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

IERS
Annual Report
2007

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IERS Annual Report 2007

Edited by Wolfgang R. Dick and Bernd Richter

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1 Foreword

The IERS Annual Report for 2007 shows the difficult balance between continuity and change that is necessary for the IERS to continue to meet its responsibilities. The EOP data embodied in the IERS now goes back more than a century but to make such data accessible in the current network-connected world requires further machine-readable metadata, as is being done by the IERS Central Bureau for all IERS products. A careful description of models given in the IERS Conventions is essential for proper analysis and interpretation but models must be continually refined and extended to encourage and to use better observations from the Technique Centers. The IERS Workshop on Conventions provided a forum and direction on how to move forward. The Earth Orientation Centre developed a strategy for maintaining consistency of EOP 05 C4 and ITRF 2005 while the Rapid Service / Prediction Centre updated the system of Bulletin A to be consistent with EOP 05 C04. Having released ITRF 2005 the ITRS Centre provided users access through its web site while the ICRS Centre along with the IERS/IVS Working Group for the Second Realization of the ICRF began analysis expected to culminate in the adoption of a new ICRF by the IAU in 2009.

The Technique Centers all worked at improving their operations and analysis. Significant events included a transition of Analysis Coordinator and the beginning of uniform reprocessing by the IGS, the start of “daily” EOP products by the ILRS, the first test fringes with the VLBI 2010 system by the IVS, and a 40% improvement in data latency in the IDS.

In the broader perspective the activities of the IERS in 2007 should be seen as prelude and preparation for major efforts toward updating the ITRF and ICRF leading eventually to greater integration of analysis of IERS products. This goal demands considerably more work on consistent modeling, parameterization, and combination.

Chopo Ma
Chair, IERS Directing Board

2 The IERS
2.1 Structure

From 2007 to 2009, 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 between 2007 and 2009.

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 (from 1 January to 31 December 2008),
Steven Fisher (since 1 January 2009)
IERS Representative to the IGS Governing Board: Claude Boucher

International Laser Ranging Service (ILRS)
ILRS Representatives to the IERS Directing Board:
Jürgen Müller, Erricos C. Pavlis
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 (until 30 April 2009), Rüdiger Haas (since 1 May 2009)
IERS Representative to the IVS Directing Board: Chopo Ma

International DORIS Service (IDS)
IDS representatives to the IERS:
Hervé Fagard (until June 2009), Frank G. Lemoine
IERS Representative to the IDS Governing Board:
Ron Noomen

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 H. Wooden (until August 2009), Brian J. Luzum (since September 2009)

Conventions Centre
Primary scientists: Brian J. Luzum, Gérard Petit
Representative to the IERS Directing Board:
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 (until 31 December 2008),
Jean Souchay (since 1 January 2009)

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

Special Bureau for the Mantle
Erik R. Ivins

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 (until 31 December 2008)

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

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 (until 31 December 2008),
Pierguido Sarti (since 1 January 2009)

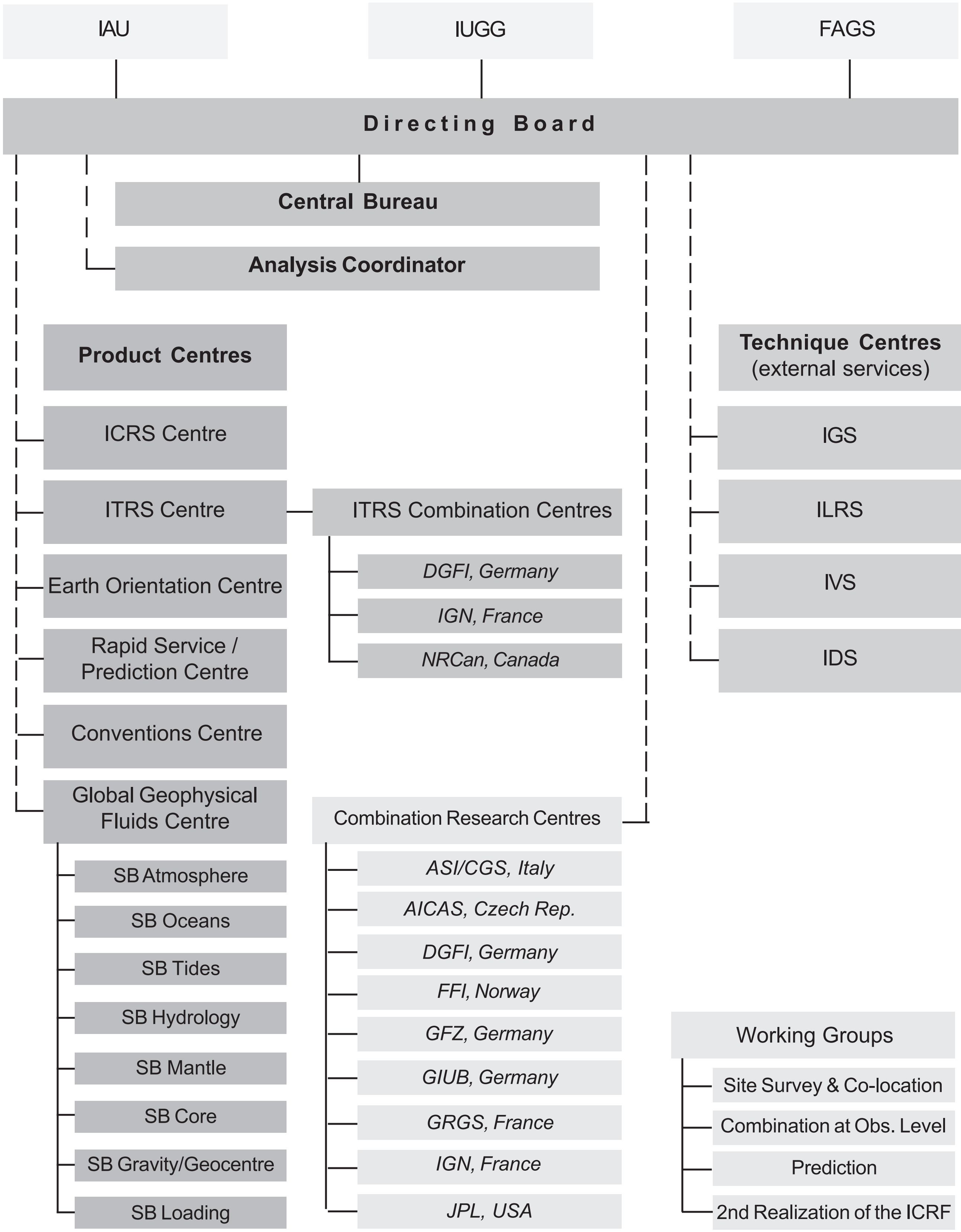
Working Group on Combination
(until 31 December 2008)
Chair: Markus Rothacher

Working Group on Prediction
Chair: William H. Wooden (until August 2009),
Brian J. Luzum (since September 2009)

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

Working Group on Combination at the Observation Level
(established in October 2009)
Chair: Richard Biancale

(*Status as of October 2009*)


IAU
IUGG
FAGS
Directing Board
Central Bureau
Analysis Coordinator
Product Centres
ICRS Centre
ITRS Centre
Earth Orientation Centre
Rapid Service / Prediction Centre
Conventions Centre
Global Geophysical Fluids Centre
SB Atmosphere
SB Oceans
SB Tides
SB Hydrology
SB Mantle
SB Core
SB Gravity/Geocentre
SB Loading
ITRS Combination Centres
DGFI, Germany
IGN, France
NRCan, Canada
Combination Research Centres
ASI/CGS, Italy
AICAS, Czech Rep.
DGFI, Germany
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 at Obs. Level
Prediction
2nd Realization of the ICRF

2.2 Directing Board

In 2007 to 2009, 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 (until August 2009), Brian J. Luzum (since September 2009)
Conventions Centre	Brian J. Luzum (since 1 January 2007)
ICRS Centre	Ralph A. Gaume (until 31 December 2008), Jean Souchay (since 1 January 2009)
ITRS Centre	Zuheir Altamimi
Global Geophysical Fluids Centre	Tonie van Dam
Central Bureau	Bernd Richter
Combination Research Centres (until 31 December 2008)	N.N.
Technique Centers Representatives	
IGS	Gerd Gendt (until 31 December 2007), Angelyn W. Moore (until January 2008), Jim Ray (from 1 January to 31 December 2008), Steven Fisher (since 1 January 2009)
ILRS	Jürgen Müller, Erricos C. Pavlis
IVS	Chopo Ma, Axel Nothnagel (until 30 April 2009), Rüdiger Haas (since 1 May 2009)
IDS	Hervé Fagard (until June 2009), Frank Lemoine
Union Representatives	
IAU	Nicole Capitaine (until July 2009), Aleksander Brzezinski (since August 2009)
IAG / IUGG	Clark R. Wilson
FAGS (until 31 December 2008)	Nicole Capitaine

2.3 Associate Members

Andersen, Ole Baltazar
Arias, Elisa Felicitas
Behrend, Dirk
Biancale, Richard
Boucher, Claude
Bruyninx, Carine
Capitaine, Nicole
Carter, William E.
Chao, Benjamin F.
Chen, Jianli
Dow, John M.
Drewes, Hermann
Fagard, Hervé
Feissel-Vernier, Martine
Ferland, Remi
Gaume, Ralph A.
Gendt, Gerd
Gross, Richard S.
Gurtner, Werner
Herring, Thomas
Ivins, Erik R.
Kolaczek, Barbara
McCarthy, Dennis D.
Melbourne, William G.
Moore, Angelyn W.
Neilan, Ruth E.
Noomen, Ron
Nothnagel, Axel
Pearlman, Michael R.
Petit, Gérard
Plag, Hans-Peter
Pugh, David
Ray, Jim
Ray, Richard D.
Reigber, Christoph
Salstein, David
Sarti, Pierguido
Schuh, Harald
Schutz, Bob E.
Shelus, Peter J.
Van Hoolst, Tim
Veillet, Christian
Vondrák, Jan
Watkins, Michael M.
Weber, Robert
Willis, Pascal
Wooden, William H.
Yatskiv, Yaroslav S.
Yokoyama, Koichi
Zhu, Sheng Yuan

Ex officio Associate Members:
IAG General Secretary: Hermann Drewes
IAU General Secretary: Ian F. Corbett
IUGG General Secretary: Jo Ann Joselyn
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: Dafydd Wyn Evans
President of IAU Commission 19: Harald Schuh
President of IAU Commission 31: Richard N. Manchester
Head of IAU Division I: Dennis D. McCarthy

(*Status as of October 2009*)

3 Reports of IERS components
3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of the year 2007. Summaries of these meetings are given below.

Meeting No. 44

April 15, 2007, Technical University of Vienna, Vienna, Austria

Introduction and approval of agenda

The agenda was adopted with a slightly changed order of items and the Minutes of the IERS Directing Board meeting # 43 were approved.

Formalities

The Chair, Chopo Ma, reported about his participation in the GGOS retreat in Oxnard, California on February 19 – 21, 2007. To prepare the retreat a questionnaire was distributed to collect the contributions and the expectations of the IAG services with respect to GGOS. As a sidelight it was estimated that all IERS activities total ~ 35 person-years.

On January 1, 2007 the lead of the Conventions Centre switched from G. Petit to B. Luzum.

ITRF 200X

Convergence of ITRF solutions

Z. Altamimi visited Munich on April 2, 2007 to start an intensive discussion on the combination processes used at IGN and DGFI. It is planned to meet four times a year.

He continued that there has been an extensive exchange of test combinations including input data, cumulative solutions per technique, selection of local ties and their weighting, and multi-technique combinations including all residuals. IGN provided the ITRF2005 ties and their sigmas. DGFI recently provided technique residuals of a new combination but not yet the tie residuals.

H. Drewes explained in his presentation the two different strategies and the possible difficulties. In the DGFI solution the scale might be affected by technique specific effects whereas the IGN solution network deformations might enter into the datum. There is always the danger that a real global change will be absorbed in the parameters. For the next ITRF it has to be discussed if the datum parameters will be derived from the definition (geocentric, metric) or from the (deforming) network realization (centre & scale of the network). H. Drewes stated that the intra-technique solutions are already in agreement at the sub-millimetre level.

Scenario for generation of the next ITRF

To generate the next ITRF new data need to be included, especially the results from the IGS and ILRS reprocessing. Z. Altamimi asked for more separate GPS co-locations with VLBI and with SLR because they are essential to strengthen the connection between VLBI and SLR, which have only 7 co-locations. The GPS Absolute

Phase Centre variation (APCV) might affect the GPS vertical component estimate. More past SLR data (1980 – 1992) are necessary for monitoring the scale and the origin, and effects of the range bias estimation and the new modelling of the troposphere / mapping function have to be studied. In total the scale difference between VLBI and SLR might be changed.

G. Gendt described the status of the IGS reprocessing activities. The reprocessing is performed by six analysis centres and three combination centres. The reprocessing will last at least one year. The IGS reprocessing will benefit from AC's software improvements, improved models (absolute antenna models, ocean loading, troposphere – GMF, GPT), improved tables of discontinuities, completion of IGS data archives. In the first run no higher order ionospheric effects or atmospheric and ocean loading effects will be considered. The reprocessing will provide weekly SINEX files incl. ERP back to 1994 (new for 1994 to 1999) and orbits & compatible sat-clocks (5-minute) with high consistency back to 1994.

Chopo Ma reiterated that the co-location sites should be included in the reprocessing. Prompted by A. Nothnagel G. Gendt explained that activities are going on to calibrate radomes, but there are many different kind of radomes as well as behaviour different under specific environmental effects.

E. Pavlis reported about the status of the ILRS network developments: 32 global stations providing tracking data regularly, Haleakala, HI station reactivated (November 2006), Arequipa, Peru station reactivated (October 2006), highly productive San Juan, Argentina station, operational since March 2006 (Argentine/Chinese cooperation), new missions; the analysis activities: ILRS official products (station coordinates and EOP) issued weekly, seven ILRS Analysis Centres (ASI, DGFI, BKG, GA, GFZ, NASA GSFC/JCET, and NERC) contributing to the official products, combination and combination back-up centres at ASI and DGFI, analysis of early LAGEOS (1976–1993) data underway for ILRS product submission to the next reference frame, POD products for geodetic satellites (initially) to be routinely available in mid-2007; the GNSS retro reflector activities, and the technical developments. The new combined solutions will be available in July.

A. Nothnagel stated that the IVS is doing the reprocessing as well and noted that there is still an inconsistency in the definition and handling of the pole tide.

F. Lemoine demonstrated that the application of the new gravity fields and atmospheric loading slightly improved the DORIS solutions, especially the annual signal.

M. Rothacher as IERS Analysis Coordinator summarized the discussion and focused in his presentation on the time table for the next generation, the input data, the models relevant for more than one technique, the list of parameters, the standards for parameterisation and the ITRS Combination Centres.

In the general discussion H. Drewes proposed a meeting of all Analysis Centres at the IUGG in Perugia. He suggested an ITRF 2007 conducted in 2008. It should include a minimum set of common parameters and models. Chopo Ma asked the Analysis Coordinators of the IERS TCs if it would be possible to meet in Perugia: IDS agreed, IGS maybe too early, IVS reprocessing maybe not possible before Perugia, ILRS agreed. M. Rothacher and Z. Altamimi should make the arrangements.

Decision process for the selection of the next ITRF

Z. Altamimi suggested the following procedure: wait for IGS and ILRS reprocessing, work in a more cooperative way between ITRF CCs (e.g. regular meetings, test combination exchanges), and submission of an unique ITRF solution to the TCs and others for evaluation.

M. Rothacher completed the previous comments by more details on the planning, the generation of the input series, the combination and the evaluation procedures. The proposed approval phase and steps were not in common consensus with Z. Altamimi.

Examination of co-location site discrepancies

Z. Altamimi pointed out that the examination of the co-location site discrepancies is very problematic and that most local ties have there own epochs. He emphasised the application of the complete set of local ties but stated that the application of the APCV degrades the solution in the combination. H. Drewes proposed to write a letter to the station managers asking for yearly local tie measurements.

M. Rothacher recommended the local ties as analysis tool because the local tie discrepancies are possibly hints for systematic effects in the space geodetic techniques. The list of some of the critical systematic effects shows that especially the mapping functions and the higher order ionospheric terms affect the height component.

New EOP series

Report from Earth Orientation Centre

D. Gambis presented the new approach for a combined solution C04(05). With the release of ITRF 2005 he sees the chance to renew the C04 series. Reasons are the extended time series, new algorithms (new models for nutation and UT1/LOD tidal variations, new approach for combination of LOD (GPS) and UT1–UTC determined by VLBI, and estimation of the formal errors. The EOC is planning to do its own combination independent of developments in the ITRF and ICRF. The EOC is ready for implementation.

W. Wooden analysed the proposed new C04(05) series. He noted major inconsistency concerns, displayed in his presentation. It was proposed that the heads of the EOC and of the RSPC as well as the IVS analysis coordinator should meet in person to understand the details of the new C04(05) series.

The ACs of the IERS TCs were asked how the C04 is used in the operational work. The ILRS use the rapid values as basic input for orbit determination, the IGS only Bulletin A, IVS Bulletin A, and IDS does not see any problem.

Chopo Ma noted the continued lack of an implementation plan and asked the EOC to set up such a plan that clearly states at what level the various users are affected. G. Petit suggested a Technical Note to give more details on the new series.

Future visions from the Rapid Service/Prediction Centre

W. Wooden reported about the recent efforts at the Rapid Service/ Prediction Centre. One of the main topics are the coordination with the Earth Orientation Centre to give feedback on the new C04(05) series, to ensure the quality of the new system and to change the RSPC bias and rate to match the C04(05) system.

New versions of the combination as well as of the prediction programs were installed and updated input series were incorporated. In the near future there will be a transition to a new operational machine as well as investigations how the IGS Ultra-Rapids can be used in the combination solution; possibly the IGS Rapid pseudo-points currently being used can be replaced.

The RSPC launched a user survey to study user behaviour and requirements. For the evaluation the 71 user responses are divided in five classes: academic users, engineers, operational, operational scientific and pure scientific users.

Here are the major results:

- Polar Motion Accuracies: Most users want accuracies of 1 milliarcsec or better.
- UT1–UTC Accuracies: Almost two thirds of all users want accuracies of 0.1 millisecond or better.
- EOP Prediction Length: There seem to be two classes of users – those who need predictions of less than 30 days and those who would like predictions of 1 year (~25%).
- EOP Data Spacing: Majority of users prefer data at 1-day intervals.
- EOP Update Frequency: Operational/Scientific users prefer predictions to be updated daily.
- EOP Data Formulation: Majority of users prefer tabular data.

There will be a WG session at the Paris Observatory during the Journées in September 2007.

Review of IERS WG on Combination and of the Combination Pilot Project (CPP)

M. Rothacher reviewed the status of the WG on Combination and of the CPP for resuming the activities after the release of ITRF2005, drawing the attention to a short meeting of the IERS WG on Combination, IERS CPP, and IERS CRCs during EGU 2007 and a meeting of the interested groups in June 2007. The intra-technique combined SINEX files are routinely generated with delays of 18 days (ILRS) up to 46 days (IDS). A complete list is available at <http://iers1.bkg.bund.de/info/listFileCPP.php>. The Technique Services will continue producing weekly combined SINEX files including the parameters coordinates, xp, yp, xpr, ypr, lod in the case of IGS and ILRS, coordinates, xp, yp, UT1, xpr, ypr, lod, de, dp in the case of IVS, coordinates, xp, yp, xpr, ypr in the case of IDS and the combined GRGS solution coordinates, xp, yp, de, dp. Weekly inter-technique solution will be produced by DGFI, ASI might begin in mid 2007, but IGN has not made a decision. The next steps for the Technique Services will be the change to generate routine SINEX files for the IERS CPP according to the standards used for the generation of the ITRF2005 time series. The Inter-Technique combination and validation centres should study different combination strategies. M. Rothacher suggested a daily rapid IERS EOP product based on the combination of VLBI Intensive Sessions (e-VLBI) with GPS rapid products to obtain highly precise rapid EOP solutions.

Workshop on Conventions and report on the Conventions update process

B. Luzum gave an overview about the ongoing work done under the lead of the Conventions Centre. Some changes were introduced in Chapter 5 (Transformation). For Chapter 5 (Transformation), Chapter 7 (Site Displacement), Chapter 8 (Tidal Variations in Earth Rotation), and Chapter 9 (Troposphere) work is in progress. Details can be found at <http://tai.bipm.org/iers/convupdt/convupdt.html>.

The IERS Workshop on Conventions will be held at the BIPM on 20–21 September 2007. The goals of the meeting are to discuss recent advances in the Conventions' models, topics without a consensus opinion and future directions for the Conventions. Discussing the presented topics loading was seen as an important point. Pre-registration is possible at the BIPM web site.

A. Nothnagel asked for a consistent use of either UT1–TAI or UT1–UTC. This could also be a subject of the CPP.

Unified Workshop on Analysis (IERS as lead organizer)

M. Rothacher suggested a unified workshop on analysis which will involve GGOS, IERS, IGS, IVS, ILRS, IDS, IGFS. The workshop will focus on problems of the individual techniques and problems common to more than one technique. Also the common understanding of all techniques for each individual technique should increase as they contribute to GGOS. There is a positive feedback from all services for this two and a half day workshop. It will be held in the San Francisco area and scheduled before the AGU 2007 Meeting probably Wednesday to Friday evening. The IERS will be the lead organizer.

Service Analysis Coordinators and Chairs were asked for ideas concerning common research projects. M. Rothacher presented a list of possible common research projects. Concrete cases could be a GGOS troposphere combination project, a GGOS portal meta data project and/or a daily rapid IERS EOP product. M. Rothacher reported about the German GGOS project funded by the Ministry for Science and Technology.

Report of IERS Working Group on the Second Realization of the ICRF

R. Gaume gave a short report on the first meeting of the ICRF-2 working group, which was held at the Vienna University on April 12, 2007. The meeting attended by 18 participants dealt mostly with organisational aspects. After the introduction the milestones and a tentative meeting schedule was discussed. The goal is to have the ICRF-2 presented and adopted at the IAU XXVII General Assembly in Rio de Janeiro in 2009. Starting with source categorization, the methods of time series generation were considered. At the IAU Symposium No. 248 "A Giant Step: from Milli- to Micro-arcsecond Astrometry", Shanghai, October 15–19, 2007 Chopo Ma will give an invited talk on ICRF-2. There is a limited opportunity for oral presentations but posters are still solicited.

Report of IERS Working Group on Site Survey and Co-location

Reflecting the goals of the WG on Site Survey and Co-location G. Johnston underlined the importance of the local tie surveys. Recent achievements were the completion of the user guide for the Axis software, a survey planning visit to Syowa / Antarctica, and the planned survey in Tahiti (GPS, SLR, DORIS) by IGN. Afterwards he presented the list for the site co-location SINEX files some technical issues were considered. Summarising he stated that only 40% of the ties are updated. It was recommended by the IERS DB that the WG leader together with the IERS CB and the IERS ITRS Centre should write a letter to those stations which have a deficit in their surveying tasks.

Status and future of the GGFC

M. Rothacher presented some general ideas on IERS products and specific ones for the GGFC. He described the present situation where new requests for products will emerge, that not all SBs of GGFC are producing operational products and that the role of IERS and GGFC is of vital importance in the framework of GGOS. On the other hand the present structure is not flexible enough to include new institutions and / or products.

He proposed a change in the Terms of Reference to allow the establishment of new product centres. The timeline should be seen in two phases. Phase A will be the submission of the proposal, the evaluation by the IERS DB and the start of a test phase. In Phase B the institution demonstrates its capability to produce operational products, which will be evaluated. At the end the institution is accepted or not as an IERS product centre.

After considerable discussion the DB accepted this general idea which should be applied for the renewing of the GGFC. T. van Dam should lead the effort for the renewal of the GGFC according the proposed procedures. The process is steered by the IERS demands and offers but should also include the ideas of the IERS TCs.

Report on GGOS (Oxnard retreat) and GEO (GEO III, Architecture III)

M. Rothacher reported about GGOS activities since the last IERS DB meeting, which were mainly done by telecons of the Executive Committee. The Workshop 2007 and the meeting at the IUGG in Perugia have been prepared. The IAG / GGOS representatives in GEO committees joined some GEO meetings to support the GEO task AR-07-03 "Geodetic Reference Frames". Letters of support were initiated by GGOS to encourage GGOS Troposphere Products ("GGOS – Atmosphere"), laser retro-reflectors for GNSS satellites, and WMO Recommendation for Reference Frames (WGS-84/EGM96).

During the GGOS retreat the various IAG components (Commissions, Services, GGOS WGs, GEO representatives) gave their reports and comments on the planned GGOS2020 reference document. Lists of the next major steps as well as the next meeting events concluded this review.

B. Richter continued by giving a short overview about the IAG/GGOS GEO activities. At the Architecture and Data Committee (ADC) meeting in Geneva on February 28 / March 1, 2007 a status review of all ADC tasks took place, with a focus on the Architecture core Tasks (AR-07-01 (interoperability) and AR-07-02 (clearinghouse) and to discuss the input of ADC to the preparation of the Ministerial Summit. Among these tasks a new task "Global Geodetic Reference Frames" initiated by GGOS has been included in the GEO Work Plan 2007–2009. Also comments and modifications for the GEO Work Plan 2007–2009 were submitted and partly included. It has been discussed whether the Reference Frame task can be presented as an early achievement at the Ministerial Summit in South Africa in November this year.

Interoperability arrangements for services are a key principal of the GEOSS Architecture and the main focus of the ADC. GEO sent out a call for participation for clearinghouse applications as an important part of the dissemination portion of GEOSS. The GEOSS Clearinghouse will need to be a client to community catalogue servers implemented in accordance with multiple catalogue service standards. At a minimum these include ISO 23950 and OGC Catalogue Service – Catalogue Service for the Web (CSW). The IERS Data and Information Service follows these developments actively by being part of the German Geoportal Bund (Government).

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

N. Capitaine informed the DB that IAU Information Bulletin 99 (January 2007) contains all the official information from the XXVIth IAU GA (IAU Resolutions, Composition of Divisions, Commissions, WGs, etc.). Her presentation included the agendas of the upcoming

Journées 2007 with 4 sessions dealing with the themes Plans for the new ICRF, Models and Numerical Standards in Fundamental astronomy, Relativity in Fundamental Astronomy, and Prediction of Earth Orientation as well as the IAU Symposium 248 "A Giant Step: From Milli- to Microarcsecond Astrometry".

Concerning the development in FAGS (Federation of Astronomical and Geophysical Services) N. Capitaine described the planned white paper, which is intended to provide the views of the current FAGS/ICSU interdisciplinary body on the prospects for a future federation in the framework of the new arrangements within ICSU for data coordination.

In order to achieve the recommendations of the Priority Area Assessment (PAA) on Scientific Data and Information, ICSU established the „Ad hoc Strategic Committee on Information and Data" (SCID) according to the ICSU Strategic Plan 2006–2011. Three member of this committee are representatives of FAGS.

Report of the Central Bureau

Due to lack of time the report was reduced to announcing the call for the Annual Report 2006. The call will be sent out although the Annual Report 2005 is still missing two inputs.

Progress has been achieved by including the IERS Data and Information system into a catalogue service for the WEB (CSW).

Meeting No. 45

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

Introduction and approval of agenda

The agenda was adopted and the minutes of the IERS Directing Board meeting # 44 were approved.

Formalities

C. Ma welcomed the new member J. Ray, who was elected by the IGS as the new delegate to the IERS Directing Board as well as D. Angermann and J. Dawson who represented the ITRS CC Munich and the WG on Co-location, respectively.

ITRS/ITRF issues

Interaction between IERS and IAG Commission 1

Z. Altamimi, as the newly elected chair of IAG Commission 1 informed the DB about its present status. The slide with the objectives highlighted the goals and in the following slides the structure with its sub-commissions and the steering committee as well as the chairpersons and members were shown. Several inter-commission study groups and working groups reflect the broad spectrum of Commission 1 and its link to the other IAG commissions and IAG services. Relevant for the IERS are IC-SG 1.1: Theory, implementation and quality assessment of geodetic reference frames, chaired by A. Dermanis (Greece), IC-WG1.1: Environment Loading: Modelling for Reference Frame and positioning applications, chaired by

Tonie van Dam (Luxembourg) and Jim Ray (USA), and IC-WG1.4: Site Survey and Co-locations, chaired by Gary Johnston (Australia).

Report from the ITRS Centre

At the ITRS/ITRF web page more information (updated DOMES number database, ITRF2005 solution and products, local ties in tables and SINEX format, co-location survey reports) have been added and new features installed: ITRF networks can be displayed per ITRF solution, networks can be displayed per technique, ITRF velocity fields can be displayed.

To study the impact of local ties Z. Altamimi performed some experiments. Based on local ties used in the ITRF2005 (22 GPS-SLR vectors, 29 GPS-VLBI vectors) and an appropriate weighting (45% of the ties are in SINEX with known measurement epoch, the others are with unknown variance) he showed that the tie residuals mainly in the up component exceed 10 mm. In an approach of fixed versus weighted ties the normalized residuals increase unevenly. In other experiments he added a 10 mm offset in height for all ties. As a result the tie residuals increased by 10 mm in the up component for GPS and changed the scale by 0.71. Repeating the same for the east and north component one can see effects in the rotation of the z-axis, respectively a shift in the z-axis and in the scale. But also changes in only one of the GPS-VLBI ties by 50 resp. 10 mm show remarkable effects on the ITRF2005. Finally he presented a list of "dubious" ties where dubious means a disagreement between local survey and geodetic space technique estimated ties.

After the IVS recognized the missing mean pole tide corrections the VLBI scale shifted by –0.5 ppb with respect to the ITRF2005. Comparisons with the SLR and Doris scales were shown.

In the final part of the presentation Z. Altamimi presented his thoughts about an ITRF2008. The basis will be new, improved and extended data series from the IERS techniques services. Data should be collected till the end of 2008 and the analysis will start at the beginning of 2009. It might be that for IGS only one reprocessed solution is available at the end of 2008.

Progress in understanding ITRF solution differences

On behalf of H. Drewes D. Angermann illustrated in his presentation the differences in the ITRF computation strategies of IGN and DGFI and their effects on the ITRF solution. He concluded that:

- The differences in the ITRF solutions can (mostly) be explained by the different computation strategies.
- The fact that the ITRF solutions are computed with different strategies and software has also some advantages, e.g.:
  - Identification of remaining problems
  - More realistic assessment of the ITRF accuracy
- The understanding of remaining differences should be further improved in close cooperation between IGN and DGFI.

- Important issues for the future are:
  - to improve the SLR and VLBI networks and the co-locations
  - to understand (and reduce) biases between techniques
  - to get homogeneously (re-)processed series from the services
  - to compute the next ITRF in close cooperation between ITRS CCs

The DB asked the ITRS CCs to generate a new ITRF with extended and/or improved data sets from IVS and ILRS together with old and new reprocessed GPS series. The ITRS/ITRF web page should have links to other survey reports.

Report of IERS Working Group on Site Co-location

John Dawson reviewed the activities of the IERS Working Group on Co-location and presented the recent achievements and technical issues to be taken into account. Repeated measurements at Monte Stromlo reflect the present day accuracy. He ended by stating that only 40% of the local ties are updated. To encourage the other 60% of observatories the IERS DB asked the ITRS Centre, the IERS WG on Co-location, and the IERS Central Bureau to write a letter to observation stations to encourage local surveys or to provide survey information.

This agenda item was complemented by a short report describing the co-location survey at Tahiti in October 2007. A significant difference of 14 mm was found in the x-direction between the Station and SLR marker.

ICRS/ICRF issues

R. Gaume, chair, in consensus with the co-director, J. Souchay, proposed a slight modification of the tasks of the ICRS Centre. In 2000 ten tasks were set up assigned to USNO and Observatoire de Paris (OP). Task 2 has now a more specific subject “Investigation of future VLBI realizations of the ICRS” and the old Task 2 “Investigation of future realizations of the ICRS” becomes “Investigation of future non VLBI realizations of the ICRS”. Task 6 “Linking the ICRF to frames at various wavelengths” becomes “Investigation concerning the ICRF objects at various wavelengths” and a new Task 9 is inserted: ”Maintenance of the link to the solar system dynamical reference frame through observations of asteroids”. In total there are now 12 tasks handed by USNO and OP. The IERS DB accepted the changes in general but asked R. Gaume to submit the modified proposal for the IERS ICRS Centre.

Earth orientation products

Status and function of current Earth Orientation products

D. Gambis explained the upgrades of the C04 solution. The current solution is described in the IERS Annual Report, a paper in the Journal of Geodesy (Gambis 2004), and a technical note by Bizouard and Gambis (2007) published only at the Earth Orientation Centre web page. The 05C04 solution is among others aligned to the ITRF2005, the IAU2000 nutation model implemented; the solution is achieved in one run over the 20 years available. D. Gambis informed the IERS DB that the EO Centre is the official centre for prediction for CNES.

W. Wooden started his status report by pointing out the distinction between the IERS Rapid Service/Prediction Centre and the EO Centre. The RS/PC is “responsible for providing Earth orientation parameters on a rapid turnaround basis, primarily for real-time users and others needing the highest quality EOP information sooner than that available in the final series published by the IERS EOC.” Based on the requirements he gave details about the current products, the standard data files, updated weekly on Thursday, the daily files updated at 17:05 UTC and Delta T values only for low accuracy users. For the combination and prediction process 16 input data sets are used, the products are disseminated via ftp, web sites and email.

Improvement of current products

D. Gambis reviewed the history of the Bulletins B, C, D, and the C01, C02, C03 series and the relation of the current Bulletin B and 05C04 products as well as the update procedure of 05C04. Finally he proposed to discontinue Bulletin B, to update 05C04 twice a week, to stop C02, C03 and IERS 96P01 but to maintain the long term C01.

The IERS DB asked D. Gambis to prepare a plan how to proceed with the proposal to change the EO products and distribution.

W. Wooden stated that currently, data produced by the RS/PC appear to meet most needs of users of near-real time, real-time, and predicted EO information. However, user needs are constantly changing (more stringent accuracy, more timely, finer resolution). The RS/PC must try to anticipate necessary changes. He discussed possible concerns about data quality, data spacing, data format, frequency of solutions, latency of information, methods of delivery, new analyses, new products, and new information. He concluded that more resources have been allocated to the RS/PC, the data latency will be reduced as the data pipeline becomes more automated (e.g., e-VLBI), and he expects additional improvements from the IERS Working Group on Prediction.

The IERS DB asked the directors of the EO Centre and the RS/PC to investigate and resolve discrepancies in UT1 between the EO Centre and the RS/PC.

New products for the future

As new products of the EO Centre D. Gambis proposed a more extended web service running under Windows and LINUX to compute Earth orientation parameters for any epoch and the matrix of Earth orientation parameters to link the ICRF with the ITRF.

M. Rothacher gave a more general outlook concerning new EO products. All future EO products should be based on the intra-technique combinations of the IERS Technique Services. Four different product types should be generated: multi-year solutions, weekly solutions, daily solutions and predictions. Considering the present status he proposed refinements especially for a combination of VLBI Intensive Sessions (e-VLBI) with GPS rapid products to obtain highly precise rapid EOP solutions. At the Unified Analysis Workshop the generation of daily SINEX files and their combination was suggested. A pilot phase under the lead of the IERS analysis coordinator will start mid to end of 2008.

Role of CRCs

M. Rothacher went over to the list of CRCs and their current activities. 80% of the work is done in relation with combination activities. Even though the CRCs need to be reviewed to see if they fulfil the proposed tasks, the questions remain whether they are visible enough and do they go for real products. The CB is asked to contact FESG, IAA and FFI about what their contribution will be in the future. The AC proposed to create a “Working group on combination at observation level”. The CB will contact R. Biancale that he should draft a charter, a list of members and a schedule for the IERS working group. A final decision was postponed.

Future of the GGFC structure

M. Rothacher gave some perspectives about possible new products of the GGFC. More input is expected from GRACE groups and for the propagation delay from the TU Vienna. Later he repeated a possible procedure to change the status of the Special Bureaus. T. van Dam, as GGFC chair, went through a proposal to the IERS DB to restructure the GGFC. The following discussion was quite controversial. The IERS DB decided that T. van Dam should not go ahead with the call for a new structure at the moment but for clarification she should draw a list of user requirements and available and/or necessary products for the next DB meeting.

Report on Workshop on Conventions

G. Petit and B. Luzum presented a short report on the IERS Conventions workshop held at BIPM, Sèvres, France, September 20–21, 2007. The main conclusions of the workshop were among others the classification of models (Class 1 – reduction, Class 2 – conventional, Class 3 – useful), the criteria for choosing models for conventional station displacements, the treatment of non-tidal loading effects, existing and proposed new models for S1/S2 atmospheric loading, the troposphere, a conventional model for the effect of ocean tides on geopotential, a model for diurnal and semidiurnal EOP variations, and recommendations for handling technique-dependent effects. It is planned that the next edition of the IERS Conventions will be published in 2009. The chairs of the Conventions

Centre are asked to compare the recommendations of the Unified Analysis Workshop with the IERS Conventions to achieve consistency.

Report on and consequences of the Unified Analysis Workshop

By invitation experts from GGOS, IERS, IGS, IVS, ILRS, IDS, and IGFS came together to hold the first Unified Analysis Workshop, which took place at the Beach Resort Monterey, Califonia on December 5 – 7, 2007. In his presentation M. Rothacher summarized the main subjects of the workshop. The participants were selected by the individual services (5–6 per service), and position papers were put together by the chairs and co-chairs of the sessions (one co-chair from each Service). The participants decided the following action items and recommendations:

- Extension of the SINEX format for other parameter types and representations
- Tests on atmospheric loading: application on the observation or solution level?
- Generation of daily SINEX files (IVS Intensives and IGS Rapids)
- Parameterization and modeling for the next ITRF
- Benchmark tests for models common to several techniques
- Documentation of AC modeling standards and parameterization
- Definition of meta data standards (e.g. SINEX meta data block)

All presentations, the position papers and the action items are available at the IERS web pages <http://www.iers.org/MainDisp.csl?pid=66-1100207>.

Report of IERS Working Group on the Second ICRF

R. Gaume gave a short overview about the activities of the Joint IAU/IERS working group to prepare a proposal for a ICRF-2. In conclusion the ICRF-2 working group schedule has slipped a little, but is still on-track for IAU General Assembly in 2009.

Report on GGOS and GEO

In his status report M. Rothacher went through the activities of GGOS since the IUGG General Assembly held in Perugia, Italy, July 2007. For the new components of GGOS – GGOS Coordinating Office, GGOS Communications and Network “Bureau”, GGOS Conventions, Models & Analysis “Bureau”, GGOS Space and Satellite Mission “Bureau” – calls for proposals will be prepared for the GGOS retreat 2008.

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

Due to a lack of time C. Wilson and N. Capitaine were not able to give their presentations on IAG, IAU and FAGS activities, but there slides were distributed in written form. For additional information N. Capitaine sent in a note to inform the IERS DB about some issues that are relevant to the IERS plans for the near future. It will be discussed during the next DB meeting.

Change of Terms of Reference

The present ToR states that:

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

Because the ToR were created in 2000 and came into force in 2001, some of the directors of the IERS centres would have to finish their term. After discussion the IERS DB decided that the relevant passage in the ToR should be changed as follows:

"The Directing Board consists of the following members".

Report of the Central Bureau

Organisation

Because it came more and more difficult to arrange the IERS DB meeting in conjunction with the AGU fall meeting alternatives were discussed. A decision will be made at the next spring IERS DB meeting.

According to the ToR working groups are limited to a term of two years with a possible one-time re-appointment. Decisions have to be made whether and how to continue with

- Working Group on Site Survey and Co-location (established in Feb. 2004),
- Working Group on Combination (established in Jan. 2004).

The Working Group on Prediction was established in Dec. 2005.

Annual Report of IERS

The Annual Report (AR) 2005 was printed and distributed in October and November 2007. The status of the AR 2006 was given. To accelerate the completion and to keep the AR close to the reported year the IERS DB decided that the final deadline for the AR 2006 will be January 15, 2008. Contributions not available at the due date will be marked in the AR as "not available". The deadline for the AR 2007 will be May 31, 2008.

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. 44, April 15, 2007, at Technical University Vienna, Austria, and No. 45, December 11, 2007, in San Francisco, USA. Between the meetings the CB coordinated the work of the DB.

Together with the Global Geodetic Observing System (GGOS), the CB prepared the GGOS Unified Analysis Workshop, held December 5–7, 2007, at the Beach Resort Monterey in Monterey, CA, USA. Ca. 45 specialists took part in this workshop. The programme, the position papers, and the presentations were published at the IERS web site. For a summary see Section 4.

The CB represented the IERS at the following meetings: WDC Meeting, FAGS Meeting, GGOS Retreat 2007, IUGG 24th General Assembly, GGOS Unified Analysis Workshop, and Geotechnologien Statusseminar.

IERS components maintain individually about 20 separate web sites. The central IERS site <www.iers.org>, established by the CB, gives access to all other sites, offers information on the structure of the IERS, its products and publications and provides contact addresses as well as general facts on Earth rotation studies. It contains also electronic versions of IERS publications, a list of meetings related to the work of the IERS, and an extended link list for IERS, Earth rotation in general and related fields. Throughout 2007 the web site was regularly enlarged and updated. Several documents about the history of IERS were compiled; these include an IERS Timeline and lists of all IERS components and officers from 1988 to 2007. Also the minutes of IERS Directing Board meetings from 1993 to 2000, most of which were provided by the former Central Bureau at Paris, were converted to PDF files and made available at the IERS web site.

The IERS Annual Report 2005 appeared in online and in printed form. The CB started also to prepare the IERS Annual Report 2006 for publication. Along with the reports of the IERS components, the Annual Reports contain information on the IERS compiled by the CB.

The CB prepared reports about IERS' activities for the International Union of Geodesy and Geophysics, the International Association of Geodesy (both for the period 2003 – 2007), and for the Federation of Astronomical and Geophysical Data Analysis Services (for the year 2006).

During the year 2007, 18 IERS Messages (Nos. 105 – 122) 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 2007 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)

The IERS Data and Information System (IERS DIS) is being developed by the Central Bureau since 2002. The system is being adapted and extended by new components continuously in order to fulfil the requirements for a modern data management and for the access to the data by the users. In this context international and interdisciplinary projects like the Global Geodetic Observing System (GGOS) or the Global Earth Observation System of Systems (GEOSS) are demanding special requirements with respect to the standardization of the data and applications on the data.

In 2007 further developments of the IERS DIS were mainly driven by the following aspects:

- enhancement of the IERS Data Management System collecting all IERS products and data from the Product Centres and extracting the metadata into the metadata database;
- extending the IERS metadata profile to the SINEX format and to a fully compliant ISO 19115 metadata profile,
- development of tools for the management of metadata (e.g. metadata editor and parser),
- development and proof of a concept to port the IERS Content Management System (CMS) – and its publication component – to the so-called Government Site Builder, the CMS used within the division of the German Federal Ministry of the Interior,
- development of concepts for an interactive data analysis tool and for the improvement of the IERS Plot Tool.

All developments are being made in close cooperation with two research projects at BKG, the projects ERIS and GGOS-D:

The aim of ERIS (Earth Rotation Information System) as a part of the research unit FOR 584 “Earth Rotation and Global Dynamic Processes” is the development of a virtual Earth rotation system for geodetic and geoscience applications. The joint project “GGOS-D: Integration of Space Geodetic Techniques as Basis for a Global Geodetic Observing System” is meant to develop the IT infrastructure and the required software for the operational service of a Global Geodetic Observing System.

Both projects are providing an information, communication, and database system as a central interface between the research partners and their applications and fields of interest. E.g. within the research unit FOR 584 the common Web portal called Earth Rotation and Global Dynamic Processes (<http://www.erdrotation.de>) realizes the entry point for all services provided by the project. The portal's homepage gives access to three subsections, one for the public presentation of the research unit, one for the information system ERIS, and one for internal communication.

One of the most important tasks in both projects deals with the data preparation and data networking. To ensure interoperability all data series are transformed into standardized data formats. Based on the XML versions developed for the IERS the XML schemata and the transformation routines are revised to harmonize the data structure and to enhance the machine readability.

While XML schemata describe the technical data structure of data series stored in XML, metadata are needed to describe the content of the series, how the data are produced, the authorship, the availability of the data, parameterization etc.

To ensure interoperability of the metadata with respect to international and interdisciplinary metadata catalogues, the IERS specific metadata profile has been extended to an ISO 19115 "Geographic Information - Metadata" standard compliant profile. Furthermore, routines have been established for automatic generation of metadata as well as a metadata editor to support the creation of metadata. A variety of interactive tools were set up. First some applications have been developed which realize interactive Web interfaces for some helpful geodetic and astronomic tools: transformations between Gregorian calendar and Julian and Besselian date / epoch, calculation of Greenwich Sidereal Time, calculation of the ephemeris of Earth, transformation between the reference systems GCRS and ITRS, and calculation of the time dependent precession and nutation matrices.

Second, if downloading data, often single data points, data of a short time period, or time series of isolated parameters are needed. The *EOP Reader* represents the first step in this direction in the context of ERIS. It allows the user to extract the EOP data of a single day from a data series of his choice by entering the date as Gregorian date or as modified Julian date.

Furthermore, a concept for an interactive tool for time series analysis has been developed. Via a graphical user interface it will allow the user to apply standard methods of time series analysis to data series of the ERIS and the IERS data archives as well as to own data. The following analysis procedures will be incorporated into the initial version of the data analysis tool: extraction of statistical values (mean value, maximum, median, etc), polynomial, sinus and spline approximations, FIR filters (high-pass / low-pass / band-pass, Moving-average, derivation), up / down sampling and shifting of the time axis, FFT, short-time FFT and power spectrum, correlation and autocorrelation, and time / frequency analysis with wavelets.

Staff

Dr. Bernd Richter, *Director*
Dr. Wolfgang R. Dick, *scientist*
Carola Helbig, *secretarian*
Dr. Alfred Kranstedt, *scientist (until May 31, 2008)*
Anja Kreutzmann, *scientist (since May 15, 2008)*
Alexander Lothhammer, *technician (on leave since Nov. 2007)*
Sandra Schneider, *technician*
Dr. Wolfgang Schwegmann, *scientist*

Publications

Dick, W. R.; Richter, B. (eds.) (2007): IERS Annual Report 2005. Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, 2007. 175 p.

