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

IERS
Annual Report
2006

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IERS Annual Report 2006

Edited by Wolfgang R. Dick and Bernd Richter

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1 Foreword

The IERS Annual Report for 2006 describes its ongoing activities in the terrestrial and celestial reference frames and in Earth orientation parameters. The major events illustrate well the connection between the IERS products and the technique services as well as the stepwise nature of progress.

In particular, the release of ITRF2005 by the ITRS Center allowed the IGS to begin improved analysis along with absolute phase center models. ITRF2005 also demonstrated the degradation of the ILRS network caused by the temporary absence of key stations in the Pacific and South America. Using ITRF2005 the EOP series were realigned with an upgraded numerical combination procedure.

The work in 2006 must be considered another phase in the major transformation of IERS product generation. The knowledge gained and questions raised in developing ITRF2005 are stepping stones to further understanding but also must be taken in the direction of obtaining better input data from the technique services, particularly in the geographic distribution and co-location of SLR and VLBI. There is much to be done.

Chopo Ma
Chair, IERS Directing Board

2 The IERS
2.1 Structure

From 2006 to 2008, the IERS had the following components. For their functions see the Terms of Reference (Appendix 1), for addresses and electronic access see Appendices 3 and 4. Dates are given for changes in 2006 to 2008.

Analysis Coordinator

Markus Rothacher

Central Bureau

Director: Bernd Richter

Technique Centres

International GNSS Service (IGS)
IGS Representatives to the IERS Directing Board:
Gerd Gendt (until 31 December 2007)
Angelyn W. Moore (until January 2008)
Jim Ray (since 1 January 2008)
IERS Representative to the IGS Governing Board: Claude Boucher

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

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

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

Product Centres

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

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

Conventions Centre
Primary scientists: Brian J. Luzum, Gérard Petit
Representative to the IERS Directing Board: Gérard Petit (until 31 December 2006), Brian J. Luzum (since 1 January 2007)

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

ITRS Centre
Primary scientist and representative to the IERS Directing Board:
Zuheir Altamimi

Global Geophysical Fluids Centre
Head and representative to the IERS Directing Board:
Tonie van Dam

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: Jianli Chen (since May 2005)

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

Special Bureau for the Core
Chair: Tim van Hoolst

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

Special Bureau for Loading
Chair: Hans-Peter Plag
Vice-chair: Tonie van Dam

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:
N.N.

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

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

Deutsches Geodätisches Forschungsinstitut (DGFI)
Primary scientist: Detlef Angermann

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

GeoForschungsZentrum Potsdam (GFZ)
Primary scientist: Markus Rothacher

Institute of Geodesy and Geoinformation of the University of Bonn (IGGB)
Primary scientist: Axel Nothnagel

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

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

Institut Géographique National (IGN)
Primary scientist: Zuheir Altamimi

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

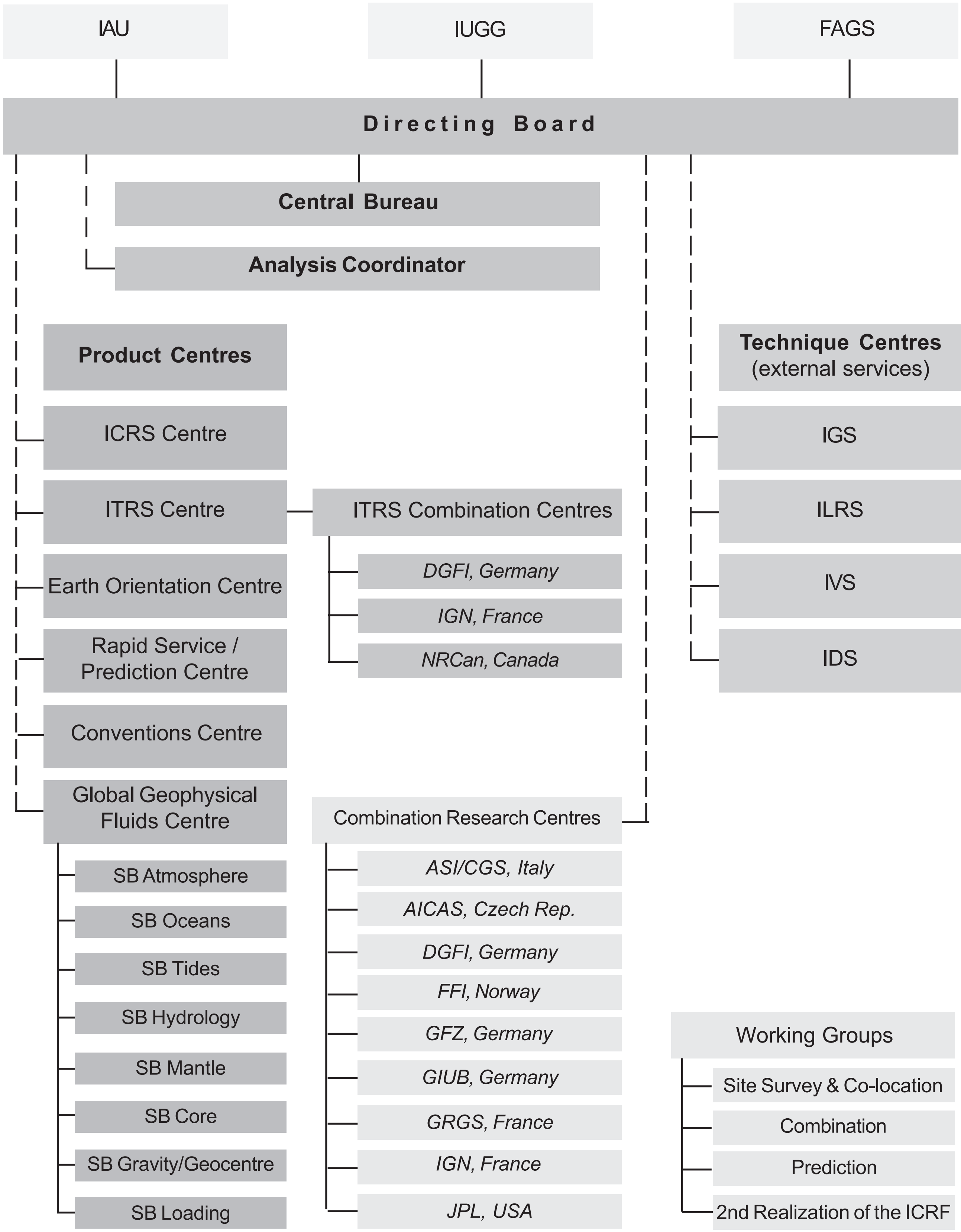
Working Groups

Working Group on Site Survey and Co-location
Chair: Gary Johnston (since January 2006)

Working Group on Combination
Chair: Markus Rothacher

Working Group on Prediction
Chair: William Wooden

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


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

2.2 Directing Board

In 2006 to 2008, the IERS Directing Board had the following members (for addresses see Appendix 2):

Chair	Chopo Ma
Analysis Coordinator	Markus Rothacher
Product Centres Representatives	
Earth Orientation Centre	Daniel Gambis
Rapid Service/Prediction Centre	William Wooden
Conventions Centre	Gérard Petit (until 31 December 2006) Brian J. Luzum (since 1 January 2007)
ICRS Centre	Ralph A. Gaume
ITRS Centre	Zuheir Altamimi
Global Geophysical Fluids Centre	Tonie van Dam
Central Bureau	Bernd Richter
Combination Research Centres	N.N.
Technique Centers Representatives	
IGS	Gerd Gendt (until 31 December 2007) Angelyn W. Moore (until January 2008) Jim Ray (since 1 January 2008)
ILRS	Ron Noomen (until 18 October 2006) Peter J. Shelus (until 18 October 2006) Jürgen Müller (since 19 October 2006) Erricos C. Pavlis (since 19 October 2006)
IVS	Chopo Ma Axel Nothnagel
IDS	Hervé Fagard Frank Lemoine (since February 2006)
Union Representatives	
IAU	Nicole Capitaine
IAG / IUGG	Clark R. Wilson
FAGS	Nicole Capitaine

2.3 Associate Members

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

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

(*Status as of February 2008*)

3 Reports of IERS components
3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of the year 2006. Summaries of these meetings are given below.

Meeting No. 42

April 8, 2006, Technical University of Vienna, Vienna, Austria

Formalities

C. Ma reported about the activities as chair. In coordination with the DB he sent a letter of support for the Australian National Geospatial Reference System.

Reports of the Unions (IAU, IAG/IUGG)

N. Capitaine presented a summary of the latest IAU and FAGS actions. This included the programme of the XXVIth IAU General Assembly in Prague from August 14 – 25, 2006 including details on Joint Discussion 16, sponsored by Division I Commission 19 together with Division X Commissions 4, 5, 7, 8, 31, 40 and titled “Nomenclature, Precession, and New models in Fundamental Astronomy”. In the list of invited papers members of the IERS DB are represented. As supplements to the IAU Resolutions of 2000 the WG on “Nomenclature for fundamental astronomy (NFA)” prepared several resolution proposals including a re-definition of TDB because there is no consensus on a description of TDB as it is currently understood. The second part of her presentation described the reorganisation of FAGS during the period 2006 – 2008. During the FAGS council meeting in Paris (March 29 / 30, 2006) the services presented their activity reports. The next step will be the preparation of a white paper by a subgroup of the FAGS Council (N. Capitaine, P. Wilkinson, R. Neilan) in close coordination with the Services Directors, the Unions and ICSU. A small allocation for the IERS is guaranteed till 2008. Due to the absence of C. Wilson his report about IAG activities was postponed.

International Projects: GGOS and GEO

M. Rothacher reported on the activities and status of GGOS. During the GGOS retreat in February 2006 the GGOS structure for 2006 – 2007 was defined. User requirements, proposals for a GGOS portal, the preparation of the GGOS workshop in October 2006, as well as the preparation of the IUGG meeting in Perugia were discussed. M. Rothacher noted that GGOS will be based on the existing IAG Services and their products. GGOS is not taking over tasks of the existing, properly functioning IAG services. With respect to the IERS he sees two critical points. The IERS Conventions Centre should interact and work together with the GGOS WG on Conventions / Modelling / Analysis. The same holds for the IERS WG on Site Co-Location and the GGOS WG on Networks. The flow of information should be guaranteed by overlapping memberships.

In the 2006 work plan of the Group of Earth Observation (GEO) members and participating organizations are asked to reach agreements on GEOSS interoperability specifications, and an inventory should be produced of existing *in-situ* observation networks organized by societal benefit area. More specific tasks are to be developed for the years 2007 – 2009 and distributed for discussion.

Report of Technique Services

IGS

A. Moore reported that the IGS has prepared a new list of co-located sites which was submitted by R. Ferland to the ITRS Centre. In addition the status of the IGS solutions contributing to the ITRF was summarized by a note from R. Ferland to the CB:

Since the meeting last December the IGS activities related to the IERS touched on three components of the ITRF2005 combination:

1. The IGS weekly solutions had been provided last August up to GPS week 1333 (05/07/30). The IGS solutions for GPS weeks 1334 (05/07/31) to 1355 (05/12/31) were reviewed and provided to complete the series up the end of 2005. This was completed before the end of January.
2. The discontinuity table were also reviewed and updated using the usual data sources. A discontinuity list was provided by TUM, derived from their GPS reprocessing, from which several additions were made to the IGS list. The list currently includes close to 450 stations, with nearly 600 discontinuities. For various reasons not all stations in the list are part of the contributed stations to ITRF2005.
3. A subset of the preliminary GPS solution, recently provided by IGN, was tested. The stations corresponding to the IGS "IGb00" realization, were used to combine/align the IGS weekly combinations for GPS weeks 1360-1361-1362 (06/01/29 – 06/02/19). Note that those weeks are not part of the ITRF2005.

The table below shows the standard deviations between the weekly combination and the IGN solution. The statistics for the currently used IGb00 are also included for comparison:

	weekly - IGN / IGb00			
week	#sta	N(mm)	E(mm)	H(mm)
1360	80	2.0 / 3.6	1.8 / 3.4	6.4 / 12.9
1361	79	2.0 / 3.5	1.6 / 3.6	6.1 / 12.5
1362	80	2.0 / 3.5	1.8 / 3.8	5.8 / 12.4

Note that the most recent data in IGb00 is already almost 3 years old (Wk 1231 – 03/08/10). There is a factor of ~ 2 improvement with the IGN solution. The statistics obtained with the IGN solution are consistent with what has been experienced with previous IGS realizations.

ILRS

R. Noomen gave an overview about the ILRS contributions to the ITRF2005. From 2003 onward the ILRS offered weekly solutions for station coordinates and EOPs as an operational product derived from observations to LAGEOS-1 & 2 and Etalon-1 & 2. In November 2005 the re-analysis of the SLR observations 1993 – 2003 was provided in the same weekly solution scheme. He concluded his presentation with the following recommendations:

1. The ILRS strongly recommends that the IERS use the current time-series of the ILRS and IVS "pos+eop" solutions for the definition of the scale of ITRF2005
2. The ILRS recommends that the IERS investigate the cause for the differences between the seasonal variations in global scale as observed by the ILRS and IVS.

IVS

A. Nothnagel reported that the first results of the CONT05 series observed over 15 days in October 2005 look very good. Currently, the VLBI databases are being reprocessed with session limits reset from the original epochs to 0.00 to 24.00 UT in order to permit better combination with the satellite techniques and to investigate the reference epoch effect on the EOP results. The IVS plans to change to routine SINEX combination on the basis of datum-free normal equations with datum definition after combination by the end of 2006. So far it is unclear to what epoch the EOP should be referred to. Currently, the IERS CPP calls for the 12.00 UT (Noon) epoch while the C04 series is computed on the basis of the 0.00 UT (Midnight) epoch. In addition to this, the IERS Rapid Service/Prediction Centre asks to stay with the middle epoch of the VLBI observing sessions, which is generally around 06:00 UT. A short discussion evolved about this problem with statements about the fact that with the EOP rates and the respective variance-covariance information every user can re-compute the EOP at the epoch of choice. However, most users do not have this information readily available and error propagation will not be carried out correctly.

IDS

F. Lemoine as the new analysis coordinator presented the two DORIS solutions contributing to the ITRF2005 prepared by IGN/JPL and LEGOS/CLS, which differ mainly in scale.

Status of ITRF

The ITRS Combination Centres DGFI (D. Angermann) and IGN (Z. Altamimi) reported about their progress for the new ITRF. NRCan (R. Ferland) activities were described already under the reports of techniques centres/IGS.

Z. Altamimi estimated the comparisons between the ITRS CCs would be finalized at the end of April / beginning of May. The evaluation group should start with its work immediately and should be ready within 2 weeks.

The evaluation group would include:

- Analysis Coordinator: Markus Rothacher
- one representative of each Technique Centres
- EOP expert: Richard Gross
- Geophysics: Geoff Blewitt
- Advisory Board Conventions: Jim Ray

Each evaluation expert should describe his procedure and findings in a short report. The final ITRF will be published as an IERS Technical Note.

Status of ICRF

R. Gaume reviewed the history, current status and future of the ICRF. The IAU will be asked to support a new ICRF with the new observations and analysis.

Convention Update Process

G. Petit presented the new electronic access to the Conventions Updates which are highlighted and marked at the margin by a vertical bar. These updates have been carried out by a group of experts that the Conventions Centre convened with the support of the Advisory Board for IERS Conventions Updates. It was reported that the chapter 7, section 7.1.5 “Ocean Pole Tide Loading” now completes the introduction of the ocean pole tide model after the inclusion of the geopotential part in Chapter 6. The files needed to implement the new model “Ocean Pole Tide Loading” are available in <ftp://tai.bipm.org/iers/convupdt/chapter7/>. Similar work is under way for the atmospheric tidal loading. Models have been provided by Tonie van Dam and Richard Ray. In the discussion there was support for a free core nutation model in the Conventions. Before publication the changes will be presented the IERS Directing Board for endorsement.

Working Group on Prediction

W. Wooden summarized the meeting of the IERS Working Group on Prediction on Thursday April 6, 2006. He went through the charter, highlighting the goals and objectives and the proposed structure. He prepared a survey to focus the work better towards user needs.

H. Schuh presented selected results of the EOP Prediction Comparison Campaign. 8 teams with 12 different prediction methods participated in this activity. The information shown was compiled into a poster presented at the EGU General Assembly. After the first experiments the rules will be slightly changed to a regular submission every week (7 days) and 21 days for the midterm prediction.

Working Group on Site Co-Location

G. Johnston, chair of the working group, was not able to participate in the IERS DB meeting but organised a meeting of his working group on Friday April 7, 2006 where presentations about current activities were given by Z. Altamimi “IGN Local Survey activities within the ITRF-PC”, J. Ray “Local Ties at the new BRFT Station” and J. Luck “Comparison of survey determined ties with SLR determined estimates”. All presentations and more information about the working group can be found under <http://www.iers.org/MainDisp.csl?pid=68-40>. In an open discussion the future status of this WG was discussed. Options include an IERS WG, IAG Service or sub-bureau of the ITRS Centre. G. Johnston will come back to this at the next IERS DB meeting.

New polar motion/UT1/nutation series from Earth Orientation Centre

D. Gambis demonstrated the new strategy for EOP determination. He explained that not only the software has been re-written but also the new nutation model IAU 2000 has been included. The daily solution is run automatically, the error estimates have been improved and the last 20 years can be analysed in one run. New approaches have been tried to combine LOD. ILRS and GPS solutions are used but there are still problems with the real-time UT1 determination using GPS LOD. D. Gambis explained the necessary steps to re-analyse the C04 series. For polar motion he proposed that the years 2000.0 to 2006.0 should be aligned to the ITRF 2005 to be consistent. The time span before 2000 might be extrapolated backwards with the linear drifts associated to EOP (ITRF2005). Further investigation is necessary here. UT1 and the nutation offsets will be treated as usual. For the ongoing analysis weekly global solutions based on CATREF (IGN software) can be produced with a delay of 4 weeks. The parameters can be station coordinates, polar motion, UT1 partially, and LOD using the space techniques SINEX solutions as input. Bulletin B would eventually be replaced by this global solution. To continue C04 for UT1 and nutation the VLBI intensive sessions and the nutation parameters are needed. An alternative method could be the use of DYNAMO (GRGS software), which would allow 6-hr EOP determination and a densified nutation solution using VLBI and GPS.

M. Rothacher offered the possibility to test most of the strategy within the IERS Combination Pilot Project (CPP).

C. Ma noted that when ITRF2005 is released the operational IERS EOP series have to be consistent with ITRF2005. However actual generation of EOP from SINEX combination needs to be handled differently and should be investigated within the CPP. Both the current method and the new combinations should run in parallel.

Z. Altamimi noted there is an urgent need for the “new” EOP series coming from the Earth Orientation Centre to ensure the consistency of EOPs after 2005. He didn’t support the idea to use DYNAMO because the programme system is not proven.

William Wooden expressed concern about the transition phase and the consequences for the Rapid Service/Prediction Centre.

Chopo Ma proposed that a change in offset and rate for the current operational series could be enough as a first step. The Earth Orientation Centre and the Rapid Service/Prediction Centre have to coordinate their actions and inform the users of the date of this realignment (action item). When available the new methods should be developed and tested within the CPP. The schedule for a transition to new EOP series has to be worked out between the two product centres taking into account the progress achieved within the CPP.

Working Group on Combination

Markus Rothacher gave a status report on what goals have been achieved to date, where are the deficits and what will be the next steps. Work related to combination has concentrated on the ITRF2005 and now should return to a focus on the pilot project. Who will participate in the CPP in the future must be confirmed. As a final vision for the CPP he developed the idea intra- / inter-technique combinations on a daily basis.

Ad-hoc Committee for leap second

Daniel Gambis gave a short overview about the ongoing discussion of the leap second. Last November at the ITU meeting the US representative of ITU brought in the proposal to freeze UT and suppress the leap second in the future. At the next ITU meeting in August this proposal will be evaluated. ITU sent a letter to various institutions including the IERS to ask their opinion. D. Gambis pointed out that the IAG in Cairns agreed to a resolution that there should be no change, i.e., UT would remain close to UT1. From the IAU perspective there is no problem to introduce the leap second as done in the past. The IERS Product Centres should respond to the ITU survey by themselves with a copy to the IERS Central Bureau.

Central Bureau

Bernd Richter gave a very short report about the activities. As stated in IERS Message 88 the ICRS Centre Report for 2001–2004 is available as Technical Note 34 in an electronic version. Printing will follow later this year. The IERS Annual Report 2004 was updated in some parts and will be printed also later this year. The IERS Data and Information System went public. The IERS has been represented several times, see items “Reports of the Unions, GGOS / GEO activities”. The preparation for the IERS workshop on geophysical fluids in Luxembourg Oct. 5–6, 2006 has been started.

Miscellaneous

Ron Noomen asked the IERS Directing Board for a letter to support laser reflectors on GNSS satellites.

Meeting No. 43

December 11, 2006, San Francisco Marriott Hotel, San Francisco, CA, USA

Introduction and approval of agenda

C. Boucher proposed to discuss the implications of the International Committee on Global Navigation Satellite Systems (ICG) but there was insufficient time. This item will be followed up by the Central Bureau and reported at the next IERS Directing Board meeting. The agenda was approved.

Formalities

C. Ma welcomed the new members E. Pavlis and J. Müller, who were elected by the ILRS as the new representatives at the IERS Directing Board. Furthermore C. Ma as chair of the IERS sent a letter to the Canadian government to express the dismay and disappointment of the IERS over the cessation of the Canadian geodetic VLBI program. Unfortunately, no response has been received yet.

ITRF 2005

The IERS Directing Board expressed its appreciation for the tremendous effort that went into the new realisation of the ITRF with its new input and combination strategies. This includes the ITRS Combination Centres as well as the Technique Services IDS, IGS, ILRS and IVS.

Z. Altamimi presented a description of the IGN process together with his understanding of the DGFI methods and gave some outline for the future process and realisation. He presented a critique of the DGFI concept for realising the ITRF.

In the following presentation H. Drewes described the DGFI strategy for the ITRF 2005 realisation. In a second talk H. Drewes tried to explain from his point of view the conceptual differences between the DGFI and IGN approaches. He emphasised that there is a significant difference in scale rate for SLR stations between the two solutions.

Z. Altamimi and H. Drewes discussed their differences in understanding about the use of Helmert transformation parameters in the combination process. M. Rothacher noted that at least for the intra-technique multi-year solutions both methods lead to almost identical results. M. Rothacher proposed that the local ties used, their weights, and the sites where velocities were set equal for different point realisations at the site should be summarized in a list. H. Drewes indicated that at some sites the vertical velocities were not equated in the DGFI combination, e.g., Wettzell. E. Pavlis demonstrated that the noise in the VLBI and SLR scale time series are at a similar level and that the variations of VLBI and SLR scale are similar in size. In various tests with SLR data the IGN and DGFI solutions performed equally except in scale. ILRS will add observations going back to 1976 to the weekly SINEX files. The ILRS requested a specific tailored ITRF2005 for SLR purposes with the scale only (without rate) to be reset. Z. Altamimi stated that a specific ITRF2005-SLR solution is available where the scale and its rate were applied in order to be fully consistent with the currently available routine ILRS time series. E. Pavlis described the evaluation procedure for EGM96 as example of a well-defined validation process. F. Lemoine reported that the ITRF 2005 is a slight improvement for DORIS. R. Ferland described how IGS is using ITRF 2005. IGS increased the number of core stations significantly. A. Nothnagel was not able to participate in the meeting and sent his point of view concerning ITRF 2005, C04 and UT1–UTC in a short memo.

New ITRF 200X

M. Rothacher presented a draft version of the future ITRF process. Not all in the presentation was based on full consensus of the three authors. Z. Altamimi stated that only a single solution for the next ITRF should be presented for evaluation. A workshop before releasing the next ITRF was proposed. N. Capitaine pointed out that it is not clear how the evaluation panel will make a decision. There was general agreement by the IERS DB that a better defined evaluation process is mandatory. C. Ma noted that this discussion is the beginning of the process for a new ITRF 200x. Sites with GPS co-located with other space geodetic techniques need to be brought into the IGS reanalysis because GPS provides the ties between VLBI and SLR. E. Pavlis noted that at a particular co-location site a technique could be weak although the local ties measurement is strong. G. Gendt indicated that 1 – 2 years would be sufficient for the IGS reanalysis.

New EOP series

D. Gambis described the new C04 time series. Although there had been discussions in a validation group, questions were raised about how often the new series should be updated and how past values in the time series might be affected. W. Wooden indicated that the proposed procedure would be a major change in the concept of C04 as the “gold” or “true” standard. The Earth Orientation Centre and the Rapid Service/Prediction Centre should not overlap functions. New products can be developed but should not be given existing names. There was general agreement by the IERS DB that a detailed written document should be prepared before the new C04 is released for general use and that additional validation should be done to mitigate any concerns before the IERS “officially” adopts the new C04 system. Also, sufficient lead time should be given for testing before the transition occurs.

W. Wooden gave a review of the improvements by the Rapid Service/Prediction Centre. ILRS analysis results are incorporated on Thursday; combined ILRS results are regularly produced on Wednesday. The Central Bureau should send out a message linked to the survey of prediction users planned by the Rapid Service/Prediction Centre in January 2007.

M. Rothacher proposed restarting the CPP (Combination Pilot Project) with the focus on producing rapid EOPs from technique service SINEX files. He proposed an informal meeting of the IERS Combination WG, IERS CPP and IERS CRCs on February 5, 2007 with the focus on combination of daily GPS rapid PM and VLBI intensive UT1.

Report and discussion on the IERS Workshop on Global Geophysical Fluids

T. van Dam reviewed the GGFC workshop held at the Grand Hyatt, San Francisco on December 5 and 6, 2006. Details (programme and presentations) are presented under <http://www.iers.org/MainDisp.csl?pid=66-1100113>. She noted various defects that have been found with GGFC data. ILRS offered to provide ongoing data for geo-centre variations and the University of Vienna is able to contribute its mapping function on a regular basis. The IERS Directing Board agreed that the GGFC chair will draft a plan for improving the GGFC data and in particular the SBL products to get more acceptance by the community.

Proposal for an IERS Working Group on the Second ICRF

R. Gaume presented the IERS / IVS Working Group on the Second Realisation of the ICRF and the corresponding IAU working group. The IERS Directing Board approved the IERS / IVS Working Group to be set up according the IERS rules. It was suggested that IAG should be involved in the approval of the next ICRF.

Report of IERS Working Group on Site Co-location

G. Johnston being excused, but he sent a report about the activity within the working group and the minutes of the latest working group meeting in Canberra on October 20, 2006.

Report of the Conventions update process

G. Petit presented the status of the ongoing update processes and stated that presently there is no agreement how to model core nutation. On September 20 and 21, 2007 the Conventions Centre will have a workshop at BIPM right after the Journées 2007 in Paris.

Report on GGOS and GEO

M. Rothacher gave a combined presentation about the activities in GGOS and GEO.

Important markers for GGOS are:

- Retreat in Oxnard, Ca., February 19 – 21, 2007,
- Session and meetings at the EGU in Vienna, Austria, April 15 – 20, 2007,
- Session and meetings at the IUGG in Perugia, Italy, July 2 – 11, 2007.

GEO activities are organised by the various committees, and the responsible IAG delegates will be invited. The 2007–2009 GEO work plan includes task AR-07-03 “Global Geodetic Reference Frames”. The next GEO summit will be held in Capetown, South Africa in November 2007.

In December 2007 a “Unified Analysis Workshop” is proposed to bring together the analysis groups of the various space geodesy techniques and the ITRS combination centres to discuss in detail the impact and problems of each technique focusing on the ITRF. The IERS is willing to be sponsor and organiser of this workshop.

Reports of the Unions (IAU/FAGS, IAG/IUGG)

N. Capitaine as IAU and FAGS representative summarised the main activities, resolutions and results of the 26th IAU General Assembly, Prague, Czech Republic, August 14 – 25, 2006 and the plans for reorganization of FAGS.

C. Wilson drew the attention to the forthcoming election of the IAG executive committee which includes the officers, heads of the commissions and important for the IERS the representatives of the IAG services. The nomination committee will contact the IERS Central Bureau.

Next IERS DB meeting

The next IERS Directing Board meeting will be held before the EGU in Vienna, Austria on Sunday, April 15, 2007.

Bernd Richter, Wolfgang R. Dick

3.2 Central Bureau

General activities

The IERS Central Bureau (CB), hosted and funded by Bundesamt für Kartographie and Geodäsie (BKG), organized and documented the IERS Directing Board (DB) Meetings No. 42, April 8, 2006, at Technical University Vienna, Austria, and No. 43, December 11, 2006, in San Francisco, USA. Between the meetings the CB coordinated the work of the DB.

Together with the GGFC, the CB prepared an IERS Workshop on Global Geophysical Fluids, held December 6–7, 2006, at Hotel Grand Hyatt in San Francisco, CA, USA. 21 specialists took part in this workshop. The presentations were published at the IERS web site. For a summary see Section 4.

The CB presented the activities of the IERS with oral and poster presentations at the Geotechnologien Statusseminar 2006 and the Geodetic Reference Frames GRF2006 Symposium. In March 2006 B. Richter took part in the FAGS council meeting in Paris and gave a report on the IERS activities.

IERS components maintain individually about 20 separate web sites. The central IERS site <www.iers.org>, established by the CB, gives access to all other sites, offers information on the structure of the IERS, its products and publications and provides contact addresses as well as general facts on Earth rotation studies. It contains also electronic versions of IERS publications, a list of meetings related to the work of the IERS, and an extended link list for IERS, Earth rotation in general and related fields. At the beginning of 2006, the web site was re-launched with a new layout and new organization (see below).Throughout 2006 the web site was regularly enlarged and updated.

The book "The International Celestial Reference System and Frame, ICRS Center Report for 2001–2004" (edited by Jean Souchay and Martine Feissel-Vernier) was published as IERS Technical Note No. 34 in online and printed forms. The IERS Annual Report 2004 appeared in printed form. The CB prepared also the IERS Annual Report 2005 for publication. Along with the reports of the IERS components, it contains information on the IERS compiled by the CB.

During the year 2006, 25 IERS Messages (Nos. 80 – 104) were edited and distributed. They include news from the IERS and of general type as well as announcements of conferences.

Address and subscription information has regularly been updated in the IERS user database. There were about 2500 users in 2006 with valid addresses who subscribed to IERS publications for e-mail and regular mail distribution.

Several questions from IERS users concerning IERS publications and products as well as Earth rotation and reference frames in general were answered or forwarded to other specialists.

IERS Data and Information System (DIS)

Since the end of 2005 the new dynamic and database-driven IERS DIS is running in operational mode. It is based on a LAMPP System, running on an Apache Web server, storing data in a MySQL database and presenting data and information via PHP. At the end of 2006 the LAMPP system was upgraded to a newer version, i.e. from Apache 1.x to 2.x, from MySQL 3.x to 5.x and from PHP 4.x to 5.x, because the newer versions get rid of several bugs, provide more options and are more stable.

The basic characteristics of the system, i.e. the usage of the eXtensible Markup Language (XML) as common technique to describe all data formats as well as the maintenance of ISO standardised metadata was already described in detail in the IERS Annual Report 2005. Because all IERS products and data are transformed into formats based on XML, the data can easily be integrated and combined and the same XML based tools can be applied on all data, like for example the IERS Plot Tool. The administration of product metadata allows to search for data with respect to content, time, location, etc. Considering the ISO 19115 standard *Geographic Information – Metadata*, the metadata can be easily distributed to so-called Meta Information Systems (MIS). MIS collect metadata from various sources, thus realizing an integrated search for data from various geo-sciences which will enlarge the users of the IERS products. In 2006 a test implementation phase was started, in order to distribute the metadata of some IERS products to the GeoPortal.Bund (<http://www.geoportal.bund.de>), an MIS to search for geo data in Germany. The Catalogue Service Web (CSW) interface of this Portal was adapted to the IERS metadata database, thus allowing to read the metadata of the IERS products and to display them within the GeoPortal.Bund Web interface.

The Plot Tool, designed in 2005 and described in the IERS Annual Report 2005, was implemented and evaluated. It consists of two main components: a Java based Plot Engine to render the plots and a PHP based user interface (Web pages) to configure the plots, to select between several plot configurations and their plot options and to invoke the Plot Engine. Since the user interface is build upon the same techniques as the IERS DIS and its Administration Tool – i.e. a LAMPP system – it can be integrated seamlessly into the existing system. The Plot Tool allows the users to visualise data from the various available products on the fly. If reasonable, datasets can be presented in one plot and compared to each other. The data for the plots are being extracted from the product versions by using their XML format descriptions. Likewise, the XML format description is being used by the administrator to define in beforehand which data from which products are available for a plot and which plot configurations are meaningful. The visualisation module provides all defined plot configurations to the user, who can choose a specific presentation from the available pre-defined configurations.

Currently the Plot Tool provides only a basic user interface which is not sophisticated enough for all external users and thus it has to be adapted especially for non expert users. However, the Plot Tool can already be used in the so called batch mode in order to create pre-defined plots automatically. The creation of such plots and their integration into the IERS web site will be realized in 2007.

Publications

Dick, W. R.; Richter, B.; Schwegmann, W.: The ICRS and the IERS Information System. In: R. Gaume, D. McCarthy, J. Souchay (eds.), The International Celestial Reference System, Maintenance and Future Realizations, Proceedings of IAU General Assembly XXV, Joint Discussion 16, Sydney, Australia, 22 July 2003. [Washington, D.C.: U.S. Naval Observatory, 2006], p. 154–157

Richter, B.; Schwegmann, W.: IERS Data and Information System. In: J. Flury, R. Rummel, C. Reigber, M. Rothacher, G. Boedeker, U. Schreiber (eds.), Observation of the Earth System from Space. Berlin, Heidelberg: Springer-Verlag, 2006, p. 321–332.

Bernd Richter, Wolfgang R. Dick, Wolfgang Schwegmann

3.3 Analysis Coordinator

Improving the IERS Products

One duty of the IERS Analysis Coordination is the steady improvement of the IERS products and the initiation of new types of products if required.

Concerning the steady improvement of the IERS products the following aspects were important during the year 2006:

- Availability of official daily / weekly products for each of the technique services
- Availability of long time series of these official products as an input to the ITRF computations
- Finalization of the ITRF2005
- Workshop on Global Geophysical Fluids

The first three topics are all strongly linked. The idea of having weekly (or daily in the case of VLBI) SINEX files as official products from each of the technique services available was already the basis for the IERS Combination Pilot Project (CPP) that started in 2004 (see previous IERS Annual Reports for more details). Only shortly later, the call for long time series was issued so that all these activities were bundled with the major goal to generate a new ITRF. As it is the first time that the ITRF is generated from time series of weekly or daily SINEX files including station positions and EOPs, the analyses and computations lasted until 2006, but by the end of the year, the new realization called ITRF2005 could be finalized (see Sections 3.6.1.1 and 3.6.1.2 of this volume). The results were presented by IGN and DGFI at the IAG Symposium on Geodetic Reference Frames (GRF2006), held at Munich, October 9–13, 2006.

The Workshop on Global Geophysical Fluids held at San Francisco aimed at a review of the products of the Special Bureaus dedicated to each type of geophysical fluids. The actual needs of the geodetic community and how these requests can be fulfilled have been discussed.

Concerning new types of IERS products, the routine generation of weekly inter-technique combination products has already been mentioned as one goal of the IERS CPP. Although technique-specific intra-technique solutions are produced on a routine basis, no institution is yet routinely generating corresponding inter-technique solutions, the final goal of the IERS CPP. We can imagine the following sequence of events:

- Once a year or every two years a new IERS200x is computed based on a consensus of new standards (models, parameterization, processing strategies, etc.) and based on completely reprocessed and recombined solutions of all techniques.

- Routine weekly intra-technique combined solutions should be produced with exactly the standards used for the most recent ITRF200x realization.
- Latency envisaged: ca. 2–3 weeks (after the combination of the intra-technique solutions); i.e. a reduction of the latency is necessary.
- Each new weekly solution has to be validated carefully concerning station problems.
- Open questions: will several Combination Centers produce these inter-technique solutions? Will there be a combination of the combination?

For the combination of the inter-technique solutions different approaches can be envisaged and should be tested with the SINEX files of the IERS CPP or the long time series generated as contributions for the ITRF2005. Let us mention three different strategies here as examples, ranging from rigorous to minimal:

- Strategy 1: “Complete and Rigorous”
- Strategy 2: “Minimal and Weekly”
- Strategy 3: “Semi-Rigorous”

Let us shortly describe the major characteristics of these solutions:

Strategy 1 (complete and rigorous)

Every week a full “ITRF/EOP” solution is produced including all old and the new weekly intra-technique combined SINEX files (comparable to the cumulative solution of the IGS). This solution is then a fully correct and rigorous combination using all available information. As parameters, site coordinates and velocities, geocenter, annual signals, jumps, EOPs should be estimated as done for the corresponding ITRF200x generation. The detection and monitoring of site problems is very important and necessary. Variance component estimation is possible or weights could be taken from the corresponding ITRF200x solution. Local ties may be introduced with their variance-covariance information. This complete solution is demanding in computer resources (memory, CPU time), but it can one-to-one be realized with the strategy developed for ITRF200x. The weights of the local ties may have to be adjusted when the number of weekly solutions increases significantly. As IERS products we then have fully updated time series of EOPs and an up-to-date set of site coordinates and velocities (new sites …), etc. on a weekly basis.

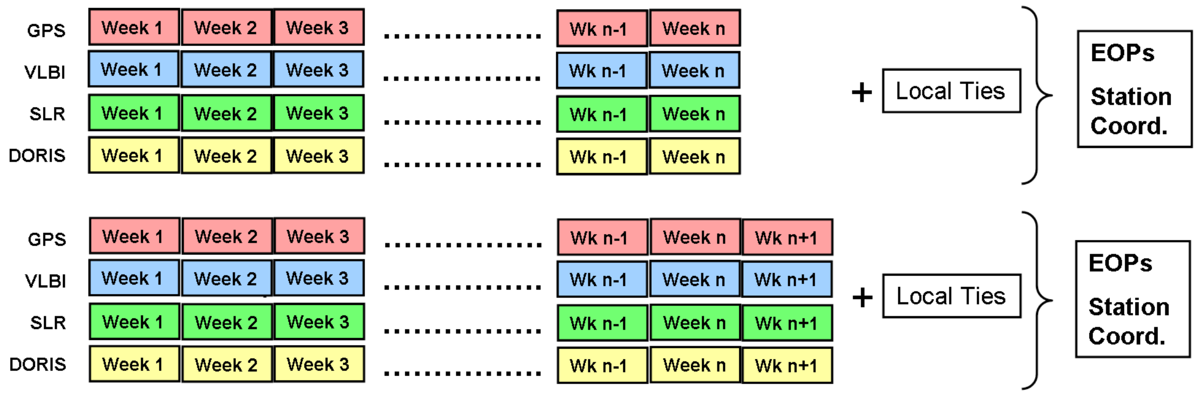


Fig. 1: Complete and rigorous inter-technique combination covering each week the full amount of data.

Strategy 2 (minimal and weekly)

Using this strategy, every week only the new weekly intra-technique combined SINEX files are processed to obtain the results for this new week. All information necessary for the combination (relative weights, local ties, datum, annual signals, etc.) are taken from the ITRF200x solution and are fixed to be compatible with ITRF200x. This solution type is certainly not a rigorous combination, but it is fast and efficient using almost no computer resources. The estimation of site velocities (and annual signals) is not possible and, therefore, coordinates of more recent sites will start to deviate after one year (quality of the velocities). It can be realized as soon as all the ITRF200x products are available. Due to the fact that the combination strategy is rather simple, other Combination Centers might join this effort. As IERS products we will obtain the most recent week of EOPs and site coordinates (resulting SINEX files are not to be used for further combinations). This strategy might be a way to go for rapid daily inter-technique combinations, but is probably sub-optimal for the weekly update cycle.

