnal) variations in UT1 due to ocean tides that are treated similarly to polar motion (the IERS publishes the daily values from which these terms have been removed, and they are to be added back after the interpolation).

Availability of new products and models

Series of the Earth Orientation Centre, in particular Bulletin B and C04 are being duplicated since January 2003 to give δX and δY in the new formulation in addition to the current issue containing $(\delta psi, \delta eps)_{1980}$.

The new files are available at the following Web/ftp sites:

– Web:
http://hpiers.obspm.fr/eoppc/eop/eopc04/eopc04_IAU2000.02
http://hpiers.obspm.fr/eoppc/eop/eopc04/eopc04_IAU2000.03

– anonymous ftp: hpiers.obspm.fr
files: /eop-pc/eop/eopc04/eopc04_IAU2000.02
/eop-pc/eop/eopc04/eopc04_IAU2000.03

Fortran subroutines

1) Transformation of $(\delta X, \delta Y)_{2000}$ to $(\delta psi, \delta eps)_{1980}$ or $(\delta psi, \delta eps)_{2000}$ and inversely are available in Fortran 77/90 at :

– Web:
http://hpiers.obspm.fr/eop-pc/models/models.html#software
files:
– ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package
– ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package.readme

– anonymous ftp: hpiers.obspm.fr
files: /eop-pc/models/uai2000.package
/eop-pc/models/uai2000.package.readme

2) Interpolation of Polar Motion at hourly scale

– Web: http://hpiers.obspm.fr/eop-pc/models/models.html#software
  files:
  – ftp://hpiers.obspm.fr/eop-pc/models/interp.f
  – ftp://hpiers.obspm.fr/eop-pc/models/interp.readme

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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 2003.

Table 1: Estimated accuracies of the techniques in 2003. 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	0.40	0.43	0.106*			
DUT[2] 1 & 3-day SLR	0.34	0.25				
IAA daily SLR	0.14	0.16				
MCC daily SLR	0.16	0.16				
GSFC daily VLBI Int			0.022			
SPBU daily VLBI Int			0.016			
GSFC twice-weekly VLBI	0.07	0.06	0.002		0.4	0.1
IAA[3] twice-weekly VLBI	0.09	0.10	0.004		(0.1)	(0.1)
IVS twice-weekly VLBI	0.04	0.05	0.004		0.4	0.1
USNO twice-weekly VLBI	0.09	0.09	0.006		0.4	0.1
IGS daily Final	0.05	0.03				
IGS daily Rapid	0.03	0.04		0.02*		
USNO daily GPS UT*			0.008*			
EMR daily GPS UT*			0.02*			
USNO daily AAM UT			0.006			

*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] In July, DUT SLR sample rate changed from 3-days to daily.

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

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 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 2003. 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	-0.05	0.07	-0.01	0.07
Y	0.04	0.07	0.05	0.07
UT1-UTC	0.001	0.021	-0.004	0.023
Bulletin A Weekly Solution (finals.data)[1]				
X	0.00	0.09	-0.02	0.09
Y	-0.04	0.09	-0.05	0.09
UT1-UTC	-0.007	0.064	-0.005	0.066
Bulletin A Daily Solution (finals.daily)				
X	0.00	0.13	-0.02	0.12
Y	-0.06	0.13	-0.08	0.13
UT1-UTC	-0.003	0.075 (0.053)[2]	0.001	0.073 (0.050)[2]

[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.

The uncertainties in the daily values listed in Bulletin A are derived from the quality of the spline fit in the neighborhood of the day in question. Table 2 shows the accuracies of Rapid Service/Prediction Centre's combination solution for the running, the weekly, and the daily products compared to the Bulletin B and C04 series maintained by the IERS EOC at the Paris Observatory. The running solution is the combination solution over the past 365-day period.

The statistics for the running solution at year's end show the agreement between the Bulletin A running combination solution and the Bulletin B/C04 series for the entire year. The comparison of the 53 weekly solutions to the Bulletin B/C04 series presents the statistics of the residuals computed over the new combination results for

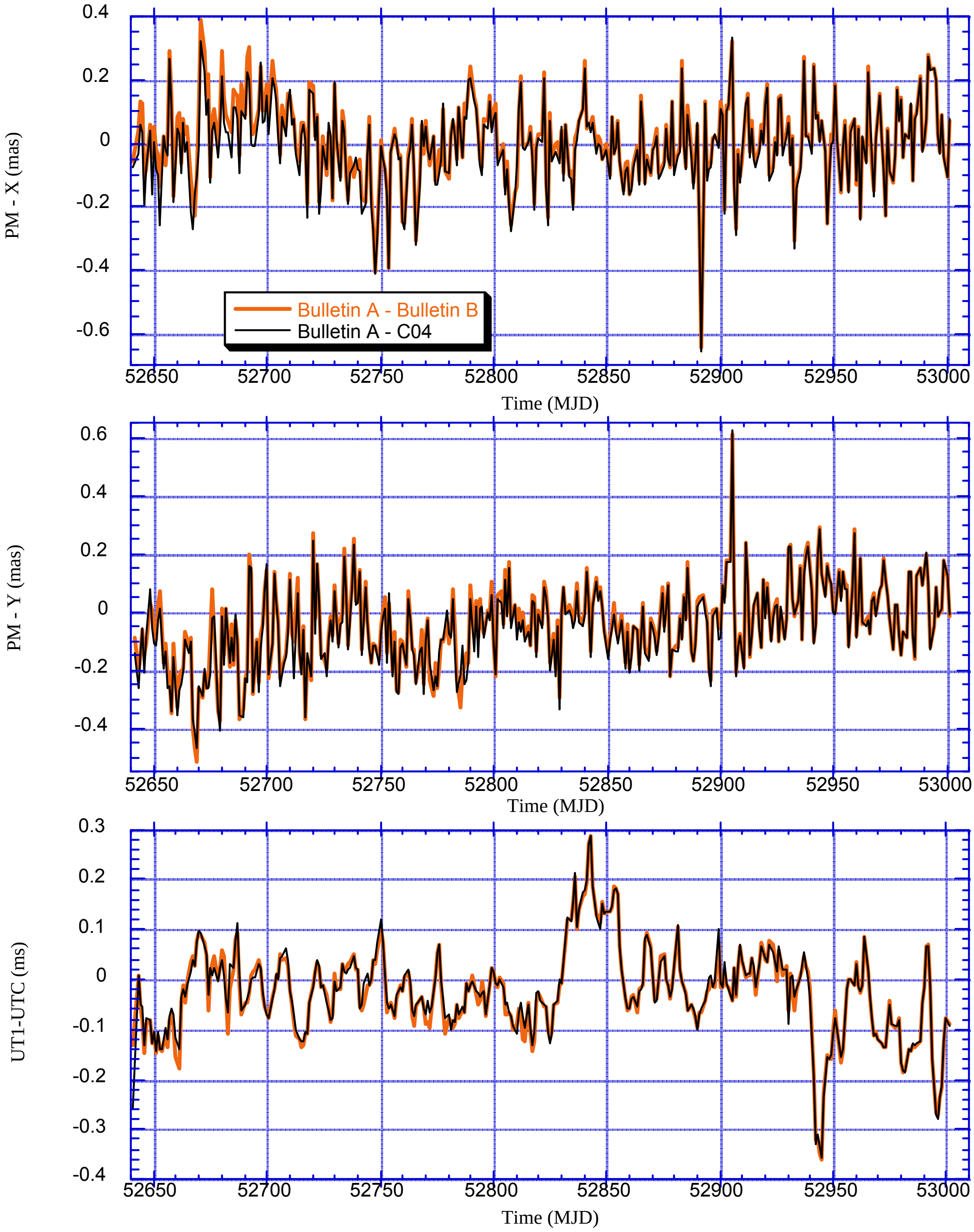

Fig. 1: Differences between Daily Bulletin A Rapid Solutions at each daily solution epoch for 2003 and the Earth Orientation Parameters available in Bulletin B and C04 series produced in March of 2004.

the 7-days prior to the solution epoch. Table 2 also presents the statistics for the daily solution 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 shown in the table.

Figure 1 presents the data used in Table 2 for the determination of the Bulletin A daily solution statistics. Figure 1 and Table 2 both indicate that the Centre's UT1-UTC solution accuracies were degraded during early January, mid- to late-July, late October, and December. These degradations were primarily the result of extended periods without VLBI data and highlight the dependence of EOP on VLBI data. The large 0.15 ms shift in the differences in UT1-UTC between mid-July to early August was traced to problems encountered with the incorporation of new global VLBI solutions into the combination. The large residual in PM-x in Figure 1 on 52892 (10 September 2003) occurred as the result of problems encountered in the initial processing of VLBI data. A similar incident appears to be the cause of the spike in PM-y differences on 52905 (23 September 2003). Additional problems with the VLBI intensive experiments occurred between 24 October and 5 November 2003 due to the temporary loss of the Kokee station and the substitution of the Westford station. 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, $(\mathrm{UT1\text{-}TAI})_n$, the smoothed time value from n days in the past, $\langle(\mathrm{UT1R\text{-}TAI})_{-n}\rangle$ is subtracted from the most recent value, $(\mathrm{UT1R\text{-}TAI})_o$.

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

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., 2003). 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 days 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 2003.

Days in Future	PM-X mas	PM-Y mas	UT1-UTC ms
1	.43	.39	.114
5	2.13	1.55	.425
10	4.22	2.29	.882
20	8.34	3.44	2.03
40	14.7	6.53	4.99
90	19.2	16.9	12.5

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 2003 are given in Table 4.

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 2003.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.12	.12	.29	.12
5	.12	.14	.29	.14
10	.14	.15	.35	.16
20	.14	.15	.44	.22
40	.17	.17	.50	.24

Predictions, of UT1-TAI up to 2013 January 1, are given in Table 5 below. 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.

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

Centre Activities in 2003

During 2003 a number of changes occurred that affected the performance of IERS Bulletin A. In January the IAU resolutions with respect to the IAU 2000A Nutation model were introduced into the Centre’s products. The finals2000A.data and the finals2000A.daily solution files were created to comply with these resolutions. These new files contain the nutation in terms of dX/dY with the effects of the free core nutation computed using the IAU2000A Nutation Theory. Due to problems with the software upgrades and the lack of VLBI intensives, the EOP solution for January 2nd was delayed until early January 3rd. In late summer, finals2000A.all was added to our list of products. The finals2000A.all file is the finals.all file converted to the IAU2000A Nutation Theory in the dX/dY paradigm.

Table 5: Predicted values of UT1-TAI, 2004-2013. 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)
2004	Jan 1	-32.389	.001
	Apr 1	-32.433	.001
	Jul 1	-32.45	.02
	Oct 1	-32.41	.04
2005	Jan 1	-32.50	.06
	Apr 1	-32.76	.09
	Jul 1	-33.0	.1
	Oct 1	-33.3	.2
2006	Jan 1	-33.5	.2
	Apr 1	-33.8	.3
	Jul 1	-34.0	.4
	Oct 1	-34.2	.4
2007	Jan 1	-34.4	.5
	Apr 1	-34.7	.6
	Jul 1	-34.9	.8
	Oct 1	-35.1	.9
2008	Jan 1	-35.	1.
	Apr 1	-35.	1.
	Jul 1	-35.	1.
	Oct 1	-35	1.
2009	Jan 1	-35.	2.
	Apr 1	-35.	2.
	Jul 1	-35.	2.
	Oct 1	-35.	2.
2010	Jan 1	-36.	2.
	Apr 1	-36.	2.
	Jul 1	-36.	2.
	Oct 1	-36.	2.
2011	Jan 1	-36.	3.
	Apr 1	-36.	3.
	Jul 1	-36.	3.
	Oct 1	-37.	3.
2012	Jan 1	-37.	3.
	Apr 1	-37.	3.
	Jul 1	-37.	4.
	Oct 1	-37.	4.
2013	Jan 1	-37.	4.

On 15 January 2003 two additional VLBI 24-hour solutions were added to the combination solution. These new VLBI solutions are the USNO R1/R4 VLBI solution and the IVS Combination EOPS VLBI solution. The addition of these series to the solution has improved the robustness of the celestial pole offset parameters. These two VLBI series, like the GSFC VLBI series, are checked daily for updates. If an update is available, then the updated series is used in the next daily solution or weekly solution.

In late January the biases and rates that are applied to the VLBI data were adjusted for the new global solution from GSFC, IAA, and USNO. This update resulted in a small correction in the UT1-UTC mean value with respect to the C04 series.

On 11 February 2003 the retrieval and updating of Saint Petersburg University VLBI intensive data was automated and added to the daily solution software package.

On 20 February 2003 the retrieval and updating of IAA VLBI 24-hr session series was automated. With the automation of this VLBI data set, all of the VLBI 24-hr and intensive sessions are currently updated in the daily solution as soon as new updates become available.

On 5 March 2003 the software was modified and code was written to handle the IAA's switch to the dX/dY paradigm to represent the motion of the pole in the celestial reference system. The IAA's dX/dY values are converted to the $\delta\psi/\delta\varepsilon$ paradigm for the actual combination process. The routine used for the conversion between dX/dY and $\delta\psi/\delta\varepsilon$ is based on the routines available in the IERS Conventions 2003 (McCarthy and Petit, 2004). However, the conventions do not give guidance in the handling of the dX/dY formal errors computed in the files. Therefore, routines were developed to convert these formal errors back to the $\delta\psi/\delta\varepsilon$ paradigm.

In June and July new VLBI global solutions required the estimation of new rates and biases for the combination software. The rates and biases for all of the SLR data sets were also re-estimated. These updates resulted in improvements to the PM-x and PM-y time series. Unfortunately, there was a problem with a VLBI intensive UT1-UTC bias correction, which was detected and corrected in early August.

In August the weekly script was modified. New routines were added to automate the retrieval of the SLR data from the mail server. This modification reduced the weekly processing time.

In late October the rates and biases were recomputed for a few data sets.

Currently, the Centre is investigating ways to improve the estimation of biases between the different Analysis Centre datasets and the C04 series.

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; x, y, UT1-UTC from CSR LAGEOS 3-day SLR; x, y from Delft University of Technology 3-day SLR and later in the year their 1-day solution; 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, $\delta\psi$, $\delta\varepsilon$ from the IERS Rapid Service/Prediction Centre; x, y, UT1-UTC, $\delta\psi$, $\delta\varepsilon$ 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 at 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 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 is available at

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

Centre Staff

For most of 2003, the Rapid Service/Prediction 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

William Wooden joined the program in late February 2003.

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

3.5.3 Convention Centre

The Convention Center is provided jointly by the Bureau International des Poids et Mesures (BIPM) and the U.S. Naval Observatory (USNO). In 2003, the work accomplished or in progress is the following.

Final edition of the IERS Conventions (2003)

After final work on remaining issues, mostly in Chapters 5 (Transformation Between the Celestial and Terrestrial Systems), 9 (Tropospheric Model), 10 (General Relativistic Models for Space-Time Coordinates and Equations of Motion) and in the general outline of the document, the final edition of the IERS Conventions (2003) was submitted to the IERS Central Bureau in November 2003. The corresponding files are available on <http://maia.usno.navy.mil/conv2003.html>. This electronic release was announced in IERS Message No. 49, and accompanied by a questionnaire to the general IERS community asking for comments on the present version and future evolution of the IERS Conventions.

Preparation for future versions of the Conventions

The IERS Convention 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. Work is currently under way to prepare for this new electronic maintenance. In addition to the electronic releases, printed versions of the Conventions will be provided at less frequent intervals or when major changes are introduced.

On the technical issues, 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 regularized position, such as the effects of geocenter motion or atmospheric loading.

Studies on the consistency of Conventions and IERS products

The BIPM has provided for a visiting scientist to conduct studies on the consistency of the Conventions and IERS products. Jim Ray, from the U.S. National Geodetic Survey, has taken this one-year position from September 1, 2003.

The Convention Center contributes to the ongoing work to implement new conventional models and procedures. Some important topics for the future include geocenter motion, impact of using global as opposed to local loading models, and network effects in the solutions of different techniques. It also will participate in new studies, such as the development of rigorous multi-technique product combinations, through collaboration in the new Combination Pilot Project.

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Ray J., Petit G., Altamimi Z., Requirements for improved definitions and realizations of the ITRF origin and geocenter motion, AGU Fall Meeting, San Francisco, 2003.

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 (Observatoire de Paris and US Naval Observatory) 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 Paris Observatory and U.S. Naval 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 (icrs-pc@hpopa.obspm.fr).

Maintenance of the ICRF

The process of maintenance of the ICRS requests revisions of the International Celestial Reference Frame whenever this is justified by an improvement in the VLBI technique and modeling, by an increase of the number of objects in the frame, or by an increase in the accuracy of radio source positions.

ICRS representation by different sets of selected sources

The axes of the ICRS are materialized by the coordinates of 212 sources in the ICRF qualified as the “defining” objects of the frame. They have been selected by the Working Group on Reference Frames of the IAU by applying quality criteria to VLBI observations from 1975–1995 (Ma et al., 1997, 1998). A different selection of sources has been proposed by Feissel-Vernier (2003) based on an analysis of time series of radio source coordinates over the period 1989–2002. As a contribution to the maintenance of the primary reference frame, the quality of the realization of the ICRS by the two sets of selected sources has been compared (Arias and Bouquillon, 2004).

The analyses have been performed by making use of two VLBI catalogues elaborated from independent VLBI analysis: RSC (BKGI) 02 R 01 and RSC (IAA) 02 R 03 (IERS, 2003). Both catalogues have been compared to ICRF-Ext.1 by using two sets of stable sources: (a) ICRF defining sources, and (b) Feissel-Vernier (F-V) stable sources. The algorithm of comparison is the one currently used at the ICRS Product Centre, which models the transformation between two systems by a global rotation of axes and three deformation parameters (IERS, 2003).

In the ICRF the sources have been classified by applying criteria based on the observational history of radio sources, the consistency of coordinates derived from different data subsets and the evidence of radio structure. F-V classification is mainly supported by the observational history of sources and the analysis of time series of radio source coordinates. 212 ICRF sources satisfied all criteria and have been classified as "defining", that is, the best adapted to define the orientation of the axes of the system. F-V has studied the stability of radio source positions by statistical analysis of the time series of the yearly averaged coordinates (standard deviation, Allan standard deviation, normalized linear drift), and obtained a set of 199 stable sources. 75% of the sources selected by F-V are either ICRF "defining" or "candidate", these latter considered as potential candidates to become defining sources in the future.

The two VLBI solutions used for these analyses are independent, and they yield to individual frames with a different space distribution of objects. When compared to a rigid frame, that is, to ICRF-Ext.1, we conclude that the orientation of the axes of the ICRS is better realized by using the set of stable sources selected by F-V (2003). This result indicates that statistical tests should be considered when selecting a set of stable sources to define the orientation of axes of the ICRS. The F-V selection spans the interval 1989.5–2002.4, whereas ICRF used observations between 1975–1995. Limiting the time span for observations to the last years favours the quality of the realization of the frame (for further details, see Arias and Bouquillon, 2004).

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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 2003, increasing the number of observations of ICRF quasars in the southern celestial hemisphere and continuing an extensive observing program in the northern hemisphere. These observations have led to the completion of a second extension to the ICRF (Fey et al. 2004b), called ICRF-Ext.2. In this ICRF extension, VLBI data obtained between mid-1995 and the end of 2002 May were used, together with older data, to extend and revise the ICRF. Revised positions of ICRF candidate and "other" sources, based on inclusion of the additional data, were presented. ICRF-Ext.1 added 59 new sources to the conventional frame. This second extension adds 50 more sources to the ICRF. For the first time, VLBA data has been used in the formation of the conventional extragalactic reference frame. Positions for the additional 109 new sources were also reported in the frame of the ICRF. All but four of the new sources are located north of –30 degrees declination. In the second extension, positions of the ICRF defining sources were held unchanged. A summary of current astrometric/geodetic observing programs and a short discussion on the evolution and future of the ICRF can also be found in Fey et al. (2004b). The ICRF-Ext.2 solution differs from that of ICRF and ICRF-Ext.1 in the use of the NMF mapping function (Niell, 1996) for troposphere modeling.

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 Gaia mission will achieve positional accuracies well beyond that presently obtained by any ground-based radio interferometric measurements. During 2003, ICRS Centre personnel were involved in a joint US-German astrometric satellite program, called AMEX, proposed to NASA as a Small Explorer (SMEX) mission. Based primarily on the cancelled German DIVA mission, AMEX involved fabrication of the instrument in the US, fabrication of the spacecraft bus in Germany, and launch on a Russian vehicle. Unfortunately, the proposed mission was not chosen by NASA administrators to proceed into Phase A. ICRS Centre personnel continued to be involved in the SIM mission, expected to launch in 2009.

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Monitor source structure to assess astrometric quality

VLBA Observations

Observations of 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. These VLBA RDV observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Centre (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames. During the calender year 2003, six VLBA RDV experiments were observed.