Rothacher, M.; Drewes, H.; Nothnagel, A.; Richter, B. (2007): Integration of Space Geodetic Techniques as the Basis for a Global Geodetic-Geophysical Observing System (GGOS-D): An Overview. In: L. Stroink (ed.): Observation of the System Earth from Space (Science Report). Status Seminar, 22 – 23 November 2007, Bavarian Academy of Sciences and Humanities, Munich. (Geotechnologien Science Report, No. 11) Koordinierungsbüro Geotechnologien, Potsdam, p. 75–79

Bernd Richter, Wolfgang R. Dick, Wolfgang Schwegmann, Anja Kreutzmann

3.3 Analysis Coordinator

For various reasons it was not possible to prepare a report for 2007 before the deadline of this publication. It is intended to give this report together with the report for 2008.

3.4 Technique Centres

3.4.1 International GNSS Service (IGS)

General

The International Global Navigation Satellite System Service (IGS) is a federation of more than 200 world-wide agencies and institutions that pool resources and expertise to provide the highest quality GNSS data, products, and services to support high-precision applications of Global Navigation Satellite Systems (GNSS). It is a service of the International Association of Geodesy (IAG), one of the associations of the International Union of Geodesy and Geophysics (IUGG).

The IGS operates a global network of GNSS tracking stations, data centers and data analysis centers to provide data and derived data products that are essential for Earth science research, multidisciplinary positioning, navigation and timing (PNT) applications and education. The IGS is committed to providing the highest quality GNSS observation data and products freely to scientific user communities. The IGS products include GNSS satellite ephemerides, Earth rotation parameters, global tracking station coordinates and velocities, satellite and tracking station clock information, zenith tropospheric path delay estimates, and global ionospheric maps. 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.), scientific satellite orbit determination, ionosphere monitoring, climatological and weather research, and time and frequency transfer.

IGS Status and Activities in 2007

Tracking Network

A total of 13 new stations were added to the IGS network in 2007, and 9 were decommissioned, resulting in the 384 stations depicted in Figure 1. Most of these return observation data on an hourly or more frequent basis, and 115 of these return data in near real time. The network supports multiple requirements for diverse applications. Many IGS stations are co-located with other geodetic techniques to promote combination and inter-comparisons of products and systems. 132 stations are designated as “reference frame stations” that consistently contribute to the IGS ITRF computations, and 134 stations are co-located with external high-precision frequency standards and are used in generating the IGS clock products. A subset of the network provides meteorological data useful for ground-based precipital water vapor measurements. All station data and products are available freely to users from four global data centers and additional regional and operational data centers. A breakdown of the stations used by the principal applications and collocations with the other geodetic techniques is shown in Table 1. A complete list-

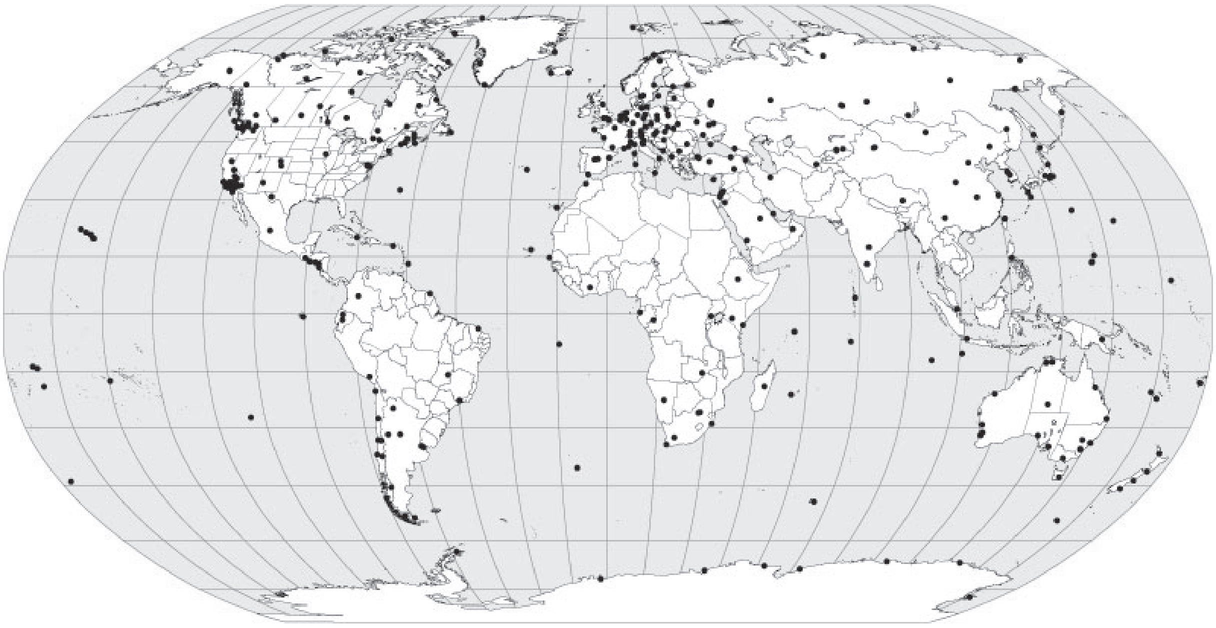


Fig. 1: IGS Global Tracking Network provides high quality tracking data used in support of diverse applications, including contributing to the realization of the ITRF.

ing of IGS network stations and related information can be found online at <http://igs.org/network/netindex.html>.

Table 1: Breakdown of stations by principal applications and co-location with other geodetic techniques.

Total Stations	**384**
Reference Frame	132
Clock Products	134
Multi GNSS (GPS+GLONASS)	84
Sub Hourly	240
Real-time	95
Co-Locations:	
VLBI Co-located	25
SLR Co-located	35
DORIS Co-located	54
Tide Gauge Co-located	103

Data Product Quality

Table 2 gives an overview of the estimated quality of the IGS core products at the end of 2007. Details related to the IGS products can be found online at <http://igs.org/components/compindex.html>.

A number of quality evaluations of the IGS products can be found in the Products section of the IGS Analysis Coordinator web site at <http://acc.igs.org/>.

Table 2: Quality of the IGS Core Products

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			

Improvements to the IGS Combined Products

The IGS Analysis Centers (see <http://igs.org/organization/centers .html#ac>) have steadily improved their precision and consistency during 2007. The combined and rapid orbit quality is depicted in Figures 2 and 3, which agree at a level of 7 mm.

Other notable items in 2007 related to the combined products include:

- Since GPS week 1406 (17-Dec-2007) the combined clock products are provided with a sampling rate of 30 s in addition to the usual 5-min products (*.clk; *.clk_30s). Three ACs (COD, JPL, MIT) are providing clock solutions with a 30 second sampling rate.
- Starting GPS week 1411 (21-Jan-2007) the absolute antenna phase model was used in the older Bernese 4.3 version (only offsets for satellite and elevations for station antennas) to generate the so-called Precise-Position-Navigation (PPN) tables in the combination summary files (for weeks 1400 to 1410 the old relative model was still used).
- The AIUB group has supported the introduction of the new Bernese 5.0 into combination procedures by developing a long-arc routine for Bernese 5.0 as needed by IGS combination analysis. The Bernese 5.0 software was implemented at GFZ in September 2007. The new software has been used in routine generation of the IGS combined products since GPS week 1446 (23-Sep-2007). It has now been transferred to NGS for use in the ACC activities there.

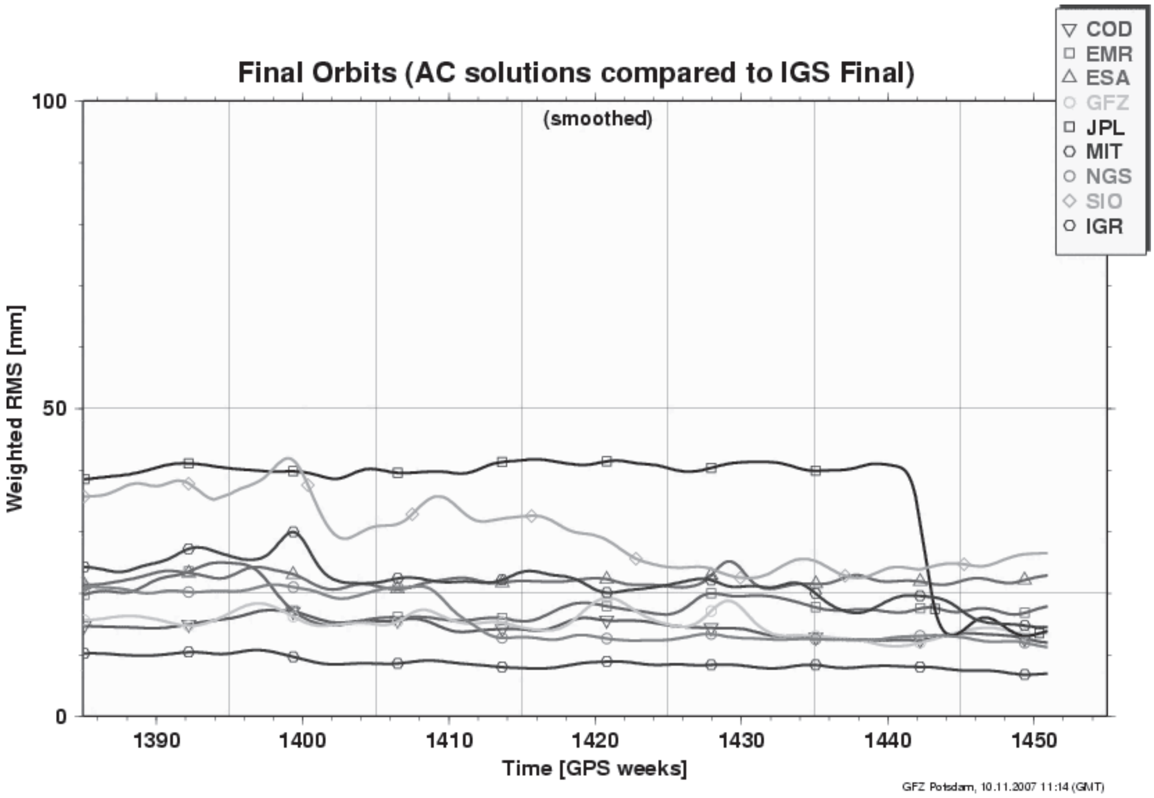


Fig. 2: Weighted RMS differences of all AC's and IGS final orbits to the IGS final combined orbit.

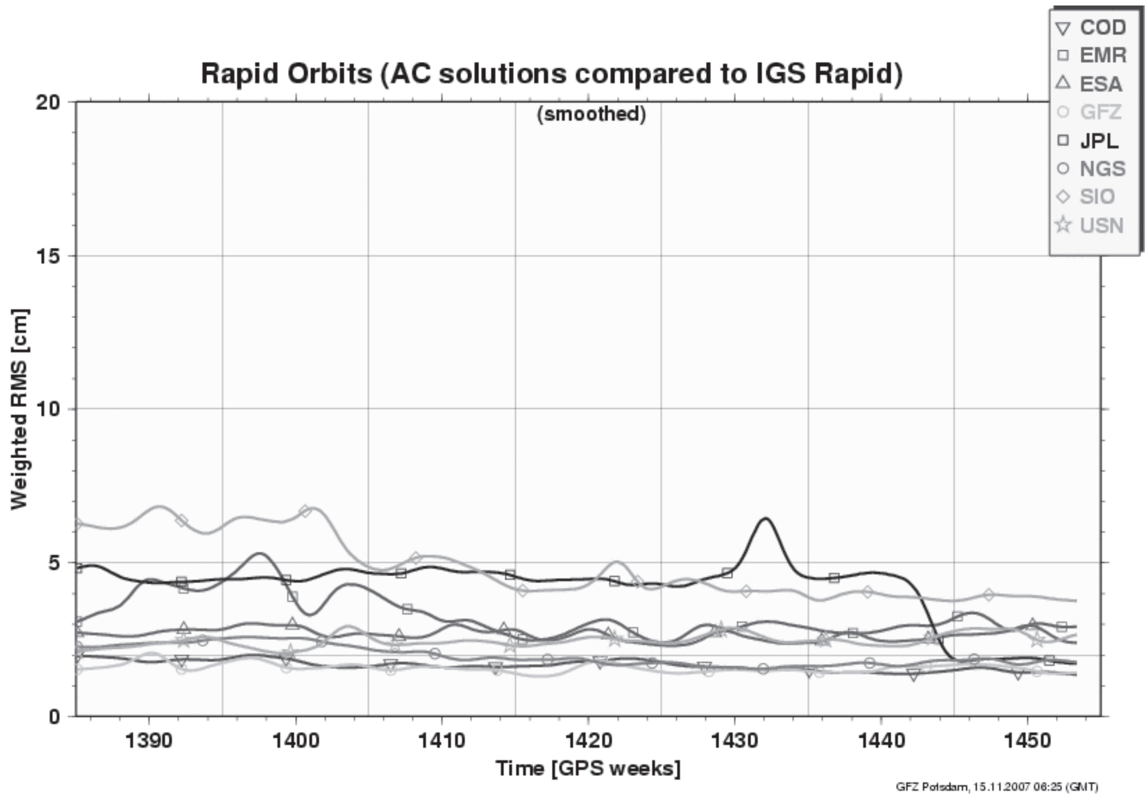


Fig. 3: Weighted RMS differences of all AC's rapid orbits to the IGS rapid combined orbit.

- The JPL weekly solutions were used for comparison only (excluded from the combined SINEX products) between GPS week 1400 and 1444. The JPL solution was reintroduced on GPS week 1445 as issues that caused inconsistent performance were resolved. Antenna height inconsistencies were corrected by JPL concurrently.
- The combined weekly SINEX solutions have progressed from about 250 stations at the beginning of the year to about 280 stations (Figure 4). The number of reference frame stations was about 120 at the beginning of the year and is now about 110 stations. Most of the ACs station processing increase came from the MIT and NGS weekly solutions. Starting with GPS week 1435 the number of stations reported by MIT increased from about 150 to about 250. Similarly, starting with GPS week 1428, the NGS solution increased from about 170 to 200.

IGS Reprocessing Campaign

The reprocessing of all historical data since 1994 has proceeded at early stage in 2007. The plan is to apply the newest analysis conventions consistently over the whole time series to resolve inconsistencies caused by many model and parameter changes in the past, especially by the introduction of the absolute antenna model in 2006.

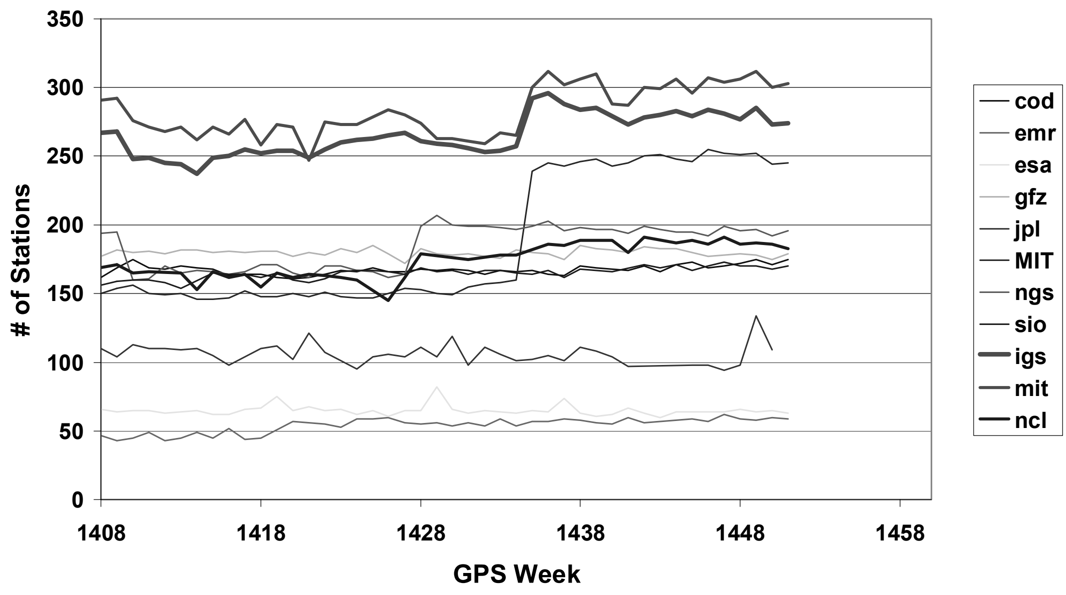


Fig. 4. Number of stations processed by Analysis Centers on a weekly basis in 2007.

In 2007, a reprocessing test campaign (GPS weeks 1042 to 1059 in early 2007) was analyzed by ESA, MIT, NGS, SIO, PDR and GFZ, and included more than 300 stations. The combination results for the station coordinates and orbit/clock/ERP revealed that there are still some issues to be resolved. An additional issue to be resolved is the lack of ACs providing clock solutions in the reprocessing campaign. Currently only ESA and MIT are providing clock solutions.

Analysis Center Coordinator Transition

The IGS Analysis Coordinator responsibility has been handed-off from GFZ to NGS, with the transition of the combination software completed by the end of 2007. Implementation of Bernese 5.0 software was required as an initial step, as the previous version was no longer being supported. The entire combination software, including all FTP (in and out) and web presentation tools, were installed on NGS hardware in November 2007, and NGS and GFZ systems were run in parallel for a one-week test period where identical results were produced by both systems. Integration of the IGS analysis within the NGS environment is being completed at end of year anticipating that the official IGS product will be generated at NGS starting end of January 2008. The GFZ processing will continue in parallel as back up until deemed unnecessary. GFZ will also continue to perform the combination for the reprocessing campaign for the foreseeable future.

Summary

Throughout 2007, the IGS has continued its delivery of high quality products to the IERS. The quality of the IGS results continues to improve, as analysis methodologies are constantly being refined and historical data reprocessed. The IGS is continuing its reprocessing campaign to strengthen its historical contribution to the realization of the ITRF. More information regarding the IGS and related activities can be found on the IGS Central Bureau web site <http://www.igs.org/> or at the Analysis Center Coordinator web site <http://acc.igs.org/>.

Steve Fisher, Robert Kachikyan, 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 2007.

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

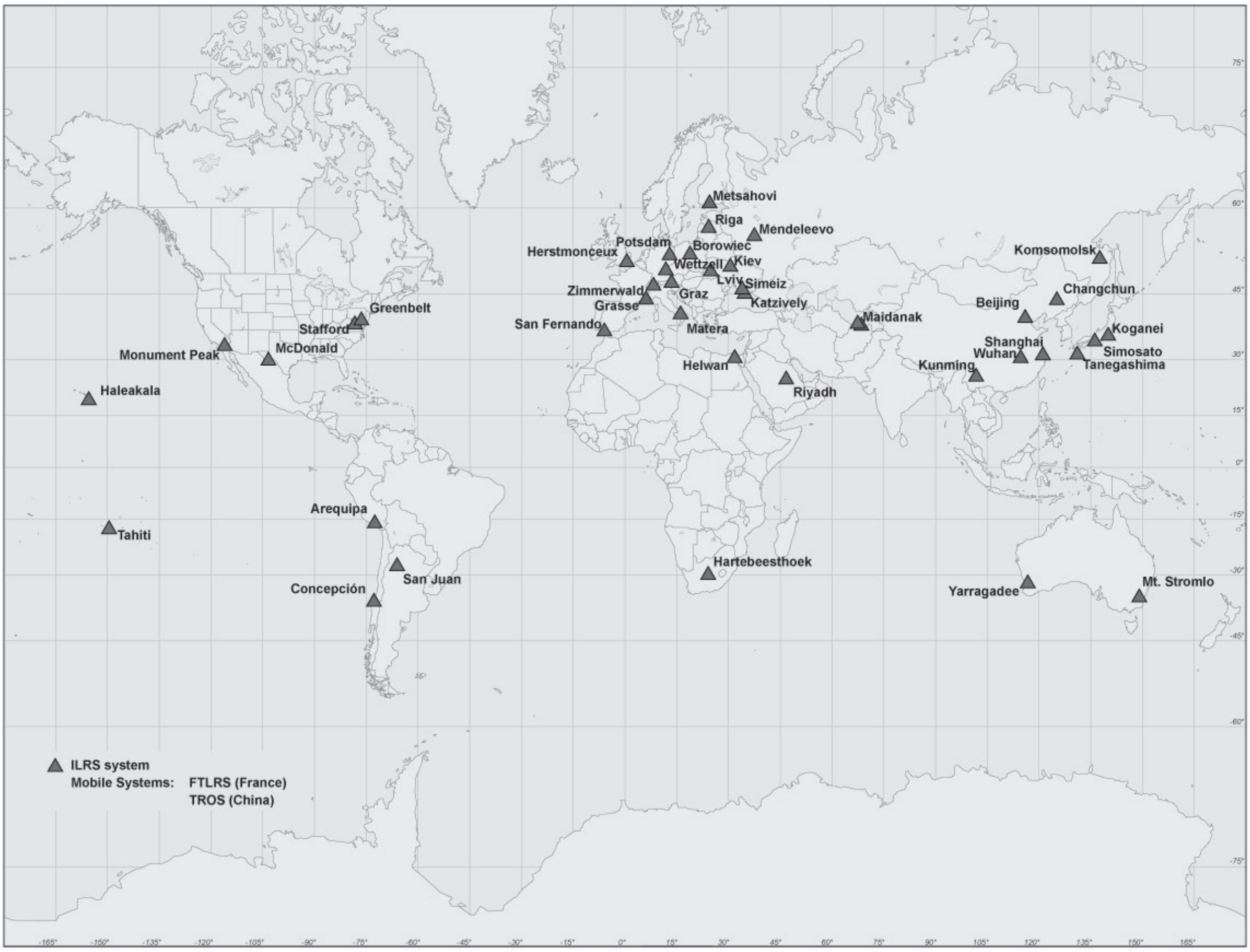


Fig. 1: The global network of SLR stations (status early 2008).

3.4.2 International Laser Ranging Service (ILRS)

Table 1: ILRS Network Tracking Statistics for 2007

Site Name	Station	Number of Passes			
		LEO	LAGEOS	HEO	Total
Arequipa	7403	2,074	218	0	2,292
Beijing	7249	1,713	339	152	2,204
Borowiec	7811	361	99	4	464
Burnie (FTLRS)	7370	167	4	0	171
Changchun	7237	4,373	774	542	5,689
Concepcion	7405	2,206	1,089	240	3,535
Graz	7839	4,813	825	529	6,167
Greenbelt	7105	1,831	321	69	2,221
Haleakala	7119	1,488	350	0	1,838
Hartebeesthoek	7501	1,535	304	35	1,874
Helwan	7831	54	0	0	54
Herstmonceux	7840	3,861	932	414	5,207
Katzively	1893	1,193	287	36	1,516
Kiev	1824	1	0	0	1
Koganei	7308	709	252	178	1,139
Kunming	7820	18	2	0	20
Lviv	1831	127	18	0	145
Maidanak	1864	509	216	141	866
Matera	7941	2,261	753	232	3,246
McDonald	7080	1,390	415	270	2,075
Monument Peak	7110	2,482	484	191	3,157
Mount Stromlo	7825	4,906	1,199	515	6,620
Potsdam	7841	1,725	304	0	2,029
Riga	1884	557	112	0	669
Riyadh	7832	3,783	975	659	5,417
San Fernando	7824	2,588	523	52	3,163
San Juan	7406	5,058	906	1,192	7,156
Shanghai	7821	968	53	3	1,024
Simeiz	1873	450	151	11	612
Simosato	7838	717	266	1	984
Stafford	7865	9	0	0	9
Tahiti	7124	19	0	0	19
Tanegashima	7358	240	70	69	379
Wettzell	8834	4,153	1,041	518	5,712
Yaragadee	7090	9,185	1,807	1,581	12,573
Zimmerwald	7810	5,973	1,219	727	7,919
Totals:	36 stations	73,497	16,308	8,361	98,166

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 with very significant contributions; in South Africa, Hartebeesthoek has proven 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. Yarragadee has been the number-one station in the network again. In 2007 it was joined by another high-yield system, the San Juan station in Argentina, to provide more uniform southern hemisphere tracking to all missions. Graz 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 acquired high repetition systems (e.g. Herstmonceux, UK, Zimmerwald, Switzerland) and these will soon be operational. Statistics of the data collected during the calendar year 2007 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 of tracked targets: Low Earth Orbiters (LEO), LAGEOS 1 & 2, and the High Earth Orbiters (HEO).

From all of the ILRS observatories (>30), 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 has been actually undergoing renovation since late 2004, which leaves only one site currently operational over the 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 new release of data from APOLLO was added to the first set of ~70 normal points, and a promise to soon make the data available in the newly adopted ILRS data format. The data look promising and comprise well over 50% of the 2007 yield.

Fig. 2: The ILRS stations with lunar capability (status early 2008).

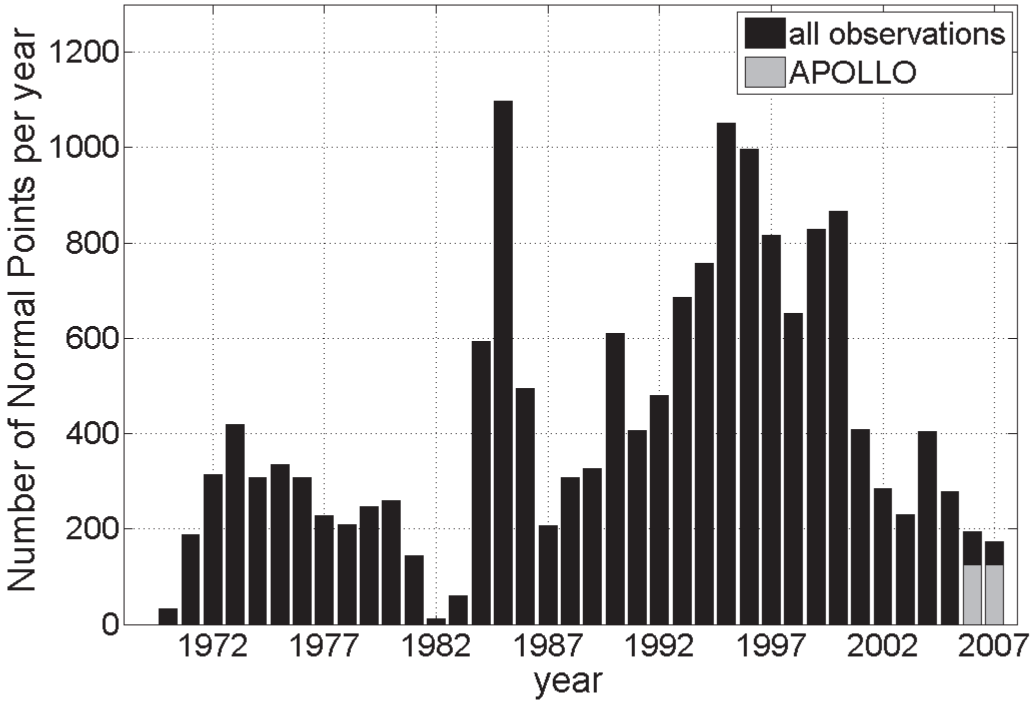


Fig. 3: The currently available LLR data set (status early 2008).

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 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 over 38 years, generating about 16000 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 and dynamics of the Earth-Moon system. LLR provides also tests of 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>

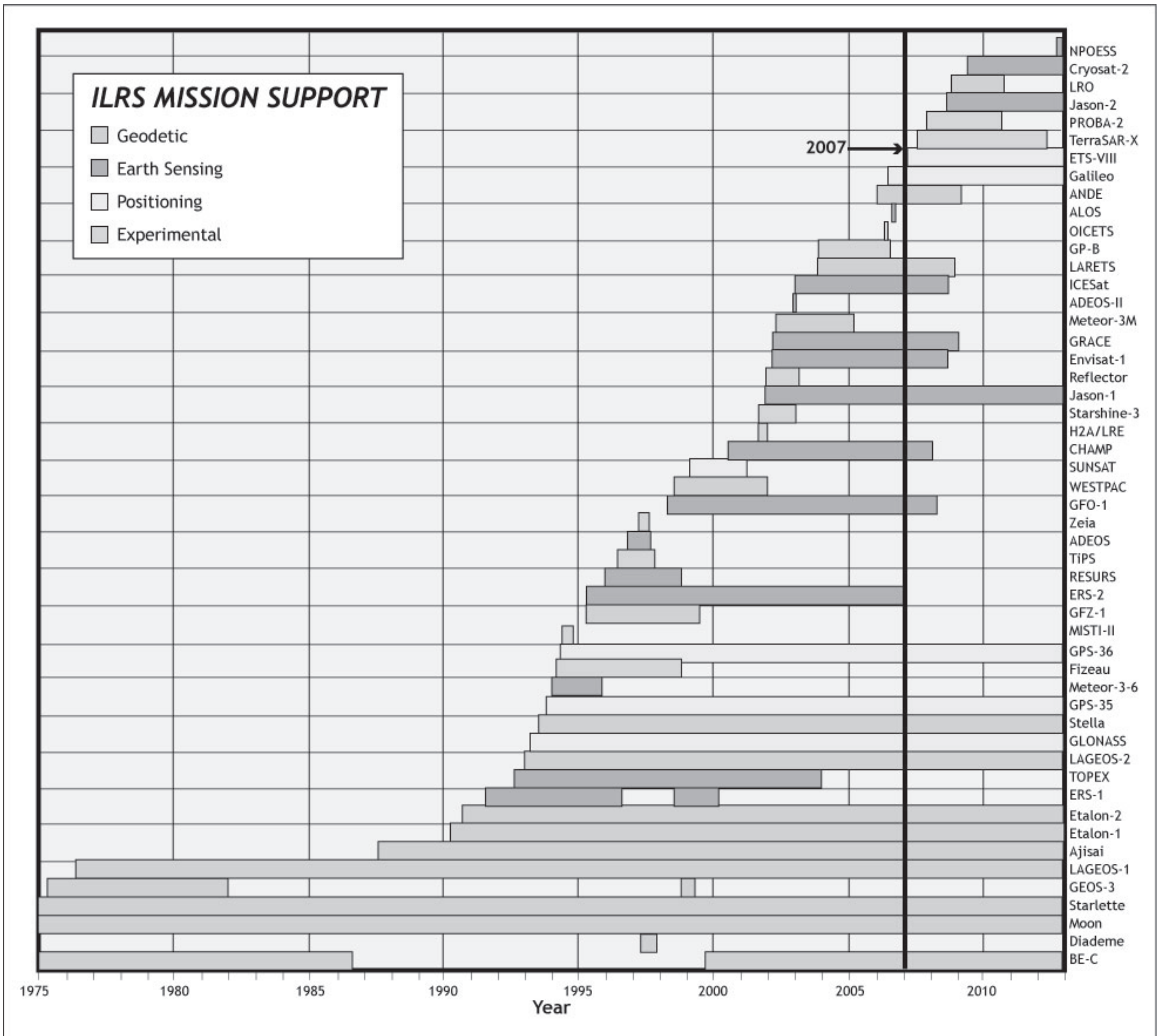


Fig. 4: The currently tracked SLR missions (status early 2008).

Missions

In 2007, a total of ~30 satellites (including the Moon) were being tracked by laser (Figure 4). During 2007 the ILRS continued its effort to develop a standardized design for retrorefrector arrays on future missions. In early 2007 the first data were collected from JAXA's geostationary ETS-8, an experimental communications, timing and positioning satellite. After a successful tracking campaign for almost a year to the date, Naval Research Lab's (NRL) ANDERRA (Atmospheric Neutral Density Experiment Risk Reduction) mission re-entered the atmosphere on Christmas day of 2007. The other half of the mission, the passive spacecraft ANDE-RRP is not expected to follow until spring of 2008 or later. On June 15, 2007, the TerraSAR-X mission was launched and has been tracked by SLR since then. It carries an X-band SAR antenna, occultation GPS, a Laser Retroreflector Array (LRA), as well as a Laser Communication Terminal (LCT). All spacecraft, including the newcomers, are regularly tracked, following a set of dynamically adjusted priorities depending on mission and science demands.

Over the past year, ILRS prepared for several demanding new missions to be launched in the near future. One of them, the Lunar Reconnaissance Orbiter (LRO), carries multiple laser technology components: a laser altimeter (LOLA) for topographic mapping and a laser transponder for one-way laser ranging (LR). It is anticipated that a significant number of the ILRS sites will participate in tracking LRO-LR when launched in late 2008.

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). The AWG added one more Analysis Center this year, the GRGS/OCA group, to increase the number of official Analysis Centers (ACs) from seven to eight. There are additionally, two Combination Centers (CCs) and several Associate Analysis Centers (AACs). The eight ACs are located at different institutes around the world: ASI/Italy, BKG/Germany, DGFI/Germany, GA/Australia, GFZ/Germany, GRGS/France, JCET/USA and NSGF/UK. ASI (primary) and DGFI (backup) are also hosting 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 them offer a quality control service for the entire network yield on a weekly basis (available via SLR e-mail) which is summarized on a quarterly basis at <http://ilrs.gsfc.nasa.gov/stations/site_info/

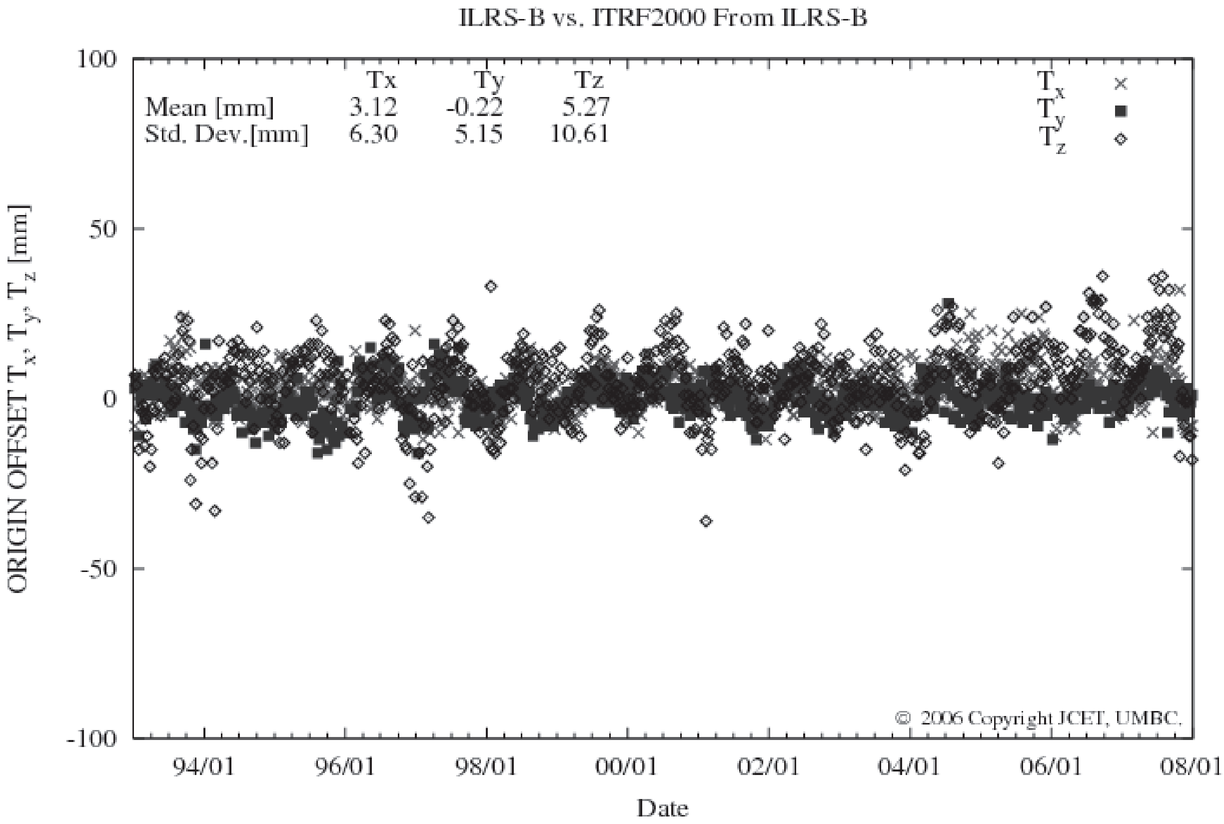


Fig. 5: Time-series of X, Y, and Z offsets of the ITRF2000 origin with respect to the weekly ILRS-B solutions' origin (proxy for "geocenter" variations) as observed by SLR (1993.0 – 2008.0).

global_report_cards/perf_2008q1_wLLR.html> (ILRS Quarterly Performance Reports).

During 2007, ILRS continued improving the models and procedures used in the analysis of the range data collected from the ILRS network. The improvements focused on the accurate determination of the target signature ("center of mass to effective reflection surface") and the accurate description of measurement biases for each system. A major effort in assessing current as well as historical data biases at all of the tracking sites resulted in the compilation of a data set used for the reanalysis of the data in 2007. Recognizing the importance of these issues, the ILRS established two task force groups dedicated to improving the target signature characterization and the communication between tracking stations and the analysts. Their effort will contribute to the timely and proper consideration of systematic biases. A first result is the characterization of the LAGEOS targets, the two satellites that by and large define the origin and scale of the ITRF series, with 1–2 mm accuracy for all of the ILRS network sites (Table 2). To put it in perspective, such accuracy limits the error on the scale definition of the ITRF at the level of 0.1–0.3 ppb.

Table 2: Site-dependent LAGEOS array corrections (CoM) and their accuracy

Site	Site	*Pulse-width*	*Detector*	*Regime*	*Processing*	*Calib.*	*LAGEOS*	*LAGEOS*
ID	*Name*	[ps]		*(single, few, multi)*	*level*	*sdt. error* [mm]	*std. error* [mm]	*CoM* [mm]
1873	Simeiz	350	PMT	No-CNTL	2.0 σ	60	70	248-244
1884	Riga	130	PMT	CNTL s→m	2.0 σ	10	15	252-248
7080	Mc Donald	200	MCP	CNTL s→m	3.0 σ	8.5	13	250-248
7090	Yaragadee	200	MCP	CNTL f→m	3.0 σ	4.5	10	250-248
7105	Greenbelt	200	MCP	CNTL f→m	3.0 σ	5	10	250-248
7110	Monument Pk.	200	MCP	CNTL f→m	3.0 σ	5	10	250-248
7124	Tahiti	200	MCP	CNTL f→m	3.0 σ	6	10	250-248
7237	Changchung	200	CSPAD	CNTL s→m	2.5 σ	10	15	250-245
7249	Beijing	200	CSPAD	No-CNTL, m	2.5 σ	8	15	255-247
7355	Urumqui	30	CSPAD	No-CNTL	2.5 σ	15	30	255-247
7405	Conception	200	CSPAD	CNTL s	2.5 σ	15	20	246-245
7501	Harteb.	200	PMT	CNTL f→m	3.0 σ	5	10	250-244
7806	Metsahovi	50	PMT	?	2.5 σ	15	17	254-248
7810	Zimmerwald	300	CSPAD	CNTL s→f	2.5 σ	20	23	246-244
7811	Borowiec	40	PMT	No-CNTL f	2.5 σ	16	23	256-250
7824	San Fernando	100	CSPAD	No-CNTL s→m	2.5 σ	30	25	252-246
7825	Stromlo	10	CSPAD	CNTL s→m	2.5 σ	4	10	257-247
7832	Riyadh	100	CSPAD	CNTL s→m	2.5 σ	10	15	252-246
7835	Grasse	50	CSPAD	CNTL s→m	2.5 σ	6	15	255-246
7836	Potsdam	35	PMT	CNTL s→m	2.5 σ	10	20	256-252
7838	Simosato	100	MCP	CNTL s→m	3.0 σ	20	40	252-248
7839	Graz	35	CSPAD	No-CNTL m	2.2 σ	3	9	255-250
7839	Graz kHz	10	CSPAD	No-CNTL s→f	2.2 σ	3	9	255-250?
7840	Herstmonceux	100	CSPAD	CNTL s	3.0 σ	6	15	246-244
7840	Hx kHz	10	CSPAD	CNTL s	-1.5,+2.5 σ	3	9	245
7841	Potsdam 3	50	PMT	CNTL s→f	2.5 σ	10	18	254-248
7941	Matera	40	MCP	No-CNTL m	3.0 σ	1	5	252-248
8834	Wettzell	80	MCP	No-CNTL f→m	2.5 σ	10	20	252-248

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 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 fifteen-year period. Similar statistics limited to the 2007 period are: 4 mm, 3 mm, 10 mm and 0.96 ppb.

Since 2003, the ILRS AWG maintains 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 the past year on a weekly basis, and were 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 every few years.

In order to fulfill the need of NEOS for as "fresh" as possible EOP information, the ILRS AWG decided in late 2007 to develop a new "daily" product, based on a 7-day arc sliding by one day each day. The results of this analysis are available to NEOS less than two days from the last observation in the analysis, and efforts are underway to further decrease the latency period. During 2007, three ACs (ASI, JCET and NSGF) contributed to the Pilot Project for this daily product. By the end of the year though two more ACs (BKG and GFZ) joined the group and it is expected that in 2008 more ACs will contribute. In 2008 NEOS will evaluate the new product and the ILRS will decide whether to evolve this PP into an official product (replacing the weekly one), or to discontinue it.

With the release of ITRF2005 in mid-2006, ILRS started preparing for the implementation of the "hybrid" version, the one scaled back to agree with SLR-implied scale (ITRF2005 SLR re-scaled). At the same time it was evident that a new reanalysis of the entire SLR data set would be necessary for the upcoming ITRFxx, so the AWG proceeded in the preparation of an intermediate TRF based primarily on ITRF2000 and ITRF2005SLR, to allow for a single consistent set of a priori positions and velocities in a single frame. This resulted in the SLRF2005 frame that was released in the fall of 2007 and starting Nov. 1, 2007, it has been adopted as the official ILRS frame to report the weekly products in. Since this frame encompasses all of the SLR sites that ever tracked in a single, accurate frame (ITRF2005SLR), ILRS posted this on the official website as the recommended frame for any SLR data analysis, including Precision Orbit Determination.

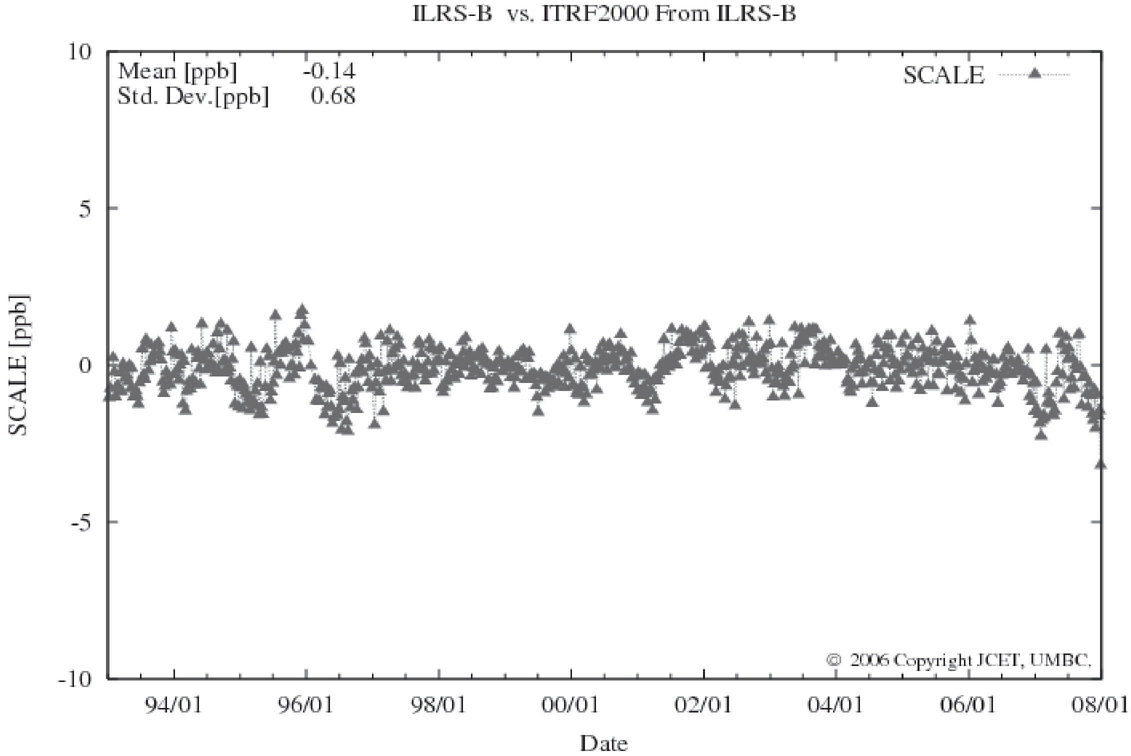


Fig. 6: Time-series of weekly solutions' difference in global scale from ITRF2000 as observed by SLR (1993.0 – 2008.0).

It is planned that in 2008, 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 (and beyond). However, recognizing the reduced number of satellites available (only LAGEOS) in the period 1983 to 1993, 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 will extend the time-span to nearly thirty 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/>. When the reanalysis is completed, a new release with the evaluation of the new products will replace the current version of these reports (currently a mixed bag of ITRF2000 and SLRF2005 referenced results).

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3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2007, 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: TRF, CRF, and EOP. Two IVS Directing Board meetings were held, one in February at the Geodetic Observatory Wettzell, Germany, and the other in September at the University of Bonn, Germany. At the Wettzell meeting, the Board elected Harald Schuh from Vienna University of Technology, Vienna, Austria as the new chair of the IVS replacing the outgoing chair Wolfgang Schlüter, BKG Germany.

The eighth *IVS Analysis Workshop* was held at the Vienna University of Technology, Vienna, Austria, on April 14, 2007, in connection with the 18th European VLBI for Geodesy and Astrometry (EVGA) Working Meeting. In April/May 2007 the fourth IVS *Technical Operations Workshop (TOW)* took place at MIT Haystack Observatory, Westford, MA, USA. The sixth *International e-VLBI Workshop* was held at Max-Planck-Institute for Radio Astronomy (MPIfR), Bonn, Germany in September 2007.