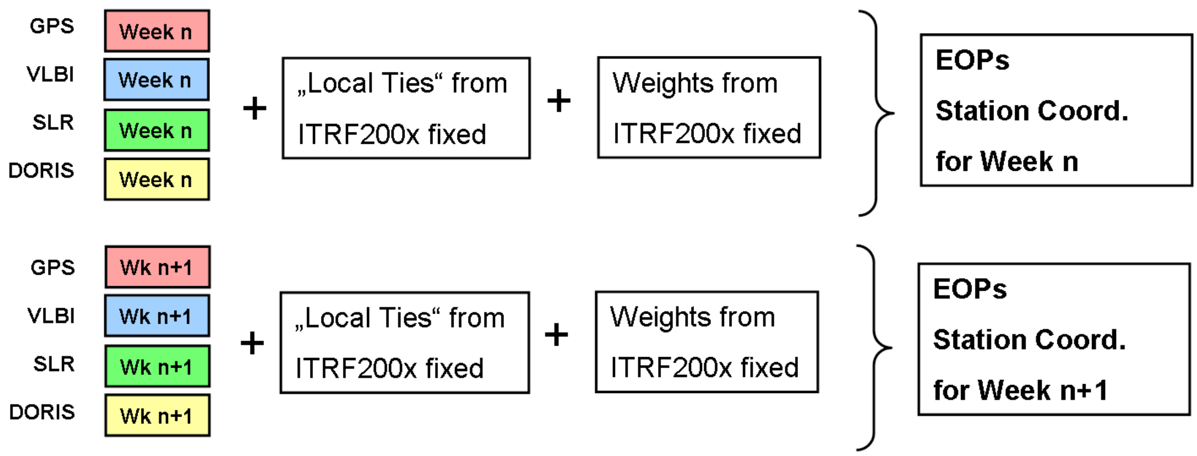


Fig. 2: Weekly inter-technique combination with a minimal effort.

Strategy 3 (semi-rigorous)

Technique services produce weekly solutions (SINEX) fully aligned to a technique-specific, ITRF200x-aligned multi-year solution (e.g., IGS: IGS05). The combination is done here as a pure stacking (no local ties, no additional datum) including weights. The consistency of the individual technique combined solutions is kept. It might take some time to realize such a strategy by the technique combination centers. Alternatively, the alignment could be done by the IERS CCs. As IERS products we will get the most recent week of EOPs and site coordinates and it is clear, that the resulting SINEX files are not to be used for further combinations.

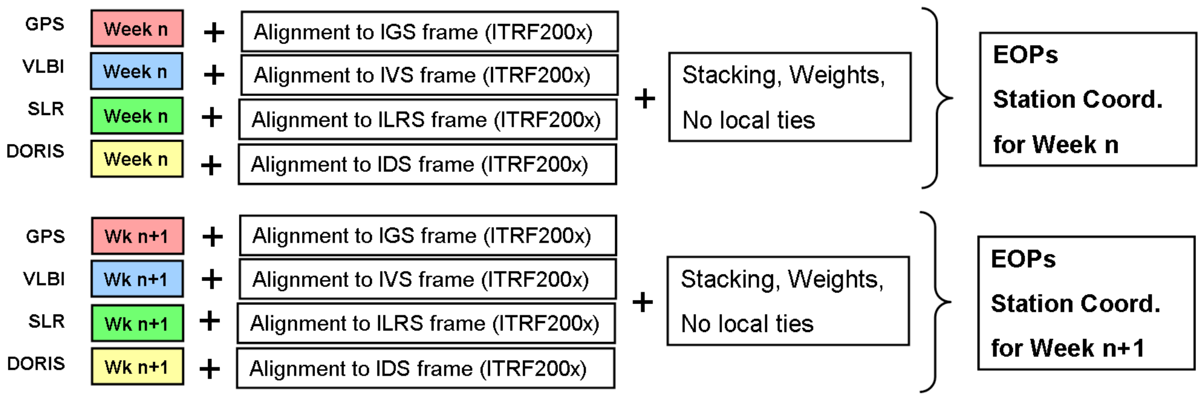


Fig. 3: Semi-rigorous combination, where the datum definition is taken from the reference frames of the individual techniques (as, e.g., IGS05 for the IGS realization of ITRF2005).

It is to be hoped that soon some of the institutions involved in combination work will start research on the best strategy to be used for weekly routine inter-technique solutions.

In addition to this weekly combined product that will have a latency of a few days, it is planned to provide a rapid daily product with very short latency. The main intention of this product is to have EOPs of high quality updated as soon as possible after the observations. Therefore, a combination of the VLBI intensive sessions and the rapid GPS solutions would be suitable for this product. A case study for such a combination procedure was done by Tesmer et al. (2006).

SINEX Version 2.02

The SINEX format description has been extended in some aspects (see IERS Messages No. 96 and 103):

1) New parameter types were added: nutation angles according to the new paradigm (IAU2000) and normalized spherical harmonic coefficients of the Earth's gravity field.

2) The inclusion of Galileo was defined regarding the station and satellite information for the specific frequencies. Thereby, the naming of the frequencies follows the RINEX 3.0 convention.

A full documentation and format description is available at <http://www.gfz-potsdam.de/pb1/IERS/sinex_v202.pdf>.

Special Meetings and Conference Sessions on Combination Issues

- IERS WG on Combination during EGU General Assembly 2006, Vienna/Austria
- EGU 2006, Vienna: Session G4 "Interactions between the three pillars of space geodesy: surface geometry, Earth rotation and the gravity field", chaired by M. Rothacher and H. Drewes
- GGOS Workshop, 08–09 October, 2006, Munich
- IAG Symposium on Geodetic Reference Frames (GRF2006), 09–13 October, 2006, Munich: Session "Combination of Space-Techniques", chaired by M. Rothacher and D. Angermann
- IERS Workshop on Global Geophysical Fluids, 06–07 December, 2006, San Francisco

Reference

Tesmer V., Thaller D., Steigenberger P., Rothacher M., Krügel M. (2006): Can low-latency UT1 estimates be improved by combining VLBI intensive and daily GPS sessions? Presented at EGU General Assembly 2006, Vienna

Markus Rothacher, Daniela Thaller

3.4 Technique Centres

3.4.1 International GNSS Service (IGS)

General

From its mission statement, the IGS is committed to provide the highest quality GPS+GLONASS observation data and products, openly and readily available to all user communities, as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multidisciplinary applications, and education. The IGS products support scientific objectives including realization of the International Terrestrial Reference Frame (ITRF) and its easy global accessibility, monitoring deformation of the solid Earth, monitoring Earth rotation, monitoring variations in the hydrosphere (sea level, ice-sheets, etc.), satellite orbit determination, ionosphere monitoring, climatological research, and time and frequency transfer. Table 1 gives an overview of the estimated quality of the IGS core products at the end of 2006.

Table 1: Quality of the IGS Core Products as of December 2007 (for details and further products see <http://igscb.jpl.nasa.gov/components/prods.html>)

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

Tracking network & station issues

In 2006, 10 IGS sites were decommissioned and 12 sites were added to the network, bringing the total at the close of the year to 380 sites. A subset of the network provides meteorological data, and more than 200 stations provide data hourly in addition to daily. Another subnetwork provides data at a 1-second sampling interval in addition to the usual 30-second data type. The station data and IGS products are available freely to all users from 4 global data centers and additional regional and operational data centers.

Analysis Issues

The IGS Analysis Centers (AC) have steadily improved their precision/consistency for the IGS Final and Rapid products (see Fig. 2 for the orbits). The orbit agreement is now at a level of 2 cm for the best ACs and the combined IGS Rapid and Final orbits agree better than 1 cm.

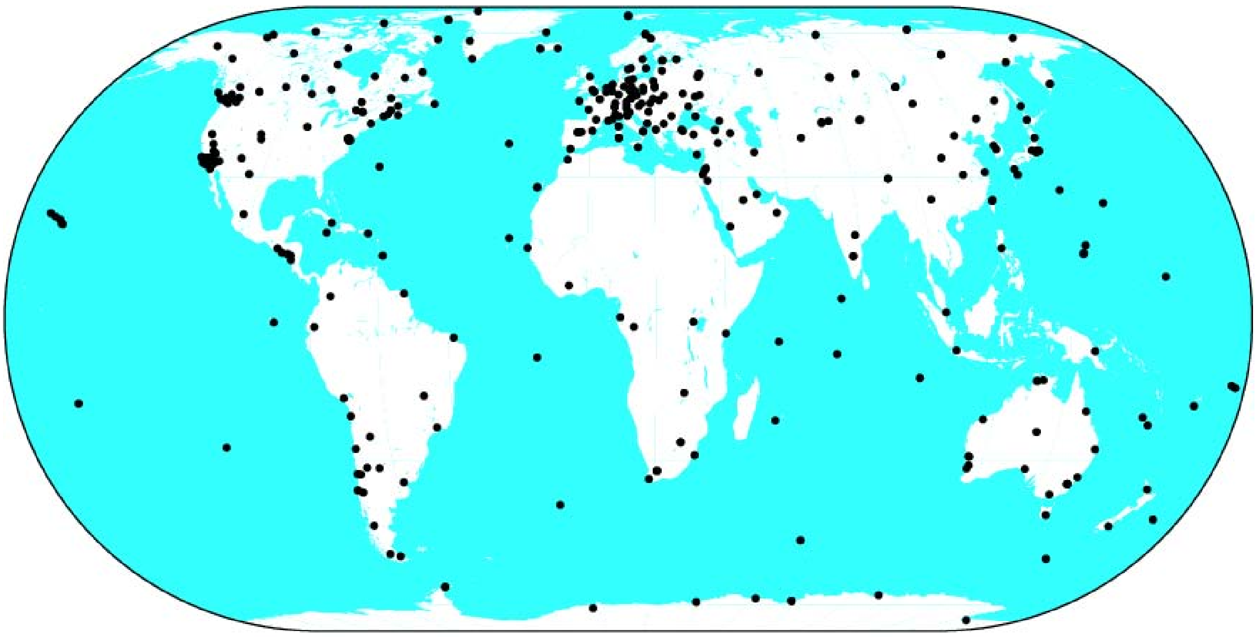


Fig. 1: IGS tracking network

Four ACs are contributing with GLONASS products based on microwave data – BKG, COD, ESA, IAC – and MCC with products based on SLR data. The SLR solution is used for comparison only. COD is the only AC analyzing combined GPS and GLONASS data in a rigorous way. The consistency of the GLONASS Final orbits is at a level of 5 to 10 cm.

Three ACs (COD, JPL, MIT) are providing clock solutions with a 30 s sampling rate. Since December 2006 (GPS week 1406) combined clock products are provided with a sampling rate of 30 s in addition to the usual 5-min products (names: *.clk; *.clk_30s).

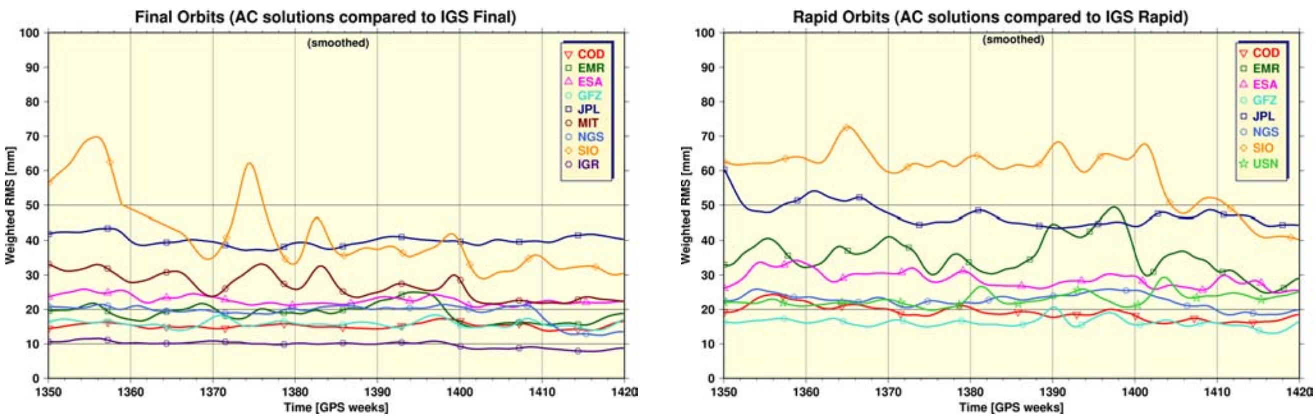


Fig. 2: Weighted RMS differences of all AC's (and IGS Rapid) orbits to the IGS Final (left) respectively IGS Rapid (right) combined orbits.

Switch to new absolute antenna models

To prepare for the introduction of the new absolute antenna model for the GNSS receivers and satellites the IGS Final products were generated with the new model in parallel to the routine products based on the relative antenna models. The goal was (1) to test the implementation in the software packages, (2) to test the effects on the IGS products and (3) to generate a new compatible reference frame IGc00. Comparisons showed a high quality of the parallel results and no significant biases, except of those in station positions and troposphere parameters which are directly connected to the new antenna models. Comparisons of the new satellite antenna model, which was derived from a mean of TUM and GFZ results using 11 years of data, to estimates from COD using one year of data showed no significant discrepancies, and so COD's antenna patterns for the GLONASS satellites were added to the new model, which completed the APCV model.

The IGS satellite antenna model was compared to the JPL model, which is derived fully independent from GRACE data. The characteristics of block specific antenna phase center variations are in a reasonable agreement. However, there exists an overall bias of 90 cm for the JPL satellite antenna z-offsets, the reason for that is not clear at the moment and is under investigation.

The IGS switched to the new antenna model after the release of the ITRF2005 in November 2006 (GPS week 1400). For the new IGS realization of the ITRF2005, the IGS05, differences between the absolute and the relative antenna models, obtained by the parallel products, were applied to the IGS station positions.

Network Combination

At the end of 2006, the IGS reference frame realization was updated including the following three aspects: 1) the switch from relative to absolute phase center, 2) the update from the realization ITRF2000 to ITRF2005, and 3) the update of the station selection for the realization. The effect of the antenna phase center change affects mainly the height component, which maps into the estimated scale offset. This effect in shown in Figure 3, where the AC's weekly average scale bias for about one year before and after the reference frame realization update is shown. The average bias goes from about +3.0 ppb to about –0.5 ppb. The nominal number of stations selected also went from 99 to 132.

The consistency of the AC's weekly solutions with respect to the IGS weekly combined is generally at the 1 to 3 mm in the horizontal components and 3 to 4 mm for the height component. Similarly, when the AC's weekly solutions are compared to the IGS cumulative solution, the consistency is at the 2 to 4 mm in the horizontal components and 4 to 6 mm in the vertical component. For the pole position and pole rate, the consistency is about 0.03 mas and 0.20 mas/d. The apparent geocenter consistency is 5 to 10 mm for the X and Y components, and 10 to 20 mm for the Z component.

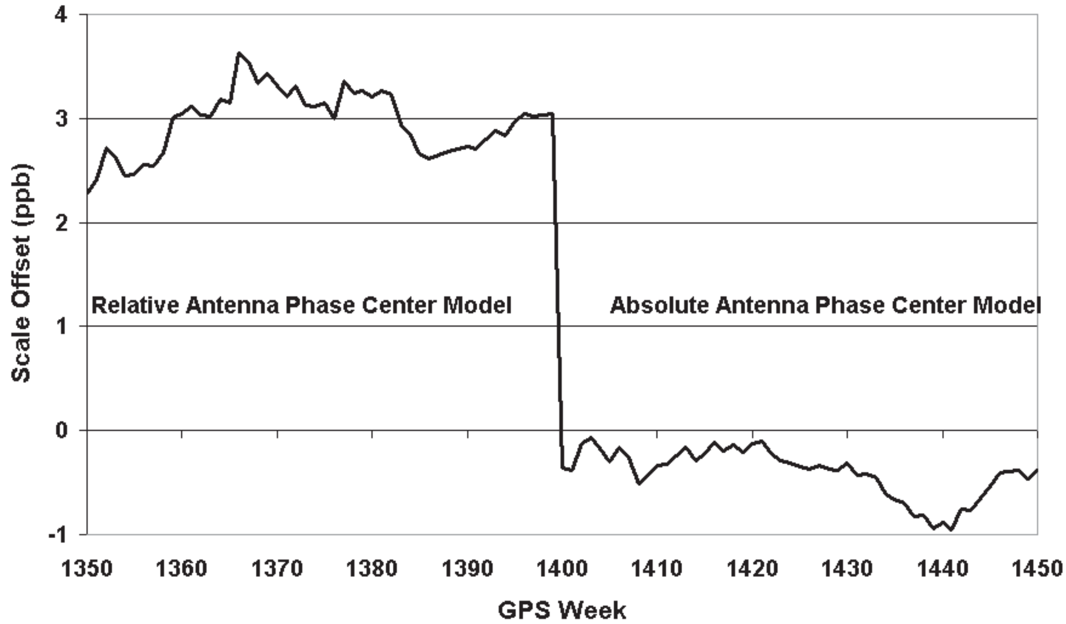


Fig. 3: Weighted average AC's scale offset with respect to the IGS realization of ITRF before and after (wk 1400) the reference frame realization change.

IGS reprocessing activity

As contribution to the next realization of the ITRF, the IGS is planning for a reprocessing of all historical data since 1994. The reprocessing will solve the problem of inconsistencies in the existing IGS station time series caused by many model and parameter changes in the past, especially by the introduction of the new absolute antenna model.

Summary

In 2006, as in the previous years, the IGS contributed significantly to the IERS activities like maintenance and extension of the International Reference Frame and provision of highly-accurate, daily-sampled Earth Rotation Parameters. The quality of the IGS products has further improved. The IGS has finished the transition from the relative to the absolute antenna models and is preparing for the reprocessing of historical IGS data. For more detailed information on further IGS activities visit the web site at the Central Bureau at JPL (<http://igscb.jpl.nasa.gov>) or the Analysis Coordinator web pages at GFZ (<http://www.gfz-potsdam.de/igsacc>).

Gerd Gendt, Angelyn Moore, Remi Ferland

3.4.2 International Laser Ranging Service (ILRS)

Introduction

The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of SLR/LLR missions, technique development, network operations, data analysis and scientific interpretation. The following summarizes the status and developments in 2006.

Network

The network of SLR/LLR stations, under the aegis of the ILRS, has been subject to change over the years. From a technical perspective, the quality of the observations has improved drastically during the past decade. At this moment, the single-shot precision of an average station is better than 10 mm (the best stations go well below that number). Also, the absolute quality of the individual observations is at the 10 mm level, with a significant number of stations doing better. The geometry of the SLR network has been a point of concern over the years. However, as of 2006 the layout of the network has improved (cf. Figure 1), in part due to the reinstatement of some key-sites that were shut down in 2004. Although the network has been dominated traditionally by stations in the Northern Hemisphere, the Southern Hemisphere now contains a number of high-quality stations, that have come online recently or that have developed and proven themselves over the past few years. In French Polynesia, Tahiti is slowly coming back online; in South America, Arequipa, Peru has returned, whereas Concepcion and San Juan are in operational service; in South Africa, Hartebeesthoek has proven

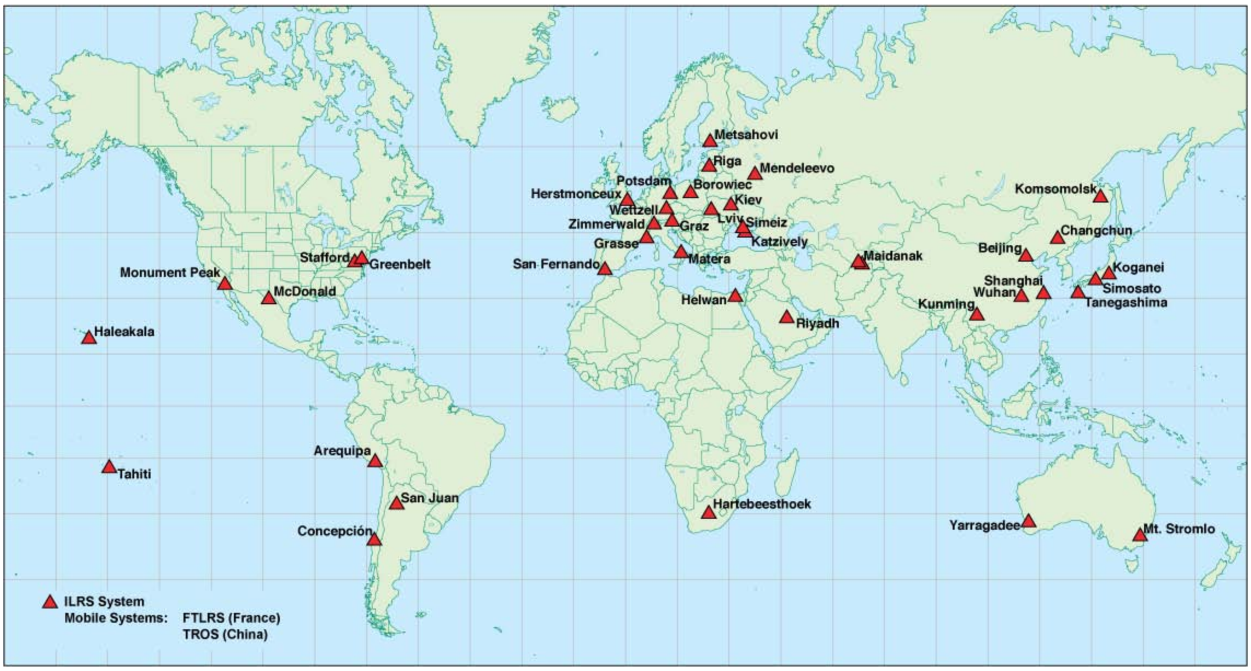


Fig. 1: The global network of SLR stations (status early 2007).

itself to be a highly reliable, top-quality, productive station; and in Australia the Mt. Stromlo station is a role model for modern, autonomous operations. The contributions from stations in the Southern Hemisphere are of course complemented by the activities of Yarragadee, on the West coast of Australia, which has been the number one station in the network on many different aspects for a long time now. Graz has continued operations with the first 2 kHz system of the network, providing impressive "pictures" of the reflector arrays on geodetic satellites like the two LAGEOS. NASA's next generation SLR system (formerly known as SLR2000) is in the final stages of development, and it is expected to reach the production line by 2008. Several other stations are also looking into acquiring high repetition systems (e.g. Herstmonceux, UK, Zimmerwald, Switzerland). Statistics of the data collected during the calendar year 2006 are summarized in Table 1, in terms of pass segments. For each of the contributing stations the tracked passes are broken down in three categories as far as the tracked targets: Low Earth Orbiters (LEO), the two LAGEOS satellites, and the High Earth Orbiters (HEO).

Among the more than 30 ILRS observatories, there are only a few sites that are technically equipped to carry out Lunar Laser Ranging (LLR) to the Moon (Figure 2). The McDonald Observatory in Texas, USA and Observatoire de la Côte d' Azur, France are the only currently operational LLR sites achieving a typical range precision of 18–25 mm. The latter is actually undergoing renovation since late 2004, which leaves only one site currently operational over the

Fig. 2: The ILRS stations with lunar capability (status early 2007).

Table 1: ILRS Network Tracking Statistics for 2006

		Number of Passes			
Site Name	**Sta.**	**LEO**	**LAGEOS**	**HEO**	**Total**
Arequipa	7403	257	37	0	294
Beijing	7249	1,338	178	91	1,607
Borowiec	7811	695	99	4	798
Changchun	7237	3,309	429	340	4,078
Concepcion	7405	1,202	591	72	1,865
Graz	7839	5,095	862	528	6,485
Greenbelt	7105	1,807	271	103	2,181
Greenbelt	7130	75	27	0	102
Haleakala	7119	130	24	0	154
Hartebeesthoek	7501	2,604	724	210	3,538
Helwan	7831	18	0	0	18
Herstmonceux	7840	3,548	930	384	4,862
Katzively	1893	671	80	27	778
Koganei	7308	228	63	16	307
Lviv	1831	47	0	0	47
Maidanak	1864	739	207	229	1,175
Matera	7941	2,680	874	193	3,747
McDonald	7080	1,115	373	334	1,822
Monument Peak	7110	4,239	899	305	5,443
Mount Stromlo	7825	5,050	1,433	634	7,117
Potsdam	7841	2,077	308	0	2,385
Riga	1884	1,056	98	8	1,162
Riyadh	7832	3,978	979	754	5,711
San Fernando	7824	1,784	261	0	2,045
San Juan	7406	3,846	1,134	882	5,862
Shanghai	7821	1,217	105	7	1,329
Simeiz	1873	433	66	2	501
Simosato	7838	1,887	442	7	2,336
Tahiti	7124	541	154	0	695
Tanegashima	7358	228	31	25	284
Wettzell	8834	4,775	984	485	6,244
Yaragadee	7090	8,999	2,044	1,330	12,373
Zimmerwald	7810	5,175	1,181	850	7,206
Totals:	33 stations	70,843	15,888	7,820	94,551

past two years. A new site with lunar capability has been built at the Apache Point Observatory, New Mexico, USA, equipped with a 3.5 m telescope. This station, called APOLLO, is designed for mm accuracy ranging. A first set of ~70 normal points taken over April to December 2006, was made available recently. The data look very promising.

The Australian station at Mt. Stromlo is expected to join this group in the future, and there are plans for establishing a lunar capability at the South African site of Hartebeesthoek, once there is a new

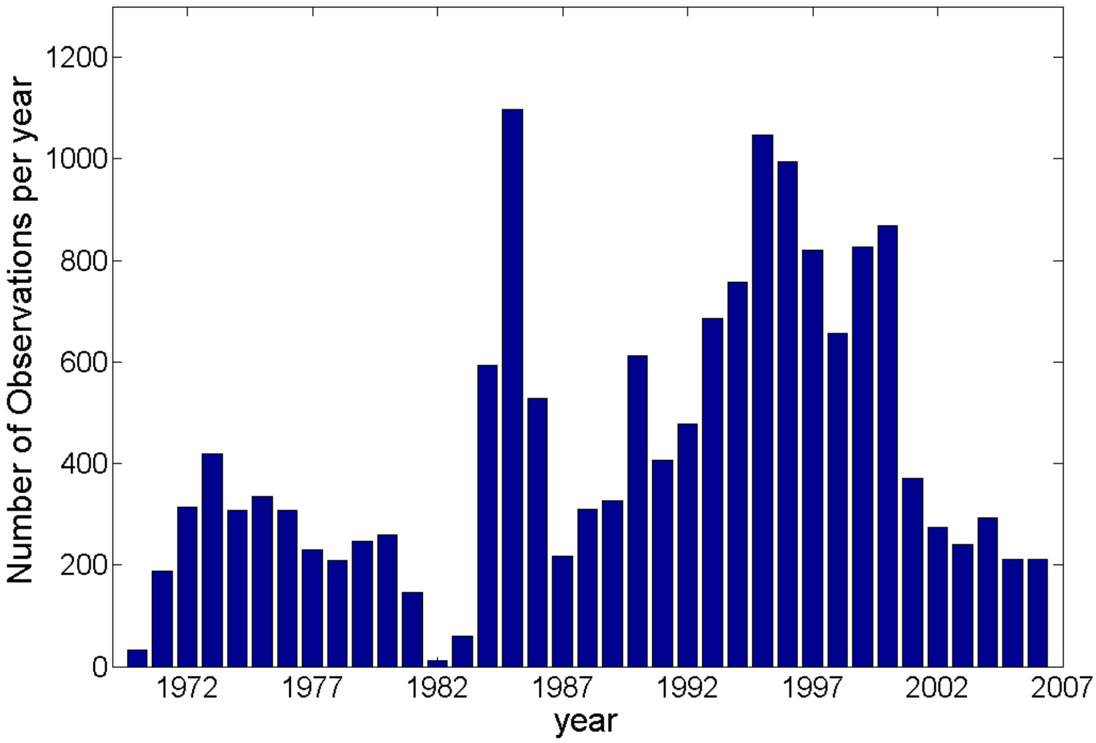


Fig. 3: The currently available LLR data set (status early 2007).

telescope installed. Today, the results from LLR are considered among the most important science return of the Apollo era. The lunar laser ranging experiment has continuously provided range data for more than 37 years, about 15800 normal points, (Figure 3).

The main scientific contributions of LLR are the determination of a host of parameters describing the lunar ephemeris, lunar physics, parameters associated with the Moon's interior, various reference frames, dynamics of the Earth-Moon system, as well as the verification of metric theories of gravity and gravitational physics, such as the equivalence principle or temporal variation of the gravitational constant. Even with current technology, LLR is an extremely challenging measurement task. For more details about the ILRS network, see the ILRS Annual Report 2005-2006: <http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/ilrsreport_2005.html>

Missions

In 2006, a total of ~30 satellites (including the Moon) were being tracked by laser (Figure 4). In late 2005, three new GLONASS s/c were placed in orbit: GLONASS-98, -99 and -100. On December 28, 2005, the first test satellite of the future European satellite navigation system Galileo: GIOVE-A, was also launched. In 2006, three more GLONASS s/c were placed in orbit: GLONASS-101, -102, and -103. The emphasis of these new missions is on navigation, SLR however is still recognized as a failsafe, proven POD technique and almost all navigation constellations plan to carry retroreflectors. The ILRS devoted considerable effort and resources during 2006 to develop a standardized retrorefrector design for such missions, in an attempt to improve data quality in the future and ensure adequate tracking for these missions. In December of 2006, three more satellites were launched successfully: JAXA's geostationary ETS-8, an experimental communications, timing and positioning satellite, and Naval Research Lab's (NRL) ANDE-RR, a pair of spherical LEO s/c to support atmospheric density studies and radar calibration. All spacecraft, including the newcomers, are regularly tracked, following a set of dynamically adjusted priorities depending on mission and science demands.

It is noteworthy that two downward-looking satellites, the 2006-launched ALOS, and ICESat, challenged the SLR network with several special requirements (any interference between the laser signal and the instrumentation is to be avoided). Many stations

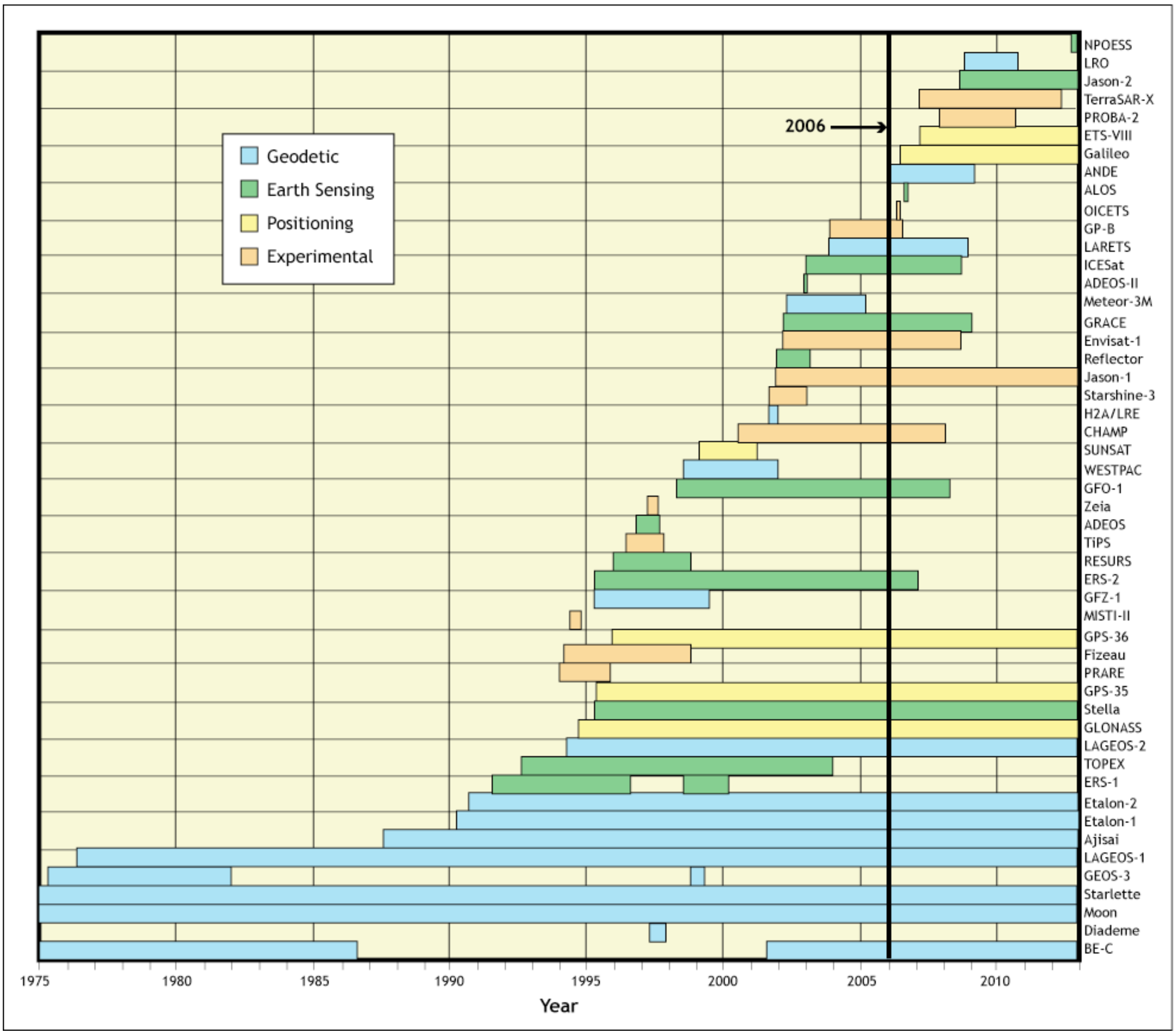


Fig. 4: The currently tracked SLR missions (status early 2007).

responded quickly and carefully to implement special, automated, real-time procedures to ensure safe tracking of these satellites. Tracking of these targets continued very successfully during 2006, resulting in an impressive record of observational passes on both targets.

Analysis and science

SLR provides an extremely valuable and unique tool to relate (the center-of-mass of) satellites to reference points on Earth's surface with unprecedented absolute accuracy: sub-centimeter at present, for about a dozen core sites. Recognizing the importance of this work, ILRS has organized and coordinated its analysis efforts through an Analysis Working Group (AWG). By late 2006, the AWG comprised of seven Analysis Centers (ACs), two Combination Centers (CCs) and several Associate Analysis Centers (AACs). The seven ACs are located at different institutes around the world: ASI/Italy, BKG/Germany, DGFI/Germany, GA/Australia, GFZ/Germany, JCET/USA and NSGF/UK. ASI (primary) and DGFI (backup) are the two CCs responsible with the combination of the contributions of the ACs into a single official ILRS product, following quality checks of the individual contributions and a thorough evaluation of the result. The majority of the AACs focus on restricted data sets, usually associated with a particular mission or world region. A number of

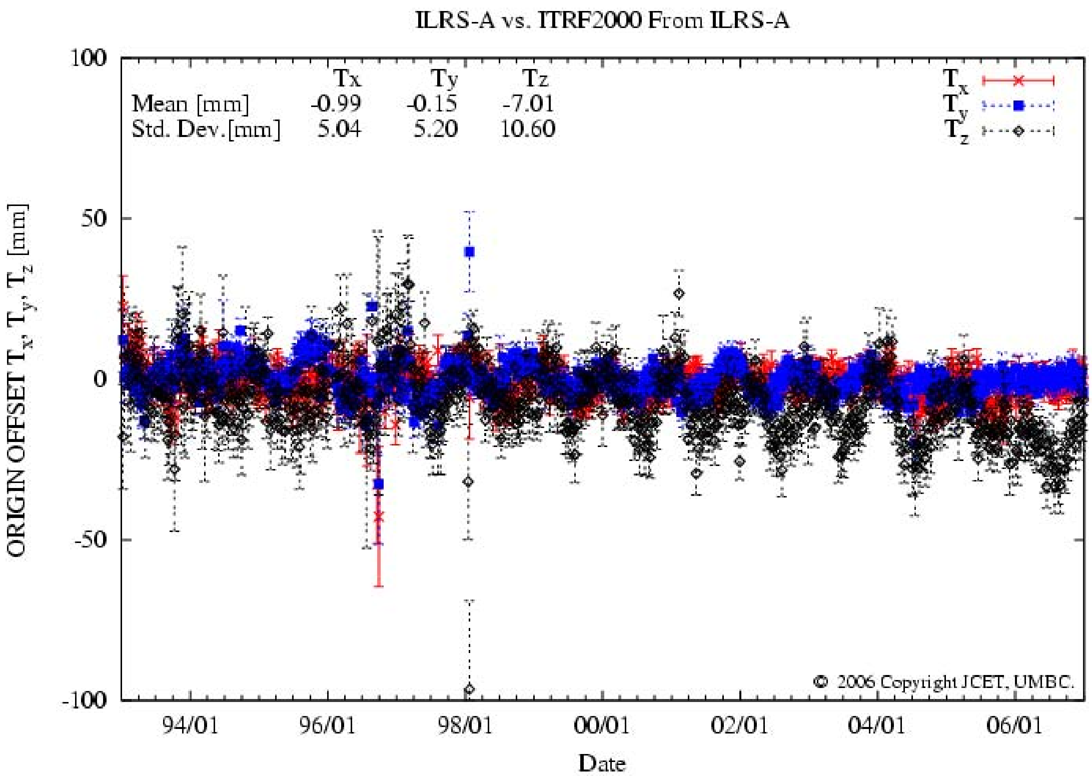


Fig. 5: Time-series of weekly solutions' origin offsets in X, Y, and Z, with respect to the ITRF2000 origin (proxy for "geocenter" variations) as observed by SLR (1993.0 – 2007.0).

them offer a quality control service for the entire network yield on a weekly basis.

During 2006, ILRS continued improving the models and procedures of the range data collected from the ILRS network. A new atmospheric delay correction model was adopted [Mendes and Pavlis, 2004], which was also adopted by IERS as part of the IERS Conventions. A major effort in assessing current as well as historical data biases at all of the tracking sites netted a wealth of information that has now become part of the standard information data set used in any reanalysis of the data. One such cycle was completed in late 2006, however, it was later discovered that due to the existence of additional engineering biases at a number of key sites, the reanalysis must be repeated in 2007. The SLR observations find their way into many cutting-edge science studies: reference frames (origin and scale), crustal deformation (relative motions), long wavelength static and time varying gravity field (direct inversion and/or calibration of solutions derived with other techniques), oceanography (sea-level change, tides), earth rotation (observation of relevant parameters), orbital mechanics (satellite motion), and fundamental physics (gravitational theory tests), to name a few. A number of these aspects will be highlighted below.

Some of the ILRS analysis products are of particular interest to IERS, either as input to Earth Orientation Parameter (EOPs) predictions or the development of the ITRF. In particular, SLR plays a uniquely important role in the definition of the origin of the ITRF and its scale.

The laser technique provides unique information on the exact location of the Earth's geocenter with respect to the tracking network (Figure 5) and along with VLBI, its absolute scale (Figure 6). Figures 5 and 6 display strong seasonal effects, but systematic effects are absent, except for a dip in Tz during 2006 (result of a known by now bias), and the trend in Tz (~ –1.8 mm/y), which is an error in ITRF2000 rather than in the current analysis. The root-mean-square (RMS) of the weekly X-Y-Z offsets and Δ-scale is 5.0 mm, 5.2 mm, 10.6 mm and 0.68 ppb, respectively, for the fourteen-year period. The same statistics for the more recent, 2006 period alone, are: 2.8 mm, 2.2 mm, 6.5 mm and 0.51 ppb, indicating the steady improvement of analysis products with time.