VLBA observations of selected ICRF sources intended to extend the ICRF to 24 GHz and 43 GHz continued in 2003. These observations are part of a joint program between the NASA, the USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory. The long term goals of this program are to 1) develop higher frequency reference frames for improved deep space navigation, 2) extend the VLBA calibrator catalog at 24/43 GHz, 3) provide the benefit of the ICRF catalog to new applications at these higher frequencies, and 4) study source structure variation at 24/43 GHz in order to improve the astrometric accuracy. During the calendar year 2003, two VLBA high frequency experiments (BR079C and BL115A) were calibrated and imaged.

The USNO Radio Reference Frame Image Database

The VLBA observations taken under the above programs provide data suitable for imaging of the intrinsic structure of the extragalactic radio sources which make up the ICRF. Images are made at the USNO and are made available for use by anyone from the USNO Radio Reference Frame Image Database (RRFID). The RRFID can be accessed on the World Wide Web at http://www.usno.navy.mil/RRFID/. The RRFID contains 3060 VLBA images of 452 sources at radio frequencies of 2.3 GHz and 8.4 GHz. A recent addition to the RRFID are VLBA images of ICRF sources at radio frequencies of 24 GHz and 43 GHz. The RRFID contains 578 images of 230 sources at these frequencies.

Extending the ICRF to higher frequencies

As a first step toward assessing the impact of intrinsic source structure at 24 GHz and 43 GHz, Gaussian component models were fitted to selected images. A core fraction, defined as the ratio of core flux density to total flux density, was also calculated (core flux density is defined as the CLEAN-ed flux density in an image contained within one synthesized beam whereas the total flux density is defined as the total CLEAN-ed flux density, i.e., the sum of all CLEAN model components).

Results of the initial structure analysis are: 1) the overall spatial extent of the sources decreases as one goes to higher observing frequencies (see Figure 1); 2) source component sizes decrease as one goes from the ICRF frequency of 8.4 GHz to 24 GHz (see Figure 2); 3) source component sizes decrease only marginally as one goes from 24 GHz to 43 GHz, i.e., sources appear to be no more compact at 43 GHz than at 24 GHz (see Figure 3); and 4) there is evidence that weaker sources are more compact (but this could be a selection affect; see Figure 4). These results suggest that reference frames defined at higher radio frequencies will be less susceptible to the effects of intrinsic structure than the ICRF.

These initial results were reported at: 1) the 201st meeting of the American Astronomical Society held in Seattle, WA in 2003 January; 2) the VLBA 10th Anniversary Meeting held in Socorro, NM in 2003 June; and 3) the 3rd General Meeting of the International VLBI Service held in Ottawa, ON in 2004 February.

ICRF source component motions

A joint program between Whitier College and the USNO to measure apparent jet velocities from the motions of source components using RRFID data at 8.4 GHz was initiated by Piner et al. (2002). To date, a total of 60 sources have been analyzed (Piner et al., 2003) Results show that the distribution of apparent component speeds peaks at low values (near 1c, where c is the speed of light) but extends to values as high as 30c. The average apparent speed for all components is 4.8c.

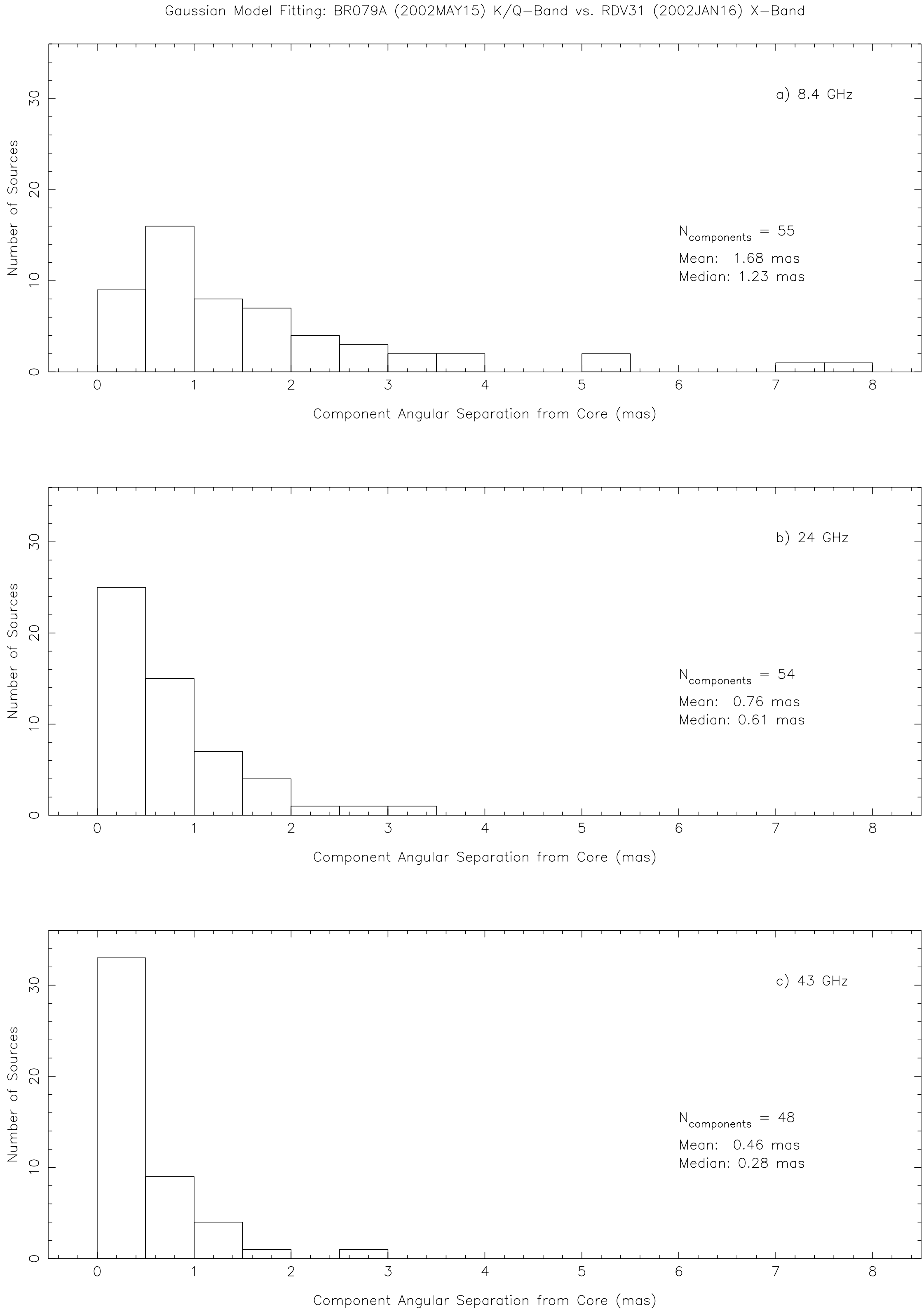

Fig. 1: Distribution of Gaussian component angular separation from the assumed core component for the 28 common sources observed on 2002 Jan 16 and 2002 May 15 at a) 8.4 GHz, b) 24 GHz and c) 43 GHz. The core is defined as the model component fitted to the image having the smallest angular size.

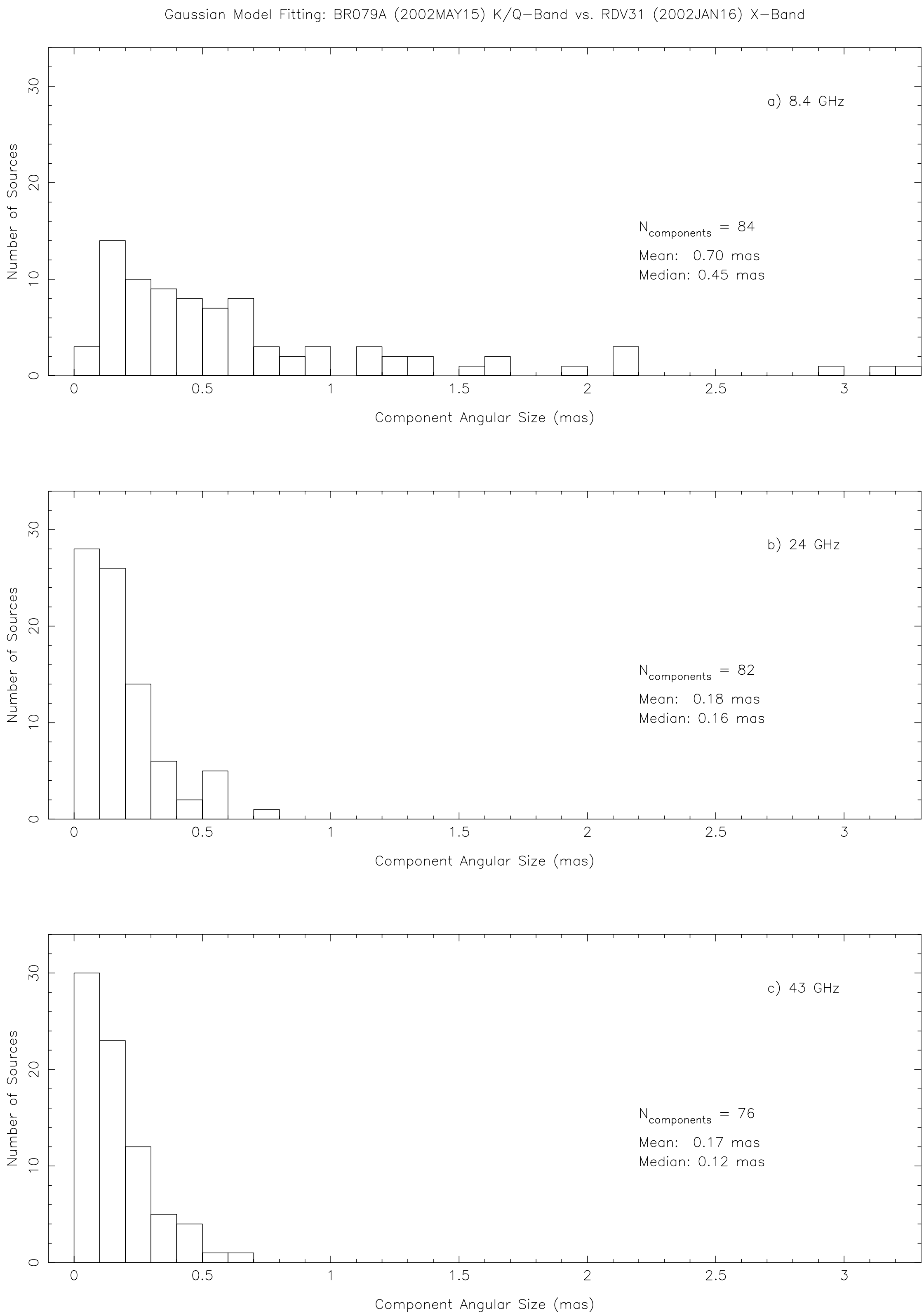

Fig. 2: Distribution of Gaussian component angular size for the 28 common sources observed on 2002 Jan 16 and 2002 May 15 at a) 8.4 GHz, b) 24 GHz and c) 43 GHz.

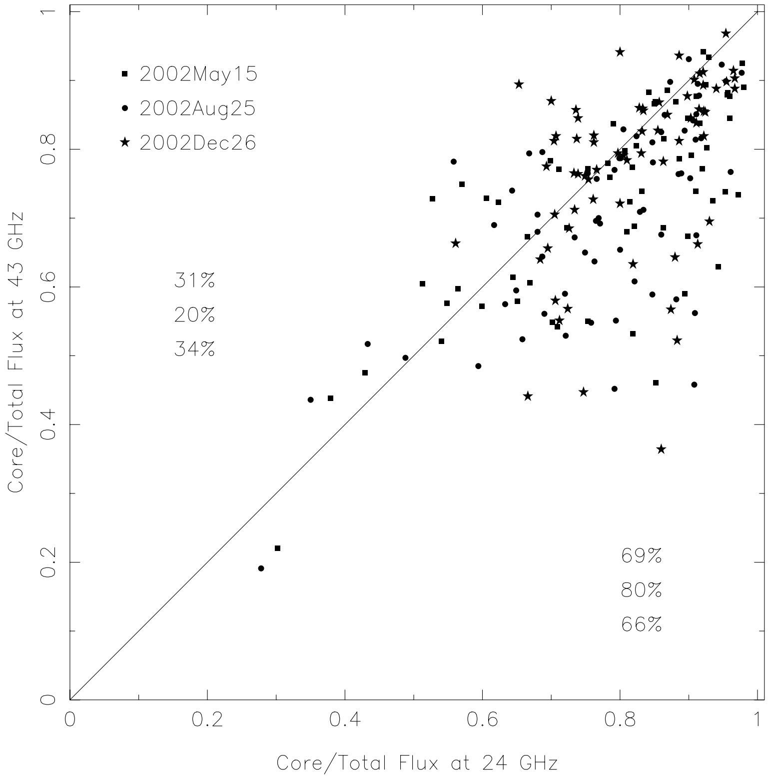

Fig. 3: Source compactness (ratio of core flux density to total flux density) at 43 GHz versus source compactness at 24 GHz for the sources observed in the VLBA experiments BR079A, BR079B and BR049C. Core flux density is defined as the CLEAN-ed flux density in an image contained within one synthesized beam. The total flux density is defined as the total CLEAN-ed flux density (i.e., the sum of all CLEAN model components).

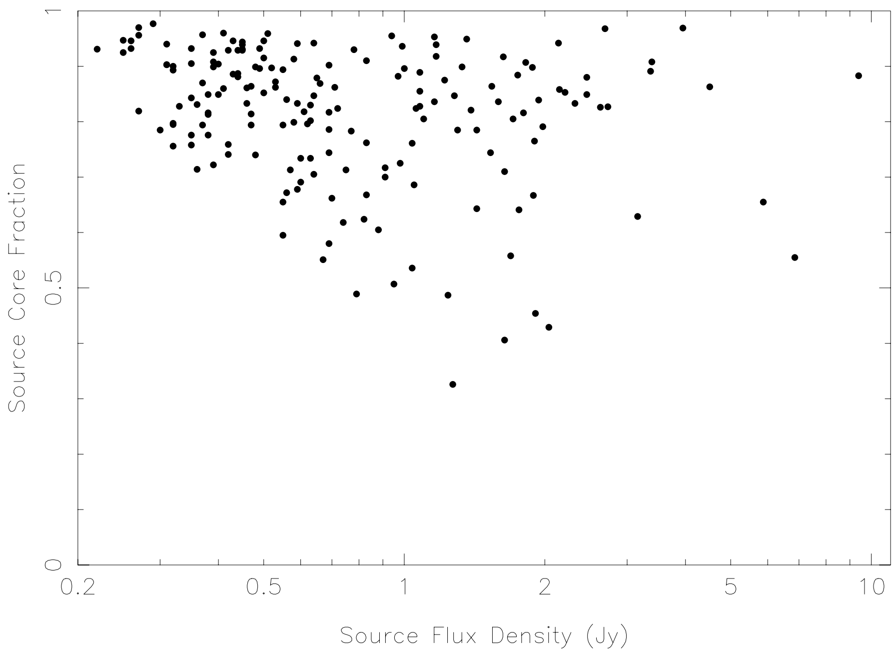

Fig. 4: The distribution of source core fraction (ratio of core flux density to total flux density) at 24 GHz versus source total flux density for the 184 ICRF source observed in VLBA experiment BL115A. Core flux density is defined as the CLEAN-ed flux density in an image contained within one synthesized beam. The total flux density is defined as the total CLEAN-ed flux density (i.e., the sum of all CLEAN model components).

Southern Hemisphere astrometry and imaging

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. Plans include strengthening the ICRF in the Southern Hemisphere by a) increasing the reference source density with additional 2.3/8.4 GHz bandwidth-synthesis astrometric VLBI observations, and b) VLBI imaging at 8.4 GHz of ICRF sources south of –20 degrees declination.

VLBI images for a total of 69 Southern Hemisphere ICRF sources were made at a frequency of 8.4 GHz using the Australian Long Baseline Array (Ojha et al., 2004). 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 shown in Fig. 5 has a mean (median) value of 0.83 (0.88) which 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. These sources are probably poorly suited for high accuracy reference frame use unless intrinsic structure can be taken into account. Many of the observed sources have never been previously imaged at milliarcsecond resolution.

This program has also yielded milliarcsecond accurate radio positions for 22 Southern Hemisphere extragalactic sources not previously in the ICRF (Fey et al., 2004a). These 22 sources all have positions south of declination –30 degrees (positions for ten of the sources are south of –60 degrees declination). The reported positions have average formal uncertainties of 0.5 mas in right ascension and 0.6 mas in declination.

Alan L. Fey, David A. Boboltz

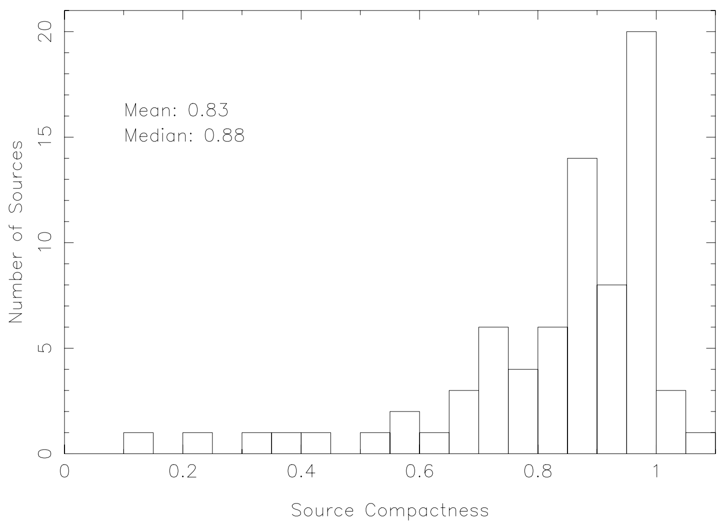

Fig. 5: Distribution of source compactness (ratio of core flux density to total flux density) at 8.4 GHz for 69 Southern Hemisphere ICRF sources. Core flux density is defined as the CLEAN-ed flux density in an image contained within one synthesized beam. The total flux density is defined as the total CLEAN-ed flux density (i.e., the sum of all CLEAN model components).

Maintenance of the time stability of ICRF

Feissel-Vernier (2003) explains in details the analysis of stability of a special set of radiosources selected with appropriate criteria, in order to show some possibility to improve the astrometric quality of the ICRF. This study follows an analysis of 3.4 million observations in 3338 VLBI observing sessions from 1980 up to May 2002 (Fey, 2002). These observations were leading to the source coordinates per session for 721 sources, resulting in time series of 110,111 individual positions. The results have been taken into consideration in the discussions lead by the IVS for the selection of sources in the future extensions of the ICRF.

Martine Feissel

Maintenance of the link to the Hipparcos catalog

During the report period (2003) progress has been achieved at USNO in two areas related to the maintenance of the Hipparcos link: UCAC project, and the extragalactic link.

For the densification of the optical reference frame the UCAC project (USNO CCD Astrograph Catalog) observing program is almost complete. By end of December 2003, 98% of the sky was covered. This all-sky survey will give 20 mas positions for stars in the 10 to 14 mag range, with a limiting magnitude of about R=16.

The 2nd data release (UCAC2) was presented in July 2003 at the IAU General Assembly (see Zacharias et al., 2004). This catalog contains over 48 million stars, all with proper motions, covering 87% of the sky. Proper motions were derived from AC2000, Tycho data, and re-measurements of AGK2, NPM and SPM plates. Work on a bright star supplement to UCAC2 started which will contain all Hipparcos and Tycho-2 stars not in UCAC2.

For the extragalactic link program 50 and 20 QSO source fields were observed with the KPNO 0.9m and the NOFS 1.3m telescopes, respectively. Work on the Space Interferometry Mission (SIM) preparations for the reference frame link continued, including the observing program at the 1.55m Strand Reflector at NOFS. Preliminary results were presented at the January 2004 AAS.

USNO has committed to completely measure all Hamburg Zone Astrograph and Black Birch Astrograph plates (see Figure 6). A set of 450 plates was shipped from Hamburg Bergedorf to USNO, Washington to be measured on StarScan. The remaining 3000 plates will follow soon. Most of these plates cover about 35 square degrees around extragalactic reference frame sources. There are at least 4 plates on each of over 500 fields, covering about 1/5 of the entire sky to a limiting magnitude of about 14 for epochs ranging mainly from 1977 to 1992. A mean position error of 50 mas per coordinate is expected for these about 3 million stars.