IVS published its 2006 Annual Report in April 2007 and three newsletter issues which keep the community informed about IVS activities. In June 2007 a Special Issue on Very Long Baseline Interferometry (<http://www.springerlink.com/content/v760312v657v/>) of the Journal of Geodesy was published. At the 18th Directing Board meeting held in September 2007 at Bonn University, IVS Working Group 4 on VLBI Data Structures was formed. The Working Group will examine the data structure currently used in VLBI data processing and investigate what data structure is likely to be needed in the future. It will design a data structure that meets current and anticipated requirements for individual VLBI sessions including a cataloging, archiving and distribution system. Further, it will prepare the transition capability through conversion of the current data structure as well as cataloging and archiving software to the new system.

Network Stations

A total of 1185 station days were used in 168 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 2007 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, Int1) on the baseline Wettzell (Germany) to Kokee Park (Hawaii, USA) and on weekend days (Saturday and Sunday, Int2) on the baseline Wettzell (Germany) to Tsukuba (Japan). The daily sessions are recorded using Mark 5 (Wettzell-Kokee) and K5 (Wettzell-Tsukuba) technology. In August 2007 a third Intensive series (Int3) was started to fill the 36-hour gap in the data series between the Int1 and Int2 Intensive sessions and to take full advantage of the electronic transfer capabilities available at the participating stations of Ny-Ålesund, Tsukuba, and Wettzell as well as at the correlator at MPIfR Bonn. Through a careful setup of operating steps and strong endeavors of the staff, UT1–UTC from these sessions is available within 24 hours after the observations, most often already within 8 hours.

IVS-T2 Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn with 12 stations per session. These sessions were observed to monitor the TRF with all IVS stations scheduled at least 3–4 times during the year.

IVS-CRF, IVS-CRMS, IVS-CRD The Celestial Reference Frame (CRF) sessions, the CRF median-south (CRMS), and the CRF deep-south (CRD) sessions, all coordinated by the U.S. Naval Observatory, provide astrometric observations that are required for improving the current CRF and extending the CRF by observing “new” sources. Seventeen sessions were observed for the maintenance of the ICRF in 2007 primarily in the southern hemisphere. Seven of them were scheduled with emphasis on the far southern hemisphere (CRD) and three with emphasis on the median south (CRMS).

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 7 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 2007.

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 research and development sessions were observed in 2007. Four of them were scheduled using Gbit/s recording rates to demonstrate the highest data rate available today and five of them were scheduled to test 512 Mbps recording modes for possible usage in the continuous VLBI campaign 2008 (CONT08). The last session was dedicated to the determination of receiver polarization leakage effects on the geodetic VLBI measurables.

The Network Coordinator's data base of station performance showed a data loss of 11.4%, slightly better (2%) compared to 2006. The most significant causes of data loss were antenna reliability (35%), receiver problems (15%), data acquisition system problems (11%), and RFI (10%).

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 had been connected at 1 Gbps in the later part of 2006 and production use of this connection started in 2007. Electronic data transfer (e-transfer) was routinely used between connected network stations and the MPIfR correlator. Initial steps have been taken to also connect the USNO correlator.

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

On January 1, 2007, a new combination process for the two IVS EOP series (rapid and quarterly solutions) was made operational. Routine combinations of IVS are now being made exclusively on the basis of datum-free normal equations in SINEX format. In 2007, five IVS Analysis Centers (BKG, DGFI, GSFC, IAA and USNO) contributed to the IVS combined products by providing input in the correct format. The rapid solutions contain only R1 and R4 sessions and new data points are added twice a week as soon as the SINEX files of the five IVS Analysis Centers are available. The SINEX file submissions should not be later than 48 hours after the correlation is completed. A Web page is automatically updated which states the timeliness of the latest submissions of the R1 and R4 sessions. As can be seen on this Web page, the timeliness requirement has been missed quite often, mostly due to logistical and personnel issues.

For the quarterly solution, updated every three months, almost all available data of 24-hour sessions from 1984 onwards are used. Since this series is designed for EOP determinations, those sessions are excluded which are observed with networks of limited extension or which are scheduled for a different purpose like radio source monitoring.

The advantage of the new combination strategy is that one common terrestrial reference frame (e.g. ITRF2005) is applied after the combined datum-free normal matrix is generated. Thus, it is guaranteed that an identical datum is used in the combination process for all input series. After datum definition the combined system of normal equations is solved (inverted) and the full set of EOP (pole components, UT1–UTC, and their time derivatives as well as two nutation offsets in $d\psi$, $d\varepsilon$ w.r.t. the IAU2000A model) are extracted. These results are added to the two EOP time series in the IVS EOP Exchange format, the rapid solution file (e.g., ivs07r1e.eops) and the quarterly solution file (e.g., ivs07q4e.eops). Companion files containing the nutation offsets in the X, Y paradigm are routinely generated through a standard transformation process (i.e., ivs07r1X.eops, ivs07q4X.eops). The weighted RMS differences between the individual IVS Analysis Centers and the combined products have been reduced over the last two years from roughly 80–100 µas to 50–60 µas in all components, which can mostly be attributed to the proper usage of models and conventions. On the IVS Analysis Coordinator's Web page additional information about the series, the residuals of the individual contributions w.r.t. the combined solution as well as comparisons with IGS and IERS EOP results are provided routinely.

At the same time the combined SINEX files (datum-free normal equations) are also available on the Web for further combination with other techniques. At present, this is done on an experimental basis only, but the IERS Analysis Coordinator is strongly pushing towards such a routine process.

Technology Development

Routine use of high-speed optical fiber connections continued to grow. MPIfR conducted regular e-transfers of data for which the Bonn correlator is the correlation target. This included data from Tsukuba, Kashima, Onsala, Ny-Ålesund, and Wettzell. All data recorded on K5 systems at Tsukuba and Kashima were transferred either to MPIfR or Haystack depending on the target correlator. Syowa (Antarctica) K5 data was physically shipped to Japan and electronically transferred to Haystack or MPIfR. All of Wettzell's daily UT1 Intensive data was e-transferred, either directly to the correlator at the Geographical Survey Institute (GSI), 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 (so-called ‘sneaker-net’). All data of the newly established Int3 Intensive sessions with Wettzell, Tsukuba, and Ny-Ålesund was e-transferred to MPIfR.

The four network stations at Kashima, Metsähovi, Onsala, and Tsukuba commenced a study on ultra-rapid Intensives using e-VLBI (e-transfer of data with near real-time correlation). Intensive-type sessions of 1-hour length were observed on two almost parallel baselines between Europe and Japan (Onsala–Tsukuba and Metsähovi–Kashima). The sessions were processed in near real-time by making use of the high-speed optical fiber connections of the four stations and the software correlators at Kashima (NICT) and Tsukuba (GSI). The work will be continued in 2008. Once the procedure (from observation to final product) has been proven to be robust and reliable, it can be employed to improve the IVS observing program, e.g., by reducing the latency for results of the Int1 or Int2 sessions. The results from the two parallel baselines will allow the investigation of systematic errors in dUT1 estimation.

The VLBI2010 Committee continued its work on designing and implementing the next generation VLBI system. The work concentrated on Monte Carlo simulations to investigate the performance of network configurations, schedules and observing scenarios, and on the broadband delay approach. The broadband approach involves the use of broadband feeds (2–15 GHz) and multiple IF channels to reliably resolve RF phase, even at low signal-to-noise ratios. It will enable extremely precise delay measurements to be made while using comparatively small and cost effective 12-m class antennas. The lower cost of these antennas will make replacement of existing, old antennas and the addition of new stations more affordable. On November 19, 2007, the combined effort and hard work of a group of scientists and engineers working on experimentally demonstrating the VLBI2010 concept came to fruition. On that day first fringes were found with the proof-of-concept hardware that has been installed at the MV-3 antenna at Goddard’s Geophysical and Astronomical Observatory (GGAO).

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3.4.4 International DORIS Service (IDS)

General

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

Network

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

In 2007 only one station was completely renovated in order to improve the long term stability of the antenna support: Toulouse, France. This was the last Alcatel antenna in the network: now all antennas in the network are the Starec model. At six stations (among which some recently renovated) the antenna support was modified, so as to remove the N-type bent adaptors located at the base of the antenna. These N-type bent adaptors are suspected of causing power loss in the long term. Finally, the equipment of the station at Papeete (French Polynesia) was completely replaced (including a third generation beacon), and the antenna was included in a global geodetic survey of this three-technique IERS co-location site (<http://ilrs.gsfc.nasa.gov/docs/Tahiti_surveyreport_0710.pdf>).

The total number of DORIS stations in the permanent tracking network remains 57. Figure 1 depicts the current co-location between DORIS stations and other IERS techniques.

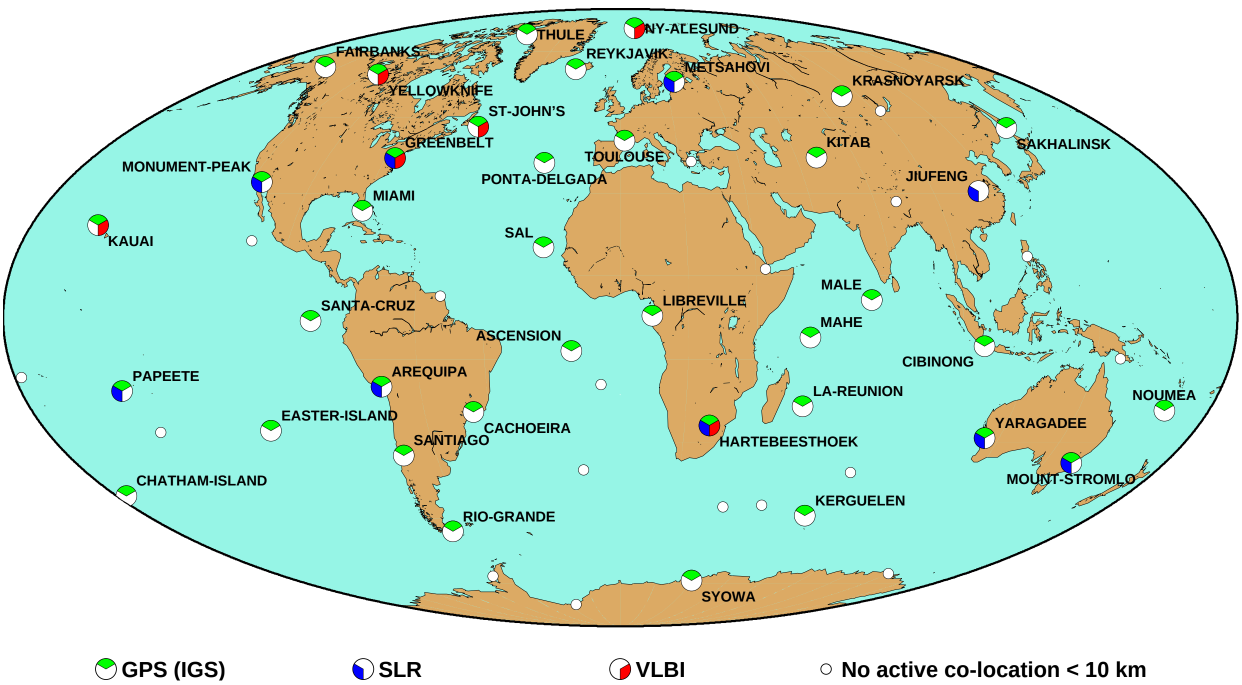

Fig. 1: DORIS Network co-locations with GPS, SLR & VLBI

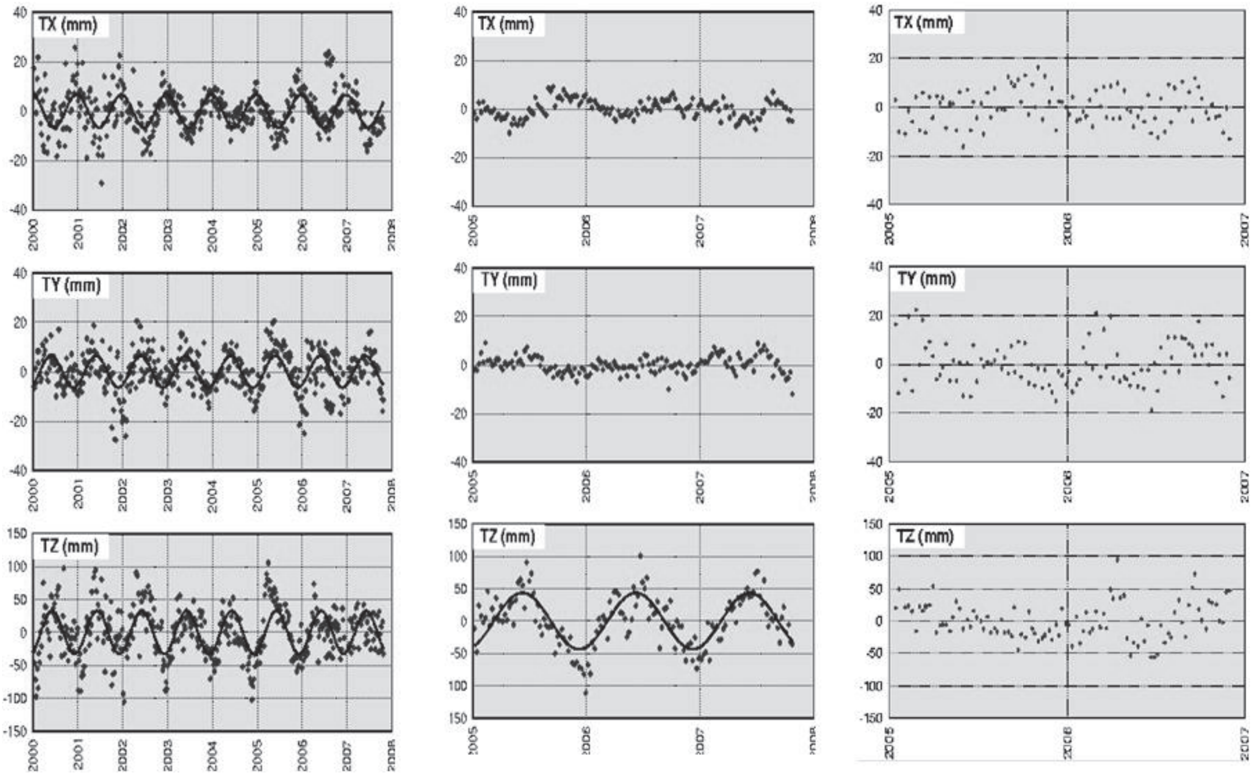

Fig. 2: Geocenter parameters (Tx, Ty, Tz) from three analysis center solutions: ***Left,*** *IGN wd05;* ***Center,*** *LCA wd18, and* ***Right,*** *GOP wd03.*

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 March 2009, and ALTI-KA (joint with the CNES and ISRO, the Indian Space Research Organization) scheduled for launch in 2009-2010. The current DORIS on-orbit DORIS satellite constellation includes: SPOT-2 (in orbit since 1990), SPOT-4, SPOT-5, ENVISAT, and Jason-1. Possible missions (not yet approved or finalized) include SENTINEL-3 (European GMES Program, ESA for 2012), Jason-3 (Jason-2 follow-on for 2012-2013), HY-2A (joint altimetric mission with CNES and the China Space Agency to include a DORIS receiver, GPS receiver and Laser Retroreflector for 2010).

Analysis Activities

The International DORIS Service has been in operation since 2003. Over the last four years receivers on the SPOT 2-4-5, ENVISAT and the JASON-1 satellites have provided DORIS Doppler data from a global network of about 50 stations. The number of Analysis Centers (AC) who have processed the data and have high level experience has progressively risen. Among them, two AC's: IGN using GYPSY/ OASIS software and LEGOS/CLS using GINS/DYNAMO software now provide solutions of station coordinates and EOP's on a routine basis to the IGN and NASA CDDIS data centers. INASAN also processes DORIS data using GYPSY/OASIS software and submitted SINEX files to the ITRF2005 solution. The two newest DORIS analysis centers, include Geoscience Australia (GA) using the NASA GEODYN software and the Geodetic Observatory Pecny (GOP) using the BERNESE software. The GOP has adapted software not originally designed to process DORIS data. The performance reached by the new analysis centers in orbit and station positions determination is very encouraging. The availability of geodetic solutions from different algorithms and software packages allows us to efficiently contribute to cross-comparison of the solutions and to the improvement of the DORIS technique.

The results of some of the preliminary tests with the new test series is illustrated in Figure 2. Some of the general conclusions from the analysis are: (1) Z translation variations are still very high; (2) Systematic yearly effects remain in the translation (IGN & LCA, black curves have annual period); (3) TRF parameters for GOP are more scattered than others; (4) Scale factors (not shown) have close behaviour (this marks an important improvement for LCA since ITRF2005); (5) more generally WRMS (not plotted here) are between 10 to 15 mm after 2003 (4 satellites available) and at the same level for each AC. The AC cumulative solution comparisons with ITRF2005 are summarized in Table 1.

Table 1: New Analysis Center Solution Comparisons with ITRF2005

ITRF2005 comparisons	Pos (mm)	Vel (mm/yr)
IGN (7 yrs)	6.5	2.0
LCA (2 yrs)	15.6	4.0
GOP (2 yrs)	11.1	7.1
Combined solution	7.0	5.7

Since the SINEX contributions of the Geodetic Observatory Pecny (GOP) are clearly on par with that of the other analysis centers, they have been welcomed into the IDS as an operational analysis center, and we look forward to their contribution for the next ITRF realization.

SAA Effect on Jason-1 and Validation of Corrective Model

It has been known for some time that the Jason-1 DORIS USO is not as stable as desired. The frequency is perturbed by passage through the South Atlantic Anomaly (SAA). The frequency is sensitive to irradiation rate and the total irradiation encountered in orbit. DORIS station positioning is perturbed if Jason-1 is included in multi-satellite solutions. *(Willis et al., Adv. Space Res. 31(8), pp. 1941–1946, 2003; CR Geoscience, 336(9), pp. 839–846, 2004). JM Lemoine and H. Capdeville* (*J. Geodesy, 2006)* have developed a correction model to apply to Jason-1 DORIS data. They have demonstrated that it improves DORIS data analysis. The NASA GSFC Precision Orbit Determination team has also tested the SAA model on the entire time series of Jason-1 orbits (computed with both DORIS and SLR). The results of these tests are illustrated in Figure 3, depicting the Jason DORIS RMS of fit to 10-day orbit solutions with and without the SAA correction. The SAA correction applied over 177 test cycles, improves the RMS of fit from 0.4078 mm/s to 0.3740 mm/s, the SLR fit from 1.482 cm to 1.440 cm, and the independent altimeter crossover fit from 5.585 cm to 5.578 cm (*Beckley et al., Geophys. Res. Lett., 2007*).

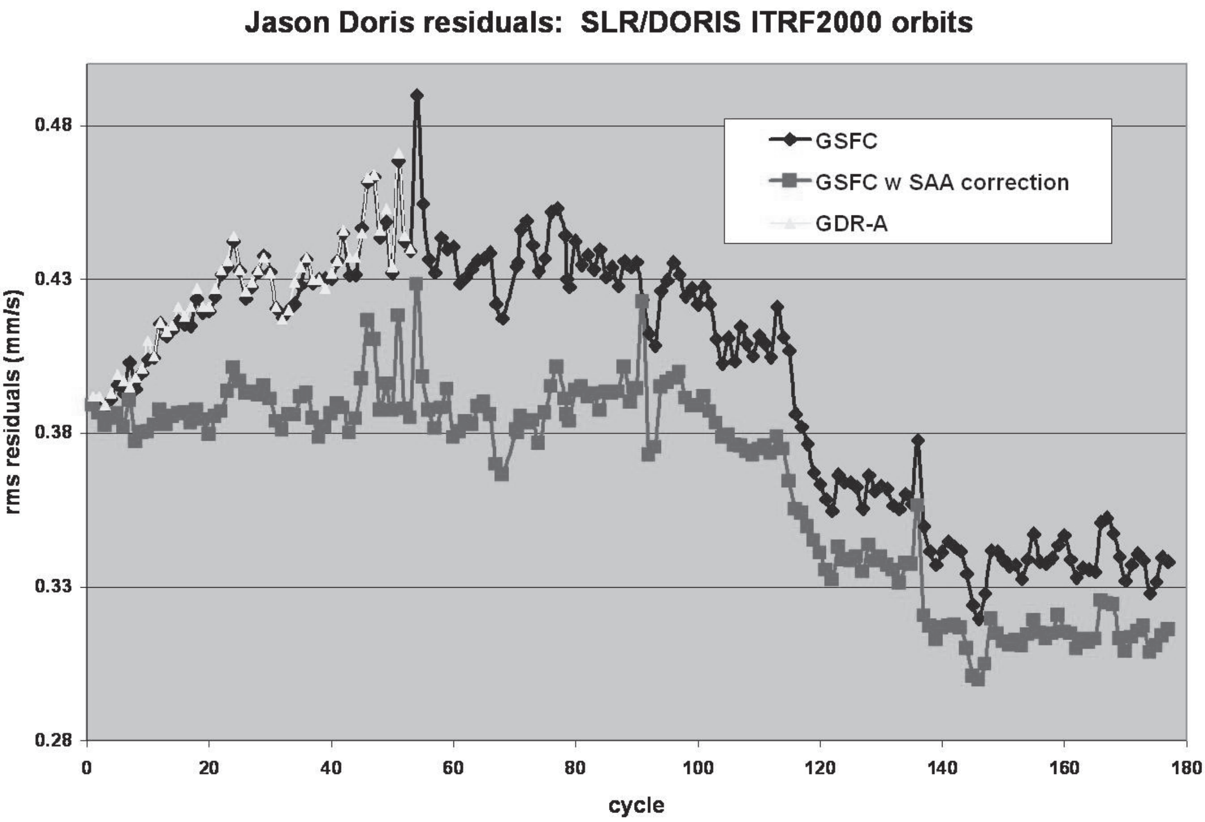

Fig. 3: Jason-1 DORIS residual RMS of fit for cycles 1–177; in blue without the SAA correction; in magenta with the SAA correction. (Computations courtesy of NASA GSFC POD center, presented at Jason Ocean Surface Topography meeting, Hobart, Tasmania, March 2007).

While we have confirmed that the POD for Jason-1 is improved using the SAA model, we cannot say that the SAA model corrects the frequency aberrations sufficiently to allow the Jason-1 data to be used in IERS combinations. At present Jason-1 data are omitted (as was the case in ITRF2005). Some experiments are planned in 2008. Since we know that the number of satellites in a DORIS solution decisively affects the EOP and station position quality, it is possible that it would be advantageous to include Jason-1 data (corrected by the SAA model) in future solutions, but only for 2002, the year both SPOT-5 and ENVISAT were launched.

DORIS Data Delivery Latency

The latency of data delivery to the IDS data centers (IGN and the NASA/CDDIS) affects the rapidity with which operationaly analysis of the DORIS data can be performed for EOP and weekly station position. With the current DORIS format, the delivery of the data depends on final preprocessing by the CNES POD team. As can be seen in Figure 4, this latency has in the past been around 25 days for most satellites. In mid-2007, a dramatic improvement was observed with data latency now on average around 15 days.

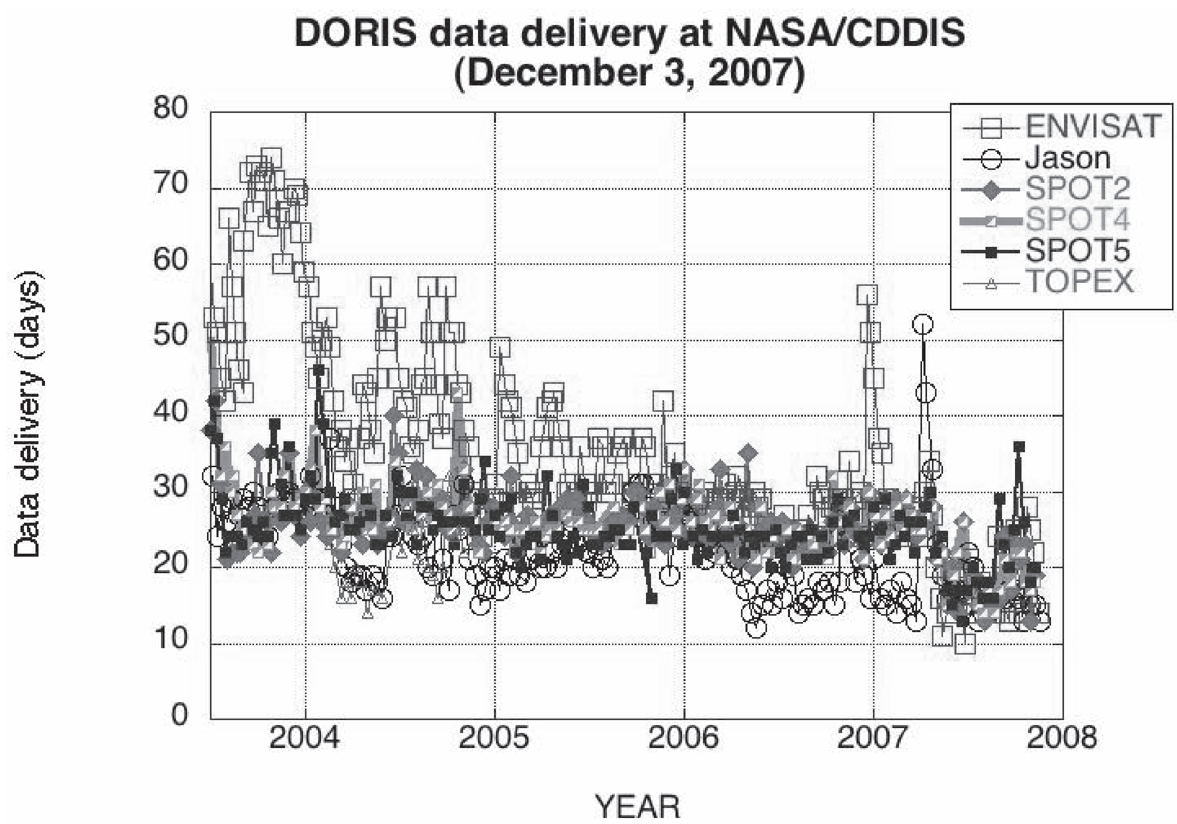

Fig. 4: DORIS data delivery latency to the NASA/CDDIS for all DORIS satellites. Note the dramatic improvement in latency in mid-2007.

DORIS Citation

We request that users of DORIS data and products use the following new citation, from the DORIS article in the Journal of Geodesy special issue (November 2006):

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*.

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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 the year 2007. According to the IERS Terms of Reference, the Earth Orientation Centre is responsible for monitoring Earth Orientation Parameters (EOP) 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 in astronomy, geodesy, geophysics, space sciences and time, i.e. series of Polar motion, Universal Time (UT1), Length of Day (LOD) and Celestial pole offsets.

Determination of EOP is in the form of combined solutions derived by the analysis centres of the different techniques. Various solutions are computed: long-term solution (IERS C01) and the operational smoothed solution Bulletin B at one-day intervals published monthly. Bulletin B is updated in the operational C04. So far, EOP and the terrestrial frame were separately computed. This led to increasing inconsistencies between both of them. On January 2005, these inconsistencies were significant for polar motion; 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

As stated in the previous IERS Annual Report for 2006, the EOP reference solutions were made consistent 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. Discrepancies at the level of 300 microarseconds were present at 2004.0 between the IERS C04 and the ITRF realization (Gambis 2004). This was as well an opportunity to upgrade the numerical combination procedure. The improvements concern routines, table dimensions and the generalization of double precisions. Using the combined polar motion solution associated with the ITRF 2005, the new solution is mainly based on the time series derived by technique centres IGS, IVS and ILRS. In addition, formal errors associated 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 05 C04. A detailed description of the new solution can be found in Bizouard and Gambis (2008) and in the Technical Note available at <http://hpiers.obspm.fr/iers/eop/eopc04_05/C04_05.guide.pdf>.

Table 1: Estimated accuracies of individual solutions compared to the combined solutions Bulletin B and 05 C04 over 2007–2008.

Individual solutions		Estimated uncertainties				
		Time	Terrestrial Pole µas	UT1 µs	LOD µs	Celestial Pole µas
VLBI - 24 h						
EOP (AUS)	01 R 01	3-4d	204	–		222
EOP (BKG)	03 R 02	1-4d	105	7.0		129
EOP (GSFC)	07 R 01	1-4d	135	5.7		86
EOP (IAA)	05 R 02	1-4d	107	6.0		118
EOP (MAO)	03 R 01	1-4d	99	7.0		152
EOP (OPA)	07 R 01	1-4d	86	6.2		60
EOP (SPBU)	05 R 01	1-4d	260	6.8		118
EOP (USNO)	06 R 02	1-4d	95	5.8		86
EOP (IVS)	02 R 01	1-4d	100	5.4		96
VLBI - Intensive						
EOP (BKG)	03 R 02	1-3 d		12.4		
EOP (GSFC)	06 R 01	1-3 d		11.3		
EOP (IAA)	05 R 01	1-3 d		13.0		
EOP (SPBU)	05 R 01	1-3 d		14.3		
EOP (USNO)	05 R 01	1-3 d		13.1		
SLR						
EOP (ASI)	03 L 02	1d	220		54.1	
EOP (IAA)	02 L 01	1d	169		31.4	
EOP (MCC)	97 L 01	1d	147		–	
EOP (OCA)	05 L 01	1d	133		–	
EOP (ILRS)	05 L 01	1d	66		17	
GPS						
EOP (CODE)	98 P 01	1d	35		14.1	
EOP (EMR)	96 P 03	1d	55		17.8	
EOP (ESOC)	96 P 01	1d	50		36.3	
EOP (GFZ)	96 P 02	1d	40		16.3	
EOP (IAA)	01 P 01	1d	190		30.1	
EOP (JPL)	96 P 03	1d	76		116.3	
EOP (NOAA)	96 P 01	1d	75		15.9	
EOP (SIO)	96 P 01	1d	47		17.9	
EOP (USNO)	03 P 01	1d	-		23.0	
EOP (IGS)	07 P 01	1d	19		9.5	
EOP (IGS)	96 P 02	1d	39		10.0	

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

Maintenance of the consistency between the current EOP 05 C04 solution in the ITRF2005 system

Introduction

The maintenance of the consistency between 05 C04 with the ITRF is essential in the field of geodynamics and satellite orbit computation. The ITRF2005 was the first rigorous combination ensuring ITRF and EOP consistency, based on time series of station positions and Earth Orientation Parameters (Altamimi et al. 2007). Its release was the opportunity to re-align the C04 to the ITRF2005 system. IERS reference EOP series, based on the combination of astro-geodetic techniques products are currently independently computed from the ITRF. This leads to the existence and increase of small

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 2007–2008.

Solutions		Terrestrial Pole mas	UT1 ms	Celestial Pole mas
Analysis daily	1-d	.040	.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 05 C04 over 2007–2008.

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
Dψ (µas)					–4	51

Table 4: Mean and standard deviation for Pole components and UT1 of the differences between various solutions and Bulletin B over 2007.3 to 2008.3.

EOP	Unit	Bull A – Bull B		Comb JPL – Bull B	
		Mean	Standard deviation	Mean	Standard deviation
X	µas	–29	27	–176	50
Y	µas	–15	31	–57	13
UT1	µs	–1	13	8	11

inconsistencies between the terrestrial reference frame and EOP. After two years, it was important to assess the level of accuracy reached for the consistency between the current 05 C04 and the ITRF2005 system.

In cooperation with the ITRS Centre we have developed a combination strategy allowing to check the ITRF2005 and IERS 05 C04 consistency with time.

Strategy of the maintenance of 05 C04 in the ITRF2005 system starting at 2006.0 using a SINEX combined extension of EOP (ITRF2005)

The 05 C04 EOP series is derived from the combination of series derived by technique centres, IGS, ILRS and IVS.

The process includes the following steps:

1) CATREF computation by the ITRS Centre of updated EOP solutions based on SINEX files of GPS and VLBI techniques
2) Comparison of this EOP solution to the current 05 C04 EOP series operationally computed by the Earth Orientation Centre.

Conclusion

Results were presented at various conferences (Altamimi et al. 2008, Gambis et al. 2008). Figure 1 gives the level of consistency obtained. It appears that after two years we are able to maintain the overall consistency within the level of 40 microarseconds between the updated series of EOP derived from CATREF processing and the 05 C04 independently computed. This is at the level of the inaccuracy reached for the current pole components estimation.

Long-term series: C 01 (1846–2007)

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 interval from 1890 until now (polar motion, celestial pole offsets, UT1–UTC since 1962). For many decades, the observations were made using mostly visual and photographic zenith telescopes. Since the advent of the space era in the 1960s, new geodetic techniques were used for geodynamics. Now, the global

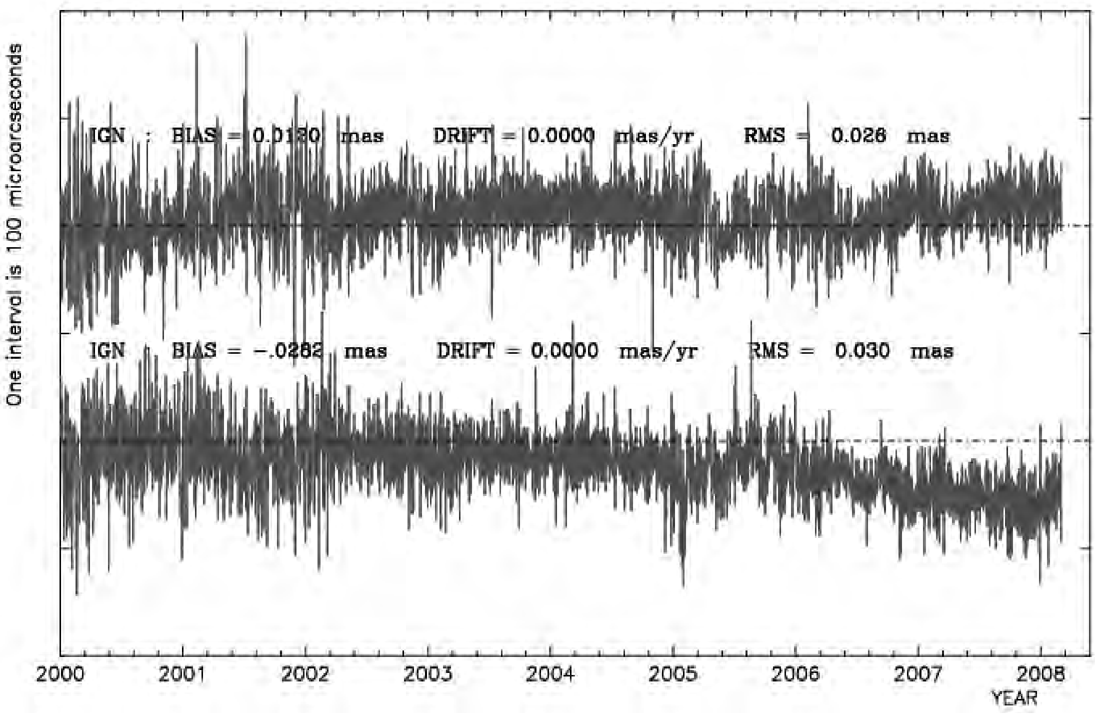

Fig. 1: Polar Motion over 2000–2008, CATREF(2008) – 05 C04

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).

1962–2007: 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

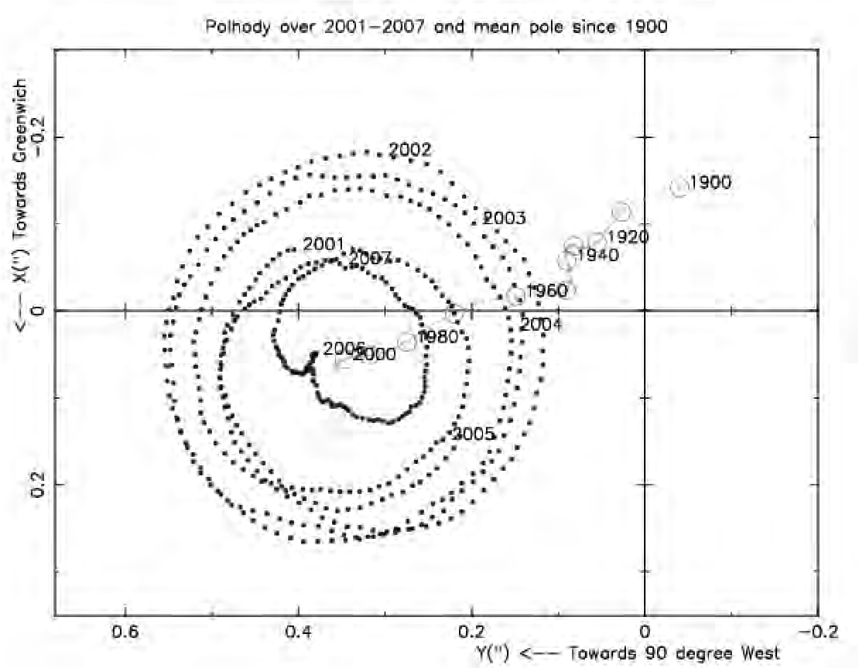

Fig. 2: Mean polar motion (1900–2010) and IERS C04 polhody over 2002–2007

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 2007 (Shiskin *et al*, 1965). Figure 2 represents the polar motion over 2001–2006 and the path of the mean pole since 1900. The table is available in Conventions 2003 (McCarthy and Petit 2004) and at <http://hpiers.obspm.fr/eop-pc/>.

Staff

Daniel Gambis	Astronomer, Head
Christian Bizouard	Astronomer
Gérard Francou	Astronomer
Teddy Carlucci	Engineer
Jean Yves Richard	Engineer (since November 2007)
Olivier Becker	Engineer (since November 2007)
Morad Saïl	Engineer (until December 2007)
Mireille Bougeard	Mathematician
Pascale Baudoin	Secretary

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Daniel Gambis, Christian Bizouard, Jean Yves Richard, Teddy Carlucci, Morad Saïl, Olivier Becker

3.5.2 Rapid Service/Prediction Centre

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Center 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 (before 14 June 2007) and 05 C04 (on and after 14 June 2007) systems of the IERS Earth Orientation Center (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 Center are given in Table 1. These estimates are based on the residuals of between the series and the combined RS/PC EOP solution for 2007.

Table 1: Estimated accuracies of the techniques in 2007. 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)
ILRS SLR	0.21	0.21			
IAA SLR	0.17	0.21			
MCC SLR	0.12	0.15			
GSFC VLBI Intensives			0.013		
SPbU VLBI Intensives			0.014		
USNO VLBI Intensives			0.013		
GSFC VLBI	0.07	0.08	0.003	0.4	0.1
IAA[1] VLBI	0.10	0.11	0.004	(0.1)	(0.1)
IVS[1] VLBI	0.10	0.15	0.003	(0.1)	(0.1)
USNO VLBI	0.08	0.12	0.005	0.4	0.1
IGS Final	0.02	0.02			
IGS Rapid	0.02	0.03			
IGS Ultra	0.05	0.06			
USNO GPS UT*			0.017*		
EMR GPS UT*			0.024*		
USNO AAM UT			0.011		

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

Operationally, the weighted spline uses as input the epoch of observation, the observed value, and the weight of each individual data point. The software computes the spline coefficients for every data point which are then used to interpolate the Earth orientation parameter time series so that x, y, UT1–UTC, $\delta\psi$, and $\delta\varepsilon$ values are computed at the epoch of zero hours UTC for each day. Since the celestial pole offset software is written in terms of $\delta\psi$ and $\delta\varepsilon$, the IAA VLBI dX and dY values are converted to $\delta\psi$ and $\delta\varepsilon$ for the combination process. The 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).

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center solutions and 97/05 C04 EOP solutions for 2007. Polar motion x and y values are in milliseconds of arc and UT1–UTC values are in units of milliseconds of time.

	Bulletin A – C04	
	Mean	Std. Deviation
Bulletin A Rapid Solution (finals.data)		
x	–0.04	0.04
y	–0.01	0.04
UT1–UTC	0.000	0.014
Bulletin A Weekly Solution (finals.data)[1]		
x	–0.02	0.06
y	–0.03	0.04
UT1–UTC	–0.014	0.029
Bulletin A Daily Solution (finals.daily)		
x	0.00	0.11
(before MJD 54265/after MJD 54300)[2]		(0.14/0.07)
y	–0.03	0.12
(before MJD 54265/after MJD 54300)[2]		(0.16/0.08)
UT1–UTC	0.012	0.060

[1] Statistics computed over the 7 day combination solution period prior to solution epoch.
[2] before MJD 54265 indicates the data compared against the 97 C04 and after MJD 54300 indicates the data after the implementation of the IGS Ultra in the combination procedures.

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 Center's combination solution for the running, the weekly, and the daily products compared to the 97/05 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 97/05 C04 series for the entire year. The comparison of the 52 weekly solutions to the 97/05 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 the 97/05 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 and standard deviations. The small bias difference in the polar motion x component appears to be due to different corrections for the change in the International GNSS Service (IGS) series due to the switch from relative phase center to absolute phase center corrections. The two large residuals in the daily polar motion in the early part of the year are the result of an unexpected change in input data format from a contributor. The larger difference in UT1–UTC is caused by differences in the way non-VLBI UT data sources are handled between the two centers. These UT1 differences are an area of ongoing investigation.

Prediction Techniques

In 2007, the algorithm for polar motion predictions was changed to incorporate the least-squares, autoregressive (LS+AR) method created by W. Kosek and improved by T. Johnson (personal communication, 2006). This method solves for a linear, annual, semiannual, 1/3 annual, 1/4 annual, and Chandler periods fit to the previous 400 days of observed values for x and y. This deterministic model is subtracted from the polar motion values to create residuals, which are more stochastic in nature. The AR algorithm is then used to predict the stochastic process while a deterministic model consisting of the linear, annual, semiannual, and Chandler terms is used to predict the deterministic process. The polar motion prediction is the addition of the deterministic and stochastic predictions. The additional unused terms in the deterministic solution help to absorb errors in the deterministic model caused by the variable amplitude and phase of the deterministic components (T. Johnson, personal

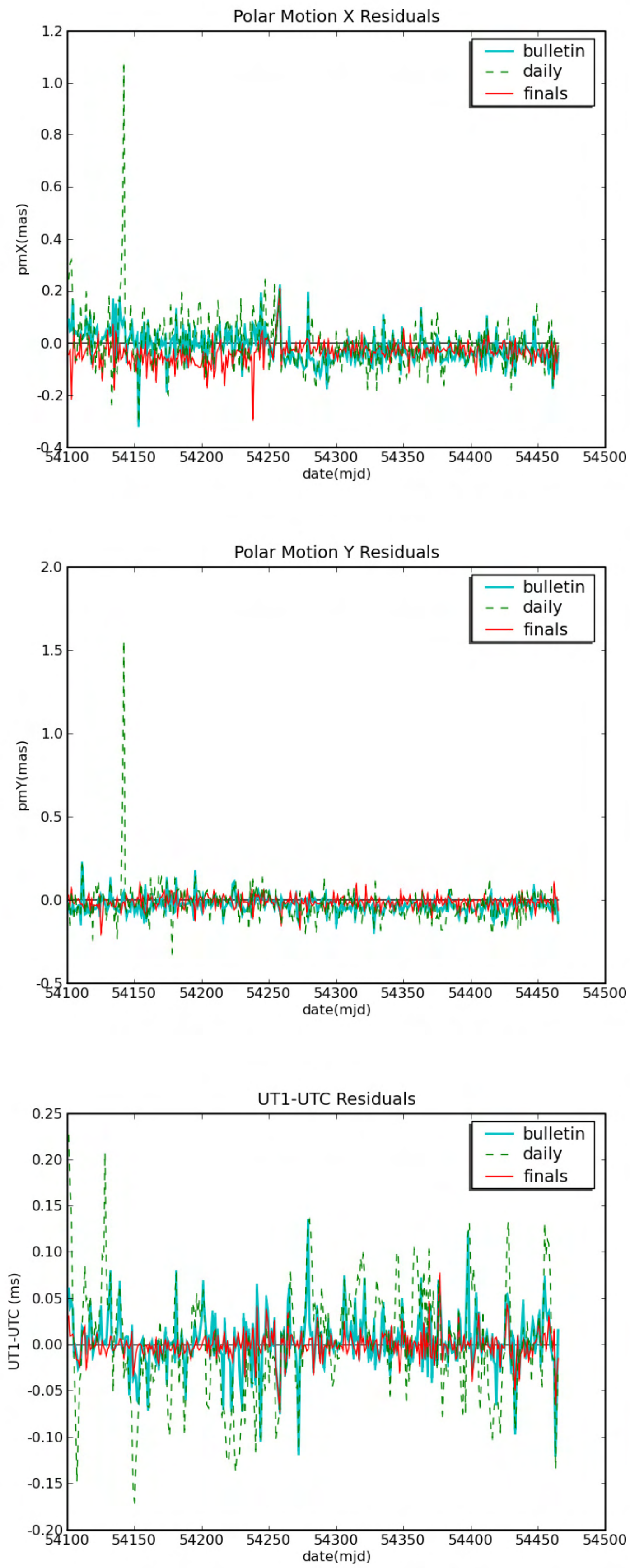

Fig. 1: Residuals between daily Bulletin A rapid solutions at each daily solution epoch for 2007 and the Earth orientation parameters available in 97/05 C04 series produced in April 2008.

communication, 2006). For more information on the implementation of the LS+AR model, see Stamatakos *et al.* (2008).

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, $(UT2R–TAI)_n$, the smoothed time value from n days in the past, $<(UT2R–TAI)_{–n}>$ is subtracted from the most recent value, $(UT2R–TAI)_0$

$$(UT2R–TAI)_n = 2(UT2R–TAI)_0 – <(UT2R–TAI)_{–n}>.$$

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

The 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 a combination of the operational NCEP and U.S. Navy NOGAPS AAM analysis and forecast data (UTAAM). 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. In October 2007, the length of AAM forecasts increased from 5 to 7.5 days. This change means that AAM forecasts are the basis of UT1 predictions out to 7 days. For more information on the use of the UT AAM data, see Stamatakos *et al.* (2008).

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 97/05 C04 solution for 2007. 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

Table 3: Root mean square of the differences between the EOP time series predictions produced by the daily Bulletin A rapid solutions and the 97/05 C04 combination solutions for 2007.