The ILRS' AWG maintains since 2003 the above time-series of weekly solutions for station coordinates and EOPs: x-pole and y-pole and excess Length of Day (LOD). These solutions are based on SLR data taken on the satellites LAGEOS-1, LAGEOS-2, Etalon-1 and Etalon-2. The organization (of generating these solutions) is such that the backup CC institute is able to take over the role of the primary institute at any time. The combinations were generated without interruptions during all of 2006 on a weekly basis, and were

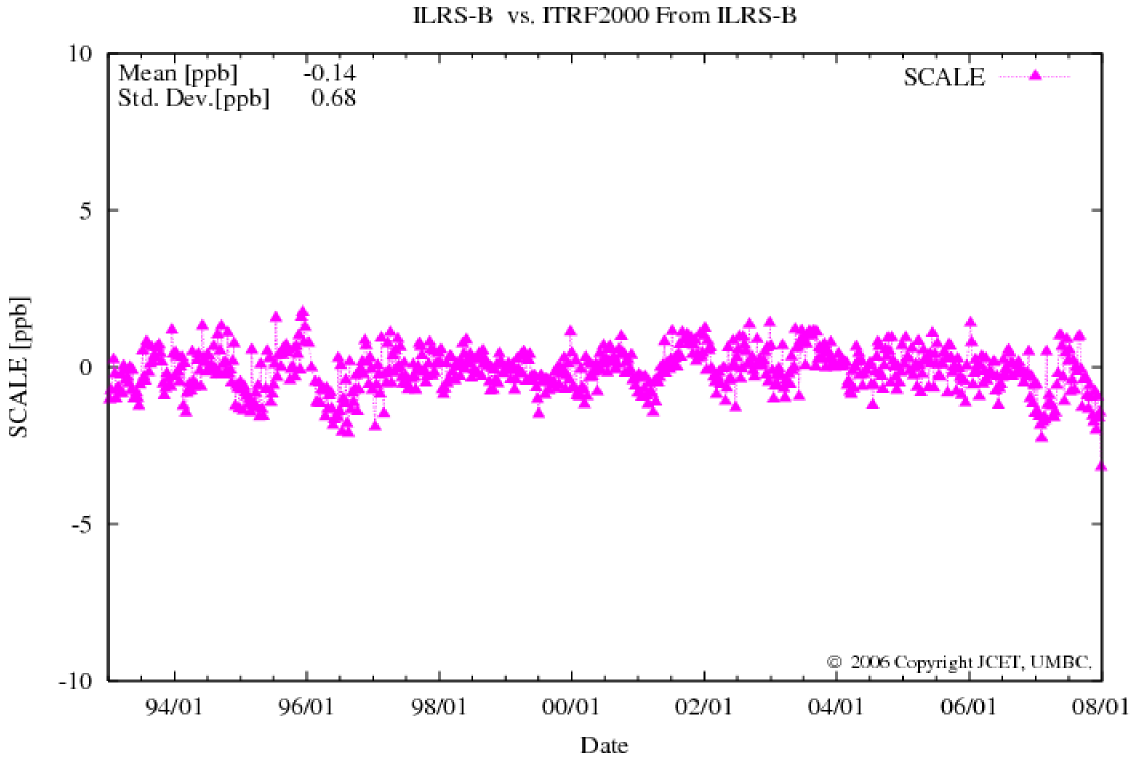


Fig. 6: Time-series of weekly solutions' difference in global scale from ITRF2000 as observed by SLR (1993.0 – 2008.0).

available to IERS every Wednesday evening (UTC). From the "operational" point of view, the combination solutions are used for a variety of purposes: the IERS Combination Pilot Project, the IERS/NEOS Bulletin A, etc. From a less frequently updated product, they were vital in the development of the new ITRF: the ITRF2005 solution, which was based on input from all four geodetic services.

The release of the preliminary ITRF2005P in mid-2006 forced ILRS to spend a significant amount of time and resources to reveal the reasons behind a seemingly significant (~ 1 ppb) scale difference between SLR and VLBI, uncovered during its development. Although SLR was still defining the origin of ITRF2005, it was excluded from the definition of global scale, which was defined entirely by VLBI in ITRF2005. The reasoning that led to this decision is a prime example that consistency is a poor measure of accuracy (biased results can be extremely consistent, though not accurate at all!). As of writing of this Annual Report (late 2007), it is now almost a year since it was discovered that the increased scale discrepancy between the SLR and VLBI contributions were due to an incorrect mean pole tide implementation in some of the VLBI AC contributions (Fig. 7). The incorrect scale of ITRF2005, which is inconsistent with POD efforts, required the development of a "hybrid" version of the ITRF2005, which is scaled back to agree with SLR-implied scale. This was called "ITRF2005 SLR re-scaled", to avoid confusing it with the original.

To improve the strength, value and reliability of its contribution to future ITRFs, the ILRS has started an effort to extend the time-series of such solutions, and by the end of 2006 it was able to deliver preliminary solutions for the period from September 1983 onwards, the onset of the so-called MERIT campaign ("Monitor Earth Rotation and Intercomparison of Techniques"). With the latest data (since 1993) being reanalyzed with improved models, it was decided to repeat the historical data analysis as well. It is thus expected that by the end of 2007, a new, completely and consistently reanalyzed series of official ILRS products will be available to IERS and the broader community, spanning at least the period September 1983 to end of 2007. However, recognizing the reduced number of satellites available (only LAGEOS), the geometry of the network, the quality of the observations and other aspects, the historical data reanalysis cannot be expected to result in data products that are of similar quality and resolution as what is being obtained from contemporary SLR observations. Nevertheless, this analysis effort

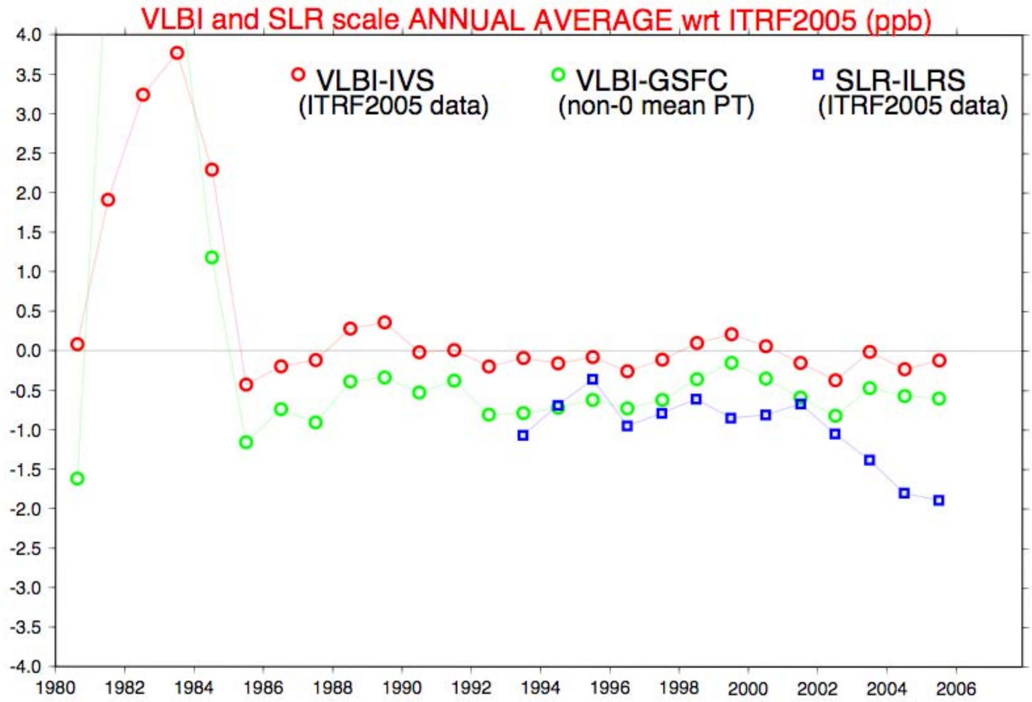


Fig. 7: Annual SLR-VLBI global scale differences with the original IVS contribution to ITRF2005 and one (VLBI-GSFC) using the correct mean Pole Tide formulation. The last 2-3 points of the SLR series indicate a trend, which however is associated with a significant change in network geometry and an erroneous bias application. (courtesy Z. Altamimi/IGN and D. MacMillan/GSFC).

will extend the time-span to 20+ years, and will provide valuable information on some of the most crucial elements of (understanding and describing) System Earth. The weekly products are evaluated during their combination and the results are archived and graphed each week by the JCET AC. Reports for the past weeks as well as the results for the current week for each of the contributing ACs and CCs are available to all via the World Wide Web at <http://geodesy.jcet.umbc.edu/ILRS_QCQA/>.

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3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2006, 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 January 2006 IVS held its fourth General Meeting in Concepción, Chile. Two IVS Directing Board meetings were held, one in January at the University of Concepción, Concepción, Chile, and the other in September at Haystack Observatory, Westford, MA, USA. IVS published its 2005 Annual Report in April 2006, the proceedings volume of the fourth General Meeting in July 2006, and three newsletter issues which keep the community informed about IVS activities. A joint IERS/IVS Working Group on the Second Realization of the ICRF, chaired by Chopo Ma, was created and was tasked with generating ICRF-2 from VLBI observations of extragalactic radio sources. The goal is to present the second ICRF to relevant authoritative bodies, e.g. IERS and IVS, and submit the revised ICRF to the IAU Division I Working Group on the Second Realization of the ICRF for adoption at the 2009 IAU General Assembly.

In 2006, IVS had to face two events that had an impact on the service products. First, the Network Station at Gilmore Creek discontinued its VLBI operations in January 2006 and the telescope—located in Fairbanks, Alaska—was mothballed for an undetermined period of time. The second event was the cessation of the Canadian VLBI operations by Natural Resources Canada in October 2006. In both events, various reasons contributed to the termination of the observations; however, the costs for required upgrades of the worn-out telescopes played a major role in both cases. Today's VLBI network is not sufficiently robust to simply compensate such events without an impact on the final products. Due to the location on the North American continent, the "lost" stations have been of extreme importance to the IVS and, accordingly, their contribution to the IVS observing program was significant. The influence on the product quality could be mitigated to some extent with stations that came online recently such as Zelenchukskaya, Russia.

Network Stations

A total of 1124 station days were used in 174 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.5 days per week, similar to previous years. The major observing programs during 2006 were:

IVS-R1, IVS-R4

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

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

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

IVS-E3 Monthly sessions using the Canadian S2 technology, coordinated by Natural Resources, Canada, designed to measure EOP and monitor TRF. Following the cessation of VLBI operations in Canada, the series was discontinued in September 2006.

IVS-CRF, IVS-CRD The Celestial Reference Frame (CRF) sessions and the CRF deep-south (CRD) sessions, both coordinated by the U.S. Naval Observatory, provide astrometric observations that are useful in improving the current CRF and in extending the CRF by observing "new" sources. Fifteen sessions were observed for the maintenance of the ICRF in 2006 primarily in the southern hemisphere. Nine of them were scheduled with emphasis on the far southern hemisphere (CRD).

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

Europe The European geodetic network, coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, continued with six sessions in 2006.

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

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had 12 sessions. These sessions included the dedicated 32-m dish at Tsukuba and are designed to monitor the domestic network within the ITRF.

IVS-R&D Ten sessions were observed in 2006 using Gbit/s recording rates to demonstrate the highest data rate available today.

The Network Coordinator's data base of station performance showed a data loss of 13.6%, slightly better (1%) compared to 2005. The most significant causes of data loss were receiver problems (21%), antenna reliability (19%), data acquisition system problems (16%), and RFI (12%). The RFI contribution has roughly doubled from the previous year, possibly due to more uniformity in attributing amplitude fluctuations to this cause.

Correlators

The correlators at Haystack Observatory (USA), the U.S. Naval Observatory (USA), and at Max-Planck-Institute for Radioastronomy (Germany) further increased their efficiency in processing data recorded on Mark 5 disk media. Several 24-hour sessions can now be correlated in less than a day. The correlator at MPIfR Bonn was connected at 1 Gbps in the later part of 2006. This connection will allow data to be transferred directly from connected network stations to the MPIfR correlator. Tests of this new link have started and production use of the connection is expected for 2007.

Data Centers

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

Analysis Coordinator

A large portion of the work in the year 2006 was devoted to the generation of the IVS input to ITRF2005. In the case of IVS, the IERS asked for individual data sets for each VLBI observing session of 24 hours duration in Solution INdependent EXchange (SINEX) format. SINEX files permit the transmission of the full variance/covariance information to interpret the quality of the solution to its full extent or to further combine the results with other solutions. This can be realized through reporting either the full variance/covariance matrix or the normal equation matrix of a solution setup pre-reduced for technique-specific parameters (e.g. clock parameters). The latter option is mainly meant for further combinations but, if required, variance/covariance information can easily be extracted through an inversion procedure which may have to include a datum definition if necessary.

In order to facilitate combination steps through a procedure which may be completely free of any datum definition, the IVS had decided that IVS Analysis Centers report datum-free normal equation matrices in their SINEX files to the IVS Analysis Coordinator. Consequently, the IVS input to ITRF2005 was also based on datum-free normal equations.

Quite a lot of effort had to be spent on eliminating problems originating from peculiarities of certain sessions which inhibited a combination in a straight forward way. Noteworthy is the fact that the Japanese regional network is linked to the global network of ITRF sites only insufficiently. This situation should be addressed in future session plans. Several sites with only very few observing days of the past (1980s) were eliminated from the station list for ITRF2005.

The final IVS data set was combined from data of Deutsches Geodätisches Forschungsinstitut (DGFI), of Bundesamt für Kartographie und Geodäsie (BKG), of NASA Goddard Space Flight Center (GSFC), of Shanghai Astronomical Observatory (SHAO), and of U.S. Naval Observatory (USNO). Unfortunately, the data of Geoscience Australia (GA) and of Kiev Main Astronomical Observatory (MAO) could not be used due to incompatibility of the data sets. For the next realization of the ITRS, however, we are confident that these difficulties will be overcome.

In parallel to the ITRF2005 investigations, a new combination strategy for the two IVS EOP series (rapid and quarterly solutions) has also been developed and tested. Preparations were made for a change from a combination of EOP on the basis of results to a combination on the basis of datum-free normal equations in SINEX format. The advantage of the new combination strategy is that one common terrestrial reference frame (e.g. ITRF2005) can be applied after the combined datum-free normal matrix is generated. This helps to avoid that systematic differences caused by different TRF used in the individual contributions enter the combination. Due to the complicated dependency on several observatories participating in the sessions in a variety of configurations, the TRF effect is almost impossible to eliminate from EOP-only solutions afterwards. For testing purposes, the application of an identical TRF to all contributions also allows a better investigation in remaining systematic effects.

Technology Development

Routine use of e-VLBI continued to grow. All data recorded on K5 systems at Tsukuba and Kashima was transferred via e-VLBI to Haystack Observatory, where it was transferred to Mark 5 disk modules and then correlated or sent to target correlators at USNO or MPIfR. Also the Syowa (Antarctica) data was transferred to Haystack from Japan, after the Syowa K5 disk media had been physically shipped to Japan. MPIfR Bonn is expected to have operational connectivity in 2007, so that the intermediate step of e-transferring data to Haystack will become superfluous for sessions that are to be correlated at Bonn. All of Wettzell's daily UT1 Intensive data was transferred via e-VLBI, either directly to the correlator at the Geographical Survey Institute, Tsukuba, Japan (Saturday–Sunday) or to a site near USNO in Washington, D.C. (Monday–Friday), where it was picked up and taken to USNO for correlation.

During 2006, a number of e-VLBI tests and experiments were conducted with the Ny-Ålesund station—one of the most remote stations in the VLBI network. Courtesy of arrangements between NASA and Norway, which jointly own an undersea fiber-optic cable from Svalbard to the mainland, these tests allowed a significant amount of data to be transferred from Ny-Ålesund to Haystack Observatory, where they were recorded on Mark 5 disk modules and shipped to the target correlator. The speed of the connection was limited to less than 100 Mbps, but plans were being discussed to increase the speed to ~300 Mbps, which would be suitable to transferring essentially all data from Ny-Ålesund via e-VLBI. Since Ny-Ålesund media have traditionally been among the most difficult to transport rapidly and reliably, the new e-VLBI connection promises a real step forward.

The VLBI2010 Committee continued the work of conceiving the next generation VLBI system. The main thrusts lay on Monte-Carlo-type simulations to determine system critical parameters as well as on prototyping and proof-of-concept efforts for the broadband delay. The strawman system is envisioned to consist of fast-slewing, 12-m diameter class antennas. The system should cover a continuous band of ~2-15 GHz and record at high data rates of possibly up to 32 Gbps. These high rates may be attained by a 'burst mode' type of operation, in which source data is captured into high-speed RAM for maybe 5 sec and then either recorded or transmitted while the antenna is slewing to the next source in the following 20 sec. Repeating this cycle continuously over a 24-hour session, a significantly higher number of observations can be collected (possibly up to 100,000). Besides rapid sky coverage, this mode of operation will quickly sample the atmosphere in all directions to allow better determination of changing atmospheric parameters.

Dirk Behrend, Axel Nothnagel

3.4.4 International DORIS Service (IDS)

General

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

Network

The DORIS permanent network is shown in Figure 1. Site logs are available at <http://ids.cls.fr/html/doris/sitelog.php3>.

The stations rejuvenation program initiated in 2000 is now almost complete, as illustrated in Figure 2. In 2006 only one station was completely renovated in order to improve the long term stability of the antenna support (Dionysos, Greece, DORISMAIL 0452, June 6, 2006) while less of a modification was carried out on the antenna support at Arequipa (Peru) and Hartebeesthoek (South Africa). The station at Arequipa was restored to operation after a long hiatus since 2003. The antenna at Djibouti (DJIB) was replaced following discovery of a tilt due to a corroded base plate (DORISMAIL 0456, July 3, 2006). A tilt was also found in the antenna at Marion Island, MARB (DORISMAIL 0449, May 23, 2006). The MARB antenna was repaired courtesy of assistance from colleagues at HartRAO (Hartebeesthoek Radio Astronomy Observatory) (DORISMAIL 0453, June 8, 2006).

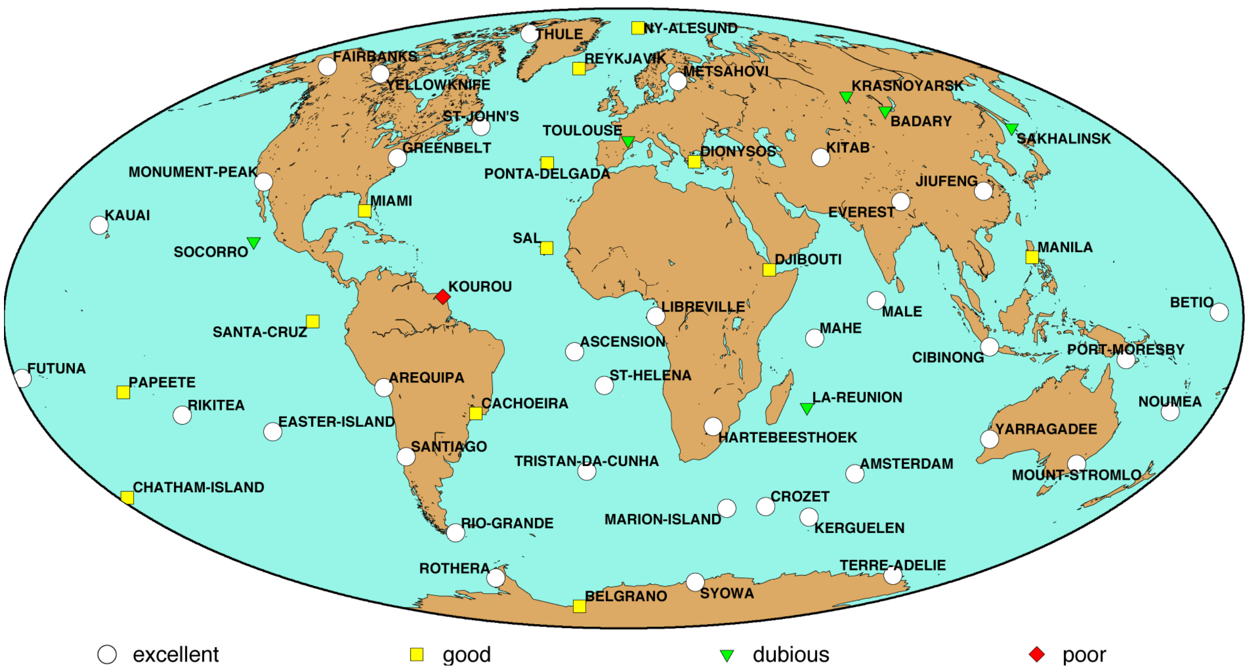

Fig. 1: The DORIS permanent stations and their estimated stability (January 2007)

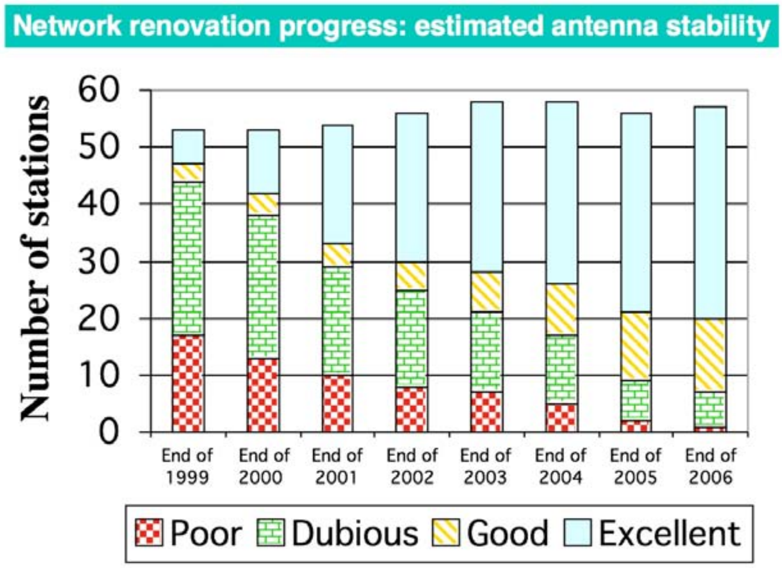

Figure 2: DORIS permanent network renovation

The following new stations were installed:

- Rikitea (French Polynesia), replacing Rapa
- Betio (Tarawa atoll, Republic of Kiribati)

The total number of DORIS stations in the permanent network is now 57, out of which only seven are considered to have dubious or poor stability (see Figures 1 and 2).

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

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

Space Segment

Three new oceanography and cryosphere observation missions will carry DORIS receivers, which will help to ensure continuity of DORIS data. These missions include Jason-2 (NASA/CNES/NOAA/EUMETSAT) scheduled for launch in June 2008, Cryosat 2 (ESA) scheduled for launch in May 2009, and SARAL/Alti-KA (joint with the CNES and ISRO, the Indian Space Research Organization) scheduled for launch in 2009-2010. The current DORIS satellite constellation includes: SPOT-2 (in orbit since 1990), SPOT-4, SPOT-5, ENVISAT, and Jason-1.

Operational Product Delivery

The latency of products delivered by the IDS is controlled in part by the delivery of DORIS tracking data to the IDS data centers (e.g. the NASA CDDIS). We show in Figure 3 the latency of DORIS data delivery typical in 2006 for the different satellites which average at present 20–30 days.

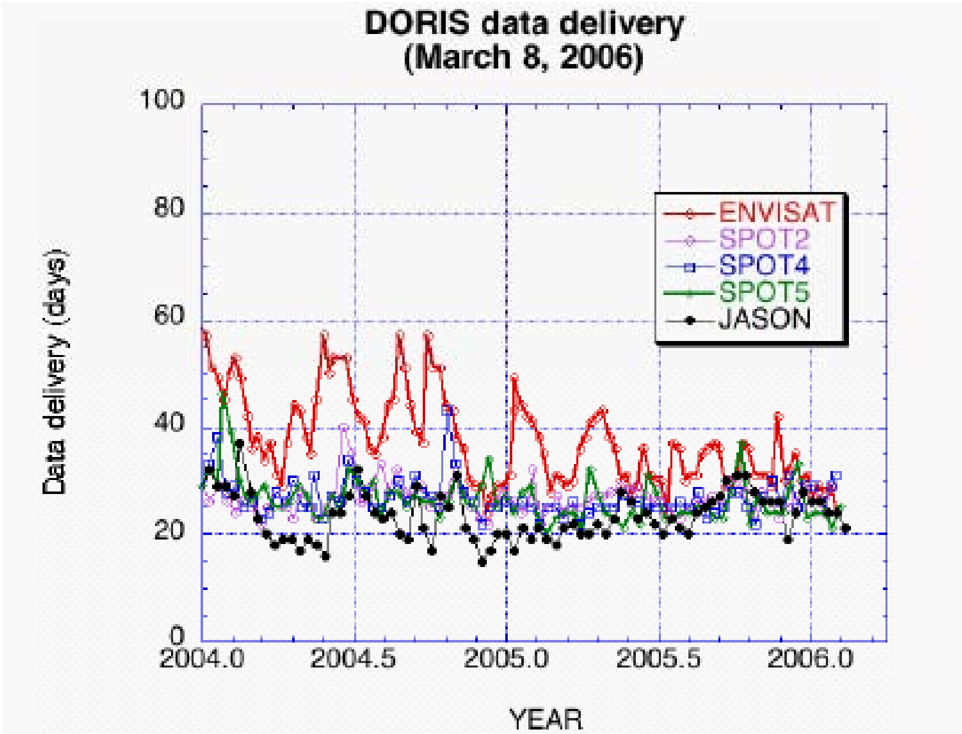

Fig. 3: Latency of DORIS data delivery to the NASA/CDDIS (2004 to March 8, 2006).

IDS Workshop, March 13–15, 2006, Venice, Italy

The International DORIS Service (IDS) workshop was held on March 13–15, 2006, in conjunction with the ESA symposium, "15 years of Progress in Altimetry", and the Ocean Surface Topography Science Team (OSTST) meeting. The purpose of this workshop was to get representatives from all IDS groups together to share information about the network, data, products, developments and results in all aspects of DORIS. The meeting was a platform for discussion and coordination of future activities. The presentations from the meeting are available at <http://ids.cls.fr/html/events/IDS2006/>. A detailed position paper was produced to outline the necessary steps to refine and improve the delivery of IDS products. This position paper is available at <http://ids.cls.fr/documents/events/IDS2006/IDS06_s1_Lemoine_coordination.pdf>.

DORIS special Issue (Journal of Geodesy)

A special issue dedicated to DORIS was published in the Journal of Geodesy (Volume 80(8-11), November 2006. The guest editor was Pascal Willis (IGN/JPL). The issue included four papers on the DORIS system and IDS, three papers on geodynamics, two papers on the ionosphere, five papers on the reference frame and Earth rotation, and three papers on DORIS technical issues. The countries of the authors and co-authors included: France (28); USA (13); UK (1); The Netherlands (1); Czech Republic (1); Switzerland (1); and Nepal (1).

New Citation

As a result of the special issue, we request that users of DORIS data and products use the following new citation:

Tavernier, G., Fagard, H., Feissel-Vernier, M., Le Bail, K., Lemoine, F., Noll, C., Noomen, R.; Ries, J.C., Soudarin, L., Valette, J.J., Willis, P. (2006), The International DORIS Service: genesis and early achievements, *Journal of Geodesy 80(8-11), pp. 403–417, DOI: 10.1007/s00190-006-0082-4*.

ITRF2005 Contributions

Three analysis centers submitted full SINEX file time series (1993–2005) for inclusion in the ITRF2005: IGN/JPL, LEGOS/CLS, and INASAN (Institute of Astronomy, Russian Academy of Sciences). The IGN/JPL and INASAN time series were based on the Gipsy software; the LEGOS/CLS solution was based on the GINS software. All the contributions from the analysis centers were based on DORIS data from SPOT-2, SPOT-3, TOPEX/Poseidon, SPOT-4, SPOT-5 and ENVISAT. Jason-1 DORIS data were not included owing to the perturbing effect of the South Atlantic Anomaly (SAA) on the Jason-1 DORIS Ultrastable Oscillator. No DORIS combination was produced for the IERS, but rather the individual analysis center contributions were directly included in the ITRF2005 solution. A detailed document was written by IDS to provide specification for the ITRF2005 computation (discontinuities, change in velocity, bad data, ...) and is available on <http://ids.cls.fr/documents/report/IDS_for_ITRF2004_v1_0.pdf>.

Tests of ITRF2005

DORIS analysts conducted extensive tests of the ITRF2005, including the preliminary versions released in the summer of 2006 by the IGN and the DGFI (ITRF2005P), and the final version released in October 2006.

Luca Cerri (CNES) analyzed Jason-1 SLR and DORIS data from cycle 110 to 145 (January 1 to December 31, 2005). The tests included pure DORIS-only orbits, and DORIS+SLR orbits, and separately tested the ITRF2000, ITRF2005P (IGN), and ITRF2005P (DGFI) solutions. For ITRF2000, the DPOD2000 corrections of *Willis and Ries* (2005) were used. The DORIS RMS of fit showed a small improvement for ITRF2005. The altimeter crossover RMS of fit for the DORIS-only orbits improved from 5.953 cm (ITRF2000) to 5.906 cm (ITRF2005P, IGN) and 5.905 cm (ITRF2005P, DGFI). As illustrated in Figure 4, the altimeter mean for these orbits shows a significant improvement, indicating the orbits are better centered in ITRF2005 compared to ITRF2000.

The improved centering is also visible in the DORIS+SLR orbits with ITRF2005P. Use the ten core SLR stations (Wettzell, Hertmonceux, Graz, Shanghai, Grasse, Zimmerwald, Monument Peak, Greenbelt, Yarragadee, McDonald) along with the ITRF2005 DORIS complement, Luca Cerri (CNES) found that the RMS of fit

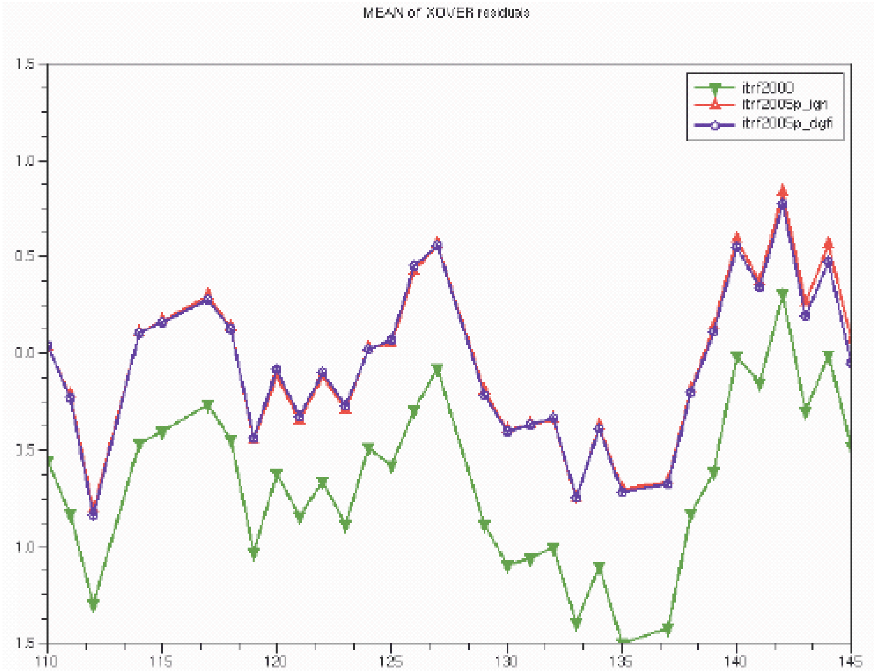

Fig. 4: Mean of Jason-1 Altimeter Crossover Residuals (cm) for DORIS-only orbits computed with ITRF2000 (green line), ITRF2005P-IGN (red line), and ITRF2005P-DGFI (blue line). The vertical scale ranges from –1.5 to +1.5 cm.

was 1.13 cm (ITRF2000), 1.50 cm (ITRF2005P-IGN), and 1.24 cm (ITRF2005P-DGFI). The global mean SLR fit was 0.23 cm (ITRF2000), 0.65 cm (ITRF2005P-IGN), and 0.35 cm (ITRF2005P-DGFI).

The LEGOS/CLS analysis center (Laurent Soudarin) tested ITRF2005P-IGN using data to all DORIS satellites in June 2004. An improvement in the RMS of fit was discerned for all the DORIS satellites except Jason-1 (see Table 1).

Table 1: RMS of fit for DORIS data in June 2004 from LEGOS/CLS analyses

Satellite	**ITRF2000 RMS, mm/s**	**ITRF2005P-IGN RMS, mm/s**
SPOT-2	0.3569	0.3536
SPOT-4	0.4160	0.4115
SPOT-5	0.3951	0.3906
TOPEX/Poseidon	0.4257	0.4244
Jason-1	0.3749	0.3771
ENVISAT	0.4792	0.4752

The NASA/GSFC POD center (Nikita Zelensky, Doug Chinn and Scott Luthcke) analyzed the tracking data for both TOPEX/Poseidon (cycles 1 to 364, 1992 to 2002) and Jason-1 (cycles 1 to 168, 2002

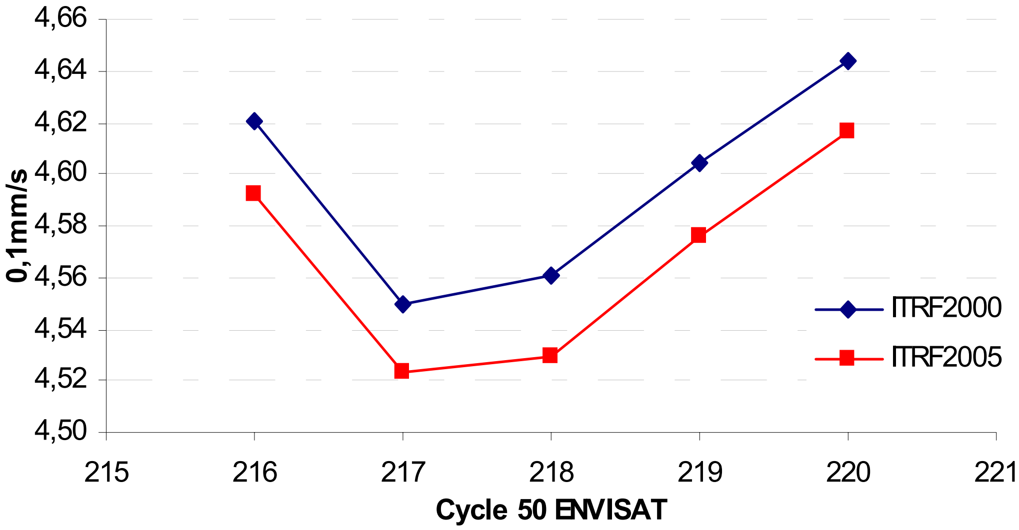

Fig. 5: DORIS fits for ENVISAT orbits based on SLR and DORIS tracking using ITRF2000 (blue line) and ITRF2005 (red line). In these tests by the CNES POD center, the DORIS performance is systematically improved with ITRF2005. The vertical scale ranges from 0.450 to 0.466 mm/s.

to 2006) to test the final ITRF2005 release. This analysis used only the stations that appeared in the ITRF2005 solution, and in particular they applied the correction SLR or DORIS solution by epoch for certain stations with multiple solutions. The GGM02C gravity was used for both TOPEX and Jason-1, and in addition for Jason-1 the South Atlantic Anomaly (SAA) correction model of J.M. Lemoine and H. Capdeville (2006) was applied. As with the CNES analysis center the Willis and Ries (2005) corrections to ITRF2000 (DPOD2000) were used. For TOPEX, while the DORIS fits improved, the SLR fits increased, and there was a slight increase in the altimeter crossover RMS of fit (see Table 2). The SLR fits for both TOPEX/Poseidon and Jason are characterized by an increase in the mean SLR residual. For Jason-1, the RMS of fit improved for the DORIS data, the SLR data, and the altimeter crossovers.

The CNES POD Center analyzed the SLR and DORIS data for ENVISAT cycle 50 (August 1 to September 4, 2006) – thus using data that were not part of the ITRF2005 solution. They showed that the DORIS fits to ITRF2005 are a systematic and consistent improvement compared to ITRF2000 (see Figure 5).

The IGN/JPL analysis center (Pascal Willis) compared the IGN/JPL solution with ITRF2000 and ITRF2005P. The most notable result was the change in the scale of the TRF. For ITRF2000, the IGN/JPL solution had a scale offset of –3.23 ppb (–21 mm), whereas for ITRF2005 the IGN/JPL solution had a scale offset of –0.78 ppb (–5 mm).

Table 2: RMS of fit for TOPEX and Jason-1 SLR and DORIS Orbits with ITRF2000 and ITRF2005

TOPEX orbits: 34 select cycles†	**DORIS RMS, mm/s**	**SLR RMS, cm**	**SLR mean, cm**	**Crossover RMS, cm**
ITRF2000	0.4864	1.805	0.104	5.460
ITRF2005	0.4863	1.846	0.319	5.472
Jason orbits: Cycles 1-168 (edit cycle 137)	**DORIS RMS, mm/s**	**SLR RMS, cm**	**SLR mean, cm**	**Crossover RMS, cm**
ITRF2000	0.3862	1.447	-0.061	5.576
ITRF2005	0.3856	1.420	0.247	5.572
† TOPEX Cycles 13-15, 85-87, 159-161, 239, 241, 308, 311, 344-360, 361-364				

In summary, the ITRF2005 solution is positive for DORIS, and shows improvements compared to ITRF2000, especially for the period after 2000, when the newest stations joined the DORIS network. The DORIS network provides orbit solutions for Jason-1 that are better centered, as shown by the mean crossover fits for both the DORIS-only and the DORIS+SLR orbit solutions. Positioning improvements are expected in the operational weekly SINEX solutions once ITRF2005 is implemented by the analysis centers. The DORIS centers will implement ITRF2005 in their routine operations during 2007, as soon as it is practical for them to do so.

Frank Lemoine, Hervé Fagard, Gilles Tavernier

3.5 Product Centres
3.5.1 Earth Orientation Centre

This section presents activities and main results concerning the Earth Orientation Centre located at Paris Observatory over 2006. The main activities of the IERS Earth Orientation Parameters (EOP), operational activities and long analyses are presented at the web site <http://hpiers.obspm.fr/eop-pc>. According to the IERS Terms of Reference, the Earth Orientation Centre is responsible for monitoring Earth Orientation Parameters including long term consistency, publications for time dissemination and leap second announcements. The Earth Orientation Centre is making available different products to a broad community of users: long-term and operational series of Polar motion, Universal Time (UT1), Length of Day (LOD) and Celestial pole offsets.

Determination of EOP is in the form of combined solutions derived by the analysis centers of the different techniques. Various solutions are computed: long-term solution (IERS C01), normal values at five-day intervals (IERS C02) and the operational smoothed solution Bulletin B at one-day intervals published monthly and providing EOP with a delay of 30 days with respect to the date of publication. Bulletin B is updated in the operational C04. So far Earth Orientation Parameters and the terrestrial frame were separately computed. This leads to increasing inconsistencies between both of them. On January 2005, these inconsistencies were at the level of 300 microarcseconds for polar motion. In order to improve consistency between both systems, the Bulletin B and C04 were recomputed and aligned to the EOP solution associated to the ITRF2005 (Altamimi et al., 2007). By the way, the procedure leading to the combined solutions was upgraded.

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

It has been necessary to re-align the solution to improve its consistency with respect to the new realization of the ITRF, i.e. ITRF2005 (Altamimi et al., 2007).

Due to the separate determination of both celestial and terrestrial reference frames and EOP, there has been a slow degradation of the overall consistency and discrepancies at the level of 300 micoarseconds were present at 2004.0 between the current IERS C04 and the ITRF realization (Gambis, 2004). We have taken this opportunity to upgrade the numerical combination procedure; the improvements concern in particular routines, table dimensions and the generalization of double precisions. Using the combined polar motion solution associated with the newly released International Terrestrial Reference Frame 2005 (ITRF 2005), we produce a better solution mainly based on the time series derived by technique centers, i.e. IGS, IVS and ILRS. In addition formal errors associ-

Table 1: Estimated accuracies of individual solutions compared to the combined solutions Bulletin and 05 C04 over 2006–2007.