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

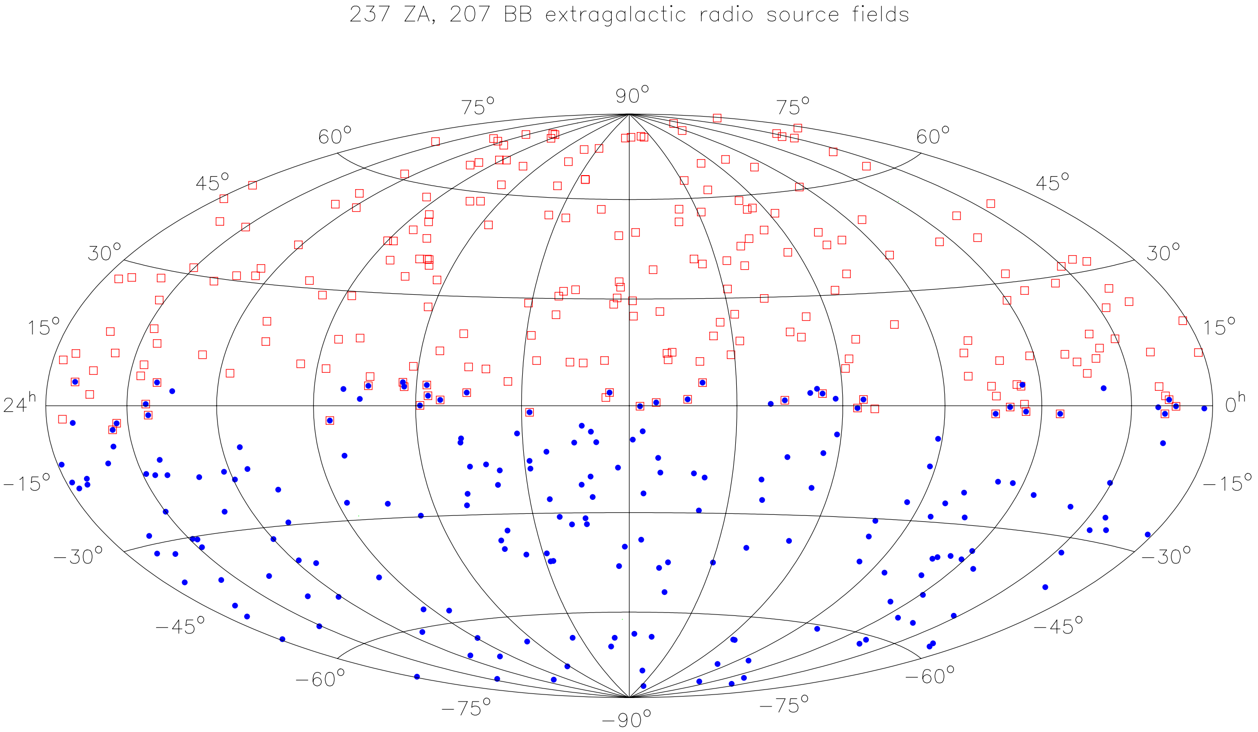

Fig. 6: Distribution of the 237 Hamburg Zone Astrograph (squares) and 207 Black Birch Astrograph (circles) plates in celestial coordinates.

Linking the ICRF to frames at various wavelengths

The latest version of the Véron-Cetty and Véron catalogue (Véron-Cetty and Véron, 2003) contains, in addition of the precedent version the objects recorded in the second release of the 2dF quasar catalogue, and of the first part of the Sloan Digital Sky Survey catalogue. Therefore, it has almost doubled the number of known quasars whereas the number of active nuclei recorded has also considerably increased. At total 48,921 quasars are included, together with 876 BL Lac objects, and 15,069 active galaxies. Among other parameters, the catalogue includes positions at J2000.0, redshifts and U,B,V photometry. When available, flux densities, expressed in Jy., at 6 cm and 11 cm are also given, but in fact a very small proportion of objects have been observed at radio wavelengths: only 2850 quasars have been recorded at 6 cm (5.8 %) and only 1418 at 11 cm (2.9 %). We have performed a cross-identification of the objects in common between the ICRF and the recent catalogues of quasars. Below a threshold of 0.4", 132 sources among the 212 defining sources (62.2 %) of the ICRF have a counterpart in the Véron-Cetty and Véron catalogue, whereas the counts are respectively 160 sources among the 294 candidate sources (54.4 %) and 69 sources among the other 102 ones (67.6 %). The coss-identification enables to determine statistics concerning various photometric and physical properties of the ICRF quasars.

Jean Souchay

Link to the the solar system dynamical reference through pulsar analysis

The ephemerides of the Earth orbiting around the sun are necessary for the reduction of pulsar observations. Therefore the idea of associating pulsar timing technique with differential VLBI astrometry should provide high quality information about the position and motion of the equator, the ecliptic, the origin point of the ICRS.

Moreover, the sole analysis of signals of various pulsars should enable to construct an astrometric catalog containing the positions and the proper motions of a large number of pulsars (more than 30 observed at Nançay radiotelescope). The possibility of using high precision accumulated data coming from intensive campaigns for more than 10 years (Cognard et al., 1995) in that aim is more and more seriously investigated. In the continuity of the recent years, the observational campaign of pulsars in 2003 was very active, with a number of about 25 pulsars observed on a regularly basis. A new receiver has been implemented which provides a factor of 2.2 improvement of the signal.

Ismael Cognard, Jean Souchay

Maintenance of the link to the solar system dynamical reference system using LLR analysis

The position of the inertial dynamical ecliptic at a given epoch with respect to the ICRS (International Celestial Reference System) can be obtained from Lunar Laser Ranging (LLR) observations. The basic definitions concerned here are:

- the inertial dynamical ecliptic of J2000 and the ICRS reference equatorial plane;
- the inertial mean equinox of J2000 $\gamma_I^{(ICRS)}$ and the origin of right ascensions $o^{(ICRS)}$;
- the inclination of the inertial mean ecliptic on the ICRS equator $\varepsilon^{(ICRS)}$.

The results given below are those mentioned in the last report. New determinations are in progress.

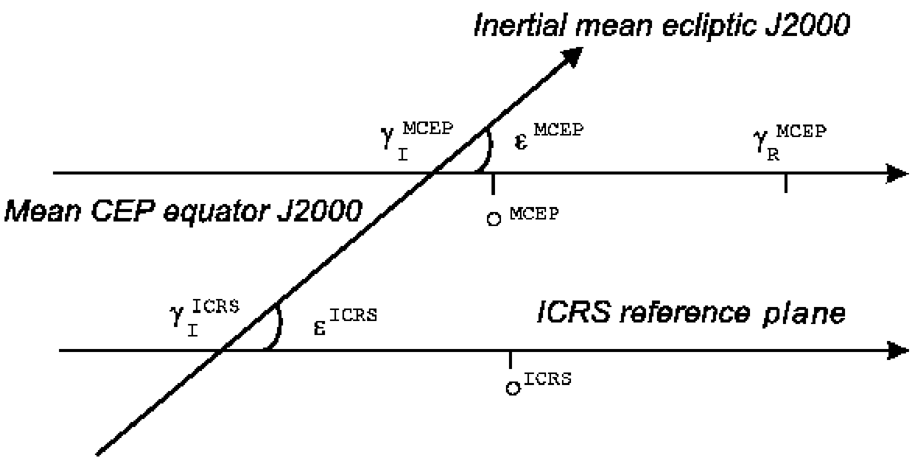

Fig. 7: Position angles of the inertial mean ecliptic of J2000.

The ICRS equator and origin of right ascensions $o^{(ICRS)}$ are involved in the transformation of the rectangular coordinates of the LLR stations in the terrestrial reference frame to the celestial J2000 equatorial coordinates. This transformation has been realized according to the lunar solution which results from weighted fits of the semi-analytical theory ELP2000-96 (orbital motion of the Moon) to the LLR observations provided between 1970 and 2002. The precession-nutation matrix PN is computed via the conventional set of values recommended by IERS (1996), in particular the nutation corrections $\delta\varepsilon$ and $\delta\psi$ of the series EOP(C04) produced by the Earth Orientation Centre. The position of the inertial dynamical ecliptic of J2000 with respect to the ICRS is defined by the angles:

$$\varepsilon^{(ICRS)} = 23° \, 26' \, 21.411\,00'' \pm 0.000\,05''$$
$$o^{(ICRS)}\,\gamma_I^{(ICRS)} = -55.4 \pm 0.1 \text{ mas}$$

By the same way, the position of the inertial dynamical ecliptic of J2000 can be obtained with respect to the reference frame linked to the mean Celestial Ephemeris Pole (CEP), noted here MCEP. In this case, we used another lunar solution, also issued from ELP2000-96 fitted to LLR data, where the precession-nutation is provided by analytical solutions: polynomial expressions of the precession and theory of nutation. Then, the position of the inertial dynamical ecliptic of J2000 with respect to the MCEP is defined by the angles:

$$\varepsilon^{(MCEP)} = 23° \, 26' \, 21.405\,64'' \pm 0.000\,09''$$
$$o^{(MCEP)}\,\gamma_I^{(MCEP)} = -14.6 \pm 0.2 \text{ mas}$$

From the 2 solutions linked to ICRS and MCEP, we also determine the correction Δp to the IAU 1976 precession constant and the value of the distance between the two inertial mean equinox of J2000 $\gamma_I^{(ICRS)}$ and $\gamma_I^{(MCEP)}$:

$$\Delta p = -3.02 \pm 0.03 \text{ mas/a}$$
$$\gamma_I^{(ICRS)}\,\gamma_I^{(MCEP)} = 44.5 \pm 0.4 \text{ mas}$$

Orbital parameters of the Moon and of the Earth-Moon barycentre have also been fit, in particular the tidal component of the secular acceleration of the lunar longitude Γ which is related to a decrease in the Earth's rotation rate and an increase of the length of the day. The most recent determination is:

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

Remarks:

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

- Usually $\gamma_I^{(MCEP)}$ is named the "inertial" dynamical mean equinox of J2000. The separation from $\gamma_I^{(MCEP)}$ to the "rotational" dynamical mean equinox of J2000 $\gamma_R^{(MCEP)}$ is 93.66 mas.

Jean Chapront, Michelle Chapront-Touzé, Gérard Francou

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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)

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3.5.5 ITRS Centre

This report summarizes the activities of the IERS ITRS Centre during the year 2003.

The main activities of the ITRS Centre during the year 2003 are:

- Surveys of co-location sites
- Relation with IGS
- Contribution to the IERS Workshop on site co-locations, Matera, Italy, October, 2003
- Maintenance of the IERS network

Surveys of co-location sites

The Institut Géographique National participated in 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. Moreover, a new ITRS Web site is developed and it is under its validation phase. This new Web site will provide site information, station positions (at any epoch) and velocities in any ITRF version in SINEX or/and table list.

Contribution to the IERS Workshop on site co-locations

The ITRS Centre contributed to the IERS Workshop held in Matera, Italy, in October 2003. A Position Paper (Altamimi et al., 2003) was prepared by the ITRS Centre with contribution from the technique services. The Position Paper was extensively discussed during its devoted session and focused on Co-location sites and their importance for the ITRF, and in particular:

- Definition of a co-location site in terms of accuracy and distance between co-located stations

- Requirements of the IERS combination centres concerning local ties: SINEX files, accuracy
- Current status of local ties in co-location sites:
  - distribution of currently operating stations of the 4 techniques
  - quality of the currently available local ties
  - list of missing local ties
  - priority list of problematic sites

Figure 1 shows the currently operating stations for the 4 techniques, and Figure 2 summarizes the currently co-located sites.

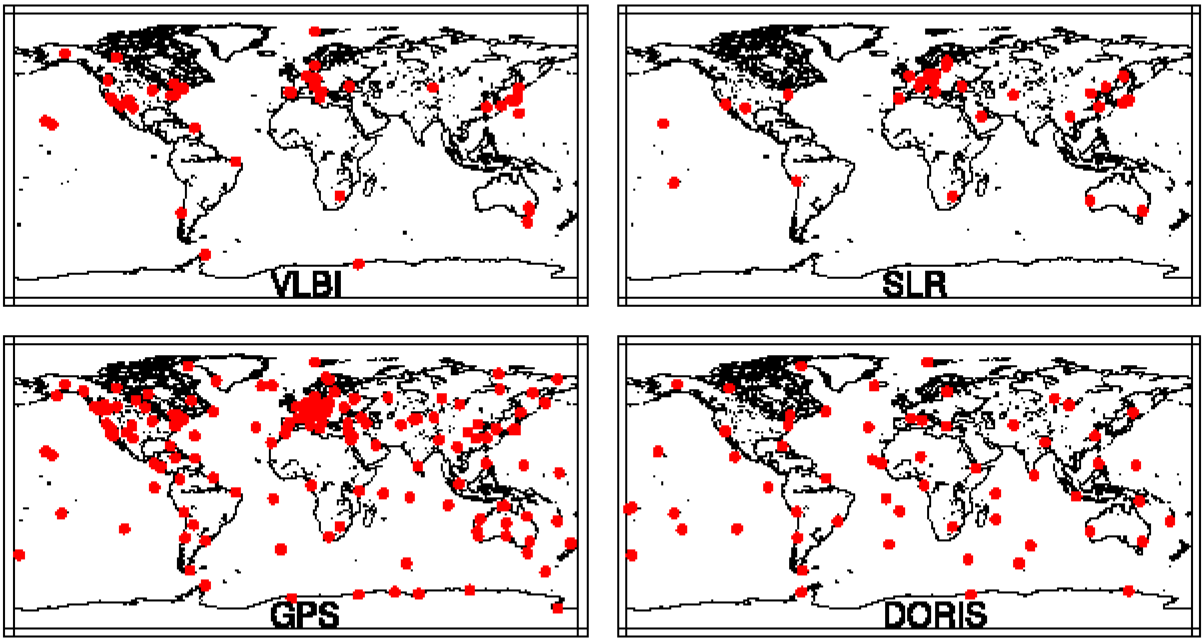

Fig. 1: Current operating sites per technique

Reference

Altamimi, Z., A. Moore, A. Nothnagel, V. Husson and H. Fagard, ITRF and Collocation Sites, in: IERS Workshop on site co-locations, Matera, Italy, 2003. (IERS Technical Note) Frankfurt am Main: BKG, 2004, in preparation.

Zuheir Altamimi, Bruno Garayt, Claude Boucher,
Martine Feissel-Vernier

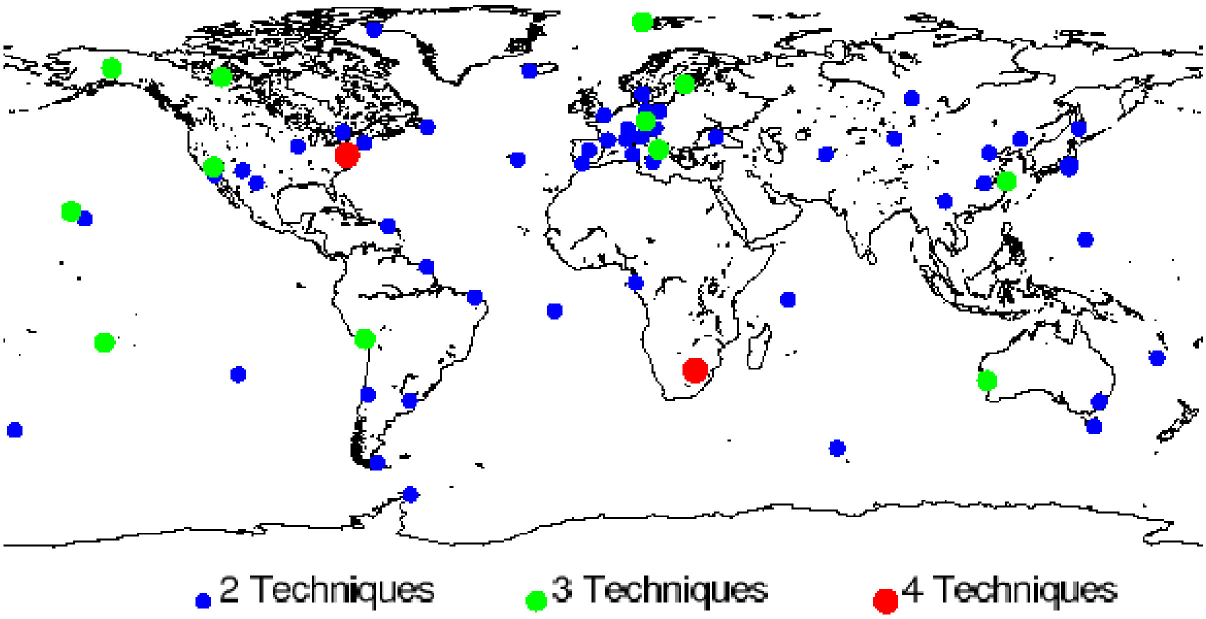

Fig. 2: Current co-locations of space geodesy techniques (1999)

3.5.6 Global Geophysical Fluids Center (GGFC)

Established by the International Earth Rotation Service (IERS) on January 1, 1998, the Global Geophysical Fluids Center (GGFC) has the responsibility of supporting, facilitating, and providing services to the worldwide research community in areas related to the variations in Earth rotation, gravitational field and geocenter that are caused by mass transport in the geophysical fluids and the induced loading effects.

Under the GGFC, eight Special Bureaus (SB) were established. They are SB for Atmosphere, Oceans, Hydrology, Tides, Mantle, Core, Loading, and Gravity/Geocenter (see below). Angular momenta and the related torques, gravitational coefficients, geocenter shift, and surface loading deformation fields will be computed for all geophysical fluids based on global observational data, and/or products from state-of-the-art models some of which assimilate such data. The computed quantities, algorithm and data formats will be standardized. The data products are, and additional ones will be, archived and made available to the scientific research community.

During 2003, a major modification of the GGFC portal website was done, giving it a more modern look and a more efficient organization of presenting information.

An article based upon a paper given at the 2002 IERS Workshop on Combination Research and Global Geophysical Fluids held in Munich, Germany, November 18 - 21, 2002, was published in 2003. Along with another earlier article, it is now posted in the GGFC website. They are (courtesy of the American Geophysical Union) :

Chao, B. F., V. Dehant, R. S. Gross, R. D. Ray, D. A. Salstein, M. M. Watkins, and C. R. Wilson, Space geodesy monitors mass transports in global geophysical fluids, EOS, Trans. Amer. Geophys. Union, 81, 247–250, 2000.

Chao, B. F., Geodesy is not just for static measurements any more, EOS, Trans. Amer. Geophys. Union, 84, 145–156, 2003.

A GGFC business meeting was held on December 8, 2003, during the American Geophysical Union's 2003 Fall Meeting in San Francisco. It was participated by all but one SB chairs, IERS DB members Bernd Richter and Markus Rothacher, ITRS Centre representative Zuheir Altamimi, as well as many interested scientists. Status of IERS and all SBs were reported, funding and data archive issues were discussed, and several action items were proposed.

The Websites (see Appendix 4) contain detailed information of GGFC and the SBs, including description and availability of archived data, useful graphics, members/associates list, call for participation, planned activities, and bibliography, etc.

Detail reports from each SB follow.

Benjamin F. Chao

3.5.6.1 Special Bureau for the Atmosphere

In conjunction with the U.S. National Oceanic and Atmospheric Administration (NOAA) the SBAtmosphere has produced data from 4 different operational meteorological centres. We have also produced data from atmospheric reanalyses, spanning back to 1948. SBAtmosphere 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. The main atmospheric excitation terms for Earth rotation/polar motion for the year 2003, based on the NCEP-NCAR reanalyses, is given in Fig. 1.

SBAtmosphere also computes the AAM terms locally, in a number of equal-area sectors distributed around the globe, as well as globally. In addition, SBAtmosphere 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. SBAtmosphere 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.

David A. Salstein

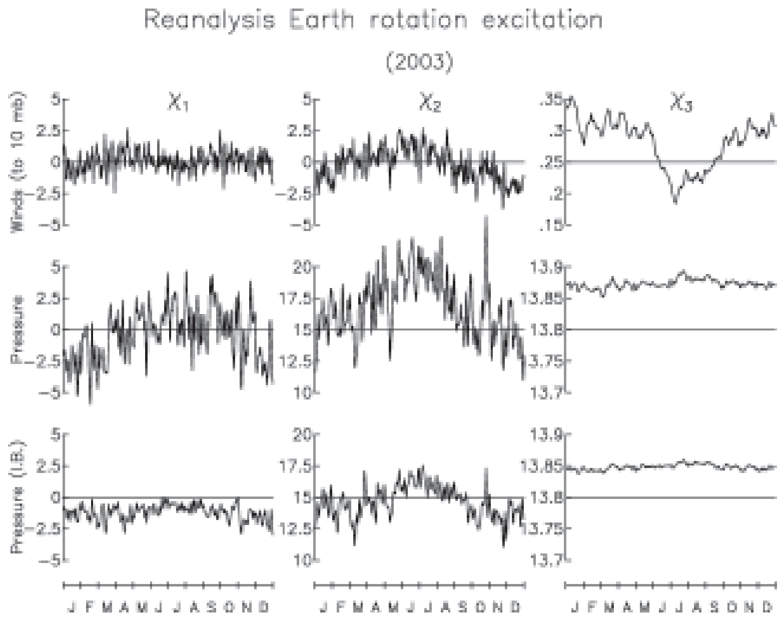

Fig. 1: Atmospheric excitation of the two components of polar motion (first two columns) and axial Earth rotation (third column), based on the winds (first row) pressure (second row) and pressure as modified by the Inverted Barometer approximation (third row). Units are nondimensional, x 10^{-7}. Information is based on the U.S. NCEP-NCAR Reanalysis system, and is given here once-daily, at 00 UT.