Days in Future	PM-x	PM-y	UT1–UTC
	mas	mas	ms
1	.42	.33	.141
1[1]	(.46/.37)	(.39/.28)	
5	2.06	1.33	.452
10	3.75	2.27	.921
20	6.92	4.26	3.29
40	12.1	8.47	7.77
90	15.3	17.7	13.4

[1] the first number indicates the data compared against the 97 C04 and the second number indicates the data after the implementation of the IGS Ultra in the combination procedures.

was introduced) indicated a better than 50% improvement in prediction error at both 10 day and 20 days into the future.

For 2007, the prediction errors were, in general, better than those of 2006. The polar motion predictions errors returned to historical levels as the amplitude of the polar motion loops is much smaller than the amplitude of the polar motion in 2007. The prediction of polar motion has been improved by the switch to the LS+AR prediction method. The UT1–UTC prediction shows a slight indication of improvement due to the switch from AAM forecast lengths being extended from 5 to 7.5 days. Further investigation to confirm this trend is needed.

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\varepsilon$ representations) are produced through the use of the KSV1996 model (McCarthy, 1996). In addition, a bias between the model and the last 20 days worth of celestial pole offset observations is computed. This bias is tapered so that as the prediction length is ex-

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily Bulletin A rapid solutions and the 97/05 C04 solution for 2007.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.11	.12	.33	.14
5	.11	.12	.33	.14
10	.11	.11	.34	.14
20	.11	.11	.33	.15
40	.11	.11	.34	.16

tended, 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 97/05 C04 for 2007 are given in Table 4.
Predictions of TT–UT1 up to 2017 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.

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; Stamatakos et al. 2008).

Center Activities in 2007

During 2007 a number of changes occurred that affected the performance of IERS Bulletin A. On 14 June, the system of the Bulletin A was changed to match the system of the new 05 C04 solution of the IERS EOC. This change made the EOPs more consistent with the ITRF. The LS+AR polar motion prediction algorithm was implemented on 25 January. Electronic-VLBI (e-VLBI) became operational for certain aspects of the VLBI Intensive observations improving the quick-turnaround UT1 combination and short-term UT1 predictions. IGS Ultra data were added to the polar motion combination on 19 July, improving the quick-turnaround polar motion combination. The improvement can be seen in the statistics presented in Tables 2 and 3. These statistics show that there was a significant reduction in the scatter of the residuals after the inclusion of the IGS Ultras. This reduction is seen in both the daily combination and 1-day daily prediction values, as expected. The ILRS Series A was added to the operational procedures on 25 January, improving the robustness of the combined polar motion solution. On 4 October, the forecast length of the AAM data increased from 5 days to 7.5 days, improving the information available for near-term UT1 forecasts. Additional efforts included improving operational software, updating and monitoring currently used datasets, and investigating potential new data sets. Additional work to increase the robustness of an alternate site to mirror data storage for the combination processing was carried out.

New global solutions were received from GSFC, USNO, IAA, and IVS VLBI analysis centers. These new solutions were examined and new rates and biases were computed.

Table 5: Predicted values of TT–UT1, 2008–2017. 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)
2008 Jan 1	65.457	0.000
2008 Apr 1	65.545	0.000
2008 Jul 1	65.60	0.007
2008 Oct 1	65.62	0.01
2009 Jan 1	65.70	0.02
2009 Apr 1	65.79	0.02
2009 Jul 1	66.2	0.2
2009 Oct 1	66.3	0.3
2010 Jan 1	66.5	0.4
2010 Apr 1	66.6	0.4
2010 Jul 1	66.8	0.5
2010 Oct 1	66.9	0.7
2011 Jan 1	67.1	0.8
2011 Apr 1	67.2	0.9
2011 Jul 1	67	1.
2011 Oct 1	67	1.
2012 Jan 1	68.	1.
2012 Apr 1	68.	1.
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	69.	2.
2014 Jan 1	69.	2.
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.	3.
2015 Oct 1	70.	3.
2016 Jan 1	70.	4.
2016 Apr 1	70.	4.
2016 Jul 1	70.	4.
2016 Oct 1	70.	4.
2017 Jan 1	70.	4.

Availability of Rapid Service

The data available from the IERS Rapid Service/Prediction Center 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, δX and δY 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 from Institute of Applied Astronomy 1-day SLR; x, y from the

Russian Mission Control Center 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 Center; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Earth Orientation Center; and predictions of x, y, UT1–UTC from the IERS Rapid Service/Prediction Center.

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; LOD from ILRS 1-day SLR; x, y, UT1–UTC from CSR LAGEOS 3-day SLR; x and y from CSR LAGEOS 5-day SLR; x and y from Delft 1-, 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 Center in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current ninety days' 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.

Center Staff

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

William Wooden	Director
Brian Luzum	Program manager, research, and software maintenance
Nick Stamatakos	Operational procedure manager, research, and software maintenance
Gillian Brockett	Assists in daily operations and support, research, and software maintenance
Merri Sue Carter	Assists in daily operations and support
Beth Stetzler	Assists in daily operations and support, research, and software maintenance

In the second half of 2007, Beth Stetzler joined the IERS Rapid Service and Prediction Center.

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Brian Luzum, Nicholas Stamatakos, Gillian Brockett,
Merri Sue Carter, Beth Stetzler, 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 provides updated versions of the Conventions in electronic form, after approval of the IERS Directing Board. In the mean time, work on interim versions is also available electronically. 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 2007, 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 continued in 2007. More technical or complex issues are first discussed, *e.g.* through the Advisory Board or on the discussion forum (<http://tai.bipm.org/iers/forum>), where topics are identified as needing investigation and possible 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 2007:

1.1 Terrestrial reference frame

A general revision of the chapter has begun with the primary goal of incorporating the ITRF 2005 into the chapter. Principal contributors to this effort are C. Boucher, Z. Altamimi, J. Ries, and U. Hugentobler.

1.2 Free Core Nutation

The free core nutation (FCN) is a free motion with variable excitation that causes the amplitude and phase of the motion to be unpredictable at some level. Because of this, the FCN was not included in the IAU 2000A nutation model, and therefore has been accommodated separately. The FCN model of S. Lambert was selected as the conventional model on 23 October 2007. Principal contributors to this effort are S. Lambert, Z. Malkin, and B. Luzum.

1.3 Terminology and models for Transformations

Modifications were made to Chapter 5 to make the chapter's terminology more consistent with current IAU recommendations. In addition, the references for the planetary fundamental arguments were revised to make them clearer. Work has begun on incorporating the IAU 2006 Precession model into the Conventions. Principal contributors to this effort are N. Capitaine, P. Wallace, and B. Luzum.

1.4 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. These can have an amplitude of 1.5 mm. Using the Ray and Ponte (Annales Geophysicae 21, 2003) tidal representation, 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 yet complete. Principal contributors to this effort are T. van Dam and R. Ray.

1.5 Lunisolar station displacements

The subroutine dehanttideinel.f, which computes the tidal corrections of station displacements caused by lunisolar gravitational attraction, has been updated by H. Manche and G. Petit. These updates include replacing subroutines DUTC and FJLDY with the SOFA subroutines iau_CAL2JD and iau_DAT and modifying the time arguments of subroutine STEP2DIU.

1.6 Tidal variations in Earth rotation

Currently, there is no conventional subroutine to compute the tidal variations in Earth rotation for the Defraigne and Smits model. A routine has been written utilizing the new software template. The subroutine is currently under external review. Principal contributors to this effort are B. Luzum and B. Stetzler.

1.7 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, *Geophys. Res. Lett.* 31, 2004) and a new mapping function, both adopted by the ILRS as of 1 January 2007. For radio techniques, since the recommended 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., *J. Geophys. Res.* 111, 2006) is now the recommended mapping function, which requires input coefficients determined from numeric weather model. For users not needing the highest accuracy, the GMF (Boehm et al., *Geophys. Res. Lett.* 33, 2006), which uses standard input coefficients, is provided. Principal contributors to this effort are J. Boehm, G. Hulley, A. Niell, E. Pavlis and J. Ray.

1.8 Ionospheric models for radio techniques

A new section regarding ionospheric models for radio techniques, including higher order terms, is under way. Principal contributors to this effort are M. Pajares and A. Krankowski.

2. Conventions Workshop

The IERS Conventions Workshop was held in anticipation of the upcoming new registered edition of the IERS Conventions. The workshop was organized to discuss relevant models for inclusion in the Conventions, to determine milestones for achieving the next registered edition, and to discuss long-term technical and institutional issues. The major results of the workshop include:

- the definition of classes of models and criteria for choosing models,
- how to deal with non-tidal loading effects and displacements,
- atmospheric loading,
- tropospheric model,
- model for ocean tide effects on geopotential,
- model for diurnal and semidiurnal EOP variations, and
- considerations for technique-dependent effects.

It was decided to tentatively schedule the next registered edition for 2009. For an executive summary of the IERS Workshop, see <http://www.bipm.org/utils/en/events/iers/workshop_summary.pdf>.

3. Procedural Topics

In an effort to make the IERS Conventions more efficient to maintain and more user-friendly, a series of procedural changes have been initiated. Below are a list of the procedural changes that were started, on-going or completed in 2007:

3.1 Conventions Update web page updated

The Conventions Update page has been modified to not only include information and links to past updates, but to also provide information and links to planned and possible changes. This provides users insight into the directions that Conventions may be taking in the near future, allowing users to plan better regarding implementation of standardized models. This improvement was made in February 2008.

3.2 Software Standardization

A topic discussed at the Conventions Workshop was the benefit of providing standardized software. In an effort to work toward that goal, a software template was designed based on the IAU Standards of Fundamental Astronomy (SOFA) software template. This template will encourage a structure that will provide consistent information for software users that should improve the utility of the subroutines.

3.3 Plan of Action

A draft plan of action has been created to define the expectations for each chapter in preparation for the next registered edition. It also clearly assigns responsibility for each chapter to a member of the Conventions Center.

4. 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 6 March 2008 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 the previous version of the chapter: Revised section 5.8.3 to make the references for the planetary fundamental arguments clear.

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 (these 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.

Chapter 9: Tropospheric Model

- 28 June 2007: 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.

5. Conventions Center Staff

Felicitas Arias (BIPM)
Brian Luzum (co-director, USNO)
Dennis McCarthy (USNO)
Gérard Petit (co-director, BIPM)
Beth Stetzler (USNO)

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 Center (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 Center. The ICRS Center 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 behavior 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 Center (icrs.pc@obspm.fr).

Maintenance and extension of the ICRF

Some activities of the Paris Observatory IVS Analysis Center (OPAR, Gontier et al., 2006) 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". We have computed the time series of radio source coordinates for approximately 500 radio sources, in parallel to the operational VLBI solutions. Most of the available diurnal VLBI sessions from 1984 involving at least three antennas are processed. The products and related statistics are made available on the OPAR Analysis Center web site <http://ivsopar.obspm.fr> in both ASCII and VOTable format. They are updated quarterly. As a contribution to the second realization of the ICRF, coordinate time series have been investigated to determine a set of sources that could be used to define the axes of the next ICRF with increased accuracy and stability. For this purpose, we developed a simple selection scheme in order to isolate 200 to 300 sources (Gontier & Lambert, 2008). We showed that using the selected sources improves the stability of the ICRF axes by about 25% with respect to the current ICRF.

On-going efforts have been made to identify the various sources of uncertainties in the nutation estimates and to minimize their effects. In this context, we have investigated the contribution of the celestial reference frame instabilities to nutation estimates (Lambert et al., 2008).

In the framework of the validation of individual VLBI references frames, individual celestial reference frames obtained in 2007 by five laboratories have been compared to ICRF-Ext.2 (Fey et al., 2004).

The reference frames analyzed

The solution RSC (AUS) 07 R 01 calculated at Geosciences Australia with the OCCAM 6.2 software is included in this report. The orientation of the celestial frame has been defined by applying a no-net-rotation constraint to the positions of 212 defining sources in ICRF-Ext.2. The a priori models are IERS 2003 for the precession, MHB2000 (Mathews et al., 2002) for the nutation. In this solution troposphere gradients have been adjusted. VLBI observations analyzed span over the period November 1979 – April 2007. Clock offsets, wet delays, gradients and EOP were considered as stochastic parameters with relevant covariance functions. VMF1 mapping function (Boehm & Schuh, 2004) has been applied for the troposphere modeling.

The individual frame RSC (BKGI) 07 R 03 elaborated at the Federal Agency for Cartography and Geodesy and the Geodetic Institute of the University of Bonn (Germany) has been evaluated using CALC 10.0 / SOLVE release 2006.12.15. The celestial reference frame has been oriented by a no-net-rotation constraint imposed to the positions of the 212 defining sources as in ICRF-Ext.1 (IERS 1999). The a priori precession and nutation models are IERS 2003. Troposphere gradients have been adjusted in the solution. The time span of the observations is January 1984 – October 2007. VMF1 mapping function has been applied for the troposphere modeling.

RSC (IAA) 07 R 02 is the extragalactic frame produced by the Institute of Applied Astronomy in Saint Petersburg, Russia with the QUASAR software. The observations range in the period August 1979 – December 2007. The celestial frame has been oriented by a no-net-rotation imposed to the positions of 212 defining sources in ICRF-Ext.2. The a priori precession and nutation models are both IAU 2000. Troposphere gradients have been adjusted in the solution.

The RSC (OPA) 07 R 04 frame was obtained at the Paris Observatory analysis center with the CALC 10.0 / Solve 2006.06.08 software. The a priori models are IERS 2003 for the precession and IAU 2000 for the nutation. A no-net-rotation constraint is applied to the 247 stable sources of Feissel-Vernier et al. (2006). The VLBI observation analyzed span over the period January 1984 – December 2007 and the NMF mapping function has been applied for the troposphere modeling. Troposphere gradients have been adjusted in the solution.

RSC (CGS) 07 R 01 is the extragalactic frame produced by the Space Geodesy Center in Matera, Italy from observations in the period August 1979 – December 2007. The software used is CALC 10.0 / SOLVE release 2006.04.05, revision 2006.04.10. The celestial frame has been oriented by a no-net-rotation imposed to the positions of 199 defining sources in ICRF-Ext.1. The a priori precession and nutation models are both IERS 1996. Troposphere gradients have been adjusted in the solution.

Positions and velocities of stations have been estimated as global parameters for the BKGI, IAA and OPA frames with a no-net-translation and a no-net-rotation constraints applied on 26 VTRF2005 stations for the BKGI, 11 VTRF2005 stations for the IAA, 35 ITRF2000 stations for the OPA and 39 ITRF2000 stations for the CGS solution. Daily station positions are estimated for the AUS frame with a no-net-translation and a no-net-rotation constraints with respect to ITRF2000 applied on a daily basis.

The characteristics of the analyzed frames are given in Table 1. Five categories of sources appear in the table: *defining*, *candidate* and *other* correspond to the classification of ICRF sources (Ma et al., 1998); *new* refers to the sources added in ICRF-Ext.2; *additional* represents sources observed in VLBI programs and not present in ICRF-Ext.2. The values of the median of the coordinate uncertainties indicate that all frames, except AUS (for sources other than *defining*), are of similar quality.

Table 1: Individual VLBI celestial reference frames analyzed. n is the number of sources, m is the median of the coordinate uncertainties. Unit: mas.

Frame	Tot.	Defining		Candidate		Other		New		Additional		dec
	N	n	m	n	m	n	m	n	m	n	m	(°)
RSC (AUS) 07 R 01	1515	210	0.05	259	0.19	4	0.32	100	0.32	942	1.68	-81;+86
RSC (BKGI) 07 R 03	1076	209	0.04	225	0.05	101	0.02	84	0.12	457	0.32	-81;+86
RSC (IAA) 07 R 02	962	212	0.06	282	0.09	102	0.03	109	0.20	257	0.47	-81;+84
RSC (OPA) 07 R 04	535	189	0.07	160	0.06	93	0.03	51	0.13	42	0.14	-81;+84
RSC (CGS) 07 R 01	637	199	0.03	213	0.03	99	0.01	67	0.06	59	0.09	-80;+84

Comparison of individual celestial frames to ICRF-Ext.2

The catalogues listed in Table 1 have been compared to ICRF-Ext.2. A revised algorithm of comparison was used. The coordinate differences between two frames are modeled by a global rotation of the axes, represented by the angles A_1, A_2, A_3, and by a deformation represented by one parameter: dz, which is a bias between the principal plane of the frame relative to that of ICRF-Ext.2. In the fitting used until 2006 slopes in right ascension and declination were modeled; as these deformation parameters proved to be negligible over some years of comparison, they have been removed from the model. Parameter dz is equivalent to the former B_δ.

$$\Delta\alpha = A_1 \operatorname{tg} \delta \cos \alpha + A_2 \operatorname{tg} \delta \sin \alpha - A_3$$

$$\Delta\delta = -A_1 \sin \alpha + A_2 \cos \alpha + dz$$

Under the hypothesis that ICRF-Ext.2 is free from deformations, the systematic effects detected in the comparisons should be interpreted as deformations in the individual frames. Defining sources common to each individual frame and ICRF-Ext.2 have been used for the comparisons. The four parameters have been evaluated by a weighted least squares fit; the equations have been weighted using the inverse of the variance of the coordinate differences. The fitted parameters allow the transformation of coordinates in the individual frames into ICRS.

Results

The results of the comparisons are shown in Table 2 for the values of the transformation parameters and in Figure 1 for the distribution of the postfit residuals.

Table 2: Transformation parameters between individual catalogues and ICRF-Ext.2. Here, N stands for the number of ICRF defining sources used for fitting the parameters. Unit: µas.

Frame	N	A_1	A_2	A_3	dz
RSC (AUS) 07 R 01	210	38 ± 58	61 ± 58	–31 ± 62	81 ± 51
RSC (BKGI) 07 R 03	209	0 ± 17	–25 ± 17	–5 ± 18	–28 ± 15
RSC (IAA) 07 R 02	212	–24 ± 19	–40 ± 19	–5 ± 10	–14 ± 17
RSC (OPA) 07 R 04	189	–35 ± 21	–11 ± 21	–14 ± 22	–15 ±18
RSC (CGS) 07 R 01	199	28 ± 22	–23 ± 21	3 ± 22	–11 ± 19

The values of the angles A_1, A_2, A_3 in Table 2 show that the individual reference frames realize the axes of the ICRF better than 40 µas, and that they are consistent at the level of their uncertainties. These uncertainties indicate that, after rotation, the inconsistency between the directions of the axes is at most 22 µas, with the exception of the AUS solution. The dz parameter quantifies the bias between the principal plane of each individual frames and that of the ICRS. For the solutions computed by AUS and BKGI, the biases are significant. In contrast, the principal planes of the OPA, CGS, and IAA frames are aligned to that of ICRS at the level of 20 µas.

Investigation of future realizations of the ICRS

Involvement by ICRS Center personnel in the celestial reference frame VLBI program continued in 2007, 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 cooperation with the International VLBI Service for Geodesy and Astrometry (IVS), a total of 17 VLBI experiments specifically dedicated to astrometric observations of

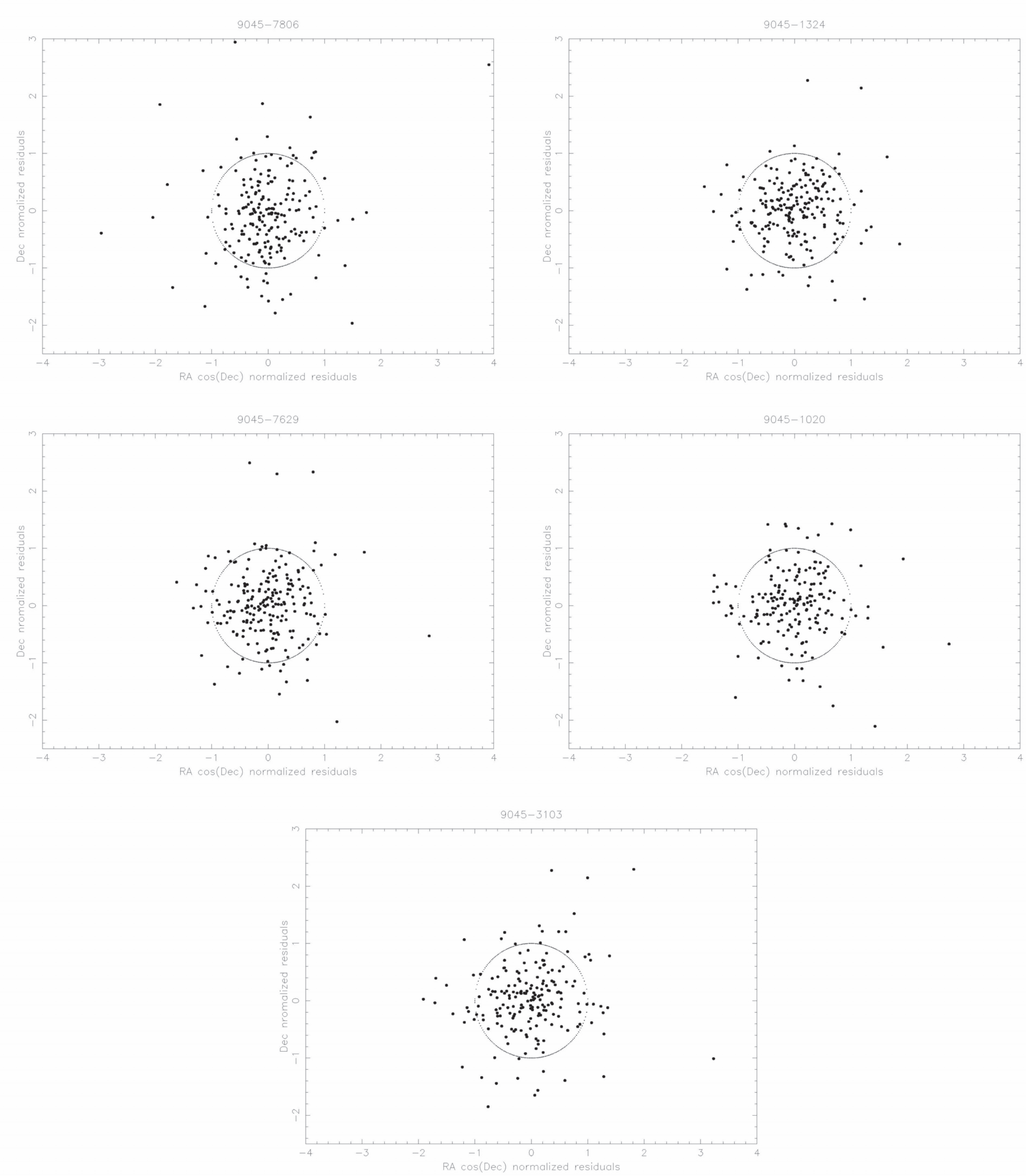

Fig. 1: Normalized residuals (ratio of the postfit residual to the uncertainty of the coordinate difference between frames). 7806: RSC (AUS) 07 R 01; 1324: RSC (BKG) 07 R 03; 7629: RSC (IAA) 07 R 02; 1020: RSC (OPA) 07 R 04; 3103: RSC (GSC) 07 R 01.

southern hemisphere celestial reference frame sources were scheduled and analyzed. The USNO and the Australia Telescope National Facility (ATNF) continue a collaborative program of VLBI research on 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. One celestial reference frame experiment, CRF-S11, was scheduled with antennas at Hobart, Australia, Hartebeesthoek, South Africa and the 70 meter Deep Space Network antenna at Tidbinbilla, Australia. In the Northern Hemisphere a major source of VLBI data continues to be the VLBA RDV series of experiments, which consist of observations of International Celestial Reference Frame (ICRF) sources at radio frequencies of 2.3 GHz and 8.4 GHz using the Very Long Baseline Array (VLBA), together with up to 10 geodetic antennas. These VLBA RDV observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames. During calendar year 2007, six VLBA RDV experiments were observed and images from four VLBA RDV experiments were added to the USNO Radio Reference Frame Image Database (RRFID). In addition VLBA observations and analysis to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2007. 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. Work on several refereed Journal articles presenting the results of the high frequency reference frame observations was initiated.

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 2007, 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 micro-satellite 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 2007 ICRS Center personnel continued design and risk reductions activities for the J-MAPS program, and began planning for execution of the program funding anticipated to begin in April 2008. A symmetric optical design was completed, and adopted as the J-MAPS program baseline. Detector development progressed (Dorland et al., 2007).

Monitor source structure to assess astrometric quality

VLBA RDV Observations and Analysis

As discussed above, observations of International Celestial Reference Frame (ICRF) sources at radio frequencies of 2.3 GHz and 8.4 GHz using the Very Long Baseline Array (VLBA), together with up to 10 geodetic antennas, continued in 2007. 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 2007, six VLBA RDV experiments were observed and images from four VLBA RDV experiments (RDV28, RDV61, RDV63 and RDV65) were added to the USNO Radio Reference Frame Image Database (RRFID) including images of 118 sources not previously imaged.

VLBA High Frequency Reference Frame

As also discussed above, VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2007. 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 2007, one VLBA high frequency experiments (BL122D) was calibrated, imaged and added to the Radio Reference Frame Image Database including images of 4 sources not previously imaged.

Several global VLBI astrometric solutions were performed using the 10 K-band VLBA experiments recorded between 2002 and 2007 in order to assess the quality of a potential high-frequency celestial reference frame. A global solution including 266 sources having three or more group delay measurements was produced. For the 191 sources with 100 or more group delays, the mean (median) formal position uncertainties were 0.07 (0.06) mas in right ascension and 0.13 (0.11) in declination. To assess the stability of the astrometric positions over time, five additional solutions were performed including the 88 sources observed in 5 or more VLBA sessions. For each solution approximately 1/5 of the sources were treated as local or "arc" parameters (i.e. a position was determined for each epoch in which the source was observed). Mean (median) weighted root-mean-square position variations were found to be 0.16 (0.13) mas in right ascension and 0.32 (0.26) mas in declination.

ICRF Maintenance in the Southern Hemisphere

In cooperation with the International VLBI Service for Geodesy and Astrometry (IVS), a total of 17 VLBI experiments specifically dedicated to astrometric observations of southern hemisphere celestial reference frame sources were scheduled and analyzed.

The USNO and the Australia Telescope National Facility (ATNF) continue a collaborative program of VLBI research on 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. One celestial reference frame experiment, CRF-S11, was scheduled with antennas at Hobart, Australia, Hartebeesthoek, South Africa and the 70-meter Deep Space Network antenna at Tidbinbilla, Australia.

A program to monitor the structure of quasars south of declination –30 degrees that are either known to be gamma-ray loud or are expected to be gamma-ray loud was initiated. The program, called TANAMI (Tracking Active galactic Nuclei with Australia Milliarcsecond Interferometry), will observe a sample of about 44 quasars at 8 GHz and 24 GHz bands, with half of the sample observed every two months. The first epoch of observations were scheduled and observed.

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 4980 Very Long Baseline Array (VLBA) images (a 20% increase over the previous year) of 636 sources (a 23% increase over the previous year) at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 1339 images (a 16% increase over the previous year) of 270 sources (a 1% increase over the previous year) 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 (2007) 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 link to radio frame sources, URAT and J-MAPS.

Software development for the pixel re-reduction of the USNO CCD Astrograph Catalog (UCAC) project was completed and 4 image profile fit models will be used for final reductions. The goal is to improve completeness, astrometric and photometric accuracy significantly over the UCAC2 release. A status report on UCAC and URAT was given at the IAU Symposium 248 in Shanghai (Zacharias, 2008).

As part of the UCAC project early epoch photographic plates were measured on the StarScan machine at USNO. Astrometric reductions were completed of about 5000 plates from the AGK2, Hamburg Zone Astrograph and USNO Twin Astrograph (Black Birch, New Zealand) programs (Zacharias et al., 2008).

The Southern Proper Motion (SPM) pixel data from Precision Measure Machine (PMM) scans of all applicable plates (Yale, San Juan program) were obtained from the Naval Observatory Flagstaff Station (NOFS) and processed through a modified StarScan pipe-

Fig. 2: USNO astrograph with 10k camera dewar at NOFS (October 2007).

line. Global x,y data were sent to Yale University for further processing to provide better proper motions for UCAC3 stars, particularly those fainter than 14th mag. A similar effort for the Northern Proper Motion (NPM, Lick Observatories) data begun.

Reductions of the deep CCD images taken of extragalactic, compact radio sources during the UCAC project continued, with 4 more observing runs reduced. A status report was presented at the IAU Symp. 248 meeting (Zacharias & Zacharias, 2008).

Monitoring a sample of 12 ICRF 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).

The primary mirror of the USNO Robotic Astrometric Telescope (URAT) was fabricated in 2007, exceeding the requirements. First light for the 10.5k by 10.5k single chip CCD camera was in October 2007 at the USNO astrograph. Although not all of the 16 outputs are working at this best effort research and development device, a prove of concept could be demonstrated including the clocked anti-

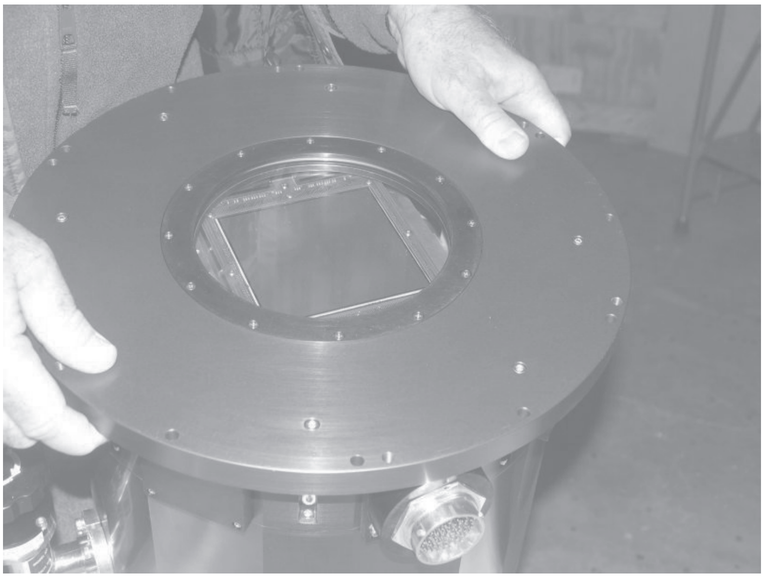

Fig. 3: 10k CCD chip inside dewar for URAT project test observations.

blooming scheme to obtain accurate positions of bright stars (Zacharias et al., 2007). 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. For an update on the URAT project see (Zacharias, 2008).

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. 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 materialized by the dynamical mean ecliptic and equinox (epoch J2000.0) related to the orbit of the Moon through the ephemerides of the semi-analytical lunar solution ELP (Chapront-Touzé M. and Chapront J., 1997). The analysis of the LLR observations enables 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; Chapront J. and Francou G., 2006).

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.

Between 1969 and 2006, over 17000 LLR normal points have been provided by three stations: McDonald (Fort Davis, Texas), Observatoire de la Côte d'Azur (Grasse, France), Haleakala (Maui, Hawaii). In 2007, only McDonald observatory was operational (76 normal points). Comparing our analyses 2008 with those made the last year, there is no change in the post-fit residuals between observed and computed values of the distance station-reflector. There is also no change in the evaluation of these two angles $\varepsilon^{(ICRS)}$ and $\varphi^{(ICRS)}$:

$$\varepsilon^{(ICRS)} = 23°26'21.411" \pm 0.001"$$

$$\varphi^{(ICRS)} = o^{(ICRS)}\gamma_I^{(ICRS)} = -0.055" \pm 0.001"$$

Optical-Radio Offsets at the Milli-arcsecond level

The quasars that form the ICRF are in general radio-compact at the level of a few mas. This would imply radio emission from the base of the radio jet, much close to the accretion disk from where the bulk of the optical emission is expected. As a result the optical to radio centroid offset for the ICRF sources should lie in the sub-mas region. Yet, since earliest astrographic plate observations (Costa & Loyola, 1998) and earliest attempts to global analysis (Silva Neto et al., 2002), up to recent CCD infrared observations (Camargo et al., 2005), some conspicuously large optical-radio offsets are found. Though a large proportion of the offsets found in the earliest works would rather represent bias in the optical stellar catalogues used therein, a statistical proportion remained unexplained. Recent observational efforts focus on the astrometric determination of the optical-radio offset for particular sources, where it may be found at the level of few tens of mas, attainable by carefully planned optical measurements. The Observatorio do Valongo/UFRJ and the Observatorio Nacional/MCT joint teams (J.I.B. Camargo and co-proposers) have been conducting astrometric observations at the SOAR telescope, 4.1m, SOI CCD camera, in the R filter, for a group of selected ICRF quasars. The SNR compound trough multiple short integrations reaches 100, to derive the objects astrometry at the 10 mas level, referred to local stellar catalogues based on the UCAC2 frame.

The ICRS Center is concerned by the continuation of this program with the same team (A.H. Andrei and co-proposers), at the ESO 2.2m telescope, using the WFI CDD camera, and R filter. Similar astrometric precision is derived. In this case the large WFI enables to directly use UCAC2 reference stars by a global reduction strategy. The same Rio de Janeiro and Paris consortium also develops a second strategy, at the same telescope and CCD camera, using R and B filters, and longer exposures that are combined to reach SNR of 1000. In this experiment pairs of quasars for which there are precise VLBI positions have their relative astrometry determined. In this way no external optical catalogue is needed but for a general orientation of the field and to calculate the pixel scale. The relative optical positions can thus be derived to the precision of a few mas and compared to the relative radio position.

These programs aim to contribute to the extension of the ICRF to the optical domain. They can also contribute to the fundamental quasar catalogues of the forthcoming SIM and GAIA missions, as well as to the tying of such frames to the ICRF itself.

First attempts of link between dynamical planetary reference frame and ICRF via VLBI observations of millisecond pulsars

An independent way to establish a link between a dynamical reference frame built on the basis of a planetary ephemeris and the ICRF, is to use VLBI observations of millisecond pulsars combined with pulsar timing.

Coordinates that are determined by using pulsar timing data are expressed in the reference frame of the planetary ephemerides used in the reduction process of the timing observations. We note (α_{TOA}, δ_{TOA}) the pulsar coordinates obtained with pulsar timing. In the other hand, VLBI observations of the same pulsars done by using ICRF sources as calibration are given directly in ICRF. Let us note (α_{VLBI}, δ_{VLBI}) the coordinates of the pulsars obtained with VLBI. The comparisons between these two sets of coordinates (α_{TOA}, δ_{TOA}) and (α_{VLBI}, δ_{VLBI}) give then the rotations between the ICRF and the dynamical reference frame of the planetary reference frame as well as possible secular drift of the dynamical reference frame if the comparisons are extended in time.

As the two methods of observations (pulsar timing and VLBI observations) are both at the mas level accuracy in the position determinations, one can estimate that such algorithm can insure a mas accuracy in the link between ICRF and the dynamical reference frame. Furthermore, as neither the pulsar timing nor the VLBI pulsar observations are included in the fit of the planetary ephemerides to observations, the algorithm of link proposed above enables also a check of the capabilities of extrapolation of the planetary ephemerides.

In 2007–2008, observations of millisecond pulsars are proposed at the European VLBI Network (EVN). Several parameters were used to make a first selection of candidates.

- The pulsar must emit strongly enough to be detectable with VLBI antennas. Usually, the minimal emitted flux of a source observed at 1.4 Ghz is about 5 mJy. This is the limit used in this selection.
- The pulsar has to have a regular timing follow-up in the northern hemisphere (Nançay Radio Telescope).
- As the goal of the VLBI observations of the pulsar is to obtain coordinates expressed directly in ICRF, ICRF sources have to

be in the vicinity of the pulsar. Usually, during VLBI acquisition, the calibration sources have to be less than 5 degrees away from the observed source.

Based on a list of 97 pulsars identified from the NRAO VLA sky survey (NVSS) at 1.4 Ghz (Han & Tian, 1999), we have selected pulsars which emit more than 5 mJy as observed by the NVSS at 1.4 Ghz, and which are also observed by the NRT for timing observations. Moreover they must have in their vicinity (less than 5 degrees away) at least one ICRF-Ext.2 source. With such criteria, we have obtained 18 possible candidates. 10 of them were already observed by the NVSS in a goal of polarization measurements but not for astrometric calibration and 8 other ones were not observed by the NVSS due to scintillations.

Furthermore, for reasons of visibility and to optimize the (U, V) coverage, we limit the candidates to have positive declination in keeping in mind that to optimize the (U, V) coverage, declination must be greater then 20 degrees. 11 pulsars remain with 3 of them having declinations about 10 degrees.

One can find in Table 3 the list of the candidate pulsars (PSR) as well as the ICRF reference sources (J). For PSR, the first column is the official J2000 denomination, the two following columns are the J2000 right ascensions in hours and declinations in degrees. The

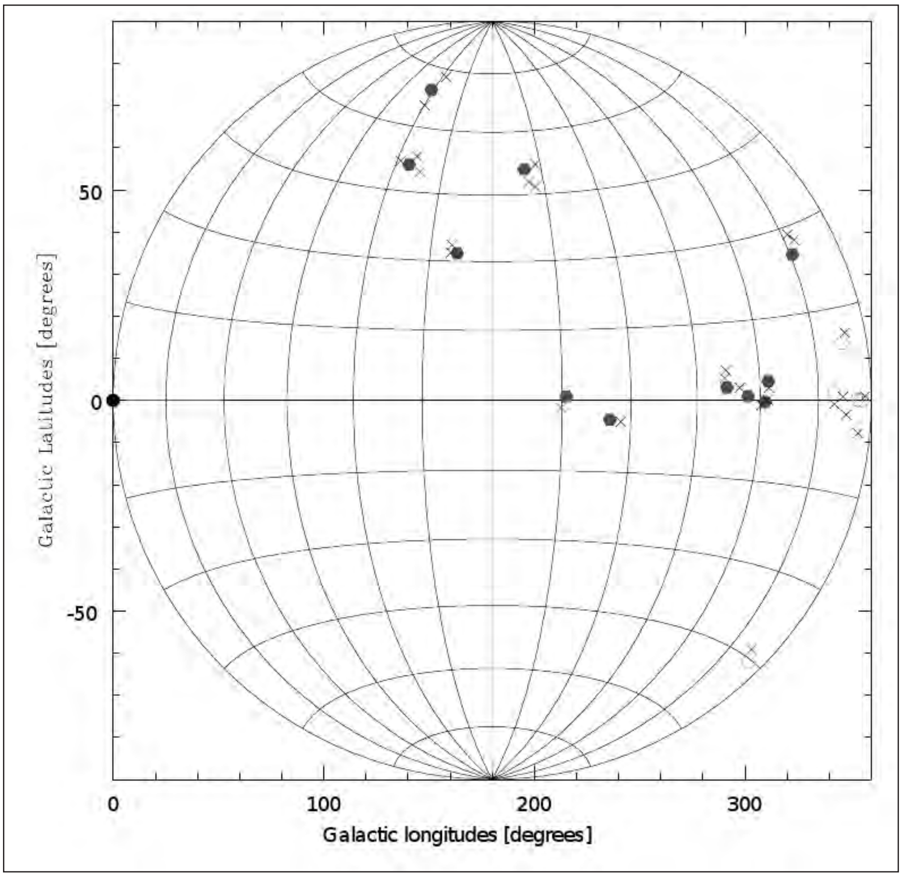

Fig. 4: Aitoff representation of galactic coordinates of VLBI best candidate PSR in red circle, of ICRF reference sources in blue cross and other possible PSR candidates.

Table 3: List of VLBI best candidate pulsars (indicated as PSR) and of ICRF reference sources in their vicinity (indicated as J). On line indicated PSR, the first column gives the official J2000 name of the pulsar, Columns 2 and 3 give respectively the J2000 right ascension and declination. Column 4 gives the flux observed by the NVSS (Han & Tian, 1999). Column 5 indicates if the pulsar was observed by NVSS or by Chatterjee (2004). On line with a first column beginning with a "J", information related to the closest ICRF reference sources are given. The first column give the J2000 ICRF-Ext.2 name of the source, Columns 2 and 3 give respectively the J2000 coordinates, and Column 4 gives the distance in degrees between the ICRF source and the pulsar.

PSR J0139+5814	01 39 19.77	58 14 31.8	4.0 ± 0.4	NVSS/C
J010245.7+582411	01 02 45.762383	+58 24 11.13664	4.799571	
PSR J0358+5413	03 58 53.70	54 13 13.6	10.3 ± 0.5	NVSS
J035929.7+505750	03 59 29.747262	+50 57 50.16150	3.257821	
PSR J0826+2637	08 26 51.31	26 37 25.6	17.1 ± 0.7	NVSS
J083052.0+241059	08 30 52.086185	+24 10 59.82046	2.602711	
J083740.2+245423	08 37 40.245686	+24 54 23.12172	2.979087	
PSR J1012+5307	10 12 33.43	53 07 02.6	4.5 ± 0.4	NVSS/C
J095738.1+552257	09 57 38.184490	+55 22 57.76914	3.142610	
J103507.0+562846	10 35 07.040267	+56 28 46.79733	4.674220	
J095622.6+575355	09 56 22.634451	+57 53 55.90445	5.299584	
PSR J1022+1001	10 22 58.05	10 01 54.0	3.5 ± 0.4	NVSS/C
J102556.2+125349	10 25 56.285332	+12 53 49.02220	2.956259	
J103334.0+071126	10 33 34.024287	+07 11 26.14780	3.864539	
J100741.4+135629	10 07 41.498080	+13 56 29.60093	5.407060	
PSR J1136+1551	11 36 03.30	15 51 00.7	21.2 ± 0.8	NVSS
J112027.8+142054	11 20 27.807260	+14 20 54.99142	4.051844	
J114505.0+193622	11 45 05.009035	+19 36 22.74139	4.326826	
PSR J1713+0747	17 13 49.52	07 47 37.5	8.0 ± 1.4	NVSS/C
J165809.0+074127	16 58 09.011464	+07 41 27.54075	3.884443	
J165833.4+051516	16 58 33.447348	+05 15 16.44446	4.563597	
PSR B1919+21	19 21 44.80	+21 53 01.8	6.0	C
J192559.6+210626	19 25 59.605360	21 6 26.162118	1.15085	
J193124.9+224331	19 31 24.916782	22 43 31.259057	2.10889	
J193510.4+203154	19 35 10.472910	20 31 54.154178	3.00675	
J194606.2+230004	19 46 6.251405	23 0 4.414187	4.99801	
PSR B1937+21	19 39 38.55	21 24 59.1	16.0	C
J192559.6+210626	19 25 59.605360	23 0 4.414187	2.77097	
J193124.9+224331	19 31 24.916782	22 43 31.259057	2.00306	
J193510.4+203154	19 35 10.472910	20 31 54.154178	1.37982	
J194606.2+230004	19 46 6.251405	23 0 4.414187	1.91866	
PSR B1952+29	19 54 22.58	29 23 17.90	8.0	
J195740.5+333827	19 57 40.549919	33 38 27.94333	4.30368	
PSR B2011+38	20 13 10.49	38 45 44.8	6.4	
J195928.3+404402	19 59 28.356628	40 44 02.09695	3.37591	
J200744.9+402948	20 07 44.944838	40 29 48.60402	2.04589	

forth column is the NVSS flux at 1.4 Ghz. The last column indicates if the pulsar was observed in NVSS (NVSS) or by Chatterjee (C). For the ICRF sources, the first column is the official ICRF denomination, the two following columns are the J2000 coordinates in ICRF and the last column is the distance in degrees from the PSR.

The proposal is done on a 18 cm basis, asking for a typical EVN array at 18 cm. As 73% of the sources have a flux smaller than 5 mJy, the technique of phase referencing will be used with an accuracy in the astrometry expected to be better than 10 mas.

One can find on Figure 4 a representation of the spatial distribution of the pulsars as VLBI best candidates as well as their associated ICRF reference sources. One may also found localizations of 5 supplementary candidates which agree with the emitted minimal flux and ICRF sources vicinity criteria but are not optimum in term of EVN visibility.

Link between the ICRF and the dynamical system through close approaches between quasars and planets: application to Jupiter

One of the most important goals still remaining to be done with respect to the ICRF is its link with the dynamical reference frame determined through the time coordinates and the trajectories of moving celestial bodies, such as the Moon, the Sun and the planets. In this chapter, we already have discussed the contribution of the Moon, from the LLR (Lunar laser Ranging) observations. In addition we have also investigated the above link through the close encounters between Jupiter and the quasars for the coming years, focusing on the period involving the future space mission GAIA and evaluating the corrections due to the relativistic deflection of quasars light around Jupiter (Souchay et al., 2007).

Statistically we found a substantial number of close encounters between Jupiter and the quasars recorded by the Véron-Cetty and Véron (2003) catalogue, during the interval 2005–2015. At total 232 close approaches phenomena were detected, with an angular distance not exceeding 10’ both for $\Delta\alpha \cos \delta$ and $\Delta\delta$ (Souchay et al., 2007). These close approaches concern not only Jupiter, whose the angular size as well as the relative important brightness might be a barrier for differential astrometry, but also its satellites trail, whose photocenters are determined with sub-pixel accuracy. Therefore differential determinations of distance between the satellites and the given quasar might be very useful to improve the position of Jupiter in the ICRF.

Moreover we have shown that in the case of grazing phenomena, the order of magnitude of the light deflection related to them is relatively big (16 mas in the best cases) in comparison with the expected GAIA precision in the determination of the coordinates of celestial objects, around 10 μas.

Linking the ICRF to frames at various wavelengths: the construction of the LQAC (Large Quasar Astrometric Catalog)

The link between the ICRF and other frames at various wavelengths 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). Any quasar is likely to be of interest to the densification of the ICRF or the link to the ICRF. Therefore to compile all the presently recorded quasars was one of our leading activities. This work is not so simple as it is supposed to be: the huge and always increasing number of quasars reckoned from various sky surveys and catalogues leads to a large quantity of data which brings various and inhomogeneous information in the fields of astrometry, photometry, radioastronomy and spectroscopy. Moreover the cross-identifications between quasars recorded in two or more catalogues is not straightforward, especially when the quality of determination of the celestial coordinates is not good. These problems were tackled in order to construct a new compilation of quasars, called LQAC (Large Quasar Astrometric Catalog) which gives for each object the equatorial coordinates, multibands photometry radio fluxes, redshift, luminosity distance and absolute magnitudes.