Individual solutions		Estimated uncertainties				
		Time	Terrestrial Pole in 0.001"	UT1 in 0.0001s	LOD in 0.0001s	Celestial Pole in 0.001"
VLBI – 24 h						
EOP (AUS)	1 R 1	3–4d	0.176	0.066		0.081
EOP (BKG)	3 R 4	1–4d	0.160	0.066		0.088
EOP (GSFC)	4 R 2	1–4d	0.152	0.059		0.076
EOP (IAA)	5 R 2	1–4d	0.177	0.066		0.083
EOP (MAO)	3 R 1	1–4d	0.166	0.081		0.108
EOP (SPBU)	3 R 3	3–4d	0.320	0.098		0.092
EOP (USNO)	6 R 1	1–4d	0.161	0.063		0.063
VLBI – Intensive						
EOP (BKG)	3 R 2	1–3 d		0.263		
EOP (GSFC)	4 R 1	1–3 d		0.257		
EOP (IAA)	5 R 1	1–3 d		0.266		
EOP (SPBU)	2 R 1	1–3 d		0.130		
EOP (USNO)	5 R 1	1–3 d		0.300		
SLR						
EOP (ASI)	3 L 2	1d	0.272		0.60	
EOP (IAA)	2 L 1	1d	0.219		0.40	
EOP (MCC)	97 L 1	1d	0.291			
EOP (OCA)	5 L 1	1d	0.236			
GPS						
EOP (CODE)	98 P 1	1d	0.060		0.34	
EOP (EMR)	96 P 3	1d	0.198		0.31	
EOP (ESOC)	96 P 1	1d	0.078		0.48	
EOP (GFZ)	96 P 2	1d	0.059		0.38	
EOP (SIO)	96 P 1	1d	0.164		0.30	
EOP (JPL)	96 P 3	1d	0.091		0.33	
EOP (NOAA)	96 P 1	1d	0.140		0.31	

** The satellite techniques provide information on the rate of change of Universal Time contaminated by effects due to non modelled orbit node motion.*

ated to EOPs are available. EOP series have been reprocessed since 1984. Pole coordinates are now fully consistent with ITRF2005. The nutation offsets and UT1 are made consistent with the International Celestial Reference Frame (ICRF) through the IVS combined solution. Tables 1 to 4 give statistics concerning the analyses of Bulletin B and EOP series 05C04. A detailed description of the new solution can be found in the Technical Note available at <http://hpiers.obspm.fr/iers/eop/eopc04_05/C04_05.guide.pdf>.

Table 2: Uncertainty of the current solution of Bulletin B and the estimated accuracies of the predictions for horizons of 5 days to 1 year for 2006–2007.

Solutions		Terrestrial Pole mas	UT1 ms	Celestial Pole mas
Analysis daily	1-d	.004	.006	0.10
Prediction	1-d	.50	.18	0.10
	5-d	2	.60	0.10
	10d	4	1.40	0.10
	30d	12	5.	0.10
	90d	50	30.	0.10
	180d	60	70.	0.10
	1-yr	76	140.	0.10

Table 3: Mean and standard deviation in microarcsecond of the differences between various combined techniques solutions and IERS 05C04 over 2006–2007.

EOP	IGS Comb – IERS 05C04		ILRS Comb – IERS 05C04		IVS Comb – IERS 05C04	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
X (μas)	3	21	–133	166	–39	91
Y (μas)	–60	19	–118	156	8	114
UT1 (μs)	9	28			4	6.6
LOD (μs)	0	11	22	54		
Dψsinε (μas)					5	50
Dε (μas)					–4	51

Table 4: Mean and standard deviation for Pole components and UT1 of the differences between various solutions and Bulletin B over 2007.

EOP	Unit	Bull A – Bull B		Comb JPL – Bull B	
		Mean	Standard deviation	Mean	Standard deviation
X	μas	–30	32	–109	37
Y	μas	–20	30	–38	15
UT1	μs	3	8	4	10

Long-term series: C 01 (1846–2006)

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

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

Mean Pole with respect to the IERS reference origin

The analyses of the observations of space geodesy require performing the transformation between both terrestrial and celestial frames via 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 IERS Terrestrial Reference Frame can be considered as the long-term trend obtained after filtering out the Chandler and seasonal terms, every year from 1900 to 2006 (Shiskin *et al.*, 1965). Figure 1 represents the polar motion over 2001–2006 and the path of the mean pole since 1900. The table is available in IERS Conventions 2003 (McCarthy and Petit, 2004) and at <http://hpiers.obspm.fr/eop-pc/>.

Normal Point Solutions: C 02 (1962–2006)

Other series, based on normal points solutions given at various time intervals, are also proposed to users, i.e. C 02 (5-day intervals, polar motion, UT1–UTC, $d\psi$, $d\varepsilon$), C 03 (one-day intervals, polar motion, UT1–UTC) (Gambis, 1997). 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

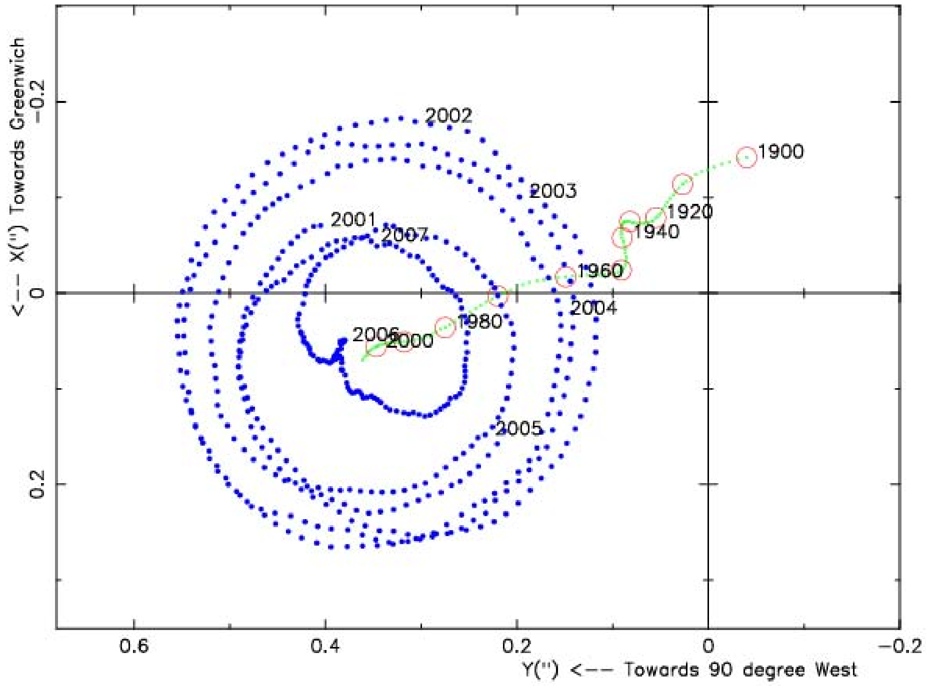

Fig. 1: Mean polar motion (1900–2010) and IERS C04 polhody over 2001–2007.

series C 02 and C 03 in which the estimation of the solution given at the central dates of the n-day interval is made using a least-square fit for all EOP components. Although the L2 estimation has been extensively used for data analysis, it has some drawbacks linked to problems of ill-conditioning and in the non-detection of outliers. Alternative methods based on robust estimators like M-Huber can be used. These estimators are a generalization of both the L1 and L2 class. They have been implemented in our analyses and are now currently used (Bougeard *et al*, 2000). Table 5 reflects the evolution of the mean uncertainties of C02 solution since 1962.

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

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

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

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

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

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

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3.5.2 Rapid Service/Prediction Centre

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Centre for the determination of the quick-look Earth orientation parameters (EOP) is based on a weighted cubic spline with adjustable smoothing fit to contributed observational data (McCarthy and Luzum, 1991a). Contributed data are corrected for possible systematic differences. Biases and rates are determined with respect to the 97 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 residuals between the series and the combined EOP solution for 2006.

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

Table 1: Estimated accuracies of the techniques in 2006. Units are milliseconds of arc for x, y, $\delta\psi$, $\delta\varepsilon$, dX, and dY and milliseconds of time for UT1-UTC.

Contributor Information	Estimated Accuracy				
Name, Type	x	y	UT1	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
CSR SLR	0.32	0.49	0.059*		
DUT SLR	0.35	0.37			
IAA SLR	0.18	0.18			
MCC SLR	0.18	0.21			
GSFC VLBI Intensives			0.018		
SPBU VLBI Intensives			0.018		
USNO VLBI Intensives			0.017		
GSFC VLBI	0.06	0.07	0.003	0.4	0.1
IAA[1] VLBI	0.07	0.11	0.003	(0.1)	(0.1)
IVS VLBI	0.10	0.08	0.004	0.4	0.1
USNO VLBI	0.07	0.09	0.003	0.4	0.1
IGS Final	0.04	0.04			
IGS Rapid	0.03	0.03			
USNO GPS UT*			0.015*		
EMR GPS UT*			0.028*		
USNO AAM UT			0.010		

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

parameter time series so that x, y, UT1–UTC, dψ, and dε values are computed at the epoch of zero hours UTC for each day. Since the celestial pole offset software is written in terms of dψ and dε, the IAA VLBI dX and dY values are converted to dψ and dε for the combination process. The LOD are derived from the UT1–UTC data. The analytical expression for the first derivative of the cubic spline passing through the UT1–UTC data is used to estimate the LOD at the epoch of the UT1–UTC data.

The only data points that are excluded from the combination 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, the input data are not corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

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 97 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/97 C04 series for the entire year. The comparison of the

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre solutions and IERS Bulletin B and C04 EOP solutions for 2006. 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 - 97 C04	
	Mean	Std. Deviation	Mean	Std. Deviation
Bulletin A Rapid Solution (finals.data)				
X	-0.06	0.05	-0.06	0.05
Y	0.00	0.06	0.00	0.06
UT1-UTC	-0.003	0.015	-0.002	0.014
Bulletin A Weekly Solution (finals.data)[1]				
X	0.00	0.06	0.00	0.06
Y	-0.05	0.05	-0.06	0.05
UT1-UTC[2]	0.013	0.025	-0.014	0.035
Bulletin A Daily Solution (finals.daily)				
X	0.00	0.11	0.00	0.11
Y	-0.06	0.10	-0.06	0.10
UT1-UTC[2]	0.009	0.065	-0.010	0.064

[1] Statistics computed over the 7 day combination solution period prior to solution epoch.
[2] Standard deviations including periods of known VLBI intensive and GPS rapid data issues.

52 weekly solutions to the Bulletin B/97 C04 series gives the statistics of the residuals computed over the new combination results for the 7 days prior to the solution epoch. The statistics for the daily solution are the differences for the day of the solution epoch. EOP accuracies for the Bulletin A rapid weekly solution for the new combination for the day of the solution run and daily solution at the time of solution epoch are similar and therefore, not included in the table.

Figure 1 shows the residuals between the daily Bulletin A rapid solution and two other series (i.e., Bulletin B and 97 C04) and presents the data used in Table 2 for the determination of the Bulletin A daily solution statistics. This year Bulletin A had only small reductions in the mean difference while he standard deviations were mostly comparable. Overall, the agreement between the Bulletin A solutions and the IERS EOC solutions is quite good.

Prediction Techniques

Polar motion predictions are based on the extrapolation of an annual and semiannual ellipse and a Chandler circle fit to the previous 400 days of observed values of x and y (McCarthy and Luzum, 1991b; Johnson, 2002). The differences between the last observed pole position and rate and those of the curve are computed. These differences are then used to adjust the extrapolated curve by an amount that decreases with the length of the forecast. In February 1998, the near-term polar motion predictions (less than about 30 days) were improved significantly by modifying the transition process from the last observed polar motion result to the long-term predictions. Continuity in the first derivatives was enforced placing great weight on the observed polar motion rate reported by the IGS in their Rapid series. The improvement was most pronounced for the shortest prediction intervals.

The procedure for UT1–UTC involves a simple technique of differencing (McCarthy and Luzum, 1991b). All known effects such as leap seconds, solid Earth zonal tides, and seasonal effects are first removed from the observed values of UT1–UTC. Then, to determine a prediction of UT1–UTC n days into the future, $(UT1–TAI)_n$, the smoothed time value from n days in the past, $<(UT1R–TAI)_{-n}>$ is subtracted from the most recent value, $(UT1R–TAI)_0$

$$(UT1–TAI)_n = 2(UT1R–TAI)_0 – <(UT1R–TAI)_{-n}>.$$

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

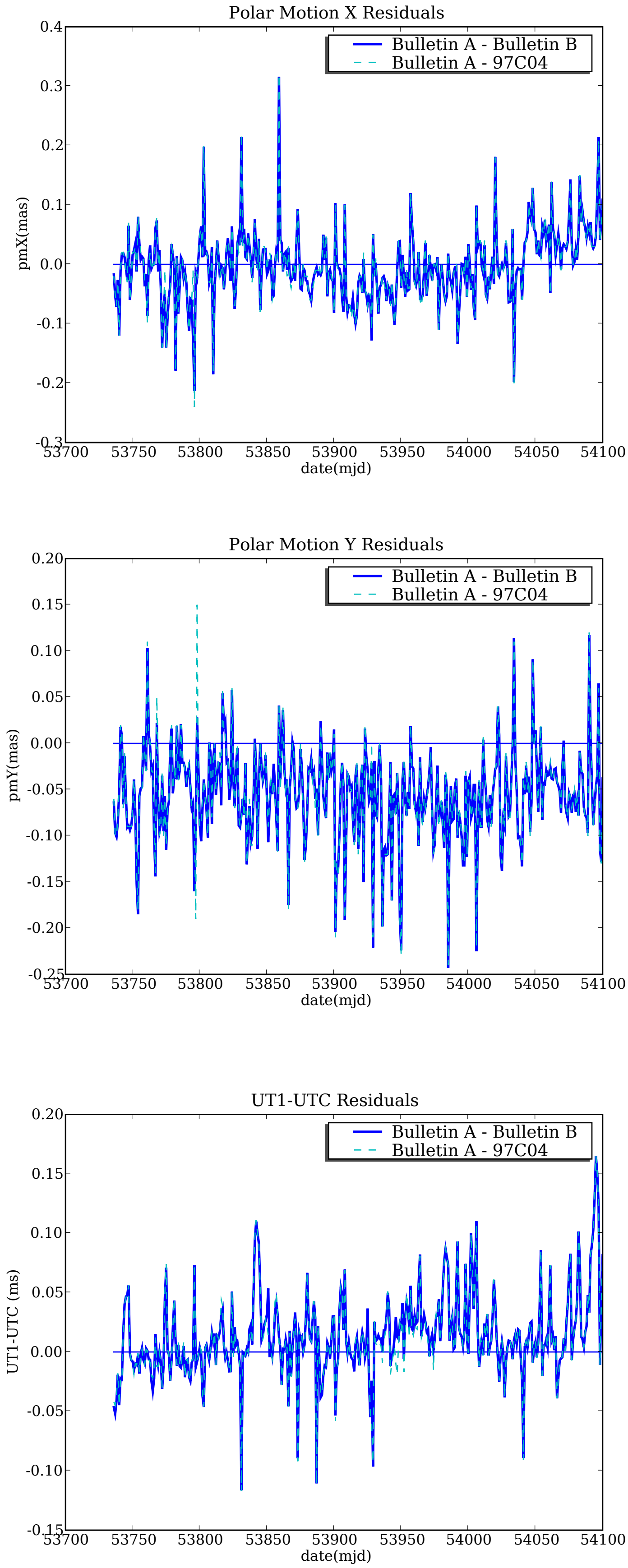

Fig. 1: Differences between daily Bulletin A rapid solutions at each daily solution epoch for 2006 and the Earth orientation parameters available in Bulletin B and 97 C04 series produced in July 2007.

The UT1–UTC prediction out to a few days 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 UT1–UTC prediction also makes use of a UT1-like data product derived from the operational NOAA AAM analysis and forecast data (UTAAM). In September 2006, the U.S. Navy NOGAPS AAM data were combined with the NOAA AAM data. AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 5 days. For longer predictions, the LOD excitations 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 can be 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 97 C04 solution for 2006. Initial estimates indicated that the UT1-UTC prediction performance would be improved by 42% at 10 days into the future by the addition of UTAAM to the combination and prediction process (Johnson et al., 2005). However, comparisons of the UT1-UTC prediction performance from 2003 to those estimated in 2001 (before UTAAM was introduced) indicated a better than 50% improvement in prediction error at both 10 day and 20 days into the future.

For 2006, the prediction errors were fairly comparable to those of 2005. Note that the statistics reported in Table 3 have been changed from standard deviation to root mean square to give a better indication of the overall accuracy of the predictions. The only unusual increase in error is for the 90-day UT1-UTC predictions that suffered from some unusually large prediction errors in the beginning of 2006. Excluding these predictions, the errors were more consistent with past prediction errors. The longer-term polar motion predictions also continued to have larger than historically computed errors. This is due to the presence of small sub-monthly retrograde loops in the polar motion. The operational prediction method does not solve for these loops although the least-squares plus autoregressive (LS+AR) polar motion prediction implemented in early 2007 may help in the future.

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\varepsilon$ representations) are produced through the use of the KSV1996 model. In addition, a bias between the model and the last 20 days worth of celestial pole offset observations is computed. This bias is

Table 3: Root mean square of the differences between the Earth orientation parameter prediction series produced by the daily Bulletin A rapid solutions and the C04 combination solutions for 2006.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.42	.36	.147
5	2.33	1.51	.518
10	4.44	2.55	1.06
20	8.25	4.72	3.11
40	16.3	9.14	6.88
90	33.5	18.7	22.1

tapered so that as the prediction length is extended, the bias becomes increasingly small. Since celestial pole offsets 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 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 the 97 C04 for 2006 are given in Table 4.

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily Bulletin A rapid solutions and the 97 C04 solution for 2006.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.13	.16	.35	.16
5	.13	.16	.35	.16
10	.12	.16	.35	.17
20	.12	.16	.38	.18
40	.15	.17	.41	.20

Predictions of TT–UT1 up to 2016 January 1, are given in Table 5. They are derived using a prediction algorithm similar to that employed in the Bulletin A predictions of UT1–UTC. Up to twenty years of past observations of TT–UT1 are used. Estimates of the expected one-sigma error for each of the predicted values are also given. These are based on analyses of the past performance of the model with respect to the observations.

Table 5: Predicted values of TT-UT1, 2007-2016. Note that UT1-TAI can be obtained from this table using the expression UT1-TAI = 32.184s - (TT-UT1).

DATE	TT–UT1 (s)	Uncertainty (s)
2007 Jan 1	65.146	0.000
2007 Apr 1	65.249	0.000
2007 Jul 1	65.341	0.000
2007 Oct 1	65.371	0.000
2008 Jan 1	65.466	0.008
2008 Apr 1	65.56	0.01
2008 Jul 1	65.64	0.02
2008 Oct 1	65.66	0.02
2009 Jan 1	65.8	0.2
2009 Apr 1	66.0	0.3
2009 Jul 1	66.2	0.4
2009 Oct 1	66.4	0.4
2010 Jan 1	66.5	0.5
2010 Apr 1	66.6	0.7
2010 Jul 1	66.8	0.8
2010 Oct 1	66.9	0.9
2011 Jan 1	67.	1.
2011 Apr 1	67.	1.
2011 Jul 1	67.	1.
2011 Oct 1	67.	1.
2012 Jan 1	68.	2.
2012 Apr 1	68.	2.
2012 Jul 1	68.	2.
2012 Oct 1	68.	2.
2013 Jan 1	68.	2.
2013 Apr 1	68.	2.
2013 Jul 1	68.	2.
2013 Oct 1	68.	3.
2014 Jan 1	69.	3.
2014 Apr 1	69.	3.
2014 Jul 1	69.	3.
2014 Oct 1	69.	3.
2015 Jan 1	69.	3.
2015 Apr 1	69.	3.
2015 Jul 1	69.	4.
2015 Oct 1	70.	4.
2016 Jan 1	70.	4.

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

Centre Activities in 2006

During 2006 a number of changes occurred that affected the performance of IERS Bulletin A. Electronic-VLBI (e-VLBI) became operational for certain aspects of the VLBI Intensive observations. Additional efforts included improving operational software, automating the process for updating data sets used in the combination, updating and monitoring currently used datasets, investigating potential new data sets, and investigating the improvement of polar motion prediction technique. Additional work on better establishing an alternate site to mirror data storage for the combination processing was carried out.

New global solutions were received from GSFC and USNO VLBI analysis centres. These new solutions were examined and new rates and biases were computed.

Collaborative efforts with colleagues at Poland's Center for Space Research showed the potential for improving our polar motion predictions by 20%–30% at 2 to 3 months into the future. Using updated software algorithms, efforts to utilize this new method into the operational software came to fruition with the incorporation of the algorithm in January 2007.

Availability of Rapid Service

The data available from the IERS Rapid Service/Prediction Centre consist mainly of the data used in the IERS Bulletin A. These data include: x, y, UT1–UTC, dX and dY from IAA VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from GSFC VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from USNO VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from IVS combination VLBI; UT1–UTC from Saint Petersburg University 1-day Intensives; UT1–UTC from GSFC 1-day Intensives; UT1–UTC from USNO 1-day Intensives; x, y, UT1–UTC from CSR LAGEOS 3-day SLR; x, y from Delft University of Technology 1-day SLR; x, y from Institute of Applied Astronomy 1-day SLR; x, y from the Russian Mission Control Centre 1-day SLR; x, y, LOD from the International GNSS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; UT from NAVY NOGAPS AAM; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Rapid Service/Prediction Centre; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Earth Orientation Centre; and predictions of x, y, UT1–UTC from the IERS Rapid Service/Prediction Centre.

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

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

ser7@maia.usno.navy.mil or through

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

Internet users can also direct an anonymous FTP to

<ftp://maia.usno.navy.mil/ser7>

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

Centre Staff

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

William Wooden	director
Thomas Johnson	program manager, research, and software maintenance
Brian Luzum	program manager, research, and software maintenance
Merri Sue Carter	daily operations and support assistance

At the end of October 2006, Thomas Johnson left USNO. Brian Luzum is now the program manager for the EOP Combination and Prediction Program. In the first half of 2007, Nicholas Stamatakos and Gillian Brockett joined the IERS Rapid Service and Prediction Centre.

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IERS Rapid Service/Prediction Center, *Proc. Journées Systèmes de Référence Spatio-Temporels*, Paris, 20–22 Sept 2004, 260–264.

Brian Luzum, Thomas Johnson, Merri Sue Carter,
Nicholas Stamatakos, Gillian Brockett, William Wooden

3.5.3 Conventions Centre

The Conventions Center is provided jointly by the Bureau International des Poids et Mesures (BIPM) and the U.S. Naval Observatory (USNO).

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

In 2006, the work accomplished or in progress is the following.

1. Technical topics

The background work of keeping track of corrections, typos and small changes that improve the readability of the documents has continued in 2006. More technical or complex issues are first debated, *e.g*. through the Advisory board or on the discussion forum <http://tai.bipm.org/iers/forum>, where topics are being identified as needing investigation and possible new developments for future versions of the Conventions. Several such topics concern contributions to the difference between the instantaneous position of a site and its adopted position, such as the effects of geocenter motion or atmospheric loading. It is expected that all effects (such as station displacement) that are periodic and have a consistent and accurate *a priori* model, expressed in closed form, should be included in the IERS Conventions. Models for long-term or non-periodic effects, which have an impact on the definition of reference frames, are also to be studied, although their inclusion as conventional effects will need to be discussed.

Work on the following major topics was started, on-going or completed in 2006:

1.1 Ocean pole tide

The ocean pole tide is generated by the centrifugal effect of polar motion on the oceans. Polar motion is dominated by the 14-month Chandler wobble and annual variation. At these long periods, the ocean pole tide is expected to have an equilibrium response, where the displaced ocean surface is in equilibrium with the forcing equipotential surface. The equilibrium model from S. Desai (JGR 107, 2002) is now the conventional model. The updated Chapter 6 "Geopotential" was released on 13 March 2006. To compute the pole tide, a "conventional mean pole" needs to be defined. This change to Chapter 7 "Displacement of reference points" was released on 1 September 2006. The new section on oceanic pole tide loading was released on 1 September 2006.

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

1.2 Atmospheric tidal loading

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

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

1.3 Ocean tidal loading

Section 7.1.1 has been rewritten and was released on 25 November 2006. As no conventional routine was available to implement the recommendations of section 7.1.1 of the IERS Conventions 2003 concerning local site displacements due to ocean tidal loading, a new Fortran routine, provided by Duncan Agnew (UCSD), has been selected after discussions and tests carried out within the Advisory Board. The code can be found on the web site at <ftp://tai.bipm.org/iers/convupdt/chapter7/hardisp.f>. In the same area, users should also note that Hans-Georg Scherneck has recently added the new TPXO.7.0 and FES2004 ocean models to his web site <http://www.oso.chalmers.se/~loading/>.

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

1.4 Tropospheric mapping function

A completely revised version of the chapter was released on 28 June 2007. For optical techniques, it describes a new model for zenith delay (Mendes and Pavlis, GRL 31, 2004) and a new mapping function, both adopted by the ILRS as of 1 January 2007. For radio techniques, since the recommended NMF (A. Niell JGR 1001, 1996), as well as other mapping functions cited in the Conventions (2003), have now been shown to have deficiencies, an expert panel was assembled to review the current recommendations. The VMF1 (Boehm et al., JGR 111, 2006) is now the recommended mapping function, which necessitates input coefficients determined from a numeric weather model. For users not aiming at the highest accuracy, the GMF (Boehm et al., GRL 33, 2006), which uses standard input coefficients, is provided.

Work on this topic involves mostly J. Boehm, G. Hulley, A. Niell, E. Pavlis and J. Ray.

1.5 Free Core Nutation model

Because of the variable nature of free core nutation (FCN), an FCN model was not included in the IAU 2000A Nutation model. An expert panel has been assembled to determine a suitable FCN model.

Work on this topic involves mostly S. Lambert, Z. Malkin, V. Dehant, N. Capitaine, and P. Wallace.

2. Dissemination of information

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

List of updates

The list of updates as of 26 July 2007 to the Conventions since the last IERS Conventions Annual Report follows (An updated list is available online at <http://tai.bipm.org/iers/convupdt/listupdt.html>):

Chapter 5: Transformation Between the Celestial and Terrestrial Systems

- 16 February 2007: Changes (provided by P. Wallace and N. Capitaine) with respect to previous version of the chapter: Revised section 5.8.3 to make the references for the planetary fundamental arguments clear.
- 22 December 2006: Correction to previous version of the chapter: Equation (14) for the Earth Rotation Angle has been corrected (noted by F. Nievinski).
- 18 October 2006: Changes (provided by N. Capitaine and P. Wallace) with respect to previous version of the chapter: Update section 5.7 to provide Table 5.4 and to make notations consistent with those in the electronic version of the table. Make the chapter's terminology consistent with the current IAU Recommendations.

Chapter 6: Geopotential

- 20 July 2006: The file desaiscopolecoef.txt.gz was corrected for an error in the column titles (from S. Desai and R. Gross).
- 22 March 2006: Changes with respect to previous version of the chapter: Corrections and precisions for some notations in section 6.5 "Effect of the ocean tides" (noted by F. Zhang). The file desaiscopole2004.txt was corrected to be consistent with the model of the Conventions (noted by M. Nitschke).
- 13 March 2006: Main changes with respect to previous version of the chapter: New section 6.3 on Oceanic pole tide (from S. Desai and J. Chen). Information on the treatment of degree 1 harmonic coefficients is given in the beginning of the chapter (from J. Ries).

Chapter 7: Displacements of reference points

- 20 June 2007:
  - The subroutine dehanttideinel.f has been updated. It remains under review for some other possible corrections (which effects should be < 0.05 mm).
  - The dutc subroutine has been corrected (from H. Manche). The effect is < 0.05 mm.
  - The step2diu subroutine has been corrected (from V. Tesmer). The effect may exceed 0.1 mm.

- 25 November 2006: Main changes with respect to previous version of the chapter:
  - Section 7.1.1 on Ocean loading has been rewritten (Contributors M. Bos, G. Petit, J. Ray, H.-G. Scherneck).
  - A conventional implementation of ocean tidal loading is recommended, using the program hardisp.f provided by D. Agnew.
- 1 September 2006: Main changes with respect to previous version of the chapter:
  - New section 7.1.5 on Oceanic pole tide loading (from S. Desai).
  - Specification of the IERS conventional mean pole as the linear model in section 7.1.4 equ 23.
  - At and around equ 24: to correct for a typo and to account for the anelastic contributions to the pole tide (from J. Wahr).
  - Subroutine dehanttideinel.f has been updated for leap seconds and commented (from J. Ray).

Chapter 8: Tidal Variations in the Earth's Rotation

- 28 April 2006: Changes with respect to previous version of the chapter: The caption of Table 8.2b has been correctly placed.
- 6 February 2006: Changes with respect to previous version of the chapter: The second paragraph provides some recommendations for users and the last paragraph corrects errors in past publications. The caption of Table 8.1 has been expanded.

Chapter 9: Tropospheric Model

- 28 June 2007: Changes with respect to previous version of the chapter: Chapter 9 has been completely rewritten. The main contributors to the new writing of the chapter are J. Boehm, G. Hulley, A. Niell, E. Pavlis.

Gérard Petit, Brian Luzum

3.5.4 ICRS Centre

Introduction

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

Maintenance and extension of the ICRF

Some activities of the Paris Observatory IVS Analysis Center (OPAR, Gontier, Lambert & Barache 2007) are linked to the ICRS maintenance and improvement of quasar catalogues, and are also in relation to the IAU/IVS/IERS working group “Second realization of the ICRF”. In parallel to the operational VLBI solutions (EOP and global terrestrial and celestial reference frames), we have computed time series of radio source coordinates for approximately 500 radio sources. Most of the available diurnal VLBI sessions involving at least three antennas from 1984 are processed. To provide time series of coordinates in ICRS, all sources are estimated as local parameters, except five sixth of the 247 stable sources (Feissel-Vernier et al. 2006) estimated as global parameters and used for the no-net-rotation condition with respect to ICRF-Ext.2 (Fey et al. 2004). To obtain time series for all observed sources six analyses are conducted. Figure 1 shows an example of time series for the source 1803+784. In a second step the series will be investigated to determine a set of stable sources that could be used to define the axes of the next ICRF. All of these products and related statistics are made available on the OPAR Analysis Center web site (<http://ivsopar.obspm.fr>, launched in October 2006) in both ASCII and VOTable format. They are updated quarterly.

Another research area is the estimation of the contribution from the instabilities in the celestial reference frame to nutation estimates, in the context of the on-going efforts to identify the various sources of the uncertainties in the estimates, and to minimize further contributions to these uncertainties (Lambert et al. 2007).

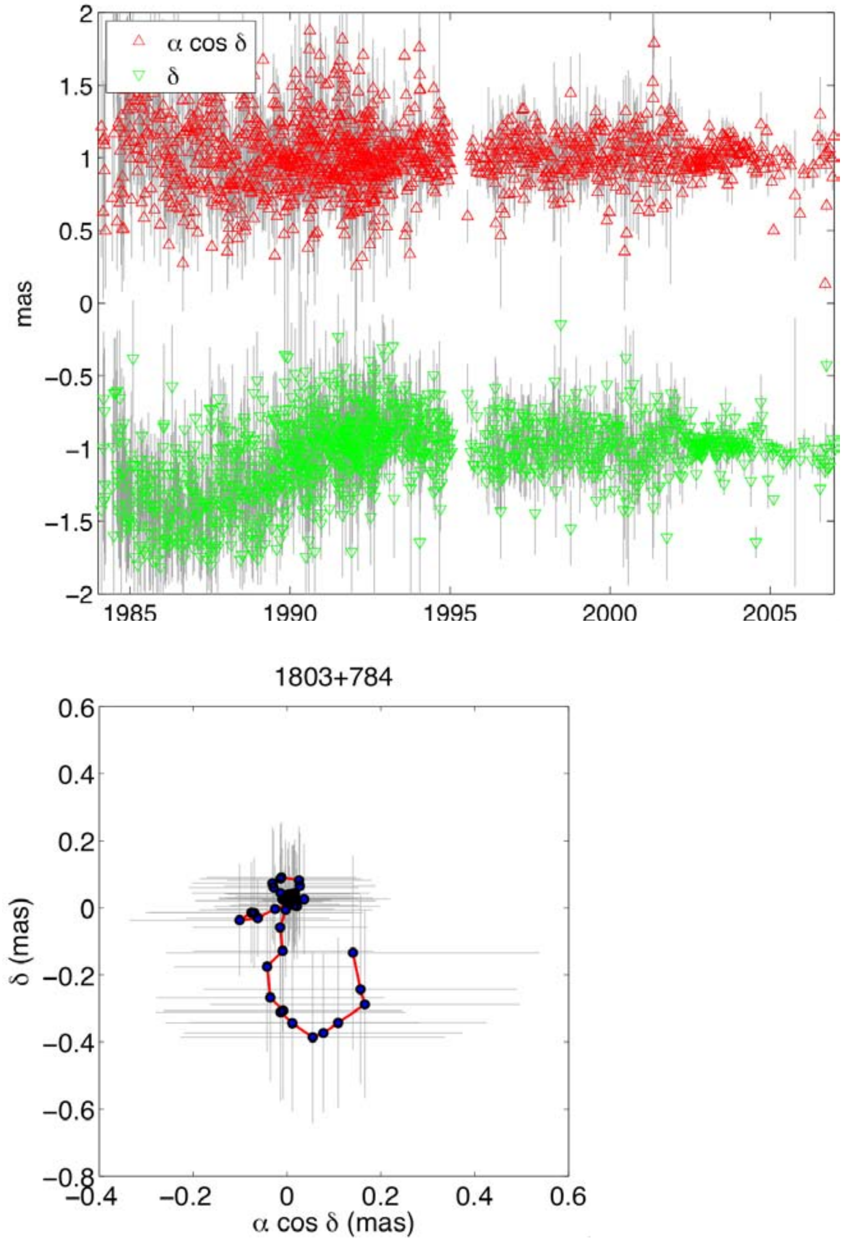

Fig. 1: Radio source 1803+784. Top: positions by sessions. Bottom: semi-annual positions.

Investigation of future realizations of the ICRS

Involvement by ICRS Centre personnel in the celestial reference frame VLBI program continued in 2006, increasing the number of observations of ICRF quasars in the southern celestial hemisphere and continuing an extensive observing program in the northern hemisphere. This observing program will eventually result in a new realization of the ICRS, tentatively called ICRF 2. Plans for the formulation of ICRF 2 were discussed at XXVIth General Assembly of the International Astronomical Union (IAU) held in Prague, Czech Republic in August 2006. In the Southern Hemisphere, the USNO and the Australia Telescope National Facility (ATNF) are collaborating in a continuing VLBI research program in Southern Hemisphere source imaging and astrometry using USNO, ATNF and ATNF-accessible facilities. These observations are aimed specifically toward improvement of the ICRF in the Southern Hemisphere, by a) increasing the reference source density with additional S/X-band bandwidth-synthesis astrometric VLBI observations, and b) VLBI imaging at 8.4 GHz of ICRF sources south of $\delta = -20°$. New milliarcsecond accurate astrometry of 34 Southern Hemisphere radios sources was obtained in 2006. In the Northern Hemisphere a major source of VLBI data continues to be the series of RDV experiments, which consist of 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. These VLBA RDV observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames. During calendar year 2006, six VLBA RDV experiments were observed and images from four RDV experiments were added to the USNO Radio Reference Frame Image Database (RRFID). In addition VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2006. These observations are part of a joint program between the National Aeronautics and Space Administration, the USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory. Images at K-band from one experiment were added to the RRFID.

In the coming decades, there will be significant advances in the area of space-based optical astrometry. Proposed and scheduled missions such as the National Aeronautics and Space Administration's (NASA) *Space Interferometry Mission* (SIM-PlanetQuest) and the European Space Agency's (ESA) *Gaia* mission will achieve astrometric positional accuracies well beyond that presently obtained by any ground-based radio interferometric measurements. In 2006, ICRS Center personnel continued their participation in the NASA SIM mission, through direct involvement in one of the SIM key science projects: *Astrophysics of Reference Frame Tie Objects*. In addition, ICRS Center personnel have been working on concept development for a microsatellite based astrometric mission, called the Joint Milli-Arcsecond Pathfinder Survey (J-MAPS), to produce milliarcsecond level astrometry for all of the bright stars up to 12th magnitude (limiting magnitude ~15–16). Together with several government and industrial partners, in 2006 ICRS Center personnel completed a preliminary concept study with the goal of better understanding mission related costs, schedule, and risks.

Monitor source structure to assess astrometric quality

VLBA RDV Imaging

As discussed above, 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 in 2006. These VLBA RDV observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames. During the calendar year 2006, six VLBA RDV experiments were observed and images from four RDV experiments were added to the USNO Radio Reference Frame Image Database (RRFID).

VLBA High Frequency Imaging

As also discussed above, VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2006. These observations are part of a joint program between the National Aeronautics and Space Administration, the USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory. During the calendar year 2006, one VLBA high frequency experiment (BL122C) was calibrated, imaged and added to the Radio Reference Frame Image Database.

ICRF Maintenance in the Southern Hemisphere

The USNO and the Australia Telescope National Facility (ATNF) are collaborating in a continuing VLBI research program in Southern Hemisphere source imaging and astrometry using USNO, ATNF and ATNF-accessible facilities. These observations are aimed specifically toward improvement of the ICRF in the Southern Hemisphere by a) increasing the reference source density with additional S/X-band bandwidth-synthesis astrometric VLBI observations, and b) VLBI imaging at 8.4 GHz of ICRF sources south of declination –20 deg. New milli-arcsecond accurate astrometry of 34 Southern Hemisphere radios sources was obtained in 2006.

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

The Radio Reference Frame Image Database

The Radio Reference Frame Image Database (RRFID) is a web accessible database of radio frequency images of ICRF sources. The RRFID currently contains 4777 VLBA images of 587 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 1339 images of 274 sources at frequencies of 24 GHz and 43 GHz. The RRFID can be accessed from the Analysis Center web page or directly at <http://rorf.usno.navy.mil/rrfid.shtml>.

Maintenance of the link to the Hipparcos catalog

During the reporting period (2006) progress has been achieved at USNO in several areas related to the maintenance of the Hipparcos link: UCAC project (work toward the final release), the extragalactic and galactic link to radio frame sources, URAT and J-MAPS. Results of all items presented here were also presented at the 2006 IAU General Assembly in Prague with publications upcoming next year.

Software development for the pixel re-reduction of the USNO CCD Astrograph Catalog project proceeded with emphasis on image profile models and double star fitting. The goal is to improve completeness, astrometric and photometric accuracy significantly over the UCAC2. Release of the UCAC3 is scheduled for 2008.

As part of the UCAC project, early epoch photographic plates are being measured on the StarScan machine at USNO to provide proper motions on the Hipparcos system. Measurement of all 2300 Hamburg Zone Astrograph and all 900 USNO Twin Astrograph (Black Birch, New Zealand program) plates were completed in 2006.

Reductions of the deep CCD images taken of extragalactic, compact radio sources during the UCAC project continued. Preliminary results were presented at the Lowell meeting (Zacharias & Zacharias, 2005) and the IAU General Assembly (Zacharias, Zacharias & Rafferty, 2006).

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

VLA and PT observations of 46 radio stars obtained at multiple epochs will be summarized in an *Astronomical Journal* paper (Boboltz et al. 2007). The radio positions (ICRF) are consistent with the optical Hipparcos Catalogue Reference Frame (HCRF) on the 1-sigma level of internal errors.