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

Three different oceanic angular momentum series are currently available from the IERS Special Bureau for the Oceans: (1) 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) 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 1999 at 3-day intervals, and (3) a series computed by Gross *et al.* (2003, 2004) from the products of a simulation of the oceans' general circulation done by the Estimating the Circulation and Climate of the Ocean (ECCO) group at JPL which spans January 1980 to March 2002 at daily intervals.

Three different oceanic center-of-mass series are currently available from the IERS Special Bureau for the Oceans: (1) 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) 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, and (3) 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.

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> 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.

References

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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. Like the other special bureaus of the GGFC, the Special Bureau for Tides generates most of its own product datasets 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 their modeling results. The data collected by the Special Bureau are publicly available via the internet at <http://bowie.gsfc.nasa.gov/tides>.

There were very few additional tidal model releases during 2003. The most important was the release by Gary Egbert and Lana Erofeeva (Oregon State University) of their TPXO.6, and two subsequent updates 6.1 and 6.2. The TPXO series of ocean tidal models are based on the assimilation of Topex/Poseidon data into a numerical hydrodynamic model. The model is now truly global, because the finite-difference grid of the numerical model has been rotated so that poles are over land. This latest solution is known to be much more accurate than earlier TPXO solutions, at least in terms of tidal elevations. The GGFC Special Bureau for Tides has used the elevations and currents of TPXO.6.2 to estimate the diurnal and semidiurnal-band Earth-rotation parameters, and these results are now publicly available.

The Special Bureau is endeavoring to obtain newer tidal EOP solutions for long-period ocean 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.

Richard D. Ray

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).

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 1979–2003, and polar motion and length of day excitation time series for 1948–2001, as well. An update performed at the end of July 2003 added NCEP data for 2002 and corrected a few problems, including setting the missing NCEP values to –999.00, and minor changes in ascii file format.

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

A new addition to our data archive is the output from CPC LDAS. 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 January 1980 through December 2003. 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.

Clark R. Wilson

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 19,050 earthquakes spanning Jan 1977 through May 2002. 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.

(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. 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 nine 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 Gravity/Geocenter

Web site

A redesign and upgrade of the SBGG website, conforming to new NASA look and feel standards for websites, has been completed and populated with new links and data sets.

Staff

Thomas Gruber agreed to become "Co-Chair" of the SBGG. He will also help to define a role (if any) between GOCE and SBGG for support. We note that this issue also spans the many of the GGFC SBs, which could provide ancillary data for offline analyses as well as operational dealiasing products. No definitive plans worked yet.

New Data available

- GRACE data (PODAAC)
- CHAMP data (ISDC)
- UTCSR SLR gravity and geocenter
- Nevada/Reno GPS load-derived low degree harmonics
- JPL GPS Geocenter time series

All suppliers asked to provide meta-data no worse than "read me" file.

Other documents created

The following documents will be available through the SBGG webpage:

- Text user guides developed for important GRACE gravity harmonic time series by affiliates of SBGG (Watkins for JPL, Bettadpur representing UTCSR, Flechtner for GFZ)
- Processing standards for GRACE
- User Guide to Gravity Products for GRACE
- Dealiasing Description (spans interest of several SBs)

These data descriptions and guides may form the basis for more general documents on harmonic products from SLR/GRACE/CHAMP/etc.

Plans for 2004

In the upcoming year, we need to promote intercomparison of products and assist validation of CHAMP and GRACE. We may also help sponsor a special campaign to compare low degree GPS load results with low degree GRACE harmonics.

Finally, we would like to begin electronic library of related papers/links.

Michael M. Watkins

3.5.6.8 Special Bureau for Loading

The Special Bureau for Loading (SBL) is tasked with providing in near real-time a consistent global solution data set describing the surface deformation, gravity signal and geocenter variations due to various surface loading processes, in reference frames relevant for direct comparison with existing geodetic observing techniques.

Currently, historical predictions of 3-dimensional surface displacements are available on the web site from the years 1990 to 2003. The data are north, east and up surface displacements determined in a Center of Earth reference frame (Farrell's Green's functions). The global deformation data have been calculated on a 2.5 degree x 2.5 degree grid using the National Center for Environmental Prediction's (NCEP) Reanalysis data set. A reference pressure field, defined as the 10-year average pressure has been removed. A modified inverted barometer ocean (*van Dam and Wahr*, 1987) is assumed with a 2.5 degree land-ocean mask.

Time series are also available for 355 ITRF sites. The 3-d deformations for the time series are calculated in the same way as for the global results. The time series start in 1990 and continue through to 2003.

The near real-time aspect of the SBL is still currently under development, however significant progress has been made. We are currently successfully downloading the European Center for Medium Range Weather Forecast's (ECMWF) sea-level pressure data set twice per day (the 00 and 06 hour data sets in the first download and the 12 and 18 hour data sets in the second download) with approximately 11 hours of latency. The ECMWF sea-level data are at 0.5 degree x 0.5 degree global sampling. We will test the data set at 2.5 degree sampling. Then we will optimize the code to handle the higher spatial resolution. We will need to compare the ECMWF data with the NCEP reanalysis data.

Upgrades to the current products are planned for the very near future:

- upgrade the land-ocean mask to 0.25 degrees (*Petrov and Boy*, 2004)
- recalculate deformations using Green's functions determined in a Center of Figure and/or Center of Mass reference frame (*Blewitt*, 2003)
- reference pressure field defined as a function of station geopotential height

In the immediate future, global deformations and IERS time series with these upgrades will be available on the web. The older files will remain on the web for comparison.

In the original SBL position paper, we stated that we would investigate the effect of topography on predicted deformations (*van Dam*, 2004 in review). The issue is that we are currently using pressure defined at 2.5 degree x 2.5 degree latitude and longitude spacing. However, we know that in many regions on the Earth, the topography, and hence the surface pressure, varies significantly over this spatial wavelength. We have estimated the effect of short wavelength topographic variability on predicted loading effects. Using Grasse, France and Lhasa, China and topography defined on a 0.125 degree grid spacing to model the change in surface pressure with height, we find that estimates of the vertical loading effect at these sites, differs by up to 0.04 and 0.1 mm peak-to-peak for Grasse and Lhasa respectively. In Fig. 1 we plot the difference between the vertical displacement calculated assuming 1) the pressure is constant and 2) the pressure varies with topography. The calculated deformations are not significantly affected by the dependence of temperature on altitude (i.e. isothermal atmosphere or lapse rate for the temperature dependence).

References

Blewitt, G., Self-consistency in reference frames, geocenter definition, and surface loading of the solid Earth, *Journal of Geophysical Research,* 10.1029/2002JB002082, Vol. 108, No. B2, 2003.

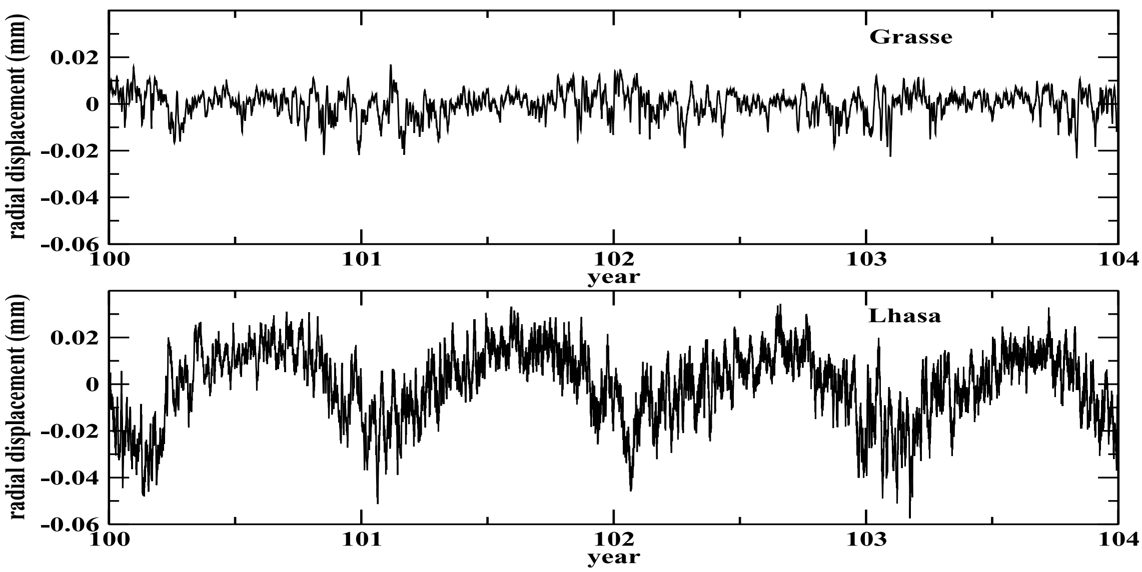
Van Dam, T.M. and J. Wahr, Displacements of the Earth's surface due to atmospheric loading: Effects on Gravity and Baseline Measurements, *J. Geophys. Res., 92*, 1281-1286, 1987.

van Dam, T.M., Effects of topographic variability on estimated atmospheric pressure loading effects, Journal of Geodesy, in review, 2004.

Petrov, L. and J.-P. Boy, Study of the atmospheric pressure loading signal in VLBI observations, *Journal of Geophysical Research,* in press, 2004.

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

Fig. 1: The effect of topography on predicted deformations



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

During the year 2003 the activities of the ITRS Combination Center at DGFI concentrated on a refinement of the combination methodology, enhancement of the combination software and tools for quality control and validation of the results. Methods for the detection of outliers, handling of local ties, and the weighting of different solutions have been improved. In order to verify the combination procedure we computed a combined TRF solution based on multi-year solutions with station positions and velocities of different space techniques. This report briefly summarises the combination methodology and presents some results as examples. For more information refer to other publications (see references), and to the DGFI reports in the IERS Annual Reports 2001 and 2002.

TRF computation

The multi-year solutions (and normal equations) of the different space techniques (VLBI, SLR, GPS and DORIS) we used for this TRF computation are summarised in Table 1.

Table 1: Summary of solutions used for TRF computation. Stations with an observation time span less than one year were excluded. The numbers in paranthesis indicate: (1) unconstrained normal equation; (2) loosely constrained solution; (3) minimally constrained solution.

AC/Solution	Data Span	# Stations orig./used	Source
DORIS			
(GRGS)00D01	1993-1998	70/69	ITRF2000 (3)
(IGN)02D04	1993-2002	111/109	IGN/CDDIS (2)
GPS			
(IGS)03P01	1996-2002	216/207	NRCan (3)
SLR			
(CRL)00L02	1990-2000	62/62	ITRF2000 (2)
(CSR)00L04	1976-2000	141/106	ITRF2000 (2)
(DGFI)01L01	1981-2001	113/96	DGFI (1)
(JCET)00L05	1993-2000	63/55	ITRF2000 (2)
VLBI			
(DGFI)02R02	1984-2002	49/49	DGFI (1)
(GIUB)00R01	1984-1999	53/53	ITRF2000 (2)
(GSFC)00R01	1979-1999	138/88	ITRF2000 (2)
(SHA)00R01	1979-1999	129/88	ITRF2000 (2)

The combination methodology is based on the following steps:
- Validation and analysis of submitted input data
- Reformatting into DOGS-CS format
- Reconstruction of unconstrained normal equations for each contributing solution

– Combination of normal equations with DGFI software DOGS-CS
  a) Combination (comparison) of solutions of each technique (intra-technique combination)
  b) Combination of different techniques (inter-technique combination)
– Final combined adjustment (weighting, local ties, datum)

Intra-technique combination

The combination of data (solutions) of the same observation technique should be done by the respective technique centres (IGS, ILRS, IVS, IDS). At present, combined multi-years solutions with station positions and velocities are produced by the IGS. We used the cumulative combined IGS solution (IGS03P01) provided by Remi Ferland (NRCan, National Resources Canada).

In case of SLR, four solutions provided by CRL (Communications Research Laboratory, Japan), CSR (Center for Space Research, USA), JCET (Joint Center for Earth System Technology, USA) and DGFI were combined. The results of Helmert transformations between the individual solutions and the combined SLR solution proof the capability of this technique to realise TRF origin and scale (see Table 2).

The four VLBI solutions provided by GIUB (Geodetic Institute, University Bonn, Germany), GSFC (Goddard Space Flight Center, USA), SHA (Shanghai Observatory, China) and DGFI demonstrate the high quality of VLBI to realise the TRF scale and to estimate precise station positions and velocities. The RMS residuals of the individual VLBI solutions w.r.t. the combined intra-technique solution are 2-3 mm for positions and about 0.5 mm/yr for velocities. The scale agrees within 0.3 ppb and 0.08 ppb/yr for the rate.

The DORIS solutions of GRGS (Groupe de Recherches de Geodesie Spatiale, France) and IGN (Institute Geographique National) agree to about 8 mm and 2 mm/yr for station positions and velocities, respectively.

Table 2: Helmert transformation results of individual SLR solutions w.r.t. combined intra-technique solution.

H.-T. Results	***CRL***	***CSR***	***DGFI***	***JCET***
Tx [mm]	-0,1	1,4	0,9	2,4
Ty [mm]	1,5	-0,6	-1,3	-5,0
Tz [mm]	0,3	1,0	0,2	0,8
Scale [ppb]	0,03	0,09	-0,26	-0,10
Tx rate [mm/yr]	0,8	0,1	-0,2	-0,4
Ty rate [mm/yr]	-1,4	-0,1	0,1	1,1
Tz rate [mm/yr]	-1,6	-0,3	1,1	-0,1
Scale rate [ppb/yr]	-0,09	0,04	-0,08	0,18
Pos RMS [mm]	4,1	4,9	2,3	3,7
Vel RMS [mm/yr]	1,6	1,4	0,7	1,2

Inter-technique combination

In the inter-technique combination, co-location sites (see Figure 1) and intra-site vectors (local ties) play a dominant role. Are the local ties sufficiently well determined to introduce them as a constraint, and are different velocity estimations at the same site identical? To find the answer, it is essential to validate the local ties and the velocity estimations at co-location sites, before combining different techniques. Table 3 summarises the corresponding results. For six co-locations (3 GPS-VLBI, 3 GPS-SLR) exist an excellent agreement between the local tie measurements and the space geodetic solutions (the absolute differences are below 5 mm). But on the other hand, there are many other co-locations, where the differences exceed 2 cm. The station velocity estimations of different techniques agree very well for eight co-locations (the absolute velocity differences are below 1 mm/yr), whereas in many other cases these differences exceed 5 mm/yr.

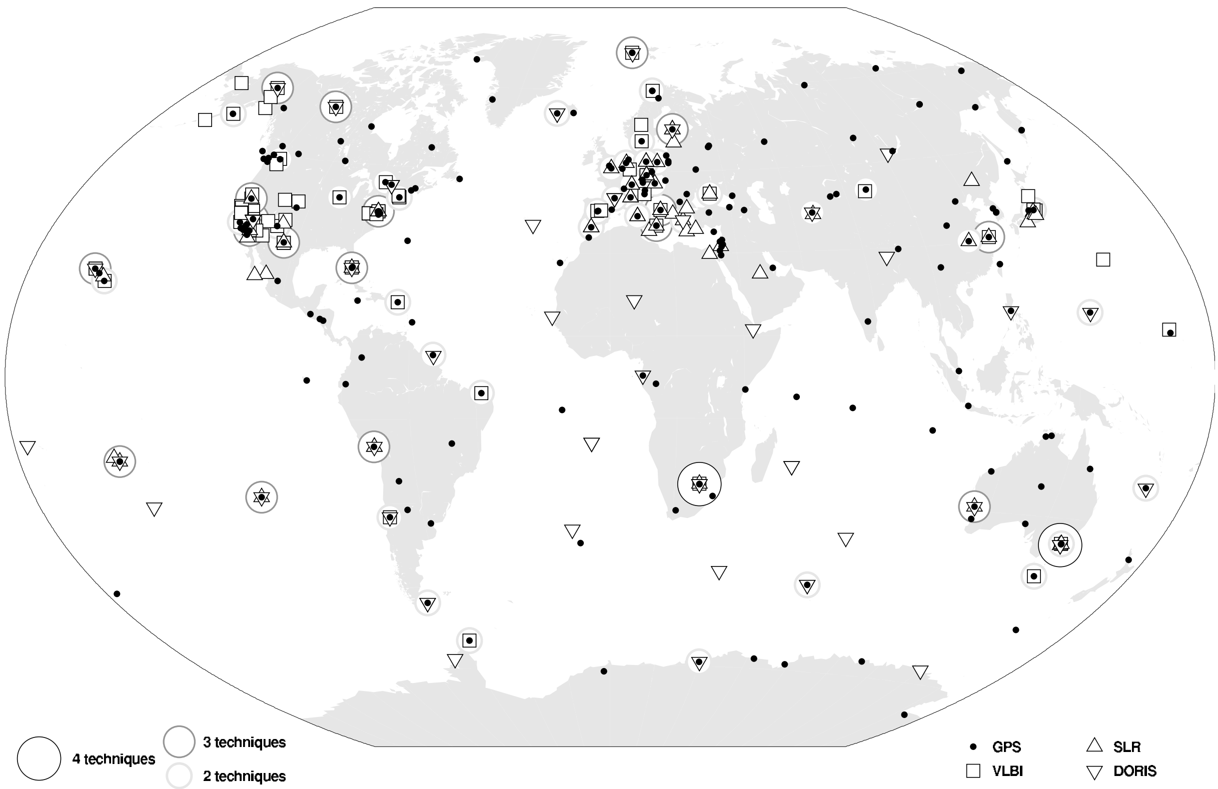


Fig. 1: VLBI, SLR, GPS and DORIS stations used for the TRF computation at DGFI. Furthermore co-location sites with two, three and four techniques are shown. Note that we excluded a number of poorly observed stations (e.g. less than one year of observations) from this combination.

An interpretation of these discrepancies is difficult and requires further research, since various factors need to be considered (e.g. systematic biases between space geodetic solutions, non-linear site motions, local site-dependent effects, errors in local tie measurements, small inconsistencies related to datum definition). Furthermore most of the co-locations are primarily GPS with other techniques, and thus the combination is an “indirect” approach mainly via the GPS station network, which is rather problematic for the identification of technique specific biases. Taking into account today’s situation regarding co-location sites and local tie accuracy, the selection of suitable local ties is an important aspect, to ensure that poorly observed local ties do not degrade the high internal accuracy of the individual space techniques within the combination. We applied an iterative procedure to select suitable co-locations and to identify sites for equating velocites (see Krügel and Angermann, 2004), and added this information in the form of pseudo-observations with appropriate weights to the combined normal equations.

Table 3: Comparison of space techniques at co-location sites. Shown are differences between local ties and space geodetic derived intra-site vectors (upper part), as well as absolute velocity differences of co-located instruments (lower part). Note that no redundant local tie information is displayed.

	GPS-VLBI	***GPS-SLR***	***SLR-VLBI***	***GPS-DORIS***	***SLR-DORIS***	***VLBI-DORIS***
# co-locations	35	24	12	21	3	1
# local surveys	30	20	10	19	3	1
Δ local ties						
< 5 mm	3	3	0	0	0	0
5 - 10 mm	6	5	2	0	0	0
10 – 20 mm	10	6	3	3	0	0
> 20 mm	11	6	5	17	3	1
Δ velocities						
< 1 mm/yr	5	2	1	0	0	0
1 – 2.5 mm/yr	13	9	5	3	0	0
2.5 – 5 mm/yr	10	8	3	9	0	0
> 5 mm/yr	7	5	3	9	3	1

Combined TRF solution and comparison with ITRF2000

To generate the final combined solution we added datum conditions and inverted the resulting normal equation system. The origin (translation and their rate) is realised by SLR, the scale and its rate by SLR and VLBI, and the orientation of the combined TRF solution by NNR conditions w.r.t. ITRF2000.

We compared the combined DGFI solution with ITRF2000 by means of a 14 parameter Helmert transformation. The results are summarised in Table 4. Both TRF solutions agree quite well in origin and scale, but it has to be considered that the datum of both

Table 4: Helmert transformation results between DGFI combined TRF solution and ITRF2000. For these transformations we used core reference stations for each technique.