One of the specificity of the LQAC is to give a flag (from “A” to “L”), indicating the presence of each quasar in one of the 12 larger quasar catalogues, 4 ones obtained from VLBI surveys (with a very good astrometry at the level of the sub-millarcsecond), and 8 ones from optical surveys. These catalogues are ranged by decreasing accuracy and are as follows:

[A] ICRF-Ext.2 (radio)
[B] VLBA/VCS (radio)
[C] VLA-0.15 (radio)
[D] JVAS (radio)
[E] SDSS (optical)
[F] 2QZ (optical)
[G] FIRST (radio)
[H] VLA+0.15 (radio)
[I] Hewitt and Burbidge (optical)
[J] 2MASS (infrared)
[K] GSC23 (optical)
[L] B1.0 (optical)
[M] Véron-Cetty and Véron (optical + radio), 2006

Note that the VLA catalogue has been voluntarily divided into two sub-catalogues, respectively with flags “D” and ”H”. The first one has an accuracy a priori better than 0”.15, the second one worse than this value.

Information, when available concern, in addition to the celestial equatorial coordinates with respect to the ICRF, the *u*, *b*, *v*, *g*, *r*, *i*, *z*, *J*, *K* photometry as well as redshift and radio fluxes at 1.4 GHz (20 cm), 2.3 Ghz (13 cm), 5.0 Ghz (6 cm), 8.4 Ghz (3.6 cm), and 24 Ghz (1.2 cm). The small proportion of remaining objects not reckoned in one of the 12 above catalogues are picked up from the Véron-Cetty and Véron (2006) compilation catalogue, with a number (instead of a letter) as a flag, indicating the original catalogue.

Our final LQAC catalogue contains 113 666 quasars, which is 33.4 % bigger than the number of quasars recorded in the last version of the Véron-Cetty and Véron (2006) catalogue, which was the densest compilation of quasars up to now. In the related paper (Souchay et al., 2008) we discuss the external homogeneity of the data by comparing the equatorial coordinates, the redshifts and the magnitudes of objects belonging to two different catalogues.

At last we used up-to-date cosmological parameters as well as recent models for galactic extinction and *K*-correction in order to evaluate at best the absolute magnitudes of the quasars. The cosmological model is based on a Friedmann-Lemaître-Robertson-Walker metric with a curvature of space *k* null, a deceleration parameter q_0 = –0.58 and a Hubble expansion factor H_0 = 72 km s^{-1} Mpc^{-1}. Notice that we evaluated the absolute magnitude of the quasars at two wavelengths, blue one (M_B) and infrared one (*Mi*).

The various steps in the construction of the LQAC are described in detail by Souchay et al. (2008) and the catalogue is already available in ASCII file at <ftp://syrte.obspm.fr/pub/LQAC/LQAC2008.ascii>.

Notice that the LQAC extended results have also been stored in Votable format compatible with Astronomy VO Data Format and VO tools like Aladin, Topcat, Voplot. This catalogue is more complete than the ASCII one. For instance we keep in this database all the original catalogue references and nominal values (with uncertainties), even when they are not unique, for each data field (magnitude, redshift, radioflux) of a given quasar.

Reductions of Mosaic-CCD observations at the CFHT and astrometric follow-up of artificial satellites

The link between the ICRF and the OCRF (Optical Celestial Reference frame) is a major goal in the very near future astrometry. It is also of great interest to link the ICRF with other frames like the dynamical reference frame. In order to achieve these tasks we have begun, since January 2007 to use the data, in FITS format, of the CFHT Legacy Survey (CFHTLS).

In a first step we have used the software provided by TERAPIX (<http://terapix.iap.fr/>), the astronomical data reduction center of the CFHTLS. This software package is mainly composed of three parts: Sextractor (<http://terapix.iap.fr/soft/sextractor>, a program that builds a catalogue of objects from an astronomical image), SCAMP (<http://terapix.iap.fr/rubrique .php?id_rubrique=105>, which reads Sextractor catalogues and computes astrometric and photometric solutions for any arbitrary sequence of FITS images in a completely automatic way) and SWARP (<http://terapix.iap.fr/rubrique.php?id_rubrique=49>, a program that resamples and co-adds together FITS images using any arbitrary astrometric projection defined in the WCS Standard, <http://fits.gsfc.nasa.gov/fits_wcs.html>).

In order to have a step by step control of this software, and to generate our astrometric solutions, we have build our own astrometric reduction software. Despite the fact that it is up to now under construction, it shows that we can obtain astrometric measurements with an uncertainty in the range of 50–100 mas. When the present developments will be achieved we plan to obtain an uncertainty of a few tens of mas or less. This is particularly of interest in the perspective of GAIA (<http://gaia.esa.int/science-e/www/area/index.cfm?fareaid=26>) because the limit magnitude achieve by CFH Telescope can reach V=25 or even V=28–29 in the Deep field programs (<http://terapix.iap.fr/rubrique.php?id_rubrique =108>). In comparison GAIA will achieve at best the 20th magnitude with an accuracy of 0.2 mas.

We are also trying to link together the 36 CCD of the MEGACAM mosaïc (<http://www.cfht.hawaii.edu/Instruments/Imaging/Megacam/>) used in the focal plane of the CFHT (<http://www.cfht.hawaii.edu/>). This specific software will be also useable with other CCD mosaïc like the WFI (<http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/>) of the ESO.

We have also carried out our own observations with the ESO 2.2m telescope, towards some deep fields of quasars. We also plan to regularly observe with the 2.0m telescope of the Observatoire du Pic du Midi (France, <http://bagn.obs-mip.fr/>) and with the 0.60m of the Belogradchik Observatory (Bulgaria, <http://www.astro.bas.bg/~aobel/equipment.html#60cm>). Of course we plan to use the 3.6m CFHT. We have submitted an observation program for the semester 2008A but it has not been retained by the QSO (Queued Service Observation, <http://www.cfht.hawaii.edu/Instruments/Queue/>) team during the phase 2 proposal submission. A new proposal will be submitted for 2008B.

Our under way projects are firstly about WMAP and secondly about the link between the magnitude variations and positions of the quasars in the sky. WMAP is a probe of the NASA that we want to observe to test the "GAIA tracking concept". WMAP is located at the second Earth-Sun Lagrange point L2, about 1.5 million kilometres from Earth, just like GAIA will be once launched in a very near future. WMAP is consequently a reasonable photo-model for the brightness and observability of GAIA. In consequence we have launched a program to observe WMAP with an optical telescope and to see if it is possible to monitor it's position and velocity with an uncertainty of 150 m and 2.5 mm/s respectively. If so, then the scientific goal of GAIA will be achieved, that is to say the correct evaluation of GAIA's position measurements. Some observations of WMAP (<http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=42754>) have already been achieved with WFI at the ESO.

The second project under study i.e. the detection of correlation between the astrometric and photometric variability in quasars, is prepared in collaboration with the Rio observatory, and will be presented during the SAB'08 meeting (<http://sab08.org/>).

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3.5.5 ITRS Centre

This report summarizes the activities of the IERS ITRS Centre during the year 2007.

ITRF2005 users interface

After the release of the ITRF2005, the ITRS Centre assists the users, especially from the GPS community in the best use of the ITRF2005 products. The dedicated web site that was constructed where all the results of the ITRF2005 are available to the users is continuously updated taking into account the user needs: <http://itrf.ensg.ign.fr/ITRF_solutions/2005/>.

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. Guidelines for requesting DOMES numbers are supplied online via the ITRF web site. Most of the new assigned sites and geodetic markers are related to the IGS/GPS network. Currently, 3233 DOMES numbers have been assigned on 2040 distinct sites.

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 their coordinates have been computed. Subsets of points can be selected and their ITRF coordinates can be requested at any epoch in any ITRF version if their coordinates are provided in the requested ITRF version.

The maps of the ITRF networks can be displayed depending of the measurement techniques and of the ITRF versions using a cartographic server. Velocity vectors can be displayed as well as tectonic plates. Site information is available with simple clicks and site selection may be used to request coordinates. 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 online for download. Additional materials are provided to illustrate and better understand ITRF products. ITRF2005 solution is available as well as ITRF2005 combination coordinate residuals and position residual time series per technique. Local ties informa-

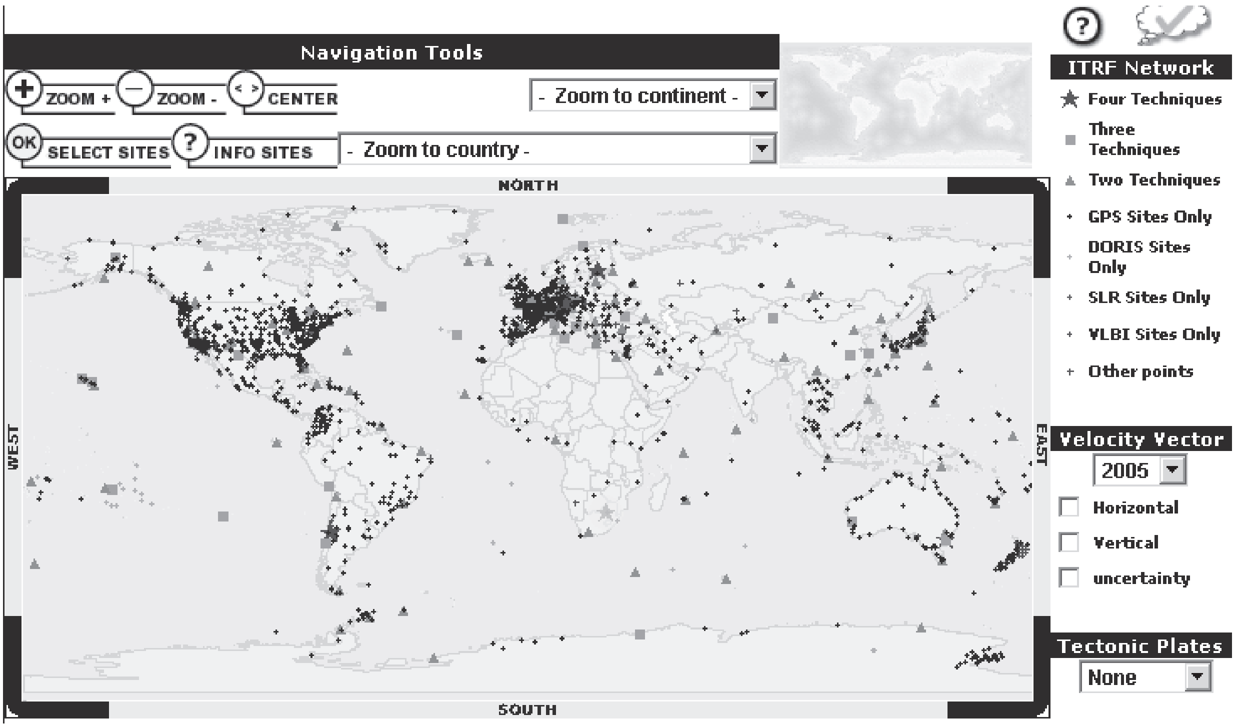

Fig. 1: ITRF web site dynamical map of the IERS network. <http://itrf.ensg.ign.fr>

tion has been updated for ITRF2005 processing and is also available for download in SINEX format or tables.

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) is a product center within the International Earth Rotation and Reference Systems Service. The GGFC supports, facilitates, and provides services and products to the worldwide research community in areas related to the variations in Earth's rotation, its shape, its gravitational field, and geocenter that are caused by mass transport of environmental fluids on its surface (atmosphere, oceans, continental water, etc.) and by the transport of internal fluids (mantle and core).

Eight Special Bureaus (SB) have been established to supply products to support community research. These include: Atmospheres, Oceans, Hydrology, Tides, Mantle, Core, Loading, and Gravity/ Geocenter.

The products provided by the SB's are based on global observational data and/or state-of-the-art model output. The products are available through the individual SB web sites that can be accessed via the GGFC portal(<http://www.ecgs.lu/ggfc/>), which is currently hosted at the European Center for Geodynamics and Seismology .

In some of the SB's, the yearly activity is high because new fluid models and data sets are constantly becoming available. The SB's take these new data sets and convert them into a product required by the research community. The annual activities of these SB's are included here. In other SB's, the fluid models or data sets are well established and upgrades occur only rarely. These SB's do not report annually. However, when a major change does occur, this WILL be documented in the Annual Report.

The importance of the products supporting the analysis of geodetic data is ever increasing. In fact, new products such as global models of tropospheric delays are required. In addition, some products are even being requested in real time. As a result of all these new user requirements, this year we began a process to reorganize the GGFC. The exact form the reorganization will take is still being discussed in the IERS Directing Board. An exact model will most likely be accepted in 2008.

As with every year, I would like to take this opportunity to thank all the volunteers who chair and maintain the respective SB's.

Tonie van Dam, Head GGFC

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. In the second mode, it updates monthly archives of the data on the FTP server at Atmospheric and Environmental Research, Inc. (AER) in Lexington, MA. Access can be obtained through the AER website and by exchange of data through the ftp protocol.

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 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 2007 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). We have also been making arrangements to receive the data from the ECMWF on a regular basis on regular temporal resolution and also on high resolution during an upcoming campaign, the CONT'08 campaign.

Results of the SBA were presented at the European Geosciences Union meeting, the American Geophysical Union meeting, meetings of the Journees de Reference Spatio Temporelles including sessions related to the campaign for prediction of Earth orientation parameters.

Acknowledgments

The U.S. National Science Foundation has supported activities, at AER of the SBA 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

Seven 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);

(5) ECCO_kf049f.oam, a series computed by Gross *et al.* (2005) from the products of a data assimilating model of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2006 at daily intervals;

(6) ECCO_kf066a2.oam & ECCO_kf066a2.chi, a series computed by Gross (2008) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2008 at daily intervals and which is available either as a series of angular momentum values (ECCO_kf066a2.oam) or as a series of effective excitation functions (ECCO_kf066a2.chi); and

(7) ECCO_kf066b.oam & ECCO_kf066b.chi, a series computed by Gross (2008) 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 2008 at daily intervals and which is available either as a series of angular momentum values (ECCO_kf066b.oam) or as a series of effective excitation functions (ECCO_kf066b.chi).

Seven 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 Isopycnal 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;
(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;
(6) ECCO_kf066a2.cm, a series computed by Gross (personal communication, 2008) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2008 at daily intervals; and
(7) ECCO_kf066b.cm, a series computed by Gross (personal communication, 2008) 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 2008 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

No report submitted.

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 February 2008 are also provided in our online data archive (at <http://www.csr.utexas.edu/research/ggfc/>). The NASA GLDAS, CPC LDAS, and GRACE data products are updated on a regular basis.

A near 30 years record (January 1979 to February 2008) of monthly terrestrial water storage (TWS) change derived from GLDAS is newly added to our online data archive. GLDAS is an advanced land surface modeling system jointly developed by scientists at the NASA Goddard Space Flight Center (GSFC) and the NOAA NCEP. GLDAS parameterizes, forces, and constrains sophisticated land surface models with ground and satellite products with the goal of estimating land surface states (e.g., soil moisture and temperature) and fluxes (e.g., evapotranspiration). In this particular simulation, GLDAS drove the Noah land surface model version 2.7.1, with observed precipitation and solar radiation included as inputs. GLDAS estimates are the sum of soil moisture (2 m column depth) and snow water equivalent. Greenland and Antarctica are excluded because the Noah model does not include ice sheet physics. The GLDAS data are provided on 1° x 1° grids and at 3-hourly and monthly intervals (0.25° x 0.25° grids are also available at both 3-hourly and monthly intervals, but are not provided here limited by disk space). Daily average TWS changes 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.

LadWorld is a 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 stream flow, 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. Monthly TWS changes, representing the sum of soil water, snow, and ground water are provided for the period January 1980 to November 2006. Details of the LadWorld models are available at <http://www.gfdl.noaa.gov/~pcm/project/ladworld.htm>.

CPC LDAS is forced by observed precipitation, derived from CPC daily and hourly precipitation analyses, downward solar and long-wave radiation, surface pressure, humidity, 2-m temperature and horizontal wind speed from NCEP reanalysis. The output consists of soil temperature and soil moisture in four layers below the ground. At the surface, it includes all components affecting energy and water mass balance, including snow cover, depth, and albedo. Monthly averaged soil water storage changes are provided on a 1 x 1 degree grid. These data are averaged from the original 0.5 x 0.5 degree grid and converted into NetCDF and standard ASCII format. The data cover the period Jan. 1980 through Dec. 2007. 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 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.

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 com-

Table 1: GGFC SBH Online Data Archive

Parameters	Sources	Information
Water Storage Change From GRACE (New!)	GRACE Release 4 (CSR)	Time Span: Apr. 2002 - Feb. 2008 Sampling Rate: Monthly, 67 Solutions GSM only (GAC not restored) Grid: 1 x 1 Degree Grid Decorrelation + 500 km Gaussian Smoothing Truncation at degree 60
Water Storage Change From GRACE	GRACE Release 1 (CSR)	Time Span: Apr/May 2002 - Jul 2004 Sampling Rate: Monthly, 22 Solutions Grid: 1 x 1 Degree Grid Gaussian Smoothing: 600, 800, 1000 km Truncation at degree 60, No C20
GLDAS Monthly Water Storage (New!)	NASA Global Land Data Assimilation System	Time Span: January 1979 – February 2008 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 - May 31, 2007 Sampling Rate: Daily Grid: 1 x 1 Degree Units: mm of water height
NOAA LadWorld Monthly Water Storage	NOAA LadWorld (Fraser)	Time Span: Jan., 1980 - Nov., 2006 Sampling Rate: Monthly Grid: 1 x 1 Degree Units: mm of water height
CPC Monthly Water Storage	CPC Land Data Assimilation System	Time Span: Jan. 1948 - Dec. 2007 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

mands 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.

In addition to the above numerical models' estimates, we also provide estimates of equivalent surface water storage using GRACE release 4 time-variable gravity observations provided by the GRACE team at the Center for Space Research (CSR), University of Texas at Austin. 67 monthly RL04 GRACE solutions, covering the period April 2002 and February 2008 are used to estimate global surface mass change on a 1 x 1 degree grid. The GRACE spherical harmonics are truncated at degree and order 60, and a decorrelation filter and 500 km Gaussian smoothing are applied.

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

Jianli Chen

Special Bureau for Mantle

The Special Bureau for Mantle provides internet access to contemporary forward model output for glacial isostatic adjustment (GIA). It is possible that internal buoyant instabilities in the mantle can drive an observable time-variation in the external gravitational field, quantifying such internal material transport with truly reliable data constraints remains highly elusive. GIA models, in contrast, are supported by a plethora of global and regional geological data. The models have widespread acceptance in the geologic, paleoenvironmental and geodetic sciences. At the one cm/yr level, global plate tectonic motions are known to be stable on a 4 million year timescale (DeMets and Wilson, 2008), and therefore, negligibly contribute to the observed secular trends in terrestrial gravity. GIA is the only known source for time-varying global crust-mantle motion involving long wavelength deep-seated mass transport, having both vertical displacement rates at the level of cm/yr, and changing with time scales of 100,000 to 1,000 years. Hence, it is this readily modeled phenomenon that has been the main focus of the GGFC Special Bureau for Mantle.

This update to the forward models include two new developments in GIA modeling: (1) A more refined Southern Hemispheric model, due primarily to the larger number of regional constraints can now be brought to bear (e.g., Ivins and James, 2004; 2005; Makintosh et al., 2007; Glasser et al. 2008) and that are now incorporated into an updated Antarctic plus Patagonia/Tierra del Fuego loading/unloading history; (2) The emergence of a new more sophisticated load/unloading ICE-5G history from the regional geochronologic constraints, such as those of Dyke et al. (2003), and incorporated into a global model by Peltier (2004) and a regional model by Tarasov and Peltier (2004). When these two advancements are then combined with GRACE analyses for secular trends in gravity over North America (Tamisiea et al., 2007; Rangelova and Sideris, 2008; Ivins and Wolf, 2008) and Antarctica (Velicogna and Wahr, 2006; Ramillien et al., 2006) a more virulent package of predictive GIA models for geoid trend emerges. The main new step forward achieved in this new suite of predictive models, now submitted to the GGFC portal, is that they make full advantage of these two improvements in load history, and utilize models of mantle radial structure that are compliant with the most recent: (i) crustal motion data from continuous

GPS observations, (ii) tide-gauge records, (iii) relative sea level data, (iv) absolute gravity observations and (v) GRACE time series. The laterally homogeneous, radially stratified, Maxwell viscoelastic modeling of Wolf et al. (2006) (accounting for constraints i – iv); Kaufmann and Lambeck (2002) (accounting for constraints i – iv, and true polar wander, using an alternative, but well-refined global load history, RSES); Paulson et al. (2007) (accounting for constraints iii and v and using ICE5G); Tamisiea et al. (2007) (accounting for constraints from iv – v, using ICE5G and additionally modeling the spatial form of the free air gravity anomaly field proximal to Hudson Bay and environs). Hereafter, the models are referred to as: WKWZ, KL02, PZW and TMD, respectively. The user may explore three variants of the first model, and two of the 2nd and 4th, thus, allowing for 8 model predictions in all. It is assumed that the user of these model output data are capable geodesists with an interest in using the GIA models for either model-corrective or purely exploratory science goals. Consequently, the time-rate of change of normalized real Stokes coefficients are supplied, beginning with the degree 2 term, up to and including l, m = 256. Although this is much higher than for GRACE analysis, where in truncation for secularly varying field should truncate well below degree and order 90. The models are run in a manner that forces mass conservation between continent and oceans throughout.

The models are simple, in that the Earth is assumed incompressible, has creep specified by linear viscoelasticity of relaxing type and the mantle-crust consists of only 4 layers; a lithosphere of thickness, h_e, rigidities μ_i, densities, ρ_i, and a density stratified inviscid core lacking solid inner core, wherein the values are set to averages from PREM, with the constraint that density jump at the core mantle boundary (CMB), the gravitational acceleration at the CMB are identical to that specified in PREM, along with the mean surface gravity of the Earth. Four main parameters are varied among the 8 models: h_e, the mantle viscosity below the lithosphere, η_{UM}, and the viscosity of two additional layers: one above the CMB, $\eta^{(1)}_{LM}$, possibly characterizing the creep strength of the post-perovskite phase of the deepest mantle (when the zone has a relatively moderate thickness of 650 km), and one additional viscosity value, $\eta^{(2)}_{LM}$, characterizing the creep strength at mid mantle depths, the top part of the lower mantle, a zone just above which slabs often are seen to lie horizontally in tomographic imaging (e.g., Huang and Zhao, 2006).

Maps of Secular Time-Rate of Change in Geoid

The 8 model predictions are shown in pairs to highlight some of the salient differences in the predictions. In Figure 1 two variants of the KL02 models are shown. (At the top of the figure Earth rheological parameters of the models are given, with red and green lettering representing values for the top and bottom maps, respectively. All maps are geoid rate in mm/yr.) A noteworthy feature is shown in the lower frame of Figure 1; the smallest prediction of geoid variability over the continents in the Northern Hemisphere, this due to the small value of the upper and deepest mantle viscosity that is assumed. Note the lack of suppressed prediction in the Southern Hemisphere, this due to the younger history of Antarctic deglaciation in IJ05. Also note in the lower frame of Figure 1, that the model resolves youthful peculiarities of the load history in southwest Greenland, with the prediction here of negative rate of surface geoid change: a feature that could mimic ice mass loss. It appears in no other Earth structure models in the suite. The effect of the most radical variability in viscosity (confined to the deepest mantle) is shown in Figure 2 for the WKWZ series of models, which relied on the ICE-3G load model (not assumed here) and used data especially sensitive to the upper half of the mantle.

Also of notable contrast is when acceptable Earth structure is derived from different data, and different starting ice load histories; giving, in the end, remarkably similar present-day geoid rate predictions. Such is the case for contrasting WKWZ and PZW models shown in Figure 3. In Figure 4 two predictions for two Earth rheological structures are shown. The two structures assumed are both found acceptable using GRACE trends in North America in the TMD series. The dual (or 'degenerate') solutions are classic in GIA studies. The 'harder' deep mantle viscosity case (TMD2 at the top frame) shows muted amplitudes interior to the continent of Antarctica relative to TMD1 (bottom frame), while more robust responses occur in the oceanic Southern Hemisphere in TMD2, due to the longer relaxation times and lower wave number responses of the lower mantle in the later model. Note in Figure 4, in contrast however, how similar the predictions are within continental Canada.

Additional Notes on the Hybrid Load Model Assumed

The main advantage of using these GIA predictions offered at the GGFC Special Bureau for Mantle web site is that there exists a more appropriate balance of glacial loading/unloading between Southern and Northern Hemispheres in the models, accounting for ICE5G and IJ05, and Patagonian loads simultaneously.

The load assumes an Antarctic, Antarctic Peninsula + Patagonian load from the Southern Hemisphere that contribute a total of 10.36 meters of equivalent eustatic sea level rise since 21 kyr BP. With the exception of additional mass that correspond to small and distributed ice masses in the far eastern parts of Siberia and Kamchatka, which amount to less than 0.3 meters of equivalent eustatic sea level rise since last glacial maximum (LGM), the Northern Hemispheric part of the ice load history relies on the chronology and mass distribution of the ICE5G model. However, in order to

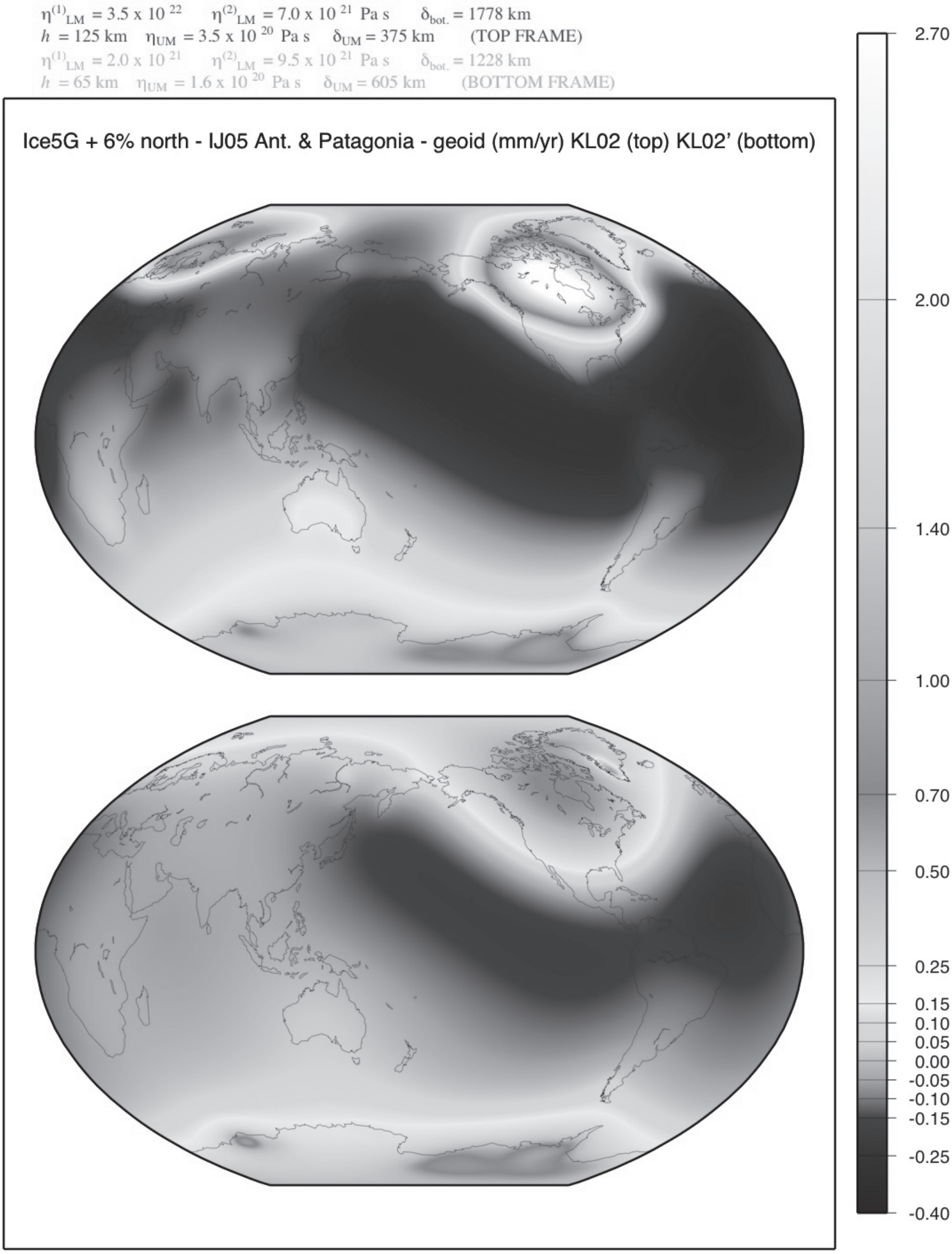

Fig. 1: Variants of the KL02 series, with the lower frame representing a case with the lowest value of upper mantle viscosity represented in the suite of models. It is of interest that Kaufmann and Lambeck (2002) selected the later set (green) parameters when accounting for present-day melting of Antarctica in their modeling scheme.

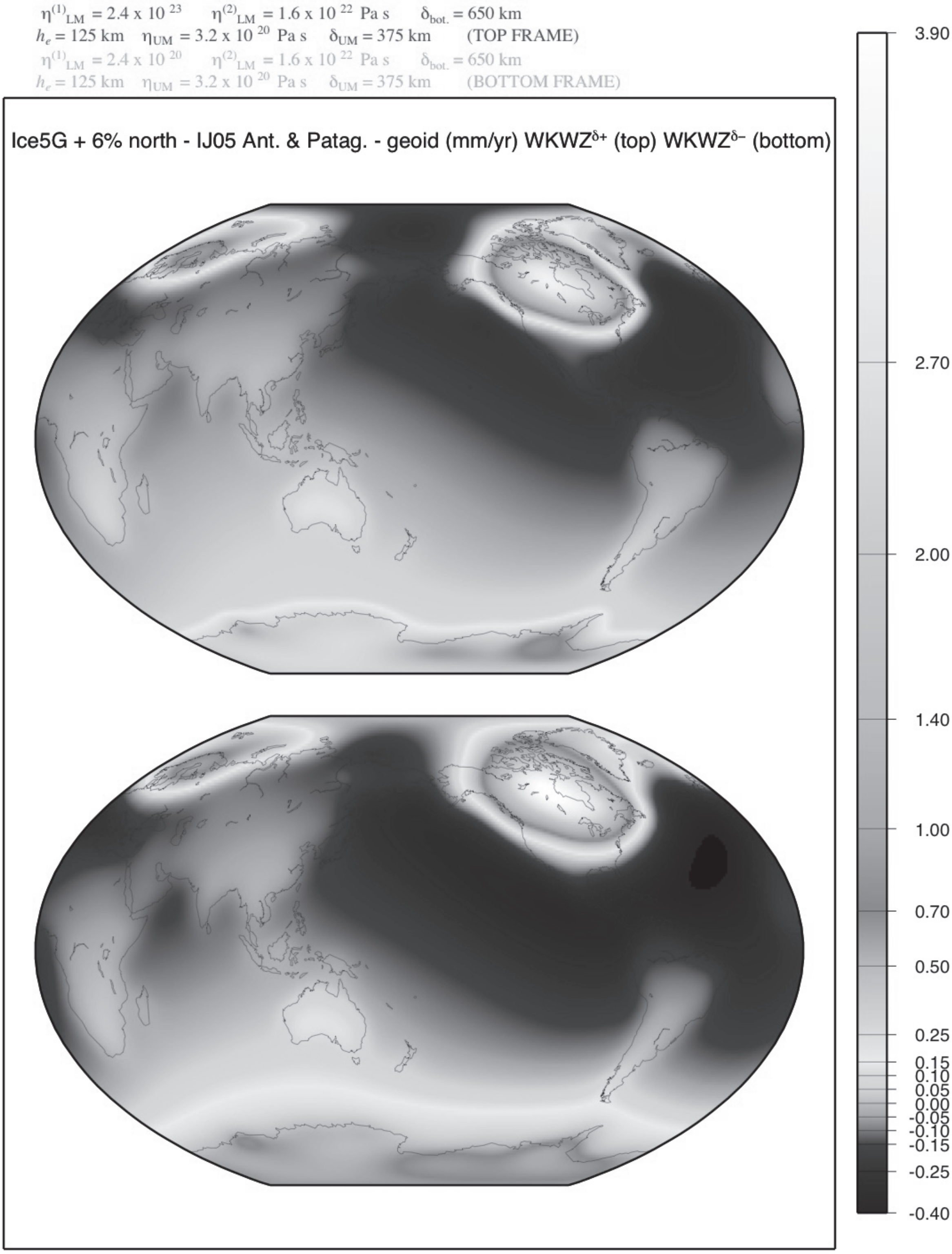

Fig. 2: Variants of the WKWZ series, with only the bottom viscosity of the mantle 650 km above the CMB being varied between top ('hard' post-perovskite) and lower ('soft' post-perovskite) frames. Three orders of magnitude difference in viscosity is assumed between the two predictions. Note, again, the larger prediction for Southern Hemisphere with the lower viscosity, now confined to a 'CMB asthenosphere'. The values of the upper and mid mantle viscosity keep rebounding geoids large in the Northern Hemisphere in both models.

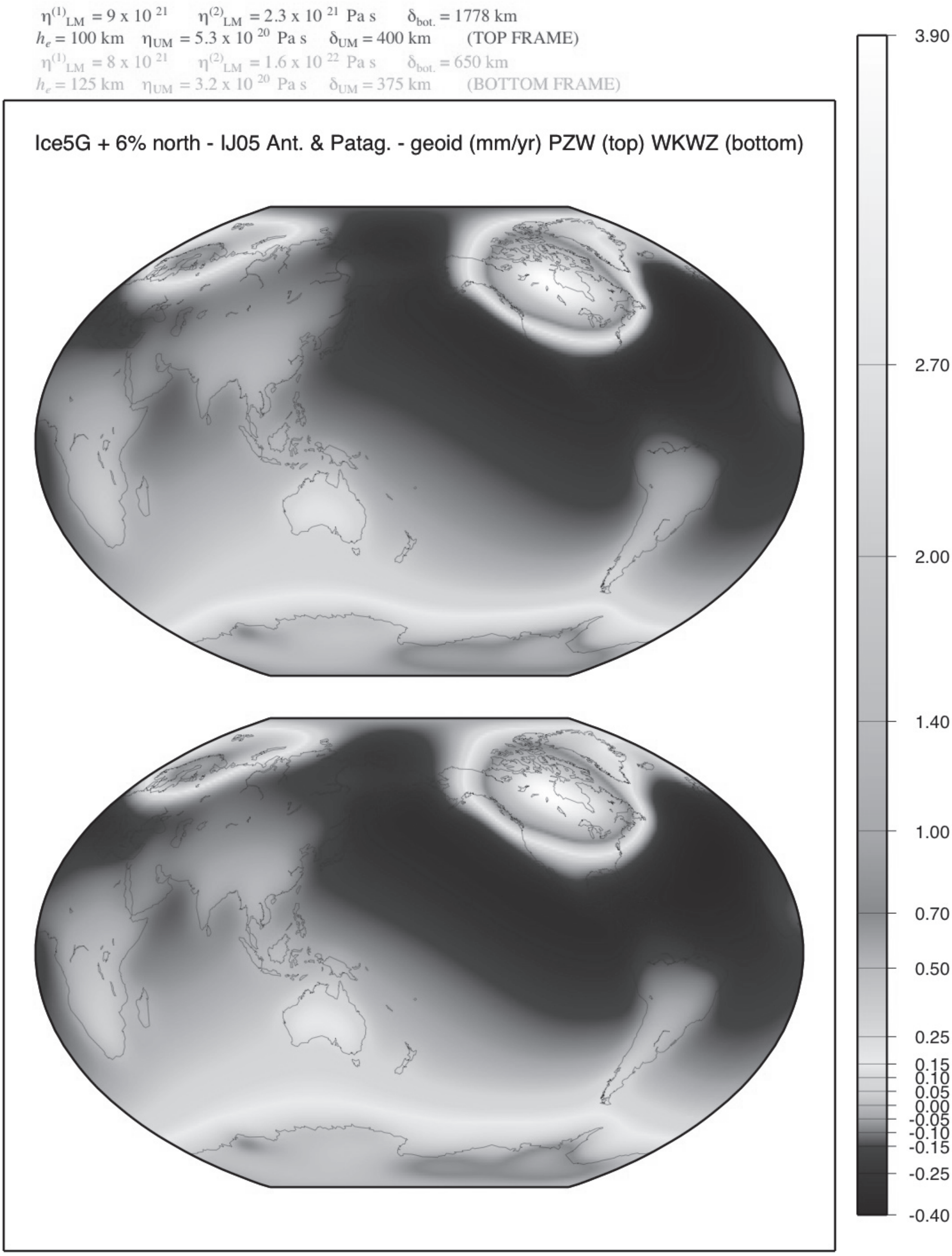

Fig. 3: Contrast between one representative stratified rheologies from the WKWZ series, with one from the PZW series. Note that there is relatively little difference between the model predictions and that the upper and deepest mantle viscosity values are similar. WKWZ and PZW used ICE3G and 5G, respectively. WKWZ used ICE3G plus Hudson Bay proximal constraints, and PZW used ICE5G with GRACE and RSL constraints.

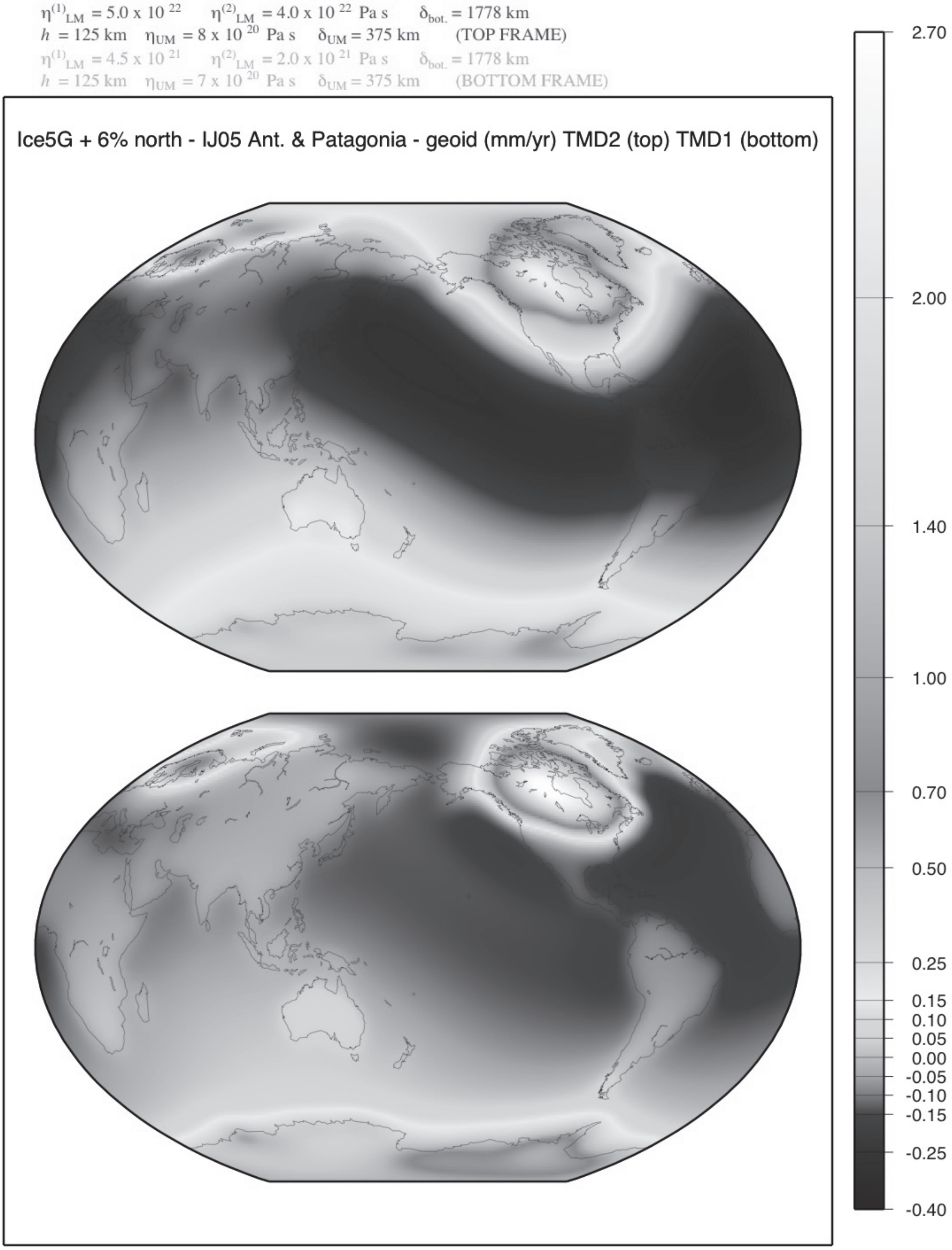

Fig. 4: Contrast between two acceptable solutions determined with the aid of GRACE trend for the Laurentide (TDM series). Note that there are relatively large differences outside of Canada.

merge the IJ05-Patagonian (PAT) models of Ivins and James (2004, 2005) with that of Peltier (2004), and still respect the data constraining the timing of sea-level rise since LGM far from the sites of the deglaciating ice sheets, along with approximate relative amplitudes of ice thicknesses at different geographic locations in the Northern Hemisphere, a simple mass-based scheme was used for merging. The modification to northern components of ICE5G required that they be increased in mass by 6% throughout the ice loading and unloading. This increase compensated for the decrease of the Southern Hemisphere in the IJ05-PAT models, with the total mean LGM sea-level rise amounting to 122.12 meters in the merged global modified IJ05-ICE5G model assumed in all calculations presented here and for those Stokes rate coefficients that are downloadable from the web site. All computations are performed using code developed by Erik R. Ivins at the Jet Propulsion Laboratory, with the exception of an associated Legendre polynomial Clenshaw summation routine kindly provided by Dr. Simon Holmes (Holmes and Featherstone, 2002).

Acknowledgement

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Erik R. Ivins

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

No report submitted.

Special Bureau for Loading

No report submitted.

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

The work of the ITRS Combination Centre at DGFI concentrated in 2007 on analyses of the ITRF computations and comparisons of the different strategies. Another focus was on the handling of non-linear station motions, which is an important issue for future ITRF realizations.

Introduction and overview

The ITRF2005 was officially released by the ITRS Centre in October 2006. At the end of 2006 the ITRF2005 results were analysed and comparisons between the IGN and DGFI solutions were performed (see IERS Annual Report 2006, section 3.6.1.1). A major outcome of the analysis and comparisons was that there is a good agreement between the ITRF2005 solutions of IGN and DGFI after appling similarity transformations. Most of the similarity transformation parameters are small within their standard deviations, except for the scale and its time variation of the SLR network. A significant difference of nearly 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 at the end of 2007. This scale discrepancy was extensively discussed within the IERS and the Techniqes' Services, in particular with the ILRS. As a consequence of the fact, that SLR observations are not consistent with the ITRF2005, it was decided by IGN to provide a second (re-scaled) ITRF2005 for SLR users. Taking into account this situation, it was necessary to perform further investigations on the ITRF computation strategies. It was agreed by IGN and DGFI to identify the differerences in the computation strategies between both ITRS Combination Centres and to perform further test computations to assess the effect of the differences on the combination results.

Comparison of IGN and DGFI combination strategies

The computation 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, velocities and EOPs. The general concept of DGFI is the combination of normal equations and the common adjustment of station positions, velocities and EOP. A comparison of the combination strategies of both ITRS Combination Centers is provided in Tab. 1.

A major difference is that IGN is estimating similarity transformation parameters between epoch solutions as well as between per-technique solutions and the combined frame. DGFI accumulates normal equations without estimating similarity transformations. The estimation of similarity transformation parameters has some prob-

Table 1: Comparison of the combination strategies of IGN and DGFI

	IGN	DGFI
Software	CATREF	DOGS-CS
Time series combination	Stacking of minimum constrained solutions, 7 transformation param.	Accumulation of normal equations, without transformations
Inter-technique combination	Combination of per-technique solutions, 14 transformation param. IGN selected set of local ties	Accumulation of per-technique normal equations, without transform. DGFI selected set of local ties
ITRF2005 datum		
– Origin	SLR	SLR
– Scale	VLBI	VLBI + SLR (weighted mean)
– Rotation	3 NNR conditions w.r.t. ITRF2000	3 NNR conditions w.r.t. ITRF2000
– Rotation rate	3 NNR conditions w.r.t. NUVEL-1A	3 NNR conditions w.r.t. APKIM2005

lems: (1) terrestrial networks in different epochs are not geometrically similar at the accuracy-level of the station coordinates (mm) due to irregular (crustal) deformations; (2) if the entire reference frame (station network) is moving with respect to the given datum, a similarity transformation from the new to the old positions by parameter estimation changes the datum and thus violates the definition of the reference system; (3) all common motions of the stations of the reference network are transformed into the similarity parameters (shift of origin, change of orientation, scale factor). According to the ITRS definition, the datum parameters of the terrestrial reference system shall be fixed in the geocenter, and coordinate changes caused by the station movements must go to the individual station coordinates and not to the datum.

Effect of co-location sites and handling of local ties

The selection and the weighting of local tie information is a critical issue for the combination of different space techniques, since the distribution of “good” co-location sites is relatively sparse (see Fig. 1). A “good” co-location site means, that the differences between the local tie measurements and the space geodetic solutions are relatively small (below 15 mm).

Co-location sites between SLR and GPS

The geographical distribution of SLR tracking stations is in particular problematic in the southern hemisphere. There are 8 co-location sites between SLR and GPS. Fig. 2 shows the observation statistics of these sites. Among them are two stations with very few SLR data (Easter Island and Conception), and Arequipa, which has been affected by post-seismic deformation after the earthquakes in June, 2001. Tab. 2 shows the different sets of co-location sites used by IGN and DGFI.