The program for the USNO Robotic Astrometric Telescope (URAT) project has been developed further (Zacharias et al, 2006). The detector development for URAT has been successful. In June 2006 a wafer run produced the world largest, monolithic CCDs with 111 million pixels (95 mm by 95 mm). Phase 1 of the URAT project will have 4 of these detectors mounted at a new focal plane assembly at the USNO “redlens” astrograph. The goal is to produce an all-sky astrometric catalog more accurate than UCAC and 2 magnitudes deeper, including proper motions and parallaxes on the HCRF utilizing Tycho-2 as reference stars.

In a joint effort with USNO and Paris Observatory, Rio de Janeiro observatory took the lead and started work on an astrometric catalog of quasars utilizing the USNO B1, GSC2.3 and SDSS DR5 catalogs. Target positions are corrected with local reductions to the UCAC (Andrei et al. 2006).

Based on a stare-mode operations concept (Zacharias & Dorland, 2006) the Joint Milli-Arcsecond Pathfinder Survey (J-MAPS) space mission has been developed further. If successful, this micro-satellite will produce an all-sky catalog on the 1 mas level for many millions of stars at a 2011 mean epoch. Combining with Hipparcos data, proper motions of better than 0.1 mas/yr can be obtained.

Linking the ICRF to frames at various wavelengths

This link appears as a major issue in the present and next decade, with the drastic increase of quasars recorded at various wavelengths, thanks to huge surveys such as the Sloan Digital Sky Survey (SDSS) and the 2dF redshift survey (2QZ). In order to complete our knowledge of the ICRF sources, we have carried out a cross-identification between the ICRF and the last release of the Véron-Cetty and Véron catalogue (2003; hereafter VV2003). The results are gathered in Souchay et al. (2006).

We have shown that a significant part of the ICRF objects are not recorded in VV2003: 17% of the defining sources, 30% of the candidate ones and 11% of the other ones. Nevertheless, the remaining common identifications enable one to point out some general trends of the ICRF quasars with respect to the average properties of quasars (magnitude, redshift, and flux at 6 cm and 11 cm) established from the large set (48 290 objects) of the VV2003 catalogue. They are relatively much brighter, much closer (according to the redshift) and their flux at radio wavelengths comparatively more dispersed as in this last catalogue. In addition to the 403 quasars belonging both to the ICRF-Ext.2 and to the VV2003 catalogue, 63 BL LAC objects and 69 active galaxies (AGN) were cross-identified.

We have also studied the sky coverage of the ICRF catalogue and the VV2003 catalogue. We have shown (Souchay et al., 2006) that some important areas exist on the celestial sphere, for which the closest ICRF quasar is at a distance greater than 10°. On the other hand the zones for which a quasar of the VV2003 catalogue is at a distance greater than 10° is limited mostly to the galactic plane.

Representation of the ICRS at the Optical Wavelength

The HCRF (Hipparcos Catalogue Reference Frame) (ESA, 1997) provides an extension of the ICRF for the optical domain, through the position, proper motion and parallaxes for 120,000 stars with 1 milli-arcsecond level astrometry. A complementary representation of the ICRS has been developed following its defining principles, namely kinematically non-rotating with respect to an ensemble of distant extragalactic objects, aligned to the mean equator and dynamical equinox of J2000.0, and realized by a list of adopted coordinates of extragalactic sources.

This representation, termed OCRF (Optical Celestial Reference Frame), is directly tied to the optical counterpart of the ICRF sources whenever feasible. Starting from an updated, presumably complete, list of QSOs (Souchay et al., 2007), initial optical positions are taken from the catalogues USNO B1.0 (Monet et al., 2002), GSC23 (HST and OATo, Zacharias et al., 2007), and from the Data Release 5 of the SDSS (2006). In the next step, the initial positions are placed onto the UCAC2 reference frame, following an alignment to the ICRF, as represented by the optical counterpart of ICRF sources as well as of the most precise sources from the VLBA calibrator list and from the VLA calibrator list. Finally the OCRF axes are surveyed through spherical harmonics, considering right ascension, declination and magnitude terms. The final resulting frame is globally tied to the ICRF at the milli-arcsecond level, and individual positions have typical accuracies better than 100mas. A first instalment of the OCRF, containing 46,000 objects, was presented in the JD16 at the Prague XXVIII IAU GA (Andrei et al., 2006). The next release will be available soon and will contain 110,000 objects.

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

Lunar laser observations (LLR normal points) consist in measurements of the round-trip travel time of the light between a terrestrial station and a lunar reflector. There are more than 17000 LLR normal points provided between 1969 and 2006 by three stations: McDonald 1969–2006 (Fort Davis, Texas), Observatoire de la Côte d'Azur 1984–2005 (Grasse, France), Haleakala 1987–1990 (Maui, Hawaii). Several analyses on the LLR data have been performed by the lunar analysis center POLAC (Paris Observatory Lunar Analyses Center) located at SYRTE laboratory (Observatoire de Paris, France). Some of them concern in particular the orientation of the solar system dynamical reference frame with respect to other reference frames.

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

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

The evaluation of these two angles is involved in the transformation of the rectangular coordinates of the LLR stations from the terrestrial reference frame to the celestial reference frame taking into account the polar motion, the Earth rotation and the orientation of the celestial pole. The precession-nutation matrix is computed with the IERS conventions using the daily corrections of the nutation in longitude and obliquity provided by IERS (Earth Orientation Center series C04). The global root mean square of the post-fit residuals between observed and computed values of the distance station-reflector over the interval [1995–2006] is 4.2 cm for McDonald observations and 3.8 cm for OCA observations. The last determination is:

$$\varepsilon^{(ICRS)} = 23°26'21.411'' \quad \text{(formal uncertainty: 0.001 mas)}$$

$$\varphi^{(ICRS)} = o^{(ICRS)}\gamma_I^{(ICRS)} = -0.055 \text{ mas} \quad \text{(formal uncertainty: 0.001 mas)}$$

These results have been realized with the weighted fits of the lunar solution ELP to the LLR observations provided between 1972 and 2006 by the LLR stations: 9634 observations from Grasse, 7143 observations from Fort-Davis and 482 observations from Maui.

Maintenance of the link to solar system dynamical reference frame using pulsar timing

In the case of pulsar timing, the solar system dynamical reference frame is realized by the dynamical mean equator and equinox at J2000 related to the planetary ephemerides used in the reduction process of the timing data. Using different planetary ephemerides implies that the deduced positions of the pulsars are expressed in different mean equators and equinoxes. Furthermore, the accuracy in the determination of pulsar positions can reach a few mas in a frame consistent with the IERS 2003 conventions implemented in the new software of reduction of the pulsar timing data, Tempo2 (Hobbs et al. 2006). Comparing positions thus gives very accurate information about the relations between the planetary ephemerides reference frames. In the other hand, if the same pulsars are also observed with VLBI, comparisons between positions deduced from pulsar timing obtained in the dynamical reference frame of the planetary ephemerides and VLBI differenced positions to ICRF sources give the direct link between the planetary ephemerides dynamical reference frame and the ICRF.

In modern planetary ephemerides, an indirect link to ICRF is obtained by using differenced positions of planets versus ICRF sources obtained during VLBI tracking of space missions. The differenced positions are given with few mas accuracy but are highly dependent on space missions. Another independent link between planetary ephemerides reference frames and ICRF is thus necessary to ensure the maintenance of the tie.

Impact of using different planetary ephemerides in pulsar timing

In a first step, we tested to use two different planetary ephemerides, the JPL DE405 (Standish 1998) and INPOP06 (Fienga et al. 2008) in the reduction process of pulsar timing. We did not want to compare these ephemerides but to estimate the impact of using one of them or the other.

We have analysed pulsar timing data for 4 different pulsars, PSR 1937+21, PSR 1909–3744, PSR 1713+07 and PSR 0437–4715. As one can see on Figure 2, no peculiar signature is induced in post-residuals by the use of DE405 or INPOP06. No significant differences are noticeable in the values of physical parameters except for the deduced new positions of the pulsars. We then have modeled these differences in terms of a rotation matrix relating the positions deduced with DE405 to those obtained in using INPOP06 such as:

$$\begin{bmatrix} PSR\ 1937+21 \\ PSR\ 1909-37 \\ PSR\ 1713+07 \\ PSR\ 0437-47 \end{bmatrix}_{DE405} = R_x R_y R_z \begin{bmatrix} PSR\ 1937+21 \\ PSR\ 1909-37 \\ PSR\ 1713+07 \\ PSR\ 0437-47 \end{bmatrix}_{INPOP06}$$

Then, the angles obtained are:

$\theta = 0.02 \pm 0.7$ mas
$\varphi = -2.0 \pm 0.9$ mas
$\psi = -2.0 \pm 0.7$ mas

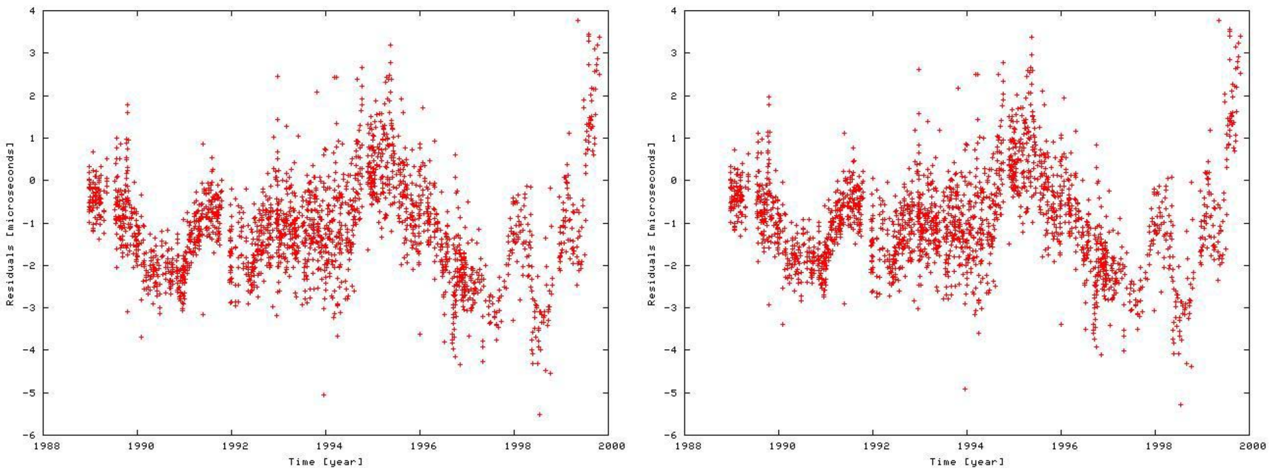

Fig. 2: PSR 1937+21: Differences between received radio signal by the Nancay observatory and the computed signal estimated using the software Tempo2 and two different planetary ephemerides: DE405 and INPOP06.

These values give the link between the reference frame defined by DE405 and the one of INPOP06. These angles are quite similar to those published by some authors (Standish 1998, Chapront et al. 1999, Simon, 2006) for comparisons established for different dynamical reference frames, DE405, ELP2000 and INPOP06, and between ICRF and these dynamical reference frames.

The first conclusion is that pulsar timing data are sensitive to planetary ephemerides only for the deduced positions of pulsars. No other parameters are significantly changed by a change in planetary ephemerides. Thus, the pulsar positions obtained by such process are directly expressed in the reference frame of the planetary ephemerides. Comparisons of pulsar positions deduced from the use of DE405 or INPOP06 in the reduction process give the rotation matrix between their reference frames.

First attempts of comparisons between VLA/VLBI positions and pulsar timing

Since the first discovery of pulsars, few programs related to VLBI or VLA observations of these objects were settled. In 1996, Bartel et al. gave results obtained by comparing positions of PSR 1937+21 with radio timing and the first positions observed using VLBI. Due to the faint signal emitted by the pulsars at VLBI wavelengths, a small number of objects of that kind have been observed since 1996. In fact, only two other objects are found in the literature: PSR 1912+57 observed by Nunes and Bartel (1998), and PSR 2021+51 observed by Campbell et al. (1996). Furthermore, this last object was not observed with radio timing by the Nançay observatory.

On the other hand, a program of pulsar observations was executed with VLA by Brisken et al. and Chatterjee et al. to estimate parallaxes (Brisken et al. 2000, Chatterjee et al. 2001, Brisken 2001). Almost 63 millisecond pulsars have been observed and their positions estimated to the accuracy of the VLA. A first attempt was then to use a sample of milliseconds pulsars observed in radio timing and in VLA. One can then estimate a matrix of rotation between the radio timing positions obtained in the dynamical frame of the planetary ephemerides used in the fit and the VLA positions obtained by differential observations to ICRF sources. This method provides the link between the dynamical reference frame of the planetary ephemerides and the ICRF at the level of accuracy of the VLA observations of pulsars. We then have found 2 pulsars PSR 1713+07 and PSR 1937+21 which were observed with VLA by (Chartterjee et al. 2001) and in radio by (Cognard et al. 2007) at Nançay observatory.

By combining with the same weight the VLA and VLBI positions of the three pulsars (PSR 1937+21, PSR 1713+07, PSR 1912+57), we have estimated a rotation matrix between the dynamical frame of INPOP used in timing reduction and the ICRF at the VLA accuracy. We have obtained the following values for the 3 angles:

$\theta = -114 \pm \ 85$ mas
$\varphi = -\ 85 \pm 135$ mas
$\psi = -121 \pm \ 80$ mas

These values are quite larger than the expected accuracy of the timing data (few mas) but are consistent with the accuracy of the VLA relative astrometry to ICRF sources. A test with a denser sample of pulsars has to be made, but it seems that the VLA observations are not accurate enough to maintain a link between the dynamical frame of the planetary ephemerides and the ICRF at a mas level.

Conclusions and perspectives

There is now an urgent need to densify the number of millisecond pulsars observed with VLBI versus ICRF sources at the mas level demonstrated by this study. This task will be taken in charge at the Besançon Observatory in collaboration with the Paris Observatory (SYRTE) and the Nançay Observatory. A procedure for preparing such observations will have to be settled on as well as a reduction process. Criteria to optimize the selection of millisecond pulsars, which have to be observed in VLBI are on the way, and a first list of candidates will be submitted to the IVS. We hope then to densify the number of points linking the dynamical frame of the planetary ephemerides and the ICRF at a mas level.

Maintenance and developments of the website of the ICRS Center

The ICRS Center website <http://hpiers.obspm.fr/icrs-pc> has been recently updated. The following products are added:

- ICRF extension 2 catalogue of sources positions (717) and associated graphs
- Physical characteristics of ICRF extension 1 radio sources
- Time series of radio source coordinates into VOTable File.

VOTable File is a standard of IVOA (International Virtual Observatory Alliance). Time series provided with this format could be read and analysed directly by all the VO (Virtual Observatory) compatible freeware tools like:

- Aladin (freeware provided by CDS of Strabourg to manipulate star or quasar catalogues and data imaging associated with these topics: see <http://aladin.u-strasbg.fr/aladin.gml>),
- Topcat (freeware provided by Taylor et al. to manipulate VOTable, to make plots and cross matching for astronomy: see <http://www.star.bris.ac.uk/~mbt/topcat>),
- Stilts (public API provided by Mark Taylor and all used to make scripts for Topcat: see <http://www.starlink.ac.uk/stilts>)
- VOPlot (freeware provided by the Virtual Observatory – India tools to make astronomy plots: see <http://vo.iucaa.ernet.in/~voi/voplot.htm>).

Using these tools we have constructed a database of quasars in standard VOTable File format containing unique and homogeneous astrometry and physical data (optic and radio). For that project we have cross-matched 8 of the largest QSO catalogues (provided by the CDS and also directly from the web site of the Survey itself).

We have developed some tools around the VO freeware Topcat and Stilts to create our own file format for QSO's with all the necessary data and references. Moreover we kept the original data (in particular information concerning the catalogue of origin) and convert it into VOTable. We have also created scripts to provide automatic cross-match and to explain the ways to easily cross match the main large QSO catalogues. This work using the VO tools was validated by comparison with results obtained by independent FORTRAN programs.

Seven selected catalogues (ICRF-Ext.2, VLBA, VLA-015, JVAS, SDSS, 2QZ, FIRST) have already been processed resulting in the following data: 99 977 QSO coordinates, 96 2005 redshifts, 95 788 U, 74 869 G, 2394 B magnitudes, 3 235 flux at GHz, 910 flux at 5Ghz and 3 876 flux at 8.4Ghz.

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3.5.5 ITRS Centre

This report summarizes the activities of the IERS ITRS Centre during the year 2006.

ITRF2005

The ITRS Centre coordinated the activities of the ITRS Combination Centres as well as the interaction with the Technique and Analysis Centres that contributed to the ITRF2005 project. The ITRS Centre coordinated also the ITRF2005 evaluation process, before the official release of the ITRF2005 products in October 2006. A dedicated web site was constructed where all the results of the ITRF2005 are available to the users: <http://itrf.ensg.ign.fr/ITRF_solutions/2005/ITRF2005.php>

Maintenance of the IERS network

The ITRS centre assigns DOMES numbers to geodetic tracking stations or markers as unambiguous identifications of points in space, independently from the technique of their tracking instruments. The IERS network database, which contains the descriptions of the sites and points, is continuously updated as DOMES numbers are assigned. DOMES number requests can be submitted on line via the ITRF web site.

ITRF web site

The ITRF web site, available at <http://itrf.ensg.ign.fr>, provides an interface to consult the IERS network database. Site and point information can be requested on line; it contains approximate coordinates of the sites, the list of their points as well as their descriptions, their DOMES numbers and the list of ITRF versions in which they have been computed. Subsets of points can be selected and their ITRF coordinates can be requested at any time in any ITRF version if their coordinates are provided in the requested ITRF version.

The ITRF web site has been updated to include a cartographic server. The maps of the ITRF networks can be displayed depending of the measurement techniques and of the ITRF versions. Velocity vectors can be displayed as well as tectonic plates. Site information is now available with simple clicks and site selection has been simplified. The dynamical map can help users to familiarize with ITRF products and can be used for educational purpose. It can also be an interesting tool to select IERS sub-network depending on the measurement techniques, co-located hosted instruments or ITRF versions.

ITRF94, ITRF96, ITRF97, ITRF2000 and ITRF2005 solutions are available for download. ITRF2005 solution is now available as well as ITRF2005 combination coordinate residuals and position residual time series per technique. Local ties information has been updated for ITRF2005 processing and is also available for download in SINEX format or tables.

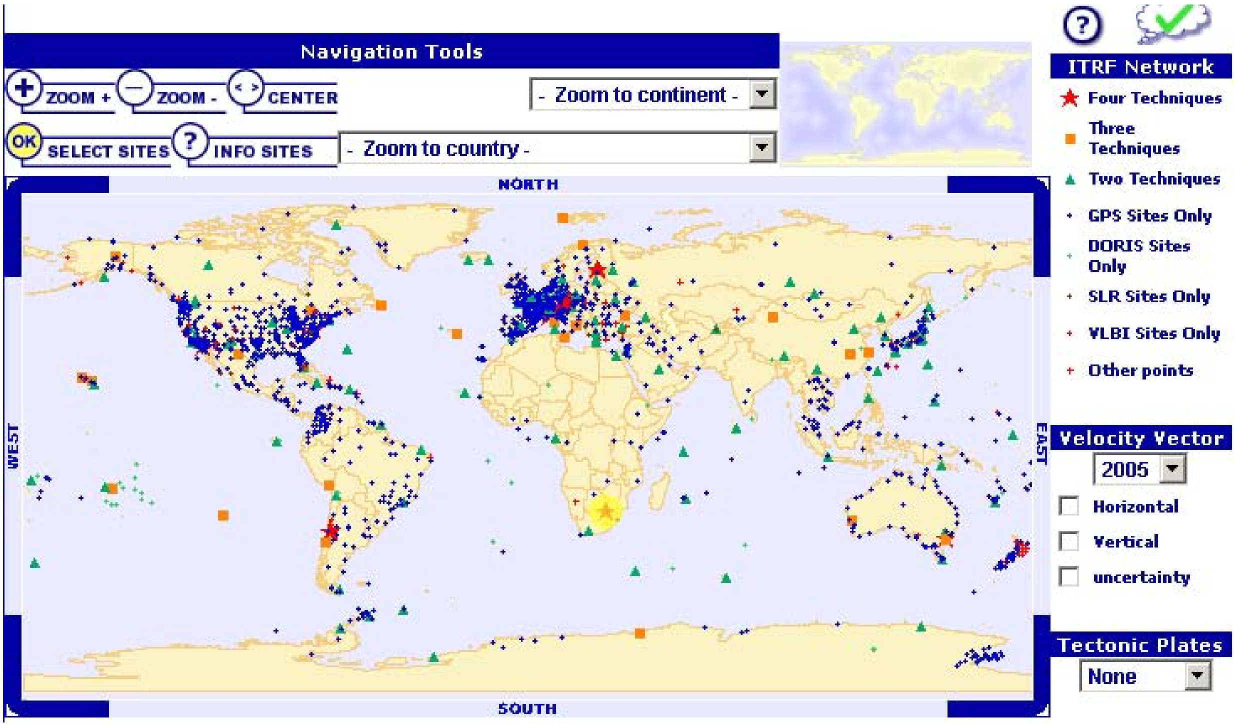

Fig. 1: ITRF web site dynamical map of the IERS network. <http://itrf.ensg.ign.fr>

Local ties of ITRF Co-location sites

The ITRS Centre has undertaken the initiative to animate the activity related to the reanalysis of available new and/or old surveys data of the ITRF co-location sites with the aim to generate SINEX files of local ties with full variance-covariance information. Starting with the available survey data at IGN, the ITRS Centre generated full SINEX files for approximately all DORIS co-located sites, using Geolab adjustment software. These SINEX files as well as other files made available by other groups (INA and CGS, Italy; BKG, Germany and Geoscience Australia) are posted at the ITRS web site. The local ties SINEX files used in the ITRF2005 computation are available at <http://itrf.ensg.ign.fr/local_surveys.php>.

Zuheir Altamimi, Xavier Collilieux, Bruno Garayt

3.5.6 Global Geophysical Fluids Center (GGFC)

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

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

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

In December 2006, the GGFC held a workshop in San Francisco to discuss the status of the GGFC and to evaluate if the format should be redesigned to better serve the geodetic community (see also Section 4 of this Annual Report). Numerous arguments for and against a redesign were discussed. In the end, the community and the GGFC chairs felt that we should consider a redesign in the long term. And in the short term, we should focus on validating and providing error assessments for the surface models and their geodetic effects. This is action represents the focus of the GGFC Special Bureaus for the coming years.

Tonie van Dam

Special Bureau for the Atmosphere

In conjunction with the U.S. National Oceanic and Atmospheric Administration (NOAA) the SBAtmosphere has produced data from several 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. That mode is under the direction of Craig Long of NOAA, since November 2006. In the second mode, it updates monthly archives of the data on the FTP server at Atmospheric and Environmental Research, Inc. (AER).

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

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.

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

During 2006 we continued investigations of using atmospheric models for more rapid subdiurnal scales. Fields from one of the NASA models can be extracted hourly, in between the six-hour analyses that are routinely used. We have been investigating the feasibility of calculations of the atmospheric excitation terms for the Earth orientation parameters. A test period was October 2002, during the special CONT'02 campaign in which measurements from Very Long Baseline Interferometry developed high temporal resolution data. Various issues involved the discontinuities at the 6-hour marks when analyses were made, and we established techniques to lessen these discontinuities. Also, we are now awaiting results from a new analysis in which a smoother signal, not subject to such discontinuities, is expected.

Dr. Katherine Quinn has been assisting in some analyses and the preparation of some new data sets, including Earth rotation/polar motion excitations from the ECMWF 40-year reanalysis (ERA-10) and a new set of NCEP reanalyses (called the NCEP-2 reanalyses).

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

Results of the SBA were presented at the European Geosciences Union meeting, the American Geophysical Union meeting, and a special workshop of the IERS Global Geophysical Fluids Center.

Analyses and forecasts are being provided to the campaign for prediction of Earth orientation parameters.

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Acknowledgments

The U.S. National Science Foundation has supported activities, at AER of the SBA, and the visit of Dr. Nastula, under Grant ATM-0429975.

David Salstein

Special Bureau for the Oceans

Introduction

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans. As part of the IERS Global Geophysical Fluids

Center, the Special Bureau for the Oceans (SBO) is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO web site at <http://euler.jpl.nasa.gov/sbo> are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, and bottom pressure.

Data Products

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

(1) ponte98.oam, a series computed by Ponte *et al.* (1998) and Ponte and Stammer (1999, 2000) from the products of a simulation run of the MIT ocean general circulation model which spans January 1985 to April 1996 at 5-day intervals;
(2) johnson01.oam, a series computed by Johnson *et al.* (1999) from the products of version 4B of the Parallel Ocean Climate Model (POCM) which spans January 1988 to December 1997 at 3-day intervals;
(3) c20010701.oam & c20010701.chi, a series computed by Gross *et al.* (2003, 2004) from the products of a simulation of the oceans' general circulation run by the Estimating the Circulation and Climate of the Ocean (ECCO) group at JPL which spans January 1980 to March 2002 at daily intervals and which is available either as a series of angular momentum values (c20010701.oam) or as a series of effective excitation functions (c20010701.chi);
(4) ECCO_50yr.oam & ECCO_50yr.chi, a series computed by Gross *et al.* (2005) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1949 to December 2002 at 10-day intervals and which is available either as a series of angular momentum values (ECCO_50yr.oam) or as a series of effective excitation functions (ECCO_50yr.chi); and
(5) ECCO_kf049f.oam, ECCO_kf049f_6hr.oam, & ECCO_kf049f_6hr.chi, a series computed by Gross *et al.* (2005) from the products of a data assimilating model of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2006 at both 6-hour and daily intervals and which is available either as a series of angular momentum values (ECCO_kf049f.oam & ECCO_kf049f_6hr.oam) or as a series of effective excitation functions (ECCO_kf049f_6hr.chi).

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

(1) dong97_mom.cm, a series computed by Dong *et al*. (1997) from the results of a version of the Modular Ocean Model (MOM) run at JPL which spans February 1992 to December 1994 at 3-day intervals;
(2) dong97_micom.cm, a series also computed by Dong *et al*. (1997) from the results of running the Miami Isopycnic Coordinate Ocean Model (MICOM) at JPL which also spans February 1992 to December 1994 at 3-day intervals;
(3) c20010701.cm, a series computed by Gross (personal communication, 2003) from the results of a simulation run of the ECCO ocean model done at JPL which spans January 1980 to March 2002 at daily intervals;
(4) ECCO_50yr.cm, a series computed by Gross (personal communication, 2004) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1949 to December 2002 at 10-day intervals; and
(5) ECCO_kf049f.cm, a series computed by Gross (personal communication, 2004) from the products of a data assimilating model of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2006 at daily intervals.

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

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

Acknowledgments

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Richard Gross

Special Bureau for Tides

There were only a few minor activities to report regarding the Special Bureau for Tides. Some additional tables of tidal Earth rotation parameters were added based on some newly developed tidal models. Our Tide Prediction Machine was unfortunately disabled because of security risks; there were two users who reported being impacted by this – in both cases they were oceanographers using the machine for standard sea level tide predictions.

Richard Ray

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 five numerical models, the NCEP (National Center for Environmental Prediction) reanalysis, the ECMWF (European Center for Medium Range Weather Forecasting) reanalysis, the CPC (Climate Prediction Center) Land Data Assimilation System (LDAS), the NASA's Global Land Data Assimilation System (GLDAS), and the NOAA LaDWorld land dynamics model. Global terrestrial water storage changes estimated from GRACE (Gravity Recovery and Climate Experiment) time variable gravity observations during the period April 2002 and November 2005 are also provided in our online data archive (at <http://www.csr.utexas. edu/research/ggfc/>). The NASA GLDAS and CPC LDAS data products are updated on a regular basis.

As a new addition to our online data archive, LaDWorld is global land dynamics model developed by scientists at the NOAA Geophysical Fluid Dynamics Laboratory. Simulated variables include snow water equivalent, soil water, shallow ground water, soil temperature, evapotranspiration, runoff and streamflow, radiation, and sensible and latent heat fluxes. This particular simulation (named Fraser and released in March 2007), differs from previous runs in the temporal extent of the simulation, which runs through November 2006. Additionally, the initial condition is one that is better equilibrated with climatic forcing. The improved initial condition removed a minor spin-up issue that had affected earlier LaDWorlds. Details of the LaDWorld models are available online at <http://www.gfdl.noaa.gov/~pcm/project/ladworld.htm>.

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

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

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

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

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

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

Table 1 summarizes the current datasets in our online data archive (<http://www.csr.utexas.edu/research/ggfc/>).

Jianli Chen

Table 1: GGFC SBH Online Data Archive

Parameters	Sources	Information
Water Storage Change From GRACE	GRACE (Gravity Recovery And Climate Experiment)	Time Span: Apr/May 2002 - Nov 2005 Sampling Rate: Monthly, 40 Solutions CSR RL01 Constrained (k20) Grid: 1 x 1 Degree Grid Gaussian Smoothing: 500, 800, 1000 km Truncation at degree 60, No C20
Water Storage Change From GRACE	GRACE (Gravity Recovery And Climate Experiment)	Time Span: Apr/May 2002 - Jul 2004 Sampling Rate: Monthly, 22 Solutions CSR RL01 Unconstrained Grid: 1 x 1 Degree Grid Gaussian Smoothing: 600, 800, 1000 km Truncation at degree 60, No C20
NOAA LaDWorld Monthly Water Storage (New!)	NOAA LaDWorld (Fraser)	Time Span: Jan., 1980 - Nov., 2006 Sampling Rate: Monthly Grid: 1 x 1 Degree Units: mm of water height
GLDAS Daily Water Storage	NASA Global Land Data Assimilation System	Time Span: Jan. 1, 2002 - April 30, 2006 Sampling Rate: Daily Grid: 1 x 1 Degree Units: mm of water height
CPC Monthly Water Storage	CPC Land Data Assimilation System	Time Span: Jan. 1980 - Dec. 2006 Sampling Rate: Monthly Grid: 1 x 1 Degree
NCEP Daily Water Storage	NCEP/NCAR Reanalysis-I Soil Moisture and Snow	Time Span: Jan. 1979 - Dec. 2004 Sampling Rate: Daily Grid: Gaussian (T62), ~1.904 x 1.875 Degree
ECMWF Daily Water Storage	ECMWF Reanalysis Soil Moisture and Snow	Time Span: 1979 - 1993 Sampling Rate: Daily Grid: 2.5 x 2.5 Degree
Water Storage	NCEP/NCAR Climate Data Assimilation System I (CDAS-1) soil moisture and snow	Time Span: 1993 - 1998 Sampling Rate: Monthly Grid: 1 x 1 degree
Water Flux	NCEP/NCAR Climate Data Assimilation System I (CDAS-1) soil moisture and snow	Time Span: 1993 - 1998 Sampling Rate: Monthly Grid: 1 x 1 degree

Special Bureau for Mantle

No report submitted.

Special Bureau for the Core

Introduction

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

Tim Van Hoolst

Special Bureau for Gravity/Geocenter

In 2006, the Special Bureau for Gravity and Geocenter continued nominal operations, functioning primarily as a portal for obtaining GRACE and SLR gravity solutions which are generally produced by groups external to the SB. We received a record number of web hits in 2006, due primarily to the increasing interest in GRACE data. SBGG personnel also participated in the development of a separate website that provides high-level data products from GRACE, and we have discussed the possibility of merging these or other related sites at some point in the future. This will continue to studied in the upcoming year as we monitor the user requests.

In addition, SBGG personnel continued to participate very significantly in the development of dealiasing products for GRACE. These products primarily include daily atmospheric and ocean mass distribution models, and often have significant overlap with the interests and motives of the other SB's. We therefore maintain at least annual communication with these SB's about the status and capability of these products for comparison and validation as needed. We expect this may become a larger job as more users migrate to the project data centers for the access of the routine gravity solutions.

Michael M. Watkins

Special Bureau for Loading

Introduction

The solid Earth is constantly impacted by loads due to mass relocations in the atmosphere, oceans, cryosphere and terrestrial water storage. These loads deform the Earth, change the gravity field and introduce perturbations in Earth's rotation. Mass redistributions occur on a wide range of time scales including those of tsunamis (minutes to hours), tides (semi-diurnal, diurnal, fortnightly, monthly, and seasonal), meteorological (several days) and climatological changes (seasonal to multi-decadal), and changes in the ice cover (years to millenniums). These deformation, if not account for correctly, affect the geodetic terrestrial reference frame and can lead to a significant degradation in accuracy. Loading signals in the vertical component significantly exceed the 10 mm level at diurnal and seasonal time scales, while secular signals associated with postglacial rebound are on the level of 10 mm/yr. Surface displacements induced by seasonal exchanges between ocean and terrestrial hydrosphere are of the order of 10 mm. Thus, achieving a reference frame with sub-millimeter accuracy requires accurate modeling of the loading signals both for station motion models and the alignment of geodetic solutions to the *International Terrestrial Reference Frame* (ITRF). It is the task of the *Special Bureau for Loading* (SBL) to provide predictions of the loading signals for research as well as operational space-geodetic analyses.

SBL goals and contributions

The SBL, which was established in 2002 in response to an expressed need for standardized loading predictions, is part of the IERS Global Geophysical Fluid Center. It has the goal to provide predictions of surface-load induced changes in the Earth's geometry, gravity field and rotation. The initial goal of the SBL was the provision of predictions of changes in Earth's geometry induced by atmospheric loading, preferably in near-real time. In 2003, time series of predicted station displacements due to atmospheric loading were made available for the stations in the main global and regional geodetic networks. These predictions (denoted as Research Products) are available for different atmospheric pressure data sets, Earth models, and computational approaches (see Van Dam et al., 2003, for more details) and they are intended mainly for research. In 2004, the semi-operational near-real time provision of station displacement as well as global grids was started. These products (denoted as Operational Products) are made available for air pressure provided by the *European Center for Medium Range Weather Forecast* (ECMWF), only (see <http://www.sbl.statkart.no/products> for more information on these products).

Atmospheric loading

In 2006, the main focus was on the error budget of the atmospheric loading computation. The goal of the SBL is to achieve predictions with an accuracy of the daily displacements of better than 1 mm in all three coordinate components. Main contributions to the error budget come from differences in the meteorological data sets themselves, miss-modeling of the topographic effect, and miss-modeling of the ocean response to atmospheric pressure and wind forcing. The reference pressure field used to compute the pressure anomaly also needs considerable attention in order to avoid a significant deformation of the ITRF reference polyhedron.

During 2006, progress was made in accurately modeling the effect of Earth's topography on the air pressure anomaly. The long-period variations in air pressure were studied in order to inform a decision on what reference pressure field to use in an ITRF context.

For the prediction of the atmospheric loading signal, the air pressure anomaly is required at a model of the Earth's surface topography with sufficient spatial resolution. The question what spatial resolution would be sufficient is not trivial. In the meteorological models, the Earth's surface is represented by a model orography, typically given with a resolution of one or more degrees. The pressure field at this model orography does not have sufficient spatial resolution to achieve the target accuracy. After some iterations with meteorological institutions (see Plag, 2007, for a summary), an appropriate process of computing pressure at topographic height was found to be based on geopotential heights of isobars. The geopotential heights of isobars are model parameters, which are provided by the meteorological centers for a number of pressure levels on a routine basis. With spatial interpolation (both horizontally and vertically), pressure at topographic height can be computed in a straightforward procedure (see Plag et al., 2007, for details).

In order to quantify the long-term variations in air pressure, decadal averages of the surface pressure fields at topographic height were computed. The topographic heights were taken from the ETOPO5 model (<http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML>) and all computations were done with 5 minutes spatial resolution. The geopotential heights were taken from the ECMWF reanalysis data set (ERA 40, <http://data.ecmwf.int/data/d/era40_daily/>), and these data allowed for the computation of four decadal averages. These decadal averages are available through the SBL web page. Variations from decade to decade are of the order of up to ±3 HPa, which translates into a maximum of ±1.5 mm in deformations. The largest interdecadal trends over the full 40 years are of the order of ±6 HPa with the maximum found mainly over the ocean off Antarctica. As a result of these studies, it is concluded that for a given meteorological data set, a reference pressure field can be computed as a decadal average. However, recent comparisons show that differences in mean pressure at topographic height for different meteorological data sets exceed the acceptable limit by far. Therefore, reference pressure fields have to be determined specifically for each data set. An issue still to be studied is how frequent changes in the meteorological models affect the mean pressure field.

Perspective

The computation of the surface pressure anomaly for loading predictions has to use pressure at topographic height, where a spatial resolution of 5 minutes appears to be sufficient. An appropriate procedure for the computation of pressure at topographic height can be based on geopotential heights of isobars. The reference pressure field has to be computed specifically for each meteorological data set in order to keep biases in the loading predictions below the 1 mm level. Based on these criteria, the SBL will recompute all operational products.

Open questions are the impact of temporal inhomogeneities in the meteorological models on the loading predictions, the error associated with the current approach to modeling the ocean response to atmospheric loading, and the spatial resolution required for the computation of loading signal from the (high-resolution) air pressure anomaly. These questions have been addressed in 2007 and will be further resolved in 2008.

Acknowledgment

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Hans-Peter Plag

3.6 Combination Centres

3.6.1 ITRS Combination Centres

3.6.1.1 Deutsches Geodätisches Forschungsinstitut (DGFI)

The activities of the ITRS Combination Centre at DGFI concentrated on the computations for the ITRF2005. This report contains an overview of the ITRF2005 input data and the combination methodology, some major results of the ITRF2005 solution of DGFI (ITRF2005D), and a comparison of the ITRF2005 solutions of IGN and DGFI.

Input data for ITRF2005

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

Tab. 1: Input data sets for ITRF2005 (NNT = no net translation, NNR = no net rotation, NNS = no net scale, NEQ = normal equations)

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

Combination methodology

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

(1) Accumulation of epoch normal equations per technique: In the epoch normal equations velocity parameters were set up and then they were accumulated separately for each technique. Minimum datum parameters were added to generate technique-specific multi-year solutions with station positions, velocities and EOP. In the case of discontinuities position and velocity parameters were set up for the corresponding stations. Time series solutions were computed by transforming the epoch solutions to the multi-year solutions. The resulting time series of station positions and datum parameters were analysed w.r.t. further discontinuities and non-linear effects. A few additional discontinuities were identified during the iterations and considered in the final accumulation.

(2) Inter-technique combination: Input for the inter-technique combination are the accumulated intra-technique normal equations for VLBI, SLR, GPS and DORIS. The parameters comprise station positions, velocities and daily EOP. Concerning the combination of EOP of the different space techniques it has to be considered, that the VLBI estimates are referred to the midpoint of a daily VLBI session (from 17 hr to 17 hr), whereas the EOP values of the other techniques are referred to 12 h. Thus the VLBI EOP estimates have to be transformed to the reference epochs of the other techniques. A key issue within the inter-technique combination is the implementation of local tie information. For this purpose the EOP are essential to validate the local tie selection and to stabilize the inter-technique combination as additional „global ties“. Other issues include the equating of station velocities of co-located instruments and the weighting between different techniques. The intra-technique normal equations are added by applying the weighting factors.

(3) Realization of the geodetic datum: The origin (translation parameters and their rates) is realized by the contributing SLR solutions and the scale and its time variation by SLR and VLBI. The orientation of the ITRF2005 is realized by NNR conditions w.r.t. ITRF2000 using „good“ reference stations to ensure consistency with the Bureau International de l'Heure (BIH) orientation at 1984.0. The kinematic datum of the final ITRF2005 solution is given by an actual plate kinematic and crustal deformation model (APKIM) derived from observed station velocities. A new model (APKIM2005) was computed iteratively from ITRF2005 input data. Fig. 1 shows the residuals of the ITRF2005D station velocities w.r.t. APKIM05D5 for 56 core stations that were used to realize the kinematic datum.