H.-T. Results	*VLBI*	*SLR*	*GPS*	*DORIS*
Tx [mm]	1,1	-2,2	-0,4	1,4
Ty [mm]	-1,1	-0,3	-1,0	-0,2
Tz [mm]	0,5	-2,5	2,2	0,7
Scale [ppb]	0,15	0,23	-0,53	0,50
Tx rate [mm/yr]	0,3	0,0	-0,4	-0,5
Ty rate [mm/yr]	-0,1	-0,7	-0,1	-0,6
Tz rate [mm/yr]	-1,0	0,0	-1,0	-0,6
Scale rate [ppb/yr]	0,03	0,11	0,15	0,02
Pos RMS [mm]	2,2	4,0	1,6	12,6
Vel RMS [mm/yr]	0,51	0,85	0,90	2,12

TRF realisations was defined in a similar way, thus this is not a completely independent outcome. The RMS residuals of the reference stations for positions and velocities are displayed for each technique separately. Figure 2 shows the station velocities of the DGFI solution in comparison with ITRF2000. There is in general a good agreement between both TRF realisations. Note that the combined TRF solution of DGFI contains less sites than ITRF2000, since we excluded a number of stations with short observation periods (e.g. < 1 yr), which in our opinion do not allow for accurate and reliable velocity estimations.

Acknowledgement

The ITRS Combination Centre at DGFI is supported by the programme GEOTECHNOLOGIEN of BMBF and DFG, Grant 03F0336C; the document no. is GEOTECH-46.

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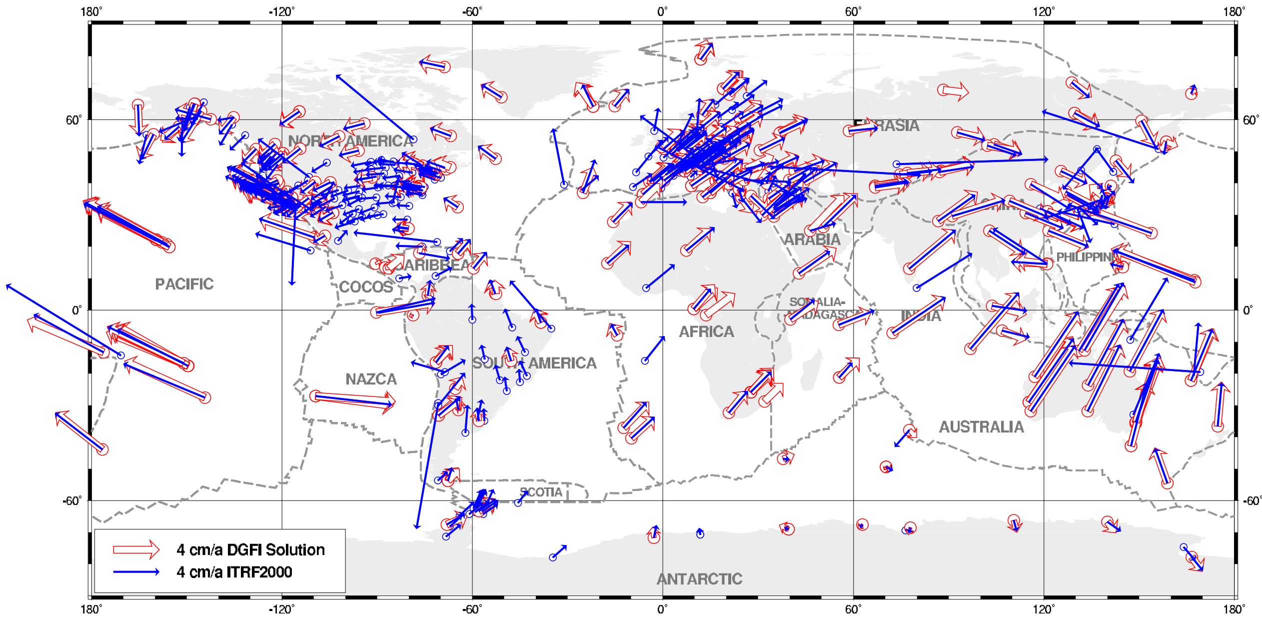

Fig. 2: Station velocities of DGFI solution compared to ITRF2000.

3.6.1.2 Institut Géographique National (IGN)

The IGN ITRS Combination Centre and the IGN Combination Research Centre concentrate their activities on software enhancement, new combination strategy development and regular analysis of Global TRF solutions as well as time series (weekly/monthly) 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 (weekly or monthly) 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 EOPs 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.

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 EOPs

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

- VLBI: 24h-session SINEX files over 1990-2003, 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 1993-2003
- GPS: Weekly solutions from the IGS Analysis Centers:
  - EMR: Natural Resources Canada: 1996–2003
  - GFZ: GeoForschungsZentrum: 1996–2003
  - JPL: Jet Propulsion Laboratory: 1996–2003
- DORIS : weekly solution provided by Institut Geographique National/Jet Propulsion Laboratory over the period 1993–2003

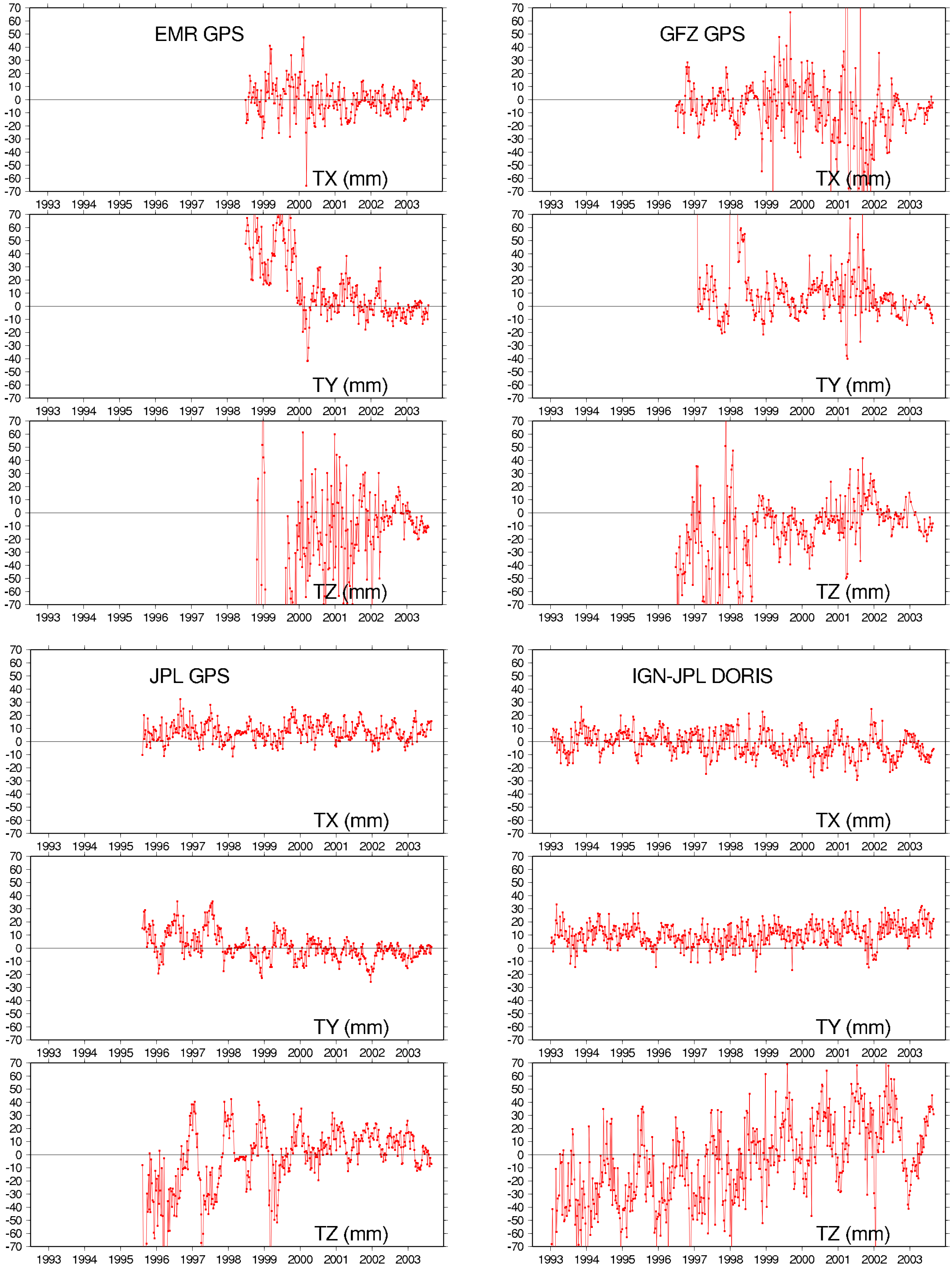

Fig. 1: Geocentre variations of GPS EMR, GFZ, JPL and the IGS combined solutions

As results from this analysis, Figure 1 illustrates the geocentre variations for 3 IGS Analysis Centers (EMR, GFZ, JPL) and the official IGS combined estimates. Figure 2 shows the geocentre results as obtained from the analysis of DORIS (IGN-JPL) and SLR (ASI) weekly solutions.

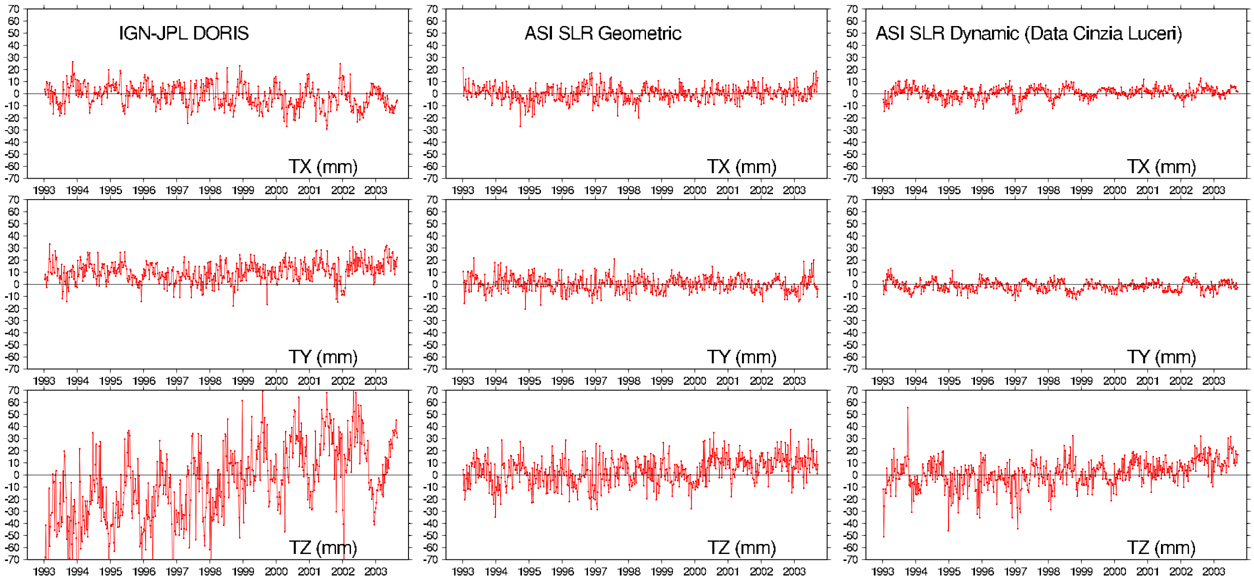

Fig. 2: Geocentre variations of DORIS (IGN-JPL) and SLR (ASI) weekly solutions

A multi-technique combination was also performed using the above described solutions over the period 1999-2003. 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.

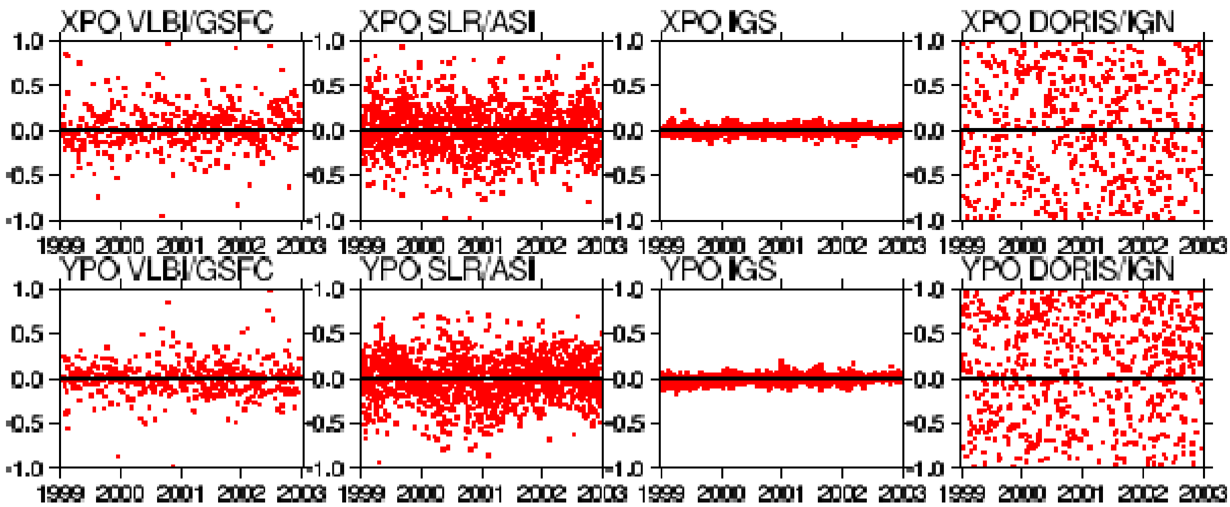

Fig. 3: Post fit residual of Polar motion per technique (mas)

As results of this combination test, Figure 3 shows the polar motion post-fit residuals over the 4 techniques.

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 200 sites homogenously distributed.

Publications

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Zuheir Altamimi, Patrick Sillard, Claude Boucher

3.6.1.3 Natural Resources, Canada (NRCan)

Background

Natural Resources Canada (NRCan) acts as an International Terrestrial Reference System (ITRS) combination center for the International Earth Rotation and Reference Systems Service (IERS). This contribution focuses on its International Terrestrial Reference Frame (ITRF) activities for 2003. The IERS objective for the TRF combination project is to have independent rigorous combinations of the TRF realization; thus providing much needed quality control. The long-term objective is to eventually produce routine weekly inter-technique (DORIS, GPS, SLR and VLBI) combinations. At NRCan, the capability to combine GPS solutions has been developed in the late 1990s and is used to routinely produce weekly solutions for the International GPS Service (IGS). The production of combined weekly inter-techniques solutions is a natural extension of the existing software capabilities.

Software Enhancements

The existing software uses the SINEX format version 1.00 directly. A modular approach was originally adopted for the software development. In its current form, the software can perform various operations on SINEX files such as: Helmert transformation, combination, comparison, etc. In their current form, the modules can handle station coordinates/velocities and ERPs (pole position/rate and length of day) along with the available covariance information using standard least-squares algorithms. Some flexibility in the format specifications allows the solutions to be made available in different SINEX "flavors". Within IGS, the files are transformed in a consistent "flavor" of the format using auxiliary information, a few computer environment commands and a preprocessor program. Before extending the software to accept the version 2.00 format, it was decided to attempt inter-techniques combination with the existing software. This was also useful to gain more experience with the solutions from the other techniques and produce some results in a timely manner. With this "temporary" approach, the required enhancements were mainly concentrated at the pre-processing stage. One preprocessor was tailored to each center solution.

Data Analysis

The original data analysis objective was to generate a combined solution for the station coordinates/velocities and ERPs using each technique solution for 1999. The analysis reported below was prepared for and presented at the European Geophysical Society 2003 conference in Nice. Due to the absence of technique solutions (except for the combined IGS solution and DORIS with only one solution available), it was decided to use a subset of the solutions available from the techniques (solution acronyms and responsible agency):

1) VLBI:
   – BKG: Bundesamt für Kartographie und Geodäsie
   – GSFD: Goddard Space Flight Center
   – NGL: Deutsches Geodätisches Forschungsinstitut
2) SLR:
   – ASI: Agenzia Spaziale Italiana
   – DGFI: Deutsches Geodätisches Forschungsinstitut
   – JCET: Joint Center for Earth Systems Technology
3) DORIS:
   – IGN: Institut Géographique National
4) GPS:
   – IGS: International GPS Service

In this combination test, the pole rates and LOD/UT parameters were not combined. The combinations of the pole rates are not expected to cause any special problems. Those are routinely included in the IGS combination. The combination of the LOD/UT may require special attention. Unused parameters were discarded after the solutions were unconstrained (when applicable). The combination process was done in two steps: an intra-technique combination and an inter-technique combination. This approach has been chosen because it is less demanding on the available resources, namely, existing software is usable with minimal upgrades. However, this approach introduces some approximations.

In the first combination step, an intra-technique combination for each technique was done on the selected VLBI (BKG, GSFD, NGL) and SLR (ASI, DGFI, JCET) Analysis Centres (ACs) solutions. Those could be processed as SINEX version 1.00. In this step, the following activities were performed: 1) standardization of the solutions to a consistent "flavor" of SINEX, 2) removal of the constraints & rescale covariance (iterative), 3) removal of the outliers (also iterative), 4) alignment of all solutions to a reference using 14 or less transformation parameters (rotation, translation, scale & rates) as appropriate, 5) combination (addition of normals) and 6) analysis of the results. The solutions for 1999 AC test solutions were combined in 13 distinct solutions, each one covering 28 days. Since the IGS solution was already the result of the combination of 7 ACs (COD, EMR, ESA, GFZ, JPL, NGS, SIO), the weekly solutions were simply combined into monthly solutions. Table 1 shows a summary of the statistics for each Analysis Center selected within each technique. Several iterations were required for the ACs within the VLBI and SLR techniques to resolve various problems and to remove outliers. The exercise showed that there is some room for improvement in the test solutions available. The GPS solutions were combined from the original ACs contributions, which were provided for the IGS SINEX combination Pilot Phase. All the solutions were aligned to but not constrained to ITRF2000.

Table 1: Average and standard deviations of the ACs after the intra techniques (VLBI/SLR/GPS) combinations for the coordinates and pole position residuals for the 1999 observations.

Technique Center	**N(mm) x/σ**	**E(mm) x/σ**	**H(mm) x/σ**	**Xp(μas) x/σ**	**Yp(μas) x/σ**
VLBI					
BKG	0.2/1.2	0.0/1.2	0.0/4.0	15/181	-15/235
GSFD	-0.2/1.2	0.0/1.1	0.0/3.0	15/151	-36/188
NGL	-0.5/6.7	-0.1/5.9	0.0/8.9	-56/310	170/277
SLR					
ASI	-0.7/7.1	0.0/5.7	0.0/18.5	51/177	8/123
DGFI	0.0/7.7	0.0/8.3	0.0/7.1	-33/416	-29/345
JCET	0.1/6.2	0.0/5.1	0.0/6.5	-12/336	19/321
GPS					
COD	1.2/2.6	0.0/3.2	-0.02174	-26/99	38/107
EMR	-3/6.7	0.8/8.2	0.2/12.2	95/187	34/202
ESA	-2.5/5.1	0.0/7.3	0.0/12.8	3/20	-20/24
GFZ	0.0/2.7	0.0/3.0	0.6/8.6	-5/58	63/70
JPL	-0.4/3.1	-0.1/3.7	0.4/8.8	7/77	3/88
NGS	-1.7/5.2	0.7/6.5	0.6/10.3	-22/296	109/283
SIO	-1.9/3.6	-0.8/4.8	-0.3/10	-26/109	40/91

Figures 1, 2 and 3 show time series of residuals for the X and Y pole positions between the combined solutions for each technique (VLBI, SLR, GPS) and the respectively selected ACs.

In the second step, an inter-technique combination was performed using 3 techniques for a solution and the relevant inter-technique local ties. Due to some instability in the alignment of the monthly solutions for VLBI, they have not been included here. It requires further analysis. Comparison of the combined solution coordinates and ITRF2000 shows RMS in the north, east and height axis of 5.9 mm, 8.9 mm and 9.5 mm respectively at the solutions epoch. Figure 4 shows the ERP's residuals between the combined solution and the GPS/SLR/DORIS techniques.

The DORIS combination, which includes only the IGN solutions, is significantly noisier than the SLR and GPS solutions. Even between GPS and SLR, there are apparent noise level differences. This causes the GPS solution to dominate the pole position combination. The combined pole positions results were then compared to Bulletin A (see Figure 5 for the time series of the differences). The noise level is about 0.1 mas for both components. There is no significant bias between the pole position series for the X component. However, there is an average bias of about 0.18 mas for the Y component.