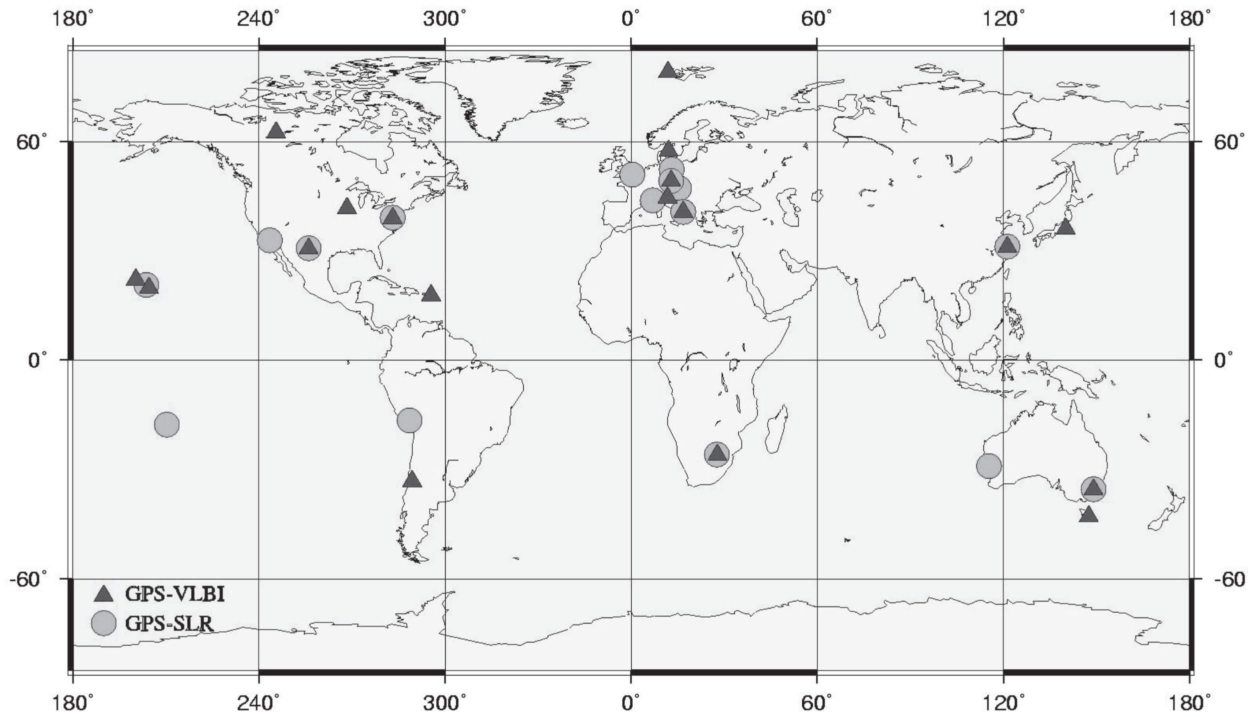

Fig. 1: Distribution of "good" co-location sites between GPS, SLR and VLBI

We investigated the effect of a different local tie selection on the combination results by means of similarity transformations. We performed two solutions with different sets of co-location sites. As shown in Tab. 3 there is an impact of almost 1 ppb on the scale difference between SLR and VLBI, if different sets of local ties are selected. However, taking into account the standard deviations for the scale offsets and time derivatives, the observed differences are not significant. Furthermore, the results depend on the similarity transformations.

Table 2: SLR and GPS co-location sites in the southern hemisphere.

Site name	**DGFI**	**IGN**
Harthebeesthoek	Used	Used
Easter Island	Not used	Used
Arequipa	Used	Used
Conception	Not used	Used
Mt. Stromlo	Used	Down-weighted
Orroral / Tidbinbilla	Used	Down-weighted
Yaragadee	Used	Down-weighted
Tahiti / Pamatai	Used	Down-weighted

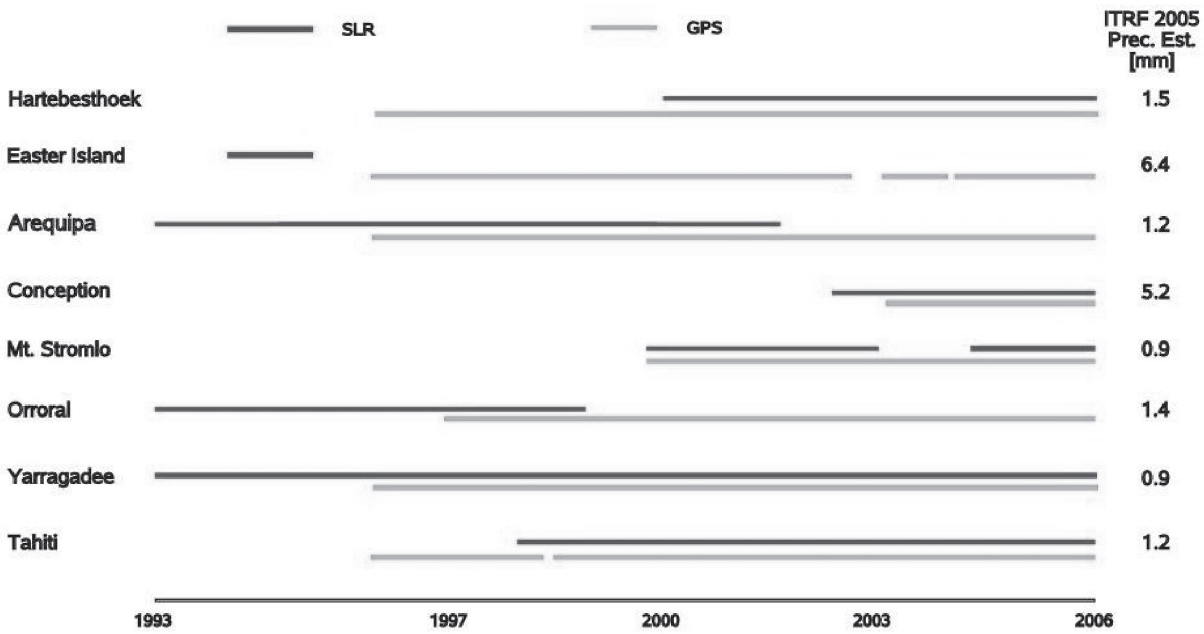

Fig. 2: Observation periods for SLR and GPS co-location sites in the southern hemisphere.

Handling of non-linear station motions

From the time series analysis of the ITRF2005 data it was found, that for most of the stations seasonal signals with amplitudes up to 2 cm are visible, especially in the height component (see Fig. 3 as an example). These seasonal signals may be caused by atmospheric and hydrological loading effects, which are presently not reduced from the original observations. In other cases, also instrumentation effects (rather than geophysical ones) may be responsible for the observed signals.

Deficiencies regarding the current reference frame computations are that the temporal variations of station positions are described only by constant velocities. Deviations of the station motions from a linear model (e.g., seasonal variations) will produce errors in the combination results. In particular for stations with relatively short observation time spans (i.e., < 2 years) seasonal variations will

Table 3: Scale differences between SLR and VLBI observations obtained from two solutions. Solution 1 refers to the local tie selection used by DGFI, and solution 2 to the IGN selection (see Tab. 2).

Solution type	Δ Scale offset [ppb]	Δ Scale rate [ppb/yr]
Solution 1	0.26 ± 0.41	0.03 ± 0.09
Solution 2	1.05 ± 0.44	0.11 ± 0.10

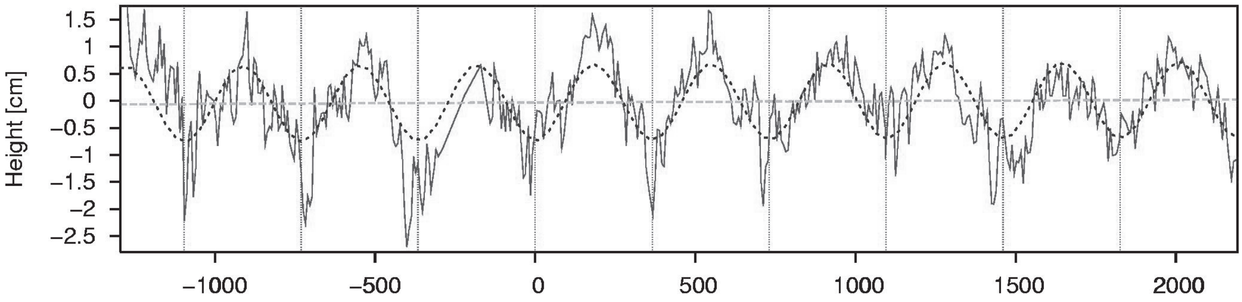

Fig. 3: Seasonal variations for the height component for the GPS station in Irkutsk, Siberia. The time is given in Julian Days (w.r.t. 1.1.2000) from 1996.5 until the end of 2005.

affect the velocity estimations. The alignment of epoch solutions to a reference frame with positions and constant velocities is also affected by non-linear station motions. The shape of these non-linear motions differs between stations. Fig. 4 shows two examples for the mean average shape of such annual variations.

While the Brasilia time series clearly shows a maximum and a minimum, Ankara has not a clear minimum. The averaged annual motions of both stations can be rather well mathematically represented by sine/cosine annual and semi-annual functions. The computation of a mean (averaged) annual motion is problematic, in particular if the seasonal variations are different over the observation time span. It is also clear, that the additional parameters will affect the stability of the solution, which is in particular a problem for stations with rather short observation time spans. Thus, the handling of seasonal variations in station positions is a challenge for future ITRF computations.

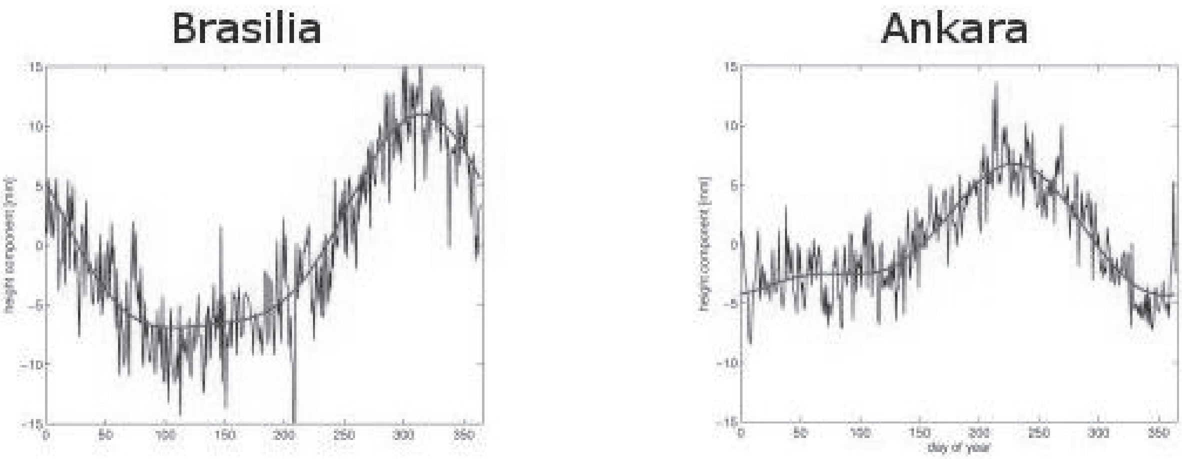

Fig. 4: Shape of the "averaged" annual signal for two ITRF2005 stations. The fitted curve represents the mathematical approximation by annual and semi-annual sine/cosine functions.

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Detlef Angermann, Hermann Drewes, Michael Gerstl,
Barbara Meisel, Manuela Seitz

3.6.1.2 Institut Géographique National (IGN)

The IGN ITRS Combination Centre concentrated its activity during the year 2007 on the analysis of new, post ITRF2005 data. More specifically two main analyses were performed:

- Assessment of the IVS VLBI scale behaviour using new reprocessed 24-session solutions where the mean pole tide correction was applied;
- Assessment of the quality of local ties in an ITRF-like combination.

Assessment of IVS VLBI and ILRS SLR scales with respect to ITRF2005

After the release of the ITRF2005 it was discovered that the IVS VLBI solutions included in the ITRF2005 construction did not include the mean pole tide correction as recommended by the IERS Conventions 2003. This correction seems to produce a constant offset of 0.5 ppb on the VLBI TRF scale. The IVS generated a new VLBI time series of 24-hour sessions that include the mean pole tide correction. This new series was analysed by the usual stacking procedure. Figure 1 illustrates the IVS VLBI scale behaviour over time with respect to ITRF2005 showing clearly the 0.5 ppb offset. We note the poor VLBI scale estimate in the early dates, whereas it stabilizes after 1988. These new results demonstrate that the scales of IVS VLBI and ILRS SLR solutions included in the

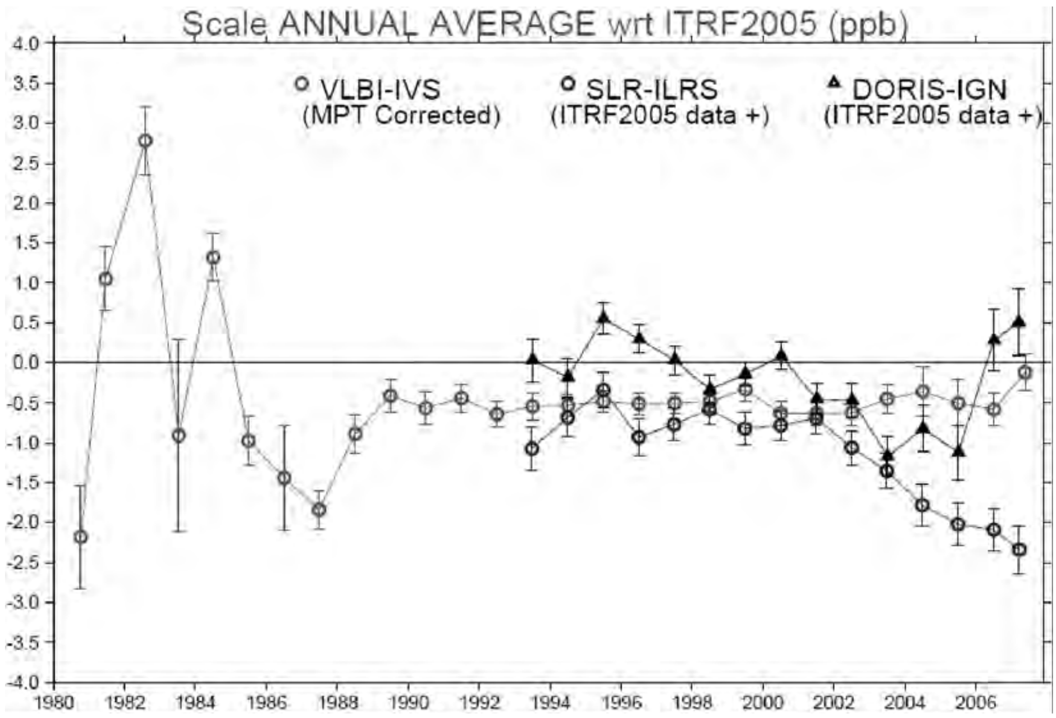


Fig. 1: IVS (mean pole tide correction applied), ILRS (ITRF2005 augmented by recent data) and DORIS-IGN (ITRF2005 augmented by recent data) scale annual averaged variations with respect to ITRF2005.

ITRF2005 combination could not be equal. In addition, data supplied for ITRF2005 augmented by recent weekly solutions from ILRS and DORISIGN were also stacked with respect to ITRF2005. The ILRS SLR scale behaviour shown in Figure 1 after or around the year 2002 still exhibits a significant drift which is certainly due to many factors, including the ILRS network changes, the geographic distribution of SLR observations and the range bias effects. From Figure 1, it could easily be seen that fitting a line over the ILRS scale yields a scale bias of about 0.5 ppb at epoch 2000.0 with respect to the new IVS VLBI solution. The ILRS is working on new reprocessed solutions where the range bias corrections have been re-evaluated for all ILRS stations. Figure 1 displays also the DORIS IGN scale behaviour over time which seems to be close to IVS scale, although it is more scattered.

Assessment of the quality of local ties in an ITRF-like combination

In order to evaluate the quality and the impact of local ties in the ITRF combinations, we selected here the most pertinent sites connecting GPS, SLR and VLBI co-located stations. Using the local ties of these co-located stations, we elaborated an ITRF2005-like combination and computed the Weighted Root Mean Scatter of the tie residuals in East, North and Up components. This test combination involves 22 GPS-SLR and 29 GPS-VLBI tie vectors. Note that GPS network enforces the connection between VLBI and SLR,

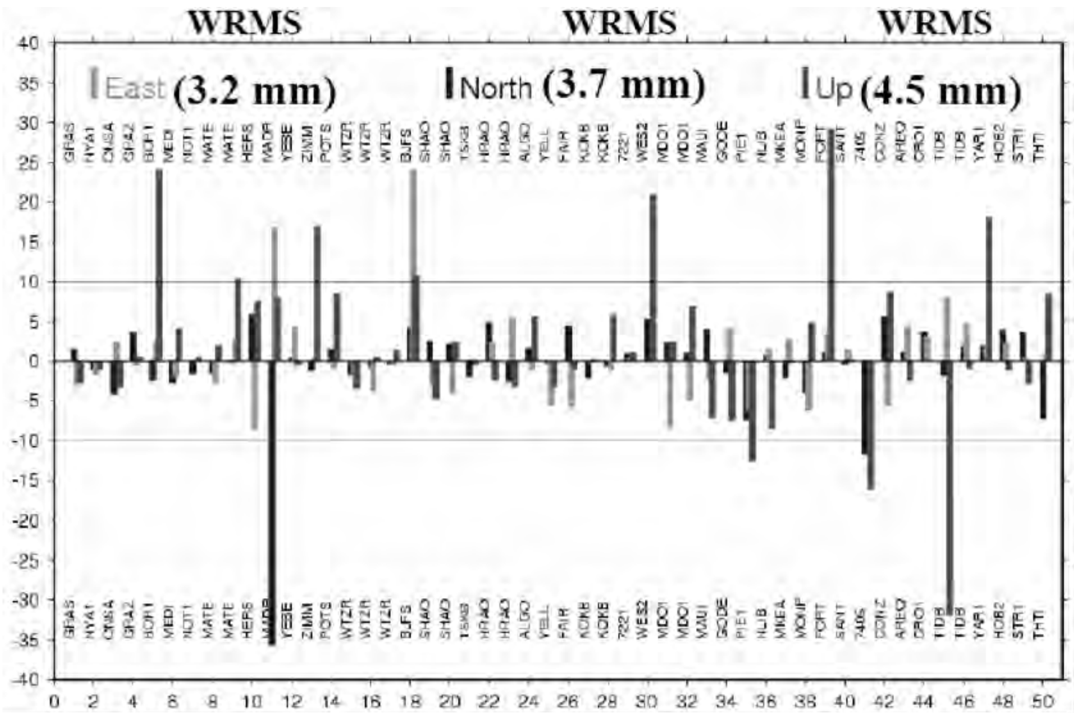


Fig. 2: Local tie residuals as results of an ITRF2005-like combination.

given the fact that there are 7 usable VLBI-SLR co-locations only, a very small number to allow reliable connection between these two techniques. As results of this test combination, Figure 2 illustrates the local tie residuals over the 51 involved sites, indicating that the local tie quality (in terms of WRMS) is at the level of 3–5 mm. Figure 2 exhibits also differences larger than 1 cm for approximately 20 % of the involved co-locations. We recall here that the usual ITRF combination incorporates the local ties with appropriate weighting in order to avoid contaminating the ITRF solution with the tie errors. Note also that the ITRF2005 combination involved about 100 SINEX files of local ties where about 45 % of them are with full variance covariance information.

Zuheir Altamimi, Xavier Collilieux

3.6.2 Combination Research Centres

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

Introduction

The Italian Space Agency's (ASI) Space Geodesy Center (CGS), located near Matera, Italy, 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 IERS Technique Centres (ILRS, IVS, IGS). Since several years, in addition to the single-technique data analysis products provided to ILRS, IVS, IGS, IERS as Analysis Center (AC), ASI-CGS consolidated its role of Combination Center (IERS CRC, ILRS CC).

Combination research activity and products

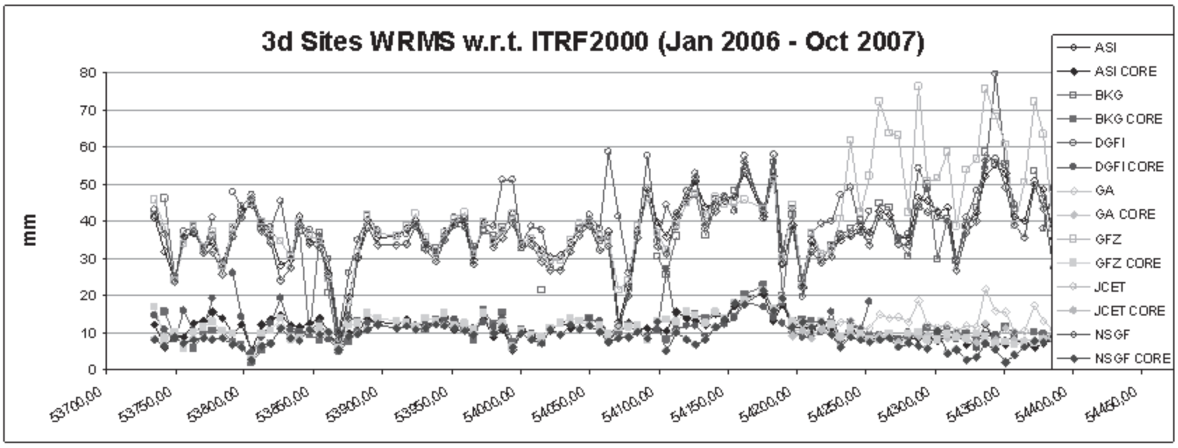
In 2007, the ASI-CGS combination activities, within the ILRS frame, have been focussed on the continuous production of the ILRS official combined weekly solution and its further analysis to prepare the new long term contribution to the ITRF, as well as on the preparation of the experimental combined ILRS orbital products. Moreover, other combination products and value-added geophysical products based on combined geodetic products have been realized, such as the Mediterranean area combined solution and the derivation of excitation functions from the estimated EOP's.

1. ILRS combined SSC/EOP weekly solution

Every Wednesday ASI-CGS issues the weekly ILRS official solution (ILRSA) derived from the combination of individual contributing SLR solutions based on the observations to Lageos 1-2 and Etalon 1-2 satellites, providing them to the users via the CDDIS and EDC archives, and hereto IERS. The combination methodology relies on the direct combination of loose constrained solutions, described in previous IERS reports. In 2007, two more AC's joined the operational weekly production (namely GA, Australia and GRGS, France), raising to eight the number of official ILRS contributing ACs. The ILRSA solutions contain:

1. Weekly coordinates of the worldwide SLR tracking network
2. Daily EOP's (xpole, ypole, LOD), ITRF2000-framed for IERS Bulletin B, ITRF2005-framed since November 2007

The transition to the new ITRF2005 was performed in November 2007 and its impact on the individual and combined solutions has been evaluated on a 2-year long time series (Jan 2006 – Oct 2007), as plotted below. Besides the expected stability for the Core Sites, a significant improvement is reflected also on the non-Core Sites, whose average differences (3d WRMS) with respect to ITRF2005 is limited by 20 cm in the case of the ILRS combined solutions, even if the apparent rising trend proves the need of frequently updating the ITRF.



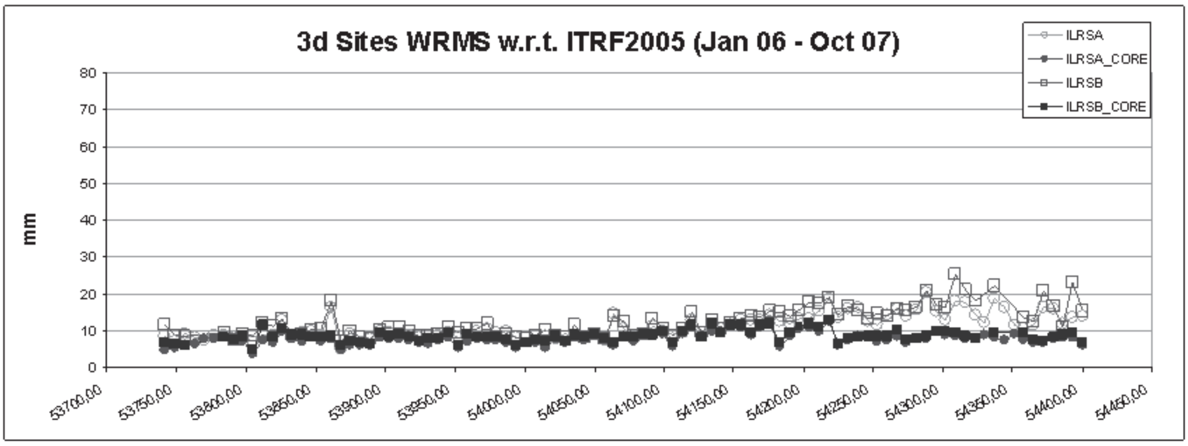


Fig. 1: ILRSA SSC differences w.r.t. ITRF2000 and w.r.t. ITRF2005 (2006–2007)

To prepare the new ILRS contribution to ITRF on a longer data span covering the majority of SLR tracking history, a critical analysis has been started in 2007 on the already submitted SSC time series from the contributing AC's, and guidelines to all AC's in order to properly analyze the older data set have been set up.

2. ILRS combined orbital weekly solution

An experimental ILRS combined orbital product has been under study since September 2007: in principle, it consists in a combined set of state vectors (SV's) for Lageos 1-2, Etalon 1-2 satellites, aligned to the EOP/SSC weekly product.

The ILRS AC's are requested to provide their orbital solutions in the form of SP3-formatted files, in the same ECEF in which they provide their 'loose' SSC/EOP solutions, with SV's every 2 minutes (Lageos) and every 15 minutes (Etalon), covering the whole week, while the ILRS CC's are requested to develop a combination procedure to provide an optimal ILRS combined product. The ASI-CGS combination procedure is under design; basically, it will include an homogeneous transformation of the SP3 files to the ITRF of reference, by using the Helmert parameters estimated in the SSC/EOP combination and reported in the weekly summary report, and a weighted average of the state vectors, based on a unique weekly weight for each AC solution reflecting the agreement of each solution to the reference ITRF (3d WRMS of SSC residuals).

The initial study phase started with the analysis of the available SP3 test files from the ILRS AC's (in 2007, ASI and DGFI only); comparison tests showed, as an initial result, a 5-cm level position agreement in the Lageos 1 orbit after the proper similarity transformation.

Table 1: ILRSA EOP differences w.r.t. IERS C04 for 2006

SAT	X mean std	Y mean std	Z mean std	VX mean std	VY mean std	VZ mean std
LAGEOS 1	**m**	**m**	**m**	**mm/s**	**mm/s**	**mm/s**
6 days	**0,001**	**0,004**	**-0,010**	**-0,001**	**0,001**	**0,001**
	0,053	**0,060**	**0,055**	**0,062**	**0,061**	**0,034**
1 day	**-0,003**	**0,006**	**-0,012**	**0,001**	**0,001**	**-0,001**
	0,035	**0,037**	**0,044**	**0,058**	**0,054**	**0,026**

3. The ASIMed solution

Twice a year, ASI-CGS produces a combined velocity solution for the Mediterranean area using its original single-technique velocity solutions (SLR, VLBI and 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. The semiannual updating profits of the improvements in the velocity field information as geodetic sites become stable in terms of their data acquisition history.

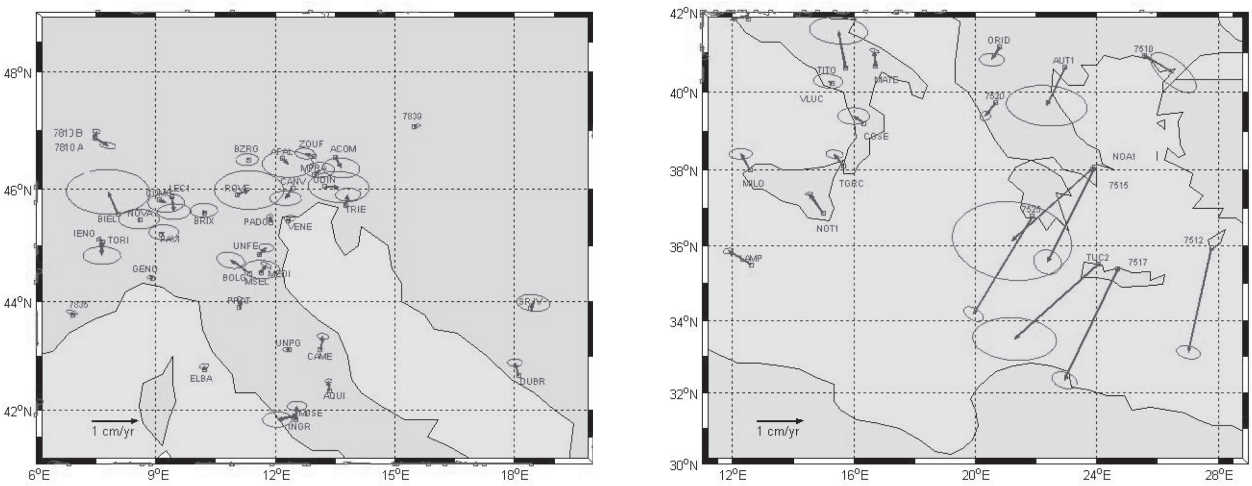


Fig. 3: Italian residual velocity field from ASIMed2007_ver2.0

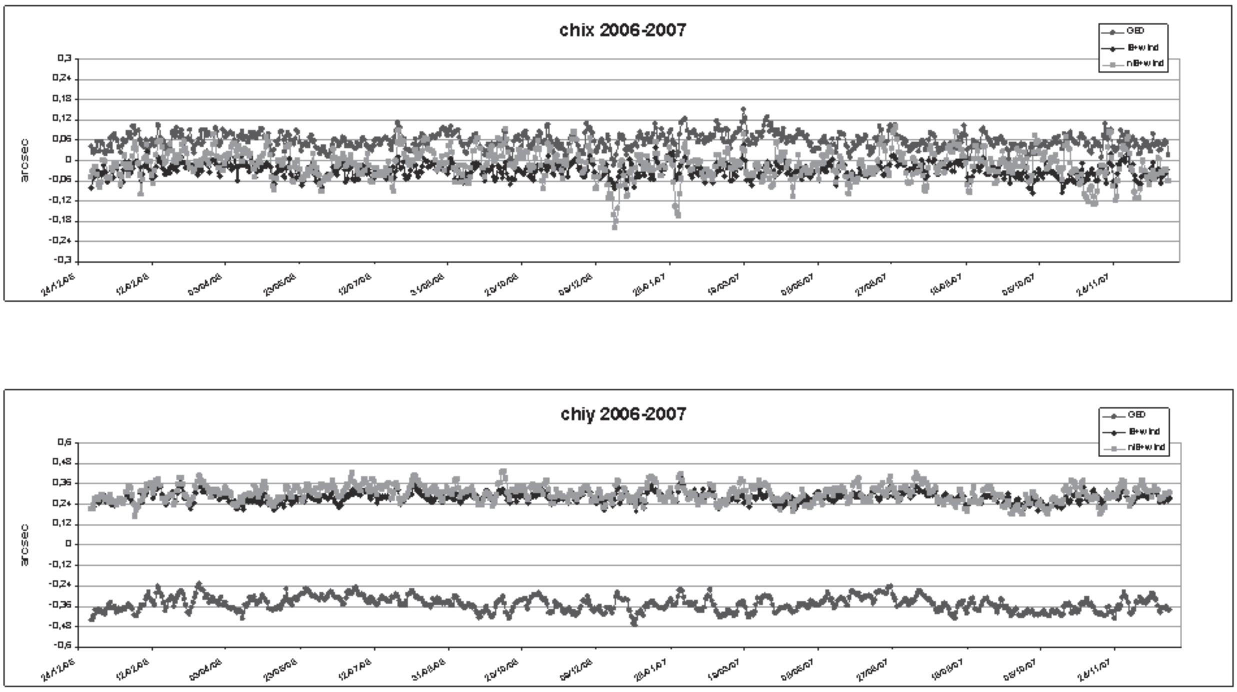


Fig. 3: x-y Excitation Functions 2006 – 2007 from ASI, SBA values

4. The EOP excitation functions

ASI-CGS continued the pre-operational production and the testing/validation phase for the geodetic excitation functions from its own estimation of EOP values (at present SLR only; the current use of CGS VLBI and GPS EOP is also under testing) to make them available on the ASI geodetic web site (<http://geodaf.mt.asi.it>): the daily geodetic excitation functions are produced every Tuesday along with the operational weekly SLR solution, staked and compared whenever possible with the atmospheric excitation functions from the IERS SBA, under the IB and non-IB assumption, including the “wind” term.

The atmospheric and geodetic excitation functions show clear similarities, not considering the expected systematic differences, as in the plots above, relevant to the x and y components. An even clearer and quantifiable correlation is shown in the z component: the linear dependence between the atmospheric and geodetic values is evident ($R^2 > 0.94$ over two years of values) as it is shown in the following plots (a systematic bias has been removed from the atmospheric values). The product is expected to be published on the GeoDAF web site during 2008.

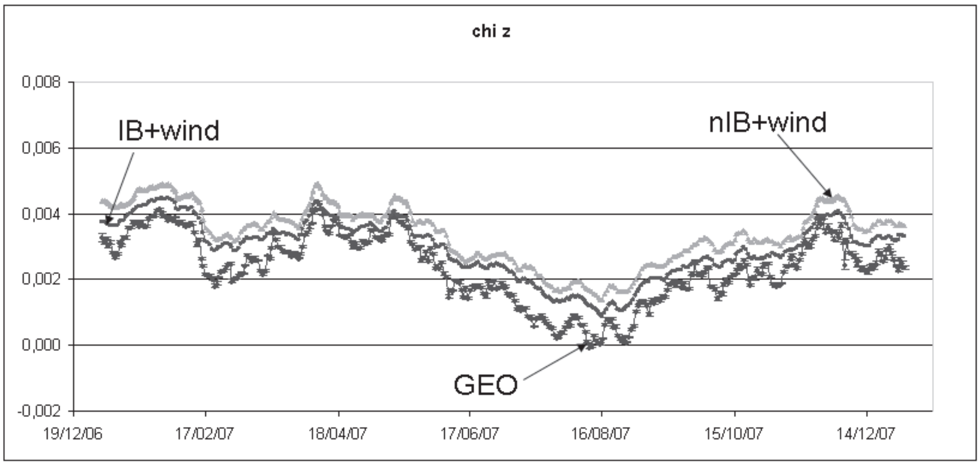


Fig. 4: z Excitation Functions 2006 from ASI, SBA values

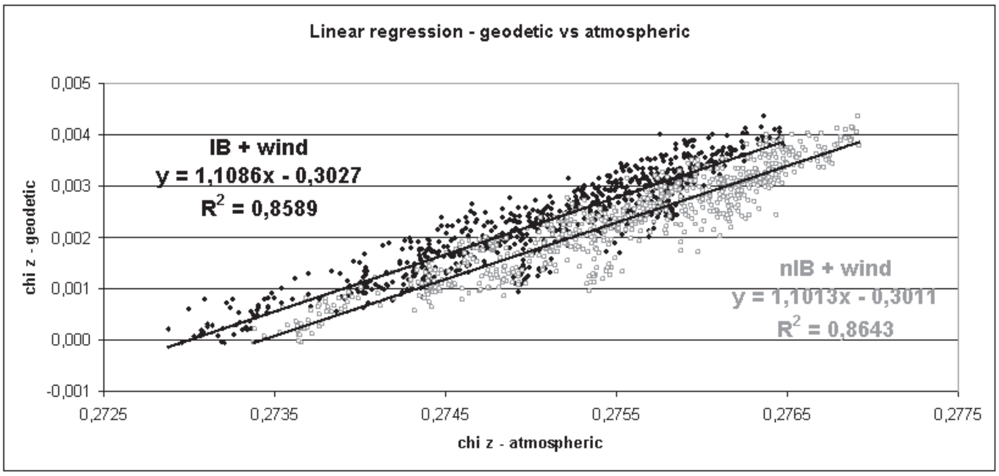


Fig. 5: Linear regression of z Excitation Functions 2006–2007 from ASI, SBA values

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

Introduction

The CRC is an integral part of the Center for Earth Dynamics Research (CEDR) that joins five Czech institutions active in astronomy and geosciences research. The combination research in preceding years was maintained principally in two different, and more or less independent, directions. In one approach we combined some of the Earth Orientation Parameters using the ‘combined smoothing’ algorithm that we recently proposed, without changing the underlying reference frames (terrestrial, celestial). In the other one, we followed the direction of combining non-SINEX particular solutions of different techniques to determine the Earth orientation parameters simultaneously with station coordinates. In 2007, we continued our activities by merging these two approaches together. Our PhD student, Vojtech Štefka, is responsible for solving this problem.

Combination of EOP and station coordinates

We started to use constraints similar to the ones used to define ‘smoothness’ of the resulting curve in Vondrák smoothing method, in order to ensure the continuity and smoothness of Earth Orientation Parameters of our non-rigorous combination. To this end, a transfer function, corresponding to appropriate value of the weight for these constraints, was empirically estimated and used to compute three-year solution. Our numerical solutions of the combination were so far based on solving full normal equation matrix, which was a rather time consuming task. Therefore, the more effective algorithm for sparse systems from the GNU Gama package (<http://www.gnu.org/software/gama>) has been recently implemented. This decreased the necessary computation time by about one order.

Staff

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Jan Vondrák, Ivan Pešek

3.6.2.3 Deutsches Geodätisches Forschungsinstitut (DGFI)

In the year 2007, the activities of the IERS Combination Research Centre at DGFI concentrated on contributions to the IERS Combination Pilot Project and the closely related German project GGOS-D as well as on updates of the SLR intra-technique combination.

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 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 Techniques' Services. Studies and inter-technique combinations performed in the year 2007 concentrated on the weighting, the handling of local ties and the datum definition. The DGFI combination software DOGS-CS has been updated and preparations for the generation of weekly combined solutions on a routine basis have been performed.

DGFI contributions to GGOS-D

Although GGOS-D is not an IERS project, the work is very closely related to the DGFI research performed as IERS Combination Research Centre. GGOS-D is funded by the German Ministry for Research and Education in the frame of the programme GEOTECHNOLOGIEN. The project involves four institutions: GeoForschungsZentrum Potsdam (GFZ), Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt am Main, Institut für Geodäsie und Geoinformation, Universität Bonn (IGG-B), and DGFI. In 2007, DGFI has performed the following major activities within GGOS-D:

- Based on the common standards and models that have been implemented in the different software packages (OCCAM for VLBI, DOGS-OC for SLR), the long time series of VLBI and SLR data have been homogeneously reprocessed at DGFI. Furthermore, the two individual SLR solutions of DGFI and GFZ were combined at DGFI.
- In cooperation with GFZ Potsdam and TU Munich, the GPS and VLBI data were reprocessed by applying different (fully homogenized) tropospheric mapping functions (solution 1: Niell Mapping Function (NMF) and constant a-priori zenith delay; solution 2: Vienna Mapping Function (VMF) and a-priori zenith delay from ECMWF). Based on these solutions the VLBI and GPS height time series were analysed and compared. Furthermore, investigations regarding the estimation of loading coefficients from the GPS and VLBI height time series have been carried out.
- A major focus of the DGFI work in 2007 was on the computation of a GGOS-D terrestrial reference frame (TRF) from the

VLBI, SLR and GPS long time series. The TRF computation consists of the two following major steps: (1) Accumulation of the time series normal equations per technique and analyis of the time series solutions; (2) Inter-technique combination of the accumulated multi-year normal equations per technique. Research objectives addressed include the handling of non-linear station motions, the developments of strategies for the selection of co-location sites and the implementation of local tie information, as well as the weighting and the datum definition of the final TRF solution.

SLR intra-technique combination

In 2007, 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. The software for a daily automatic combination with seven days input solutions has been developed and tested for automatic processing. Also in 2007 the test phase for a weekly combination of orbit solutions started. The software is in development.

Acknowledgements

This work was partly funded by the project GGOS-D within the GEOTECHNOLOGIEN programme of the Federal Ministry of Education and Research (BMBF: Bundesministerium für Forschung und Technologie), FKZ 03F0425C.

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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 six 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 software will automatically detect if the spacecraft is in cruise mode or is orbiting around a central body. In the latter case, the central body is automatically identified and a state-of-the-art gravity field for the central body is read from a file. If the central body is the Earth, all dynamics will be represented in a local geocentric space-time frame of reference. If the central body is another body in the Solar system (any planet, natural satellite, or a „big“ comet or asteroid), all dynamics will be represented in a Solar system barycenter space-time frame of reference with the origin at the center of mass of the central body. If the spacecraft is in cruise mode, all dynamics will be represented in a Solar system barycenter space-time frame of reference with the origin at the center of mass of the Solar system. These celestial reference frames are consistent to the mm level for Earth satellites within GEOSAT. Another improvement is that all bodies between the spacecraft and the Sun is tested for possible eclipse effects and the fraction of reduction in light on the spacecraft is accounted for. If the spacecraft is not in cruise mode and the central body is not the Earth, the trajectory of the central body can be calculated if the data allow it.

In GEOSAT the „spacecraft“ can either be an artificial satellite, a planet, a natural satellite of a planet, an asteroid, or a comet. Preliminary orbits are available in GEOSAT for the 300 largest asteroids and for the largest comets. With this software it will be possible to reduce terrestrial error contributions in the analyses of deep space tracking data. Off cause, all „terrestrial-like“ parameters for a celestial body (different from the Earth) can, if the tracking data allow it, be estimated. Signal delays (for MW and SLR) through the neutral atmosphere of the Earth is calculated from 3D raytracing using time-series of numerical weather data from the European Center for Medium-range Weather Forecast. Other important improvements and changes have been 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 e.g. a station with two GPS receivers and one VLBI instrument will have three estimates of this parameter. If the results are consistent, these parameters can be estimated as a single parameter represented by a microwave-dependent parameter in a second run. The same can be tested for clock parameters for collocated clocks etc.

The project 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 installed an array of 10 computers with altogether 40 cpu’s, 60 GB Ram, and 10 TB disk space.

Present analysis status:

- We have produced OMC files (Observed minus Calculated and observation partial derivatives wrt potential solve-for parameters) for the period Jan 2000 to Dec 2007 for VLBI, GPS and SLR. Data from around 170 GPS stations are included.
- We have produced combined (at the observation level) approximately 1000 arcs (24 hours each) of either VLBI + SLR +

GPS (when VLBI is available) or SLR + GPS. We have performed extensive testing to find a proper parameterization at the combination level and found that one quite tightly constrained atmospheric parameter needs to be estimated for all MW data within a collocated station. Furthermore, if different MW instruments are connected to the same H-M clock, one single linear clock drift estimated parameter is sufficient. Off cause, each MW instrument must have each own estimated clock offset. One example is the GPS receivers NYAL and NYA1, and the VLBI instrument at Ny-Ålesund, where the estimated clock offsets of the two GPS receivers differ by typically 10–20 picoseconds. Note that the antennas and cables are not identical. The cable lengths are also different. For each arc a single combined set of coordinates is estimated for each station in addition to eccentricity vectors between the antenna phase centers.

Future plans

- Produce SRIF arrays for all VLBI + SLR + GPS or SLR + GPS arcs between Jan 2000 to Dec 2007.
- Combine these arrays to a multi-year global solution with times series of e.g. the coordinates of one reference marker per station and the eccentricity vectors.
- Write software to represent GEOSAT solutions in the SINEX format.
- 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 Institute of Geodesy and Geoinformation of the University of Bonn 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 2007, combination research has again been devoted to the combination of the IVS Analysis Center's contributions to the regular IVS products. This research lead to a new combination process for the two IVS EOP series (rapid and quarterly solutions) which has been made operational on January 1, 2007. Routine combinations of IVS are now being made exclusively on the basis of datum-free normal equations in SINEX format. In 2007, five IVS Analysis Centers (BKG, DGFI, GSFC, IAA and USNO) contributed to the IVS combined products by providing input in the form of datum-free normal equations. The rapid solutions contain only R1 and R4 sessions and new data points are added twice a week as soon as the SINEX files of the five IVS Analysis Centers are available. For the quarterly solution, updated every three months, almost all available data of 24-hour sessions from 1984 onwards are used. Since this series is designed for EOP determinations, those sessions are excluded which are observed with networks of limited extension or which are scheduled for a different purpose like radio source monitoring.

The advantage of the new combination strategy is that one common terrestrial reference frame (e.g. ITRF2005) is applied after the combined datum-free normal matrix is generated. Thus, it is guaranteed that an identical datum is used in the combination process for all input series. After datum definition, the combined system of normal equations is solved (inverted) and the full set of EOP (pole components, UT1–UTC, and their time derivatives as well as two nutation offsets in dpsi, depsilon w.r.t. the IAU2000A model are extracted. These results are added to the two EOP time series in the IVS EOP Exchange format, the rapid solution file (ivs07r1e.eops) and the quarterly solution file (ivs07q4e.eops). Companion files containing the nutation offsets in the X, Y paradigm are routinely generated through a standard transformation process (ivs07r1X.eops, ivs07q4X.eops). At the same time the combined SINEX files (datum-free normal equations) are also available on the web for further combination with other techniques. The weighted RMS differences between the individual IVS Analysis Centers and the combined products have been reduced from roughly 80 – 100 µas to 50 – 60 µas in all components.

As part of the quality assessment of the combination process, long-term time series of station positions of each individual IVS Analysis Center, derived from the submitted normal equations, have been compared with each other. Through this, systematic offsets in the height component of up to 1 cm have been detected between solutions analysed with the VLBI analysis software packages OCCAM and CALC/SOLVE. In order to find the reason for these discrepancies several models used in both software packages have been compared in close cooperation with the VLBI group at DGFI. It turned out that the systematic offsets were mainly caused by differences in the pole tide model. In the CALC/SOLVE solutions, a model for the annual mean pole was used, basically setting the mean pole coordinates to zero, which was not in agreement with the IERS Conventions 2003. Therefore, all analysis centers using CALC/SOLVE reprocessed their solutions with the conventional pole tide model according to the IERS Conventions 2003 and most of the discrepancies disappeared. Since the IVS input to ITRF2005 was affected by the same inconsistency, the ITRF2005 may be affected by this oversight, though not to the full extent.