ITRF2005 solution of DGFI (ITRF2005D)

The ITRF2005D solution comprises station positions, velocities and daily EOP estimates as primary results. In addition epoch position residuals and time series of translation and scale parameters are obtained from the combination. Due to the use of discontinuities in the coordinates' time series, many stations get various solutions with different position and velocity estimations. Furthermore co-

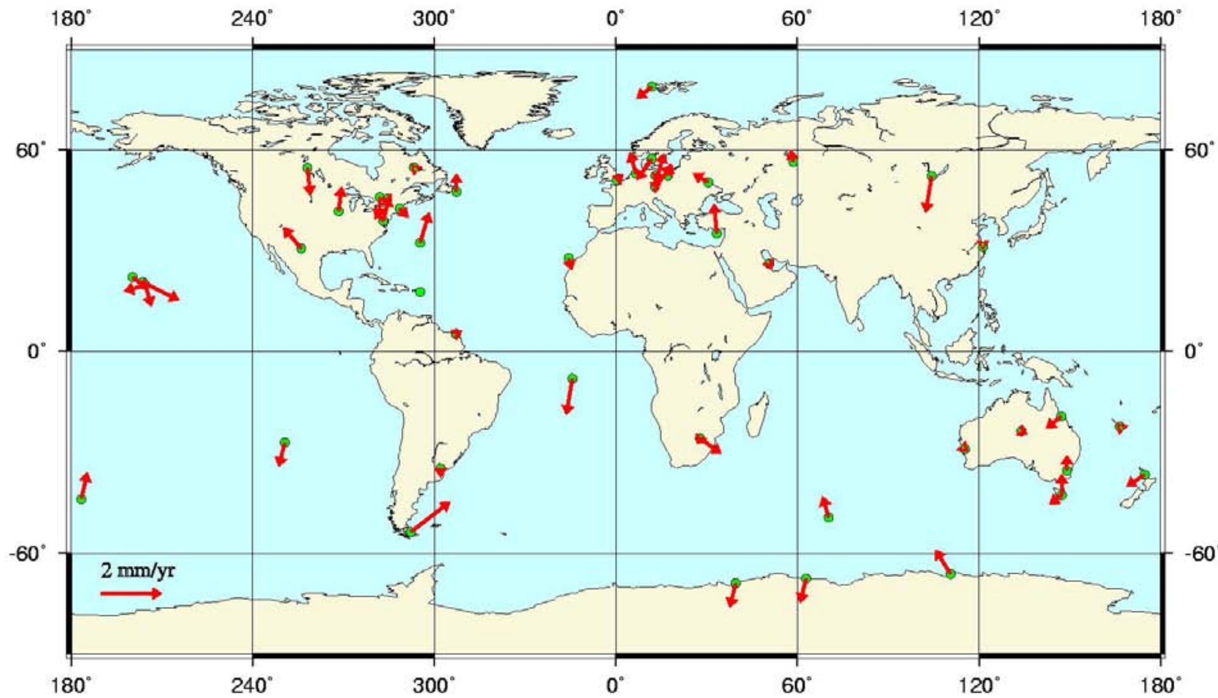

Fig. 1: Station velocity residuals for the 56 core stations, which were used to define the kinematic datum of the ITRF2005D solution w.r.t. APKIM05D5.

location sites may have different station velocities for co-located instruments, if their estimated velocities differ significantly.

Fig. 2 and 3 show the horizonal and vertical station velocities of the ITRF2005D solution. The terrestrial pole coordinates of the ITRF2005D solution w.r.t. IERS C04 are displayed in Fig. 4. There is a significant improvement since mid of 1999, when GPS-derived pole coordinates were included in the combination.

Comparison of ITRF2005 solutions of DGFI and IGN

Two solutions of the ITRF2005 were computed by the ITRS Combination Centres at IGN and DGFI. The combination strategy of IGN is based on the solution level by simultaneously estimating similarity transformation parameters w.r.t. the combined frame along with the adjustment of station positions and velocities. This method is different from the combination on the normal equation level applied at DGFI.

For comparisons we performed similarity transformations between both solutions. These transformations were done separately for each space technique by using „good" reference stations. Most of the transformation parameters agree within their estimated standard deviations, except for the scale and its time variation of the SLR network. A significant difference of about 1 ppb (offset at the reference epoch 2000.0) and 0.13 ppb/yr (rate) between the DGFI and IGN solutions has been found, which accumulates to nearly 2 ppb in 2006.

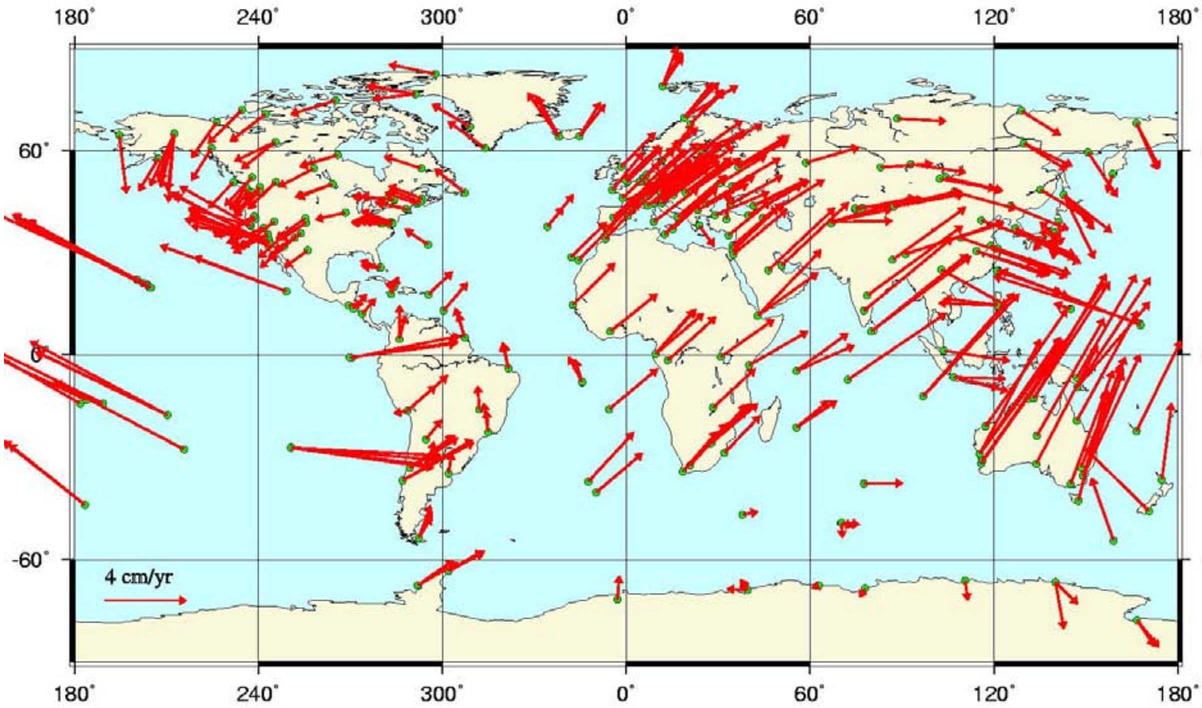

Fig. 2: Horizontal station velocities of the ITRF2005D solution. Note that only velocities with σ_{vel} < 1 cm/yr are drawn.

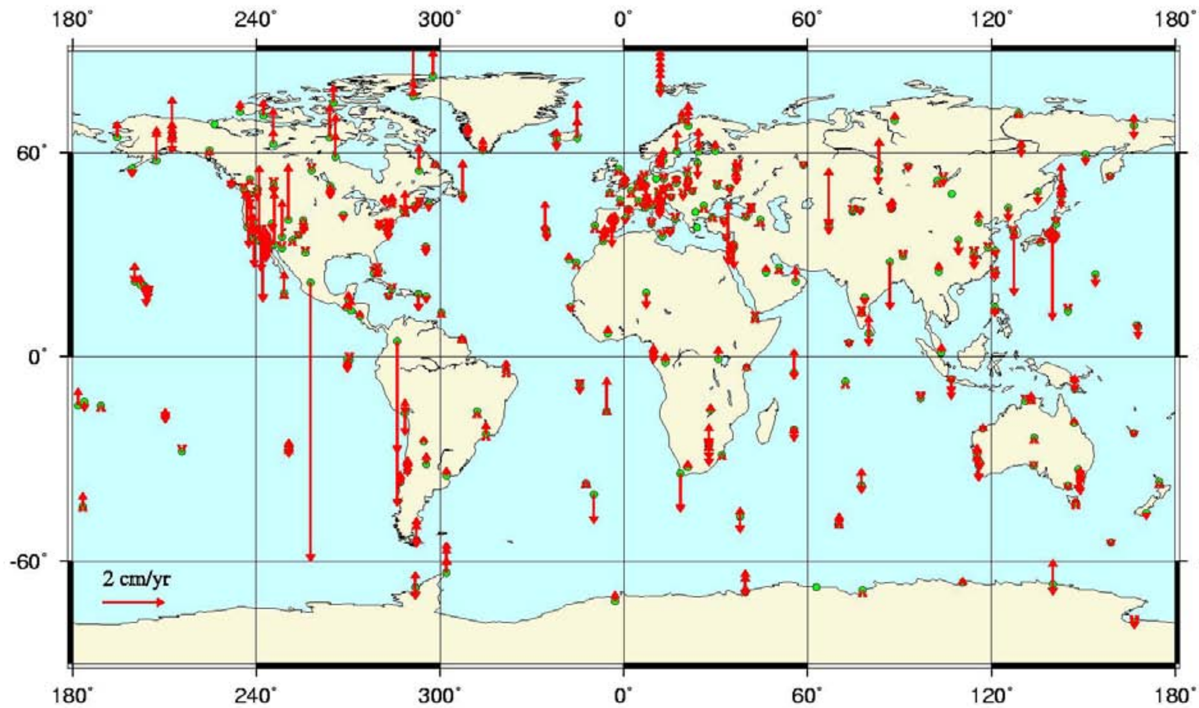

Fig. 3: Vertical station velocities of the ITRF2005D solution. Note that only velocities with σ_{vel} < 1 cm/yr are drawn.

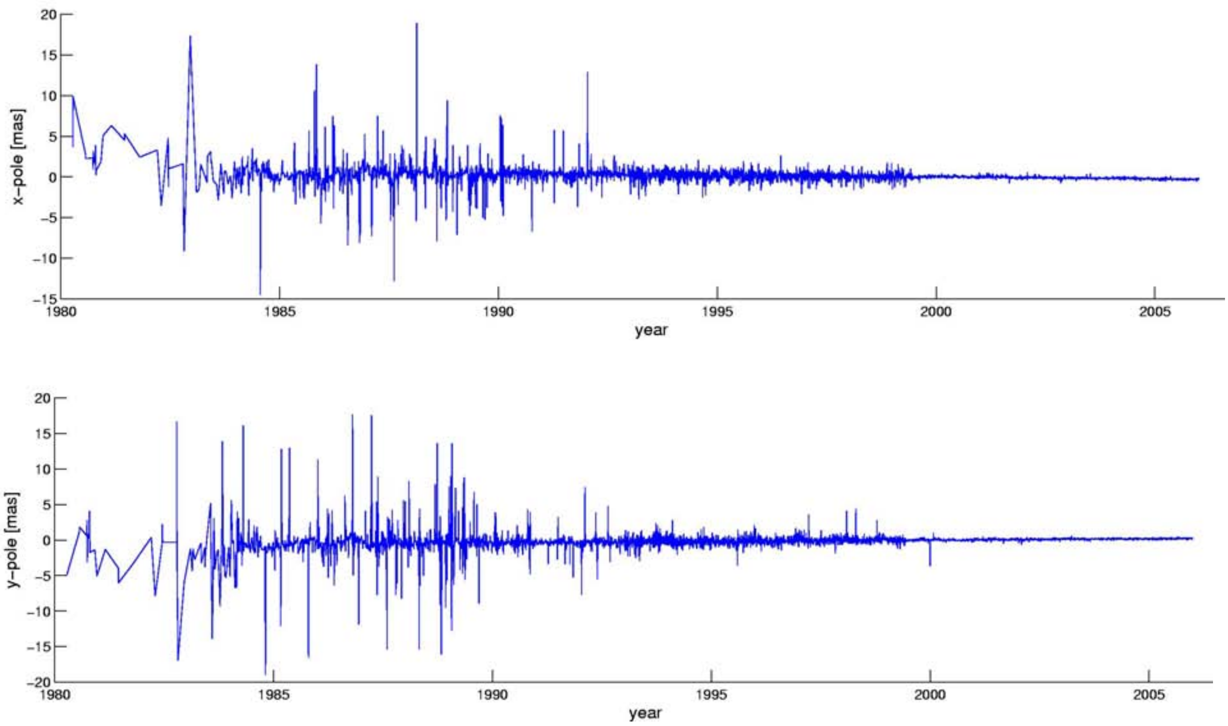

Fig. 4: Terrestrial pole coordinates of ITRF2005D solution w.r.t. IERS C04 series.

The RMS differences for station positions and velocities show a very good agreement (after similarity transformations). This holds in particular for „good“ stations with several years of continuous observations without discontinuities (Table 2). For weakly estimated stations (e.g., observation time less than 2.5 years, or several solutions needed due to discontinuities) larger discrepancies do exist, which however mostly reside within their standard deviations.

Table 2: RMS differences for station positions and velocities between the IGN and DGFI solutions for ITRF2005 for „good“ reference stations (25 VLBI, 22 SLR, 57 GPS, 40 DORIS stations).

IGN - DGFI	VLBI	SLR	GPS	DORIS
Positions [mm]	0.79	1.82	0.31	3.32
Velocities [mm/yr]	0.34	0.66	0.14	1.11

Thus a major problem in the ITRF2005 is the significant difference in the SLR scale. The analysis of weekly SLR solutions of the ILRS Combination Centre (ILRSA) in 2006 has shown that its scale is in reasonable good agreement with the ITRF2005 solution of DGFI, whereas there is a significant scale bias of about 2 ppb w.r.t. the IGN solution (see Fig. 5), which is equivalent to a difference of 1.3 cm in SLR station heights. Because of this discrepancy, IGN provided a second (rescaled) ITRF2005 solution for SLR users.

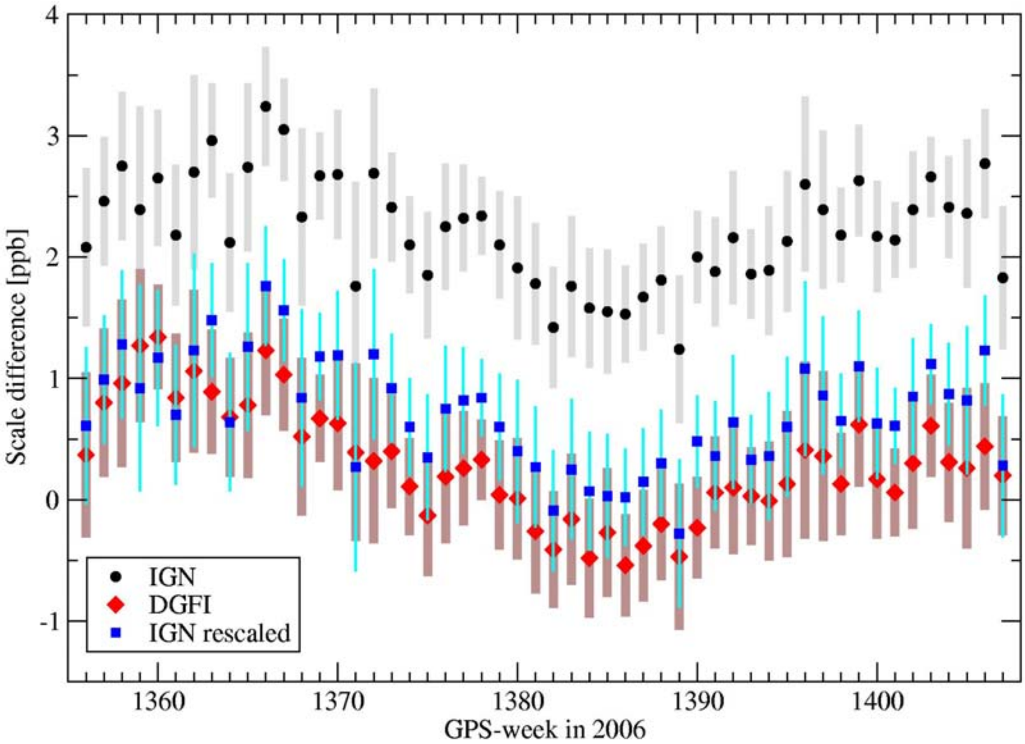

Fig. 5: Scale of ITRF2005 solutions of IGN and DGFI w.r.t. weekly SLR solutions combined by the ILRS Combination Centre A (ILRSA).

The fact, that IGN and DGFI provided each one solution for ITRF2005 using different software and combination strategies has provided for the first time the basis for a decisive validation and quality control of the terrestrial reference frame results. The problem of the significant difference in the SLR scale is subject to further analysis. It has been agreed by IGN and DGFI to perform further test computations to assess the effect of differences in the combination strategies. Since the availability and spatial distribution of high-quality co-location sites is not optimal, the handling of local ties is a very critical issue within the inter-technique combination, which need to be further investigated.

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Manuela Krügel, Barbara Meisel

3.6.1.2 Institut Géographique National (IGN)

The IGN ITRS Combination Centre concentrated its activity during the year 2006 on the production of the ITRF2005.

For the first time, the ITRF2005 benefited from the contribution of the two other ITRF combination centres, namely Deutsches Geodätisches Forschungsinstitut (DGFI) and Natural Resources Canada (NRCan). Comparisons between intra and inter-technique combinations of the three ITRF combination centres were undertaken that allow improving the final ITRF2005 reliability.

ITRF2005

Contrary to previous ITRF versions, the ITRF2005 integrates time series of station positions and daily Earth Orientation Parameters (EOPs). The time series solutions are now provided in a weekly basis by the Services of the International Association of Geodesy (IAG): International services of satellite techniques (IGS, ILRS, IDS) and in a daily (VLBI session-wise) basis by the IVS. Reasons for which it was decided to use time series of station positions and EOP as input to ITRF2005 include:

- Monitoring of non-linear station motions and all kinds of discontinuities in the time series: Earthquake related ruptures, site instability, seasonal loading effects, etc.;
- Examining the temporal behaviour of the frame physical parameters, namely the origin and the scale;
- Rigorously and consistently including EOPs in the combination and ensuring their alignment to the combined frame.

ITRF2005 Input data: Space Geodesy Solutions

One set of times series per space geodesy technique was considered as input to the ITRF2005 combination. These solutions are the official time series provided by the international services of the 4 techniques, known as Technique Centres (TC) by the IERS. Note that these official TCs' solutions result from a combination at the weekly (daily) basis of the corresponding individual solutions provided by the Analysis Centres (AC) participating to the activities of each TC. Official time series were submitted to the ITRF2005 by the International VLBI Service (IVS), the International Laser Ranging Service (ILRS), and the International GNSS Service (IGS). At the time of the ITRF2005 release, official weekly combined solutions from the International DORIS Service (IDS) were not available, so that individual solutions were submitted by two DORIS analysis centres, namely Institut Géographique National (IGN) in cooperation with Jet Propulsion Laboratory, and the Laboratoire d'Etudes en Géophysique et Océanographie Spatiale (LEGOS) in cooperation with Collecte Localisation Satellites (CLS), designated hereafter by (LCA). A specific analysis of DORIS solutions submitted to the ITRF2005 was performed prior to the ITRF2005 release. Table 1

Table 1: Summary of Submitted Solutions to ITRF2005

TC – AC	Time span	Type of constraints/solution	EOPs
IVS	1980.0-2006.0	Normal Equation	Polar Motion, rates, UT1, LOD
ILRS	1992.9-2005.9	Loose; variance-covariance	Polar Motion, LOD
IGS	1996.0-2006.0	Minimum; variance-covariance	Polar Motion, rates, LOD
IDS - IGN-JPL	1993.0-2006.0	Loose; variance-covariance	Polar Motion, rates, LOD
IDS - LCA	1993.0-2005.8	Loose; variance-covariance	Polar Motion, rates, LOD

summarizes the submitted solutions to ITRF2005, specifying the data-span, their type, the originally applied constraints and the nature of the included EOPs. Table 2 lists all the Analysis and Combination Centres for each one of the 4 techniques which contributed to the time series submitted to the ITRF2005.

The ITRF2005 is composed of 608 stations located at 338 sites as illustrated in Figure 1, with an imbalanced distribution between the northern hemisphere (268 sites) and the southern hemisphere (70 sites).

ITRF2005 Input data: Local Ties in Co-location Sites

As illustrated by Figure 1, there are in total 84 co-location sites for which local ties are available for the ITRF2005 combination. They are distributed as follows: 52 sites with two techniques, 26 with 3 techniques and 6 sites with 4 techniques. There are about 10 co-location sites where local ties are not available. Note also that, unfortunately, not all these co-located instruments are currently operating. For instance, among the 6 sites having 4 techniques, only two of them are currently operating: Hartebeesthoek, South Africa and Greenbelt, MD, USA.

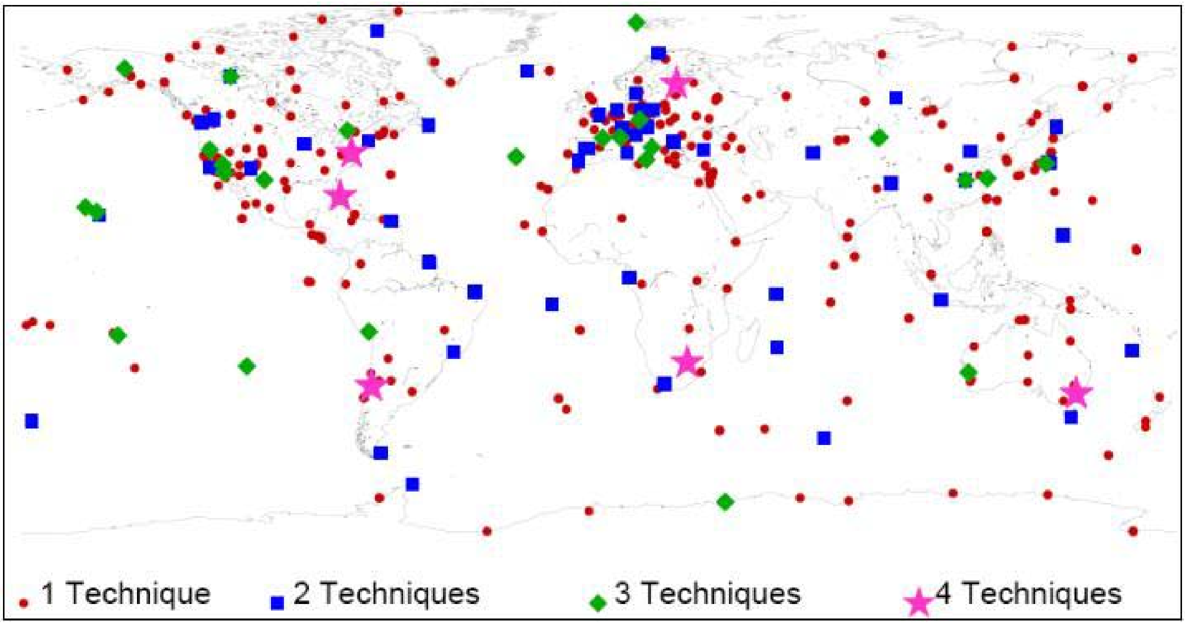

Fig. 1: ITRF2005 Sites with Co-located Techniques

Table 2: Analysis and Combination Centres Contributed to ITRF2005

TC ACs CC	**Institution**
IVS	http://ivscc.gsfc.nasa.gov/
BKG	Bundesamt für Kartographie und Geodäsie, Leipzig, Germany
DGFI	Deutsches Geodätisches Forschungsinstitut, Munich, Germany
GSFC	NASA Goddard Space Flight Center, Greenbelt, MD, USA
SHAO	Shanghai Observatory, Chinese Academy of Sciences, China
USNO	U.S. Naval Observatory, Washington D.C., USA
GIUB	Institut für Geodäsie und Geoinformation der Universität Bonn, Germany
ILRS	http://ilrs.gsfc.nasa.gov/
ASI	Agencia Spaziale Italiana, Matera, Italy
DGFI	See above
GFZ	GeoForschungsZentrum, Potsdam, Germany
JCET	Joint Center for Earth System Technology, at GSFC, USA
NSGF	NERC Space Geodesy Facility, formerly RGO Satellite, Laser Ranging Group, UK
ASI	See above, Primary ILRS-CC
DGFI	See above, Backup ILRS-CC
IGS	http://igscb.jpl.nasa.gov/
CODE	Center for Orbit Determination in Europe, Astronomical Institute of the University of Bern, Switzerland
ESOC	European Space Operations Center, European Space Agency, Darmstadt, Germany
GFZ	See above
JPL	Jet Propulsion Laboratory, Pasadena, CA, USA
NOAA	National Oceanic and Atmospheric Administration, NGS, Silver Spring, MD, USA
SIO	Scripps Institution of Oceanography, La Jolla, CA, USA
MIT	Massachusetts Institute of Technology, Cambridge, MA, USA
NRCan	See above
IDS	http://ids.cls.fr/
IGN	Institut Géographique National, Paris, France
LCA	Laboratoire d'Etudes en Géophysique et Océanographie Spatiale (LEGOS), in cooperation with Collecte Localisation Satellites (CLS), Toulouse, France
	IDS Combination Centre does not exist at the time of writing

The usual procedure adopted for the ITRF combination is to use the local ties as independent measurements with proper weighting. For the ITRF2005, about 45% of the available local ties are provided in SINEX files with full variance-covariance information as well as the measurement epochs: all sites in Australia; three sites in Italy: Medicina, Noto and Matera; Wettzell and Concepcion; and all the DORIS co-location sites were re-adjusted by the ITRS Centre in order to generate full SINEX files. The other 55% of the available local tie vectors were converted to SINEX format, following the procedure described in the ITRF article and technical notes. All the local tie SINEX files used in the ITRF2005 combination are available at <http://itrf.ensg.ign.fr/local_surveys.php>. The local tie

SINEX files were introduced in the ITRF2005 combination as independent solutions, in the same way as the long-term space geodesy solutions. Empirical variance factor estimation for each one of the individual local tie solutions (SINEX files) is operated following the procedure described in (Altamimi et al., 2002). The global combination is iterated as necessary and new variance factors are estimated at each run and in such a way that any position component should not exhibit a residual exceeding a certain chosen threshold. For the ITRF2005 solution it was decided to avoid having a position or velocity normalized residual (raw residual divided by its observation a priori error) exceeding a threshold of 4. Note that in each iteration, new individual variance factors are estimated which are then used to re-scale the individual matrices for the next iteration. A list of local tie vectors, together with their uncertainties as extracted from the re-scaled SINEX files, is also available at the same place as the SINEX files as mentioned above. In addition, all the post-fit residuals of the ITRF2005 combination are available at <ftp://igs.ensg.ign.fr/pub/igs/itrf2005/>. These residuals reflect, site by site, the level of agreement between the local ties and space geodesy estimates. There are some important co-located sites where we observe discrepancies larger than or equal to 1 cm, between local ties and space geodesy estimates. These discrepancies mean that either local ties or space geodesy estimates (or both) are imprecise or in error. Example of such sites are: GPS/VLBI: Westford, USA and Fortaleza, Brazil; GPS/SLR: Zimmerwald, Switzerland and Herstmonceux, UK. In order to preserve the implied co-locations in the combination, the local ties having normalized residuals exceeding the threshold of 4 were down-weighted rather than rejected, through the usage of appropriate variance factor as mentioned above.

ITRF2005 Main Results

In addition to the usual ITRF products (station positions and velocities), other important ITRF2005 results are also available to the users, namely:

- Full ITRF2005 and per technique SINEX files containing station positions, velocities and EOPs with complete variance-covariance matrices;
- Time series of station position residuals as results from the stacking of the individual time series of the 4 techniques;
- Geocentre time series from SLR and DORIS. There is no useful geocentre motion information from GPS/IGS, the submitted weekly solutions being aligned to ITRF2000;
- Full time series of EOPs consistent with the ITRF2005.

All the ITRF2005 files are available at the dedicated ITRF2005 web pages <http://itrf.ensg.ign.fr/ITRF_solutions/2005/ITRF2005.php>.

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3.6.2 Combination Research Centres

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

Introduction

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

Combination research activity and products

In 2006, the ASI-CGS combination activities have been focussed on the continuous provision of the official ILRS combined weekly solution, on the Mediterranean area combined solution and on the development of value-added geophysical products based on combined geodetic products.

1. ILRSA Weekly Solutions

The main lines of the ASI-CGS combination methodology rely on the direct combination of loose constrained solutions, described in previous IERS reports. ASI-CGS operates since June 2004 as the primary ILRS Combination Centre ("ILRSA") in charge of providing weekly combined solutions, from individual contributing SLR solutions based on the observations to Lageos 1-2 and Etalon 1-2, to the users at the CDDIS and EDC archives.

The official ILRSA solutions contain:

1. weekly coordinates of the worldwide SLR tracking network,
2. daily EOPs (xpole, ypole, LOD), ITRF2000-framed for IERS Bulletin B.

The ILRSA solutions are provided with a quality report allowing the monitoring of each contributing solution and of the combined product; in the following plot, the WRMS values of the site coordinate ITRF2000 residuals (all sites and core sites) are reported for the period of interest. The 1-cm level for the Core Sites residuals wrt ITRF2000 is maintained throughout 2006.

In the following, the residuals of ILRSA EOP values w.r.t. the IERS EOP C04 are reported. The weighted mean/std of the residuals (x_P: –0.12+/–0.15 mas; y_P: –0.10+/–0.15 mas; lod: 0.003+/–0.045 ms) indicates the quality level of the ILRS contribution to IERS EOP products.

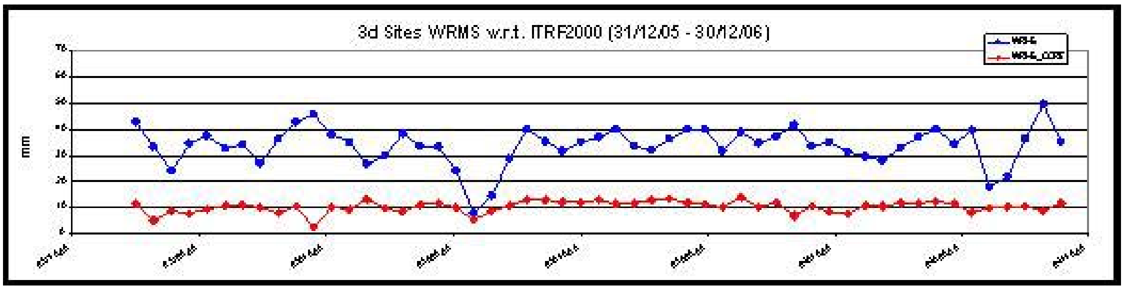

Fig. 1: ILRSA SSC differences w.r.t. ITRF2000 for 2006

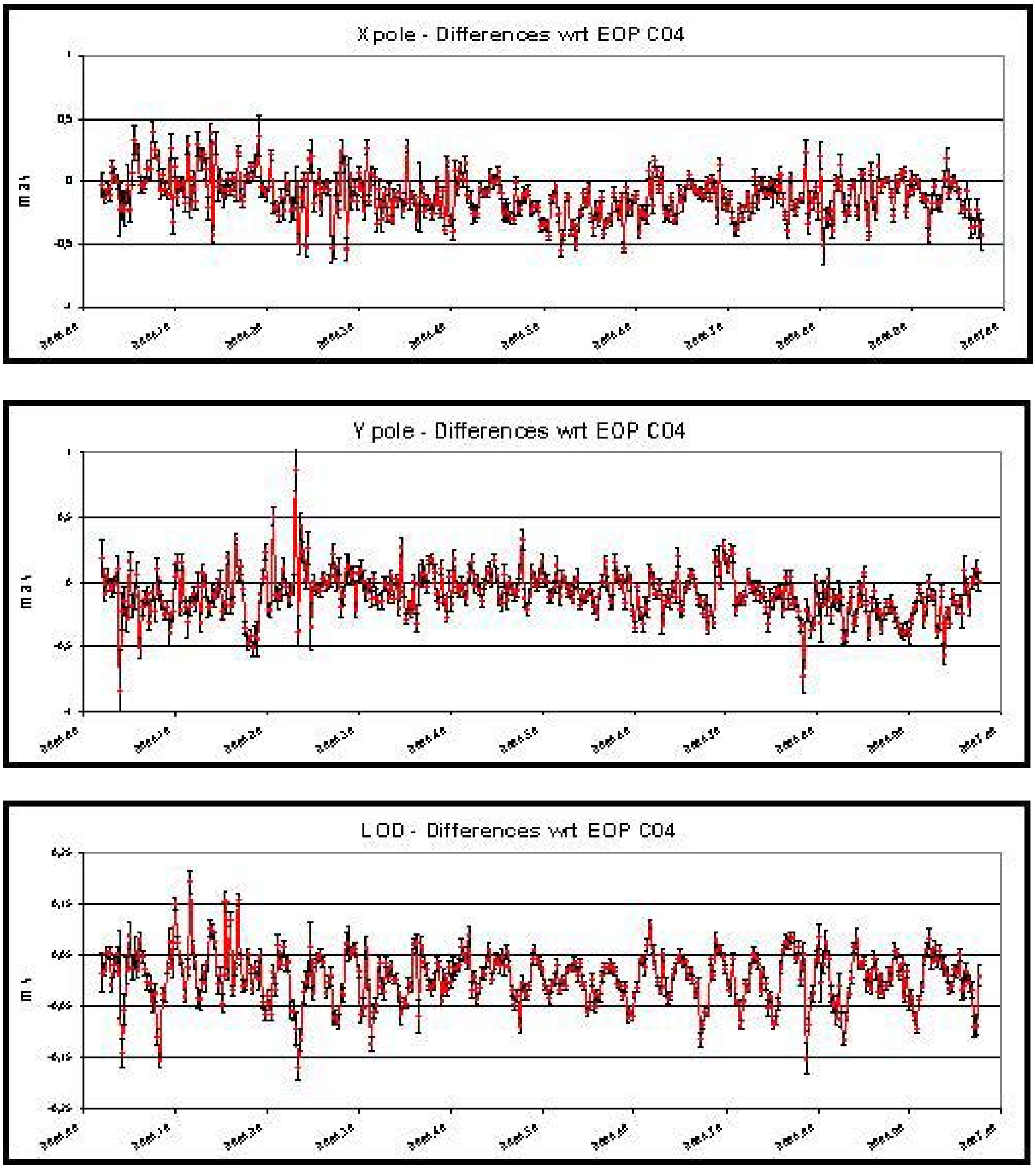

Fig. 2: ILRSA EOP differences w.r.t. IERS C04 for 2006

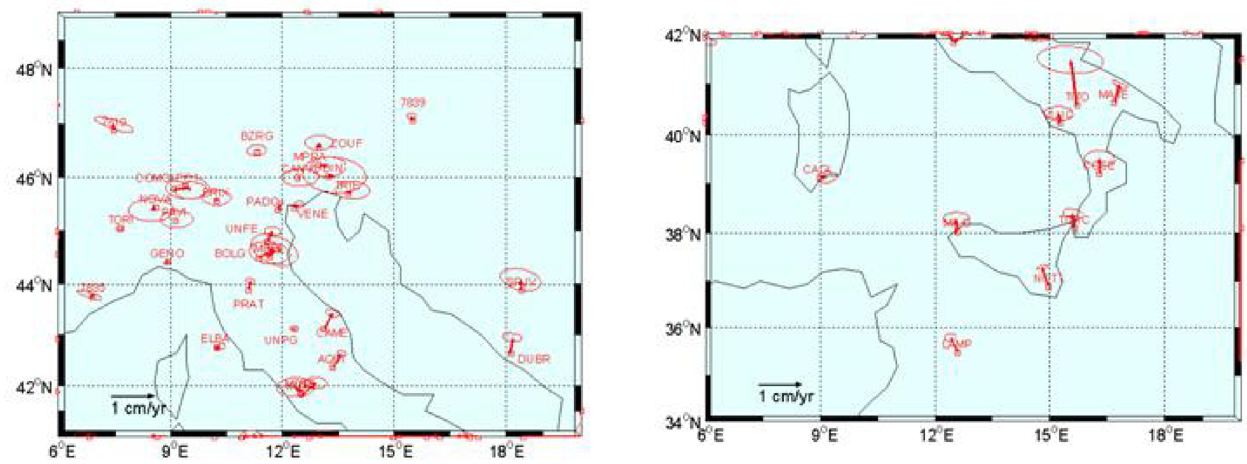

Fig. 3: Italian residual velocity field from ASIMed2006_ver2.0

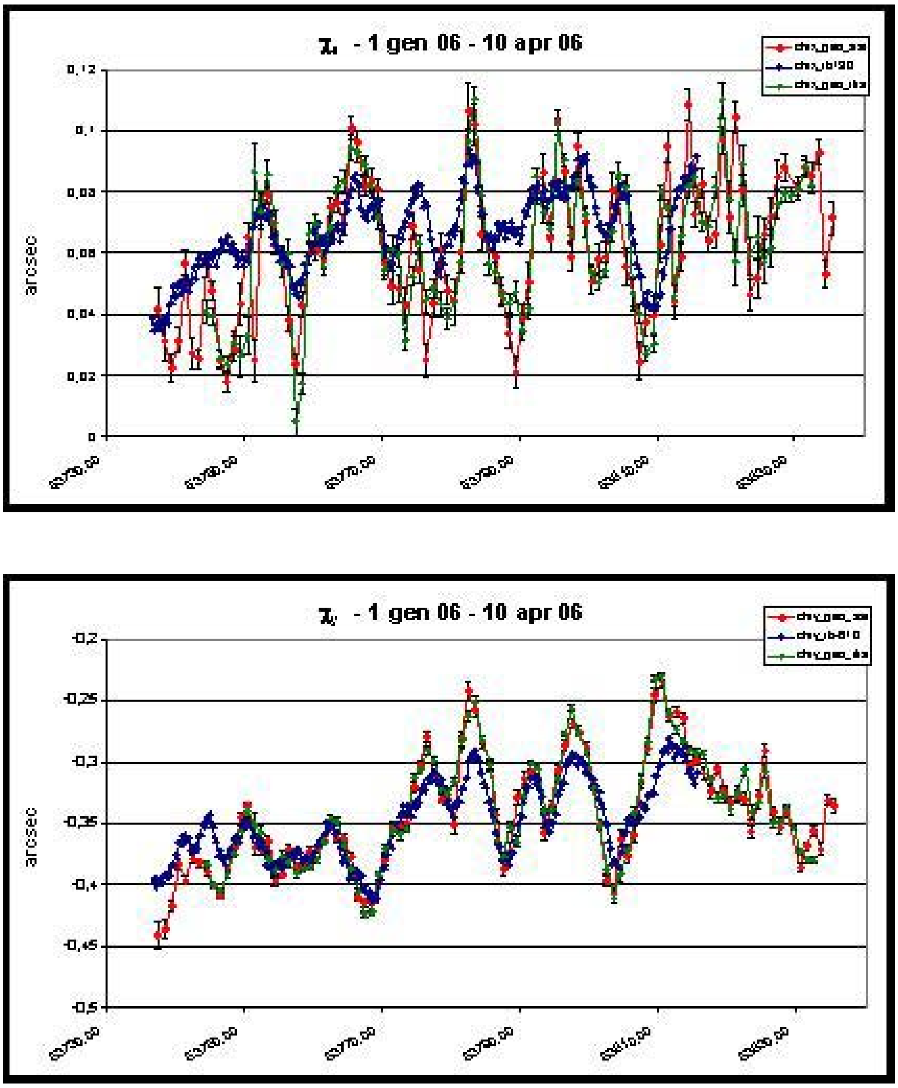

Fig. 4: ASI-CGS EOP Excitation Functions Jan–Apr 2006 (under testing)

3. The EOP excitation functions

Twice a year, ASI-CGS produces a combined velocity solution for the Mediterranean area using its own mono-technique velocity solutions (SLR, VLBI, GPS) that cover the whole data span acquired by the three co-located systems from the beginning of acquisitions in Matera. The ASIMed solution (<http://geodaf.mt.asi.it/html_old/ASImed/ASImed_06.html>) gives a detailed picture of the residual velocity field in the area, profiting of the dense permanent GPS coverage.