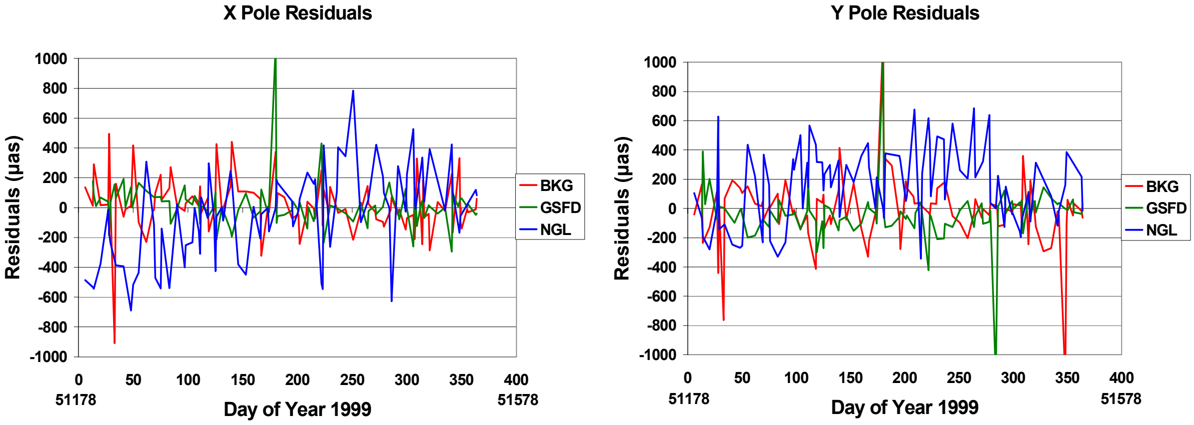

Fig. 1: VLBI combined X&Y pole position minus ACs estimates

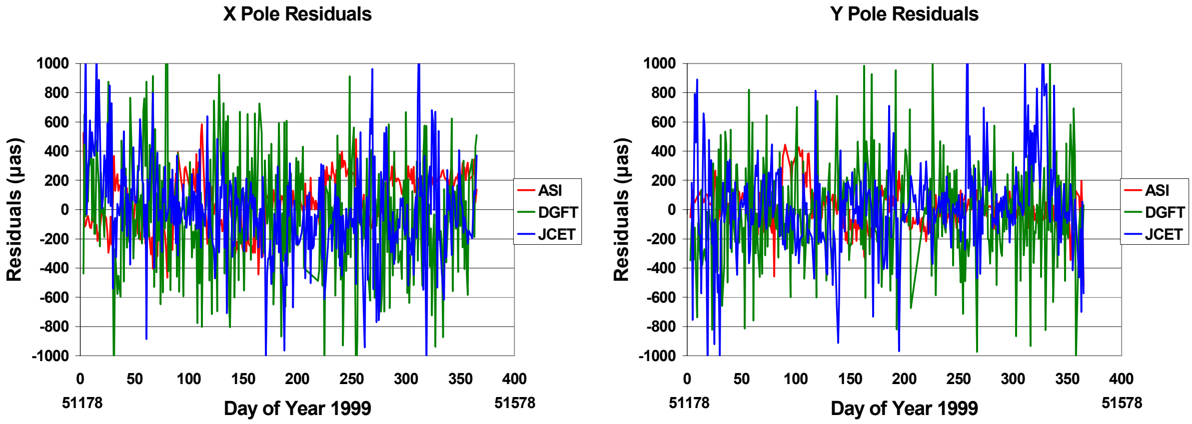

Fig. 2: SLR combined X&Y pole position minus ACs estimates

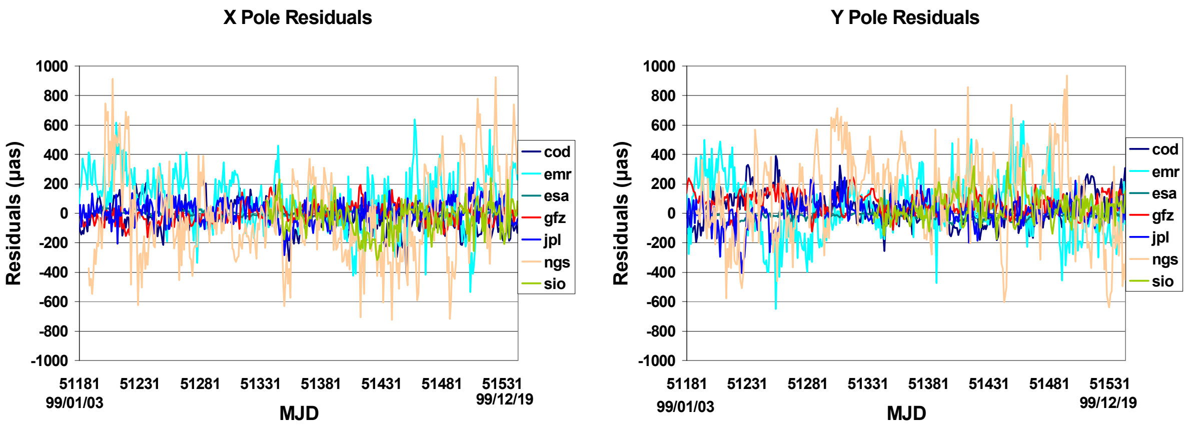

Fig. 3: IGS combined daily X&Y pole position minus ACs estimates

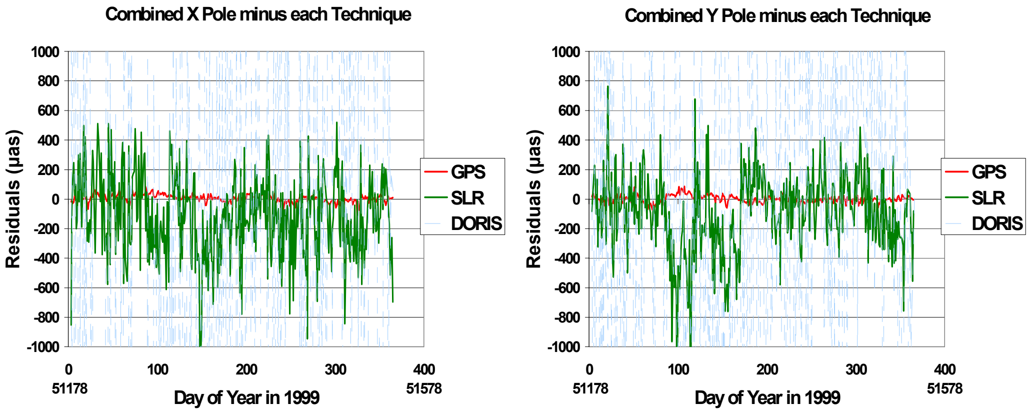

Fig. 4: Residuals between the combined (GPS/SLR/DORIS) and each technique

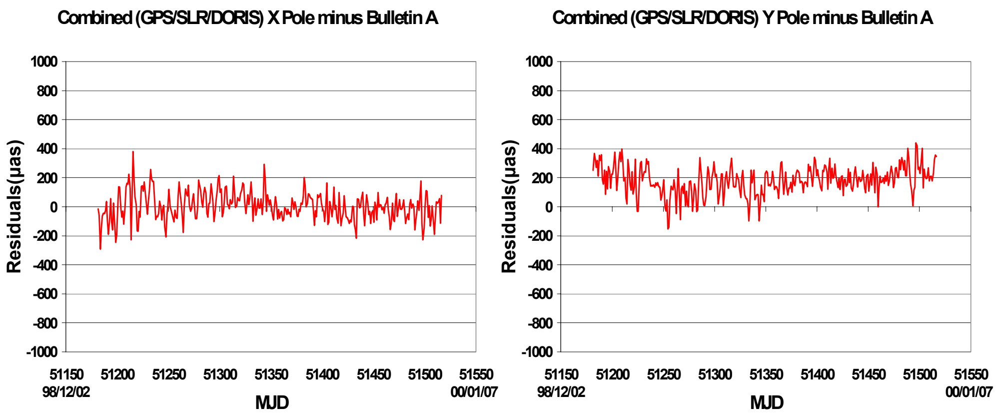

Fig. 5: Comparison of the combined pole position with respect to Bulletin A

Future Work

The short to medium term activities related to the TRF combination at NRCan will be concentrated in completing the analysis and extending the software capabilities. The combination effort on the 1999 test observations has so far indicated that there are still problems within the techniques. For example there are many station coordinates inconsistencies leading to outliers, as well as formatting and unconstraining issues. Solution consistencies can certainly best be resolved by/within each technique.

Rémi Ferland

3.6.2 Combination Research Centres
3.6.2.1 Agenzia Spaziale Italiana (ASI) - Centro di Geodesia Spaziale (CGS)

Introduction

The ASI Space Geodesy Center (CGS), located at Matera, is a Fundamental Geodetic Station, hosting three permanent Space Geodetic systems (SLR since 1983, VLBI since 1990, GPS since 1995) providing raw observation data, acquired, screened and archived continuously and then forwarded to the technique-dedicated organisations (ILRS, IVS, IGS). Moreover, a parallel, wide activity of data analysis has been developed in time, leading to the issue of several geodetic products, on a regular basis those submitted to the international geodetic organisations (ILRS, IVS, IGS, IERS), on request those solicited by scientific groups to perform joint research activities. The multi-technique feature of the Matera station has made the geodetic technique combination methods and applications a top priority objective of the data analysis activities performed at CGS, developed especially in the most recent years.

Combination research activity

In 2003, a predominant part of the combination research activity performed at CGS has been dedicated to the evaluation of the “loose” approach applied to the global solutions combination and to the development of related SW procedures.

Differently from the “fiducial” approach, based on the combination of solutions in the same reference frame, the “loose” approach foresees a combination of loose solutions without estimating and removing a relative rotation between their reference frames; constrained solutions can be preprocessed to remove a-priori constraints and then loosened by applying a *loosening transformation* [1]. The combination is performed along the lines of the iterative weighted least square technique; each solution is combined using its full covariance matrix rescaled by a factor, computed at each iteration, fulfilling the conditions that the normalized χ^2 of the combination be close to unity and each solution contribution to the total χ^2 be equally balanced.

The CGS SW procedures, based on the loose combination algorithms, have been implemented in the completely general case, to handle site coordinates, site velocities, EOP, EOP rates and including ITRF2000 local ties to connect site domes of different techniques.

To evaluate the method and the SW procedure, the “loose” combination approach has been applied, as a test case, to a subset (6 weeks) of multi-technique (DORIS, VLBI, SLR, GPS), multi-centre (INA, GSFC, ASI, IGN, DGFI, CODE) weekly solutions submitted to the CRC SINEX Combination Campaign, as presented in [2]; besides the operative advantage that the ‘loose’ approach is simpler than the fiducial approach, quality remarkable results have been obtained (e.g. coordinate residuals (w.r.t. ITRF2000) of the combined weekly solutions about 4 mm WRMS; EOP X, Y residuals (w.r.t. C04) below 0.3 mas WRMS; UT1 residuals about 0.1 ms WRMS).

Combination products

In 2003, two main combination products have been defined and realized:

1. the intra-technique (SLR) weekly solution, in response to the Call-For-Proposal for the ILRS "Position+EOP" Pilot Project;
2. a Mediterranean, inter-technique velocity solution to lighten the critical tectonics of the area.

The CGS SLR combined solution has been issued since 2003, July, to participate to the ILRS POS+EOP Pilot Project section, aiming to select official ILRS centres to be in charge of producing combined SLR solution to be submitted to IERS.

The CGS solution is produced weekly by a fully automated procedure; the procedure strategy consists of three main steps:

- Pre-processing
- Combination
- Quality check and delivery

The procedure reads sequentially the available SINEX loose solution files participating to the Pilot Project, relevant to the 7-day period to be analysed and verifies their integrity and looseness level; the screened solutions are iteratively loose combined as sketched in the previous paragraph; data editing is performed: i.e. 'weak' sites (i.e. those with less than 10 normal points in the weekly arc) and/or solution parameters presenting too high uncertainties with respect predefined thresholds are eliminated. When the normalized χ^2 of the solution is almost unitary (i.e. less than 1.5 and more than 0.5), iterations stop and the combined product is transformed in the ITRF2000 frame, delivered to ILRS together with a "quick-look" report and archived at CGS too. Details on the procedure have been presented in [3].

The ASIMED solution is a multi-technique velocity solution for the Mediterranean area, produced at CGS twice a year and issued on <http://geodaf.mt.asi.it>: it is obtained by combining the CGS global solutions (VLBI, SLR), providing the stability and reliability of the global reference frame, with a regional, dense GPS solution. Each single technique solution has very different features: as far as the 2003 realization is concerned, the VLBI solution (1979 – 2001) is a minimal constrained velocity solution; the SLR solution (1984 – 2001) is a constrained velocity solution, while the GPS solution consists in a loose daily position time series continuously updated, starting from 1995.

The optimal creation of a velocity solution, combining position solutions, is another facet of the combination methods; its critical aspects are the correct use of all possible solutions information (e.g. the complete covariance matrix of each network position solution), system upgrades (e.g. GPS receiver replacement or modification), reference standard updates (e.g. ITRF updates, impacting on GPS orbits). The original SW developed at CGS implements algorithms taking into account the investigations performed on these aspects.

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Giuseppe Bianco, Roberto Devoti, Roberto Lanotte, Vinceza Luceri, Cecilia Sciarretta

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

Introduction

The CRC is an integral part of the Center for Earth Dynamics Research (CEDR) that joins five Czech institutions active in astronomy and geosciences research (Research Institute of Geodesy, Topography and Cartography, Astronomical Institute, Faculty of Civil Engineering, Faculty of Natural Sciences, Institute of Rock Structure and Mechanics). The combination research is maintained principally in two different directions that would hopefully converge to a single combination method in future. 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

The original combined smoothing algorithm, worked out in 2000 (Vondrák & „epek 2000), was later slightly modified, in order to account for long-periodic (60 days and longer) systematic errors in GPS observations of length-of-day and celestial pole offset rates that we found in previous years (Gambis et al. 2003, Vondrák et al. 2003). The necessary calibration of GPS-based celestial pole offset rates against VLBI-based celestial pole offsets was used, prior to combination of both series. The calibration was made on intervals 8-15 days long (integer number of intervals between VLBI sessions), and the differences found were removed from GPS data.

Two new combinations of the celestial pole offsets by VLBI (IVS) with their rates by GPS (CODE) were made in 2003, and presented at EGS-AGU-EUG Joint Assembly and IAU 25^{th} General Assembly, respectively. The combined solutions are made for the interval 1994.3–2002.6 (Vondrák 2003a), and 1994.3–2003.0 (Vondrák 2003b), and they are compared with the new model of precession-nutation IAU2000. It is shown that while the *a priori* uncertainties of celestial pole offsets (reported by IVS) is practically equal to the *a posteriori* values derived from the combination, it is not the case for their rates measured by GPS – here the *a posteriori* values are about four times bigger than the *a priori* values (reported by CODE). In spite of this, the combination with GPS helps improving the VLBI-alone solution, both in resolution and accuracy. The consistency of the combined solutions with IAU2000 model is on the level of 0.10–0.15 mas, if the dominant long-periodic part due to FCN (period of about 435 days) is removed. Statistically significant are also smaller differences with annual, monthly and semi-monthly periods, and amplitudes of 0.03–0.04 mas.

Combination of EOP and station coordinates

A method for combining non-SINEX solutions of different techniques to obtain simultaneously station coordinates and Earth orientation parameters was further tested using VLBI, GPS, SLR and Doris data collected for the IERS Sinex Combination Campaign. The method is based on combining position vectors of the stations in the celestial reference frame, with constrains to separate celestial pole offset from polar motion and to tie EOP between different epochs (Kostelecký & Pešek 2003).

Systematic differences between the techniques affect the combination, especially when the combination was made over the whole one year interval (Pešek & Kostelecký 2003a). The results became more stable when monthly solutions were combined independently (Pešek & Kostelecký 2003b). In this case, the effect of combination on EOP is characterized by increments from adjustment of 0.17 mas and 0.021 ms for polar motion and time correction, respectively. Uncertainty of station coordinates decreased from 0.057 m to 0.042 m.

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Dr. Ivan Pešek
Prof. Aleš „epek

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Jan Vondrák, Cyril Ron, Jan Kostelecký, Ivan Pešek

3.6.2.3 Deutsches Geodätisches Forschungsinstitut (DGFI)

During the year 2003 the activities of the IERS Combination Research Centre at DGFI were mainly concentrated on the following topics:
- Investigations related to TRF datum realisation
- Analysis of time series of datum parameters and station positions
- Improvement of automated SLR intra-technique combination
- Contributions to the IERS SINEX Combination Campaign
- Quasi-rigorous combination of VLBI and GPS using CONT02 data

TRF datum realisation

The space geodetic observation techniques contribute in different ways to the realisation of the TRF datum. We used solutions and normal equations of the different techniques to study the covariance information of the datum parameters (e.g. origin, scale). In addition, time series analysis of datum parameters contribute to identify strengths and weaknesses of the space techniques. For the definition of the kinematic datum we propose to use kinematic models based on geodetic observations (e.g. APKIM) instead of geophysical models (e.g. NNR NUVEL-1A) to ensure that the no net rotation condition is more accurately fulfilled (Drewes and Meisel, 2003).

Analysis of time series

The time series of station positions and datum parameters, obtained from VLBI, SLR, GPS and DORIS solutions, were analysed w.r.t. non-linear signals (e.g. seasonal) and jumps, and were compared at co-location sites to investigate systematic biases between techniques. The observed non-linear effects in site positions and datum parameters are in conflict with the assumption of constant station velocities (Angermann et al., in press).

Automated SLR intra-technique combination

DGFI participates as analysis and combination centre in the ILRS. The products (station positions and earth orientation parameters) are generated on a weekly basis. The objective of the combination centre is to compute a combined solution in an automated process using individual SLR solutions. For this purpose software and scripts were developed for quality control and combination (Kelm, 2003).

IERS SINEX Combination Campaign

In the framework of this IERS project, DGFI has provided SLR, VLBI and GPS solutions and has combined weekly (or session-wise) solutions of different techniques containing station positions and EOPs. Important tasks were the handling of local ties, the weighting of the solutions, and the realisation of the datum for the individual and weekly combined solutions (Krügel and Meisel, 2003).

CONT02 combination

A joint project of FESG (Forschungseinrichtung Satellitengeodäsie, TU München) and DGFI aims towards a rigorous combination using the CONT02 VLBI data and global GPS data. The computations of daily unconstrained GPS normal equations were done at the FESG with the Bernese software; the VLBI normal equations were generated at DGFI with the OCCAM software. Much care was taken to adapt common models and parameterisations for the data analysis. First results show the advantages of such a rigorous combination, though some details need to be further studied (Thaller et al., in press).

Acknowledgement

The IERS Combination Research Centre at DGFI is supported by the programme GEOTECHNOLOGIEN of BMBF and DFG, Grant 03F0336C; the document no. is GEOTECH-47.

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Detlef Angermann, Hermann Drewes, Rainer Kelm, Manuela Krügel, Barbara Meisel, Volker Tesmer

3.6.2.4 Forschungseinrichtung Satellitengeodäsie, Technical University of Munich (FESG)

1. Introduction

At FESG as a Combination Research Centre (CRC) mainly the following research topics were covered during 2003:

- IERS Campaign to align EOPs to ICRF/ITRF2000,
- IERS SINEX Combination Campaign,
- Analysis of subdaily ERPs from GPS and VLBI,
- Analysis of nutation rates from GPS and nutation offsets from VLBI,
- Combination of GPS and VLBI solutions for the CONT'02 campaign.

2. IERS Campaign to Align EOPs to ITRF2000/ICRF

The work concerning the "IERS Analysis Campaign to align EOPs to ITRF2000/ICRF" was finished at the beginning of 2003 with a presentation at the EGS General Assembly 2003 in Nice. Most of the differences between the submitted EOP series were not due to the different alignments to ITRF2000 station coordinates, but due to different formats and sample rates, unevenly spaced VLBI data with larger gaps, incorrect signs in UT1–UTC (LOD) estimations from satellite techniques and the use of different interpolation schemes. Compared to these problems the influence of the constraining method seems to be small. As a major result, we could show that there is a considerable inconsistency of about 0.2 mas in the y-pole coordinate between the official IERS C04 series and the newly computed series correctly aligned to ITRF2000 (see Figure 1).