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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 2007:

- Subdaily Earth rotation parameters from GPS and VLBI
- SLR combination including low-degree harmonics of the Earth's gravity field
- Combined Earth Orientation Parameters
- Combination of the GPS ground network and Low Earth Orbiters (LEOs)

Subdaily Earth Rotation Parameters from GPS and VLBI

The space geodetic techniques GPS and VLBI are able to observe subdaily variations in Earth rotation that are mainly caused by ocean tides. As the periods of these tides are well-known, their amplitudes can be estimated in a weighted least squares adjustment using subdaily ERP time series as pseudo-observations. Such subdaily ERP models were determined from homogeneously reprocessed GPS and VLBI longtime series. The GPS series (Steigenberger et al., 2006) covers the time period January 1994 till October 2005 with an ERP spacing of 2 hours. The VLBI solution was computed by Goddard Space Flight Center from 3804 VLBI sessions between 1980 and 2007 with a parameter spacing of 1 hour. The largest tidal amplitudes of the GPS and VLBI subdaily ERP models estimated from these series as well as the IERS2003 model (McCarthy and Petit, 2004) are shown in Fig. 1. The polar motion amplitudes in general agree on the level of 4.2 to 9.4 µas, the UT1 amplitudes differences are between 0.5 and 1.1 µs. The maximum differences can reach up to 16.9 µas and 2.4 µs, respectively.

As the GPS and VLBI subdaily ERP models discussed above showed a high level of consistency, a simple combined GPS/VLBI model has been computed. Tab. 1 lists the RMS differences of the GPS and VLBI single-technique models and the combined model w.r.t. the IERS2003 model. A significant RMS reduction of 15 and 40 % could be achieved for diurnal and semidiurnal prograde polar motion, respectively. For retrograde polar motion, the RMS differences of the combined model are slightly worse compared to the GPS model but smaller by a factor of almost two compared to the VLBI model. For UT1, the impact of the combination is smaller: the

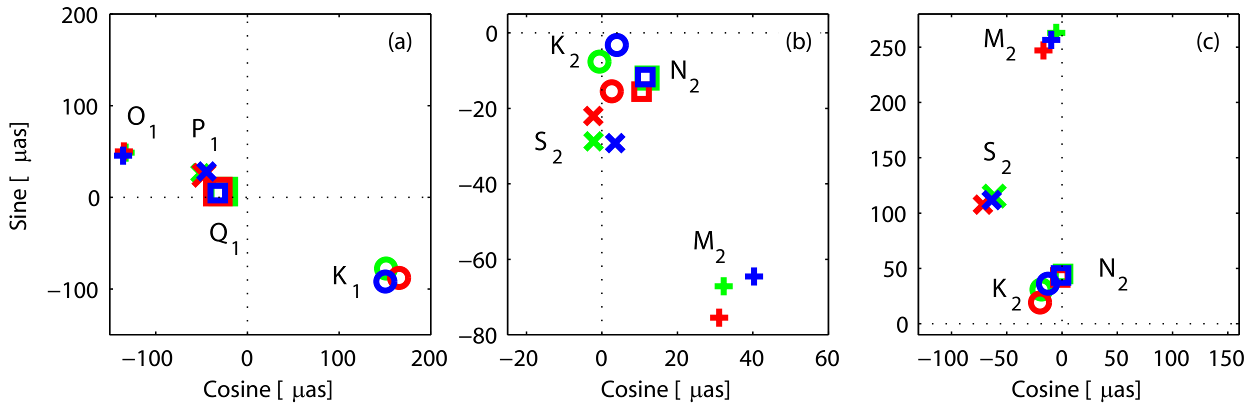

Fig. 1: Major tidal amplitudes in polar motion from GPS (blue), VLBI (red) and the IERS2003 model (green): (a) diurnal prograde polar motion; (b) semidiurnal prograde polar motion; (c) semidiurnal retrograde polar motion.

diurnal RMS differences of the combined model are slightly larger than that of the single-technique solutions whereas for semidiurnal UT1, the RMS values of the combined model are almost the same as for the GPS-only model.

Table 1: Mean RMS differences of the GPS and VLBI single-technique and the combined subdaily ERP models w.r.t. the IERS2003 model.

	GPS	VLBI	Combined
Prograde diurnal polar motion [µas]	4.2	4.3	3.7
Prograde semidiurnal polar motion [µas]	2.7	3.3	2.0
Retrograde semidiurnal polar motion [µas]	2.8	5.8	3.1
Diurnal UT1 [µs]	0.38	0.38	0.44
Semidiurnal UT1 [µs]	0.60	0.67	0.59

Combined Earth Orientation Parameters

Since the space-geodetic techniques GPS and VLBI now have a long history of data, the time series of Earth orientation parameters (EOP) that can be estimated covers more than a decade. Although computing a solution for the entire time span including station coordinates, velocities and all EOPs in only one step yields the most consistent parameters, it may be very time consuming. Therefore, the question arises how large the differences are compared to the full solution if the time series of EOP is computed from sub-intervals of data, e.g., one day, one week, one year, etc.

We compared time series of EOPs derived from daily solutions with the time series derived from a full solution for the time span 1994 until 2006. Figure 2 shows the differences exemplarily for the x-pole in case of a combined GPS-VLBI solution (WRMS of the differences: 76.7 µas). It becomes clear that the largest differences are visible in the early years, whereas only marginal differences are present for epochs later than approximately 1997. Similar comparisons were done for the GPS-only time series and the VLBI-only time series. As regards the GPS-only time series, the results look similar to those for the combined time series (WRMS of the differences: 70.7 µas), whereas the comparison between the daily VLBI solutions and the multi-year VLBI solution shows differences of the same size for the whole time span (WRMS of the differences: 177.8 µas) that are in the order of the differences seen for the early years of the combined time series (Fig. 2). From this behavior it can be concluded, that time series of EOP derived from daily solutions differ most from a multi-year solution if the observing network of the corresponding day is clearly weaker than the full network of the multi-year solution.

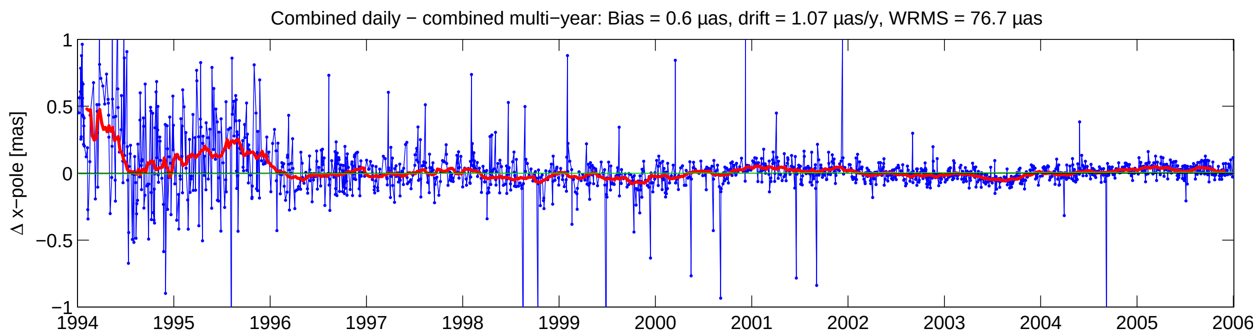

Fig. 2: Comparison of time series of x-pole derived from daily solutions with the time series derived from a full solution for the time span 1994 until 2006 (combined GPS-VLBI solution).

SLR Combination Including Low Degree Harmonics of the Earth's Gravity Field

Weekly SLR solutions for the years 1993–2007 with estimated low degree gravity field coefficients were used to check the correspondence between the geometric translations and the degree one gravity field coefficients. Both sets of parameters represent the same phenomenon – the motion of the geocenter – and should give approximately the same result. We calculated two multiyear-solutions – in the first one, the gravity field coefficients were fixed to their a priori values and the geometric translations were set up as parameters and estimated. In the second solution, the degree one gravity field coefficients were estimated. In Figs. 3–5 the time series of the parameters are presented. There is a good agreement between the geometric translations and the gravity field coefficients, the discrepancy seen in the time series of the Y-translation and the S11 coefficient might be caused by the influence of the a priori reference frame and by crustal deformations. The correlation between these two sets of parameters is on the level of 0.97–0.99.

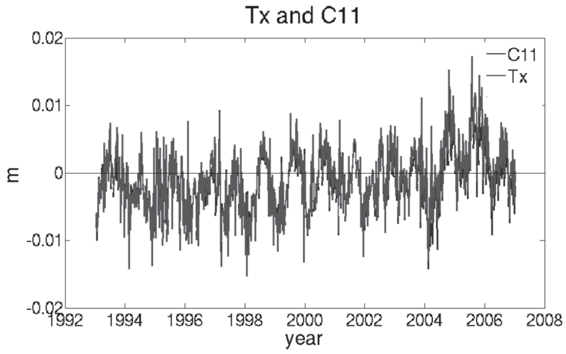

Fig. 3: X-translation and gravity field coefficient C11.

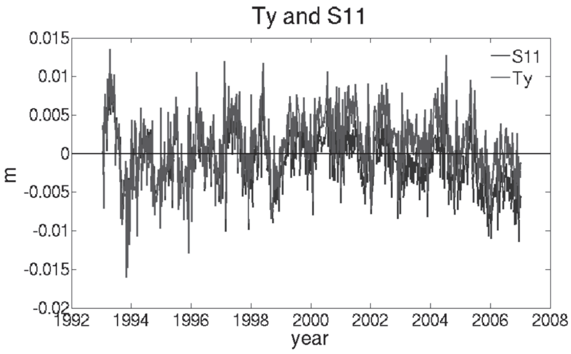

Fig. 4: Y-translation and gravity field coefficient S11.

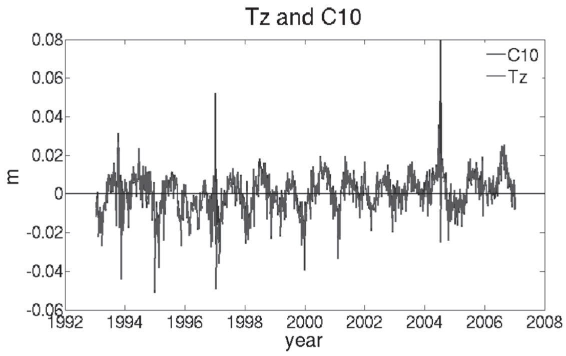

Fig. 5: Z-translation and gravity field coefficient C10.

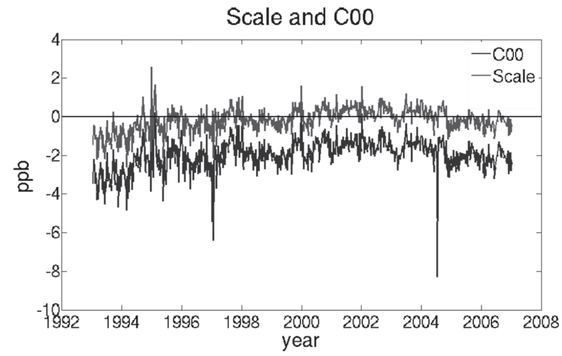

Fig. 6: Scale and gravity field coefficient C00.

The C00 gravity field coefficient and the geometric scale were compared in the same way, the result is shown in Fig. 6. Since the correspondence between geometric scale and C00 is not as direct as in the case of translations and degree one gravity field coefficients, it is likely that these parameters can be estimated simultaneously. Indeed in the normal equation system the correlation between them is on the level of 0.006, which means that they are separable. In the long term we see in Fig. 6, however, that besides a constant bias of about 1.8 ppb, a high correlation of about 0.93 exist between the time series.

Combination of the GPS Grund Network and Low Earth Orbiters (LEOs)

The IERS CRC at GFZ has continued determining station positions, Earth Orientation Parameters (EOPs), 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-networks, 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 GRACE. The dense and accurate CHAMP and GRACE data allow a high resolution of the sought for reference frame parameters.

Processing the data of the year 2004 in the framework of GGOS-D, 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 step. 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.

The combination of LAGEOS and GRACE on the normal equation level was analyzed for the generation of low-degree harmonics. In addition, preparations were made for a new LEO mission, the TerraSAR-X mission, which also carries the GPS two-frequency receiver of type CHAMP and GRACE. TerraSAR-X POD results produced operationally indicate few centimeter orbit accuracies in the sequential processing mode.

Acknowledgements

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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. (2008). 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, D. Feraudy*)

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 1 cm 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, in addition to empirical dynamical parameters, following ILRS recommendations. Final results are obtained with a three 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 in an operational way, at GEMINI/OCA in Grasse, France, which became an official ILRS AC at the end of 2007. Some differences exist between the two parameterisations; in particular atmospheric loading is accounted for the CRC project, but is not included in products delivered to ILRS, affecting the geocentre motion.

1.2 DOPPLER Orbitography and Radiopositioning Integrated by Satellite (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 degree coefficients (up to 50), ITRF2005 and an 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 is performed using 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, H. Capdeville, L. Soudarin*)

The period 2007–2008 is associated with the intensification of the operational activities in delivering weekly NEQ to the CRC Combination Centre in Paris and solutions to IGS (including EOP, Orbits and stations coordinates). The weekly solutions were delivered for evaluation during a period of 8 months and at the end of May 2008 the group was officially labelled Analysis Centre of the IGS.

The significant improvements are the automatic processing activities as well as the development of a new pre-processing program called “Prairie” able to take in charge the Glonass data. The routinely processed network by the CNES-CLS IGS Analysis Centre contains now around 85 GPS sites. The latency of the processing is now 10 days.

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 inten-

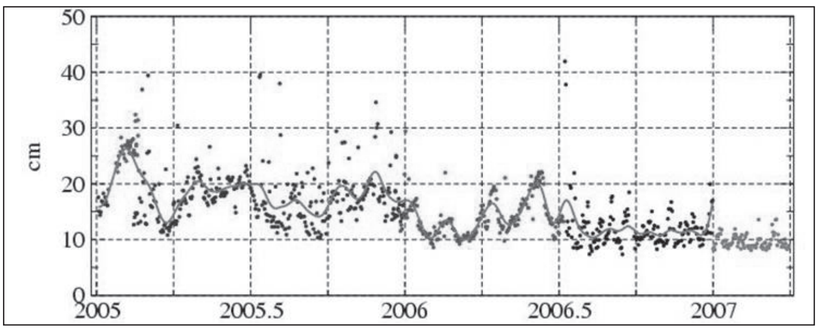

Fig. 1: Internal orbit overlappings (non weighted 3D RMS).

Table 1: GPS products quality compared to IGS combined solution.

<u>Orbits vs IGS Combined orbit:</u> TX = 2 +/- 1.5 mm ; TY = 0.3 +/- 1 mm ; TZ = -2 +/- 3 mm RX = -17 +/- 35 µas ; RY = -75 +/- 65 µas ; RZ = 38 +/- 60 µas Scale = 1 + /- 0.05 ppb ; WRMS3D : 3.2 +/- 0.35 cm
<u>Stations vs IGS05 (bias + rms)</u> Nord = 0 +/- 2.5 mm ; Est = 0 +/- 1 mm ; Up = 0 +/- 6 mm
<u>Pole vs IGS solution (bias + rms)</u> Xp = 5 +/- 25 µas ; Yp = 43 +/- 30 µas ; LOD = -1.5 +/- 32 µs Xp_rate = -56 +/- 90 µas/day ; Yp_rate = -6.5 +/- 90 µas /day

sive 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). Based on these data, weekly normal matrices 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 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 in 2007 is ITRF2005 (Altamimi et al. 2007) 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 the EOP results with those published by the IVS indicates an agreement at the 0.2 mas level.

2 Combination procedure using DYNAMO at Paris Observatory (*J.Y. Richard, 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 <iers1.bkg.bund.de>) 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 2005–2008. 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. (2008).

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 2005–2008 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 tech-

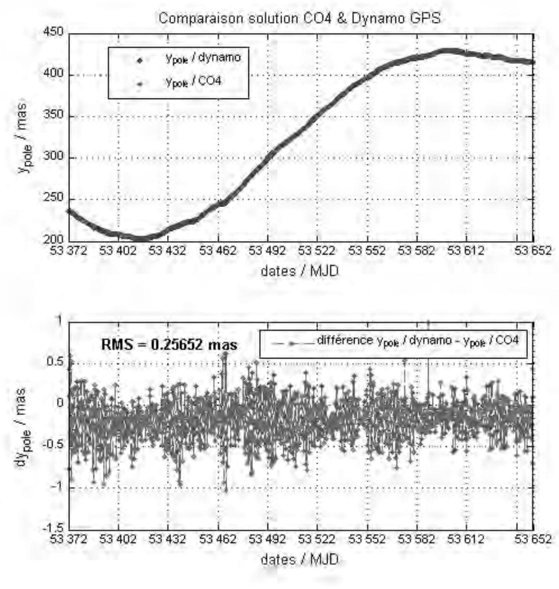

Fig. 2: Y pole 40 cumulated GPS weeks compared to IERS EOP CO4.

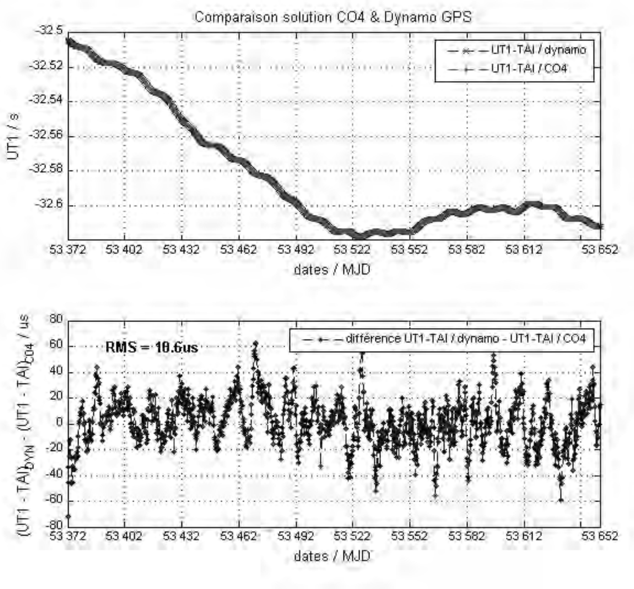

Fig. 3: UT1–TAI 40 cumulated GPS weeks compared to IERS EOP C04.

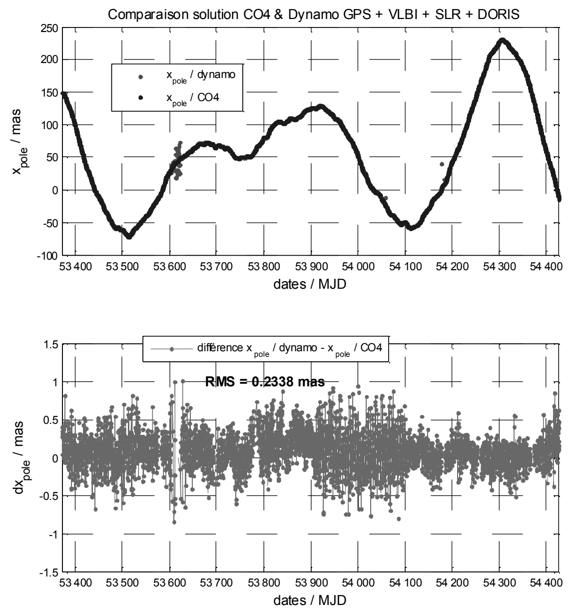

Fig. 4: X pole compared with IERS EOP CO4, residuals rms = 234 µas over 2005–2007.

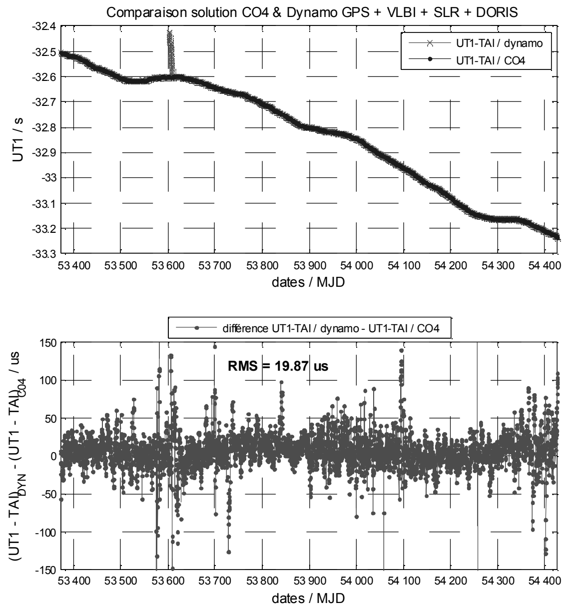

Fig. 5:UT1–TAI compared with IERS EOP C04, residuals rms = 19.9 µs over 2005–2007.

niques can have significant effects on the final estimation quality. Figures 2 and 3 show the X pole and UT1 dynamo solutions over forty weeks of 2005 cumulated using only GPS observations. Continuity constraints are fixed to 2 mas for X and Y poles and 30 µs for UT1.

2.2 Second step: inter-technique combination

The four intra technique NEQs derived over the three years are then accumulated into a single NEQ containing EOP at six-hour intervals. In this process local ties associated with ITRF2005 were considered. A global reference frame consistent with ITFR2005 is obtained, station positions rates being fixed to ITRF values in the process. Figure 4 and 5 show results with combination of the four techniques GPS, VLBI, DORIS, and SLR. The weighting set are for GPS = 5.212, SLR = 1.709, VLBI = 1.927, and DORIS = 1.102. The continuity constraint on Earth parameters are weak, 2 mas for X pole and Y pole and 20 ms for UT1.

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 mod-

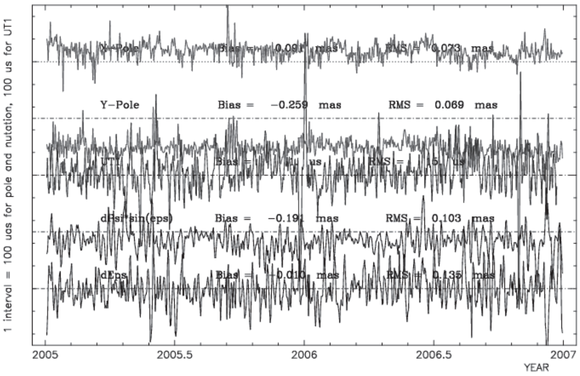

Fig. 6: EOP: differences of GRGS solution with 05C04 over 2005–2006. From top to bottom: X and Y-pole, UT1 and nutation offsets. RMS are about 0.070 mas for pole and 12 microseconds for UT1.

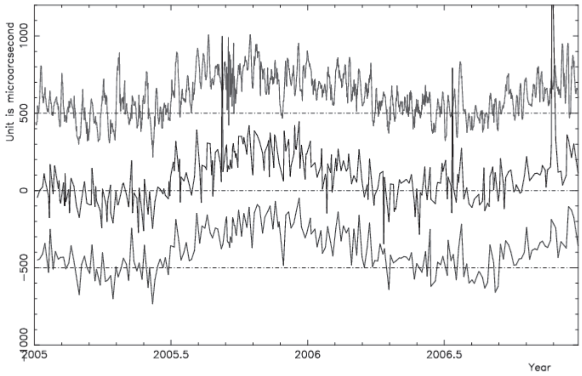

Fig. 7: Plots showing the differences between the GRGS combined solution and combined intra-technique solutions IVS, LRS and IGS for X-pole component over 2005–2006.

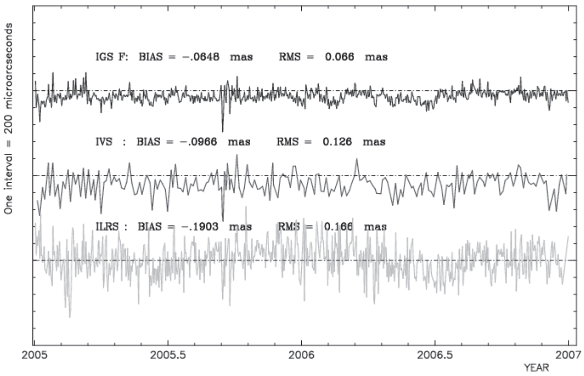

Fig. 8: Nutation offset dx relatively to the IAU 2000 nutation model. Nutation drifts derived from GPS analyses at 12 h-intervals allow to densify nutation series derived from 24-h VLBI sessions. From top to bottom, GRGS combined, GSFC and IAA solutions.

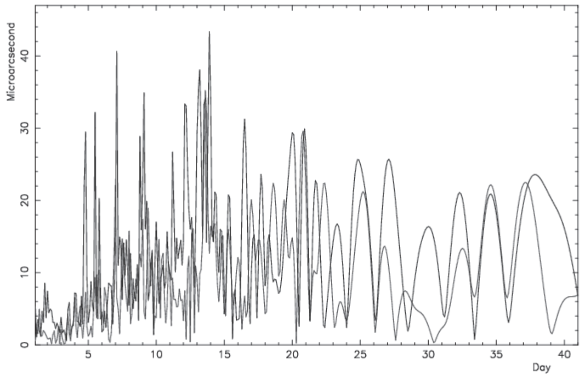

Fig. 9: LSQ periodogram of nutation offsets dx (blue) and dy (red) relatively to MHB2000 nutation model. Significant peaks appear in particular at 7 days and at fortnightly time scales.

elled by a piecewise linear fit to yield values at 0:00 hour. Figure 6 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.

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 combined 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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3.6.2.8 Institut Géographique National (IGN)

Intra-technique combination

The stacking procedure implemented in the Combination and Analysis of Terrestrial Reference Frames (CATREF) software is based on a Euclidian similarity. This relationship links every individual frame with the stacked frame, which is estimated simultaneously with the 7 Helmert parameters that parameterize this relationship. The independent analysis of their temporal behaviour is of great importance for guiding the choice of the origin and scale of the ITRFs. So the stacking procedure is regularly conducted for each geodetic technique by extending the input frame time series with the most recent data. This procedure also ensures a constant assessment of the geodetic product using a limited number of parameters of interest that are meaningful for reference frame analyses.

The station position residual time series from VLBI, SLR and GPS that are by-products of the ITRF2005 stacking analyzes have been also extensively studied in Ray et al., 2008 and Collilieux et al., 2007.

Helmert parameter analysis

A particular attention has been paid to the understanding of the SLR scale and translation variations over time. The influence of the SLR range bias handling strategy on the SLR scale has been carefully studied and has been shown to significantly impact the SLR scale behaviour. A temporal de-correlation method has been developed to optimally estimate SLR station range biases from SLR data (Coulot et al., 2008). Supplementary analyses have been led to study SLR translation and scale variations related to the network effect. The use of additional constraints on station displacements may reduce the aliasing effect occurring between global bias parameters and station individual motions (Collilieux et al., 2008), see Figure 1.

ITRF and EOPs consistency

The availability of frame time series makes possible a rigorous combination of the station positions and EOPs from the space geodetic techniques (Altamimi et al., 2007). This joint combination enforces the mutual consistency between the estimated secular frame and its consistent set of EOPs. ITRF2005 combination strategy is applied regularly to all available data sets from IERS technique services including the most recent data, in cooperation with the IERS Earth orientation centre. This procedure can be used to assess the consistency between the EOP series 05C04 and the ITRF2005 (Altamimi et al., 2008).

Multi-technique combination at the observation level

IGN, being part of the Groupe de Recherche en Géodésie Spatiale (GRGS), has been involved in the IERS Combination Pilot Project (CPP). Research on the combination of station positions and Earth

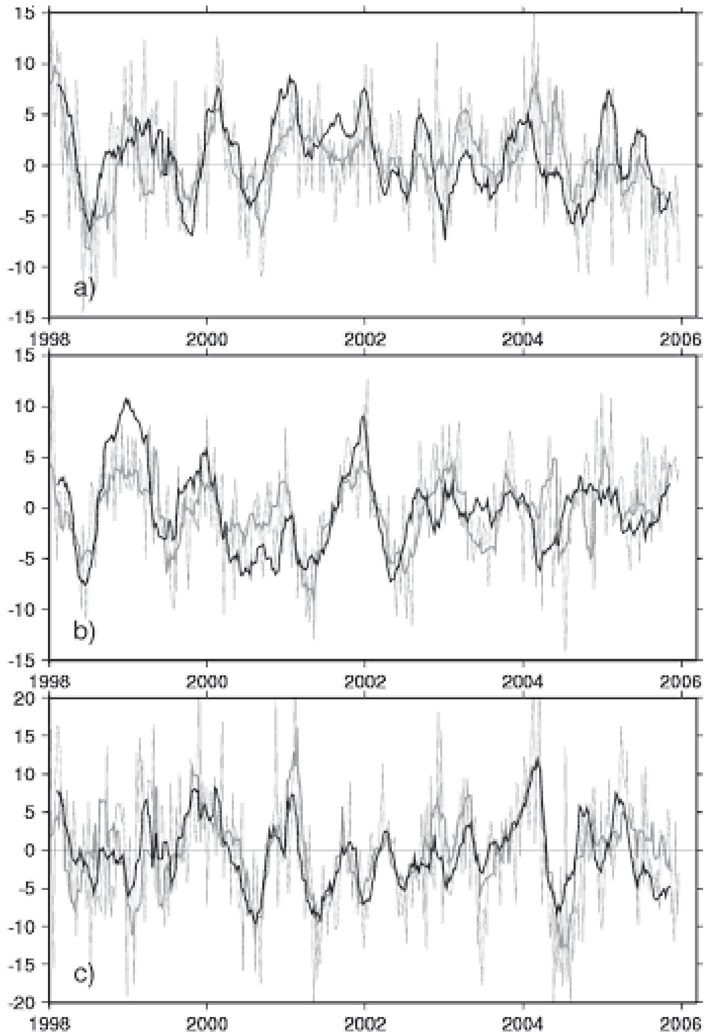

Fig. 1: ILRS solution Helmert parameters from ITRF2005 analysis, in light gray. Estimated parameters constrained with GPS results according to Collilieux et al., 2008, in black. Solid lines correspond to 10 weeks average values.
a) X component, b) Y component, c) Z component.

Orientation Parameters (EOPs) at the observation level has been carried out (Coulot et al., 2007) and is still underway. A new modeling of the station position parameters, which involves Helmert parameters directly in the observation equations, is being implemented to ensure that the combined reference frame is well defined and self-consistent. Eight months of data from SLR (LAGEOS I and II), VLBI, DORIS (SPOT2, SPOT4, SPOT5, ENVISAT, JASON), and GPS have been stacked using this model. First results demonstrate its benefit for estimating time series of multi-technique reference frames. Currently, the impact of the introduction of local ties on the combined frame is studied as well as the proper way to use them. To ensure a better consistency of this combined reference frame, the use of other common parameters like zenithal tropospheric delays or multi-technique satellite orbital parameters will be investigated.

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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 (AAM), 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 2007, three such reference series were generated: (1) SPACE2006, consisting of values and rates for polar motion and UT1 spanning September 28, 1976 to February 10, 2007 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) COMB2006, consisting of values and rates for polar motion and UT1 spanning January 20, 1962 to February 10, 2007 at daily intervals, was generated by additionally including the BIH optical astrometric measurements with the space-geodetic measurements used to generate SPACE2006; and (3) POLE2006, consisting of values and rates for just polar motion spanning January 20, 1900 to January 21, 2007 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 COMB2006. These three reference series can be obtained by anonymous ftp to <ftp://euler.jpl.nasa.gov/keof/combinations/2006>. A report describing the generation of these series [Gross, 2007] is also available at this site.

The near-real-time Earth orientation requirements of the interplanetary spacecraft navigation teams are met by once-per-day 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 AAM measurements from the National Centers for Environmental Prediction (NCEP) that are used as proxy length-of-day measurements. In addition, short-term predictions of the EOPs are produced. 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 2007 were largely concerned with both evaluating alternate sources of AAM forecasts and with evaluating the potential impact of oceanic angular momentum (OAM) forecasts on UT1 predictions [Gross et al., 2008]. Predictions of UT1 are improved when dynamical model-based forecasts of the axial component of AAM are used as proxy length-of-day (LOD) forecasts. For example, JPL's predictions are improved by nearly a factor of 2 when AAM forecast data from NCEP are used. Given the importance of AAM forecasts on the accuracy of UT1 predictions, other sources of AAM forecasts should be sought. So the angular momentum of the forecasted wind fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) was evaluated as a potential alternate source of AAM forecasts.

JPL's Kalman Earth Orientation Filter was run 73 times during 19 March 2004 to 22 July 2004 to predict polar motion and UT1. These runs were reprocessed using AAM forecasts from ECMWF instead of from NCEP. Since the angular momentum of only the 5-day wind forecasts from NCEP are used at JPL to predict UT1, only the 5-day wind forecasts from ECMWF were used during the reprocessing. It was found that if no AAM forecasts are used to predict UT1, the error in the predictions grows rapidly, becoming 33.7 cm after just 7 days. But when AAM forecasts are used, the error is dramatically reduced, becoming only 19.2 cm after 7 days with the NCEP forecasts, and 20.1 cm with the ECMWF forecasts. Thus, during this time period, AAM forecasts produced by ECMWF have nearly the same impact on UT1 predictions as those produced by NCEP.

To assess the potential impact of OAM forecasts on UT1 predictions, an OAM series was added to the AAM forecasts and the predictions regenerated. Since actual OAM forecasts are not currently available, analyses from the ECCO/JPL data assimilating ocean model kf066b were treated as if they were forecasts. Adding OAM to AAM forecasts was found to improve the accuracy of the UT1 predictions only slightly, reducing the error of the 7-day prediction from 19.2 cm to 17.9 cm when added to the NCEP AAM forecasts, and from 20.1 cm to 19.4 cm when added to the ECMWF forecasts.

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 2007

One meeting was held in 2007 at EGU in Vienna jointly with the GGOS Networks and communication working group. 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. A particular emphasis was placed on attempting to establish a new methodology for monitoring collocation vectors in near real time. The current survey methodology is episodic and as such will not pick up variations to the collocation vector between surveys. The need to continually refine accuracies was also discussed. With the GGOS aim of refining the accuracy of the ITRF below the 1mm level it becomes imperative that component accuracies are well below that level of accuracy. Current local tie accuracies are at the 1 – 5 mm level and as such need to be refined further.

As usual the meeting also stressed the need to continue to develop the concept of Local Ties as a key component of the technique combinations and reference frame definition and to ensure all collocated sites have up to date tie information.

Other Activities

Geoscience Australia continues to undertake monitoring surveys at the Australian sites. A new calibration pier at Mt Stromlo has been constructed in an attempt to refine the accuracy of the Minico near real time IVP monitoring system. The IVP was showing an apparent seasonal motion through the Minico system. It is believed that the tallest of the four calibration piers was actually moving seasonally and this was biasing the IVP results at the 0.5 mm level.

Plans are also being developed for local tie infrastructure at the Yarragadee site which will have a 12 m VLBI telescope installed in 2009. A methodology for surveying the relationship between the VLBI dish, Moblas 5 system, Proposed NGSLR system and the variety of GNSS sites is being developed.

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.

Pierguido Sarti from the Italian Istituto di Radioastronomia (IRA) reports that in 2007 they have completely re-surveyed Medicina VLBI-GPS eccentricity and Noto elevation axis using terrestrial observations.

Future Meetings

The working group has planned to meet again at the AGU2008 meeting in San Francisco, US.

Gary Johnston

3.7.2 Working Group on Combination

The major three items addressed in this report are (1) the ongoing research in the German GGOS-D project, (2) the development of software by a few groups to combine the space geodetic techniques on the observation level, and (3) the Unified Analysis Workshop in December 2007 in Monterey. A lot of additional material concerning combination may be found in Section 3.6 of this report. The huge amount of combination work done for the ITRF generation is described in Sections 3.5.5. and 3.6.1. and will not be addressed here.

GGOS-D Project

Since GGOS-D is one of the major projects presently aiming at a rigorous combination of the different space geodetic techniques, we will shortly present the status of the project here. By the end of 2007, the time series of SINEX files from the individual space techniques except DORIS were all available, processed in a homogeneous way according to well-defined common standards. The software packages involved were modified to follow these standards not only concerning modelling, but also parameterization. A DORIS solution with daily resolution was contributed by Pascal Willis. This solution did not follow yet all the details of the standards agreed upon in the GGOS-D project. A solution according to the GGOS-D standards is planned, however. For VLBI as well as SLR, two solutions were generated based on two independent software packages. For GPS, the second solution is not yet finished for the entire time interval from 1994 to 2006.

Combination tests have been performed with the various series concerning:

- Combination of the technique-specific solutions (VLBI, SLR)
- Combination of troposphere zenith delay and gradient parameters derived from VLBI and GPS solutions
- Combination of subdaily ERPs from GPS and VLBI
- Combination of UT1–UTC from VLBI and LOD from GPS
- Combination of nutation offsets from VLBI and nutation rates from GPS
- Local ties between the individual techniques

The generation of a full TRF solution based on these homogeneous, reprocessed solutions is a primary goal of the project, but has not yet been finished.

Detailed comparisons have been made, however, between these reprocessed series and the corresponding series of the IAG Technique Services and the IERS. These comparisons show the refined quality of the reprocessed series. Especially in the case of GPS a considerable improvement in consistency and homogeneity has been achieved compared to the official IGS solutions. A planned reprocessing organized by the IGS will most probably cure this deficiency in the next 1–2 years.

More information about the project GGOS-D is available at <http://www.ggos-d.de> and in the papers listed at the end of this report.

Combination of the Space Geodetic Techniques on the Observation Level

In the last few years some groups and institutions started to work hard on the combination of the major space geodetic techniques on the observation level. The first question certainly is, to what extent a rigorous combination can be done on the normal equation (or variance-covariance) level (by one or more software packages) and where a combination on the observation level is a necessity.

If we assume that the computers at our disposal have infinite resources (memory, CPU time, disk space, ...) and that we are able to achieve that a set of software packages is using exactly the same models and parameterizations, a combination including all common parameters is feasible on the normal equation level and is fully equivalent to a combination on the observation level. Since our computer resources are not infinite, however, and the various software packages are still quite diverging there are some good reasons to integrate the techniques on the observation level, within one unique software package:

- The capability to process all the different observation types in one software system is ideal in the sense that the consistency of the models (standards and conventions) and parameterizations is guaranteed. On the longer run it is extremely demanding to keep different software packages to conform to the same models and parameterizations etc. With only one package, the software updates will more or less automatically be realized for all observation types, reducing the work load significantly compared to a group that might be using different packages for different observation types.
- The estimation of parameters with a very high temporal resolution or the estimation of stochastic quantities is possible and poses no problems. With more than one package involved, the size of the normal equation systems to be generated and then combined to encompass all the common parameters (e.g., clock parameters of ultra-stable oscillators connected to the VLBI and the GPS instrumentation) might just be too large to handle, especially with the full variance-covariance information.
- It is possible to set up a variance-covariance component estimation based on the original observations to improve the weighting of techniques and observation groups with respect

to each other to answer questions such as “Is an elevation-dependent weighting reasonable?”, “For which techniques should it be done?”, etc.).

- For some possible future applications like observations from satellites with VLBI senders, GPS receivers and SLR retro-reflectors onboard (co-location in space) or satellites with a radio telescope onboard observing quasars will ask for orbit determination based, e.g., on GPS and VLBI observations. Since orbit force models and orbit parameterization are not well-standardized, it would be very difficult to use different software packages in this case. Most of the VLBI packages of today have no orbit determination capability anyway.

The development of a software package that is capable of processing all the major space geodetic techniques at a very high level of sophistication is a long-term goal that requires many man-years of work. It has to be said, that for the majority of problems to be addressed nowadays (weighting factors between techniques, local tie issues, handling of systematic biases, …), the necessary studies can already be done based on normal equation systems or variance-covariance solutions.

Presently, the major software developments in this field are taking place at the Goddard Space Flight Center (GSFC; software GEODYN), at the Groupe de Recherches de Géodésie Spatiale in Toulouse (GRGS; software GINS/DYNAMO), at the GeoForschungs Zentrum in Potsdam (GFZ; software EPOS), and at the Astronomical Institute, University of Berne and Technical University of Munich (AIUB and TUM; software BERNESE).

Recently the processing of VLBI data has been implemented into GEODYN, making it thus suitable for the processing of the major techniques. GINS/DYNAMO is capable of analyzing (among others) GPS, SLR, DORIS and VLBI data. Even the processing of LLR data is part of GINS and the GRGS activities. GRGS is processing and combining all the techniques now on a routine basis. The combination is done based on normal equations. The GFZ software EPOS has been used since a long time to analyse a large variety of observation types (GPS, SLR, DORIS, altimetry XO, inter-satellite measurements, …). Only VLBI is not yet included in this package. The BERNESE GPS Software is presently being modified to allow for the processing of SLR measurements to LAGEOS-type satellites, VLBI, DORIS and gravity mission data.
Other packages might follow.

One of the problems faced by an institution working on a combination on the observation level is the fact, that the institution or group has to understand all the processing details of all the major space geodetic techniques. In principle, such an institution has to reach the level of performance in processing the various space geodetic techniques that is equal or close to the performance of the best analysis centers of the corresponding service. In addition, the group has to be able to process large amounts of data from all the major techniques. To gain the experience to process 10–20 years of data from each of the techniques is a non-trivial and extremely time-consuming effort. As long as the solutions produced by an institution combining the techniques on the observation level are not among the best of the various technique services, it will be difficult to compete with a combination based on the solutions of the individual services. But, as computers get faster and faster, and cheaper as well, these processing capabilities will eventually arise.

Unified Analysis Workshop in Monterey, 2007

This was the first workshop under the umbrella of both GGOS and IERS, with themes concerning the common, integrating and unifying aspects of the analysis of the individual space geodetic techniques. Participation was on invitation only and the participants were selected by the individual services to have a high level of expertise present at the workshop for the themes to be discussed.

A detailed description of the Unified Analysis Workshop is given in Section 4.2

Meetings and Workshops

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

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Thaller, D., M. Krügel, M. Rothacher, V. Tesmer, R. Schmid, D. Angermann (2007): Combined Earth orientation parameters based on homogeneous and continuous VLBI and GPS data, *Journal of Geodesy*, 81, 529–541, DOI 10.1007/s00190-006-0115-z.

Markus Rothacher

3.7.3 Working Group on Prediction

Introduction

The IERS Working Group on Prediction (WGP) was tasked to determine what Earth orientation parameter (EOP) 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>). The task to determine what prediction products are needed by the user community has been answered by means of the EOP prediction survey developed by the WGP. Broad participation in the survey was solicited by IERS from those on the IERS mailing lists, those who receive IERS Rapid Service/Prediction Center (RS/PC) products, and any others thought to have an interest in EOP predictions (see IERS Message No. 104). The task to understand fundamental properties of input data sets and algorithms is in progress. A repository for data sets and results was established at the University of Luxembourg, input data sets were identified and placed in the repository, algorithms were identified, and information on various algorithms was gathered. A session on "Prediction, Combination, and Geophysical Interpretation of Earth Orientation Parameters" was part of the 2007 Journées meeting in Meudon, France. At the close of that session, a panel drawn from the membership of the WGP discussed critical issues that need to be resolved for progress to be made in EOP prediction.

WG Meetings

Because the Journées meeting is an important forum for researchers in the fields of Earth rotation, reference frames, astrometry, and time, significant WGP participation was anticipated and one purpose of the scheduled EOP prediction panel discussion was to solicit input and suggestions from the other conference attendees on the topics being considered by the WGP. The WGP met on 18 September 2007 after the closing of the Journées conference to discuss feedback from the panel discussion, plans for the repository, and comparison criteria for algorithms.

Additional informal meetings among the WGP members were held at the 2007 April European Geophysical Union (EGU) meeting in Vienna and at the 2007 December American Geophysical Union (AGU) meeting in San Francisco. Survey results, input data considerations, algorithm considerations, methodology for making comparisons, and future plans were discussed.

EOP Prediction Survey Results

Given the variety of high-precision applications that need EOP predictions, the first task of the WGP was to determine whether the current IERS products are adequate or whether modifications and/or improvements are necessary to meet more stringent requirements. To understand the needs of various users, the survey respondents were asked to characterize what type of user they were and then to specify their requirements in terms of desired accuracies and characteristics of EOP predictions. Although each category of user has different needs, the survey confirmed that most users need polar motion accuracies of 1 milli-arcsecond or better and UT1–UTC accuracies of 0.1 millisecond or better. The survey also confirmed that there is a large group of operational users that need daily predictions, tabular data, one-day spacing, and predictions up to 30 days. Although some users would like long-term predictions, the terms of reference under which the IERS RS/PC operates has been reconfirmed by the survey results. However, there is a need for increased accuracy and the efforts of the WGP to examine algorithms and incorporate potential new sources of data appears to address that need. In addition there seems to be a growing interest in daily and sub-daily predictions which require more timely measurements of EOP quantities and some increased processing capability.

WG Activities

The EOP prediction survey results were summarized in a paper given at the EGU Meeting in Vienna. Although much work on input data sets and algorithms has been accomplished, significant effort remains to complete a comprehensive assessment of the current state-of-the-art. Several questions remain such as loss of information if all data sets are reduced to a common epoch and the sensitivities of missing data sets to the prediction process. Geodetic data sets are available but additional geophysical data sets are needed for testing. In terms of algorithms, additional tests need to be run to determine their robustness in the event of certain pathological situations and their reliability in an operational setting. Specific algorithm questions remain with respect to problems associated with individual prediction methods. Future plans include determining optimum parameters for combination prediction algorithms, geophysical causes of prediction errors, and examining pathological timeframes for prediction. Other areas of investigation/issues are identified in the papers of session IV of the Journées meeting (esp., *Proc. Journées Systèmes de Référence Spatio-Temporels* 2007, pp. 200–201). The expectations of the WGP are to have definitive user requirements, a comprehensive look at prediction methods, a comprehensive look at new data sets, and to produce an IERS technical note describing current-state-of-the-art EOP prediction.

For a detailed summary of the activities of IERS Working Group on Prediction through September 2007, see *Proc. Journées Systèmes de Référence Spatio-Temporels* 2007, pp. 145–150.

Future Meetings

In order to minimize travel costs, the WGP will continue to utilize the opportunity to meet in conjunction with major conferences such as the EGU in the spring and the AGU in the fall. However, most interaction among the members will continue to be by electronic means.

William Wooden

3.7.4 IERS/IVS Working Group for the Second Realization of the ICRF

Membership

The IERS/IVS Working Group had the following membership:

O. Titov, Australia
R. Heinkelmann, Austria
G. Wang, China
F. Arias, France
P. Charlot, France
A.-M. Gontier, France
S. Lambert, France
J. Souchay, France
G. Engelhardt, Germany
A. Nothnagel, Germany
V. Tesmer, Germany
G. Bianco, Italy
S. Kurdubov, Russia
Z. Malkin, Russia
E. Skurikhina, Russia
J. Sokolova, Russia
V. Zharov, Russia
S. Bolotin, Ukraine
D. Boboltz, USA
A. Fey, USA
R. Gaume, USA
C. Jacobs, USA
C. Ma, USA, chair
L. Petrov, USA
O. Sovers, USA

Activities

The activities of the Working Group included generation of VLBI results in preparation for the new realization, presentations at various scientific meetings, and two working meetings.