2. The ASIMed solution

ASI-CGS is developing a geophysical value added product based on its own estimation of EOP values (at present SLR only; the use of VLBI and GPS EOP is also planned) to be available on the ASI geodetic web site <http://geodaf.mt.asi.it>: the geodetic excitation functions in comparison, if possible, with the atmospheric excitation functions from the IERS SBA. The product, after the definition and prototyping phases, undergoes a testing/validation phase started in the examined period and to be continued in 2007.

Giuseppe Bianco, Vincenza 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. The combination research is maintained principally in two different directions. On the one hand, we combine some of the Earth Orientation Parameters using the 'combined smoothing' algorithm that we recently proposed, without changing the underlying reference frames (terrestrial, celestial). On the other hand, we follow the direction of combining non-SINEX particular solutions of different techniques to determine the Earth Orientation Parameters simultaneously with station coordinates. In 2006, we started to consider a possibility of merging these two approaches together (see below).

Combination of EOP and station coordinates

As a response to a call for producing weekly combinations, the method of non-rigorous combination was slightly modified. The tests proved that it is suitable to produce such very short-term solutions. To avoid lack of data and stabilize the solution though, it is necessary to use a longer data interval. Namely, 13-daily data was used for weekly solutions, with further overlap of VLBI data to assure time corrections over the whole interval.

The ilrsb and ign-wd04 intra-techniques solutions were used for SLR and Doris, respectively. CPP data was used for GPS, and for VLBI, the data was recovered from CPP singular normal equations using vtrf2005 station coordinates.

Rms errors of the weekly combinations decreased during the three years of solutions from 6 mm to 4 mm, indicating improved quality of the data. Effect of combinations on EOP did not exceed 0.26 mas, 0.45 mas and 0.18 ms, for pole coordinates x, y and time corrections, respectively (Pešek & Kostelecký, 2006).

The possibility of using constraints similar to the ones used to define 'smoothness' of the resulting curve in Vondrák smoothing method started to be investigated to ensure the continuity of Earth Orientation Parameters of our non-rigorous combination. To this end, PhD student Vojtech Štefka was hired whose task is to consider this problem.

Staff

Astronomical Institute:
Dr. Jan Vondrák (Primary Scientist)
Dr. Cyril Ron
Vojtech Štefka

Department of Geodesy:
Prof. Jan Kostelecký (Head of CEDR)

Dr. Ivan Pešek
Prof. Aleš Cepek

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Pešek I., Kostelecký J.: 2006, Simultaneous determination of Earth orientation parameters and station coordinates from combination of results of different observation techniques, Studia Geoph. et Geod., 50 (2006), 537-548.

Jan Vondrák, Ivan Pešek

3.6.2.3 Deutsches Geodätisches Forschungsinstitut (DGFI)

The activities of the IERS Combination Research Centre at DGFI can be divided into the following major topics:

- Refinements of the SLR intra-technique combination (ILRS-B)
- DGFI contributions to the project "GGOS-D"
- DGFI contributions to the second realization of the ICRF (ICRF2)
- Analysis of systematic effects in CRF solutions
- DGFI contributions to the IERS Combination Pilot Project

SLR intra-technique combination (ILRS-B)

Since June 2004, DGFI serves as the official ILRS Backup Combination Center (ILRS-B). It computes on a weekly basis a combined SLR solution as an official product (SINEX files with station positions and EOPs) for the ILRS and as input for the weekly combination of SLR data with other techniques within the IERS Combination Pilot Project. During 2006, DGFI has refined the intra-technique combination methodology and software for an automated combination of the individual SLR solutions. The variance component estimation, which was mainly implemented for an automatic weighting, turned out to be a useful tool also for outlier analysis of the input solutions.

DGFI contributions to the project "GGOS-D"

The project "Integration of Space Geodetic Techniques as a Basis for a Global Geodetic-Geophysical Observing System (GGOS-D)" is a joint project of the "GeoForschungsZentrum Potsdam (GFZ)", the "Bundesamt für Kartographie und Geodäsie (BKG)", the "Institut für Geodäsie und Geoinformation, Universität Bonn (IGGB)" and DGFI funded by the German Ministry for Research and Education in the frame of the programme GEOTECHNOLOGIEN. Although GGOS-D is not an IERS project, the work is very closely related to the DGFI research performed as IERS Combination Research Centre. The DGFI activities within GGOS-D include the following items:

- Contributions to the definition of unified GGOS-D processing standards, models and parameterizations and implementation in the software packages DOGS-OC (for SLR) and OCCAM (for VLBI);
- Generation of fully consistent observation time series of SLR and VLBI observations;
- Computation of a GGOS-D reference frame based on the consistent VLBI, SLR and GPS observation time series;
- Development of combination procedures to generate consistent time series of geodetic-geophysical parameters, such as station and Quasar coordinates, EOPs, troposphere parameters, and low-degree spherical harmonics of the Earth gravity field.

DGFI contributions to the ICRF2

The IVS has established a Working Group (WG) for the second realization of the ICRF (ICRF2) during the IAU General Assembly in Prague 2006, which will deal with all efforts related to the observational data. DGFI actively takes part in this WG by submitting catalogues, source position time series and other type of results. A first goal of the WG is to identify sources with time-variant positions by examining time series of estimated source positions. Tests are currently done at DGFI to estimate such time series from single session solutions using an NNR datum over all sources w.r.t. a CRF solution computed at DGFI.

Analysis of systematic effects in CRF solutions

In 2006, the effect of various analysis options on VLBI-determined CRF was investigated at DGFI:

- different tropospheric mapping functions and gradient models;
- choice of data set (neglecting sessions before 1990 and 21 astronomic sessions);
- handling of sources that may not be assumed to have time-invariant positions;
- handling of the station network (estimate the station positions per session, as positions and velocities over 20 years, or fix them to apriori values).

The biggest, clearly systematic effects in the estimated source positions up to 0.5 mas were found to be due to the different gradient models. The choice of the data set does generally not have a significant influence. This holds also (with several exceptions) for different options how to treat the sources which are assumed to have time-invariant positions. Furthermore it turned out that fixing station positions to values not consistent to the solution itself can noticeably affect CRF solutions.

DGFI contributions to the IERS Combination Pilot Project

Within the IERS Combination Pilot Project (CPP), DGFI provides individual SLR and VLBI solutions and combined SLR solutions (ILRS-B) to the ILRS and IVS, respectively. DGFI has been accepted by the IERS as a Combination Centre for the inter-technique combination of the weekly/daily SINEX files provided by the Technique Services. The SINEX files were analysed regarding the suitability for a rigorous combination. We investigated different strategies for the weekly inter-technique combination and performed test computations. We implemented variance component estimation to estimate weighting factors for the different space technique. The handling of local ties within the weekly combination is subject of further investigations.

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Manuela Krügel, Barbara Meisel, Volker Tesmer

3.6.2.4 Forsvarets forskningsinstitutt (FFI)

Introduction

FFI has during the last 25 years developed a software package called GEOSAT (Andersen, 1995) for the combined analysis of VLBI, GNSS (GPS, GALILEO, GLONASS), SLR and other types of satellite tracking data (DORIS, PRARE and altimetry). The observations are combined at the observation level with a consistent model and consistent analyses strategies. The data processing is automated except for some manual editing of the SLR observations.

In the combined analysis of VLBI, GNSS and SLR observations, the data are processed in arcs of 24 hours defined by the duration of the VLBI session. The result of each 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

After five years of development and validation a completely new version of the GEOSAT software is ready for routine processing of space geodesy observations and tracking data towards spacecrafts in the Solar system.

The most important improvements and changes were described in previous IERS Annual Reports.

The new version of GEOSAT has two very useful features:

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

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

single parameter represented by a microwave-dependent parameter in a second run. The same can be tested for clock parameters for collocated clocks etc.

The goal several years ago was to demonstrate the concept of simultaneous combination of different types of data at the single observation level with very limited amounts of data. Now we plan to go one step further with the processing of several years of VLBI+SLR+GNSS data including 100-200 GNSS stations per day. We have for this purpose recently installed an array of 10 new computers with altogether 40 cpu's, 60 GB Ram, and 10 TB disk space. A number of scripts have been written so that analysis of years of data can be initiated and distributed to the cpu's by a single command.

Future plans

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

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Per-Helge Andersen

3.6.2.5 Institute of Geodesy and Geoinformation of the University of Bonn (IGGB)

The IGGB has been operating an IERS Combination Research Center (CRC) since 2001 in cooperation with the Deutsches Geodätisches Forschungsinstitut (DGFI) in Munich. The CRC and its efforts are closely linked to the tasks of the Analysis Coordinator of the International VLBI Service for Geodesy and Astrometry (IVS) hosted by IGGB.

In 2006, most of the investigations concentrated on the preparations for a rigorous combination of VLBI solutions on the basis of pre-reduced (de-composed) normal equations in SINEX format. Prior to the combination which mainly consists of stacking of the normal equation matrices, all elements of time dependent parameters have to be transformed to identical epochs. The requirement for identity also applies to all a priori values of the parameters to be estimated at the end. In order to account for the different qualities of the individual contributions, i.e. individual normal equations, to the IVS normal equation combination, weighting factors were determined and tested for their suitability. One way of determining weighting factors is to use variance component estimation. Its basic idea is to compute individual variance factors for each group of observations instead of one common a posteriori variance factor. Here, a group of observations consists of the estimated parameters of one contribution. The estimated variance factors can then be used for re-weighting each contribution. It is planned to generate the official combined EOP series of the IVS exclusively on the basis of combinations of datum-free normal equations in SINEX format from January 1, 2007 onwards. The DOGS-CS software of DGFI will be used for the routine combinations.

In parallel to this, investigations have been started in cooperation with DGFI to generate consistent VLBI solutions from two different software packages. The resulting normal equations are meant for subsequent combinations not only within the VLBI technique but also with other space-geodetic techniques like GPS and SLR. Geophysical models as well as the parameter space is being made consistent in order to eliminate any known sources of systematic deviations. In this project, also software is being developed for the extraction of the full normal equation matrix from the Calc/Solve software and subsequent pre-reduction of VLBI specific elements of the normal equations, e.g. the clock parameters.

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”, FKZ 03F0425D.

Axel Nothnagel, Thomas Artz, Sarah Böckmann

3.6.2.6 GeoForschungsZentrum Potsdam (GFZ)

Introduction

Most of the work related to the IERS CRC at GFZ is embedded in the project "GGOS-D" (see Section 3.7.2 "WG on Combination" for more details). The major features of this project are the high degree of standardization of the modeling and parameterization between the software packages used, the consistent reprocessing of all observations and the exchange of datum-free normal equation systems (NEQs). Thus, the resulting time series of parameters are very homogeneous and a rigorous combination of the individual contributions is possible. The following topics were studied in 2006:

- Comparison of station coordinates and troposphere parameters from long time series of GPS and VLBI
- Combination of Earth orientation parameters (EOP) based on homogeneous NEQs
- Combination of GPS data from a ground network and Low Earth Orbiting satellites (LEO)

Reprocessed GPS and VLBI long time series of station positions and troposphere parameters

The impact of different mapping functions on station heights and troposphere zenith delays has been studied by comparisons of homogeneously reprocessed GPS and VLBI solutions. Altogether four different GPS solutions covering the time interval 1994–2005 have been computed in a joint effort of GFZ Potsdam, TU München and TU Dresden (Steigenberger et al., 2006). These solutions only differ by the mapping function applied:

- NMF: Niell Mapping Function, Niell 1996
- GMF: Global Mapping Function, Boehm et al. 2006a
- IMF: Isobaric Mapping Function, Niell 2001
- VMF1: Vienna Mapping Function, Boehm et al. 2006b

Whereas NMF and GMF are empirical mapping functions, IMF and VMF1 require input data from a numerical weather model providing a more realistic modeling of the troposphere. The Deutsches Geodätisches Forschungsinstitut (DGFI) München computed four VLBI solutions also applying these four mapping functions for comparisons with the GPS solutions.

Figure 1 shows the mean differences of the station heights (lower triangle of the figure) and the troposphere zenith total delays (ZTD, upper triangle of the figure) between solutions NMF, GMF, IMF and VMF1. All comparisons with solution NMF show a clear latitude-dependent systematic pattern due to the deficiencies of the NMF. In particular the height differences of up to more than 1 cm and the ZTD differences of up to 6 mm in Antarctica are striking. But also in the northern hemisphere a slightly latitude-dependent pattern is visible. As this systematic effect is present in both, the GPS and

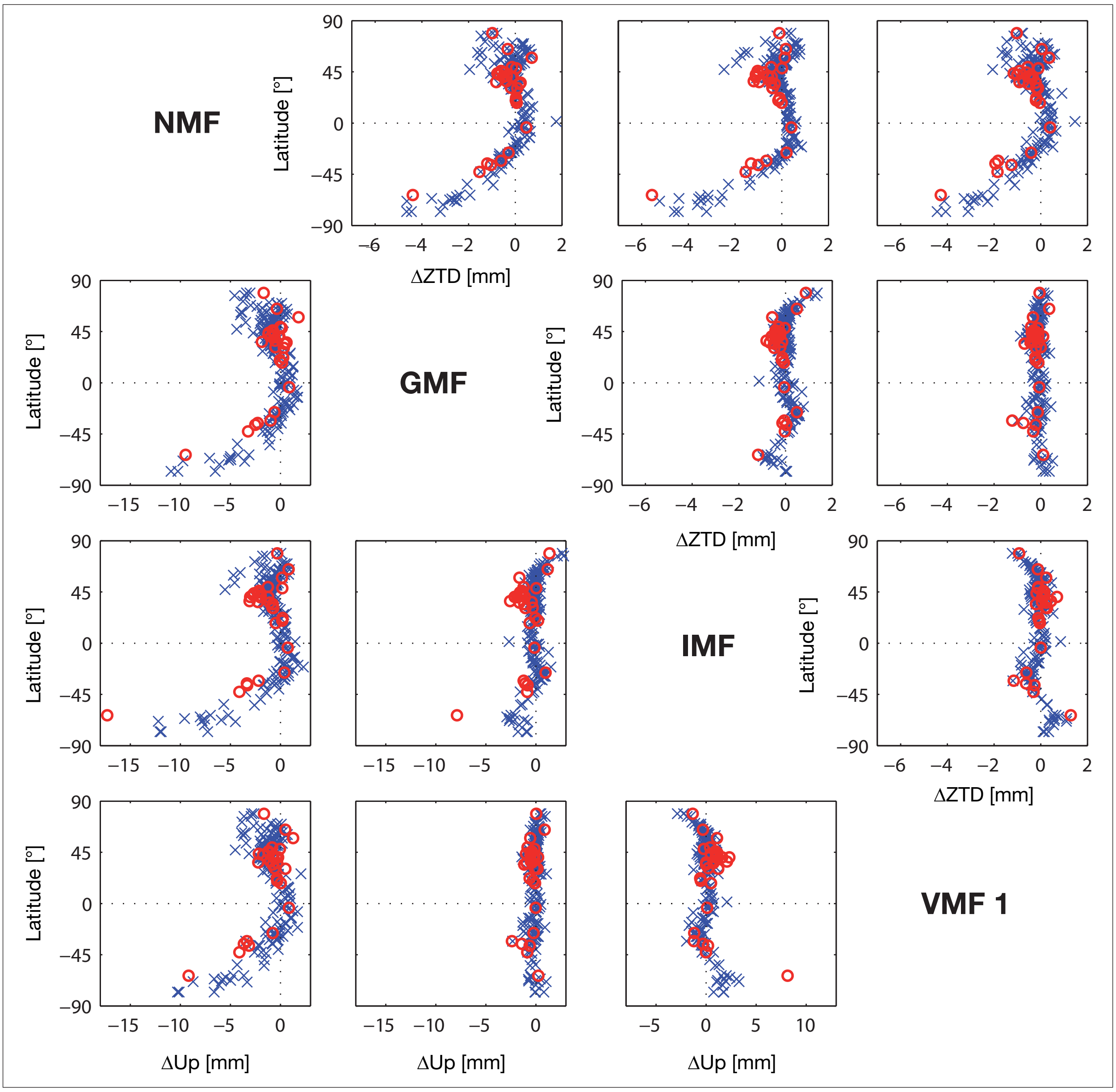

Fig. 1: Effect of different troposphere mapping functions on GPS- and VLBI-derived station heights and troposphere zenith total delays: the differences refer to the solution IDs given on the diagonal (e.g., the lowest plot on the left hand side shows the coordinate differences between solutions NMF and VMF 1). GPS-derived differences are indicated by blue crosses, VLBI-derived differences by red circles. (For a color version of the figure see the online version of this report at <www.iers.org>.)

the VLBI solutions, it is obvious that this behavior is related to the mapping function. Solution IMF also shows a slight latitude-dependent bias compared to GMF and VMF1 although this effect is much smaller than for the NMF. On the other hand, there is no systematic pattern visible in the comparisons of solutions GMF and VMF1. This is what we would have expected, as the GMF and the VMF1 were generated in a consistent way (Boehm et al. 2006a).

These significant differences between the GPS- and VLBI-derived troposphere zenith delays and station heights computed with *different* mapping functions emphasize the importance of using the *same* mapping function when combining solutions of both space-geodetic techniques. On the other hand, the good agreement of GPS and VLBI station positions and troposphere zenith delays computed with the *same* mapping function encourages the rigorous combination of both techniques.

Combination of Earth Orientation Parameters

When performing an inter-technique combination of Earth Orientation Parameters, the different epochs and time spans covered by the individual techniques have to be handled. In the case of GPS and SLR, the data are more or less continuous, so that a time series of EOP with a temporal resolution of 24 h can be coupled to the "normal" day, i.e., from 0 h UTC until 24 h UTC. Unfortunately, the 24-h VLBI sessions do not fit into this scheme as they start typically between 17:00 and 19:00 UTC. Independent of whether the EOP are parameterized as offset and drift for each 24-h interval or as a piece-wise linear polygon with values at the interval boundaries, the EOP estimated from VLBI do not represent the same information as those estimated from GPS or SLR, and, thus, the combination is not straightforward. One method is to attribute the EOP derived from the VLBI session to that 24-h interval of the GPS/SLR estimates to which the major part of the VLBI session belongs (see Fig. 2a), although this implies that there will be no contribution to the parameters set up for the first day.

However, in the ideal case, all observations should be correctly attributed to the appropriate interval of EOP, which means implicitly that the VLBI sessions must be split into two parts: one part from the start of the session until midnight, and, the second part, from midnight until the end of the session. In order to realize this ideal case, we used NEQs containing EOP with an hourly resolution. When combining these NEQs from VLBI and GPS (and SLR), the sub-daily resolution is transformed into a 24-h resolution (see Fig. 2b). With this procedure it is guaranteed that the estimated daily parameters represent solely the information of the corresponding time span and no information is neglected.

For assessing the difference between these two methods shown in Fig. 2, NEQs for one year of VLBI and GPS data have been generated and combined. Figure 3 shows the difference for the y-pole as an example. In terms of WRMS of the residuals, the difference is 18.2 µas and 18.3 µas for the x- and y-pole, respectively. In order to better evaluate the order of magnitude of the differences, the correctly combined time series using the NEQs with a sub-daily resolution is compared to the single-technique solution of GPS and to the C04 series as well (Fig. 3), resulting in a WRMS for the y-pole residuals of 39.8 µas and 82.0 µas, respectively. Thus, one can see that the impact of the combination method is not as large as the fact of combining different contributions or even the differences to external series. However, the differences are not negligible if high-quality time series are to be generated.

Further analyses of the EOP time series are documented in Thaller et al. (2006).

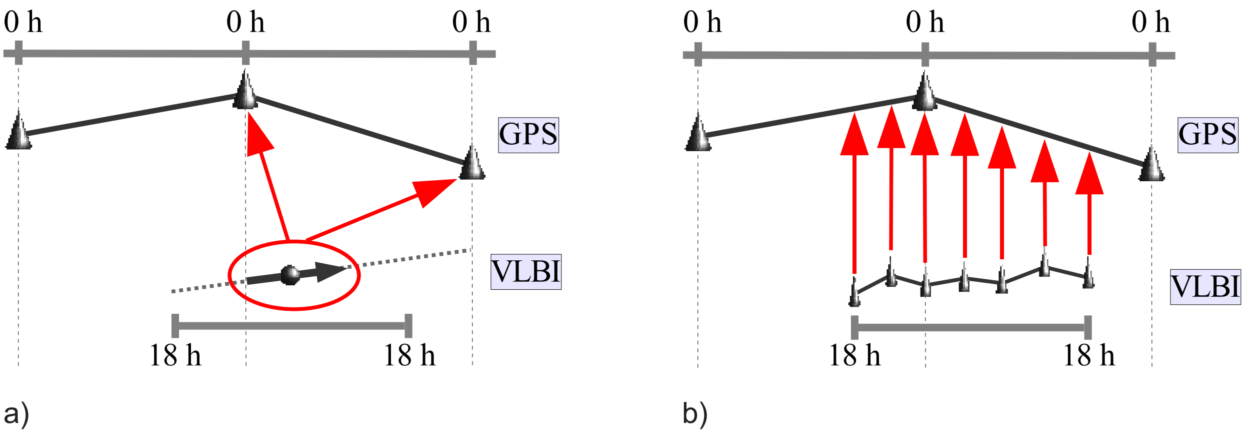

Fig. 2: Integration of the VLBI sessions into the 24-h polygon 0:00 – 24:00 UTC: a) based on offset and drift per session, b) based on a piece-wise linear polygon with sub-daily resolution ("correct" combination).

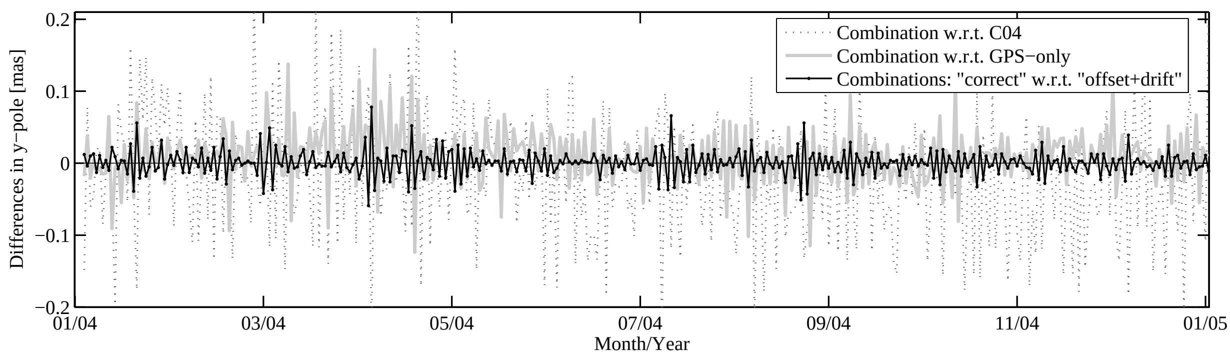

Fig. 3: Comparison of different time series of y*-pole coordinates.*

Combination of GPS and Low Earth Orbiters (LEOs)

The IERS CRC at GFZ has continued determining station positions, Earth Orientation Parameters, and spherical harmonic gravity field coefficients of low degree in the integrated mode using its EPOS software, see Zhu et al. (2004). The advantage of the integrated approach is the simultaneous and consistent processing of all available observational data and the estimation of all parameters including those needed to accurately account for the deficiencies of dynamic, geometric and observational models. The constellation processed comprises GPS ground stations of the IGS and GFZ network, the GPS satellites, as well as the Low Earth Orbiters (LEOs) CHAMP and GRACE. The observational data include GPS and SLR tracking data to the GPS and LEO satellites, as well as accelerometer, attitude, and K-Band inter-satellite measurements collected on-board the LEOs, where the K-Band data are specific to the two GRACE satellites. The dense and accurate CHAMP and GRACE data allow a high resolution of the sought for reference frame parameters.

Processing data of the year 2004 in the framework of the GGOS-D project, it could be proved in terms of reduced residuals and reduced scatter of parameter time series that the integrated mode delivers more accurate results than the commonly applied sequential processing of the GPS and the LEO constellations. With a rather loose datum definition and solving for the aforementioned parameters, the integrated mode directly gives insight into the correlations and the separability of the estimated parameters. Thus it became clear that the possibility exists of estimating the geometric and the dynamic reference frame in one run. The results have been compared to time series derived independently from pure SLR observations to the LAGEOS satellites and to routine products from the GRACE mission.

Acknowledgements

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Markus Rothacher, Daniela Thaller,
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3.6.2.7 Groupe de Recherches de Géodésie Spatiale (GRGS)

Abstract

A rigorous approach to simultaneously determine both a terrestrial reference frame (TRF) materialized by station coordinates and Earth Orientation Parameters (EOP) is now currently applied on a routine basis in a coordinated project of the Groupe de Recherches de Géodésie Spatiale (GRGS). To date, various techniques allow the determination of all or a part of the Earth Orientation Parameters: Laser Ranging to the Moon (LLR) and to dedicated artificial satellites (SLR), Very Large Baseline Interferometry on extra-galactic sources (VLBI), Global Positioning System (GPS) and more recently DORIS introduced in the IERS activities in 1995. Observations of these different astro-geodetic techniques are separately processed at different analysis centres using unique software package GINS DYNAMO, developed and maintained at GRGS: GPS at CLS, Toulouse (S. Loyer) and NOVELTIS (T. Lalanne), Doris at CLS, Toulouse (L. Soudarin), SLR at the Observatoire de la Côte d'Azur, Grasse (F. Deleflie, Ph. Bério), LLR at CNES, Toulouse (J. Ch. Marty) and at the Observatoire de Paris (G. Francou), VLBI at the Observatory of Bordeaux (G. Bourda, P. Charlot).

The final combination as well as the validation and various post analyses are performed at the Observatoire de Paris (D. Gambis, T. Carlucci, J.Y. Richard). An exhaustive description can be found in Gambis et al. (2007). In the following sections, each component is presenting a general description of its procedures as well as recent significant improvements.

1 Analyses of the Observations of the various techniques using GINS

1.1 Satellite Laser Ranging (SLR), OCA/GEMINI, Grasse (*F. Deleflie, P. Bério*)

Observations of LAGEOS 1 and 2 satellites have been processed over 9-day arcs with 2-day overlaps. The network comprises about 30 observing stations. The final RMS values are in the range of 1cm for both satellites. Weekly normal equations are derived relative to a range bias per week, per station and per satellite, station coordinates and EOP at 6-hour intervals. Final results are obtained with a two week delay. Two modifications were recently implemented: the use of the difference between the centre of reflection and the centre of mass as dependant of the type and power of the laser and the use of the tropospheric correction derived from ECMWF meteorological models. In addition, SLR observations are currently processed at GEMINI/CERGA in Grasse, France, since October 2007 in the frame of the International Laser Ranging Service (ILRS).

1.2 DOPPLER Orbit determination (DORIS), CLS, Toulouse (*L. Soudarin*)

A new processing chain including several evolutions has been set up in 2007. Its main characteristics are a new set of models was defined for the orbit computation. The GRACE-derived gravity model EIGEN-GL04S which includes annual and semi-annual terms of the low coefficients (up to 50); the latest ITRF2005; a priori tropospheric zenith delays, derived from ECMWF meteorological model. In addition an updated version of the software is used (GINS 7.2). the data processing is now fitted for a weekly delivery of the products requested by IDS and CRC. The analysis of the data from Jan. 2007 are performed with this new chain. Satellites processed are SPOT2, SPOT4, SPOT5 and ENVISAT. These evolutions lead to improvements of the determination of the coordinates times series, EOP, scale factor, geocentre. For example, the precision of the weekly positioning estimated from 2-year coordinate time series is now in a range of 6 to 18 mm for all the stations (weighted 3D rms).

1.3 Global Positioning System (GPS), CLS (*S. Loyer*) and NOVELTIS, Toulouse (*T. Lalanne*)

Over the period 2003 to 2006, the activity of GRGS concerning GPS data analyses developed significantly. The main objectives were to raise the quality of the results to the level reached by the best IGS Analysis Centers and to organize the daily processing of the observations of a global network of stations as well as promote GINS. The significant improvements concern the use of the recent radiation pressure model (Dobler, 2006), the resolution of phase ambiguities for global networks (Loyer, 2006), the pre-processing of observables and in particular the weighting and the processing over 3 days (continuity of phase measurements from noon to midnight), the introduction of phase corrections “wind-up” and the adoption of the corrections of absolute centres of phases of antennas, the unification of zero-difference and double-difference functions and the implementation of PPP (Precise Point Positioning) for the estimation of station coordinates

The GRGS processes GPS data since the beginning of 2004 and delivers precise orbits from about 70 stations. From the processing of GPS, NEQ are regularly sent to the combination centre at the Observatoire de Paris. The latency is about 4 weeks. The various steps (pre-processing, NEQ derivations, weekly stacking and results validation) are now automatized.

1.4 Very Long Baseline Interferometry (VLBI), Observatoire de Bordeaux (*G. Bourda, P. Charlot*)

VLBI data acquired on a regular basis by the International VLBI Service for Geodesy and Astrometry (IVS) are processed using the GINS software in order to estimate the Earth Orientation Parameters (EOP) and station positions. These include both IVS intensive sessions (i.e. daily one-hour long experiments) and the so-called IVS-R1 and IVS-R4 sessions (i.e. two 24-hour experiments per week). The fact that intensive sessions are included in the data processing is essential for the sake of improving the global combination of all techniques.

Based on these data, weekly normal equations are produced for combination with the data acquired by the other techniques (SLR, GPS, DORIS). The free parameters include station positions and the five EOP along with clock and troposphere parameters. The clocks walks are modelled using piecewise continuous linear functions with breaks every two hours. The tropospheric zenith delays are modelled in a similar way except that breaks are applied every hour. The a priori terrestrial reference frame used is VTRF2005 (Nothnagel, 2005) while the celestial frame is fixed to the ICRF (Ma et al., 1998, Fey et al., 2004). Overall, a total of 20 stations have been used in such sessions. The final post-fit weighted RMS residuals for the VLBI time delay is of the order of 30 picoseconds (i.e. about 1 centimetre) for the IVS-R1 and IVS-R4 sessions, and less for the intensive ones. Comparison of our EOP results with those published by the IVS (i.e. the combined series ivs06q3e.eops available at <http://ivscc.gsfc.nasa.gov/products-data/product-tables/bkg-products-eops.html>) indicates agreement at the 0.2 mas level.

2 Combination procedure using DYNAMO at Paris Observatory (*D. Gambis, T. Carlucci*)

The datum-free normal equations (NEQs) weekly derived from the analyses of the different techniques are collected and stacked at Paris Observatory to derive solutions of station coordinates and Earth Orientation Parameters (EOP). Two approaches are made: the first one consists in accumulating normal equations derived from intra-technique single run solution in a single run combined solution; the second one leads to weekly combinations of NEQs. Results are made available at the IERS site <ftp.iers.org> in the form of SINEX files. The strength of the method is the use of a set of identical up-to-date models and standards in unique software for all techniques. In addition the solution benefits from mutual constraints brought by the various techniques; in particular UT1 and nutation offsets series derived from VLBI are densified and complemented by respectively LOD and nutation rates estimated by GPS. The analyses we have performed are extending over a two year period, i.e. 2005–2006. They show that the accuracy and stability of the EOP solution are very sensitive to a number of critical parameters mostly linked to the terrestrial reference frame realization, the way that minimum constraints are applied and the quality of local ties. We present thereafter the procedures which were applied, recent analyses and the latest results obtained. For an exhaustive presentation, refer to Gambis et al. (2007).

2.1 First step: intra-technique solution

The combination is performed in two steps. Weekly NEQs derived by the dedicated analysis centres have been cumulated for each technique over 2005–2006 to derive a single run solution. Stations minimum variances are applied. The mean measurement residuals lead to the determination of the weight of each technique in the global combination. The weighting procedure is based on the variance component estimation method as suggested by Helmert and described in Sahin et al. (1992). The weights determined in these analyses have been fixed in the operational combinations. The relative weights are used in the matrices combinations. They should be carefully considered since contributions to EOP and station coordinates are different according to techniques. For instance, VLBI is the only technique to determine both UT1 and nutation offsets whereas satellite techniques can only bring some information on their respective rates. GPS-derived polar motion is more accurate. SLR brings a constraint in the long-term stability of the latter components. In addition, changes in the weights of the respective techniques can have significant effects on the final estimation quality.

2.2 Second step: inter-technique combination

The four intra technique NEQs derived over the four months are then accumulated into a single NEQ containing EOP at six-hour intervals. In this process local ties associated with ITRF2000 were considered. A global reference frame consistent with ITFR2000 is obtained, station positions rates being fixed to ITRF values in the process.

3 Assessment of the EOP solutions derived

EOP are computed with respect to the IERS EOP C04 (Gambis, 2004) used as the reference and corrected by the diurnal and sub diurnal model (Ray et al., 1994). Station position corrections are computed with respect to ITRF2000 positions (Altamimi et al., 2002) corrected with models from the IERS conventions (McCarthy and Petit, 2004). As previously mentioned, station velocity rates are held fixed to ITRF2000 values. This appears not to be critical over time intervals limited one year. Polar motion and UT1 are derived at 6-hour intervals whereas pole offsets are derived on a 12-hour basis. For the sake of comparisons, EOP sub-diurnal values are modelled by a piecewise linear fit to yield values at 0:00 hour. Figure 1 shows the difference of this combined solution with C04 used as the reference and their RMS. The values obtained show the good quality of the results obtained. Note the significant bias in Y-Pole due to the current inconsistency between the C04 and the ITRF2000. This inconsistency was removed by the realignment of the 05C04 respectively to ITRF2005 system.

Figure 2 shows the differences for X-pole between the GRGS combined solution and combined intra-technique IVS, ILRS and IGS “2005-2006”. Figures 3 and 4 present other results concerning the nutation series obtained in the process.

4 Conclusion

The combination process based on datum-free NEQ is now done on a routine basis since the beginning of 2005 in a coordinated project within the frame of GRGS. The project is still in a research phase for the processing of individual techniques as well as for the final combination. We already demonstrated the good quality of the results for EOP as well as for station coordinates. The global com-

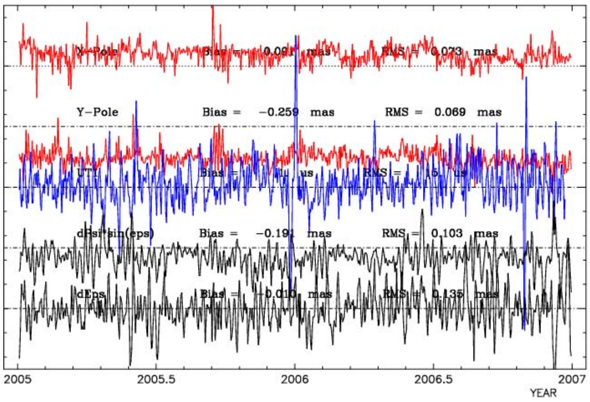

Fig. 1: EOP: differences of GRGS solution with 05C04 over 2005–2006. From top to bottom: X and Y-pole, UT1 and nutation offsets. RMS are about 0.070 mas for pole and 12 microseconds for UT1.

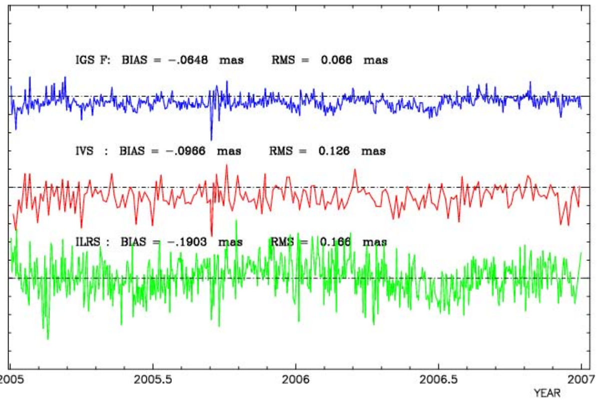

Fig. 2: Plots showing the differences between the GRGS combined solution and combined intra-technique solutions IVS, ILRS and IGS for X-pole component over 2005–2006.

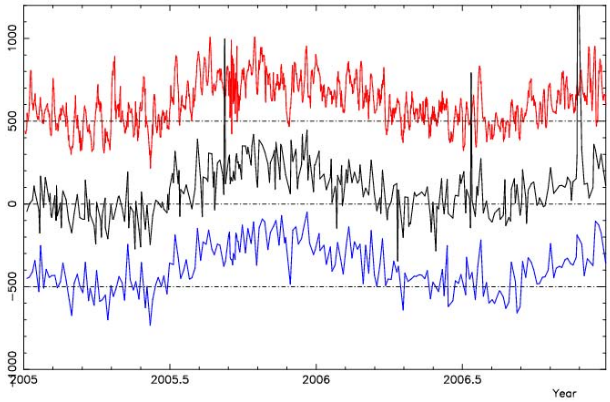

Fig. 3: Nutation offset dx relatively to the IAU 2000 nutation model. Nutation drifts derived from GPS analyses at 12 h-intervals allow to densify nutation series derived from 24-h VLBI sessions. From top to bottom, GRGS combined, GSFC and IAA solutions.

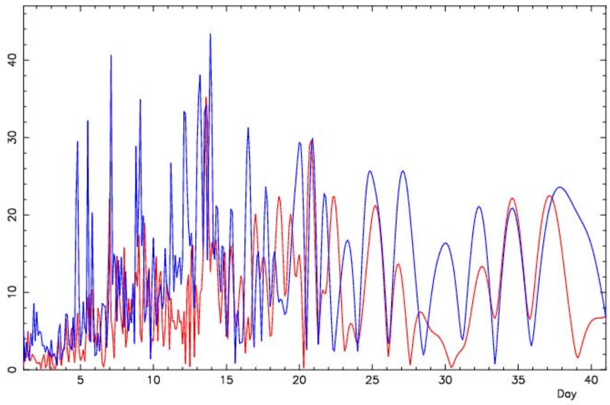

Fig. 4: LSQ periodogram of nutation offsets dx (blue) and dy (red) relatively to MHB2000 nutation model. Significant peaks appear in particular at 7 days and at fortnightly time scales. (See the online version of this Annual Report for a colour version.)

bined solution benefits from the mutual constraints brought by the different techniques. Better results are expected after the improvement in the processing of the individual techniques. The strength of the method is the use of a set of identical up-to-date models and standards in unique software. In addition the solution benefits from mutual constraints brought by the various techniques; UT1 and nutation offsets derived from VLBI are constrained and complemented by respectively LOD and nutation rates estimated by GPS. Before EOP and station coordinates be derived on an operational basis with an optimal accuracy different problems have to be studied and solved. It appears that the EOP and station coordinate solutions are sensitive to a number of critical parameters linked to the terrestrial reference frame realization mostly local ties whose errors propagate in an unpredictable way in the station coordinates and EOP series. We are here in a context of service oriented researches. This implies that we have to find and apply the optimal values for the critical parameters involved, minimum constraints for stations, EOP continuity constraints and techniques weights. This “tuning” is essential to provide to the community, consistent, accurate and stable products.