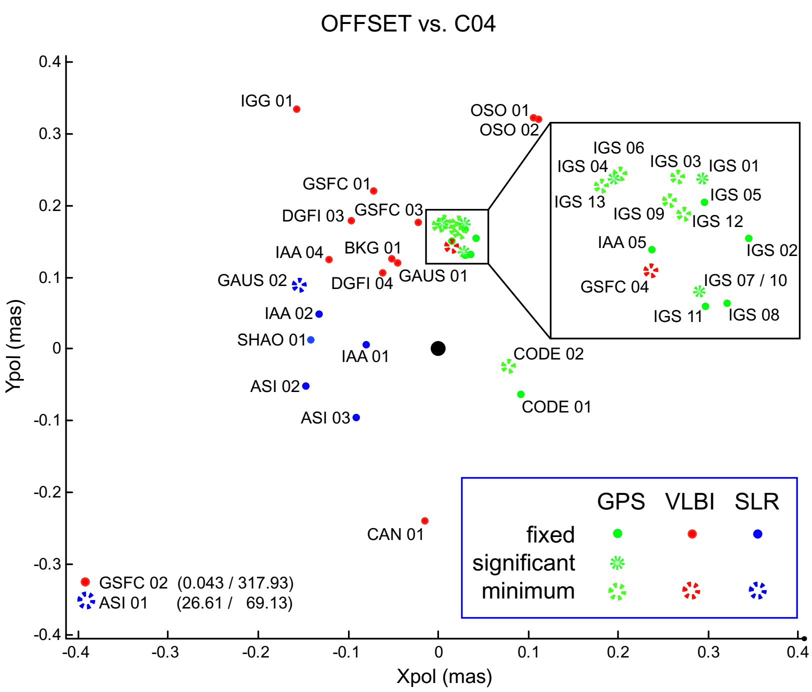

Fig. 1: X- and Y-pole offsets w.r.t. the C04 series for EOP series from GPS, VLBI and SLR solutions that were correctly aligned to ITRF2000 using different constraints. (For a colour version of this figure see the online version of this report at www.iers.org.)

Therefore, the official IERS products (C04 series and ITRF2000) are not really consistent at the present accuracy level. Only a rigorous combination of EOPs and ITRF can solve this problem. This result is very comparable to associated studies within the IERS SINEX Combination Campaign. The results of this campaign will be incorporated into the IERS Combination Pilot Project and the studies on combination strategies will be continued within this new project.

3. IERS SINEX Combination Campaign

Since the campaign itself started in May 2002, we already reported about the work concerning this campaign in the IERS Annual Report 2002. The main task performed during 2003 was the incorporation of an SLR solution series into the comparison and combination studies. Only one solution series was selected for each of the three techniques (GPS, VLBI and SLR), namely the GPS solution from CODE, the VLBI solution from DGFI and the SLR solution from ASI. The results of the inter-technique combination were presented at the EGS General Assembly 2003 in Nice (Thaller, Rothacher 2003a) and at the Geotechnologien-Statusseminar 2003 in Munich (Thaller, Rothacher 2003b). At this stage the connection between the three techniques was realized only via the Earth rotation parameters (x-/y-pole, UT1–UTC), as the application of the local tie information was implemented into the software at a later date (see the last topic of this report). The studies showed once more quite clearly that the y-pole of the results derived from the individual space geodetic techniques are shifted by about 0.2 mas compared to the C04 series (see Figure 2).

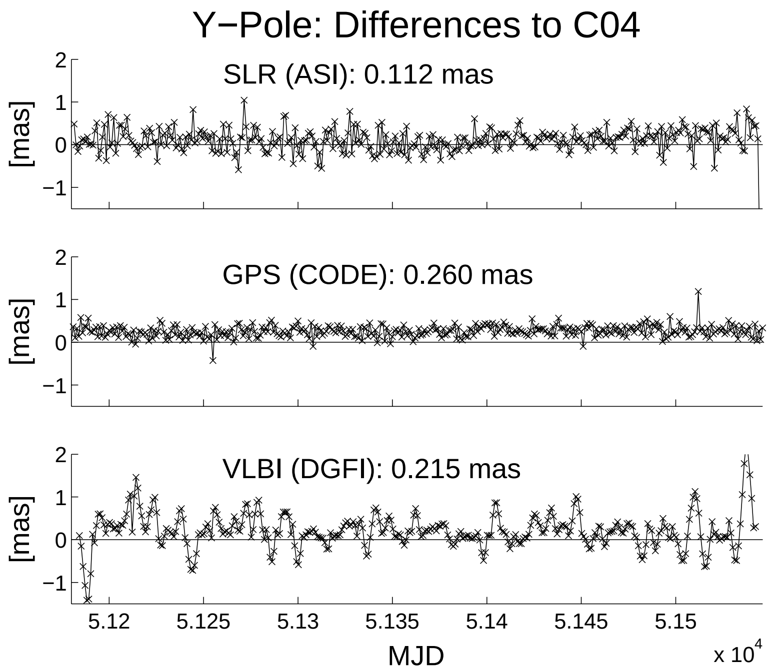

Fig. 2: Y-pole offsets w.r.t. the C04 series for EOP series from GPS, VLBI and SLR solutions submitted to the IERS SINEX Combination Campaign.

4. Analyses and Combination of Subdaily ERPs from GPS and VLBI

The most recent harmonic analysis of subdaily ERP series from GPS and VLBI shows a very good agreement with studies of the subdaily tidal excitation in polar motion and length of day (LOD). Nevertheless, there are still some inconsistencies between the results from GPS and VLBI. Besides a combination of different space geodetic techniques in the various analysis processes a combination of the original subdaily time series in advance of the time series analysis could be useful. Therefore, we are developing a new combined subdaily time series from GPS and VLBI. This combined time series should remove problems with large data gaps and unevenly spaced data, mainly from VLBI. Moreover, we can enhance the signal-to-noise ratio. Problems arise from the adjustment of different time variable offsets and different error levels in the two series. In addition, GPS provides only the first derivative of UT1–UTC. On the basis of Jan Vondrak's combined smoothing (Vondrak, Cepek 2000), we designed a three-step combination. In a first step we remove the low frequency variations of each single time series and adjust a kind of running mean level for both series. In a second step both time series are combined in a weighted least squares estimation with a very weak smoothing in order to keep as high frequencies as possible. In the last step we resubstitute a mean low frequency part. For UT1–UTC, all these steps are done with the time integral of LOD from GPS. Preliminary results of this combination attempt are very promising. The combined subdaily time series shows a much smaller scatter and RMS than each individual time series, even though the tidal harmonic analysis yields the full information on subdaily tidal excitation. Now we are testing several parameter configurations for the three mentioned steps to identify the strength and weakness of different combination schemes.

5. Combination of GPS and VLBI for the CONT'02 Campaign

CONT'02 was a 2-weeks campaign of continuous VLBI measurements during October 2002 with eight participating stations. In close cooperation with the DGFI – an IERS CRC as well – the VLBI data of this campaign were combined with the data of a global GPS network on the normal equation level. Since not only station coordinates and Earth orientation parameters are common to GPS and VLBI, but also troposphere parameters can be determined by both techniques, troposphere zenith delays were estimated every two hours for each station and horizontal gradients were set up once per day for each station. The studies comprise the influence of the local tie information on the combination results, the comparison and evaluation of the subdaily ERP results (2-hour resolution) with other subdaily models as, e.g., the model of the IERS Conventions (Ray96), the handling of the troposphere parameters in the combination, and the impact of using absolute instead of relative phase centre variations in the GPS analysis (for satellites and ground stations).

First results were presented at the IUGG General Assembly 2003 in Sapporo (Thaller et al. 2003c). From studies of the eight local ties we concluded that only the local tie for the station Kokee Park seems to be too bad for the combination. The comparison of the troposphere parameters estimated independently by both techniques looked quite promising (see Hartebeesthoek as one example in Figure 3), and the results are, apart from a small bias, in good agreement as well with the data from the water vapor radiometer at Onsala (Rothacher et al. 2003). A combination of troposphere parameters is still in progress and the systematic biases have to be investigated in more details. Therefore, a satisfactory combination for the troposphere could not be finalized till the end of the year. With the chosen subdaily resolution for the ERPs, the Ray96 model can be seen as an independent tool for evaluating the ERP results, because this model was derived from altimetry and not from GPS and VLBI. It turned out that in most cases the GPS/VLBI results match the model reasonably well.

Acknowledgement

This work is funded within the framework of the Geotechnologien-Projekt by the German BMBF.

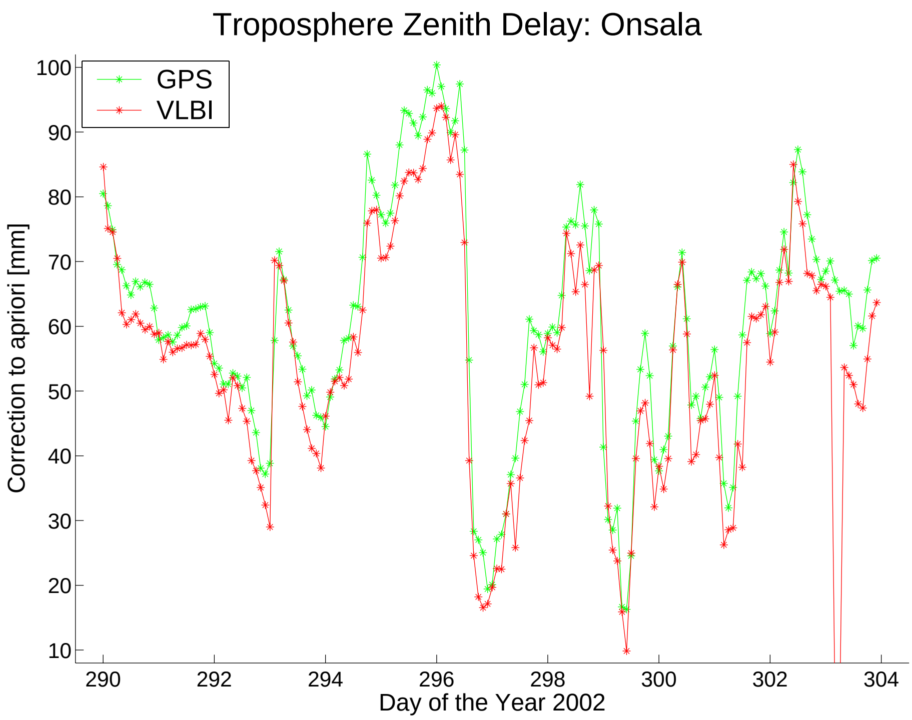

Fig. 3: Troposphere zenith delays from GPS and VLBI for the CONT'02 Campaign. The bias of about 4 mm between GPS and VLBI is caused by the height difference of 13.7 m between the techniques. (For a colour version of this figure see the online version of this report at www.iers.org.)

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Markus Rothacher, Daniela Thaller, Robert Dill

3.6.2.5 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 analyzed 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 2003 undergone extensive changes and improvements. This work will continue through 2004. No major IERS-related multiyear analyses have been performed with the software in 2003.

The most important changes implemented in 2003 are described in the following.

A new major software component of GEOSAT has been developed for 3D raytracing through the atmosphere. A complete 3D atmospheric model provided daily by ECMWF is input to the software. Based on the available tracking (VLBI, GPS, or SLR) for that specific date, a set of tables for each active station is automatically generated with information about the time delay in the different elevation and azimuth directions. Also statistical information concerning the variability of relevant parameters are extracted from the ECMWF data. This information is used in the estimation filter as time-dependent parameter constraints. In typically 70 % of the so far analyzed sessions this seems to be a very good strategy. In principle it should be possible to investigate the quality of the ECMWF numerical weather model regarding the pressure, temperature and humidity parameters. No mapping functions are used anymore in GEOSAT. Different interpolation schemes are under testing. An interpolation strategy has been found where the interpolation error is presently 1 mm or less down to an elevation cutoff of 2.7 degrees. A new model/parameterization for the atmospheric delay is under consideration in GEOSAT. The status is that some individual VLBI-only sessions have been analyzed. A clear reduction in a posteriori residuals (typically 20-25 %) is observed using the ECMWF data. The Grueger model is default for the MW refractive index and the Ciddor model is default for the optical or near optical wavelengths. The Ciddor model implementation has been verified against Ciddor's own software.

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

A model for thermal deformation of the VLBI antenna structure has been included. Thermal coefficients and thermal time delays can in principle be estimated.

The station eccentricity file has been checked in great detail and updated with all the most current log files of VLBI, GPS, and SLR. The eccentricity information is treated as a new observation type in GEOSAT in addition to the VLBI, GPS, and SLR observation types.

The GEOSAT software calculates one set of station coordinates and velocities for a reference marker at a colocated station in addition to the eccentricity vector to each different antenna reference point. The software has been extended so that observations from several active VLBI systems, GPS receivers and SLR systems all will contribute to the estimation of the parameters for the station reference marker. The instruments could be operating either simultaneously or in different time windows.

The IERS 2003 Conventions have been fully implemented including the new EOP parameterization.

The absolute GPS satellite antenna phase center table published by Rothacher recently has been implemented as an a priori model. The parameters will be estimated during the analysis.

All relevant partial derivatives have been verified against numerical partial derivatives.

In the global processing of several years of data the stable sources listed by Feissel et al. will automatically be estimated as constants while the others will be estimated as random walk parameters or session parameters. A set of defining stations satisfying certain criterias is automatically estimated as constants where the other stations are estimated as constants during a certain interval (between one day and one month).

Future plans

We plan to implement an orbital overlap scheme for automatic evaluation of the orbit quality (GPS, LAGEOS). Observations from the GALILEO navigation system will be applied when available. Only minor changes in GEOSAT are required for this extension.

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Per Helge Andersen

3.6.2.6 Geodetic Institute of the University of Bonn (GIUB)

The GIUB and the Deutsches Geodätisches Forschungsinstitut (DGFI) jointly form an IERS Combination Research Center. Continuing last years investigations the GIUB group has been carrying out research in the areas of generating time series of earth orientation parameters (EOP) and of combining VLBI solutions on the basis of datum-free normal equations.

Since early 2000, combined VLBI EOP time series have been generated from input provided by up to six IVS Analysis Centers. Until the end of 2002 the EOP data sets contained observing results of polar motion (x_p, y_p), earth rotation phase (UT1) and nutation angle offsets with respect to the IAU1980 nutation model ($d\psi$, $d\varepsilon$). From January 1, 2003 onwards, a second series is routinely generated and disseminated where celestial pole offsets (X, Y) in the frame of the non-rotating origins of the IAU2000 Resolutions and the MHB2000 nutation model are listed. Since VLBI analysis software packages have not yet been modified for a direct estimate of the new nutation paradigm, the offsets are simply transformed from the old paradigm to the new one using a routine kindly provided by Christian Bizouard of Paris Observatory.

In order to provide a quasi-continuous series of the earth's phase of rotation (UT1) the IVS regularly observes so-called Intensive sessions on single baselines. In recent months observations on a second baseline, Tsukuba (Japan) to Wettzell (Germany), have been included in the series of Wettzell - Kokee Park (Hawaii) observations adding UT1 data points also on Saturdays. Since each VLBI baseline contributes its own peculiarities a consistent integration of the new series into the existing one is required. The GIUB CRC investigates effects unique to the Tsukuba - Wettzell baseline which have to be calibrated for a consistent integration of the series.

Another field of research is the rigorous combination of VLBI solutions containing station coordinates and EOP on the basis of datum-free normal equations. After a number of preparatory steps have been completed the DOGS-CS software of DGFI has successfully been employed for the combination of a small series of test sessions generated by three IVS Analysis Centers. Critical areas have been the interpolation of the EOP epochs which have not been identical in all submissions and the number of TRF datum parameters which have to be fixed for a stable solution.

The work reported here has kindly been funded by the German Bundesminister für Bildung und Forschung (BMBF) under the Geotechnologien Project "Beobachtung des Systems Erde aus dem Weltraum", IERS - 03F0336B.

Axel Nothnagel, Dorothee Fischer, Christoph Steinforth, Markus Vennebusch

3.6.2.7 GeoForschungsZentrum Potsdam (GFZ)

Within the reporting period the activities of GFZ in the framework of the IERS Combination Research Center have been concentrated on two topics:
(a) the co-location of techniques onboard of satellites, and
(b) the possible impact of LEO data on IERS basic products.

Collocation of techniques

In 2003 intensive studies and tests have been performed using the software and procedures developed in 2002. This resulted in a number of improvements. The tests also clearly showed the benefits of the onboard co-location method for the following investigations:

(a) the determination of the phase center correction of an onboard GPS receiver,
(b) the investigation for significant differences between the GPS and SLR terrestrial reference frames, and
(c) to strengthen the relation between these two frames.

The achieved results will be presented at the EGU 2004 meeting.

Impact of LEO data

The research on the possible impact of LEO satellite missions on IERS basic products have been continued in 2003. The identified software modifications to the EPOS-OC software at GFZ have been executed. A method for an integrated adjustment of LEO (used: CHAMP and GRACE) and ground GPS data has been developed. As the tests based on a small number of arcs have been very successful, preparations were started for a quasi-routine processing of the data of some years. Also first tests with JASON data gave very positive results.

The latest multi-year solution of the GFZ IGS AC for the station positions of the IGS network (using very loose a priori weights) confirmed the results of last year's study about the satellite antenna phase center offsets and scale errors in GPS solutions (Zhu et al. 2003). The solution clearly shows time variations of the scale, which are significantly correlated with the increasing number of Block IIR satellites.

Reference

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Franz-Heinrich Massmann, Sheng Yuan Zhu, Chuang Shi

3.6.2.8 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 proposed from year 2000 to study the combination of five techniques (SLR, LLR, VLBI, GPS and DORIS) at the observation level. The goal is to obtain a global and homogeneous solution of the Earth Orientation Parameters (EOPs): universal time UT1, pole motion, nutation corrections in longitude and obliquity, as well as station coordinates.

The adopted strategy consists in combining with the GRGS's DYNAMO software the normal equations resulting from processing the GRGS's GINS orbitography software for individual techniques, except for LLR which is processed by the CAROL software. The optimal relative weights between each technique are obtained by using the Helmert's optimal variance-covariance method.

A first approach was done by Ph. Yaya in his doctorate work until 2002. He could reach promising results over a 3 month test period which has incited us to persevere in this approach.

In order to study more thoroughly the merits of such a technique we decided to perform an complete analysis over a full year, 2002. Hence the main activity in 2003 was:

- at first to check and to improve if necessary the processing of SLR, DORIS, VLBI and GPS observations in the GINS software in order to get at least as good results compared to those ones from the international services;
- then to define the parameterization: 6 h resolution for all series of orientation parameters, weekly station solutions (from Sunday to Saturday);
- at last to process all available 2002 data: SLR on Lageos, Lageos2, Starlette and Stella, DORIS on SPOT2/4/5, Topex, Jason1 and Envisat satellites, GPS from 80 stations and VLBI. LLR data from the Grasse and McDonald stations were processed separately by the CAROL software.

In summary, individual technique number of observations and mean residuals are for:

- VLBI: from 100 to 10000, 0.02 to 0.08 ns for VLBI, depending on the type of sessions;
- SLR: a few thousands/week, 1 cm to 3 cm depending on satellites,
- DORIS: 0.4 to 0.5 mm/s,
- GPS: around 1 cm phase and 60 cm range,
- LLR: 30 obs./month, 40 cm.

The combination processing started already end of 2003 and goes on in 2004.

All normal matrices have been also converted in SINEX format so that they could be exported to be treated by other software, like for instance by the CATREF software at IGN.

This work is shared within GRGS between the Paris Observatory (N. Capitaine, J. Chapront, G. Francou, D. Gambis, A.-M. Gontier), OCA/CERGA (D. Coulot, P. Exertier), CNES (R. Biancale, J.-M. Lemoine), IGN/LAREG (Z. Altamimi), CLS (L. Soudarin) and Noveltis (S. Loyer).

Richard Biancale

3.6.2.9 Institut Géographique National (IGN)

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

3.6.2.10 Institute of Applied Astronomy (IAA)

Research groups and staff

Two research groups of the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA) were involved in 2003 in the IERS CRC related activity:

1. Laboratory of Space Geodesy and Earth Rotation (LSGER)
   Dr. Zinovy Malkin, Head; Natalia Panafidina
   Contact: malkin@quasar.ipa.nw.ru
2. Laboratory of Ephemeris Astronomy (LEA)
   Prof. George Krasinsky, Head; Nadia Shuygina
   Contact: 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 various EOP series.

A special study was performed to investigate possible approaches to the optimal modelling of systematic differences between the EOP series submitted to the IERS (Malkin, 2003).

Combination of weekly EPN solutions of individual analysis centers

In 2003 we finished the first stage of this work - the recomputation of the official weekly EPN solutions using the method described in the previous report (IERS Annual Report 2002). This series is submitted on a regular basis to the EPN Central Bureau in the framework of the EPN Geodynamical Project.

A new IAA combined coordinate time series for GPS stations of the EPN network has been started. For this computation we use all available weekly solutions of individual Analysis Centers. To obtain a weekly combined solution we use the following approach.

In the first step the Analysis Centers' specific constraints are removed from the individual solutions using a priori coordinates and covariance matrices contained in the SINEX files (Brockmann, 1996). Then covariance matrices of deconstrained solutions are rescaled in order to obtain homogeneous solutions. Rescaling is done in such a way that the mean error of the input solution computed for non-fiducial stations equals the mean error of deconstrained solution computed for the same set of stations.