In order to facilitate the distribution of relevant VLBI results directories were established in the IVS data system, procedures were established for submitting files, and standard formats were devised. The following groups generated and submitted source position time series:

Geoscience Australia
Paris Observatory
BKG (Germany)
DGFI (Germany)
Institute of Applied Astronomy (Russia)
Main Astronomical Observatory (Ukraine)
Goddard Space Flight Center (USA)
U.S. Naval Observatory

These time series are to be analyzed to decide the criteria for selecting defining sources and to identify unstable sources that will require special handling. In addition, the following groups generated and submitted source position catalogues:

Geoscience Australia
Main Astronomical Observatory (Ukraine)
Goddard Space Flight Center (USA)
U.S. Naval Observatory

These catalogues are to be used to identify systematic errors and to determine the actual level of uncertainty of the source positions as a group.

Meetings

Relevant presentations were made by Working Group members at the following meetings:

18th meeting of European VLBI for Geodesy and Astrometry, April 12–13, Vienna

Sokolova, J., Malkin, Z.: On comparison and combination of radio source catalogues

Tesmer, V.: Effect of various analysis options on VLBI-determined CRF

Journées 2007, September 17–19, Meudon

Ma, C.: Progress in the 2nd realization of ICRF

Charlot, P. et al.: Selecting ICRF-2 defining sources based on source structure

Malkin, Z., Yatskiv Ya.: Next ICRF: Single global solution versus combination

Titov, O.: Reference radio source apparent proper motions

Bolotin, S.: Influence of different strategies in VLBI data analysis on realizations of ICRF

Sokolova, J.: Effect of the reference radio source selection on VLBI CRF realization

IAU Symposium 248, A Giant Step: from Milli- to Micro-arcsecond Astrometry, October 15–19, Shanghai

Ma, C.: The second realization of the ICRF with VLBI

Charlot, P.: Source structure: an essential piece of information for the next generation ICRF

The Working Group had short meetings at the Vienna Technical University on April 12 and at the Paris Observatory on September 19 to discuss some the issues related to the next ICRF. The major issues to be addressed are:

- Selection of defining sources
- Treatment of source position variations
- Improvement of geophysical and astronomical modeling
- Selection of data
- Integration of ICRF, ITRF and EOP
- Generation of final catalogue

Chopo Ma

4 IERS Workshops

4.1 IERS Workshop on Conventions

The IERS workshop on Conventions was held on September 20–21 at the BIPM. A total of 65 participants from about 15 countries attended the workshop. The group photo (taken on the second day) may be found at <http://www.bipm.org/en/events/iers/iers_documents.html>.

The Scientific Organizing Committee consisted of F. Arias, B. Luzum, G. Petit (chair), J. Ray, B. Richter, J. Ries, M. Rothacher, H. Schuh, T. van Dam, and P. Wallace.

The workshop programme, including all the presentations, may be found at <http://www.bipm.org/en/events/iers/iers_documents.html>. Additional contributions, provided after the workshop, and this summary may also be found on that same page.

This document is an extended summary of the presentations, discussions, and recommendations of the workshop. Without directly following the order in the workshop programme, it is structured in a list of 11 items, and concludes with a list of the recommendations.

1. Classification of models
2. Criteria for choosing models
3. Non-tidal loading effects
4. New models
5. Possible additions to the Conventions
6. Technique-dependent effects
7. Terminology concerning reference systems
8. Practical application to the rewriting of some parts of Conventions (2003)
9. Electronic diffusion of the Conventions
10. Links with other fields of geodesy
11. Next registered edition

1. Classification of models

The Position paper “Principles for conventional contributions to modelled station displacements” (<http://www.bipm.org/utils/en/events/iers/Conv_PP1.txt>), hereafter PP1, proposes to classify the models and effects to be considered in the scope of the Conventions into three categories:

Class 1 (“reduction”) models are those recommended to be used *a priori* in the reduction of raw space geodetic data in order to determine geodetic parameter estimates, the results of which are then subject to further combination and geophysical analysis. The Class 1 models are accepted as known *a priori* and are not adjusted in the data analysis. Therefore their accuracy is expected to be at least as good as the geodetic data (1 mm or better). Class 1 models are usually derived from geophysical theories. Apart from a few rare exceptions, the models and their numerical constants should be based on developments that are fully independent of the geodetic analyses and results that depend on them. A good example is the solid Earth tide model for station displacements.

Class 2 ("conventional") models are those that eliminate an observational singularity and are purely conventional in nature. This includes many of the physical constants. Other examples are the ITRF rotational datum, specifying the rotation origin and the rotation rate of the ITRF. As indicated by their name, Class 2 may be purely conventional or the convention may be to realize a physical condition. When needed, choices among possible conventions are guided by Union resolutions and historic practice, which may differ in some cases.

Class 3 ("useful") models are those that are beneficial (or even necessary in some sense) but are not required as either Class 1 or 2. This includes, for instance, the zonal tidal variations of UT1/LOD. An accurate zonal tide model is not absolutely required in data analysis though it can be helpful and is very often used internally in a remove/restore approach to regularize the *a priori* UT1 variations to simplify interpolation and improve parameter estimation. In addition, such a model is very much needed to interpret geodetic LOD results in comparisons with geophysical excitation processes, for instance. Class 3 also includes models which cannot fulfil the requirements for Class 1 such as accuracy or independence from geodetic results, but are useful or necessary to study the physical processes involved. Class 3 model effects should never be included (that is, removed from the observational estimates) in the external exchange of geodetic results unlike Class 1 effects. Serious misunderstandings can otherwise occur.

R1 Classification of models

It is proposed to distinguish three classes of models in the Conventions. Class 1 ("reduction") covers models which are physically based, accurately determined and needed to obtain usable results in data analysis; Class 2 ("conventional") models are also needed but are based on conventional choice; Class 3 ("useful") includes the other models.

2. Criteria for choosing models

The IERS Conventions should strive to present a complete and consistent set of the necessary models of the Class 1 and Class 2 types, including implementing software. Where conventional choices must be made (Class 2), the Conventions provide a unique set of selections to avoid ambiguities among users. The resolutions of the international scientific unions and historical geodetic practice provide guidance when equally valid choices are available, but models of the highest accuracy and precision are always preferred.

Class 3 models are included when their use is likely to be sufficiently common, or to minimize potential user confusion.

For station displacement contributions, the Conventions should clearly distinguish models which are to be used in the generation of the official IERS products from other (Class 3) models. Models in the first category, used to generate the IERS realization of the celestial and terrestrial reference systems and of the transformation between them, are referred to as “conventional displacement contributions”.

Conventional displacement contributions should be of the Class 1 type (essential and geophysically based) and generally obey the following selection criteria, as specified in PP1:

- Include subdaily tidal variations: Since the beginning of space geodesy, the basic observational unit has consisted of data processing integrations for 1 solar day or multiples. This choice provides a natural filter to dampen variations with periods near 24 and 12 h (and higher harmonics) caused by environmental, geophysical (tidal), and technique-related sources. However, 1-day integration by itself is inadequate for the highest accuracy applications. Unmodelled subdaily site variations can efficiently alias into other geodetic parameters, such as the 12-h GPS satellite orbits, and also alias into longer-term effects. In order to minimize such difficulties, all tidal displacements with periods near 24/12 h and having amplitudes of about 1 mm and greater should be included *a priori* using conventional models. The most accurate models available should be applied, but any residual model errors will be strongly attenuated in data processing that use 24-h integrations (or multiples).
- Model corrections must be accurate: It is imperative that when adjustments are applied directly to observational data based on any model, the errors introduced by the model must be much smaller than the effect being removed. This should be true over the full spectral range affected but especially over intervals equal to or smaller than the geodetic integration span. If random errors in the subdaily band are increased, for instance, at the expense of reducing systematic variations at seasonal periods in 1-day processing samples, then it is clear that the corrections should not be applied *a priori*. Instead, suitably filtered corrections may be considered in *a posteriori* studies without suffering any degradation of the original geodetic analysis.
- Models must be independent of the geodetic data: In order to avoid circular reasoning and the possibility of propagating geodetic errors into conventional geophysical models, the applied models should be fully independent of the geodetic analyses which depend on them. Ideally they should be founded on geophysical theories and principles that do not directly derive from

geodetic results. Only in a few exceptional cases where geophysical theory is inadequate (such as some parameters of the nutation model) is it necessary to rely upon geodetic estimates within an adjusted geophysical framework.

- Prefer models in closed-form expressions: For practical reasons of implementation, portability, and independence of processing venue, closed-form analytical models for site displacements are most attractive.
- Allow flexibility in interpretation of geodetic results: To the extent that geodetic results are sensitive to any particular geophysical effect and the models for that effect are not necessarily uniquely well realized or accurate, it is often desirable to measure the relative performance of alternative models. In order to do so easily, geodetic results should be presented to researchers in a form that readily facilitates such comparisons as much as possible. Generally this implies strong preference for *a posteriori* treatment of model displacements that are outside the subdaily band rather than requiring multiple processings of the same data with various different *a priori* models. Note that this recommended practice is consistent with the traditional approach that has been used to interpret excitation of Earth orientation variations, for example.

These considerations are summarized in the following recommendation.

R2: Choosing models for conventional station displacements

It is recommended that conventional station displacements include only Class 1 ("reduction") models, plus any technique-specific effects. Some specific criteria are that complete daily & sub-daily tidal variations should be included, and that models must be accurate (with respect to observation errors), as independent of geodetic data as possible, and preferably in closed-form expressions for ease of use. In addition, it should be sought to maintain flexibility to evaluate different models easily *a posteriori* when accuracy is questionable.

The classification of models and general criteria for their use and implementation should be explicitly stated in the Conventions, as stated in the next recommendation:

R3: Recommended Revision of Conventions Introduction

It is recommended that the Introduction of the IERS Conventions be amended to include, in substance, the guiding principles and the selection criteria presented in R1 and R2 above.

3. Non tidal loading effects

Non-tidal loading effects are considered in PP1 and in the Position paper "Towards a conventional treatment of surface-load induced deformations”, hereafter referred to as PP2 (<http://www.bipm.org/utils/en/events/iers/Conv_PP2.pdf>).

As a brief summary, PP1 recommends not to include non tidal loading effects as conventional site model contributions and to expand Chapter 7 to discuss these effects as Class 3 models. PP2 recommends developing a dynamic reference Earth model (DREM) as the outcome of a sequence: first a model for atmospheric loading, then for the hydrological cycle, finally for all significant geophysical processes.

These views are compatible considering that PP1 describes the generation of reference frames now and in the coming years, while PP2 describes (i) studies to be conducted now and in the next years, for which models are needed, and (ii) future possible application to the generation of reference frames when models fulfil the conditions. It is not possible at this time to state when this will be possible as DREMs should cover with adequate uncertainty the full range of significant geophysical processes in order to be used for reference frame generation.

3.1 PP1: Handling Non-Tidal Displacements

Following section 2, PP1 specifically recommends that displacements due to non-tidal geophysical loadings not be included in the *a priori* modelled station positions, that is, in the “conventional displacement contributions”. These effects fail all contribution selection criteria given above. Even if the somewhat arbitrary preference for models in closed-form expression (which is inconsistent with non-tidal models) is relaxed, the other more important criteria cannot be ignored. The most serious obstacles are:

- Reliability in the subdaily band: At best, non-tidal environmental models attempt to compensate mostly for seasonal variations, which are well outside the normal integration intervals for space geodetic data. None of the available global circulation models properly account for dynamic barometric pressure compensation by the oceans at periods less than about two weeks. Instead, both “inverted barometer” (IB) and non-IB implementations are produced as crude approximations of the actual Earth system behaviour even though these are both recognized as unreliable in the high-frequency regime. While effective at longer periods (especially seasonal), the undesirable and unknown degradation that would affect subdaily integrations is not an acceptable side-effect.
- Inaccuracies of the models: The basic types of studies and analyses that are normally considered a precondition to the adoption of a conventional model are mostly lacking for non-tidal models. Documentation of error analyses is a basic requirement that must be fulfilled. Specific studies on comparisons of products,

systematic effects and possible combination techniques are necessary: Some references may be found in PP1.

- Models must be free of tidal effects: Any non-tidal displacement corrections applied should be strictly free of tidal contaminations, otherwise the geodetic results will be adversely affected.
- Risk of long-term biases in the reference frame: Because environmental models do not yet conserve overall mass or properly account for exchange of fluids between states, use of non-tidal models in solutions for the terrestrial reference frame will generally suffer from long-term drifts and biases that are entirely artificial. This is an unacceptable circumstance.
- Need for new datum requirements for the reference frame: As an example, introducing pressure-dependent non-tidal site displacement contributions into standard geodetic solutions would necessitate the adoption of a global reference atmospheric pressure field. Such expansion of the ITRF datum to include such non-geodetic quantities may not be welcome nor understood by users.
- Need to easily test alternative models: As noted in section 2, it is vital to be able to compare different non-tidal models easily and efficiently, something that is not facilitated by direct inclusion of the models into geodetic analyses. It is far simpler to make such comparisons and studies *a posteriori* as has been done for many years in research into the excitation of Earth orientation variations. However, in solutions where non-tidal displacements have been applied, the full field of corrections used must be reported in new SINEX blocks that will need to be documented and may nevertheless permit only an approximate removal of the non-tidal corrections if the applied sampling is finer than the geodetic integration interval.

Therefore non-tidal displacements must not be included in operational solutions that support products and services of the IERS. Nevertheless the non-tidal loading effects can be readily considered in *a posteriori* studies with no loss whatsoever. For this purpose, it is recommended that models of non-tidal station displacements be made available to the user community through the IERS Global Geophysical Fluid Centre and its special bureaux, together with all necessary supporting information, implementation documentation, and software. Expansion of the IERS Conventions, Chapter 7, could include some essential aspects of this material to inform users, as Class 3 models. Continued research efforts are strongly encouraged, particularly to address the outstanding issues listed above.

R4: to include non-tidal models as Class 3

It is recommended that IERS Conventions, Chapter 7, be expanded to include the essential aspects of using non-tidal models in *a posteriori* studies and research, in order better to inform users.

3.2 PP2: Handling Non-Tidal Displacements

PP2 describes steps that would be needed to obtain a consistent description of Earth shape, gravity field and rotation at the accuracy level of 10^{-9} or better in an integrated approach. It proposes to extend the definition of the "regularized coordinates" by introducing a displacement field with components provided by the following actions:

- Improving the operational prediction of displacements due to atmospheric loading.
- Setting up an operational computation of ocean-bottom pressure anomalies and the computation of the induced surface displacements.
- Setting up an operational computation of terrestrial water storage anomalies and the computation of the induced surface displacements.
- A consistency check based on mass conservation should be used to link the 3 components above and to ensure that large errors in mass conservation are detected/avoided.

PP2 concludes with 3 recommendations that make up steps to establish a Dynamic Reference Earth Model (DREM):

- Recommendation 1 (atmosphere only): Recognizing that atmospheric loading is a geophysical process inducing surface displacements at sub-daily to interannual time scales significant at an accuracy level of 1 ppb, and that signals of atmospheric loading in the shape, gravity field and rotation of the Earth can be predicted with high accuracy, it is recommended that, as a first step, a dynamic reference model is developed and validated that consistently predicts with low latency the atmospheric loading signal in the surface displacement, gravity field and rotation of the Earth and that these predictions are taken into account in the determination of the ITRF as well as the products providing low-latency access to ITRF.
- Recommendation 2 (hydrological cycle): Recognizing that mass redistribution in atmosphere, oceans, and terrestrial hydrosphere are inherently related through processes in the global hydrological cycle, that these mass redistributions cause surface displacements at sub-daily to interannual time scales significant at an accuracy level of 1 ppb, and that the feedback between the individual components (reservoirs) of the hydrological cycle as well as the solid Earth also cause significant signals in the shape, gravity field and rotation of the Earth, it is recom-

mended that a dynamic Earth model is developed and validated that consistently predicts the geodetic signals of mass redistribution in the global hydrological cycle and that accounts for the geophysical interactions between the reservoirs of the hydrological cycle and the solid Earth.

- Recommendation 3 (all relevant geophysical processes): Recognizing that monitoring of point motion and detection of “anomalous motion” are key applications of a modern global reference frame and space geodetic techniques, and that for many applications a predictive reference frame is required, and that such a reference frame needs to be based on a DREM, it is recommended that a DREM is developed that accounts for all known geophysical processes significant at the level of 1 ppb and that predicts consistently the signals in Earth shape, rotation and gravity field caused by these processes.

Discussions determined that the change in the definition of “regularized coordinates” (associated with the ITRF) envisioned in PP2 does not appear realistic in the foreseeable future. However studies towards a DREM, following the steps proposed in PP2, should be promoted. Given the wide range of geophysical processes involved, it was not clear which practical steps could be taken.

R5: Recommend the IERS DB to promote the development of a DREM

It is recommended that the IERS DB promotes the development of a dynamic reference Earth model.

4. New models

Following previous work initiated by the Conventions Centre and the Advisory Board, a number of papers have been presented at the workshop, mostly in session 1 “Recent advances and validations of the IERS Conventions models”. The final discussion led to the proposition of updating the Conventions for the following models:

4.1. S1/S2 atmospheric loading

A model for S1/S2 atmospheric loading is provided by T. van Dam and R. Ray. The model is based on the S1/S2 model by Ponte and Ray (2003). The effect can be as large as 1 to 2 mm for station height components at equatorial regions and is significantly smaller at higher latitudes.

J. Böhm and V. Tesmer (<http://www.bipm.org/utils/en/events/iers/Boehm.pdf>) applied this model for the whole history of VLBI observations. Work is continuing to quantify the influence of this model on VLBI solutions.

J. Ries (additional contribution, see <http://www.bipm.org/utils/en/events/iers/Ries_s1_s2_slr.pdf>) applied this model to 6 months of SLR data and found a small improvement in the variance of the residuals.

It was recognized that the model is well founded, that the magnitude of the effect is significant and that the expected accuracy of the model is sufficient. Although the benefits are hardly visible in the results of VLBI and SLR analysis, the tests show that the model is valid and still indicate an improvement. In addition, it is likely to be useful for GPS analysis due to the resonance of this effect with the orbital period. Like for other loading effects, the compensating counter motion of the solid Earth due to fluid loading effects (translation of the observing network relative to the instantaneous centre of mass) should be included in the modelled station displacements, at least for those techniques that observe the dynamical motions of near-Earth satellites and respond to the centre of mass of the total Earth system. (See section 8.3)

4.2. Troposphere model

The recent update of Chapter 9 of the Conventions does consider horizontal gradients in the general formulation of the tropospheric delay, but no conventional *a priori* values are provided for these gradients.

P. Steigenberger, V. Tesmer, J. Böhm (<http://www.bipm.org/utils/en/events/iers/Steigenberger.pdf>) have investigated the use of *a priori* gradients in the analysis of GPS and VLBI observations. They show that there is a clear systematic behaviour of station coordinates if no residual gradients are estimated, but that there is hardly any difference if gradients are estimated unconstrained in the solutions. However when gradients are estimated and constrained, as in VLBI, there are systematic effects of order 40 µas on source declinations and < 2mm on station latitude. Therefore it is recommended to include in the tropospheric model a hydrostatic gradient due to the equatorial bulge.

4.3 Conventional model for the effect of ocean tides on geopotential

R. Biancale (<http://www.bipm.org/utils/en/events/iers/Biancale.pdf>) presented a software package based on the FES2004 ocean tide model and its application to the EIGEN gravity field models. It is proposed to adopt this package as conventional and to include it in Chapter 6 of the Conventions. Therefore FES2004 would be the conventional model of ocean tides, consistently for geopotential and displacement. (This should be made clear in Chapter 7.)

In addition a S1/S2 atmospheric tides model (Biancale & Bode model) derived from ECMWF 3-hour surface pressure fields, expressed in a similar form, is proposed.

It is also proposed to add a S1 ocean tide model (provided by F. Lyard at LEGOS). This S1 tide model is not purely gravitational, but the hydrodynamic ocean tide is constrained by the S1 atmospheric tide (see above). It is provided for users who cannot use ocean circulation models (such as MOG2D from LEGOS) which include the S1 response of the ocean to the atmospheric pressure.

4.4 Model for diurnal and semidiurnal EOP variations

The conventional model for diurnal and semidiurnal EOP variations (Chapter 8) has not changed since IERS Conventions (1996). R. Ray (<http://www.bipm.org/utils/en/events/iers/Ray_Richard.pdf>) considered the need to upgrade this model. New global tidal models are much improved over the TPXO.2 model used in 1996. However, a tidal model for EOP also requires global current velocity, but few such models are available. Also a model should add atmospheric thermal tides to oceanic effects but no clear consistency is obtained between air-tide models. Therefore it is considered that more work is still necessary at this stage.

R6: Recommended new conventional models

It is recommended to add new conventional models: a model for S1/S2 atmospheric loading as provided by T. van Dam and R. Ray; a model for the tropospheric hydrostatic gradient due to the equatorial bulge; a model for the effect of ocean tides on geopotential based on FES2004 tidal model. Work on a new model for diurnal and semidiurnal EOP variations should be pursued.

5. Possible additions to the Conventions

Besides the new models mentioned above, additional material to the Conventions is also under consideration. Two topics are specifically proposed.

5.1. Propagation of radio waves through the ionosphere

Dispersive effects of the ionosphere on the propagation of radio signals are classically accounted for by linear combination of multi-frequency observations. In past years it has been shown that this approach induces errors on the computed time of propagation that can reach 100 ps for GPS. For wide-band VLBI observations, the induced errors might reach a couple of ps. It is proposed to gather in a new section the estimation of the effect of higher-order neglected ionospheric terms and possible conventional models for these.

5.2. Better documentation for relativistic models

Needed improvements are generally small changes, but occur in many different parts of the Conventions. They concern the terminology used, information on the magnitude of effects, and more detail on time of propagation model for ranging techniques. In addition a section on clock synchronization and transformations of proper time to coordinate time (applied to GNSS) is recommended. See a review of possible improvements in the presentation by S. Klioner (<http://www.bipm.org/utils/en/events/iers/Klioner.pdf>).

6. Technique-dependent effects

Reports were presented from the analysis coordinators of the IVS, the IGS and the ILRS. For IVS (<http://www.bipm.org/utils/en/events/iers/Nothnagel.pdf>), thermal expansion, gravitational sag and tumbling of reference point were mentioned as well as the general question of local ties. For IGS (<http://www.bipm.org/utils/en/events/iers/Ray_IGS.pdf>), antenna phase model, satellite orbit models, satellite attitude models, satellite signal polarization models, ionospheric delay modelling (see section 5.1), inter-modulation signal delay biases, SP3 orbit frame and relativistic effects for GPS clocks (see section 5.2) were covered. For ILRS (<http://www.bipm.org/utils/en/events/iers/Pavlis.pdf>), satellite force model, satellite attitude model, satellite centre-of-mass offset and measurement biases were mentioned, along with the possible relation to other techniques.

R7: Technique-dependent effects

Technique services should maintain documentation on their technique-specific effects. Links to this documentation should appear in the IERS Conventions.

In addition, topics that concern (or may concern) several techniques could be specified in the Conventions. Examples are the following:

- IVS needs a reference temperature to model antenna thermal deformation. A "GPT-like" function, based on the present conventional model GPT, averaged over one year, might be sufficient to represent the true average temperature with adequate uncertainty (a few K). Harmonic representation of higher order may be useful (to be considered in a future version of the routine GPT). When defined, such a conventional reference temperature should be used whenever needed, as all measurement techniques have temperature dependence.
- Non gravitational acceleration affects all satellites (GNSS/SLR), but the precise implementation of models is to be considered as technique-dependent. However, a general description might be useful in the Conventions.

7. Terminology concerning reference systems

Terminology concerning reference systems has been a recurrent topic for years. It mostly impacts Chapter 4 of the Conventions. It is addressed in the presentation (<http://www.bipm.org/utils/en/events/iers/Boucher.pdf>) which discusses also the IUGG resolution on ITRS passed at the 2007 IUGG GA in Perugia. It also presents the IAG Inter-Commission Working Group (WG 1.3) on 'concepts and terminology related to Geodetic Reference Systems', chaired by C. Boucher which aims at defining such a terminology. Note also a link with the IAG study group SC1.2-SG1- IC-SG1, on 'Theory, implementation and quality assessment of geodetic reference frames' (jointly Commission 1, ICCT, IERS) chaired by A. Dermanis.

For direct application to the IERS Conventions, one option is to first update, in Chapter 4, the part describing the elaboration of the latest realization (so far ITRF2005). When the IAG inter-commission WG has concluded its work, the whole chapter should be reconsidered in view of the WG report.

8. Practical application to the rewriting of some parts of Conventions (2003)

8.1 Conventions introduction

This is described in sections 1 and 2 above, concluding with R2 in section 2.

8.2 Conventions Chapter 4

PP1 made the specific recommendation that the text of the IERS Conventions, Chapter 4, section 4.1.3, be replaced starting from the 4th paragraph to the end of the section with the following new text:

"The general model connecting the instantaneous *a priori* position of a point anchored on the Earth's crust at date t, X(t), and a regularized position $X_R(t)$, is $X(t) = X_R(t) + [\Sigma_i dX_i(t)]$. The purpose of the introduction of a regularized position is to remove mostly high-frequency time variations (mainly geophysically excited) using conventional corrections $dX_i(t)$ in order to obtain a position with regular time evolution. Among other reasons, such regularization permits improved estimation of the actual instantaneous station positions based on observational data. In this case, $X_R(t)$ can be expressed by using simple models and numerical values. The current station motion model is linear (position at a reference epoch t_0 and velocity): $X_R(t) = X_0 + X' * (t – t_0)$.

The numerical values are (X_0 , X'), which collectively constitute a specific TRF realization for a set of stations determined consistently. For some stations it is necessary to consider several discrete linear segments in order to account for abrupt discontinuities in position (for example, due to earthquakes or to changes in observing equipment).

Conventional models are presented in Chapter 7 for the currently recognized $dX_i(t)$ corrections, namely those due to solid Earth (body) tides, ocean tidal loading, polar motion-induced deformation of the solid Earth (pole tide), ocean pole tide loading, and loading from the atmospheric S1/S2 pressure tides. All of these models, except the atmospheric S1/S2 pressure tides, include long-period variations outside the subdaily band. While not necessary, this approach is recommended in order to maintain consistency with longstanding practice and to minimize user confusion. Station displacements due to non-tidal loadings are not recommended to be included in operational solutions but studies for research purposes are encouraged.

The compensating counter motions of the solid Earth due to all the fluid loading effects ('geocenter motion' of the observing networks relative to the ITRF origin) should generally be included in the modelled station displacements, at least for those techniques that observe the dynamical motions of near-Earth satellites, which respond to the centre of mass of the total Earth system.

Additional station-dependent corrections may be recommended by the various Technique Services due to effects that are not geophysically based but nonetheless can cause position-like displacements. These generally affect each observing methods in distinct ways so the appropriate models are technique-dependent and not specified by the IERS Conventions."

8.3 Changes to Chapters 4, 5 and 7

Position paper 3 (<http://www.bipm.org/utils/en/events/iers/Petit_PP3.pdf>) intends to give directions so that the question of the origin of the terrestrial reference system (i.e. "geocentre motion") is treated in a consistent manner throughout the Conventions. When a phenomenon (such as the ocean tides) causes displacements of fluid masses, the centre of mass of the fluid masses moves and must be compensated by an opposite motion of the centre of mass of the solid Earth. The stations, being fixed to the solid Earth, are subject to this counter-motion. There is considerable confusion in the use of "geocentre motion" to represent the vector between the "instantaneous centre of mass of the whole Earth" (here noted CM) and the "origin of ITRF" (here noted CF). However a consistent practice in the recent IERS applications has been to use this vector as oriented "from CM to CF", so that it is proposed to use this convention in all cases. It could help to use a new name for this vector, e.g. "origin translation". Implications on different chapters of the Conventions include:

In chapter 7, the "tidal" component of the origin translation associated with all modelled loading effects should be modelled at the observation level, following the procedure used for ocean loading in the update 25/11/2006 of Conventions.

In chapter 4, the description of ITRF elaboration should mention explicitly the conventional procedure used to account for the "seasonal" component of the origin translation.

In chapter 5, the EOP formulation should be specified in the transformation TRS-CRS. As the EOP values used are referenced to the ITRF origin, it is to be mentioned explicitly that ITRF coordinates (i.e. not referred to the instantaneous CM) should be used.

9. Electronic diffusion of the Conventions

B. Luzum and G. Brockett (<http://www.bipm.org/utils/en/events/iers/Luzum_Conv.pdf>) considered several options for the electronic dissemination of the Conventions. From the discussion following, it seemed to emerge a consensus that the system of occasional 'registered editions' which are produced with an interval of a few years is still preferred. For the time being, the registered edition will remain the 'paper' edition, which is used in a wider community than the IERS.

The current approach of providing updates between registered editions through electronic means in both TeX and PDF files with full archiving of successive evolutions is supported. Additional electronic augmentations to the Conventions will be explored in the future as resources permit.

B. Luzum and M.S. Carter (<http://www.bipm.org/utils/en/events/iers/Luzum_Soft.pdf>) reviewed the current situation of Conventions software from a software engineering perspective and proposed some guidelines to improve the situation. In particular, the inclusion of test cases for accepted software and the improvement in the documentation of the code were seen as achievable goals. Additional improvements such as improved error trapping, formal version control, improved formal testing, improved consistency between subroutines, and providing code in additional languages, while beneficial, are not seen as practical at this time.

M. Gerstl (<http://www.bipm.org/utils/en/events/iers/Gerstl_Soft.pdf>) recommended that the Conventions software be fully normalized and proposed some technical choices. Such an approach has merits but would require more manpower than is currently available.

In following discussions it was determined that minimum requirements were to provide all source code on the Conventions web site, to ensure version control, to provide documentation on the arguments, and to provide test cases. The importance of this issue was stressed, because very often the software itself is the *de facto* convention, much more than the description of the model in the Conventions or in the literature.

R8: IERS Conventions software

It is recommended that, when a model needs to be coded in an independent routine or set of routines, the Conventions Centre will provide all source code on the Conventions web site along with documentation on the arguments and test cases, and will ensure version control.

10. Links with other fields of geodesy

J. Ihde (<http://www.bipm.org/utils/en/events/iers/Ihde.pdf>) presented conclusions of the IAG Inter Commission Project 1.2 “Vertical reference frames” which he chaired. ICP1.2 considered draft Conventions for the definition and realization of a Conventional Vertical Reference System (CVRS) and also recognized the need for conventions for the definition and realization of an absolute gravity reference system (IGSN71 – IAG WG in preparation). The continuation of this work is proposed as an IAG Inter-Commission Working Group for the Global Vertical Reference System (GVRS).

11. Next registered edition

During the session “Evolution of the Conventions” and in the final general discussion, it was widely recognized that a new registered edition is needed, which should implement the conclusions of this meeting. It is foreseen that it could appear in the time frame 2008/2009.

R9: Next registered edition of the IERS Conventions

It is recommended to assemble a new registered edition of the IERS Conventions, implementing the conclusions of this workshop, aiming at a publication date in 2009.

Summary of Recommendations

R1: Classification of models

It is proposed to distinguish three classes of models in the Conventions. Class 1 ("reduction") covers models which are physically based, accurately determined and needed to obtain usable results in data analysis; Class 2 ("conventional") models are also needed but are based on conventional choice; Class 3 ("useful") includes the other models.

R2: Choosing models for conventional station displacements

It is recommended that conventional station displacements include only Class 1 ("reduction") models, plus any technique-specific effects. Some specific criteria are that complete daily & sub-daily tidal variations should be included, and that models must be accurate (with respect to observation errors), as independent of geodetic data as possible, and preferably in closed-form expressions for ease of use. In addition, it should be sought to maintain flexibility to evaluate different models easily *a posteriori* when accuracy is questionable.

R3: Recommended Revision of Conventions Introduction

It is recommended that the Introduction of the IERS Conventions be amended to include, in substance, the guiding principles and the selection criteria presented in R1 and R2 above.

R4: To include non-tidal models as Class 3

It is recommended that IERS Conventions, Chapter 7, be expanded to include the essential aspects of using non-tidal models in *a posteriori* studies and research, in order better to inform users.

R5: Recommend the IERS DB to promote the development of a DREM

It is recommended that the IERS DB promotes the development of a dynamic reference Earth model.

R6: Recommended new conventional models

It is recommended to add new conventional models: a model for S1/S2 atmospheric loading as provided by T. van Dam and R. Ray; a model for the tropospheric hydrostatic gradient due to the equatorial bulge; a model for the effect of ocean tides on geopotential based on FES2004 tidal model. Work on a new model for diurnal and semidiurnal EOP variations should be pursued.

R7: Technique-dependent effects

Technique services should maintain documentation on their technique-specific effects. Links to this documentation should appear in the IERS Conventions.

R8: IERS Conventions software

It is recommended that, when a model needs to be coded in an independent routine or set of routines, the Conventions Centre will provide all source code on the Conventions web site along with documentation on the arguments and test cases, and will ensure version control.

R9: Next registered edition of the IERS Conventions

It is recommended to assemble a new registered edition of the IERS Conventions, implementing the conclusions of this workshop, aiming at a publication date in 2009.

Gérard Petit, Brian J. Luzum,
and the workshop organizing committee

4.2 GGOS Unified Analysis Workshop

In cooperation with the GGOS Executive Committee the IERS Central Bureau organised the first GGOS Unified Analysis Workshop, taking place in Monterey, California, USA from December 6 to 8, 2007. By invitation representatives of the IAG services (GGOS, IERS, IGFS, IGS, IVS, ILRS, IDS) were selected by these individual services, 5 – 6 per service, in total 44 scientists.

The scope of the workshop was to support one of the important goals of GGOS, which is to advance the combination and integration of the various space and in-situ geodetic techniques. This goal can only be achieved with the help of all the IAG Services, and especially the IERS and IGFS.

Even if considerable progress has been made in the effort towards a rigorous combination of the various space geodetic techniques (e.g. the realization of ITRF2005, making use of a new approach based on time series of SINEX files), there are still many deficiencies (missing parameters), inconsistencies and systematic effects to be addressed. Therefore the important topics of the workshop were the following:

- Assessment of technique-specific systematic biases affecting the co-location on the ground and on satellites
- Step by step inclusion of all parameter types common to more than one observation technique
- Definition of common standards for all these parameters and their a priori values/models
- Improvements in combination strategies and rigorousness
- Development of new products based on a rigorous combination of the space geodetic techniques
- Setup of a common data portal for the products and data, and the definition of meta data and data flow

The workshop was intended to be a forum to exchange information and results and thus increase the common understanding of all the technique representatives for each of the individual techniques as they contribute to GGOS.

Position papers were put together by the chairs and co-chairs of the six sessions, which were in details:

- Session 1: Details of Product Generation of the Services and Future
- Session 2: Technique-Specific Biases and Effects at Co-Location Sites/Satellites

- Session 3: Standardization/Extension of Common Parameterization
- Session 4: Combination Strategies and Aspects
- Session 5: New Products Based on Inter-technique Combinations
- Session 6: GGOS Portal and Meta Data Flow

The detailed programme including the position papers and presentations is available at <http://www.iers.org/MainDisp.csl?pid=66-1100207>.

The workshop ended with the following action items and recommendations:

- Extension of the SINEX format for other parameter types and representations
- Tests on atmospheric loading: application on the observation or solution level?
- Generation of daily SINEX files (IVS Intensives and IGS Rapids)
- Parameterization and modeling for the next ITRF
- Benchmark tests for models common to several techniques
- Documentation of AC modeling standards and parameterization
- Definition of meta data standards (e.g. SINEX meta data block)

The detailed and updated list can be found at <http://www.iers.org/documents/workshop2008/presentations/UAW_Action_Items_Status_Apr08.pdf>.

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.
- ITRS Combination Center(s)
- Research 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.

ITRS COMBINATION CENTER(S)

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 Center.

RESEARCH CENTER(S)

Research Center(s) are responsible for carrying out research on a specific subject. They are established by the DB and are related to a corresponding Product Center. Research Center(s) are limited to a term of 4–5 years.

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.
- 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.

October 28, 2008

Appendix 2: Contact addresses of the IERS Directing Board

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Chopo Ma
(address see below)

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Product Centres Representatives

Earth Orientation Centre Representative

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Rapid Service/Prediction Centre Representative

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Conventions Centre Representative

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Technique Centers Representatives

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Union Representatives

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(*Status as of October 2009*)

Appendix 3: Contact addresses of the IERS components

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Central Bureau

IERS Central Bureau
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Product Centres

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Working Groups

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Working Group on Combination at the Observation Level

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(*Status as of October 2009*)

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-doris.org/

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/

Working Groups

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

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

2MASS	Two Micron All Sky Survey
2QZ	2dF redshift survey
AAC	Associated Analysis Centre
AAM	Atmospheric Angular Momentum
AC	Analysis Centre
AC	Analysis Coordinator
ACC	[IGS] Analysis Center Coordinator
ADC	Architecture and Data Committee
AER	Atmospheric and Environmental Research Inc.
AGU	American Geophysical Union
AICAS	Astronomical Institute, Academy of Sciences of the Czech Republic
ANDERRA	Atmospheric Neutral Density Experiment Risk Reduction
APCV	Antenna [or Absolute] Phase Centre Variation
APKIM	Actual Plate KInematic and crustal deformation Model
APSG	Asia-Pacific Space Geodynamics
AR	Annual Report
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
B1.0	USNO-B1.0 Catalog
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
CEDR	Center for Earth Dynamics Research
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques
CF	origin of ITRF
CFHT	Canada-France-Hawaii Telescope
CFHTLS	CFHT Legacy Survey
CGS	Centro di Geodesia Spatiale, ASI
CHAMP	CHAllenging Minisatellite Payload
CLS	Collecte Localisation Satellites
CM	instantaneous centre of mass of the whole Earth
CMB	core-mantle boundary
CMS	Content Management System
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
CRMS	CRF mediansouth [sessions]
CSR	Center for Space Research, University of Texas
CSRIFS	Combined Square Root Information Filter and Smoother (program)
CSW	Catalogue Service Web
CVRS	Conventional Vertical Reference System
DB	Directing Board
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
DREM	Dynamic Reference Earth Model
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
ERIS	Earth Rotation Information System
ERP	Earth Rotation Parameters
ESA	European Space Agency
ESOC	European Space Operations Center, ESA
EUMET-SAT	European Organisation for the Exploitation of Meteorological Satellites
e-VLBI	Electronic transfer VLBI
EVN	European VLBI Network
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FCN	Free Core Nutation
FESG	Forschungseinrichtung Satellitengeodäsie, Technical University of Munich
FFI	Forsvarets forskningsinstitutt
FIRST	Faint Images of the Radio Sky at Twenty-Centimeters
FITS	Flexible Image Transport System
FTLRS	French Transportable Laser Ranging Station
FTP, ftp	File Transfer Protocol
GA	General Assembly
GA	Geoscience Australia
GAC	GRACE Average of non-tidal atmosphere and ocean Combination
GAOUA	Main Astronomical Observatory of the Ukrainian Academy of Sciences
GCM	Gravity Satellite only Monthly solutions
GCRS	Geocentric Celestial Reference System
GEO	Group on Earth Observations
GeoDAF	Geodetic Data Archiving Facility
GEOSS	Global Earth Observation System of Systems
GFZ	GeoForschungsZentrum Potsdam
GGAO	Goddard's Geophysical and Astronomical Observatory
GGFC	Global Geophysical Fluids Centre
GGOS	Global Geodetic Observing System
GGOS-D	GGOS – Deutschland (Germany)
GIA	glacial isostatic adjustment
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
GMES	Global Monitoring of Environment and Security
GMF	Global Mapping Function
GNSS	Global Navigation Satellite System
GNU	GNU's Not Unix
GOP	Geodetic Observatory Pecny
GPS	Global Positioning System
GPT	Global Pressure and Temperature
GRACE	Gravity Recovery and Climate Experiment
GRGS	Groupe de Recherches de Géodésie Spatiale
GSC23	[Space Telescope] Guide Star Catalog 2.3
GSFC	Goddard Space Flight Center
GSI	Geographical Survey Institute
GSM	GRACE Satellite only Model
GVRS	Global Vertical Reference System
HCRF	Hipparcos Celestial Reference Frame
HEO	High Earth Orbiter
HST	Hubble Space Telescope
IAA	Institute of Applied Astronomy, St. Petersburg
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICP	[IAG] Inter Commission Project
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
IC-SG	[IAG] Inter-Commission Study Group

IC-WG	[IAG] Inter-Commission Working Group
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)
IGFS	International Gravity Field 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)
IGSN71	International Gravity Standardization Net 1971
ILRS	International Laser Ranging Service
ILRSA	ILRS Combination Centre
INA	= INASAN
INAF	Istituto Nazionale di Astrofisica
INASAN	INstitut AStronomii Rossijskoj Akademii Nauk (Institute of Astronomy of the Russian Academy of Sciences)
IRA	Istituto di Radioastronomia
IRIS	International Radio Interferometric Surveying
ISO	International Organization for Standardization
ISRO	Indian Space Research Organization
IT	Information Technology
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
IVP	invariant reference point
IVS	International VLBI Service for Geodesy and Astrometry
JADE	JApanese Dynamic Earth observation by VLBI
JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth System Technology, GSFC
J-MAPS	Joint Milli-Arcsecond Pathfinder Survey
JPL	Jet Propulsion Laboratory
JVAS	Jodrell Bank-VLA Astrometric Survey
KEOF	Kalman Earth Orientation Filter
LaD	Land Dynamics
LAREG	Laboratoire de Recherche en Geodesie
LCA	LEGOS in cooperation with CLS
LCT	Laser Communication Terminal
LDAS	Land Data Assimilation System
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LEO	Low Earth Orbit(er)
LGM	last glacial maximum
LLR	Lunar Laser Ranging
LOD	Length of Day
LPCE	Laboratoire de Physique et Chimie de l'Environnement
LQAC	Large Quasar Astrometric Catalog
LR	laser ranging
LRA	Laser Retroreflector Array
LRO	Lunar Reconnaissance Orbiter
MAO	= GAOUA
mas	milliarcsecond(s)
µas	microarcsecond(s)
MCC	Russian Mission Control Centre
MCT	Ministério da Ciência e Tecnologia, Brasília
MERIT	Monitoring Earth Rotation and Intercomparison of Techniques
MICOM	Miami Isopycnic Coordinate Ocean Model
MIS	Meta Information System
MIT	Massachusetts Institute of Technology
mJy	milli-Jansky
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)
MW	microwave
NASA	U.S. National Aeronautics and Space Administration
NCAR	U.S. National Center for Atmospheric Research

NCEP	U.S. National Centers for Environmental Prediction
NCL	University of Newcastle upon Tyne
NEQ	normal equation
NERC	Natural Environment Research Council, UK
NetCDF	Network Common Data Form
NGS	U.S. National Geodetic Survey
NGSLR	[NASA's] Next Generation SLR
NICT	National Institute of Information and Communications Technology
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
NPM	Lick Northern Proper Motion Program
NPS	(U.S.) Naval Postgraduate School
NRAO	[U.S.] National Radio Astronomy Observatory
NRCan	Natural Resources, Canada (formerly: EMR)
NRL	Naval Research Laboratory
NRT	Nançay Radio Telescope
ns	nanosecond(s)
NSGF	NERC Space Geodesy Facility
NVSS	NRAO VLA sky survey
OAM	oceanic angular momentum
Obs.	Observatory, Observatoire
OCA	Observatoire de la Côte d'Azur
OCRF	Optical Celestial Reference Frame
OGC	Open Geospatial Consortium
OP	Observatoire de Paris
OPAR	Paris Observatory IVS Analysis Center
OV	[HST] orbital verification
PAA	Priority Area Assessment
PC	Product Centre
PHP	PHP: Hypertext Preprocessor
PI	Principal Investigator
PM	Polar Motion
PMM	Precision Measure Machine
PNT	positioning, navigation and timing
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})
PPN	Precise-Position-Navigation
PRARE	Precise RAnge and Range-Rate Equipment
PREM	Preliminary Reference Earth Model
PSR	pulsar(s)
PZT	Photographic Zenith Tube [or Telescope]
QSO	Queued Service Observation
R&D	Research and Development
RDV	Research and Development (sessions) with the VLBA
RFI	radio frequency interference
rms, RMS	Root Mean Square
RRFID	USNO Radio Reference Frame Image Database
RSC	Radio Source Coordinates
RSES	Research School of Earth Sciences
RS/PC	IERS Rapid Service/Prediction Center
SAA	South Atlantic Anomaly
SAR	Synthetic-aperture radar
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
SCID	Ad hoc Strategic Committee on Information and Data
SDSS	Sloan Digital Sky Survey
SIM	NASA’s Space Interferometry Mission
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SLR	Satellite Laser Ranging
SNR	signal-to-noise ratio
SOAR	Southern Astrophysical Research
SOI	SOAR Optical Imager
SPBU	St Petersburg University

SPM	Yale/San Juan Southern Proper Motion Program
SRIF	Square Root Information Filter array
SYRTE	(Laboratoire) Systèmes de Référence Temps-Espace
TAI	Temps Atomique International (International Atomic Time)
TANAMI	Tracking Active galactic Nuclei with Australia Milliarcsecond Interferometry
TC	Technique Centre
TEMPO	Time and Earth Motion Precision Observations
TERAPIX	Traitement Elementaire, Reduction et Analyse des PIXels
ToR	Terms of Reference
TRF	Terrestrial Reference Frame
TT	Terrestrial Time
TU	Technical University
TUM	Technical University of Munich
TWS	terrestrial water storage
UCAC	USNO CCD Astrograph Catalog
UFRJ	Universidade Federal do Rio de Janeiro
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
VCS	[NRAO] VLBA Calibrator Source Survey
VLBI	Very Long Baseline Interferometry
VMF, VMF1	Vienna Mapping Function
VO	Virtual Observatory
VOTable	(Virtual Observatory) XML format for the exchange of tabular data
WCS	World Coordinate System
WFI	Wide Field Imager
WG	working group
WGP	IERS Working Group on Prediction
WMAP	Wilkinson Microwave Anisotropy Probe
WMO	World Meteorological Organization
WRMS	Weighted Root Mean Square
XML	eXtensible Markup Language
yr	year