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Patrick Charlot, Sylvain Loyer, Laurent Soudarin, Florent Deleflie

3.6.2.8 Institut Géographique National (IGN)

Intra-technique combination

The software package Combination and Analysis of Terrestrial Reference Frames (CATREF) has been updated to include internal constraints. Those can be used to define the output reference frame origin, scale and orientation when stacking mono-technique reference frames (intra-technique combination) (Altamimi et al., 2006). The frame time series provided by the IAG services mainly IVS, ILRS, IGS and IDS, have been analyzed using CATREF software to estimate long term mono-technique frames and Helmert parameter time series. The internal constraints were applied in order to preserve the intrinsic origin and scale of SLR and the scale of VLBI solutions. Monitoring of such defined Helmert parameters is shown to be advantageous and therefore their continuous analysis is essential to qualify solution internal quality and to study the behavior of the individual technique frame definition over time. In order to illustrate the internal constraint feature, Figure 1 shows the intrinsic translation and scale components of the ILRS time series (submitted to ITRF2005), using this approach, while Figure 2 shows the scale of VLBI time series.

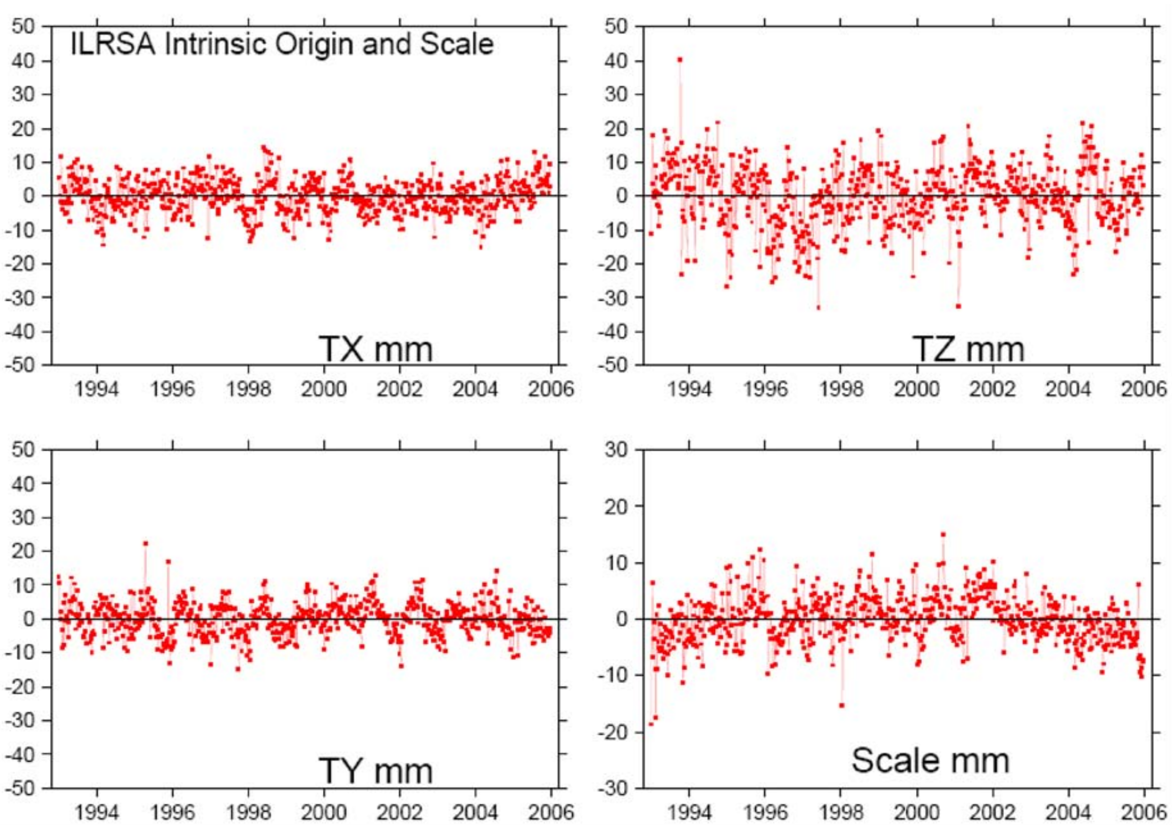

Fig. 1: Time series of the translation components and scale factor of the ILRS solution submitted to ITRF2005, as determined by CATREF software using the approach of internal constraints.

Time series analysis

Position residual time series from ILRS, IVS and IGS have been investigated to look for common signals and systematic errors. Firstly, spectral analyses have been performed to look for specific technique frequencies and systematic errors. Secondly, correlation computations have been carried out for residual position time series at co-location sites with sufficient common data. Due to sampling heterogeneities and time-varying position uncertainties, suitable methods and tools have been developed and applied to these data sets. Such analyses show some discrepancies between technique non linear motion estimations but also point out good agreement at some co-location sites and also in some area of the world at the annual frequency, especially in the height component (Collilieux et al., 2007). Figure 3 shows residual height time series for four co-location sites. Smoothed curves represent the correlated signals contained in the couple of time series. One can observe impressive agreement for some time series or some discrepancies well located in time. Such analyses are essential for future developments since they can lead to the definition of additional equality constraints when combining data at the observation level.

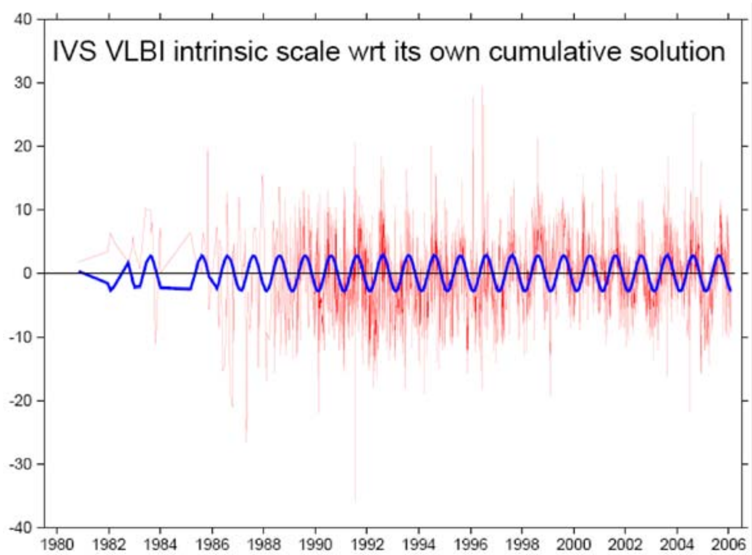

Fig. 2: Time series of the scale of VLBI solution submitted to ITRF2005, as determined by CATREF software using the approach of internal constraints.

No-Net-Rotation condition

The No-Net-Rotation condition (NNR condition) is used to define the orientation of the ITRF. Currently, this condition is ensured by minimizing three rotations between the ITRF velocity field and an external velocity field which verify the NNR condition. A method has been developed to generate an NNR velocity field from an ITRF solution: the ITRF velocity field is first interpolated over a grid by means of least-squares collocation. Then the rotation which allows the interpolated velocity field to satisfy a NNR condition is explicitly estimated and can be applied to the original ITRF velocity field (Legrand, 2007). Such an analysis has been used to evaluate the ITRF2005 NNR-condition implementation at about two millimeters per year, which is consistent with other published NNR velocity field estimated from space geodesy (Altamimi et al., 2007).

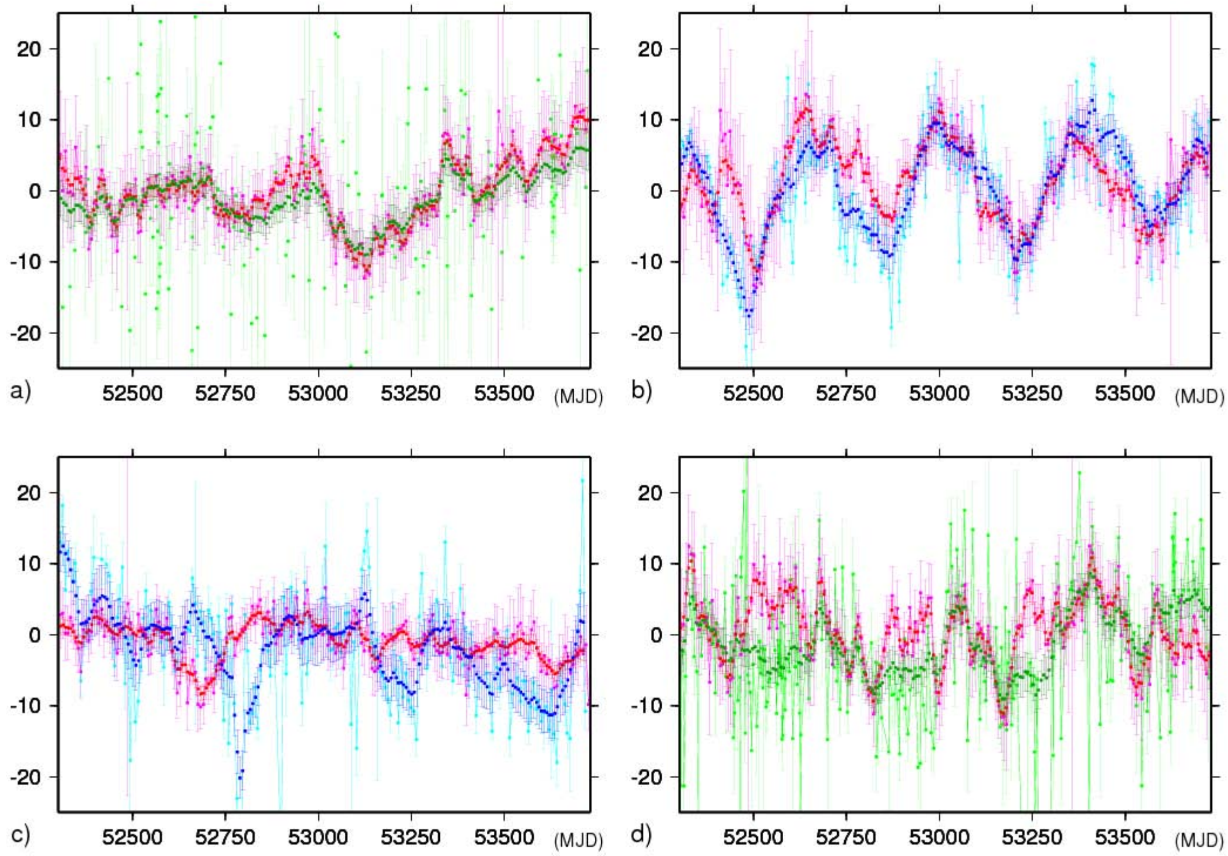

Fig. 3: Height residual time series at four co-located sites. a) Hartebeesthoek: 7232 (VLBI) and HRAO (GPS). b) Yarragadee: 7090 (SLR) and YAR2 (GPS). c) Wettzell: 8834 (SLR) and WTZR (GPS). d) Ny-Alesund: 7331 (VLBI) and NYA1 (GPS). IGS, IVS and ILRS height residual time series are respectively plotted in magenta, light green and cyan. Smoothed curves produced are plotted over in solid red for GPS, dark green for VLBI and solid blue for SLR.

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Xavier Collilieux, Zuheir Altamimi, David Coulot, Juliette Legrand

3.6.2.9 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 2006, three such reference series were generated: (1) SPACE2005, consisting of values and rates for polar motion and UT1 spanning September 28, 1976 to January 7, 2006 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) COMB2005, consisting of values and rates for polar motion and UT1 spanning January 20, 1962 to January 7, 2006 at daily intervals, was generated by additionally including the BIH optical astrometric measurements with the space-geodetic measurements used to generate SPACE2005; and (3) POLE2005, consisting of values and rates for just polar motion spanning January 20, 1900 to December 21, 2005 at monthly intervals, was generated by additionally including the ILS optical astrometric measurements with the other optical astrometric and space-geodetic measurements used to generate COMB2005. These reference series can be obtained by anonymous ftp to <ftp://euler.jpl.nasa.gov/keof/combinations/2005>. A report describing the generation of these series [Gross, 2006] 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 2006 were largely concerned with assessing the ITRF2005 Earth orientation series by comparing it to other EOP measurements and to global geophysical fluid models. Unlike previous realizations of the terrestrial reference frame, the ITRF2005 realization was constructed by simultaneously combining time series of station positions and Earth orientation parameters. So, besides site positions and velocities, the set of ITRF2005 products also includes a series of combined Earth orientation parameters. The ITRF2005 Earth orientation series was assessed by comparing it with other combined EOP series and with models of surface geophysical fluids. Ideally, assessments of EOP series should be done with independent data. However, since all available combined EOP series, including the ITRF2005, IERS C 04, and SPACE2005 series, are constructed from the same basic set of SLR, VLBI, and GPS measurements, they are not completely independent of each other. But because Earth orientation variations on subdaily to interannual time scales are known to be predominantly caused by atmospheric, oceanic, and hydrospheric effects, and because models of these effects are independent of Earth orientation measurements, it may be possible to use models of global geophysical fluids to independently assess the ITRF2005 Earth orientation series. This possibility was explored by comparing the ITRF2005, IGS Final combined GPS, and SPACE2005 polar motion excitation series to daily averaged atmospheric angular momentum from the NCEP/NCAR reanalysis project, daily averaged oceanic angular momentum from the ECCO/JPL data assimilating ocean model, and monthly averaged hydrospheric angular momentum from the Land Dynamics (LaD) model. In addition, mass conservation of the global geophysical fluids was imposed when using them to assess the EOP series.

The correlation with the sum of the global geophysical fluid models was found to be the same for all three observed polar motion excitation series with the correlation coefficients for the (x, y)-components being (0.81, 0.90). In addition, the same variance of (66%, 80%) of each of the three observed series was explained by the models. So, all three observed polar motion excitation series were found to agree equally well with the sum of the global geophysical fluid models. All that could be concluded about the accuracy of the new ITRF2005 combined polar motion excitation series was that it is at least as accurate as the SPACE2005 and IGS Final combined GPS series.

Acknowledgments

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

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Richard Gross

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

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

Site Survey and Standards

- Develop, test, compare and set standards on site survey methods, including observational techniques, network design, classical adjustment, geometrical modelling and/or direct measurement techniques for invariant point determination, reference frame alignment, software implementation and SINEX generation. This will include the development of a standards document for undertaking site surveys;
- Preparation and coordination of a Pilot Project (PP) on site survey. The PP includes test campaigns to be used for the comparison of different approaches to local tie surveys addressing each of the technical elements;
- Develop standards for the documentation of site surveys, including survey report content and format; and
- Suggest a pool of expertise to provide advice to survey teams, as required, on standards for site surveys.

Coordination

- Liaise with local and international survey teams undertaking site surveys at important co-location sites;
- Liaise with the technique combination groups to ensure WG site survey products meet user requirements;
- Coordinate as required and make recommendations to observatories as to survey scheduling and re-survey frequency;
- Develop and distribute software tools to the community to assist in the generation of site survey products, including SINEX generation software; and
- Provide a forum to raise the profile of site survey as a critically important independent geodetic technique.

Site Survey Research

- Investigate new site survey methodologies, including observational techniques, observational modelling, invariant point definition, geometrical modelling and/or direct measurement techniques for invariant point determination, reference frame alignment and structural deformation analysis.

Future Planning

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

Meetings in 2006

Two meetings were held in 2006. The first meeting was held at EGU in April 2006 at Vienna. The minutes and copies of presentations from that meeting can be found at <http://www.iers.org/MainDisp.csl?pid=68-40>. The meeting was well attended and presentations from a number of speakers illustrated current topics of interest. The meeting stressed the need to continue to develop the concept of Local Ties as a key component of the technique combinations and reference frame definition.

The second meeting was held at the ILRS workshop in Canberra. Although this was a smaller meeting it did concentrate more directly on Local Tie issues with SLR stations. The minutes from that meeting are available at the web page mentioned above.

Other Activities

Geoscience Australia continues to develop guidelines document for Local Tie Surveys. A draft of this document should be available by EGU2007 for the broader working group to discuss.

IGN is now undertaking routine local tie surveys at numerous sites and offers this service to observatory operators who are unable to complete their own surveys.

Geoscience Australia will also visit the Syowa, Antarctica, VLBI site to undertake survey planning and design for a later complete Local Tie Survey. This preliminary visit will occur in January 2007.

The Canberra meeting highlighted the benefit of exchanging survey data and reduction utilities as a means of standardising and calibrating survey analysis techniques.

Future Meetings

The working group has planned to meet again at the EGU2007 meeting in Vienna, Austria.

Gary Johnston

3.7.2 Working Group on Combination

IERS Combination Pilot Project (CPP)

One major project of the working group still is the IERS Combination Pilot Project (CPP) that started already in 2004 (see IERS Annual Report 2004 for more details). However, many developments within the IERS during the last years were running in parallel (new ITRF computations, Call for long-time series, CPP), so that the original intention of the CPP, i.e., a routine generation of weekly combined inter-technique solutions could not be achieved yet. Nevertheless, the first step is already successfully completed: Each of the technique services provides routinely an official weekly / daily intra-technique combined solution.

GGOS-D Project

The project “GGOS-D” is one of the major projects concerning the combination of space geodetic techniques and, therefore, should be mentioned here, too. GGOS-D is funded by the German Ministry of Education and Research (BMBF) within the Geotechnologien programme, with four institutions involved: GeoForschungsZentrum Potsdam (GFZ), Deutsches Geodätisches Forschungsinstitut (DGFI) in Munich, Institute of Geodesy and Geoinformation of the University of Bonn (IGG-B), and Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt/Main. Within this group, a broad variety of expertise concerning the analysis of GPS, VLBI, SLR, altimetry and Low Earth Orbiter (LEO) data is available so that high-quality solutions for all of these techniques could be generated. All partners agreed on detailed standards for their analysis strategy concerning a priori models and parameterization so that the resulting normal equation systems are as homogeneous as possible and allow for a rigorous combination. The level of agreement and the remaining analysis noise can be assessed as two different contributions for each of the techniques are available, at least for GPS, VLBI and SLR. An overview about the software packages used and the time span of data that is analyzed is given in Table 1. Similar to the analysis of the data, the inter-technique combination is performed with two different software packages as well.

Table 1: Generation of consistent time series within the GGOS-D project.

Technique	Software	Institution	Resolution	Period
SLR	DOGS	DGFI	1 week	11/1992 – 12/2006
SLR	EPOS	GFZ	1 week	10/1992 – 12/2006
VLBI	OCCAM	DGFI	1 day	01/1984 – 12/2006
VLBI	Calc/SOLVE	IGG-B / BKG	1 day	01/1984 – 12/2006
GPS	EPOS	GFZ	1 week	Several months
GPS	Bernese	GFZ	1 day	01/1994 – 12/2006
LEOs	EPOS	GFZ	3 days	01/2004 – 12/2004
Altimetry	DGFI software	DGFI		01/1993 – 12/2005
Combination	DOGS-CS	DGFI	1 day / 1 week	01/1984 – 12/2006
Combination	Bernese	GFZ	1 day / 1 week	01/1984 – 12/2006

Besides the agreement on common standards and a homogeneous reprocessing of the whole time span of data, the parameter space used within GGOS-D marks an important extension compared to standard solutions provided by the technique-specific analysis centers:

- station coordinates,
- Earth orientation parameters (all five angles including their time-derivatives),
- station-specific troposphere parameters for GPS and VLBI (zenith delay and horizontal gradients),
- spherical harmonic coefficients of the Earth's gravity field of degrees zero to two for SLR and LEO solutions.

Due to the extended parameter space, the individual techniques can be linked by more parameters than solely the station coordinates and EOPs. Furthermore, the correlations and interactions between all the estimated parameters can be studied, and the impact of combining the individual contributions can be assessed.

More information about the project GGOS-D is available at <http://www.ggos-d.de>.

Meetings and Workshops

See Section 3.3 "Analysis Coordinator" (this volume) for a detailed list.

Markus Rothacher, Daniela Thaller

3.7.3 Working Group on Prediction

Introduction

The IERS Working Group on Prediction (WGP) was proposed at the IERS Directing Board meeting in December 2005 and work began early in 2006. The group was designed to address fundamental questions concerning IERS predictions and to determine what can be done to improve the IERS prediction of Earth orientation. Specifically, the WGP was tasked to determine what prediction products are needed by the user community and to examine the fundamental properties of the different input data sets and algorithms (see IERS website <http://www.iers.org/MainDisp.csl?pid=167-1100082>). There are two areas of investigation: the input data (geodetic and geophysical information) and the algorithms used to process the data. The WGP establishment grew out of IERS Rapid Service/Prediction Center (RS/PC) concerns about the continued relevance of current products, new accuracy requirements, the impact of new data sets, and viable new prediction methodologies and the desire to build on the interest generated by the EOP Prediction Comparison Campaign of the Technical University of Vienna and the efforts of the IERS Combination Pilot Project (see section 3.7.2). Another expectation of the RS/PC was a definitive assessment of the current state-of-the-art in EOP prediction.

Goals and Objectives

The goals and objectives of the WGP are the following:

1. Determine the desired Earth orientation parameter (EOP) prediction products – What is needed by the user community?
2. Determine the importance of the input data – What new data sets are available? Are data sets interchangeable? Are some sources inherently better?
3. Determine which types of input data create an optimal prediction – What is the noise of the series? What smoothing is best? What geophysical phenomena are being measured?
4. Determine the strengths and weaknesses of the prediction algorithms – Which algorithms perform best under what circumstances? How can problems be mitigated?
5. Determine the interactions between series and algorithms that are beneficial or harmful - What qualities of certain data sets make them well-suited or poorly-suited for certain algorithms?

WG Meetings

The first meeting of the WGP was held on 6 April 2006 at the European Geophysical Union meeting in Vienna. The topics discussed included an overview of the project, a review of the charter highlighting the goals and objectives, and the proposed structure. In addition, a draft survey form to determine what IERS prediction products users need was discussed. Several useful suggestions were made and subsequently incorporated into the survey form and the planned activities. Efforts were made to determine who besides the individuals on the IERS and RS/PC mailing lists should be solicited to participate in the user survey.

A planning meeting with the subgroup chairs and the WGP chair was held at the 2006 December American Geophysical Union meeting in San Francisco. The user survey form was finalized and plans were made for the analysis of anticipated survey data. Also, plans were made for presentations at the EGU and a potential workshop in conjunction with another technical meeting. Additional tasks were specified for the input data subgroup and the algorithms subgroup.

WG Activities

The plans and activities of the WG were summarized in a paper given at the December 2006 AGU Fall Meeting in San Francisco. Specific algorithm topics discussed included prediction methods, formulations, flow diagrams, accuracy dependencies, and problems associated with individual prediction methods. Specific input data concerns to be addressed include minimizing data latency, sensitivities to missing data, loss of information at common epochs, new potential geophysical fluids information, and optimum combination of data. Other plans include determining optimum parameters for combination prediction algorithms, geophysical causes of prediction errors, and examining pathological timeframes for prediction. In addition the opportunity and the timeframe for participation in upcoming EOP prediction user survey were highlighted.

EOP Prediction Survey

The first task of the WGP was to determine whether the current RS/PC products, which were developed more than 15 years ago, are adequate or whether modifications and/or improvements are necessary to meet more stringent requirements. Therefore, a short EOP user survey was developed by the WGP and posted on the RS/PC website to address goal #1. The IERS invited participation from those on the IERS mailing lists, those who receive IERS RS/PC products, and any others thought to have an interest in EOP predictions (see IERS Message No. 104). The survey consisted of 10 questions that involved mostly checking boxes with a limited number of options. The intent was to categorize the various classes of users and their accuracy requirements. The form was to be easy to complete and still provide enough characteristics to help the WGP focus its effort. Given the variety of high-precision applications which need EOP predictions, what characteristics (type, accuracy, data spacing, data span, form, *etc*.) are required and are new products needed.

Future Meetings

Presentations are planned for the April 2007 European Geophysical Union Meeting in Vienna and also for the September 2007

Journées Meeting in Meudon, France. It is hoped that a special session on “EOP Combination and Prediction” can be included in the Journées meeting. That meeting will also be an opportunity to solicit additional feedback on WP activities.

William Wooden

4 IERS Workshop on Global Geophysical Fluids

This workshop was organised to take an insightful review of where the Global Geophysical Fluids Centres (GGFC) are and to discuss options for potential changes to the structure of the GGFC such that today's users can easily find the models and data sets that they need. It took place at the Hotel Grand Hyatt, San Francisco, USA, on December 06 – 07, 2006.

The main goal of the workshop was to determine whether the GGFC was adequately addressing the needs of the community. The original concept of a Global Geophysical Fluids Centre within the IERS, consisting of Special Bureaus defined by the fluids themselves, was an excellent first step to serving the needs of the geodetic community. Ten years on, the community and their needs have changed as the precision of the geodetic observations has been significantly increased. The division of the GGFC along the lines of the fluids generating a geodetic effect may no longer be sufficient. Therefore the time is right to consider a restructuring of the GGFC.

More than 25 participants followed the invitation for two days. Invited speakers addressed the community needs and what other communities could contribute to the GGFC.

F. Flechtner titled his paper "What can GGFC get from Gravity missions?" He demonstrated that short-term mass variations on sub-daily to annual time scales caused by mass redistributions in the Earth's subsystems, i.e. the atmosphere, the oceans, the lithosphere, the hydrosphere and the cryosphere are aliased into the monthly GRACE gravity field solutions if not corrected properly. To eliminate short-period non-tidal atmospheric and oceanic mass anomalies from monthly mean GRACE gravity estimates the AOD1B product was developed at GFZ which is based on 6-hourly ECMWF Operational Analysis meteorological data and an ocean model forced with ECMWF data, too. Hydrological mass variations are not yet taken into account. Therefore the prime outputs from GRACE are monthly maps of the continental hydrological cycle. Nevertheless projects started to assimilate GRACE and to provide hydrological mass variations on daily basis (e.g. TIVAGAM). If assimilated by the GGFC time series could be made available of 6-hourly and monthly-mean (corresponding to the GRACE gravity field solutions) atmospheric, oceanic and combined as well as ocean bottom pressure mass variations (AOD1B RL04) based on ECMWF forcing, mean field 2001+2002, mass-conserving OMCT, vertical integrated pressure, surface pressure (for OBP), harmonized land/water mask and L1/L2 standards.

M. Watkins with his presentation "What can GGFC do for Global Gravity Missions?" followed these ideas but also stated that most of the analysts are interested in running alternate de-aliasing models provided e.g. by the GGFC. Therefore he recommended that the IERS should strongly consider becoming an integral part of the analysis system of upcoming missions through a demonstration focused on re-analysis and possibly growing to a more operational role (as for Earth orientation).

The Earth rotation community needs were formulated by R. Gross. To model the angular momenta precise information is necessary about the motion and the mass redistribution of all geophysical fluids, e.g. atmosphere, oceans, hydrosphere, mantel, core on global and regional scales and subdaily to decadal time scales. For the various torques (tidal, gravitational, friction, mountain, viscous, electromagnetic) adequate external, surficial and internal data from earth are required.

After the definition of needs all chairs of the special bureaus except the hydrology and core SB's demonstrated their products and capabilities.

During the discussion various defects were found within some GGFC special bureaus and data sets. Data should be improved in the areas of reliability, the state of the art, improved documentation, common formats and units, precision information. After additional data sets, e.g. mapping functions and GRACE products were requested, the ILRS offered to provide ongoing data for geo-centre variations and the University of Vienna is able to contribute its mapping function on a regular basis.

More detailed information on the workshop and all presentations can be found at

<http://www.iers.org/MainDisp.csl?pid=66-1100113>.

At its subsequent, 43rd meeting, the IERS Directing Board agreed that the GGFC chair will draft a plan for improving the GGFC data and in particular the SBL products to get more acceptance by the community.

Bernd Richter

Appendix 1: IERS Terms of Reference

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

The primary objectives of the IERS are to serve the astronomical, geodetic and geophysical communities by providing the following:

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

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

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

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

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

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

The IERS accomplishes its mission through the following components:

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

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

TECHNIQUE CENTERS (TC)

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

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

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

PRODUCT CENTERS (PC)

PCs are responsible for the products of the IERS.

Such centers are the following:

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

COMBINATION CENTER(S)

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

IERS ANALYSIS COORDINATOR (AC)

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

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

CENTRAL BUREAU (CB)

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

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

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

DIRECTING BOARD (DB)

The Directing Board consists of the following members:

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

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

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

The Chairperson is one of the members of the DB elected by the

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

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

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

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

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

WORKING GROUPS

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

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

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

- Draft charter clearly specifying:
    - Proposed goals (two pages at maximum),
    - Proposed structure of the group or project,
    - Working plan including schedule / deadlines including the anticipated end of work,

- Candidate for a chairperson to be appointed by the DB (optional),
- Initial list of members,
- Proposed plans for an operational phase (if applicable),
- Draft IERS message to inform the IERS community.

IERS ASSOCIATE MEMBERS

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

IAG General Secretary
IAU General Secretary
IUGG General Secretary
President of FAGS
President of IAG Commission 1
President of IAG Subcommission 1.1
President of IAG Subcommission 1.2
President of IAG Subcommission 1.4
President of IAG Commission 3
President of IAG Subcommission 3.1
President of IAG Subcommission 3.2
President of IAG Subcommission 3.3
President of IAU Commission 8
President of IAU Commission 19
President of IAU Commission 31
Head of IAU Division I

IERS CORRESPONDENTS

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

December 11, 2007

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(*Status as of February 2008*)

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

Central IERS web site

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

Products

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

Earth orientation data

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

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

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

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

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

Conventions

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

International Celestial Reference Frame

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

International Terrestrial Reference Frame

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

Geophysical fluids data

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

Publications

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

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

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

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

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

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

IERS Components

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

Analysis Coordinator
Web site: http://www.gfz-potsdam.de/pb1/IERS/iersAC_index.html

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

Product Centres

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

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

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

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

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

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

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

Technique Centres

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

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

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

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

Combination Centres

ITRS Combination Centres

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

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

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

Combination Research Centres

Web site: http://www.gfz-potsdam.de/pb1/IERS/iersAC_index.html

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

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

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

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

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

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

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

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

Working Groups

Working Group on Site Survey and Co-location
Web site: http://www.iers.org/MainDisp.csl?pid=68-38

Working Group on Combination
Web site: http://www.iers.org/MainDisp.csl?pid=69-41

Working Group on Prediction
Web page: http://www.iers.org/MainDisp.csl?pid=167-1100082

IERS/IVS Working Group on the Second Realization of the ICRF
Web page: http://www.iers.org/MainDisp.csl?pid=198-1100160

Appendix 5: Acronyms

2QZ	2dF redshift survey
AAM	Atmospheric Angular Momentum
AC	Analysis Centre
AC	Analysis Coordinator
AER	Atmospheric and Environmental Research Inc.
AGN	Active Galactic Nuclei
AGU	American Geophysical Union
AICAS	Astronomical Institute, Academy of Sciences of the Czech Republic
APCV	Antenna Phase Centre Variation
APKIM	Actual Plate KInematic and crustal deformation Model
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
BMBF	Bundesministerium für Bildung und Forschung, Germany
CATREF	Combination and Analysis of Terrestrial Reference Frames
CB	Central Bureau
CC	Combination Centre
CCD	Charge-Coupled Device
CDDIS	NASA Crustal Dynamics Data Information System
CDS	Centre de Données astronomiques de Strasbourg (formerly: Centre de Données Stellaire)
CEDR	Center for Earth Dynamics Research
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques
CGS	Centro di Geodesia Spatiale, ASI
CHAMP	CHAllenging Minisatellite Payload
CLS	Collecte Localisation Satellites
CNES	Centre National d'Etude Spatiale
COD	= CODE
CODE	Centre for Orbit Determination in Europe
CONT	continuous VLBI session
CPC	Climate Prediction Center
CPP	IERS Combination Pilot Project
CPU, cpu	central processing unit
CRC	Combination Research Centre
CRD	CRF deepsouth sessions
CRF	Celestial Reference Frame
CSR	Center for Space Research, University of Texas
CSRIFS	Combined Square Root Information Filter and Smoother (program)
CSW	Catalogue Service Web
DB	Directing Board
Dep., Dept.	Department
DGFI	Deutsches Geodätisches Forschungsinstitut
DIS	IERS Data and Information System
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
ECCO	Estimating the Circulation and Climate of the Ocean
ECMWF	European Center for Medium Range Weather Forecasting
EDC	EUROLAS Data Center
EGU	European Geosciences Union
EMR	Energy, Mines and Resources Canada (replaced by NRCan)
ENSG	Ecole Nationale de Sciences Geographiques
EOC	Earth Orientation Centre
EOP	Earth Orientation Parameters
ESA	European Space Agency
ESOC	European Space Operations Center, ESA

e-VLBI	Electronic transfer VLBI
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FCN	Free Core Nutation
FFI	Forsvarets forskningsinstitutt
FTP, ftp	File Transfer Protocol
GA	General Assembly
GAOUA	Main Astronomical Observatory of the Ukrainian Academy of Sciences
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFZ	GeoForschungsZentrum Potsdam
GGFC	Global Geophysical Fluids Centre
GGOS	Global Geodetic Observing System
GGOS-D	GGOS – Deutschland (Germany)
GIUB	Geodetic Institute of the University of Bonn (now IGGB)
GLDAS	NASA's Global Land Data Assimilation System
GLONASS	Global Orbiting Navigation Satellite System, Russia
GLOUP	GLObal Undersea Pressure
GMF	Global Mapping Function
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRGS	Groupe de Recherches de Géodésie Spatiale
GSFC	Goddard Space Flight Center
HCRF	Hipparcos Celestial Reference Frame
HEO	High Earth Orbiter
hr	hour
HST	Hubble Space Telescope
IAA	Institute of Applied Astronomy, St. Petersburg
IAC	Information-Analytical Centre, Russia
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICG	International Committee on Global Navigation Satellite Systems
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
ICSU	International Council for Science
ID	Identification/Identifier
IDS	International DORIS Service
IERS	International Earth Rotation and Reference Systems Service (formerly: International Earth Rotation Service)
IGGB	Institute of Geodesy and Geoinformation of the University of Bonn (formerly GIUB)
IGN	Institut Géographique National
IGR	IGS rapid (orbit)
IGS	International GNSS Service (formerly: International GPS Service)
ILRS	International Laser Ranging Service
ILRSA	ILRS Combination Centre
IMF	Isobaric Mapping Function
INA	= INASAN
INASAN	INstitut AStronomii Rossijskoj Akademii Nauk (Institute of Astronomy of the Russian Academy of Sciences)
IRIS	International Radio Interferometric Surveying
ISO	International Organization for Standardization
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
ITSS	see Raytheon ITSS
ITU	International Telecommunication Union
IUGG	International Union of Geodesy and Geophysics
IVOA	International Virtual Observatory Alliance
IVS	International VLBI Service for Geodesy and Astrometry
JADE	JApanese Dynamic Earth observation by VLBI
JCET	Joint Center for Earth System Technology, GSFC
J-MAPS	Joint Milli-Arcsecond Pathfinder Survey
JPL	Jet Propulsion Laboratory
KEOF	Kalman Earth Orientation Filter
LaD	Land Dynamics
LAMPP	Linux Apache MySQL PHP Perl [group of open-source computer programs]
LAREG	Laboratoire de Recherche en Geodesie

LCA	LEGOS in cooperation with CLS
LDAS	Land Data Assimilation System
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LEO	Low Earth Orbit(er)
LLR	Lunar Laser Ranging
LOD	Length of Day
LPCE	Laboratoire de Physique et Chimie de l'Environnement
MAO	= GAOUA
mas	milliarcsecond(s)
µas	microarcsecond(s)
MCC	Russian Mission Control Centre
MERIT	Monitoring Earth Rotation and Intercomparison of Techniques
MICOM	Miami Isopycnic Coordinate Ocean Model
MIS	Meta Information System
MIT	Massachusetts Institute of Technology
MJD	Modified Julian Day
MOM	Modular Ocean Model
MPIfR	Max-Planck-Institut für Radioastronomie / Max Planck Institute for Radio Astronomy
ms	millisecond(s)
µs	microsecond(s)
NASA	U.S. National Aeronautics and Space Administration
NCAR	U.S. National Center for Atmospheric Research
NCEP	U.S. National Centers for Environmental Prediction
NEQ	normal equation
NERC	Natural Environment Research Council, UK
NetCDF	Network Common Data Form
NGS	U.S. National Geodetic Survey
NMCA	Norwegian Mapping and Catastre Authority
NMF	Niell Mapping Function
N.N.	Nomen Nominandum [vacant, to be nominated]
NNR	No-net-rotation
NOAA	U.S. National Oceanic and Atmospheric Administration
NOFS	USNO Flagstaff Station
NOGAPS	[U.S.] Navy's Operational Global Atmospheric Prediction System
NRAO	[U.S.] National Radio Astronomy Observatory
NRCan	Natural Resources, Canada (formerly: EMR)
ns	nanosecond(s)
NSGF	NERC Space Geodesy Facility
OATo	Osservatorio Astronomico di Torino
OBP	Ocean Bottom Pressure
Obs.	Observatory, Observatoire
OCA	Observatoire de la Côte d'Azur
OCRF	Optical Celestial Reference Frame
OMCT	Ocean Model for Circulation and Tides
OP	Observatoire de Paris
OPAR	Paris Observatory IVS Analysis Center
PC	Product Centre
PHP	PHP: Hypertext Preprocessor
PI	Principal Investigator
PM	Polar Motion
POCM	Parallel Ocean Climate Model
POD	Precise [or Precision] Orbit Determination
POLAC	Paris Observatory Lunar Analyses Center
PP	Pilot Project
ppb	parts per billion (10^{-9})
PPP	Precise Point Positioning
PRARE	Precise RAnge and Range-Rate Equipment
PT	(SDSS) Photometric Telescope
PZT	Photographic Zenith Tube [or Telescope]
QSO	Quasi-Stellar Object [quasar]
Raytheon ITSS	Raytheon Systems Company Information Technology & Scientific Services
R&D	Research and Development
RDV	Research and Development (sessions) with the VLBA
RFI	radio frequency interference
RINEX	Receiver INdependent EXchange format
rms, RMS	Root Mean Square
RRFID	USNO Radio Reference Frame Image Database
RS/PC	IERS Rapid Service/Prediction Center
SAA	South Atlantic Anomaly

SB	Special Bureau
SBA	Special Bureau for the Atmosphere
SBC	Special Bureau for the Core
SBGG	Special Bureau for Gravity/Geocenter
SBH	Special Bureau for Hydrology
SBL	Special Bureau for Loading
SBO	Special Bureau for the Oceans
SDSS	Sloan Digital Sky Survey
SHAO	Shanghai Observatory
SIM	NASA's Space Interferometry Mission
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SLR	Satellite Laser Ranging
SPBU	St Petersburg University
SRIF	Square Root Information Filter array
sta.	station
SYRTE	(Laboratoire) Systèmes de Référence Temps-Espace
TAI	Temps Atomique International (International Atomic Time)
TC	Technique Centre
TEMPO	Time and Earth Motion Precision Observations
TIVAGAM	Time-variable gravity and surface mass processes
TRF	Terrestrial Reference Frame
TT	Terrestrial Time
TU	Technical University
TUM	Technical University of Munich
UCAC	USNO CCD Astrograph Catalog
UCSD	University of California, San Diego
Univ.	University
URAT	USNO Robotic Astrometric Telescope
URL	Uniform Resource Locator
USN	= USNO
USNO	United States Naval Observatory
UT, UT0, UT1, UT1R	Universal Time
UTAAM	NOAA AAM analysis and forecast data
UTC	Coordinated Universal Time
VLA	Very Large Array
VLBA	Very Long Baseline Array, NRAO
VLBI	Very Long Baseline Interferometry
VMF1	Vienna Mapping Function
VO	Virtual Observatory
VOTable	(Virtual Observatory) XML format for the exchange of tabular data
WG	working group
WGP	IERS Working Group on Prediction
wk	week
WRMS	Weighted Root Mean Square
XML	eXtensible Markup Language
yr	year
ZTD	zenith total delay