In the second step all deconstrained individual solutions are transformed to ITRF2000 using Helmert transformation. Now we use 6 parameters computed using all stations of the individual solutions. Then all the solutions are combined using sequential least squares estimation. Weighting factors are introduced for individual solutions to account for their different accuracy.
For outlier detection we compute differences between individual solutions and the combined one, and stations with differences greater

than three mean errors for a given GPS week are rejected. Then the combination procedure is redone without these stations.

This work is supposed to be continued for a TRF+EOP combination.

LEA group

Determination of EOP from combination of SLR and VLBI data

A combined analysis of VLBI and SLR measurements at the observation level is carried out for improving the accuracy and time resolution of EOP. Both SLR and VLBI observations are processed by the same software ERA, using the same astronomical constants and models for different kinds of measurements.

At the first stage condition equations for VLBI and SLR observations are obtained from independent processing of each technique. For VLBI measurements the zenith component of troposphere delay and its gradients are adjusted as stochastic signals for each day of observation. Both coordinates of quasars and site coordinates are not improved in this solution. For SLR data we used laser ranges to geodetic satellites LAGEOS, LAGEOS 2, and Etalon 1 and 2. The short arc technique with an arc length of 7 days is applied to all SLR measurements to adjust orbital parameters along with the radiation pressure coefficient and along-track acceleration, which are considered as non-stochastic.

At the second stage the SLR and VLBI condition equations are mixed to determine corrections to parameters mentioned above along with five Earth rotation parameters. A Kalman filtering procedure is used to solve the system of condition equations. Combining SLR and VLBI measurements on one-day arcs makes it possible to improve the standard deviations of pole coordinates in comparison with those obtained by each technique separately (Shuygina, 2004). Applying the Kalman filtering method also allows to derive EOP variations with subdiurnal periods.

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Shuygina, N. V., 2004, Determination of EOP from combination of SLR and VLBI data at the observational level. In: Proc. Journees 2003 “Astrometry, geodynamics and solar system dynamics: from milliarcseconds to microarcseconds”, N.Capitaine and A. Finkelstein (eds.), in press.

Zinovy Malkin, Natalia Panafidina, George Krasinsky, Nadia Shuygina

3.6.2.11 Jet Propulsion Laboratory (JPL)

Introduction

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

Data Products

Reference series of Earth orientation parameters are generated annually at JPL. During 2003, three such reference series were generated: (1) SPACE2002, consisting of values and rates for polar motion and UT1 spanning September 28, 1976 to January 11, 2003 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) COMB2002, consisting of values and rates for polar motion and UT1 spanning January 20, 1962 to January 11, 2003 at daily intervals, was generated by additionally including the BIH optical astrometric measurements with the space-geodetic measurements used to generate SPACE2002; and (3) POLE2002, consisting of values and rates for just polar motion spanning January 20, 1900 to December 22, 2002 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 COMB2002. These reference series can be obtained by anonymous ftp to <ftp://euler.jpl.nasa.gov/keof/combinations/2002>. A report describing the generation of these series [Gross, 2003] 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 2003 were largely concerned with using the three-corner-hat method to estimate the uncertainties in polar motion and length-of-day measurements taken by the space-geodetic techniques of SLR, VLBI, and GPS during 1997-2002 [Chin *et al.*, 2004]. In the three-corner-hat method the signal common to each series is eliminated by forming pair-wise differences between the series, thus requiring that the measurements be given at the same epoch. From the variances of the differenced series, the uncertainty of each series can be recovered when reasonable assumptions are made about the correlations between a subset of the series. Of the series studied, it is found that the IGS Final combined series has the smallest polar motion and length-of-day uncertainties. The results for the VLBI series are found to be unreliable due to the predominant amount of interpolation error present in the results that is caused by the need to interpolate the sparse, irregularly sampled VLBI measurements to the epochs of the other series. Better knowledge of the inherent uncertainties of individual space-geodetic series can lead to better combined series when the combinations are generated by techniques, such as the Kalman filter, that use measurement uncertainties as weights.

References

Chin, T. M., R. S. Gross, and J. O. Dickey, Multi-reference evaluation of uncertainty in Earth orientation parameter measurements, *J. Geodesy*, submitted, 2004.

Gross, R. S., Combinations of Earth orientation measurements: SPACE2002, COMB2002, and POLE2002, Jet Propulsion Laboratory Publ. 03-11, 28 pp., Pasadena, Calif., 2003.

Richard Gross

4 IERS Meetings

4.1 IERS Retreat 2003

Introduction

The reasons for the IERS Retreat 2003 were manifold:

- the dramatic increase in accuracy of space geodetic results in the last few years:
  - Site coordinates at 10^{-9},
  - Earth Orientation Parameters at 10^{-9},
  - Gravity field soon at a similar level,
- the Technique Services have been well established:
  - Better coordination of technique products,
  - Much better situation to go for consistent and rigorously combined products,
- many new missions and projects posing new challenges:
  - Gravity missions (CHAMP, GRACE, GOCE, ….),
  - Altimetry missions (JASON-1, ENVISAT, ICESAT, …),
  - Astrometry missions,
  - IGGOS
- and first impression on the new IERS structure (about 2 years old).

The IERS Retreat 2003 was organised by the IERS CB and took place at the Observatoire de Paris from March 31 to April 1, 2003, followed by an IERS Directing Board meeting on April 2, 2003. Representatives from all IERS components and the Technique Centres were invited as well as external experts from various fields of interest (altimetry, astronomy, global gravity field, new satellite missions, rigorous combination and consistency considerations, IGGOS).

Course of events

The retreat started with an overview of the present situation presented by the various components:

1. The IERS internal components (PCs, GGFC, CRC, CB) answered the following questions:
   - What is the status of the original proposal and the products?
   - What changes are envisaged for the present products?
   - What products are planned for the future?
2. The Technique Centres (IGS, IVS, ILRS, IDS) and
3. the external experts reported about important developments and answered questions concerning:
   - How does the IERS contribute to this project / service?
   - What does the project / service expect to get from the IERS?
   - How can the project / service contribute to the IERS?

To prepare the discussion all presenters were asked to send in a "half page" contribution stating the principle ideas. In Annex III (see Web site) the "half page" statements are summarized for the IERS components (Product Centres (PC), Central Bureau (CB), Global Geophysical Fluid Centres (GGFC), ITRF Combination Centres (ITRF CC), Combination Research Centres (CRC)), the Technique Centres (IGS, ILRS, IVS, IDS) and the external experts.

The IERS vision and goals were worked out in groups to put together a list of future requirements and future products. The groups representing the fields "astronomy", "gravity and geophysical fluids", "technique centres" (including altimetry), "combination" and "IGGOS" had to find answers to the following questions:

- What are the future requirements?
- What does the IERS offer already?
- What are the deficiencies of the present IERS to fulfil these requirements?
- What are the future IERS products and how do they look like?

The outcome of the group discussions to the listed five topics is given in Annex IV (see Web site).

Finally the organizational and structural consequences were discussed with the focus on:

- What are the organizational / structure consequences?
- Working groups, Pilot projects, Call for Participation?
- Action items and persons in charge?

Outcome and decisions

Outcome and decisions by the IERS DB as a consequence of the IERS Retreat are the following:

Decisions

1. New naming of IERS:

The IERS was renamed in:

International Earth rotation and Reference systems Service (IERS)

(Service international de la rotation de la Terre et des systèmes de référence)

The new name better reflects the fact that the activities of the IERS do not only consist in producing Earth orientation parameters but also in defining and maintaining the celestial and terrestrial reference systems and frames. IAU, IUGG/IAG and FAGS have been informed.

2. Statements concerning IGGOS:

- IERS, as a joint service of IAU and IUGG, sees its role as contributing to the astronomical as well as to the geodetic and geophysical communities.

- IERS agrees with and supports the proposed vision and the overall goals of IGGOS.
- IERS will contribute to IGGOS, as a service, with its multi-technique products including terrestrial and celestial reference frames as well as Earth orientation parameters, Conventions, Global Geophysical Fluids Centre activities and its data base / information system. IERS will also contribute its expertise in combination and co-location of techniques.
- IERS is interested in a close cooperation with the International Centre for Global Gravity Field Models as a component of the International Gravity Field Service to ensure the consistency of the products.
- To accomplish its goals IERS depends on the contributions of the IGS, ILRS, IVS and the planned IDS. This is formally recognized through the structure of the IERS and of these services.
- The IERS looks forward to working with IGGOS as it proceeds to implement its vision and goals.

3. Gravity field community:

To have a better link to the gravity community, that is also using the IERS products, a representative of IGFS (especially ICGEM) will be invited to the IERS DB meetings as permanent guest. A close relationship is important to ensure the consistency between IERS and gravity field products (including the IERS Conventions).

4. Altimetry:

The IERS DB would also be interested in a closer connection to the altimetry community.

5. Global Geophysical Fluid Centres:

There was a clear statement of the IERS DB that the GGFC are an essential part of the IERS structure due to the significant interaction between the GGFC and the other IERS components. The GGFC products are of importance for the understanding of temporal and spatial variations of EOP and station positions as well as for numerous applications in geosciences.

6. Combination Pilot Project

It was decided that the IERS SINEX Combination Campaign should evolve into a pilot phase of **routine product generation**, the ”IERS Combination Pilot Project”. The aim of the combination pilot project is the rigorous combination of station coordinates, EOP series, and quasar coordinates from weekly SINEX files of all major space geodetic techniques including time series of all three components: station- and quasar coordinates as well as EOP.

The Call for Participation (CfP) will allow for the following type of contributions:

- Technique Centres (or groups combining at the observation level): They contribute routinely with "weekly" (= session for VLBI, = week for GPS, SLR, DORIS) technique-specific SINEX files,
- Combination Centres: They routinely combine "weekly" SINEX files from all major space geodetic techniques containing station coordinates, EOP and quasar coordinates into combined consistent weekly IERS products (series of weekly station (and quasar coordinates) and daily EOPs),
- Associated Combination Centres: They routinely produce at least one special combined product for the IERS. Examples: combined subdaily EOP series, combined nutation offset series, combined troposphere or ionosphere products etc.

The Combination Pilot Project will be organized and coordinated by the Working Group on Combination (see below).

Organizational Consequences

Establishment of Working Groups

1. Working Group on Combination

The WG will be set up according to the IERS Terms of Reference (see Appendix 1).

Initial members are: IERS AC, 1 representative of each PC, 1 representative for all CRC, 1 representative of each TC, 1 representative of each ITRF CC, IERS CB and representatives of the groups answering the CfP for the "Combination Pilot Project" and being accepted by the proposal evaluation.

The charter of the WG will be drafted till the beginning of May and discussed within the initial members of the WG.

The WG will prepare the CfP for the "Combination Pilot Project" and release it by the end of June / beginning of July 2003. All responses received till Sept. 15, 2003 will be evaluated by the WG and a proposal will be sent to the IERS DB for approval. The pilot project will start on January 1, 2004.

Apart from the coordination of the Combination Pilot Project the WG will work on:

- Document with guidelines / definitions for a rigorous combination,
- Input definitions and standards for combination,
- Product specification (routine combined products and long time series of past data),
- Handling of and guidelines for site problems,

- Validation issues.

2. Working Group on ITRF datum

It is planned to reconstitute the WG on ITRF datum within the IERS frame work according to the ToR.

3. Working Group on Site Co-location

A WG on Site Co-location will be set up within the IERS in accordance with the CSTG. As chair of the WG John Long is foreseen, who already headed the CSTG subcommission on ISGN. The charter and the initial member list of the WG will be discussed within the IERS DB.

Planned workshops

1. Workshop on Site Co-location

A first workshop dealing with the main topics of the WG: site surveying, adjustment of local networks, SINEX generation with full variance-covariance information and other co-location issues (e.g. environmental parameters) will be held in Matera / Italy in October 2003. (For a report see Section 4.2.)

2. Workshop on Combination

To discuss the first experiences of the Combination Pilot Project a workshop is planned in the fall of 2004.

Web site

More information on the IERS Retreat 2003, including the Appendices mentioned above, is available at

http://www.iers.org/iers/meetings/IERS-Retreat-2003/

Jan Vondrak, Markus Rothacher, Bernd Richter

4.2 IERS Workshop on site co-location surveys

An IERS Workshop devoted to “site co-location survey objectives, methods and issues“ took place in Matera, Italy, on October 23-24, 2003.

Presently the quality of the station coordinates results from the various space techniques is in the order of a few millimetres in the horizontal and about 1 cm in the vertical component. Precise local ties are the perfect link to enable a rigorously combination of all space observing techniques by their common parameters in order

- to study the systematics going along with each space technique and,
- to establish a unique, high-precision terrestrial reference frame.

In previous analyses one of the major limiting factors was the characteristic and the availability of accurate local tie information for all the co-located sites around the globe. In 5 sessions attention was given to:

- Co-location sites and their importance for the ITRF
- Site surveys
- Analysis and SINEX
- Reporting and Archiving
- Planning for 2004

More than 30 participants from Australia, South Africa, USA and Europe discussed various examples, analysis methods and survey strategies. Finally guidelines for co-location site surveys and report templates were proposed. The potential availability of survey teams as well as the planning for surveys in 2004 were investigated.

The important recommendations are the following:

- Local ties between co-located instruments should be determined with an accuracy of 1 mm, with full variance/covariance information, available in SINEX format.
- Local survey measurements should have the same importance as and should be treated like any of the space geodetic techniques. Site coordinates (VLBI, GPS, SLR, DORIS) should be better tied to the ground. The local ties quality should be such that they can be assumed true for the combination.
- All GPS sites close to other geodetic techniques should be part of the IGS routine processing.
- A database will be established at IERS (Central Bureau and ITRS Centre) for all information in connection with site co-location (list of co-location sites, local ties in SINEX, co-location instruments, site maps and pictures, survey reports, survey status, site events and history ...).

To support the local tie activities an IERS Working Group on Local Survey will be suggested for adoption by the IERS Directing Board. The charter of the working group will be the coordination and assistance in local tie analysis as well as SINEX file generation.

The workshop information (programme, presentations and recommendations) is available at the IERS Web page

http://www.iers.org/workshop_2003_matera/

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

Appendix 2: Contact addresses of the IERS Directing Board

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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://ggfc.gsfc.nasa.gov/

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://ggfc.gsfc.nasa.gov/
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
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International GPS Service (IGS)
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International VLBI Service (IVS)
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International DORIS Service (IDS)
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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/

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Web page: http://www.iers.org/iers/crc/gfz/

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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.
AGK2	Zweiter Katalog der Astronomischen Gesellschaft
AGU	American Geophysical Union
AICAS	Astronomical Institute, Academy of Sciences of the Czech Republic
APKIM	Actual Plate Kinematic Models
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
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
CEO	Celestial Ephemeris Origin
CEP	Celestial Ephemeris Pole
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques
CfP	Call for Participation
CGS	Centro di Geodesia Spatiale, ASI
CIP	Celestial Intermediate Pole
CLS	Collecte, Localisation, Satellites
CMB	core-mantle boundary
CNES	Centre National d'Etude Spatiale
COD	= CODE
CODE	Centre for Orbit Determination in Europe
CONT	continuous VLBI session
CPC	Climate Prediction Center
CPP	IERS Combination Pilot Project
CRC	Combination Research Centre
CRF	Celestial Reference Frame
CRL	Communications Research Laboratory
CRS	Celestial Reference System
CSR	Center for Space Research
CSRIFS	Combined Square Root Information Filter and Smoother
CSTG	Commission on International Coordination of Space Techniques for Geodesy and Geodynamics
DANOF	Département d'Astronomie Fondamentale
DB	Directing Board
DEOS	Delft Institute for Earth-Oriented Space Research
DGFI	Deutsches Geodätisches Forschungsinstitut
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DOGS	DGFI Orbit & Geodetic Parameter Estimation Software
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
EC	Executive Committee
ECCO	Estimating the Circulation and Climate of the Ocean
ECMWF	European Center for Medium Range Weather Forecasting
EGNOS	European Geostationary Navigation Overlay Service
EGS	European Geophysical Society
EGU	European Geosciences Union

EMR	Energy, Mines and Resources Canada (replaced by NRCan)
ENSG	Ecole Nationale de Sciences Geographiques
EOC	Earth Orientation Centre
EOP	Earth Orientation Parameters
EPN	European Permanent GPS Network
ERA	Earth Rotation Angle
ERP	Earth Rotation Parameters
ESA	European Space Agency
ESOC	European Space Agency Operational Center
EU	European Union
EUG	European Union of Geosciences
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FAQ	Frequently Asked Question
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
GAUS	Geoscience Australia
GCRS	Geocentric Celestial Reference System
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
GLONASS	Global Orbiting Navigation Satellite System, Russia
GLOUP	GLObal Undersea Pressure
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRGS	Groupe de Recherches de Géodésie Spatiale
GSFC	Goddard Space Flight Center
GSFD	VLBI solution by GSFC
IAA	Institute of Applied Astronomy, St. Petersburg
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICCT	IAG Inter-Commission Committee on Theory
ICGEM	International Centre of Global Earth Models
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
IDS	International DORIS Service
IERS	International Earth Rotation and Reference Systems Service (formerly: International Earth Rotation Service)
IGFS	International Gravity Field Service
IGGOS	Integrated Global Geodetic Observing System
IGN	Institut Géographique National
IGS	International GPS Service
ILRS	International Laser Ranging Service
INASAN	INstitut AStronomii Rossijskoj Akademii Nauk (Institute of Astronomy of the Russian Academy of Sciences)
INDIGO	Inter-service Data Integration for Geodetic Operations
IRIS	International Radio Interferometric Surveying
ISGN	International Space Geodetic and Gravimetric Network
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
JPL	Jet Propulsion Laboratory
KEOF	Kalman Earth Orientation Filter
KPNO	Kitt Peak National Observatory
LAREG	Laboratoire de Recherche en Geodesie
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)
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)
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
NetCDF	Network Common Data Form
NGL	VLBI solution by DGFI
NGS	U.S. National Geodetic Survey
NIPR	National Institute for Polar Research
NMF	Niell Mapping Function
NNR	No-net-rotation
NNT	No-net-translation
NOAA	U.S. National Oceanic and Atmospheric Administration
NoE	EU Network of Excellence
NOFS	USNO Flagstaff Station
NPM	Lick Northern Proper Motion Program
NRAO	U.S. National Radio Astronomy Observatory
NRCan	Natural Resources, Canada (formerly: EMR)
NUVEL	Northwestern University Velocity Model
OCA	Observatoire de la Côte d'Azur
OP	Observatoire de Paris
PC	Product Centre
PHP	PHP: Hypertext Preprocessor
PM	Polar Motion
POCM	Parallel Ocean Climate Model
PPARC	Particle Physics and Astronomy Council, UK
ppb	parts per billion (10^{-9})
PRARE	Precise RAnge and Range-Rate Equipment
PZT	Photographic Zenith Tube (Telescope)
QC	quality control
QSO	Quasi-Stellar Object (quasar)
RDV	Research and Development (sessions) with the VLBA
rms, RMS	Root Mean Square
RRFID	USNO Radio Reference Frame Image Database
SB	Special Bureau
SBC	Special Bureau for the Core
SBGG	Special Bureau for Gravity/Geocenter
SBL	Special Bureau for Loading
SBO	Special Bureau for the Oceans
SCAR	Scientific Committee on Antarctic Research
SHA	Shanghai Observatory
SIM	NASA's Space Interferometry Mission
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SLR	Satellite Laser Ranging
SOD	CNES Service d'Orbitographie DORIS
SOFA	Standards Of Fundamental Astronomy
SPBU	St Petersburg University
SPM	Yale/San Juan Southern Proper Motion Program
SRIF	Square Root Information Filter array
SSALTO	Segment Sol multi-mission d'ALTimétrie, d'Orbitographie et de localisation précise
SW	software
TAI	Temps Atomique International (International Atomic Time)
TC	Technique Centre
TEC	Total Electron Content (Total Electron Count)
TECU	TEC Unit

TEMPO	Time and Earth Motion Precision Observations
TEO	Terrestrial Ephemeris Origin
TN	IERS Technical Note
TOW	Technical Operations Workshop
TRF	Terrestrial Reference Frame
TRS	Terrestrial Reference System
TT	Terrestrial Time
Univ.	University
UCAC	USNO CCD Astrograph Catalog
URL	Uniform Resource Locator
USN	= USNO
USNO	United States Naval Observatory
UT	University of Texas
UT, UT0/1	Universal Time
UTC	Coordinated Universal Time
UTCSR	= CSR at University of Texas
VLBA	Very Long Baseline Array, NRAO
VLBI	Very Long Baseline Interferometry
VTRF	VLBI terrestrial reference frame
VUGTK	Research Institute of Geodesy, Topography and Cartography, Czech Republic
WG	working group
WRMS	Weighted Root Mean Square
XML	eXtensible Markup Language